The Human Footprint and the Last of the Wild

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In Genesis, God blesses human beings and bids us to take dominion over the fish in the sea, the birds in the air, and every other living thing. We are entreated to be fruitful and multiply, to fill the earth, and subdue it (Gen. 1:28). The bad news, and the good news, is that we have almost succeeded.

There is little debate in scientific circles about the importance of human influence on ecosystems. According to scientists' reports, we appropriate over 40% of the net primary productivity (the green material) produced on Earth each year (Vitousek et al. 1986, Rojstaczer et al. 2001). We consume 35% of the productivity of the oceanic shelf (Pauly and Christensen 1995), and we use 60% of freshwater run-off (Postel et al. 1996). The unprecedented escalation in both human population and consumption in the 20th century has resulted in environmental crises never before encountered in the history of humankind and the world (McNeill 2000). E. O. Wilson (2002) claims it would now take four Earths to meet the consumption demands of the current human population, if every human consumed at the level of the average US inhabitant. The influence of human beings on the planet has become so pervasive that it is hard to find adults in any country who have not seen the environment around them reduced in natural values during their lifetimes—woodlots converted to agriculture, agricultural lands converted to suburban development, suburban development converted to urban areas. The cumulative effect of these many local changes is the global phenomenon of human influence on nature, a new geological epoch some call the "anthropocene" (Steffen and Tyson 2001). Human influence is arguably the most important factor affecting life of all kinds in today's world (Lande 1998, Terborgh 1999, Pimm 2001, UNEP 2001).

> THE HUMAN FOOTPRINT IS A GLOBAL MAP OF HUMAN INFLUENCE ON THE LAND SURFACE, WHICH SUGGESTS THAT HUMAN BEINGS ARE STEWARDS OF NATURE, WHETHER WE LIKE IT OR NOT

Yet despite the broad consensus among biologists about the importance of human influence on nature, this phenomenon and its implications are not fully appreciated by the larger human community, which does not recognize them in its economic systems (Hall et al. 2001) or in most of its political decisions (Soulé and Terborgh 1999, Chapin et al. 2000). In part, this lack of appreciation may be due to scientists' propensity to express themselves in terms like "appropriation of net primary productivity" or "exponential population growth," abstractions that require some training to understand. It may be due to historical assumptions about and habits inherited from times when human beings, as a group, had dramatically less influence on the biosphere. Now the individual deci-

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sions of 6 billion people add up to a global phenomenon in a way unique to our time. What we need is a way to understand this influence that is global in extent and yet easy to grasp—what we need is a map.

Until recently, designing such a map was not possible, because detailed data on human activities at the global scale were unavailable. The fortunate confluence of several factors during the 1990s changed this situation. Rapid advances in earth observation, using satellite technology pioneered by NASA and other space agencies, meant that, for the first time, verifiable global maps of land use and land cover were available (Loveland et al. 2000). The thawing of the cold war and calls for efficiency in government meant that other sources of global geographic data, for example, on roads and railways, were released to the public by the US National Imagery and Mapping Agency (NIMA 1997). Improved reporting of population statistics at subnational levels enabled geographers to create global digital maps of human population density (CIESIN et al. 2000). Finally, advances in geographic information systems (GIS) have provided the integration technology necessary to combine these data in an efficient and reproducible manner. Although the datasets now available are imperfect instruments, they are of sufficient detail and completeness that scientists can map the influence of humans on the entire land's surface.

We call our map of human influence "the human footprint," conscious of its similarity to the ecological footprint, a set of techniques for estimating the amount of land or sea necessary to support the consumption habits of one individual, population, product, activity, or service (Wackernagel and Rees 1996). The human footprint represents in some sense the sum total of ecological footprints of the human population. It expresses that sum not as a single number, however, but as a continuum of human influence stretched across the land surface, revealing through its variation the major pattern of human influence on nature.

Mapping the human footprint

Our technique for mapping the human footprint grows out of a recent tradition of wilderness mapping (McCloskey and Spalding 1989, Lesslie and Malsen 1995, Aplet et al. 2000, Yaroshenko et al. 2001), which focuses on defining human influence through geographic proxies, such as human population density, settlements, roads, and other access points, and includes factors such as the size and remoteness of an area. However, except for the Sierra Club map of wilderness (McCloskey and Spalding 1989) that was created before the widespread use of GIS and incorporated only one of the data types we use here, none of these earlier efforts were made at the global scale.

Advances have been made in understanding human disturbance globally since George Marsh first asked, "To what degree are the processes of nature threatened by human activity?" in his 1864 work, *Man and Nature* (quoted in Hannah et al. 1994; see also Lowdermilk 1953, Thomas 1956, and Bennett 1975). More recent efforts include the human disturbance index (Hannah et al. 1994, 1995), which used digitized maps from Rand-McNally atlases and other sources to classify areas as "human-dominated," "partially disturbed," or "undisturbed"; according to that index, nearly three-quarters of the habitable surface of the planet is disturbed at least in part by human use. The Global Methodology for Mapping Human Impacts on the Biosphere (GLOBIO; UNEP 2001) estimates the amount of disturbance on flora and fauna according to their distance from human infrastructure (e.g., roads, pipelines, settlements). Originally focused on scenarios of historic, current, and future impact in the Arctic region, these analyses have recently been expanded to the global scale (see *www.globio.info* for updates). The human footprint has important parallels to all these efforts, which, though approaching the question using a variety of data sources and methodologies, arrive at largely the same answer.

To map the human footprint, we used four types of data as proxies for human influence: population density, land transformation, accessibility, and electrical power infrastructure. Nine datasets that represent these four data types (table 1) were selected for their coverage, consistency, availability, and relevance, but they provide only an incomplete description of human influence on nature. For example, most of these datasets do not include Antarctica or many small oceanic islands, and thus we had to exclude these areas from our analysis. In addition, we confined our analysis to the terrestrial realm, because a different set of inputs would be required to map human influence in the oceans. Effects of pollution, global warming, increased exposure to ultraviolet radiation, and other global phenomena, although they have important consequences for terrestrial ecosystems, are not included. For this analysis we focused on the direct measures of human infrastructure and population that have the most immediate impact on wildlife and wild lands and for which geographic data were readily available. To combine the nine datasets, we needed to (1) present them in one map projection, using a consistent set of coastal boundaries and regions; (2) express them as overlaying grids at a resolution of 1 square kilometer (km^2); and (3) code each dataset into standardized scores that reflected their estimated contribution to human influence on a scale of 0 to 10 (0 for low human influence, 10 for high).

These codes were based on published scientific studies and consultation with a range of biologists, social scientists, and conservationists, as summarized below.

Human population density. The number of people in a given area is frequently cited as a primary cause of declines in species and ecosystems (Cincotta and Engelman 2000), with higher human densities leading to higher levels of influence on nature. A recent study by Brashares and colleagues (2001) showed that 98% of the variation in extinction rates in national parks in Ghana over a 30-year period could be explained by the size of the park and by the number of people living within 50 km of it—the higher the density and the smaller the park, the higher the extinction rate. Others have

Table 1. Geographic datasets used to map the human footprint.

Dataset type	Dataset name	Year	Sources	Reference
Population density	Gridded Population of the World	1995	CIESIN	CIESIN 2000
Land transformation	Global Land Use/Land Cover version 2	1992–1993	USGS/UNL/JRC	Loveland et al. 2000
	Vector Map Level 0 Built-Up Centers	1960s–1990s	NIMA	NIMA 1997
	Vector Map Level 0 Population Settlements	1960s–1990s	NIMA	
	Vector Map Level 0 Roads and Railways	1960s–1990s	NIMA	
Access	Vector Map Level 0 Roads and Railways	1960s–1990s	NIMA	NIMA 1997
	Vector Map Level 0 Coastline			
	Vector Map Level 0 Rivers (major rivers defined as rivers represented by continuous polygons to the sea)			
Electrical power infrastructure	Defense Meteorological Satellite Program, Stable Lights	1994–1995	NOAA/NGDC	Elvidge et al. 1997a
Biome normalization	Terrestrial Biomes	2001	WWF	Olson et al. 2001
	Terrestrial Biogeographic Realms	2001	WWF	

CIESIN, Center for International Earth Science Information Network, Columbia University; JRC, Joint Research Centre of the European Commission; NGDC, National Geophysical Data Center; NIMA, National Imagery and Mapping Agency; NOAA, National Oceanic and Atmospheric Administration; UNL, University of Nebraska, Lincoln; USGS, US Geological Survey; WWF, World Wildlife Fund for Nature, United States

Note: Although the Vector Map Level 0, ed. 3, datasets were published in 1997, the datasets on which they are based are derived from Defense Mapping Agency Operational Navigational Charts developed from the mid-1960s through the early 1990s.

found similar results for national parks in the western United States and small reserves across Africa (Parks and Harcourt 2002, Harcourt et al. 2001, respectively). Robinson and Bennett (2000) note that, in terms of sustainable hunting levels, the land's carrying capacity for people who depend exclusively on game meat will not greatly exceed one person per km^2, even under the most productive circumstances. Simple mathematics suggests that the greater the number of people, the more resources that will be required from the land, as mediated by their consumption rate (Malthus 1798, Wackernagel and Rees 1996).

Beyond this general understanding, there is little guidance in the literature about how human influence exactly scales with human population density (Forester and Machlis 1996). The consequences of interactions between human population density and the environment depend on the nature of the interaction and the particular species, ecosystems, or processes in question. In this study, we used a continuum approach, in which human influence scores for densities between 0 and 10 persons per km^2 increased linearly from 0 to 10 and the score above 10 persons per km^2 was held constant at 10. We assume that human influence attributable solely to human population density reaches an asymptote at some level, though at what density that influence evens out is uncertain; we chose 10 persons per km^2 as an estimate.

Land transformation. Called the single greatest threat to biological diversity, land transformation has resulted in loss and fragmentation of habitat in many different ecosystem types (Vitousek 1997). Moreover, fragmentation often facilitates additional negative consequences to species and ecosystems beyond the simple loss of habitat, in concert with other processes and over time (Crooks and Soulé 1999, Laurance and Cochrane 2001). Human beings transform land to build settlements, grow food, and produce other economic goods (e.g., Geist and Lambin 2002); different land uses, however, differ in the extent to which they modify ecosystem processes and affect the quality of habitat for different species (Goudie 1986, Forman 1995). Growth of agriculture over the last 30 years has led to large changes in worldwide rates of nitrogen fixation and phosphorus accumulation in soils and water and increased demands on fresh water for irrigation (Tilman et al. 2001).

We assigned the maximum score (10) to built-up environments; lower scores (6, 7, or 8, depending on level of input) to agricultural land cover; and lower scores still (4) to mixed-use cover. Other types of land use, notably extensive grazing lands in arid areas, are difficult to map and are most likely underestimated in our analysis. We assigned a value of 0 to all other land cover types—forests, grasslands, and Mediterranean ecosystems, for example—although those cover types are subject to various kinds of human uses.

Land transformation also includes the direct effects of roads and railways on species and ecosystems. Not all species and ecosystems are equally affected by roads, but overall the presence of roads is highly correlated with changes in species composition, including increases in nonnative invasive species, decreased native species populations through direct and indirect mortality, and modification of hydrologic and geomorphic processes that shape aquatic and riparian systems (Trombulak and Frissell 2000). Lalo (1987) estimated that 1 million vertebrates a day are killed on roads in the United States. Forman and Deblinger (2000) estimated that the effects of American roads extend over a band approximately 600 meters (m) wide. The nominal spatial accuracy of all of the NIMA datasets (table 1) is 2 km. Therefore, we assigned a score (8) for the direct effect of roads and railways within a 2 km buffer to ensure that we captured the actual location of the road as mapped, although we may be overestimating the spatial extent of influence. While we recognized that road influence depends on the type of road and the amount of traffic passing along it, we were unable to include these factors in our analysis because of the imprecision of the datasets. The effect of overlapping influence from multiple roads on the same location was not included.

We also used the independently derived NIMA datasets on settlements (represented by points with 2 km buffers) and built-up areas. The settlement data include a large variety of settlement types, such as camps, buildings, and monuments, but the vast majority of features are of unknown type. We assigned each point a score of 8. The built-up areas, which typically represent the largest cities as polygons in the NIMA database, were assigned a score of 10.

Human access. Roads, major rivers, and coastlines provide opportunities for hunting and extraction of other resources, pollution and waste disposal, and disruption of natural systems, as well as social and economic gain (Gucinski et al. 2001). As a result, designating areas of remoteness is a common element of many wilderness-mapping exercises (e.g., Lesslie and Malsen 1995, Aplet et al. 2000). Hunting of wildlife no longer supplies a significant source of food in the western world, but it does in most of the rest of the world. Such hunting, with its associated disruption of ecosystems, is of major concern (Robinson and Bennett 2000), because it could result in some forests ecosystems being "emptied" by overhunting (Redford 1992). In tropical ecosystems, access from rivers and the coast may be more important than access from roads (Peres and Terborgh 1995).

To measure the area affected by access, we estimated the distance a person could walk in one day in a difficult-to-traverse ecosystem (e.g., moist tropical forests) as 15 km (see, e.g., Wilkie et al. 2000). We acknowledge, however, that this approach oversimplifies the complex relationship between human beings and roads, a relationship that varies by ecosystem type and cultural context. All areas within 2 to 15 km of a road, major river, or coast were assigned a modest human influence score (4) that reflects intermittent use. Major rivers were defined roughly as those that reach the sea and are wide enough

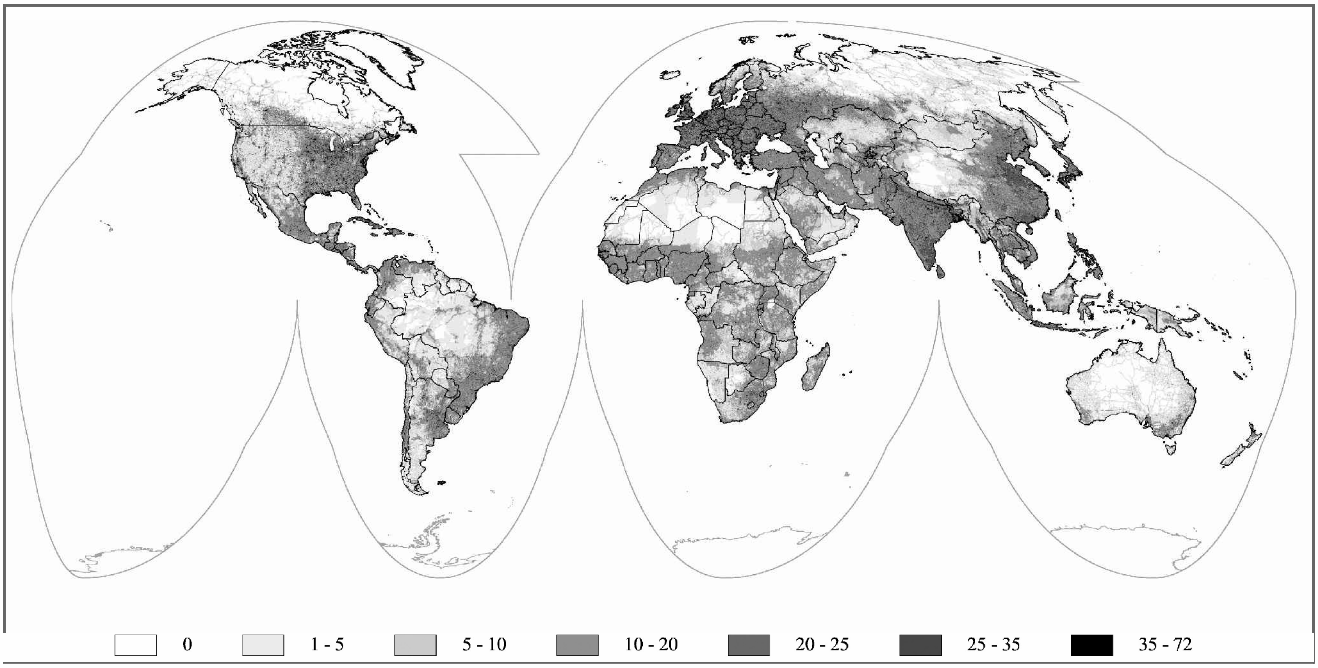

Figure 1. The human influence index. Scores range from 0 to a maximum of 72; higher scores indicate greater human influence, lower scores less human influence. Analysis indicates that 83% of the land surface is influenced by one or more of the following factors: human population density greater than one person per square kilometer (km^2); agricultural land use; built-up areas or settlements; access within 15 km of a road, major river, or the coastline; and nighttime light bright enough to be detected by satellite sensor. Almost 98% of the areas where rice, wheat, or maize can be grown (FAO 2000) is influenced by one or more of these factors. The analysis excludes Antarctica and most oceanic islands, and national boundaries are not authoritative.

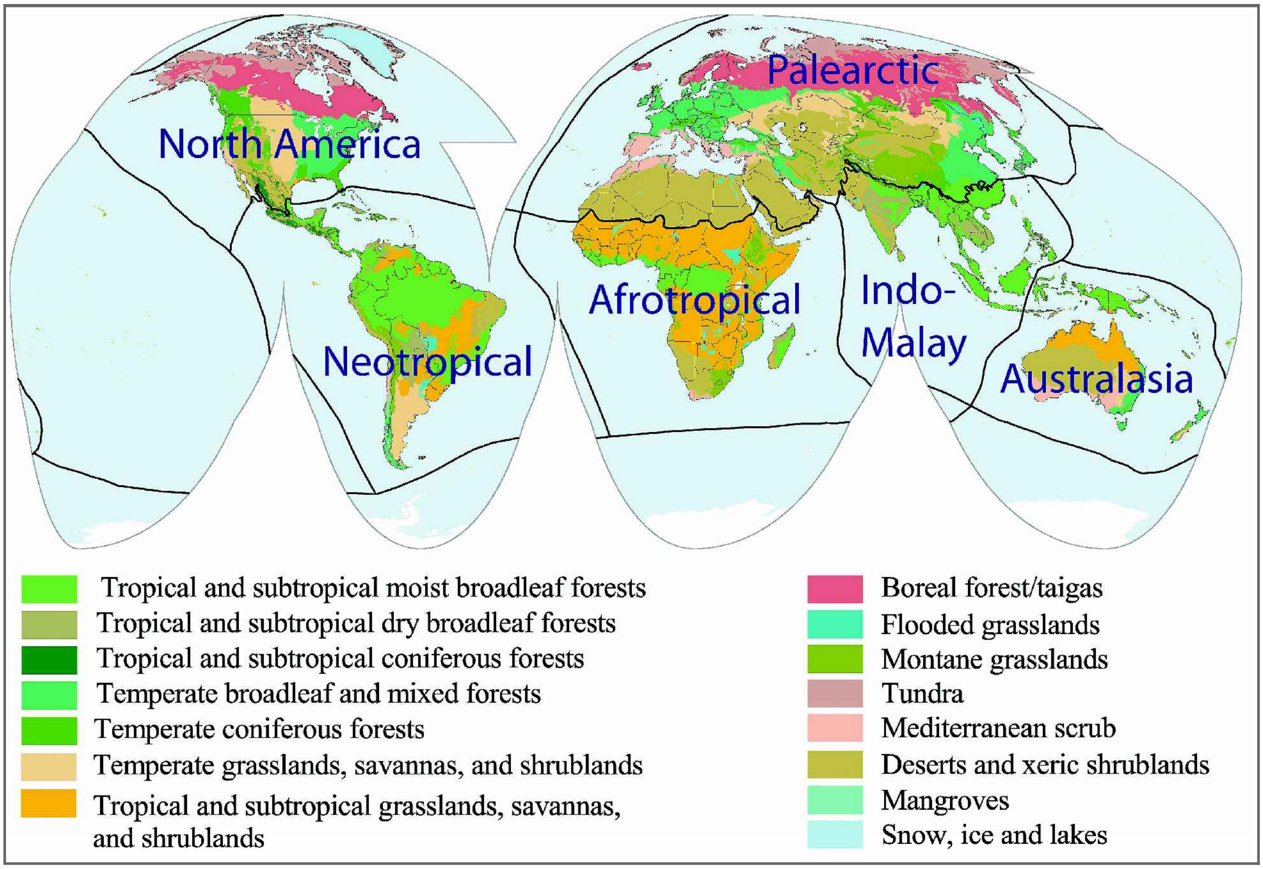

Figure 2. Biomes and biogeographic realms that are used to normalize human influence (Olson et al. 2001). Figure used with permission from World Wildlife Fund–United States.

to be recorded as polygons in the NIMA database, although this definition most likely underestimates the extent of access along rivers, since any river wide enough to float a dugout canoe is a potential access point. We did not include the effects of waterfalls or dams, which limit access upriver, because data were inadequate. Thus, access along some waterways may be overestimated.

Power infrastructure. Many of the dramatic changes in human influence that are due to land use change and access during the 20th century have literally been fueled by fossil energy. Before the industrial revolution, the human capacity to modify the environment was limited by human and animal muscle power, what McNeill (2000) called the "somatic energy regime." Today one human being with a bulldozer can apply the power of 300 horses to modify the environment. Electrical power provides an excellent estimate of the technological development of a local area (Elvidge et al. 1997a) and the use of fossil fuels. In the United States, where electrical power is available nearly everywhere, the lights visible at night from satellites provide a proxy of population distribution and have been correlated with human settlements (Sutton et al. 1997, Elvidge et al. 1997b). We assigned a score of 10 to areas that have lights visible more than 89% of nights, 8 to areas with lights visible 40% to 88% of nights, 4 to areas with lights visible less than 40% of nights, and 0 to areas where no lights were visible.

Summing the scores. We summed the human influence scores for each of the nine datasets to create the human influence index (HII) on the land's surface (figure 1). Overall, 83% of the land's surface, and 98% of the area where it is possible to grow rice, wheat, or maize (FAO 2000), is directly influenced by human beings (HII > 0). The theoretical maximum (72) is reached in only one area, Brownsville, Texas, USA, but the top 10% of the highest scoring areas looks like a list of the world's largest cities: New York, Mexico City, Calcutta, Beijing, Durban, São Paulo, London, and so on. The minimum score (0) is found in large tracts of land in the boreal forests of Canada and Russia, in the desert regions of Africa and Central Australia, in the Arctic tundra, and in the Amazon Basin. The majority of the world (about 60%), however, lies along the continuum between these two extremes, in areas of moderate but variable human influence.

The human influence index, like the GLOBIO methodology or the human disturbance index, treats the land surface as if it were a blank slate on which human influence is written, but we know this is not the case. The distribution of major ecosystem types and the human histories of different regions modify the biological outcomes of human influence (cf.

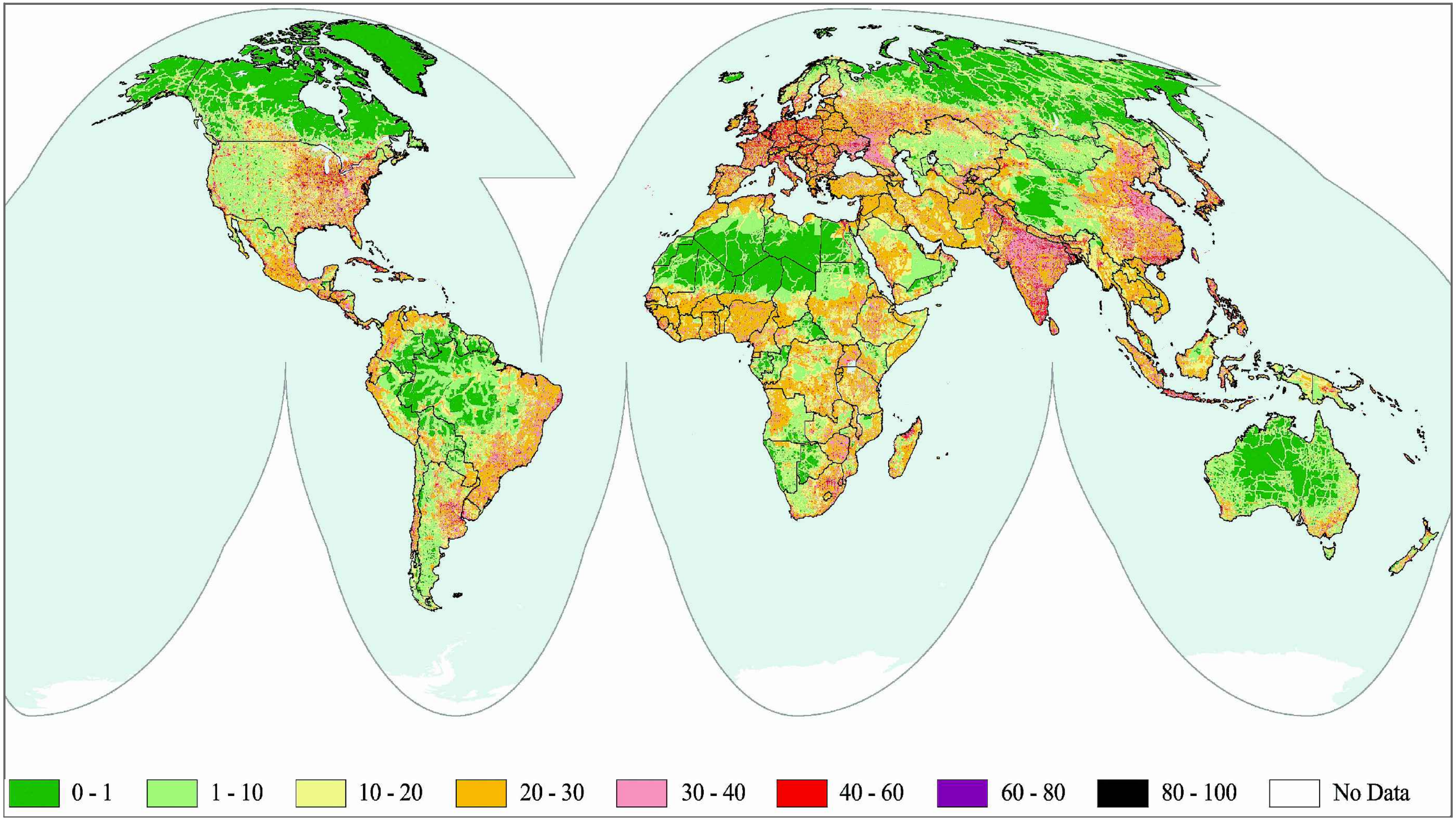

Figure 3. The human footprint, a quantitative evaluation of human influence on the land surface, based on geographic data describing human population density, land transformation, access, and electrical power infrastructure, and normalized to reflect the continuum of human influence across each terrestrial biome defined within biogeographic realms. Further views and additional information are available at "Atlas of the Human Footprint" Web site, www.wcs.org/humanfootprint. Data are available at www.ciesin.columbia.edu/wild_areas/. National boundaries are not authoritative.

Chapin et al. 2000). For example, an absolute score of 25 in the mixed broadleaf forests of North America might have a different effect, and definitely has a different biological context, than the same score in the rain forests of the African tropics. Because we were interested in the interaction between human influence and the natural environment, we normalized human influence scores within large, regionally defined biomes, which were differentiated within still larger biogeographic realms (e.g., Palearctic, Indo-Malay, Neotropic), in accordance with the geographic definitions provided by the World Wildlife Fund–US Conservation Science Program (figure 2; Olson et al. 2001). We assigned a revised score of 0 to the grid cell with minimum HII value in each biome in each realm and a score of 100 to the cell with maximum value, stretching intermediate values linearly between these extremes (table 2, pp. 901, 902).

The result is the human footprint (figure 3). The human footprint expresses as a percentage the relative human influence in every biome on the land's surface. A score of 1 in moist tropical forests in Africa indicates that that grid cell is part of the 1% least influenced or "wildest" area in its biome, the same as a score of 1 in North American broadleaf forest (although the absolute amount of influence in those two places may be quite different). In fact, there is considerable variation in levels of both overall and mean human influence between biomes (table 2). Examining the human footprint on a larger scale shows the patterns of roads, settlements, land uses, and population density for a particular area—the geography of human influence. For example, on a map of the northeastern United States (figure 4), urbanization in the coastal region is clearly visible, as are major highway corridors along the shore and up the Hudson River and Connecticut River valleys. Relatively wilder areas appear in the Catskills, Adirondacks, and Green Mountains.

We propose that this geography of human influence is roughly the inverse of the geography of natural processes and patterns in the region. Given what we know about the effects of the input factors on nature, we expect that where human influence is highest, ecosystems will be most modified and species under the most pressure from human activity. Where the human footprint values are lower, we expect more intact and functional natural communities. The exact consequences of human influence in any given location are complicated, however, and depend on the history of the place, the types of the current influence, and the parts of nature that we are concerned with (Redford and Richter 1999). We know that some aspects of nature survive, and even thrive, in the midst of our cities, while even in the wildest places, human influence frequently has reduced or is reducing natural values. Yet it is in these wildest places that the greatest freedom and opportunity to conserve the full range of nature still exists.

Finding the last of the wild

It follows from mapping the human footprint that it is also possible to map the least influenced, or "wildest," areas in each biome. We searched through the human footprint to find the "10% wildest areas" in each biome in each realm around the world (the biomes that fell within the 10% cutoff on the HII are listed in table 2). From this set of wildest areas, we selected the 10 largest contiguous areas as the "last of the wild" (figure 5), because such large, intact tracts of relatively undisturbed ecosystems are particularly important for conserving biological diversity (Newmark 1987, Grumbine 1990). Some of the areas defined as the last of the wild are well over 100,000 km^2 in some biomes; in other biomes, we could not find even 10 areas larger than 5 km^2. The size of areas depends on the spatial pattern of human influence above the 10% level; in most biomes, however, roads or patterns of settlement are sufficient to divide one wild area from another. The proportion of area represented by the last of the wild varies dramatically among biomes, depending on the statistical distribution of human influence. Thus, over 67% of the area in the North American tundra is captured as last of the wild, while the 10% wildest area of the Palearctic tropical and subtropical moist broadleaf forests (all in China) encompasses less than 0.03% of that biome.

In total, we selected 568 last-of-the-wild areas, representing all biomes in all the realms. A complete listing of the last-of-the-wild areas can be found on our Web sites, where we characterize each of these wild areas by population density, road density, biome, and region (Atlas of the Human Footprint: *www.wcs.org/humanfootprint*; geographic datasets: *www.ciesin.columbia.edu/wild_ areas/)*. Many of these wild areas contain existing protected areas, but many do not, just as some contain roads and settlements, while others do not. The list of last-of-the-wild areas is a guide to opportunities for effective conservation—these are the places where we might conserve the widest range of biodiversity with a minimum of conflict. They are not and should not be interpreted as a self-contained prescription for complete nature conservation. For example, in the Afrotropical realm, all 10 of the last-of-the-wild areas in the tropical and subtropical moist broadleaf forests biome fall in Central Africa (figure 6). Other parts of the African moist broadleaf forests, in West Africa or Madagascar, are also important for conservation, but their conservation takes place in the context of higher levels of human influence.

There are many ways of using the human footprint to define areas of interest for conservation, depending on the desired conservation objectives. Although area size is often important, for some applications, it may be useful to identify the wildest areas in each biome, regardless of size, for example, the wildest 1% of areas ("seeds of wildness"). Others might use the human footprint to find the areas facing the greatest threat, although those areas may already have lost much of what made them biologically distinct. Whether defining "seeds" or the "last of the wild" or measuring threats, the human footprint provides a flexible tool for identifying areas at different points along the human influence continuum.

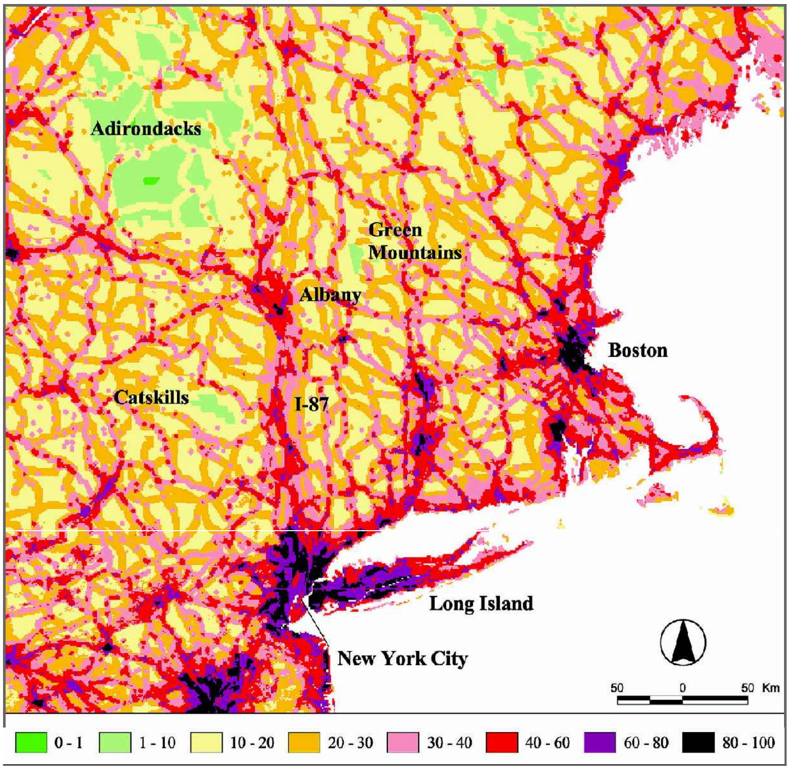

Figure 4. The "human footprint" in the northeastern United States.

Interpreting the human footprint and the last of the wild

The measures of human influence used in this study have many shortcomings that the reader needs to be cognizant of when interpreting the results. First, it is important to acknowledge that although population density, land use changes, access to roads and rivers, and lights visible at night, for example, have been and continue to be drivers of the human impact on nature, drivers are not inevitably harmful. The human footprint does not measure impact per se; rather, it suggests areas of influence where humans have more or less responsibility for biological outcomes. Thoughtful practices and careful planning can mitigate the human influence on ecosystems, as conservation biology and restoration ecology have shown (Stevens 1995). In fact, one of the more interesting uses of the human footprint may be to identify places where sensitive species thrive despite high levels of human influence and determine which human behaviors enable coexistence.

Second, even with modern mapping tools, tremendous effort and expense are required to develop the input datasets used here—in fact, many of these data were developed for the first time only in the 1990s and only through large, government-funded projects. As a result, the datasets tend to lag behind the patterns they seek to depict: growing populations, new road construction, and clearing of new land for human uses. Similarly, the methods used to develop the datasets have shortcomings that result in imperfect representations—underestimates of the amount of grazing lands or insufficient detail about the kinds of settlements or the locations of roads, for instance—that also tend to cloud our view of the extent and severity of human influence. Moreover, there are simply mistakes in these global datasets: Chunks of roads are missing, rivers are more (or less) accessible than they appear, population densities vary unusually across national boundaries, agricultural areas are inaccurately mapped, and so on. Because of these problems, the reader should take care in drawing conclusions from the human footprint for local areas, while not losing sight of the global pattern and its significance.

Finally, our ability to interpret patterns of human influence that are based on geographic features is constrained by the complexities of human interactions with nature and our limited understanding of them. For example, we know that the distance people travel from roads and rivers is less in the temperate zone than in the tropics and that per capita consumption in the developed world results in impacts not just locally, but across the globe. Yet we don't know enough about either of these to assess them globally in a consistent manner. We make no strong claims about any of our coding systems, except to suggest that understanding how surrogate measures quantitatively translate into impacts, or how they should be weighted against each other, is an important area of research. As Rojstaczer and colleagues (2002) recently pointed out, our understanding of the global environmental impact of human beings is in its infancy, and therefore all measures should be considered cautiously. However, we also need to be aware that, though we don't understand everything about human influence on nature, we understand enough to be concerned.

In the near term, one avenue for refining our understanding of the human footprint is to study human influence at regional, national, and local levels. By restricting the area of interest, scientists can use more accurate and detailed datasets; modify the coding functions to respect regional, cultural, and biological differences; and define normalization criteria in ways appropriate for local conservation and management goals. The methods of defining the human footprint and the last of the wild are general and can be applied locally as well as globally to understand where nature may be most pressed and how that pressure may be released.

Implications for conservation practice

The human footprint and last of the wild should give us all pause as we consider our relationship to nature and the types of conservation efforts that we might pursue in the 21st century. This analysis indicates that conservation today proceeds in the context of dramatic, and in some places overwhelming, human influence. For most ecosystems, the greatest near-term threats are from direct human activities like those measured by the human footprint: transformation of land for agriculture and for suburban and urban development, direct

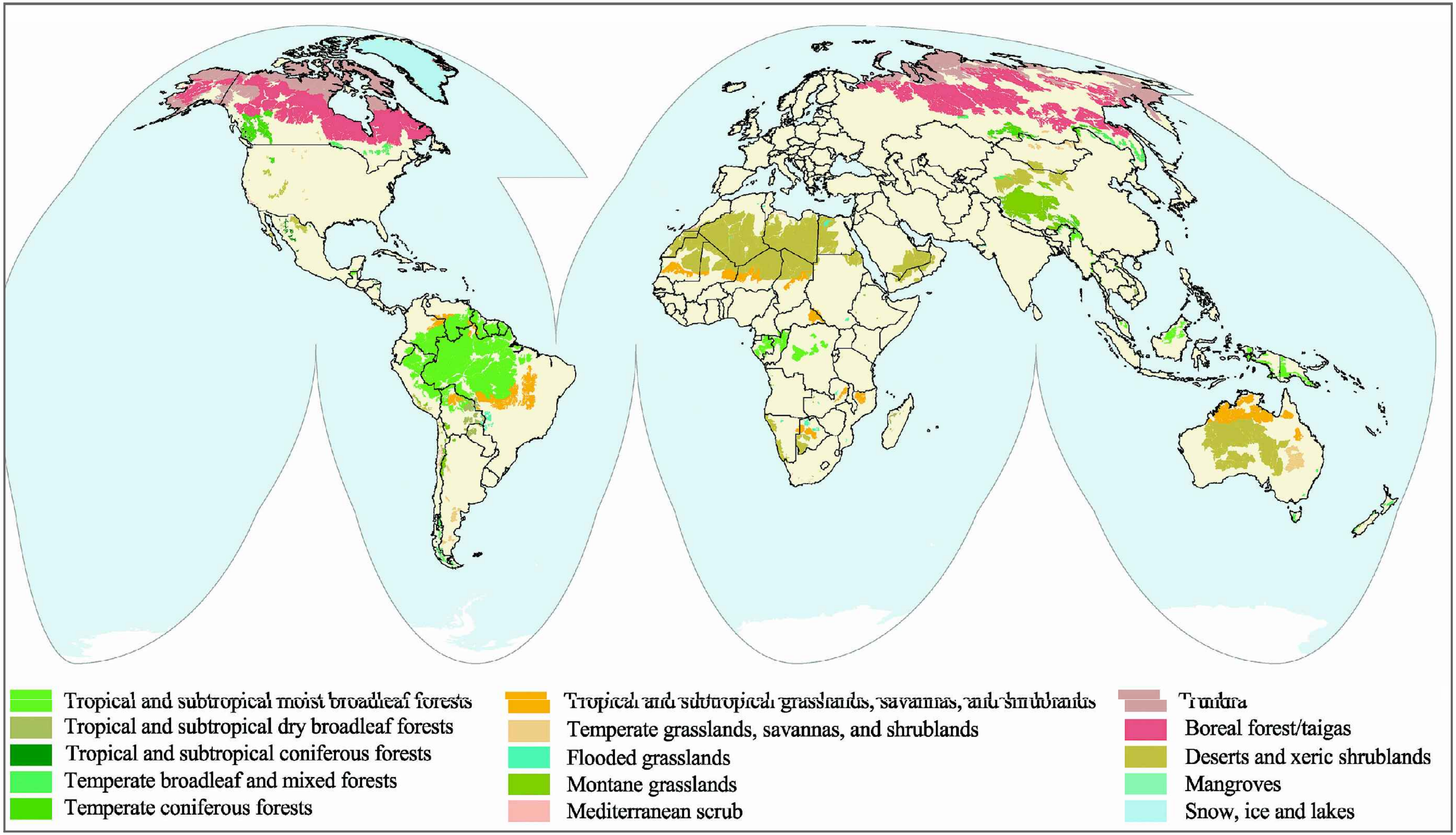

Figure 5. The "last of the wild," showing the ten largest "10% wildest cutoff" areas by biome and realm on the land surface. The full list is available at **www.wcs.org/humanfootprint;** ***geographic data is available at*** **www.ciesin.columbia.edu/wild_areas/.**

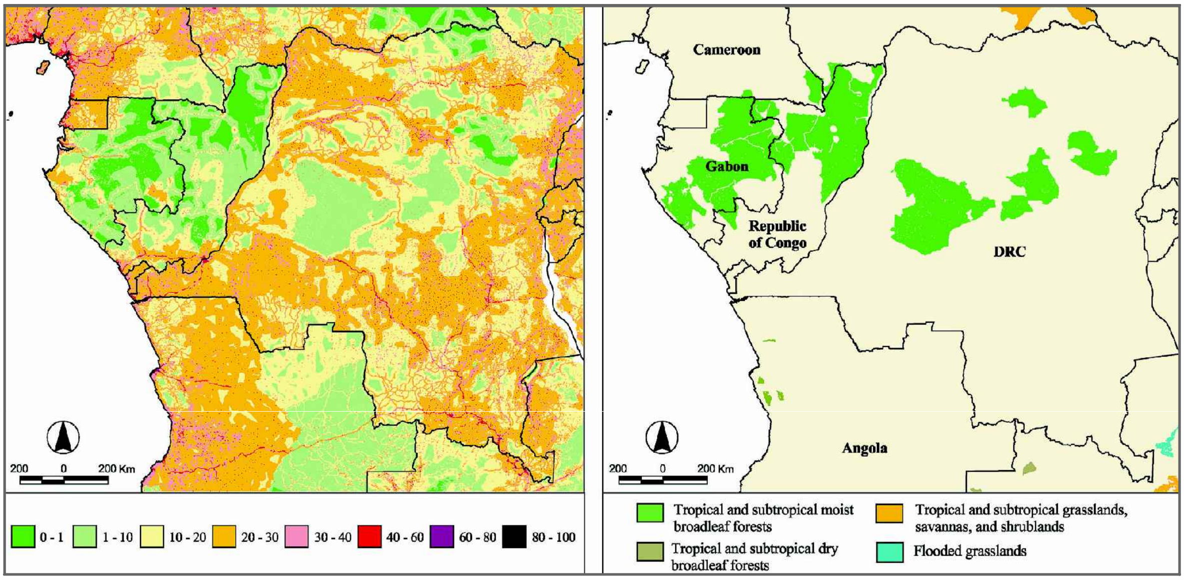

Figure 6. The human footprint and the last of the wild in Central Africa.

effects of roads and indirect effects of the access that roads afford, a power infrastructure that not only pollutes and modifies the climate but also enables extensive land transformation and road construction, and, ultimately, greater consumption of resources by an increasing human population (6 billion now and estimated to be 8 billion by 2020; UN Population Division 1993). Although not a complete catalog of conservation challenges, the human footprint provides an important basis for understanding conservation efforts on a global scale.

The human footprint permits us to organize conservation efforts along an axis of human influence. The kinds of conservation actions that are possible and the types of conservation targets that are available will often depend on the intensity of human influence. Where human influence is high, conservation will be limited in terms of the kinds and numbers of conservation targets available (for example, elk, cougar, and wolves have already been extirpated from the northeast United States). Conservation practice will typically focus on restoring ecosystems, reconnecting habitat fragments, and reintroducing extirpated species in landscapes cumulatively influenced by roads, human land uses, and high human population density. Where human influence is low (e.g., last-of-the-wild areas), a wider range of conservation targets and actions may be possible. These targets and actions could include creating and managing areas of limited human use (i.e., protected areas) and working with relatively smaller populations of local people and their institutions to moderate the outcomes of human influence, while maintaining existing conservation targets, as in Central Africa. Intermediate levels of human influence lend themselves to mixed strategies of preservation, conservation, and restoration, which are most efficiently planned at landscape or regional scales (Noss 1983, Sanderson et al. 2002). The cumulative nature of the human footprint means that, in areas

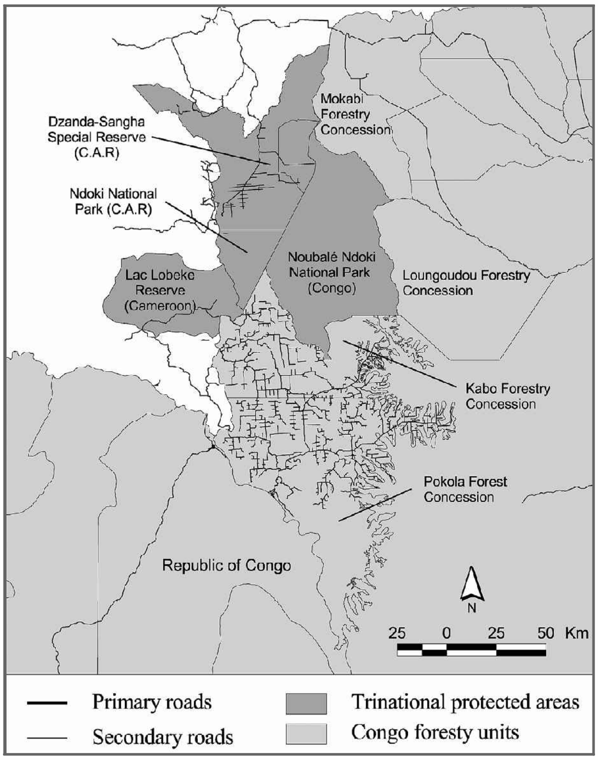

Figure 7. The Ndoki-Likouala Landscape Conservation Area in the trinational region of the Republic of Congo, Cameroon, and Central African Republic (C.A.R.). Primary roads, like those that are used to map the human footprint, are shown as a thick line. Most conservation threats in the region are a result of access along secondary roads, however, which are shown as thin lines and are not currently captured by global datasets. Roads data are courtesy of Frederic Glannaz (2001), Congolese Industrielle des Bois, northern Congo.

Table 2. *Summary of the human influence index scores by realm and biome.*

Realm	Biome	Area (km^2)	Minimum	Maximum	Mean	Standard deviation	10% wildest cutoff
Afro-tropical	Tropical and subtropical moist broadleaf forests	3,487,709	0	60	12.42	6.47	6
Afro-tropical	Tropical and subtropical dry broadleaf forests	189,751	1	37	11.11	5.57	5
Afro-tropical	Tropical and subtropical grasslands, savannas, and shrublands	13,983,895	0	60	11.81	5.95	6
Afro-tropical	Temperate grasslands, savannas, and shrublands	25,615	1	36	13.12	5.14	5
Afro-tropical	Flooded grasslands	458,499	0	54	11.59	5.41	5
Afro-tropical	Montane grasslands	863,265	0	56	16.20	5.37	6
Afro-tropical	Mediterranean scrub	93,732	0	60	15.85	7.86	6
Afro-tropical	Deserts and xeric shrublands	2,398,645	0	56	9.07	5.87	6
Afro-tropical	Mangroves	74,585	2	60	20.10	6.30	8
Australia–Asia Pacific	Tropical and subtropical moist broadleaf forests	1,156,438	0	50	10.88	5.83	5
Australia–Asia Pacific	Tropical and subtropical dry broadleaf forests	87,813	4	44	18.19	5.07	8
Australia–Asia Pacific	Temperate broadleaf and mixed forest	733,539	0	64	12.89	7.81	6
Australia–Asia Pacific	Tropical and subtropical grasslands, savannas, and shrublands	2,164,911	0	54	3.71	3.85	5
Australia–Asia Pacific	Temperate grasslands, savannas, and shrublands	629,594	0	50	6.32	6.19	5
Australia–Asia Pacific	Montane grasslands	67,639	0	32	7.03	3.56	3
Australia–Asia Pacific	Mediterranean scrub	803,405	0	64	9.37	6.77	6
Australia–Asia Pacific	Deserts and xeric shrublands	3,572,106	0	64	2.40	3.21	5
Australia–Asia Pacific	Mangroves	26,592	2	32	9.22	3.23	5
Indo–Malay	Tropical and subtropical moist broadleaf forests	5,395,598	0	60	17.60	7.23	6
Indo–Malay	Tropical and subtropical dry broadleaf forests	1,528,071	2	58	19.89	5.99	8
Indo–Malay	Tropical and subtropical coniferous forests	96,028	5	50	17.65	4.84	10
Indo–Malay	Temperate broadleaf and mixed forest	148,763	0	46	13.63	6.67	5
Indo–Malay	Temperate coniferous forests	64,075	0	46	15.47	7.67	5
Indo–Malay	Tropical and subtropical grasslands, savannas, and shrublands	34,681	14	52	22.54	5.84	18
Indo–Malay	Flooded grasslands	27,855	0	48	13.60	6.72	5
Indo–Malay	Montane grasslands	4,337	4	34	17.43	4.90	7
Indo–Malay	Deserts and xeric shrublands	1,085,536	4	56	21.25	6.12	9
Indo–Malay	Mangroves	114,232	4	54	21.11	5.94	9
Neotropical	Tropical and subtropical moist broadleaf forests	9,226,889	0	64	8.04	7.74	6
Neotropical	Tropical and subtropical dry broadleaf forests	1,779,363	0	60	12.63	8.08	6
Neotropical	Tropical and subtropical coniferous forests	321,948	1	56	17.24	5.48	7
Neotropical	Temperate broadleaf and mixed forest	395,543	0	56	9.87	6.82	6
Neotropical	Tropical and subtropical grasslands, savannas, and shrublands	3,410,947	0	64	10.66	6.86	6
Neotropical	Temperate grasslands, savannas, and shrublands	1,636,497	0	64	11.22	7.80	6
Neotropical	Flooded grasslands	323,357	0	64	11.72	7.86	6
Neotropical	Montane grasslands	811,134	0	46	8.47	5.44	5
Neotropical	Mediterranean scrub	148,516	0	64	17.91	8.17	6
Neotropical	Deserts and xeric shrublands	1,168,615	0	64	15.96	6.12	6
Neotropical	Mangroves	121,156	1	62	19.63	7.89	7

Table 2. (continued)

Realm	Biome	Area (km^2)	Minimum	Maximum	Mean	Standard deviation	10% wildest cutoff
North America	Tropical and subtropical dry broadleaf forests	51,009	0	54	14.71	8.41	6
North America	Tropical and subtropical coniferous forests	288,921	0	46	10.28	5.31	5
North America	Temperate broadleaf and mixed forest	2,838,104	0	68	17.79	9.50	7
North America	Temperate coniferous forests	2,303,350	0	68	10.28	8.77	7
North America	Boreal forests and taigas	5,091,934	0	60	2.07	3.89	6
North America	Tropical and subtropical grasslands, savannas, and shrublands	80,595	0	72	21.86	9.73	7
North America	Temperate grasslands, savannas, and shrublands	3,092,350	0	68	13.75	8.27	7
North America	Tundra	4,238,074	0	50	1.88	2.58	5
North America	Mediterranean scrub	121,268	0	64	16.93	11.45	6
North America	Deserts and xeric shrublands	2,322,298	0	64	9.55	6.52	6
North America	Mangroves	5,004	5	52	19.20	5.96	10
Palearctic	Tropical and subtropical moist broadleaf forests	509,896	4	52	18.03	4.83	9
Palearctic	Temperate broadleaf and mixed forest	8,663,974	0	68	20.94	7.66	7
Palearctic	Temperate coniferous forests	1,701,438	0	60	11.64	7.89	6
Palearctic	Boreal forests and taigas	9,945,699	0	68	5.13	6.06	7
Palearctic	Temperate grasslands, savannas, and schrublands	4,712,174	0	64	15.13	7.20	6
Palearctic	Flooded grasslands	334,501	0	60	17.13	9.67	6
Palearctic	Montane grasslands	3,373,792	0	46	7.69	6.25	5
Palearctic	Tundra	4,040,179	0	54	2.36	3.71	5
Palearctic	Mediterranean scrub	2,103,829	0	60	17.87	7.22	6
Palearctic	Deserts and xeric shrublands	17,324,845	0	60	6.21	6.20	6

Note: The 10% wildest cutoff score designates last-of-the-wild areas.

with intermediate levels of influence, often one factor of influence (e.g., roads or land use) may predominate and thus conservation measures should be targeted toward that factor. It is possible to imagine conservation strategies mapped out for different parts of the human influence continuum, based on the hypothesis that if human influence increases as it has for the last 100 years, conservation strategies will increasingly shift from preservation to restoration—with the concomitant increases in cost, time, and difficulty—much as they already have in the United States and Europe.

Meanwhile, we need to be careful not to read the maps of the human footprint and the last of the wild too literally. Although there is no doubt that the human footprint expresses an important perspective on the world, it is also true that, in its details, it contains inaccuracies (as noted above), and it is mapped at a scale coarser than most conservation efforts. For example, deep in the Central African forests, the Wildlife Conservation Society (WCS) works with the government of the Republic of Congo to conserve Nouabalé-Ndoki National Park (figure 7). The thicker roads shown on this map are those that appear in the data layer of roads in the human footprint, but it is the finer network of logging roads that most concerns WCS conservationists. Successful conservation of the Nouabalé-Ndoki forests and the animals that live there requires having biological and social scientists on the ground to monitor the real levels of impact, as well as to determine who is influencing the ecology of an area and how to work with them to mitigate the negative consequences of human activity. The human footprint as it exists today is too inexact to inform us much at the scale of site-based conservation action, but it does provide a way of seeing our relationship to the planet that connects local decisions to their worldwide impacts.

Conclusions

The global extent of the human footprint suggests that humans are stewards of nature, whether we like it or not. The long-term impact of human influence, positive or negative, benign or catastrophic, depends on our willingness to shoulder responsibility for our stewardship. Conservation organizations and biological scientists have demonstrated surprising solutions that allow people and wildlife to coexist, if people are willing to apply their natural capacity to modify the environment to enhance natural values, not degrade them, while making their living. An important step in generating the willingness to use human capacity for, rather than against, nature is to acknowledge the human footprint.

Part of that acknowledgment is a commitment to conserving the last of the wild—those few places, in all the biomes around the globe, that are relatively less influenced by human beings—before they are gone. In large part, this conservation effort will require legal, enforced limits on human uses of natural areas and the knowledge and capacity to manage well in all of the world's biomes. It will also require a willingness to forgo exhausting the last portions of natural ecosystems for short-term economic gain, because once they are gone, it will be very difficult and expensive to bring them back, if they can be brought back at all. To conserve the last of the wild, we must invest our talent and our resources to reclaim a more balanced relationship with the natural world.

Meanwhile, biological scientists, policymakers, and conservationists need to understand and conserve across the gradient of human influence (Margules and Pressey 2000, Miller and Hobbs 2002). The maps presented here provide a framework for understanding conservation efforts in the context of relative differences in human influence. It is possible to find portions of nature everywhere. Where we live in the New York City metropolitan area, magnificent hawk migrations have returned in the fall, though populations still show the effects of past insults, including "varmint shoots" and DDT. Native species continue to survive in small pockets of forest and salt marsh, despite having to contend with trash and competition from invasive species. The waters of the Hudson River and the harbor are cleaner than they have been in years, thanks to legal protections and conscientious local and upstream communities, but they still lack the abundance of fish and other life that once thrived there. We have some solutions, and nature, fortunately, is often resilient if given half a chance.

But the most important acknowledgment is for human beings, as individuals, institutions, and governments, to choose to moderate their influence in return for a healthier relationship with the natural world. We need to reinterpret the colors of the human footprint, so that red signifies where nature is most nurtured and green where wildness thrives. It is possible, and we join with our colleagues in the scientific community to suggest that it is also necessary, to transform the human footprint and save the last of the wild.

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