On the protection of "protected areas"

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Tropical moist forests contain the majority of terrestrial species. Human actions destroy between 1 and 2 million km^2 of such forests per decade, with concomitant carbon release into the atmosphere. Within these forests, protected areas are the principle defense against forest loss and species extinctions. Four regions—the Amazon, Congo, South American Atlantic Coast, and West Africa—once constituted about half the world's tropical moist forest. We measure forest cover at progressively larger distances inside and outside of protected areas within these four regions, using datasets on protected areas and land-cover. We find important geographical differences. In the Amazon and Congo, protected areas are generally large and retain high levels of forest cover, as do their surroundings. These areas are protected *de facto* by being inaccessible and will likely remain protected if they continue to be so. Deciding whether they are also protected *de jure*—that is, whether effective laws also protect them—is statistically difficult, for there are few controls. In contrast, protected areas in the Atlantic Coast forest and West Africa show sharp boundaries in forest cover at their edges. This effective protection of forest cover is partially offset by their very small size: little area is deep inside protected area boundaries. Lands outside protected areas in the Atlantic Coast forest are unusually fragmented. Finally, we ask whether global databases on protected areas are biased toward highly protected areas and ignore "paper parks." Analysis of a Brazilian database does not support this presumption.

biodiversity | tropical forest | conservation | deforestation

With species extinction rates running ≈100 times the background rate and poised to increase another 10-fold (1), assessing the success of conservation efforts is vital. For birds, the best-known taxon, recent efforts have substantially reduced the extinction rate, even as the number of species threatened with extinction has increased dramatically (1, 2). Does such success apply to all species? Habitat destruction is the leading cause of species endangerment, and establishing protected areas is the principal defense (3, 4). Protected areas cover ≈12% of the earth's land surface and serve many strategic purposes, including the preservation of species. An obvious question is whether protected areas "work" to protect biodiversity by retaining natural vegetation cover (5). Such protection is necessary, if not sufficient, to protect biodiversity (6).

Tropical moist forests contain the large majority of terrestrial species (3), and so we focus on them. Human actions such as logging and cultivation (7) destroy between 1 and 2 million km^2 of such forests per decade, with concomitant releases of carbon into the atmosphere (3). Even more forest is damaged by fires and selective harvesting (8, 9, 10). Four regions—the Amazon, Congo, South American Atlantic Coast, and West Africa—once constituted about half the world's tropical moist forest (3). We measure forest cover at progressively larger distances inside and outside of protected area boundaries for these regions.

We ask three questions with regard to protected areas. First, at a given distance, do protected areas retain more natural vegetation [supporting information (SI) Fig. S1] than adjacent unprotected lands? (And if there are differences, do these relate to differing management objectives?) Second, how fragmented is the natural vegetation within protected areas? [Other things being equal, highly fragmented vegetation will be of less value for protecting biodiversity (11).] Finally, are protected areas large enough to sustain viable populations of the species we wish to protect (12)?

Measuring Success

There are many measures of a protected area's success (13). When considering just species protection, many protected areas may be in the wrong place to be most effective in saving species (14).

Results of studies asking whether particular protected areas are effective range from an emphatic "no" (15, 16, 17) to an equally emphatic "yes" (8, 18, 19). The range of answers means that effectiveness must depend on many local factors, including political and economic ones.

Are there any generalities, or must we analyze each protected area individually? There are two large-scale quantitative assessments. Vanclay (20) has disparaged one of these (21) as statistically flawed. Certainly, its measure of effectiveness—questionnaire results from park employees and researchers (21)—clearly lacks independent quantification.

The second assessment comes from DeFries *et al.* (22), who explicitly quantify deforestation in and around 198 (moist and dry tropical forest) protected areas worldwide. The main conclusion is suggested by the paper's declarative title: "Increasing isolation of protected areas in tropical forests over the past twenty years". Certainly, the paper itself fleshes out this result in detail and recognizes considerable geographical variation in the results. To understand this paper better, we mapped out these results (see *SI Text*). In doing so, we found the geographical differences to be the most compelling, as we shall relate. Although this is essentially only a matter of emphasis, it opens paths of inquiry.

Our data and analyses differ from those of Defries *et al.* in that we do not describe rates of change. This limits some inferences of whether protected areas actually protect forest. That said, we find that whether protected areas do protect natural vegetation cover depends on a complex of factors than vary geographically and contextually.

We use global datasets to quantify remaining natural vegetation in and around protected areas in four tropical moist forests. We also estimate the fragmentation of the forests and how much area lies within a given distance inside the protected area boundaries. We do this for several different management categories. The Amazon and Congo are "wilderness forests," the two largest remaining tracts of tropical moist forest, whereas the Atlantic Coast and West Africa forests are biodiversity "hotspots" (23). These are regions with high numbers of endemic species (>1,000 endemic plants) and high levels of habitat loss (<30% of natural habitats remaining.) We initially chose the two New World regions because we have extensive field experience there and feel that they provide the important geographical contrasts that we wish to explore. We added the two areas in Africa because they are clearly analogous to the two New World regions. Importantly, we compare our results

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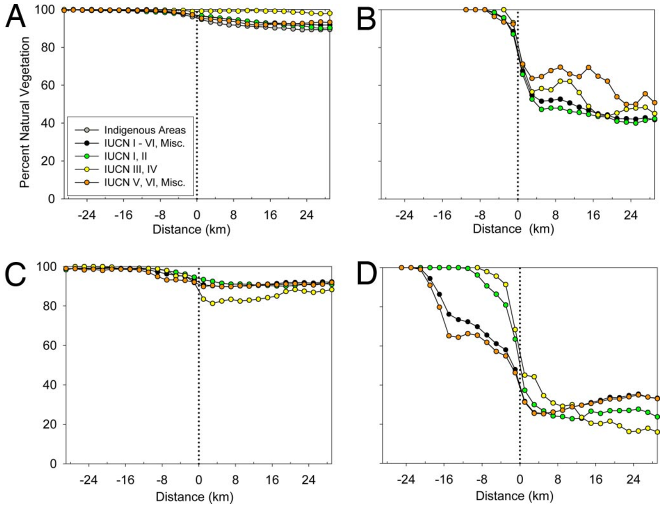

Fig. 1. Percentage of natural vegetation inside and outside protected areas in the four geographic areas of analysis: Amazon forest (*A*), Atlantic coast forest (*B*), Congo forest (*C*), and West African forest (*D*). IUCN categories are arranged in descending order of protection from I to VI. Categories I–IV are managed for biodiversity protection, whereas Categories V and VI are subject to multiple-use management. All protected areas are taken from the WDPA. Negative distances are inside protected areas; positive distances are outside. See also Fig. S2.

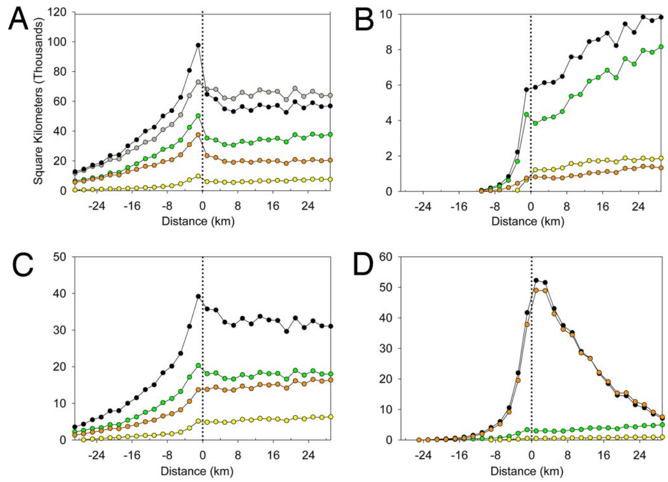

Fig. 2. Number of square kilometers included in the analysis at each 2-km distance increment in the four regions (see also Fig. S3). See Fig. 1 legend for symbol definitions.

from the global protected area database with an independent one that covers most of the two New World regions.

We survey tropical moist forests because they contain the large majority of terrestrial species (24, 25) and their conversion to open pastures, crops, and other human-dominated ecosystems is clearly visible in remote sensor images.

Quantifying deforestation, fragmentation, and the size of remnant habitats is a coarse approach to an issue as complicated as determining whether protected areas protect species. It overlooks many threats, only some of which we discuss below, and ignores the fact that some protected areas are not established for the purpose of species protection. There is always a tradeoff between generality and specificity. As we noticed above, there are many specific studies that are certainly interesting in themselves but completely miss the general patterns we uncover in this article.

Unlike other studies, ours is geographically and categorically comprehensive; we examine protected areas of multiple management types across four large tropical forests on two continents. Ours is an all-inclusive assessment of how natural vegetation changes with distance across protected area boundaries. With this scope comes limitations, of course, and our data are static; we do not look at changes over time. Nonetheless, visualizing the distribution of natural vegetation in and around protected areas is essential if conservation scientists are to make informed decisions regarding current and future protected areas (26).

Results

The World Database on Protected Areas (WDPA). The distribution of natural vegetation in and around protected areas differs greatly depending on the region. Fig. 1 shows the percentage of natural vegetation in 2-km annuli in from, and out from, the boundary of protected areas in the Amazon, Atlantic Coast, West African, and Congo forests in various categories of World Conservation Union (IUCN) protected areas (see also Fig. S2). IUCN categories are arranged in descending in order of protection from I to VI. Categories I–IV are managed for biodiversity protection, whereas Categories V and VI are subject to multiple-use management (see *Materials and Methods* for details and *SI Text* for definitions of management categories). Protected areas of all management categories located in wilderness forests (Amazon, Congo) contain high percentages of natural vegetation, as do the lands around them. In contrast, protected areas of all management categories in hotspots (Atlantic Coast, West Africa) show a sharp change at the protected area boundary, with much more natural vegetation inside than out. In West Africa, the amount of natural vegetation inside protected areas is lower than in the other three regions and remains so until well inside the reserve boundary. The *SI Text* provides maps of these regions, the categories of protected areas involved, and the land cover types.

Fig. 1 breaks down protected areas by IUCN category within region. The percentage of natural vegetation within protected areas is very similar in all categories in every region, with one exception: West Africa. Here, IUCN Categories V, VI, and “miscellaneous” perform poorly relative to Categories I and II and III and IV.

Fig. 2 shows the total land area involved in the above calculations. The different shapes of the relationships reflect geometric constraints. Inevitably, there is progressively less land at increasing distances inside a reserve. For regions where protected areas are small—the Atlantic Coast and West African forests—there is almost no area further than 10 km inside the boundary. Outside the boundary, the available land at different distances reflects the size and isolation of the protected areas. In the Atlantic forest, the protected areas are small and isolated, so the area outside the boundary increases with distance. In West Africa, the protected areas are also small, but the amount of land outside these areas declines with distance because of the high density of protected areas (primarily uncategorized “forest reserves”).

Significantly, whereas putatively well-protected areas (IUCN categories I and II) have the largest total areas in both regions of South America, they constitute only a small component of West Africa’s protected areas (see Table S1 for a regional breakdown of the number of protected areas of by category, average size, and corresponding variability of sizes). Also apparent is that West Africa is the only region with most reserves classified, if at all, in the lowest IUCN categories. Indeed, unclassified protected areas (primarily extractive forest reserves) make up the bulk of protected areas in the region. This has significant implications for the combined results for West Africa, especially as compared to the Atlantic Coast, where very few protected areas lack IUCN classification. Across all regions, IUCN Categories III and IV are consistently the least represented.

For a given amount of deforestation, the degree of fragmentation of natural vegetation can vary; it can cluster in a single large

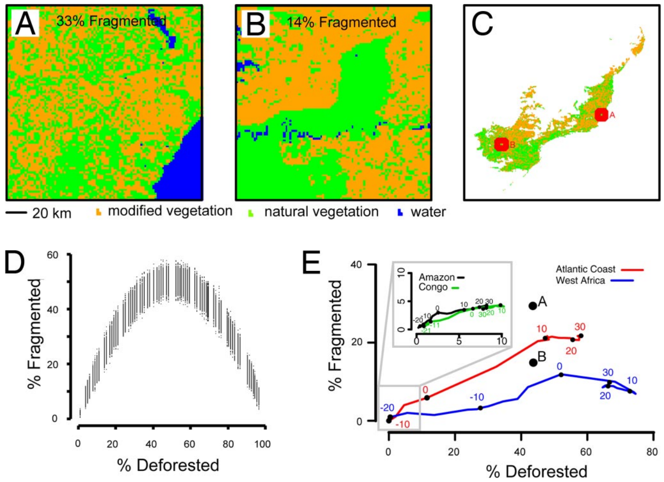

Fig. 3. Fragmentation measurements for differing percent natural vegetation across the four regions analyzed. (*Upper*) Two areas (*A* and *B*, both 200 km^2) experiencing similar deforestation (40–45%) but different levels of fragmentation. The map outline in *C* highlights the locations of the two plots in the Atlantic coast region of analysis. (*Lower*) (*D*) The range of fragmentation possible from 1,000 randomly deforested landscapes. (*E*) The fragmentation and deforestation values in and around protected areas in the four regions of analysis. Black circles on lines correspond to the distance in (negative values) or out (positive values) from protected area boundaries. Distance values (in kilometers) are located immediately above each circle. All protected area categories were combined for the analysis. The deforestation and fragmentation results of the two areas shown in *A* and *B* are highlighted by the letters A and B.

fragment or be widely scattered. In practice, the amount of fragmentation follows the patterns of deforestation, but it need not. The top panel of Fig. 3 shows how different amounts of fragmentation (two 200-km^2 plots, both with between 40% and 45% remaining forest) can result in two radically different landscapes. One has many small forest fragments (Fig. 3*A*), the other has mostly intact forest cover in the southeast and few forests elsewhere (Fig. 3*B*). The corresponding values of the metric explained in the methods are shown in Fig. 3*E* as points A and B.

Our metric readily compares points with different fragmentation but similar deforestation, but has an obvious limitation when it comes to comparing different levels of deforestation. At very low and very high levels of deforestation (the results are trivially symmetric), there can be only low levels of fragmentation; only at intermediate levels can there be widely different levels of fragmentation. We simulated 1,000 randomly deforested landscapes to illustrate in Fig. 3*D* the likely ranges of fragmentation for varying levels of deforestation. Real landscapes are nonrandom, with contingent fragments, and so are generally much less fragmented than simulated ones.

To compare landscapes, one should simply plot the fragmentation metric against deforestation, expecting the former to peak when deforestation is 50%. We do this in Fig. 3*E*.

The Amazon and the Congo show nearly identical patterns of fragmentation; it increases in both places as deforestation increases. For deforestation of $<$10%, the Atlantic Coast Forest and West Africa are also broadly similar. It is at higher levels that differences emerge. For a given level of deforestation, the Atlantic Coast forest is far more fragmented than West Africa, and where the boundaries of the protected areas lie on the two axes of deforestation and fragmentation is also very different. In West Africa, areas both immediately inside and outside of protected areas have $\approx$50% deforestation, the maximum amount of fragmentation as expected by chance. In contrast, in the Atlantic coast, there is much less deforestation near the boundaries ($\approx$10%) and somewhat less fragmentation. Some 10 kilometers outside a protected area, West Africa is mostly deforested ($\approx$75%) and so has a low fragmentation, whereas coastal Brazil is 50% deforested and is highly fragmented.

In all areas of analysis, the highest deforestation and fragmentation patterns inside protected areas occur within 4 km of the boundary. For the Amazon and Congo forests, less than 30% of the protected land is further inside the protected areas than this distance. For the Atlantic Coast and West African forests, the equivalent numbers are 85% and 70%, respectively. This places most protected land in the two hotspots near the sharply defined boundaries seen in Fig. 1 *A* and *C*.

Fig. 4 provides finer scaled (Landsat 5 imagery) examples of the broad patterns seen in Fig. 1. For example, Fig. 4*A* shows a portion of Jaú National Park, a remote IUCN Category II protected area within the Brazilian Amazon. There is no obvious difference inside and outside the park. Fig. 4*B* shows Sooretama Biological Reserve (IUCN Category Ia, Brazilian Atlantic coast forest), and Fig. 4*D* shows Nini-Suhien National Park (IUCN Category II protected area) and Ankasa River Forest Reserve (herein classified as a "miscellaneous" protected area) in Ghana, West Africa. Both images (Fig. 4 *B* and *D*) highlight a remarkable change at the reserve's boundary. Nonetheless, the protected areas are in three different IUCN classes. Okomu Forest Reserve, (IUCN Category II, Nigeria, Fig. 4*C*) provides a case history of the difficulties of managing protected areas, explored at length by Oates (27). As originally planned, it was one of only five West African protected areas covering $>$1,000 km^2. Less than 200 km^2 of natural forest remain within the reserve, albeit with a sharply defined boundary.

The Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (IBAMA) Protected Area Database. As we shall discuss presently, a key concern is whether the WDPA provides a reasonable set of protected areas from which to draw our conclusions. An obvious limitation of the WDPA is that it presents data in two forms: the mapped protected areas we have analyzed thus far, and point locations with associated data on the size of the protected area (see *SI Text* for a detailed explanation). For West Africa, the Congo, and many other areas worldwide, the point data add only a few percent extra to the mapped protected areas. Unfortunately, for the Amazon and Atlantic coast, the point data increase the total area by 50%, and for the Atlantic Coast by nearly five fold. In *SI Text*, we do the only analysis possible—we imagine the protected areas to be circular with an area equal to the known value and centered on the location specified (for a well explicated discussion of the implications of this method, see ref. 14). Not surprisingly, such hypothetical protected areas encompass substantial deforested areas, which in all probability the correctly delineated areas do not. Fortunately, for Brazil, which covers most of the Amazon and Atlantic Coast forest, there is an independent database available from IBAMA (www.ibama.gov.br/).

Fig. 5 contrasts data from the IBAMA and from WDPA. The far greater areas encompassed by the IBAMA data are obvious. For the Amazon, the two datasets broadly agree in the percentage of natural vegetation cover inside and outside of protected areas. For the Atlantic coast forest of Brazil, they do not. There is much less forest within the areas IBAMA specifies, a point to which we will return.

Discussion

Most protected areas in the Congo and Amazon are remote, large, and almost completely forested and sit within large, also nearly completely forested landscapes. The Amazon and Congo forests contain reserve networks of all management categories that incorporate multiple large protected areas. Large forested areas exist far inside protected area boundaries. Under such circumstances, an analysis of vegetation change is unnecessary: there could not have been extensive changes in forest cover either inside or outside the

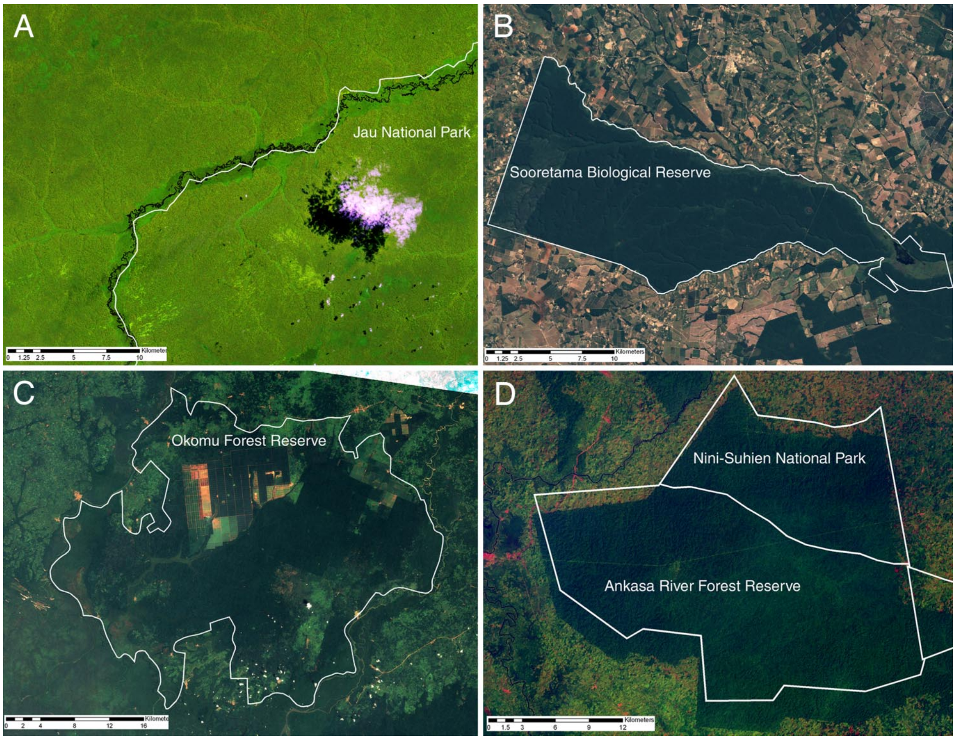

Fig. 4. Images of four protected areas of differing IUCN categories made by using satellite (LandSat 5) imagery. (*A*) Brazil: Jau National Park (IUCN II). (*B*) Brazil: Sooretama Biological Reserve (IUCN Ia). (*C*) Nigeria: Okomu Forest Reserve (IUCN II). (*D*) Ghana: Nini-Suhien National Park (IUCN II) and Ankasa River Forest Reserve (Miscellaneous). The white line indicates the boundary of the protected areas (as reported by the WDPA), which are all enclosed, except for the top left, where the park lies to the east of the boundary.

boundaries. Relatively few protected areas are on the fringe of these regions. They are in areas of rapid and extensive deforestation. As DeFries *et al.* (22) demonstrate, they are becoming ever more isolated, even if the protected areas are not losing much forest cover.

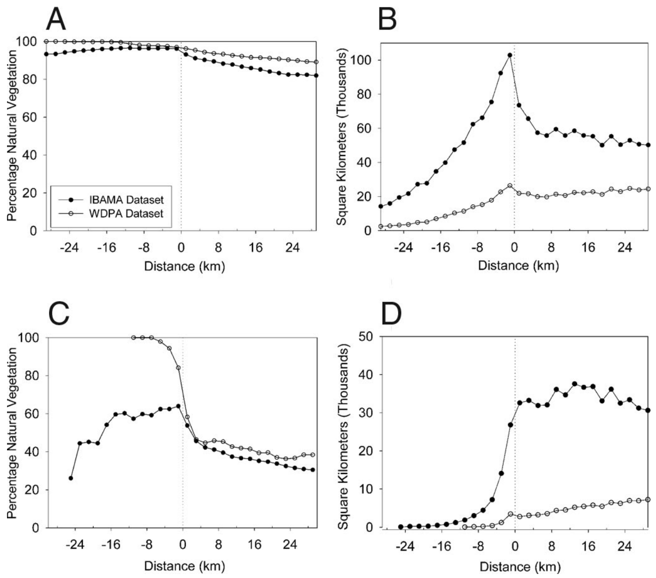

Fig. 5. Comparison between the WDPA (open circles) and the IBAMA (filled circles) datasets for two regions of Brazil. On the left is the percentage of natural vegetation inside and outside protected areas in the Brazilian Amazon forest (*A*) and Brazilian Atlantic coast forest (*C*). On the right is the number of square kilometers included in the analysis at each 2-km distance interval for the Brazilian Amazon forest (*B*) and Brazilian Atlantic coast forest (*D*). All protected area categories have been combined. Negative distances are inside protected areas; positive distances are outside.

In contrast, protected areas in West Africa and the Atlantic Coast typically house the last remaining forests in these regions. They are generally small. The Atlantic Coast forest has only 15 protected areas (IUCN Categories I or II) that are >200 km^2, for a total area of $\approx$7,500 km^2 (some of which is not tropical moist forest); the comparable numbers for West Africa are 10 protected areas totaling $\approx$8,500 km^2.

Deforestation inside protected areas reduces the effective size (22) of the protected areas still further. Within protected areas, intact core areas in the Atlantic Coast and West African regions are almost invariably small. Although areas further than 2 km inside IUCN Category class I–IV reserves in the Atlantic Coast Forest and West Africa retain $>97\%$ and $>90\%$ of their area as natural forest cover, $<3{,}000$ km^2 and $<7{,}000$ km^2 of those regions are that deep within protected areas, respectively. This is only 39% and 54% of all protected land in the two regions. The furthest interior points are only 12 km and 26 km, respectively, from the nearest boundary in the Atlantic Coast and West Africa.

In the Atlantic Coast, the forest outside protected areas is highly fragmented, but forest does remain. That this area still retains forest cover outside of protected areas reflects legal considerations. Most of the Atlantic Coast study area falls within Brazil, where the local laws and practices regulate deforestation and, in conjunction with topography, result in a highly fragmented but relatively well-forested landscape. (The contrast in Fig. 3 is between fragmented forests in Brazil and an equally forested but far more continuous forest in Argentina.) High fragmentation is ecologically detrimental, but does create more opportunities to connect existing protected areas (28), as well as to create new ones.

So, are protected areas protected? The superficial answer is "yes," forest cover is high inside reserves and strikingly higher than in surrounding areas with high levels of human impact. In addition, there seem to be negligible differences between management categories, perhaps allaying concerns about the globally increasing designation of IUCN Category V and Category VI protected areas. The complexity of our results rejects any such simple summary, however. There are several issues in determining protection.

***De Facto* Versus *de Jure* Protection.** Landscapes may escape deforestation because, like those in the Amazon and Congo, they are remote, or because they are on steep mountain slopes, have poor soils, or other features that protect them from human exploitation (29). Such places are protected *de facto*, and the effects of their designation as reserves may be negligible. Their effectiveness at withstanding human impact is simply untested.

More subtle comparisons of reserves within, say, the Amazon to detect whether protected reserves do better (by some metric) than unprotected areas are possible. Clearly, such studies need to carefully constrain confounding factors that are shown here to be substantial when inter-regional comparisons are involved. Such carefully constrained regional comparisons suffer the obvious lack of generality.

Conversely, protected areas may be ostensibly protected *de jure*. Many reserves in West Africa and the Atlantic Coast—Sooretema (Fig. 4*B*), for example—seem to be obvious examples of areas that retain forest only because of the laws that protect them. Outside such reserves, the forest is gone. Examples such as Sooretema notwithstanding, there are other examples in the Atlantic Coast where the distinction is not so clear; many of the protected areas are in mountains and involve land too steep to support crops or grazing.

To claim that *de jure* protection works requires not just the illusion of a sharp distinct boundary paired with a lack of some natural feature that might otherwise provide that protection (30). Rather, the all-important proof is that deforestation inside the protected area has stopped. Within the protected areas of the regions we consider, DeFries *et al*. (22) found only two examples of $>5\%$ loss of forest over 20 years of a sample of more than 80. Although not common, other well-documented examples exist (15, 16, 31), including Okomu (Fig. 4*C*) in West Africa (27).

The apparent scarcity of such examples suggests that most reserves are protected *de jure*, but a higher level of proof is required. Simply, claiming *de jure* protection requires studies of (say) forest cover over time across a set of protected areas that are unlikely to be protected *de facto*. Again, these constraints mean that although one might obtain locally specific conclusions, generalities are difficult.

IUCN categories are intended to summarize the different extents of *de jure* protection. Indeed, the recently observed increase in global coverage of the protected area network is due in large part to the designation of lowly categorized reserves (IUCN V, VI) (32). This has prompted discussion as to whether these protected areas differ from more highly categorized areas in their ability to conserve biodiversity (32). Descriptions of their management objectives would certainly lead to that conclusion (see Table S2). We find that IUCN categories do not differ much in their relative forest covers inside and outside reserves, except in West Africa, where most protected areas lack IUCN categories. Although this would seem promising for the inclusion of Category V and VI protected areas in the global network, it may be that our analysis is simply too coarse to pick up on the differences related to management categories. Alternatively, the results may indicate that on-the-ground management, not global classification schemes, dictates the outcome of protected areas.

Size Matters and so, too, Must the Matrix. Preserving forest cover may be a necessary criterion for assessing protected area effectiveness, but it is not sufficient (33). Although they effectively retain natural vegetation, many protected areas in the hotspot regions are too small to contain species with large ranges. For example, surveys of forest fragments find that those less than 100 km^2 lose their most vulnerable forest birds on a time scale of several decades or shorter because their populations are too small to be viable (34, 35). Such results clearly depend on the species concerned; some species might survive in fragments this small, whereas wide-ranging top predators would likely be lost from areas substantially larger (12).

More generally, our results are optimistic: natural forest cover may remain >2 km inside protected areas, but that does not mean that hunting, logging, and other activities do not eliminate species from inside them (33, 36).

We do not address the issue of how isolated the protected areas are. Using a 50-km buffer, DeFries *et al.* (22) found that $\approx 70\%$ of the buffers experienced habitat loss over the last 20 years, as opposed to only 25% of administratively protected areas (see Fig. S4). Importantly, protected areas with the greatest deforestation were those in south and southeast Asia that were relatively small, an attribute held by most protected areas in the Atlantic Coast and West African regions of our analysis. Based on their results, Defries *et al.* concluded that protected areas do protect, but that the loss of habitat adjacent to protected areas has severe ecological implications.

Where Are the "Paper Parks?" Paper parks are those administrators describe with enthusiasm that in reality provide little or no protection. Ref. 3 provides an example from Cebu in the Philippines, and Oates (27) discusses the problem generally for West Africa. We did not find such places, but it is possible that our results are circular. We take the areas that IUCN considers to be protected and from them analyze only those for which the WDPA provides digitized boundaries. Likely, these are the best of the best protected areas. We, or anyone else, claiming them to be effective may be looking at a highly biased sample. Might there be large numbers of parks designated only on paper that provide little protection (7) but which we have omitted?

This concern motivated our looking at the IBAMA data for the Atlantic Coast forest. The inclusion of these data suggests that large fractions of protected areas are deforested (Fig. 5), but it would be wrong to think these are poorly protected paper parks. The protected areas that IBAMA defines include the Tres Picos state park in Rio de Janiero, an extensive area of forest well protected by its mountainous terrain. It also includes a large planning region that, certainly, is mostly cattle pasture, but has long been so. Yet, this region encompasses the reserves of Poço das Antes and União, areas of active land acquisition, and private lands that receive conservation easements (37). Thus, the low forest cover within many of the putatively protected areas in the IBAMA dataset reflects an ambition to protect more land, not the failure to protect existing protected areas. For regional differences in coverage between datasets, see Table S3.

Management Implications. In the Amazon and Congo forests, protected areas are large and remote. Keeping them remote will likely keep them protected, but the challenge will be formidable. Extensive infrastructure developments are planned for the Amazon (38), and several Congo basin countries such as Gabon have leased large areas for logging (39). For the Amazon, Laurance *et al.* (40) refute claims that yet-to-be-built roads will be less damaging than existing roads. Human impacts, including fires that destroy forest, are almost all close to roads (41). Hence, environmental advocates should consider opposing roads and other infrastructure developments. *De facto*, these actions would create "mega-reserves" (42).

As noted, the efficacy of *de jure* protection is not yet obvious in the Amazon and Congo. Deforestation challenges some peripheral protected areas of the Amazon. Determination of whether they continue to retain their forest cover requires a more detailed analysis than that presented here.

In the Atlantic Coast and West African forests, protected areas are small. In West Africa, deforestation and fragmentation encroach further within administrative boundaries than any other

ENVIRONMENTAL SCIENCES

region in our analysis. In both places, because of their small size, protected areas will likely lose species, however well they protect forest cover per se. Thus, any opportunities to connect forest fragments by restoring degraded habitats should be a priority (37). The unusually fragmented forests (Fig. 3) outside protected areas in the Atlantic Coast provide an opportunity to do just that, unique within the four regions we consider.

Materials and Methods

We present methods here in brief only (see *SI Text* for details). The World Wildlife Fund provides a product that separates the earth into unique vegetative biomes and ecoregions (43). Biome 1 defines the extent of moist forest, from which we selected those forests occurring in four regions. Within these regions, we used the Global Land Cover (GLC) 2000 product (44) as the source for current land cover. The GLC 2000, the most current global land cover dataset available, classifies the earth into 23 categories of vegetation at a 1-km^2 resolution, with high accuracy (45). We considered each 1-km^2 pixel to have experienced human disturbance if it was in GLC Categories 16 (cultivated and managed areas), 17 (mosaic of cropland with tree cover or other natural vegetation), 18 (mosaics of cropland, with shrubs or grass cover), 19 (bare areas), or 22 (artificial surfaces and associated areas). We considered all other categories to be natural vegetation.

We calculated the percentage of fragmentation from the revised GLC 2000. We did this by summing the length of edge (the boundary between human-dominated landscapes and natural vegetation) within each distance interval. The length of edge was calculated at the 1-km^2 resolution of the GLC 2000 map. Each sum was divided by the maximum possible edge within each distance bin—a 1-km^2 checkerboard of natural and human dominated landscapes—to obtain a percentage.

We included in our analysis all protected areas available as polygons in the 2006 WDPA (46). The WDPA includes areas classified by IUCN into Categories I, II, III, IV, V, VI; Indigenous Areas; and Miscellaneous areas (see Table S2). For ease of analysis, we combined these categories in various ways, noting that they differ substantially in their promise of conservation effectiveness. Although many protected areas are surrounded by management buffer zones, the WDPA does not delineate these, thus hindering our ability to address these areas explicitly.

Because our analysis provides a complete enumeration of the status of all pixels inside and outside the boundary of protected areas, we are not dealing with statistical samples.

In addition to the data presented here, we used two other datasets. First, we analyzed a large set of WDPA data that present only the point location and area of protected areas. Second, and only for Brazil, we used a different classification of protected areas. These datasets have considerable limitations and alter some of the details presented here, but not the overarching conclusions. We discuss the secondary WDPA dataset at length in *SI Text*.

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