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Special Section Essay

Conservation in Sustainable-Use Tropical Forest Reserves

CARLOS A. PERES

Centre for Biodiversity Research, School of Environmental Sciences, University of East Anglia, Norwich NR47TJ, United Kingdom, email c.peres@uea.ac.uk

Introduction

Although tropical forests retain most of the world's terrestrial species, the relative merits of different approaches to ensure the long-term persistence of those species remain highly contentious. Most would agree, however, that both establishing protected areas and exercising some form of restraint on extraction of forest resources are among the most effective of all viable conservation measures. Deforestation, wildfires, logging, and hunting are among the leading drivers of species losses in tropical forests, and de facto or de jure protection from these threats can be conferred by either effective enforcement of regulations or physical remoteness.

Attempts to assess conservation success of protected areas at large scales have rested primarily on conventional use of remote sensing to quantify spatial or temporal differences in rates of change in land cover due to deforestation and wildfires, rather than on empirical demographic or community-level metrics (Gaston et al. 2008). However, the former approaches fail to detect most types of subcanopy anthropogenic disturbances that also result, directly or indirectly, in species losses (Peres et al. 2006). Moreover, the effects of habitat loss and degradation on population extirpations and declines are nonlinear, so vegetation cover alone is rarely a robust proxy for the viability of terrestrial biotas. Remote-sensing data show vast tracts of apparently intact tropical forests, but in reality levels of hunting and other forms of extraction in these areas are often unsustainable (Peres & Lake 2003). Fundamental questions yet to be answered include whether ostensibly intact protected areas retain full complements of forest species and how the extent of cryptic patterns of disturbance is related to human population density in both protected and unprotected areas.

I considered the global to regional emergence of sustainable-use reserves, emphasizing the world's largest tropical forest region, Amazonia. Sustainable-use reserves often have intermediate levels of disturbance, so I examined the degree of use of natural resources by resident communities and used human population density as a proxy for level of extraction. In both protected and unprotected areas, I also estimated responses of game vertebrate assemblages to hunting on the basis of the relative biomass extracted from a subset of the forest fauna. I used analyses of covariance (ANCOVA) to examine the association between human density and game biomass harvested across different reserve categories. Finally, I considered the long-term capacity of sustainable-use forest reserves to maintain populations of all resident species.

Survey of Sustainable-Use Reserves

The number and extent of protected areas worldwide have increased nearly 14-fold over the past 50 years. By 2010, >120,000 reserves covered approximately 21 million km^2, including 12.2% and 6.4% of Earth's terrestrial and marine biomes, respectively (WCMC 2011). However, there are far fewer reserves formally designated as strictly protected. Over 86% of all protected areas worldwide permit some form of human use (Fig. 1). For example, only <0.01% of the aggregate area of 980 marine reserves (covering approximately 19% of the world's coral reefs) are relatively undisturbed no-take areas (Mora et al. 2006).

The International Union for Conservation of Nature defines reserves as strictly protected (categories I–II) or sustainable-use (categories III–IV) areas. Sustainable-use reserves are often comanaged by local communities to support local livelihoods and preserve cultural legacies and ecosystem services. Both strictly protected and sustainable-use reserves, however, include areas with different management objectives that legally or illegally contain human communities at varying densities. Strictly protected ($n = 13{,}411$) and sustainable-use reserves ($n = 52{,}124$) represent 38.6% and 61.4%, respectively, of all protected areas worldwide, but the prevalence of

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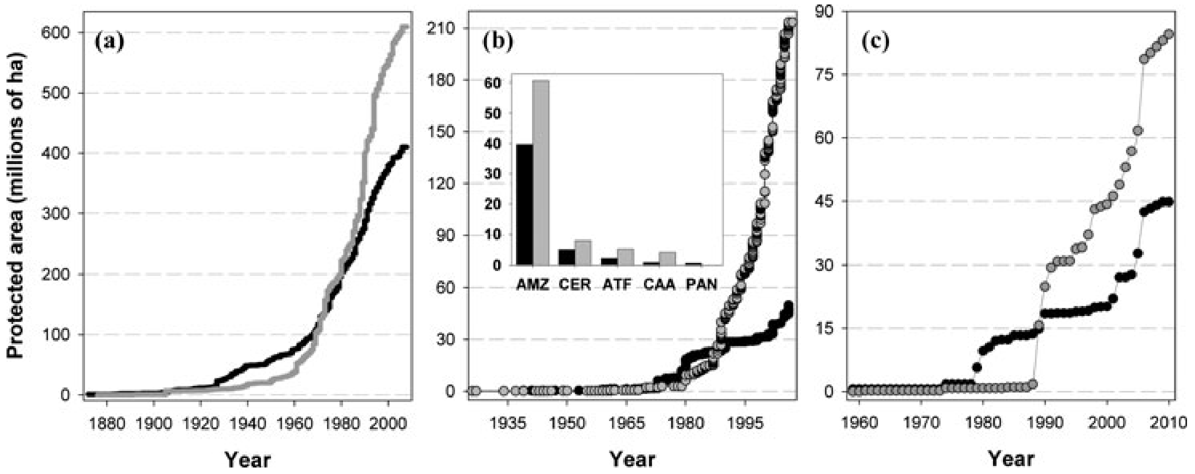

Figure 1. Extent of terrestrial protected areas over time in (a) terrestrial biomes worldwide (data from WCMC 2011), (b) Brazil (data from the Brazilian Ministry of Environment [MMA]), and (c) the Brazilian Amazon (data from the Brazilian Ministry of Environment [MMA] and Amazonian state agencies) (black lines and circles, strictly protected reserves; gray lines and circles, sustainable-use reserves). Data compiled in (a) include all reserves for which an International Union for Conservation of Nature category was assigned. Inset in (b) shows the aggregate areas (in millions of hectares) of all strictly protected (black bars) and sustainable-use reserves (gray bars, excluding indigenous territories) in each of the 5 major Brazilian biomes (AMZ, Amazonia; CER, Cerrado; ATF, Atlantic Forest; CAA, Caatinga; and PAN, Pantanal).

sustainable-use reserves is much greater in the Neotropics than in tropical areas of Africa and Asia (WCMC 2011).

Sustainable-use reserves in Brazil are charged with the difficult mission of ensuring both the usufruct access rights of local communities to natural resources and the persistence of all species and ecological processes (MMA 2000). Policies supporting sustainable-use reserves are relatively recent and firmly grounded in social and political demands from disenfranchised communities rather than in the desire to conserve biological diversity per se. Strictly protected areas in Brazil were far more prevalent before the 1980s, when they were seen as reliable conservation instruments. Since 1991, however, approximately 63.1 million ha of new sustainable-use reserves were created in Brazilian Amazonia, accounting for 51.5% of the total designated protected area excluding indigenous lands (Fig. 1). Designation was motivated by the intensification of land struggles, the subsequent political organization of many local communities, and the emergence of extractive reserve initiatives. As a result, the total number and combined extent of sustainable-use reserves and indigenous territories now outweigh that of strictly protected areas by factors of 5.5 and 4.1, respectively.

Nonprivate conservation areas across Brazilian Amazonia now encompass approximately 2,197,485 km^2 in 721 protected areas, amounting to 44% of the region (IMAZON 2011). This accounts for 12.6% of Earth's total terrestrial protected area, excluding Antarctica. Of the protected area in Brazilian Amazonia, 1,174,258 km^2 are in reserves managed by federal and state environmental agencies, approximately 1,086,950 km^2 are Indian Lands under the jurisdiction of FUNAI (National Indian Foundation), and 9700 km^2 are *quilombos* (designated Afro-Brazilian communal territories). Thus, 80.4% of the area covered by protected areas in the Brazilian Amazon has been allocated to forest reserves where human residents are empowered to pursue their livelihoods indefinitely. Yet little is known about the conservation success of these reserves and how to best manage them for the long-term persistence of both traditional livelihoods and biotic integrity.

Below-Canopy Conservation Success of Amazonian Reserves

As of 2007, mean human population density per square kilometer within Amazonian strictly protected reserves (0.32 [SD 0.78], $n = 37$) was considerably lower than in either sustainable-use (16.8 [SD 106.2], $n = 86$) or indigenous reserves (6.4 [SD 31.5], $n = 294$). Excluding unoccupied reserves, human population density was negatively related to reserve area (slope $= -0.52$, $R^2 = 0.\ 60$, $n = 398$, Fig. 2). Human population density ranged from fewer than 0.01/km^2 in reserves >1 million ha to over 100/km^2 in reserves <100 ha. For indigenous territories, the relation between area and population density was stronger ($R^2 = 0.70$, $n = 294$) and had a steeper regression slope than either extractive reserves or strictly protected reserves ($F_{1395} = 11.7, p < 0.001$). Strictly protected reserves may be completely uninhabited (Fig. 2), but otherwise share the same relation between population density and area as other human-occupied reserves ($F_{1395} = 0.32, p = 0.57$).

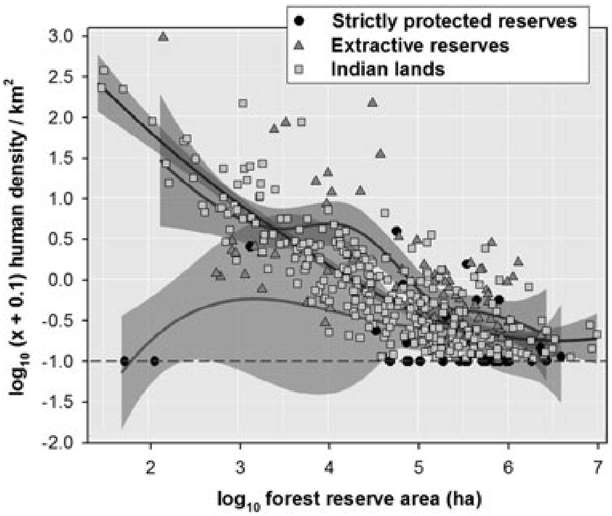

Figure 2. Relation between forest reserve size and the human population density in 417 protected areas in Brazilian Amazonia (data from Instituto Socio Ambiental [2011] and personal communication with protected-area managers) (light gray squares, indigenous territories [$n = 294$*]; dark gray triangles, extractive reserves [*$n = 86$*]; solid circles, strictly protected reserves [*$n = 37$*]). Reserves along dashed gray line are unoccupied (human density = 0). Gray areas around LOESS smoothed curves represent 95% CIs.*

Vertebrate populations meet the subsistence protein needs of millions of forest dwellers worldwide, and the value of those vertebrates for local livelihoods exceeds that of any other nontimber resource in tropical sustainable-use reserves. Fluvial and road networks render these reserves widely accessible to hunters (Peres & Lake 2003), but hunting pressure depends on local consumer demand and thus human population size. I, therefore, assessed the degree to which species have been depleted by hunting in otherwise undisturbed forests inside and outside protected areas. Building on a previous study (Jerozolimski & Peres 2003), I assembled a database—56,065 kills of 38 mammal species from 79 hunting studies representing 113 settlements across 7 Amazonian countries—from both published and unpublished sources, including my studies at 8 indigenous and nontribal (*caboclo*) settlements. The sizes and locations of these settlements and the total sampling effort (number of consumers $*$ number of sample days) were known, so site- and species-specific mean per capita biomass harvest rates (grams per person per day) could be calculated. I also quantified the human density associated with each hunting catchment on the basis of the size of each village and neighboring settlements within a 20-km radius. I estimated the proportion of the total biomass extracted from the 10 large-bodied species with the lowest fecundity (slow breeding and long lived) on the basis of population growth rates (λ) < 1.3. Species with low population growth rates are preferred by hunters across the Amazon (Jerozolimski & Peres 2003) and the Congo basins (Fa et al. 2005), but hunting patterns change whenever local populations of preferred species become depleted, when hunters gradually shift to smaller-bodied species with higher fecundity.

Local communities in sparsely settled areas derived a much larger proportion of their game biomass from species with low population growth rates than species with high population growth rates. On average, species with low population growth rates accounted for >80% of the biomass harvested where human density was <0.03 person/km^2, but <40% in areas with >1 person/km^2 (Fig. 3a). Although this relation does not account for geographic variation in carrying capacity for different species, many densely settled communities in both low- and high-productivity areas shifted to smaller-bodied, high-fecundity species. In particular, the dietary transition from species with low population growth rates to species with high population growth rates occurred well before human density reached 1 person/km^2, a density threshold below which hunting by tropical forest dwellers is generally assumed to be sustainable (Robinson & Bennett 2000). This finding is relevant given that Amazonian subsistence hunters with low incomes are often severely limited in terms of ammunition, time, and energy and regard pursuit of large-bodied species as most cost-effective per unit of spent ammunition. Furthermore, there were no significant differences in responses of multiple prey species to differences in human population density ($F_{1107} = 0.04$, $p = 0.84$) or ethnicity ($F_{3105} = 0.25$, $p = 0.86$) between protected and unprotected areas.

As a heuristic exercise, I estimated the area of human-occupied reserves that would be associated with a given pattern of game harvest for all sites for which reliable data on both human density and game harvest were available. For offtakes to remain dominated by species with low population growth rates (>50% of total biomass)—which could be interpreted as sustainable across the landscape—sustainable-use reserves would have to be >100,000 ha (Fig. 3b). Also, only hunters from sparse settlements within reserves approaching 1 million ha would be able to restrict their offtake to preferred species with low population growth rates.

Long-Term Role of Sustainable-Use Reserves in Retaining Tropical Species

Human densities within and adjacent to tropical forest reserves worldwide differ widely. The increasing isolation of protected areas (DeFries et al. 2005) and burgeoning

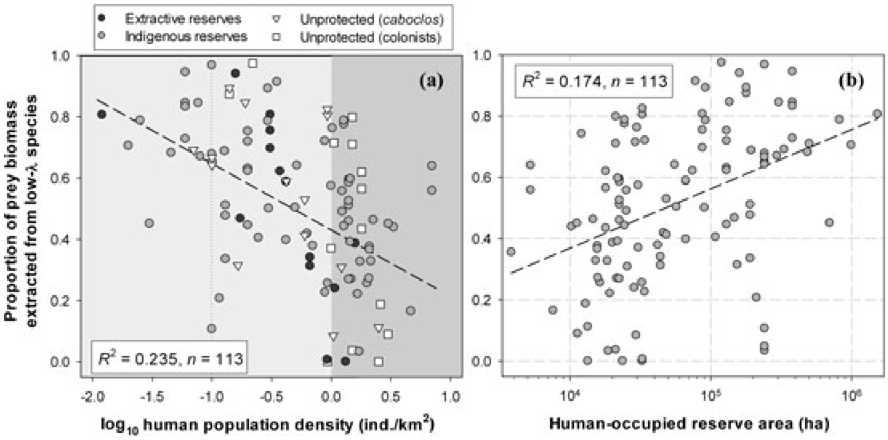

Figure 3. (a) Relation between human population density (HPD) within a 20-km radius of Amazonian settlements and the proportional biomass of low-fecundity vertebrate species ($\lambda < 1.3$) extracted from the aggregate number of prey items consumed at these settlements. (b) The size of forest reserves that these settlements would occupy for any given pattern of offtake, predicted on the basis of the linear regression between HPD and reserve area for all Amazonian indigenous, extractive, and strictly protected reserves for which human population sizes are known (data from Jerozolimski & Peres [2003] with new data added).

human populations in surrounding areas (Wittemyer et al. 2008) militate against the long-term persistence of many species within reserve boundaries. Lowland Amazonia is atypical of many tropical forest regions in that human population densities within reserves are usually greater than those outside. Yet the degree to which natural resource extraction can be defined as sustainable is largely governed by human density. Many Amazonian extractive reserves and their analogues have relatively high human densities, often because their residents were subsidized historically (e.g., by high rubber prices), and local initiatives to create an extractive reserve are usually instigated by politically savvy communities in heavily settled areas. Consequently, population sizes of several game species in many Amazonian sustainable-use reserves with >0.1 person/km^2 have declined (Fig. 3) (Peres & Palacios 2007). For species with low population growth rates, high human population densities reduce the effective reserve area. Moreover, most Amazonian sustainable-use reserves have annual human population growth rates of 2.7% to 4.2% (IBGE 2010), which doubles overall consumer demand every 16–27 years even if net migration is zero.

Over 370 million ha globally is under formal or informal community-based management, and including agroforestry areas would likely double or treble this total (Molnar et al. 2004). However, addressing the long-term interests of both species conservation and local communities in the mission of sustainable-use reserves is a huge challenge.

Hunting has often been intense in Amazonian extractive and indigenous reserves settled by relatively dense human populations, and many populations of large-bodied game species have been extirpated in these reserves (Peres & Palacios 2007). But game vertebrates represent only one type of nontimber forest resource that is exploited at unsustainable levels in many areas with high human density, and unsustainable hunting is not the only factor driving subcanopy forest degradation that cannot be detected with conventional remote sensing (Peres et al. 2006). Yet, most reserves across a wide range of categories and human population densities have so far been largely effective in retaining relatively intact forest cover (Nepstad et al. 2006; Joppa et al. 2008; Soares-Filho et al. 2010). Several densely settled sustainable-use reserves, however, have been deforested and severely degraded (e.g., Pedlowski et al. 2005). By December 2009, Amazonian sustainable-use reserves had lost 298,500 ha of forest after they were formally established, whereas 108,100 ha have been deforested in strictly protected reserves (IMAZON 2011). For example, >6.3% of the 970,570 ha Chico Mendes Extractive Reserve has been deforested to accommodate >10,000 head of cattle, an 11-fold expansion in pasture area since the reserve was created in 1990. This prominent extractive reserve was originally set aside to ensure land-tenure rights of approximately 3000 families of rubber tappers and Brazil-nut gatherers. However, most of these families have gradually shifted their livelihoods from nontimber resource extraction to livestock husbandry, in part to compensate for the shortfall in available animal protein resulting from depleted populations of game (G.K.C. Rosas, personal communication).

A total of 45.1% and 47.3% of the aggregate area designated in the Brazilian Amazon before December 2010 as sustainable-use and strictly protected reserves, respectively, exhibit some level of anthropogenic canopy disturbance as determined from satellite images (IMAZON 2011). Protected areas in Amazonia and most other tropical forests have extremely limited funds and staff, so enforcing reserve regulations and comanaging natural resources with local communities are usually prohibitively expensive. Each of the 305 staff assigned to oversee one or more of 163 state-managed protected areas across Brazilian Amazonia (excluding Rondônia) on average has jurisdiction over 63,520 ha (194 staff) within strictly protected reserves and 403,280 ha (111 staff) within sustainable-use reserves (IMAZON 2011). On a positive note, this institutional capacity is 3.2-fold greater than in 1993 (Peres & Terborgh 1995), despite the addition of approximately 1,035,000 km^2 of protected area over this period.

Indigenous, caboclo, and smallholder communities across Amazonia do substantially aid in meeting several conservation objectives, including prevention of illegal logging, mining, and deforestation within tribal lands, suppression of rampant land speculation, and protection of communal subsistence fisheries. In all these cases, local residents operating in areas with little governance intentionally or inadvertently suppress forest conversion and degradation, which are often driven by the private sector. However, not all species can be maintained under the jurisdiction of traditional communities. The key question, therefore, is what levels of biological integrity can one realistically hope to maintain given different scenarios of land-use and consumer population density.

The often raucous parks-versus-people debate is largely counterproductive and has little effect on policy or government agencies managing tropical protected areas. Setting aside >700,000 km^2 of sustainable-use reserves in Amazonia has resulted in little spatial redistribution of human residents. In fact, most boundaries of Amazonian protected areas are delineated and their management categories assigned on the basis of prior human occupation rather than on biological criteria. Yet involuntary human displacements from protected areas, with or without compensation, are ethically questionable, monetarily prohibitive, and politically unfeasible. Rather, conditional agreements with clear targets to be carried out by local communities remain the best available option to achieve conservation success. This often requires developing local capacity through training; regulation of immigration; setting sustainable harvest quotas; and zoning no-take areas within reserve boundaries. These targets are expensive and labor intensive, and may deflect conservation resources away from strictly protected areas. However, many conservation approaches can also benefit local communities outside protected areas, where the rate of forest conversion is likely to be higher. Sustainable-use reserves alone will not lift millions of tropical forest dwellers out of poverty and they should not be seen as key instruments of income generation. Yet such reserves can contribute to the persistence of key ecosystem services and viable populations across the entire range of species life histories (and sensitivity to disturbance and harvest) if they can be embedded within larger reserve networks that include strictly protected areas.

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