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Amazonian Nature Reserves: An Analysis of the Defensibility Status of Existing Conservation Units and Design Criteria for the Future

CARLOS A. PERES* AND JOHN W. TERBORGH

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Abstract: Many tropical nature reserves are woefully understaffed or exist only on paper. Without effective implementation, tropical reserves cannot count on in situ enforcement and consequently are subject to a wide range of invasive threats. Weak institutional structures are aggravated by reserve designs that facilitate rather than discourage unlawful human activities. Taking into account severe financial and institutional constraints, we consider the current status of forest reserves in lowland Amazonia. We ask how the criteria by which reserves are delimited may affect the efficiency with which the contained areas are defended. In a GIS analysis, we found that 40 to 100% of the area of all existing nature reserves in Brazilian Amazonia are directly accessible via navigable rivers and/or functional roads. Such access greatly facilitates the illegal harvest and conversion of forest resources in a region where each guard is responsible for protecting an area larger than the State of Delaware. Cost effective defense of large areas can be achieved through appropriate delimitation of reserves along watershed divides and by efficient deployment of limited infrastructure and personnel. Given current and probable future levels of financial resources allocated to reserve maintenance in Amazonia, any new nature reserves in this region should be designed and situated so that their defensibility is maximized. Defensibility criteria should complement site considerations based on biological criteria, such as presumed centers of diversity and endemism.

Las Reservas Naturales Amazónicas: un análisis del estado relativo de protección de las unidades de conservación existentes y del criterio de diseño para el futuro

Resumen: Muchas reservas naturales tropicales se encuentran desastrosamente atendidas o existen sólo en papeles. Sin una implementación efectiva, las reservas tropicales no pueden contar con una implementación in situ de la ley y en consecuencia están sujetas a un amplio espectro de amenazas invasores. Las estructuras institucionales débiles se ven agravadas por diseños de reservas que facilitan más que desalientan las actividades humanas fuera de la ley. En este estudio, consideramos el estado actual de las reservas de bosques en las tierras bajas de la Amazonía, tomando en cuenta las severas restricciones financieras e institucionales. Nos preguntamos cómo el criterio por el cual las reservas son delimitadas puede afectar la eficiencia con la cual las áreas contenidas son defendidas. A través de un análisis de SIG, encontramos que entre un 40 y un 100% del área de todas las reservas naturales existentes en la Amazonía Brasileña resulta directamente accesible por medio de ríos navegables y/o rutas funcionales. Este tipo de acceso facilita la riección ilegal y la conversión de recursos forestales en una región donde cada guardia es responsable de proteger un área mayor que el Estado de Delaware. Una defensa de grandes áreas, eficiente desde un punto de vista de costos, se puede lograr a través de una delimitación adecuada de las reservas a lo largo de las líneas divisorias de aguas y mediante un empleo eficiente de los limitados recursos de infraestructura y personal. Dados los niveles de los recursos financieros presentes y probablemente futuros.

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Paper submitted July 26, 1993; revised manuscript accepted March 16, 1994.
Introduction

Tropical-forest nature reserves are experiencing mounting human encroachment, raising concerns over their future viability even in remote areas. Long-term maintenance of nature reserves in economically marginal areas of the tropics is particularly problematical because protection is based on severely restricted funding from politically and administratively weak governments. Many tropical forest reserves consequently operate on skeletal budgets, are chronically understaffed, lack the most basic infrastructure, and cannot count on effective institutional support to enforce conservation legislation. Such frailties render reserves susceptible to a wide range of illegal activities—in hunting, fishing, logging, mining, land clearing—carried out by both individuals and corporations. Worse, the frequent inactivity of guards, who are often unarmed and lacking authority to make arrests, to prosecute violators leads to a general disregard of reserve boundaries and regulations. Once it is observed that the responsible authorities are unable to intervene, large-scale invasions by colonists, poachers, loggers, and miners may ensue and jeopardize the reserve’s biological resources.

The Amazon basin consists of some 7.05 million km$^2$ of lowland tropical forest in contiguous parts of Brazil, Peru, Ecuador, Colombia, Bolivia, Venezuela, and the Guianas (Tron 1978). The location of nature reserves in this region has been profoundly influenced by biogeographic analyses purporting to locate centers of diversity and endemism for a number of plant and animal taxa (Haffer 1969; see also Prance 1977, 1982; Whitmore & Prance 1987). Reacting to newly available biogeographical information, Wetterberg et al. (1976) produced the first comprehensive proposal for establishing conservation areas in Amazonia and recommended 30 high-priority areas for preservation. Proposed conservation areas coincided with centers of endemism identified by overlaying distribution maps for birds, lizards, butterflies, and woody-plants (Haffer 1969; Vanzolini 1970; Prance 1975; Brown 1975). Recently, this approach was reinforced and expanded by an international workshop ("Biological priorities for conservation in Amazonia," Manaus, Brazil, January 1990), which proposed 94 priority conservation areas for the Amazon Basin (Conservation International 1991). Many criteria were incorporated in the analysis, including phyogeographic regions, centers of biodiversity and endemism, and types of soils and climate (Rylands 1990a). The resulting map is available to planners, politicians, and conservationists.

The maps prepared by these conservation plans have led to the establishment of nearly 20 new nature reserves. Among the first were 10 in Brazilian Amazonia resulting directly from the proposals by Wetterberg et al. (1976, 1981; see reviews in Padua & Quintão 1984; Forceta 1991). More recently, the Manaus Workshop sparked the creation of eight ecological stations, which were decreed by the Brazilian State of Amazonas to coincide with proposed high-priority conservation areas (C. Miller, personal communication). Moreover, a comprehensive environmental blueprint entitled "Ecological and Economic Zoning of Amazonia," which has been carefully considering proposals from the Manaus Workshop, is being prepared by Brazilian government agencies. When implemented, the blueprint is likely to have sweeping implications for Amazonian conservation, both within and outside Brazil.

The biogeography of a limited number of taxa has been the primary consideration in identifying priority areas for conservation in Amazonia. Criteria of efficiency and effectiveness of protection have hardly entered the planning process (see Forceta 1991:133). Ignoring such practicalities in the design of new reserves is risky. The job of procuring and keeping resources to implement and maintain a reserve may pale before the physical threats that may have to be repulsed.

We urge that henceforth criteria of defensibility be incorporated into the process of designing and selecting future Amazonian nature reserves, so as to discourage and deter external pressures. We suggest that, in addition to biological considerations, reserve design in Amazonia should take into account the realities of low-budget implementation and weak or nonexistent enforcement of conservation policy. We do not propose any specific areas for protection, such as those recommended on the basis of intrinsic biological criteria (see Terborgh & Winter 1983; International Council for Bird Preservation 1992). Rather, we focus on the pragmatic issue of how to design and locate reserves to minimize implementation costs and maximize defensibility against existing and future external threats.

We begin our analysis with an overview of the numbers, sizes, and types of conservation units in Amazonia. We next consider practical design criteria, such as re-
serve configuration and location of boundaries with respect to avenues of access, especially roads and navigable rivers. We then suggest criteria for maximizing the defensibility of protected areas given the assumption of meager investments in infrastructure and human resources. Finally, we propose some practical guidelines for designing future Amazonian reserves.

Methods and Definitions

Data on Amazonian parks were obtained from published and unpublished reports of Amazonian natural resource agencies (see Instituto Brasileiro do Meio Ambiente e Recursos Naturais Renovaveis [IBAMA] 1990; Dias et al. 1991) and international nongovernmental organizations (Bylands 1990b, 1991; World Conservation Monitoring Centre 1992). Uniformly scaled maps of reserves were prepared for the Amazonian region of each Amazonian country using a digitizing table (Kurta XLC 3648) and a desktop Geographic Information System (GIS; Strategic Mapping 1990) to obtain measurements of total areas and perimeters. GIS-derived area measurements, when regressed against the areas of 50 reserves for which data were available, accounted for 99.8% of the variation, affirming the accuracy of the GIS procedure.

In a separate analysis based on high-quality 1:250,000 maps, available only for Brazilian Amazonia (Projeto Radam Brasil [RADAM] 1973–1981), we classified the geographic positions of existing reserves in relation to the total length of the watershed in which they are found. Watershed length was calculated using digitized linear measurements (broken down into 10-km segments) of the principal open-water fluvial course draining a reserve, from its headwaters to its final confluence with the Amazon (Solimões) River. Meandering of river channels was ignored because the maps we used indicate pronounced differences in river linearity across Amazonia. Reserves were then assigned to one of four position categories along the principal watercourse (lower, central/lower, central/upper, and upper), depending on where their geometric centers fell with respect to watershed length.

In the context of Brazilian Amazonian reserves, we also measured accessibility to illegal incursion as a function of nonlinearized lengths of navigable rivers (open water visible from space) and roads traversing or forming the boundaries of reserves, as resolved by the best available maps for the region (Defense Mapping Agency 1966–1988; RADAM 1973–1981; Institut für Angewandte Geodäsie 1986). Our measure of accessibility assumes that extraction of forest products (game, timber) in Amazonia is limited by transportation and that most rivers and roads within reserves are accessible to unauthorized intruders. We further assume that visitors will be willing to walk up to, but not more than, 10 km from the nearest navigable river or road to extract forest products, and accordingly we designated as accessible all such portions of reserves. The 10-km criterion is based on our own field experience and information obtained from tribal and nontribal Amazonians (Terborgh et al. 1986; Peres 1990). For instance, a 10-km walk is often reported as the maximum hunting radius for highly profitable game, such as tapirs (Tapirus terrestris) in unflooded (terra firme) forest (Bodmer et al. 1990; personal communication). Moreover, 10 km matches the recommended strip width for proposed buffer zones to be placed around Amazonian conservation units (Wetterberg et al. 1976; Decree 99.274/6th June 1990, National Environmental Council).

One potential weakness of our measure of accessibility is that it overlooks the large variation in human densities around reserves and associated differences in intensity of land use and intrusion pressure, all of which are subject to change over time. The 10-km criterion applied here is likely to be conservative because it neglects the potential for canoe traffic at high water on myriad forest streams that course underneath a closed canopy and hence are invisible in the RADAM side-scanning images.

Our classification of conservation units follows that of IBAMA, the Brazilian Institute of Environment and Renewable Natural Resources (Nogueira-Neto & Carvalho 1979; Instituto Brasileiro de Desenvolvimento Florestal 1988; Dias et al. 1991; IBAMA 1991), with some slight modifications. We wish to emphasize the distinction between strict nature reserves and other types of conservation units that legally permit various forms of resource extraction. Here, nature reserve means areas set aside for absolute or nearly absolute protection of representative biotas and ecosystems. Nature reserves, including national parks, biological reserves, and ecological stations, are established for nonconsumptive purposes, are strictly protected by law, and impose severe restrictions on human activities.

Production reserves, comprising national forests, extractive reserves, and game reserves, are defined as conservation units subject to forest and game management and are intended for sustainable production of timber and non-timber products. State or federal concessions to extract resources may be granted either to private interests, such as timber companies, or to communities of nontribal Amazonians operating independently or through cooperatives.

Indigenous reserves are distinguished in a third category because they exist on a substantially different legislative basis (Davis & Wall 1993). Indigenous reserves in Brazil are typically administered by an independent government agency, the National Indian Foundation. The category includes both indigenous and anthropo-
logical reserves (Brazil), indigenous reserves and res-
guardos (Colombia), and designated Amerindian lands 
(Guyana).

Results and Discussion

The Conservation System in Amazonia

An extensive network of 459 nature, production, 
and indigenous reserves is designated on paper for all 
Amazonian countries, although many of these have yet to be 
formally decreed (World Conservation Monitoring Centre 
1992). Reserves are widely distributed across the 
region, although many important gaps remain (Fig. 1). 
Nearly half (47%) of all designated reserves are smaller 
than 1000 km². Conservation areas between 1000 and 
10,000 km² account for another 41%, and those larger 
than 10,000 km² account for the remaining 12% (Fig. 
2). Nature reserves have an average area of 4765 km² 
(sd = 7815 km², range = 0.1–57,740 km², n = 117) 
and in general tend to be larger than production forests 
(mean = 3626 km², sd = 5823 km², range = 0.4–37,900 km², n = 94) and indigenous reserves (mean = 
4003 km², sd = 9870 km², range = 0.5–83,380 km², n = 
248).

One quarter (117 of 459) of all Amazonian conserva-
tion units are nature reserves, and theoretically have 
comprehensive protection. These account for 41% of 
the region’s total acreage under some form of institutional 
protection. The remaining conservation units in-
clude 94 production and 248 indigenous reserves, 
which respectively account for 15% and 44% of all non-
private land with some degree of protection.

Extensive systems of indigenous reserves are retained 
primarily by Colombia and Brazil. Over 18 of the 38 
million hectares of Colombian Amazonia are allocated 
to indigenous groups. In Brazil, approximately 20% of 
the Amazon area consists of indigenous reserves under 
the jurisdiction of the National Indian Foundation. 
The future value of these areas for biodiversity preservation 
is debatable, as several Brazilian tribes have already 
begun a process of outright liquidation of their resource 
capital (Redford & Stearn 1993). Resource depletion 
has taken the form of large land concessions granted to 
logging companies and goldminers and small-scale 
leases of forested land for a variety of exploitative uses 
(Economist 1993). If indigenous areas are to serve as 
stable strongholds of biological diversity, current prac-
tices will need to be replaced by enforced limits on the 
rights of indigenous peoples and colonists (Peres 1994).

Conservation planning is well developed on paper in 
all Amazonian countries other than Suriname and Guya-
ana, but in practice nature reserves often lack adequate 
protection. For example, only 10 of 35 nature reserves 
in Brazilian Amazonia employ even one local guard (By-
lands 1991). Although IBAMA maintains an extensive 
network of administrative outposts in small towns, the 
locations of these offices are often far from the nearest 
reserve. Current staffing results in an average of one 
park guard per 6053 km² of nature reserve. To put this 
in perspective, the density of guards in the 367 units of 
the U.S. National Park Service is more than 70 times 
greater (Table 1).

Understaffing is a consequence of a low governmental 
priority placed on conservation needs. Low priority re-
sults in severe financial constraints, aggravated by 
inflected administrative structures and competition with 
politically stronger government sectors (see Foresta 
1991 for historical review of political commitment on 
conservation in Amazonia). Apart from the financial and 
staffing limitations of park agencies, Amazonian park 
guards lack power to arrest violators and receive little 
or no backing from local police forces. Even if all these 
hurdles are surmounted, enforcement efforts are pur-
seued in a procedural vacuum without the benefit of legal 
precedents. Enforcement of protective legislation is 
therefore almost nonexistent, and the nature reserves of 
Brazilian Amazonia are consequently experiencing a 
wide range of anthropogenic threats to biodiversity (Ta-
ble 2).

A lack of financial and political will can lead to aban-
donment of conservation units as soon as conflicts with 
larger economic interests arise. Some examples of this 
include central-government decisions to overrun exist-
ing reserves with road construction and settlement pro-
tects throughout the southern flank of Brazilian Amazonia 
(Fearnside & Ferreira 1984); plans to exploit 12 
established conservation areas in Bolivia; and encroach-
ment of national parks by petroleum and mining com-
panies in Ecuador (World Conservation Monitoring Centre 
1992). In several of the worst cases, nature re-
erves have suffered from unencumbered disturbance 
to such a degree that they have been legally downsized 
or deagazetted within a few years of establishment (World, 

Many of the human threats confronted by nature re-
erves could be reduced if reserves were designed and 
located to maximize their defensibility under difficult 
financial conditions. In practice, reserves can be pro-
tected from hunters, loggers, miners, and other illegal 
intruders by physical inaccessibility as well as by stra-
gategic deployment of personnel.

Reserve Area versus Perimeter

Circles minimize perimeter length per unit of enclosed 
area and have consequently been proposed as optimal 
shapes for reserves (Wilson & Willis 1975). The size of 
existing nature reserves in Amazonia is a good predictor
of perimeter length, explaining 90% of its variation ($r = 0.951, n = 63$). The same is true for top-priority conservation areas proposed by the Manaus Workshop ($r = 0.955, n = 62$), even though the size range of these areas is nearly six-fold greater than that of existing reserves (Fig. 3). A considerable expenditure on patrolling and surveillance efforts would be required should reserve perimeters be equally accessible.

Accessibility of Brazilian Nature Reserves

Taking advantage of high-quality RADAM maps available only for Brazil and employing the 10-km criterion described above, we found that a mean of $75 \pm 19\%$ of the areas of existing nature reserves in Brazilian Amazonia are accessible to intruders entering by foot from included or adjacent rivers and roads. This parameter fell
of rivers and permit access to commensurately greater areas. But the absolute amount of inaccessible "core habitat," beyond the practical limits imposed by physical distance, clearly increases with reserve size. We view large core areas as indispensable to safeguarding populations of important biotic elements, such as top predators and preferred game and timber species.

Controlling river or road traffic in and out of a reserve would in principle require a guardpost with similar levels of staff and infrastructure for each access point. The cost of protection thereby increases linearly with the number of entrance and exit points. To examine this further, we determined the number of access routes in nature reserves of Brazilian Amazonia and conservation areas proposed by the Manaus Workshop for the entire region.

The number of rivers and roads providing potential access to conservation areas increases with their size and perimeter. This is true for both existing nature reserves (area: \( r = 0.73, n = 30, p < 0.001 \); perimeter: \( r = 0.77, n = 30, p < 0.001 \)) and proposed priority conservation areas (area: \( r = 0.42, n = 69, p < 0.001 \); perimeter: \( r = 0.37, n = 69, p = 0.002 \)). These results confirm that even the largest lowland Amazonian reserves and designated priority areas, given their present configurations, are highly vulnerable to incursion. Size alone is an ineffective defense because commensurately greater resources are not allocated to protect larger reserves. In Brazilian Amazonia, for instance, there is no relationship between the size of nature reserves and the number of guards (\( r = 0.27, p = 0.14, n = 30 \)) or total personnel employed (\( r = 0.05, p = 0.79, n = 30 \)). We therefore propose that new Amazonian reserves should, as much as possible, be delimited so as to gain the benefit of passive protection.

The Upper Watershed Reserve Model

Passive protection can be maximized by drawing boundaries along watershed divides, wherever practical. Watershed divides represent the least accessible points in the landscape and therefore, as boundaries, provide passive protection to the greatest possible degree. Second, locating boundaries along topographic divides protects intact watersheds and their aquatic resources. A complete watershed in a roadless landscape, no matter how large, can be controlled at a single point—where the contained stream exits the zone of protection (Fig. 5). By concentrating personnel at that point, effective protection of the entire watershed can be achieved at minimum expense.

However, most Amazonian nature reserves are either bisected and/or bordered by navigable rivers in the legal public domain. From a defensibility standpoint, such reserves suffer from multiple disadvantages: (1) every river that traverses a reserve calls for at least two guard-
Table 2. Categories of current threats to biodiversity faced by 29 federal and one state nature reserves in Brazilian Amazonia.

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| Road-building operations                              |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Adjacent land development                             |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Hydroelectric development                             |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
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| Unpreventable with Improved Design                    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Inadequate management                                 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Road-building operations                              |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Adjacent land development                             |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Hydroelectric development                             |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Military activity                                     |    |    |    |    |    |    |    |    |    |    |    |    |    |    |

<sup>a</sup> National parks: 1—Araguacu, 2—Amazonia, 3—Pacifica Novo, 4—Pico da Neblina, 5—Cabo Orange, 6—Jari, 7—Serra do Divisor, 8—Monte Roraima.

<sup>b</sup> Biological reserves: 9—Rio Trombetas, 10—Jari, 11—Lago Pinipuba, 12—Aubari, 13—Guaporé, 14—Gurupi, 15—Tapinapé, 16—Uatumá.


Modified from Blythe and 1996.
posts (Fig. 5a); (2) inhabitants of legal settlements on a bank opposite a reserve boundary have direct access to the reserve (Fig. 5b); and (3) even frequent fluvial patrols by guards would be ineffective in averting illegal (and undetectable) activities farther inland (Fig. 5).

An upper watershed approach to reserve design in Amazonia would simultaneously protect distinct biological assemblages in successive interfluvia and address the issue of species complementarity within reserve networks (Pressey et al. 1993). Also, locating Amazonian reserves in headwater regions would help maintain the spawning grounds of many migratory fish species (Ribeiro 1983; Goulding et al. 1988) and preserve a supply of potable water for downstream residents. Headwater regions often contain more topographic diversity than downstream areas and thus may include a greater variety of aquatic and terrestrial habitats. The watershed approach would protect riparian corridors and their hydrologic regimes, the latter being critical to maintaining the complex dynamics of landform mosaics, plant succession, and associated biodiversity (Salo et al. 1986; Kalliola et al. 1992; Puhakka et al. 1993; Naiman et al. 1993).

Biodiversity Gradients along Watersheds

If future Amazonian reserves are to be situated in headwater regions, it becomes important to consider how biodiversity is distributed along the length of river basins in both the aquatic and terrestrial realms. In the aquatic realm, zonation of riverine fish faunas is strongly differentiated with respect to stream order (Horwitz 1978; Goulding et al. 1988; Ibarra & Stewart 1989), as is the hydrological regime. Frequency of flooding and sediment concentration increase upstream, while amplitude and duration of flooding increase downstream. The richness of Amazonian fish communities increases downstream (Ibarra & Stewart 1989), an observation that is supported by a clear correlation between water discharge and species diversity (Garutti 1983). In particular, a number of large-bodied, aquatic vertebrates, including the Amazonian lungfish or pirapucú (Arapaima gigas), giant river turtle (Podocnemis expansa), and pink dolphin (Inia geoffrensis) rely heavily on

Figure 3. The relationship between total area and total perimeter of existing nature reserves and proposed high-priority conservation areas (combination of the two highest priority levels as proposed by the Manaus Workshop [Conservation International 1991]) in Amazonia. Dashed lines represent the theoretical curve showing the lowest possible increment in perimeter length/expected if reserves and priority areas were shaped as perfect circles.

Figure 4. The relationship between the size of 29 Brazilian Amazonian reserves and the proportion of the total reserve area that is accessible on foot, assuming a 10-km radius from the nearest point along navigable rivers and/or functional roads.
whitewater flooded forests (várzea) and are often missing in headwater regions. Moreover, many fish species of downstream pelagic habits make lateral migrations into várzea and igapó (Ribeiro 1983; Cox-Fernandes & de Merona 1988; Goulding et al. 1988). These are also expected to be missing in headwater regions.

On the other hand, recent fish collections in fast-flowing terra firme headwater streams in both the Guianan and Brazilian Shields appear to be extremely diverse and have yielded numerous undescribed and possibly endemic species (I. Rapp and Py Daniel, personal communication). The occurrence of unique elements in the aquatic faunas of both upstream and downstream sections of Amazonian rivers thus argues for the creation of reserves in both regions.

The ecological and evolutionary influence of rivers on Amazonian terrestrial biotas generally increases with distance from the headwaters, as rivers broaden to become more effective barriers to terrestrial organisms (Wallace 1849; Ayres & Clutton-Brock 1991; Capparella 1992; Haffer 1992; Peres et al. submitted). Greater duration and intensity of floods, lateral river-channel migration, and floodplain succession in lower river basins generally result in greater between-habitat (B) but not necessarily within-habitat (A) biological diversity along downstream sections of rivers. Headwater floodplains are more briefly and lightly flooded, and, accordingly, their associated forests are more similar to those of the adjacent upland (Puthalika et al. 1993).

Topographic gradients across Amazonia are extremely weak, as illustrated by the fact that ocean-going vessels routinely navigate more than 3000 km upstream. Consequently, the upper watersheds of major lowland Amazonian rivers contain most if not all of the terrestrial vertebrate alpha-diversity found in their central-lower catchment areas, a pattern that has been explicitly documented along the Rio Jurua for birds, primates, small nonvolatile mammals, and frogs (Peres et al., unpublished data).

Flooded forest and river island species, however, may be excluded from or represented in low densities in headwater regions (Remsen & Packer 1983; Rosenberg 1990). The floras of downstream flooded (várzea and igapó) and unflooded forests are strongly differentiated (France 1979), and many plant species typical of downstream flooded forests may therefore be poorly represented in headwater sites. Junk (1989) estimates that roughly one fifth of the 4000-5000 Amazonian tree species are tolerant to periodic flooding of several weeks to many months, even though flooded forests account for only 4% of the region. A second set of reserves complementing those in headwater regions should thus be set aside to capture downstream biotas.

Conservation of Downstream Biotas

Clearly, the size, location, and design of nature reserves along Amazonian watersheds will explicitly have to take into account the countercurrent longitudinal biodiversity gradients in the terrestrial and aquatic realms. Downstream reserves should be designed partly for the purpose of conserving aquatic resources, with particular attention to the watercourse itself and its fringing várzea or igapó forests. Here, the approach of controlling whole watersheds at strategic entry points is not applicable, and other approaches will have to be deve-
opined. Greater investment in guards and other personnel for downstream reserves can readily be justified by the vital economic importance of aquatic resources to the human population of Amazonia (Smith 1979; Petere 1982).

Watershed Coverage by Existing Nature Reserves

At present only three Amazonian national parks (Manu in Peru, Jau in Brazil, and Canaima in Venezuela) encompass all or a substantial proportion of a major watershed. Other nature reserves tend to sprawl over two to several watersheds and to include only a minor fraction of any one. In Brazil, for instance, only one Amazonian nature reserve covers an area equivalent to at least one quartile of the length of its main watershed axis (Fig. 6).

From a fluvial perspective, the nature reserves of Brazilian Amazonia are more or less evenly distributed between headwater regions and the confluence of major tributaries with the Amazon River (Fig. 6). But the distribution of protected areas is very uneven across watersheds. Some major watersheds benefit from multiple reserves, while many others contain none. The existing array of nature reserves in Amazonia thus embodies weaknesses at two levels. First, there needs to be a better dispersion of protected areas across drainages, and, second, both upstream and downstream conservation areas should be designed to maximize passive defensibility and cost effectiveness of enforcement personnel.

Proposed Priority Conservation Areas

The map prepared by the 1990 Manaus Workshop features several dozen high-priority areas for conservation action in Amazonia. These priority areas were intended to represent centers of endemism and diversity, but the evidence on which the areas were designated was often highly subjective, based on the personal experiences of participants. Available evidence on endemism and species density gradients in Amazonia is greatly weakened by heterogeneity of sampling effort, clustering of collecting sites, and large geographical gaps between sampling localities, any or all of which may account for apparent range discontinuities (Gentry 1986, 1989; Nelson et al. 1990; Oren & Albuquerque 1991). Large gaps between some high-priority conservation areas tend to correspond to subregions that received little or no previous sampling (Juruá River: Peres et al., unpublished data). Consequently, the Manaus Workshop map should not be taken as an unqualified picture of reality. Instead, it should be recognized as a good-faith effort to locate biologically important regions within Amazonia, with the understanding that the information upon which it is based will be subject to continuing revision.

To the degree that the Manaus Workshop map does accurately portray biologically distinctive areas within Amazonia, it should be noted that the locations of many of them, as well as those in previously published maps for individual forest-dwelling taxa, lie in the upstream portions of river basins (Francé 1982; Brown 1987). We therefore suggest that headwater reserves, if appropriately located and delimited, can satisfy both biological and defensibility criteria.

Costs of Implementing Reserves

Espírito Santo and Faleiros (1992) recently estimated at US$524 million the total cost of implementing the existing 99 National Parks, State and Federal Biological Reserves, Ecological Stations (or Reserves), National Forests, Extractive Reserves, and Environmental Protection Areas in the Legal Brazilian Amazon (a politically defined region of 5 million km²). Included were the costs of land purchase, demarcation, management plans, infrastructure, and equipment. Maintenance costs, including staff salaries, were estimated at US$29.5 million for the first five years, and US$27.1 million for subsequent years.

By far the largest component of the estimated cost (82%) was that for land acquisition. The complex land tenure system in Brazil is such that most Amazonian nature reserves are not entirely owned by the national or state governments: only 13 of 32 federal nature reserves in this region are wholly in the public domain (Espírito Santo & Faleiros 1992). Overall, private landholdings and claims amounted to 65% of the Legal Brazilian Amazon in 1990. States under strong development
pressure are already at least 83% in private hands (Maranhão and Acre), if not entirely so (Mato Grosso and Tocantins). Clearly, the matter of land property rights looms as a major impediment to implementing the currently designated conservation system in Amazonia. Proposals to add to the existing system will have to take into account the rapidly rising cost of repossessing land from private ownership. The infinite green horizon seen by anyone who flies over the Amazon seems reassuring, but is an illusion. The reality is that much of the land is already under claim.

Recommendations

Our watershed reserve model calls for a two-tiered structure of Amazonian reserves targeted to both the upstream and the downstream sections of major watersheds. A system of large (>1 million ha), inviolate nature reserves encompassing the upper sections of intact drainage basins would permit maximum control over boat traffic at minimal cost in personnel and infrastructure and would be intrinsically more resistant to human incursion than nearly all existing reserves. Preference in locating new nature reserves should be given to drainage currently lacking them. On the south bank of the Amazon within Brazil, unprotected basins include the upper sections of the Teles Pires (Pará/Mato Grosso), Iriri (Pará), and Jutai rivers (Amazonas), and some tributaries of the Juruá and Purús rivers (Acre). Networks of geographically clustered nature reserves could be interconnected by corridors running along headwater divides (Harriss 1985). A similar linkage approach has recently been proposed for Venezuelan parks (Yerena & Romero 1992).

An additional system of nature reserves in central-lower watersheds should be established to complement those in headwater regions. Downstream reserves will be essential to safeguarding representative várzea and igapó habitats, as well as important commercial fisheries. Such flooded-forest reserves will assure the continued functioning of intact habitat mosaics with their high productivity and distinct biodiversity (Prance 1979; Junk 1989) and will preserve the lateral migration of downstream aquatic organisms as well as the seasonal movements of forest wildlife using both flooded and unflooded forests (see Peres 1993). Almost inevitably, downstream reserves will have to be located in areas of relatively high human densities and therefore cannot be expected to protect nature in pristine form. Effective implementation of such reserves may require greater local-community participation, a process currently being tested by the Projeto Mamirauá in the lower Japurá river (Polshedk 1993; J. M. Ayres, personal communication).

Control posts should be located downriver of both headwater and flooded-forest reserves, either on the river bank or on floating docks in deep water at which boats could conveniently stop. Wherever practical, posts should be located within ready access of small towns, because it is difficult to recruit and retain competent personnel for duty in remote locations.

A new institutional approach to training and support of reserve personnel must be adopted if reserves are to be effectively defended in the future. Park guards in Amazonia are commonly recruited locally from the lowest social stratum. Accordingly, guards tend to be uneducated, poorly paid, and ill equipped. Such individuals are easily intimidated and hesitate to assert themselves to curtail unlawful activity. Effective enforcement of conservation policy depends entirely on the authority and respect given to guards. Therefore, it is imperative that guards be better trained and supplied with standard uniforms, weapons, and ammunition and be empowered to confiscate illegal materials and arrest violators.

Additional nature reserves are needed to increase the representation of fully protected areas in Amazonia and to fill some of the many large gaps between existing reserves. The existing system of nature reserves should be overhauled to the extent that large reserves can be redrawn, interconnected, and consolidated into comprehensive reserve networks. Small reserves should be retained unless the cost of maintaining them draws resources from more important reserves elsewhere.

Finally, we suggest that strict nature reserves should not be compromised by economic activities other than ecotourism if full complements of flora and fauna are to remain intact (Robinson 1993). A complementary network of production and indigenous reserves will assist in minimizing habitat fragmentation and maintaining biodiversity within the Amazonian landscape, but they should be designed to buffer and supplement rather than to replace an inviolate system of strictly protected nature reserves.

Acknowledgments

This report was prepared with the support of a Cooperative Agreement between the Center for Tropical Conservation at Duke University and the U.S. Agency for International Development. The views expressed are those of the authors and should not be attributed to either of these organizations or to the U.S. government. Fieldwork by C. A. Peres conducted prior to this analysis was funded by the Wildlife Conservation Society. We thank Julie Johnson and Carel van Schaik for making this project possible, and Chris Sharpe of the World Conservation Monitoring Centre, Cambridge, England, for facilitating access to data on South American protected areas. Carlos Miller of Fundação Vitória Régia Amazônica kindly provided an update on newly created Amazonian reserves. Lou Ann Dietz provided access to un-
published reports of the World Wildlife Fund. We thank Marty Jarrel for help with data analysis and Carol van Schaik and two anonymous reviewers for comments on the manuscript.

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