A Conservation Gap Analysis of Brazil's Amazonian Vegetation

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Abstract: *Vegetation types lacking protection in the existing conservation units of the nine states in the Brazilian Legal Amazon were identified, and locations were noted where these vegetation types could be protected. Maps of vegetation, protected areas, and semi-protected areas, such as Amerindian and forestry reserves, were digitized and overlaid using a geographic information system. There are 28 natural vegetation types in the Brazilian Legal Amazon. Locations of new areas for protection were selected using a minimum criterion of protecting at least one example of each vegetation type in each state (here called "vegetation zones"). There are 111 vegetation zones in the Legal Amazon, of which only 37 (33%) have some portion of their area protected. There are few protected areas in the most heavily deforested states along the southeastern fringe of the forest. In Maranhão, where 60% of the original forest had been lost by 1990, only one of 10 vegetation types is protected. Negotiating agreements with indigenous tribes, and to a lesser extent with extractivists who harvest nontimber products from the forest, represents a major opportunity to increase significantly the area and representativeness of the conservation units. Additional conservation units need to be established quickly before rapidly increasing deforestation and land prices preclude this opportunity; otherwise, some vegetation types may virtually disappear.*

Un análisis de conservación de la vegetación Amazónica del Brasil

Resumen: *Se identificaron tipos de vegetación carentes de protección dentro de las unidades de conservación de los nueve estados del Amazonas legal del Brasil y se establecieron los lugares donde esos tipos de vegetación podrían ser protegidos. Los mapas de vegetación, las áreas protegidas y las áreas semi-protegidas tales como las reservas Amerindias y forestales fueron digitalizadas y sobre-impuestas utilizando Sistemas de Información Geográficos. Existen 28 tipos de vegetación natural dentro del Amazonas legal del Brasil. La localización de nuevas áreas a proteger fueron seleccionadas utilizando criterio mínimo de proteger al menos un ejemplar de cada tipo de vegetación en cada estado (llamados aqui "zonas de vegetación"). Existen 111 zonas de vegetación en el Amazonas legal, de las cuales sólo 37 (33%) tienen protegida alguna porción de su área. Hay pocas áreas protegidas en los estados más deforestados a lo largo del borde sud-oriental de la selva. En Maranhao, donde hasta 1990 se había perdido el 60% de la selva original, solo 1 del los 10 tipos de vegetación se encuentra protegido. La negociación de acuerdos con tribus indígenas y en menor medida con aquellos que extraen productos no-maderables de la selva, representa una gran oportunidad para incrementar significativamente el área y representatividad de las unidades de conservación. Se necesita establecer rápidamente unidades de conservación adicionales, antes de que de la deforestación en rápido incremento y los precios de la tierra impidan esta oportunidad. En caso contrario, ciertos tipos de vegetación pueden virtualmente desaparecer.*

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Introduction

Decisions regarding protection of natural ecosystems require information on the biological importance of different areas and on the political and social factors affecting each area. It is important to identify areas of high conservation priority so that reserves can be established to protect biological and ecological diversity.

We used vegetation-type classifications to assign conservation priority to areas in the Brazilian Legal Amazon. The vegetation types are classified on a map produced by the Brazilian Institute of Geography and Statistics (IBGE) and the former Brazilian Institute of Forestry Development (IBDF) (IBGE & IBDF 1988). IBDF is now part of the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA), and the map is known as the "IBAMA map." Amazonian vegetation types from this map are defined in Table 1. Our use of vegetation types does not imply that other criteria should not also be applied, nor does it mean that areas we did not identify are unimportant. We sought to evaluate additional areas not already protected by the Brazilian government, and we assume that areas already protected will continue to be protected.

Natural vegetation types on the IBAMA map are used to define vegetation zones, or the area within each of the nine states in Brazil's 5×10^6 km^2 Legal Amazon that is covered by one of the vegetation types. The areas of biological priority indicated by the vegetation zone criterion are not particularly large. Applying other criteria produces much larger areas of high priority. One reason for setting aside large areas is the need for redundancy: Brazil has sacrificed protected areas in the past, which implies that protected areas will not necessarily survive indefinitely (Fearnside & Ferreira 1985; Foresta 1991). For example, Sete Quedas National Park was flooded by the Itaipu Dam in 1982, and there are current plans to sacrifice the turtle protection functions of the Rio Trombetas Biological Reserve when the Cachoeira Porteira Dam is built (Fig. 1). Also, illegal logging and goldmining activities are carried out within a number of protected areas (Peres & Terborgh 1994).

Establishing Priorities

A problem with establishing objective criteria for assigning biological importance is the varying levels of knowl-

Table 1. Natural vegetation types in the Brazilian Amazon.*

Category	*Code*	*Group*	*Subgroup*	*Class*
Dense forest	Da-0	ombrophilous forest	dense forest	alluvial Amazonian
	Db-0	ombrophilous forest	dense forest	lowland Amazonian
	Dm-0	ombrophilous forest	dense forest	montane Amazonian
	Ds-0	ombrophilous forest	dense forest	submontane Amazonian
Non-dense forest	Aa-0	ombrophilous forest	open	alluvial
	Ab-0	ombrophilous forest	open	lowland
	As-0	ombrophilous forest	open	submontane
	Cs-0	seasonal forest	deciduous	submontane
	Fa-0	seasonal forest	semideciduous	alluvial
	Fs-0	seasonal forest	semideciduous	submontane
	La-0	woody oligotrophic vegetation of swampy and sandy areas		open arboreous
	Ld-0	woody oligotrophic vegetation of swampy and sandy areas		dense arboreous
	Lg-0	woody oligotrophic vegetation of swampy and sandy areas		grassy-woody
	LO-0	areas of ecological tension and contact		woody oligotrophic vegetation of swampy and sandy areas—ombrophilous forest
	ON-0	areas of ecological tension and contact		ombrophilous forest—seasonal forest
	Pf-0	areas of pioneer formations		fluvio-marine influence
	SM-0	areas of ecological tension and contact		savanna—dense ombrophilous forest
	SN-0	areas of ecological tension and contact		savanna—seasonal forest
	SO-0	areas of ecological tension and contact		savanna—ombrophilous forest
Non-forest	Pa-0	areas of pioneer formations		fluvial influence
	rm-0	ecological refugium	high altitude	montane
	Sa-0	savanna	*cerrado*	open arboreous
	Sd-0	savanna	*cerrado*	dense arboreous
	Sg-0	savanna	*cerrado*	grassy-woody
	Sp-0	savanna	*cerrado*	parkland
	ST-0	areas of ecological tension and contact		savanna—steppe-like savanna
	Td-3	steppe-like savanna	Roraima grasslands	dense arboreous
	Tp-3	steppe-like savanna	Roraima grasslands	parkland

**Source: Instituto Brasileiro de Geografia e Estatística (IBGE) and Instituto Brasileiro do Desenvolvimento Florestal (IBDF) 1988.*

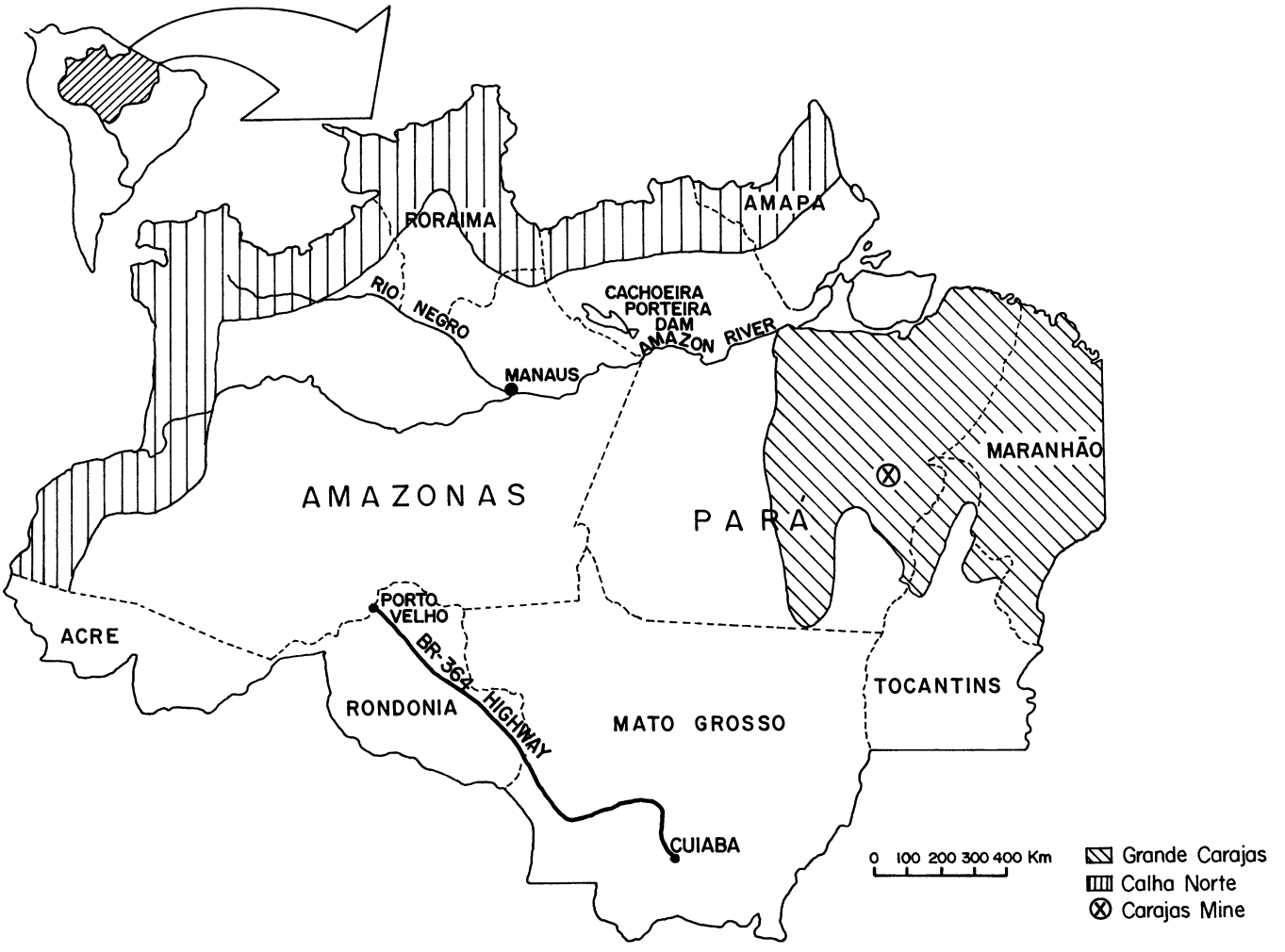

Figure 1. Brazil's Legal Amazon region.

edge about different ecosystems and geographic locations in Amazonia. Most biological diversity is found in heavily collected areas (Nelson et al. 1990). An alternative criterion would give highest priority to areas that have had very little study to avoid the loss of unknown but potentially valuable biodiversity.

The degree of threat posed by current exploitation and development also varies greatly among regions and vegetation types. Threatened areas include the *várzea* (white-water floodplain) forest, where the ease of water access combined with valuable timber species (such as *ucuuba* or virola—*Virola* spp.) have made this the primary source of timber in the region. In upland areas, locations with high concentrations of valuable trees, such as Rondônia's stands of *cerejeira* or cherrywood (*Torresea acreana* Ducke) and *mogno* or mahogany (*Swietenia macrophylla* King), have made them a prime target for logging, which includes activity in Amerindian reserves (Fearnside 1990*a*). A combination of ranching development, largely for purposes of land speculation, and charcoal production for pig-iron smelting in the Grande Carajás Program area has focused pressure on the forest types of that area, including the vine forests of western Maranhão (see Fearnside 1989*a*, 1989*b*). Plans for highway construction include the Trans-frontier Highway, planned for strategic reasons to parallel all of Brazil's international borders in Amazonia (*Jornal do Brasil*, 12 August 1991), and roads under the Calha Norte Program for military bases along the borders north of the Amazon River (Setubal et al. 1986). Settlement along these roads is to be promoted for strategic reasons (Setubal et al. 1986; Fearnside 1990*a*). In the case of western Acre, soil quality is presented as a justification for development (EMBRAPA 1988). These developments pose a threat to forests in the area.

Ecotones between the various types of savanna and forest, classified as "areas of ecological tension" in the IBAMA vegetation classification system (Table 1), are under the greatest pressure. The transition between forest and *cerrado* (central Brazilian scrub savanna) is under great pressure because of its proximity to major centers of population and because of the demand for timber and

charcoal, for example, in the southcentral part of the country. Grain production, especially soybeans, has been rapidly increasing as a source of pressure on the forest-*cerrado* ecotones. These vegetation types are easier to clear than denser forest types and have not been sheltered from the expansion of government-subsidized ranching programs. The Superintendency for Development of the Amazon (SUDAM) at least theoretically suspended approval of new projects in "dense forest" areas in 1979, but projects continued to be approved in practice. On 12 October 1988 the *Programa Nossa Natureza* (Our Nature Program) again suspended incentives. On 16 January 1991 a law (no. 167) limited incentives, only to be reversed on 17 April 1991 (Decree no. 101). Not until 25 June 1991 was a decree (no. 153) issued barring "concession of incentives that entail deforestation in areas of primary forest and destruction of primary ecosystems" (Article 15, paragraph 3).

Satellite data indicate the forest-*cerrado* transition zone is suffering the fastest deforestation (Fearnside 1990*b*, 1993*a*). Greatest pressure on the vegetation types located along the forest-*cerrado* boundary is also shown in a map analysis by Kangas (1990) using a 1:10,000,000-scale map of Holdridge life zones (Tosi 1983) and a series of simulated deforestation scenarios postulating various patterns of expansion of deforested areas from existing highways and towns.

Opportunities for Ecosystem Protection

As levels of threat vary so do levels of opportunity for creating protected areas. When opportunities present themselves, this factor must be considered. But efforts to establish new reserves should not be guided exclusively by the pursuit of opportunities, as has happened in the past. An overall strategy based on biological priorities must be devised.

One kind of opportunity arises from conflicting political claims to territory. Conflict between the states of Amazonas and Pará for *várzea* areas along the northern bank of the Amazon River is one example. Extractive reserves offer another major opportunity in which marketable products occur in relatively high density and local populations of extractivists (for example, rubber tappers) organize to manage these resources (Fearnside 1989*c*; Allegretti 1990).

Amerindian reserves represent a major opportunity for preserving natural ecosystems, provided these areas are used for this purpose. Amerindian reserves cannot now be considered protected in the absence of special negotiations with the tribes that declare parts of their reserve lands as conservation units. Indigenous peoples may not always use their reserves in environmentally benign ways. For example, the nontraditional productive system of the Navajo in the southwestern United States has led to severe soil erosion due to overgrazing by sheep (Brown 1981:48). Examples found in Brazil include tribes in Rondônia that allow goldminers and loggers to exploit tribal areas in exchange for a portion of the profits such as the Cinta Larga who allow mahogany logging in seemingly isolated portions of the reserve (J. Ferraz, personal observation).

Materials and Methods

We analyzed the 1:5,000,000-scale IBAMA vegetation map (IBGE & IBDF 1988), a simplification of the 1:1,000,000-scale maps produced by the RADAMBRASIL Project (Projeto RADAMBRASIL 1973–1983). The RADAMBRASIL maps were derived from 1:250,000-scale side-looking airborne radar (SLAR) imagery, in conjunction with field checking at approximately 3500 points at which forest inventories were conducted in the Legal Amazon. While the IBAMA map undoubtedly contains errors, and the present study cannot be more reliable than the map upon which it is based, the map does provide a useful starting point for a kind of analysis that needs to be applied to other existing and future maps. For protected and indigenous areas, we used maps (also at a scale of 1:5,000,000) produced by Conservation International (1990*a*, 1990*b*) for the Workshop-90 meeting held in Manaus in January 1990 (Rylands 1990).

We analyzed the maps to identify protected areas within each state and to identify areas of each vegetation zone that could be protected within the existing system of Amerindian areas. The maps were digitized, and areas of each vegetation type were tabulated by state and protection status using the ARC/INFO geographical information system (GIS) at the U.S. Geological Survey's (USGS) Earth Resources Observation Systems (EROS) Data Center, Sioux Falls, South Dakota. Geographic (latitude-longitude) coordinates for features on the vegetation map were calculated from the polyconic projection of this map; for the other maps, coordinates could be obtained directly. The GIS was used to overlay the vegetation with three additional layers: states, indigenous areas, and parks and reserves. The resulting digital data for the Legal Amazon were projected onto the Lambert Azimuthal Equal Area projection to allow correct measurements of area.

Some slight differences between the vegetation map and the other maps resulted in "sliver" polygons along the edges of the map, but these were minor and tended to overlap. The cases in which the border of Brazil on the vegetation map was outside the border shown on the other maps were balanced by cases in which the reverse was true. The vegetation map was clipped to conform to the protected-area map, leaving any cases of areas that were on the protected-area map but outside the vegetation map coded as "off map" and excluded from

the analysis. The presence of sliver polygons indicates that there was not a perfect match between the source maps. In most cases, errors were minor, considering the size of the regions. The sliver polygons were distributed as follows: 41 polygons of 0–500 km^2, 5 polygons of 500–1000 km^2, and 1 polygon each of 1708 km^2, 2056 km^2, and 2124 km^2. An analysis of more detailed source maps would be needed to avoid these discrepancies.

It should be emphasized that the coarse scale of the map used (1:5,000,000) means that many types of natural ecosystems are not represented: unique vegetation types either may be too small to appear at this scale or may have been lumped with other categories in the legend. In the future, more refined maps should be made to identify and protect these areas. Nevertheless, it is important, using the present map scale, to make a start by identifying the areas in which it is grossly apparent that protection is needed. The results of the exercise must be regarded as a minimum, not as a proposal for sufficiently protecting biological diversity.

Results and Discussion

Deforestation

The present extent of deforestation in relation to the original areas of forest cover is presented in Table 2 for the nine states of the Legal Amazon. By 1990 deforestation had reached 415.2 $\times$ 10^3 km^2, or 9.7%, of the area originally forested as defined in Table 1. In 1991 the cleared area increased by an additional 11.1 $\times$ 10^3 km^2, to total 426.3 $\times$ 10^3 km^2 (10–11% of the area originally forested). Deforestation has advanced to alarming proportions in states such as Maranhão and Tocantins. The lower percentage affected in some other states, such as Pará and Mato Grosso, is a reflection of the immense land area of these states: Because deforestation is unevenly distributed within these states, the impact on forest in the areas most affected is much greater than suggested by the percentage at the state level. The prevalence of endemism means that such concentrated disturbances can have severe effects on species restricted to these areas.

It is also important to remember the invalidity of the common but misleading practice of calculating the percentage of deforestation using as the denominator the land area of the political units instead of the original area of forest. In the case of Tocantins, for example, only 8.5% of the state's land area was deforested by 1990, but this represents 39.2% of the original forest. In Maranhão 35.9% of the state's land area had been deforested by 1990, representing 60.2% of the forest.

Parks and equivalent reserves in Brazilian Amazonia compose a small percentage of the region (Table 3). As of 1992, only 13 million ha, or 2.7%, of the Legal Amazon had been set aside in reserves, even on paper. This represents 3.0% the natural vegetation appearing on the IBAMA map. Current plans identify a target of 17 million

Table 2. Extent of deforestation in the Brazilian Legal Amazon.[a]

State	*Original IBAMA Forest Area[b] (10^3 km^2)*	*Original INPE Forest Area[c] (10^3 km^2)*	*Deforested Area (10^3 km^2) (%)*				
			January 1978	*April 1988*	*August 1989*	*August 1990*	*August 1991*
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
	Deforestation Exclusive of Hydroelectric Dams						
Acre	154	152	2.6 (1.7)	8.9 (5.8)	9.8 (6.4)	10.3 (6.8)	10.7 (7.0)
Amapá	132	115	0.2 (0.2)	0.8 (0.7)	1.0 (0.9)	1.3 (1.1)	1.7 (1.5)
Amazonas	1561	1481	2.3 (0.2)	17.3 (1.2)	19.3 (1.3)	19.8 (1.3)	20.8 (1.4)
Maranhão	155	143	65.9 (46.1)[c]	90.8 (63.5)[d]	92.3 (63.5)[d]	93.4 (65.3)[d]	94.1 (65.8)
Mato Grosso	585	528	26.5 (5.0)	71.5 (13.5)	79.6 (15.1)	83.6 (15.8)	86.5 (16.4)
Pará	1218	1139	61.7 (5.4)	129.5 (11.4)[d]	137.3 (12.1)[d]	142.2 (12.5)[d]	146.0 (12.8)
Rondônia	224	215	6.3 (2.9)[c]	29.6 (13.8)	31.4 (14.6)	33.1 (15.4)	34.2 (15.9)
Roraima	188	164	0.2 (0.1)	2.7 (1.7)	3.6 (2.2)	3.8 (2.3)	4.2 (2.6)
Tocantins/Goiás	58	59	4.2 (7.1)	21.6 (36.7)	22.3 (37.9)	22.9 (38.9)	23.4 (39.7)
Legal Amazon	4275	3996	169.9 (4.3)	372.8 (9.3)	396.6 (9.9)	410.4 (10.3)	421.6 (10.5)
			Forest Flooded by Hydroelectric Dams				
			0.1 (0.0)	3.9 (0.1)	4.8 (0.1)	4.8 (0.1)	4.8 (0.1)
			Deforestation from All Sources				
			169.9 (4.3)	376.7 (9.4)	401.4 (10.0)	415.2 (10.4)	426.4 (10.7)

[a] *Source: Fearnside (1993a) for 1988–1991 values; 1978 values remeasured by Skole & Tucker (1993) from Tardin et al. (1980); see Fearnside (1993b).*
[b] *Measured from the IBAMA map (IBGE & IBDF 1988).*
[c] *Measured by the National Space Research Institute (INPE). These forest areas are defined by appearance on LANDSAT-TM images and are most consistent with the deforested-area estimates in columns 4–8. They have therefore been used to calculate the percentages.*
[d] *Maranhão and Pará values include 57.8 $\times$ 10^3 km^2, 39.8 $\times$ 10^3 km^2, respectively, of "old" (approximately pre-1960) deforestation (now largely under secondary forest).*

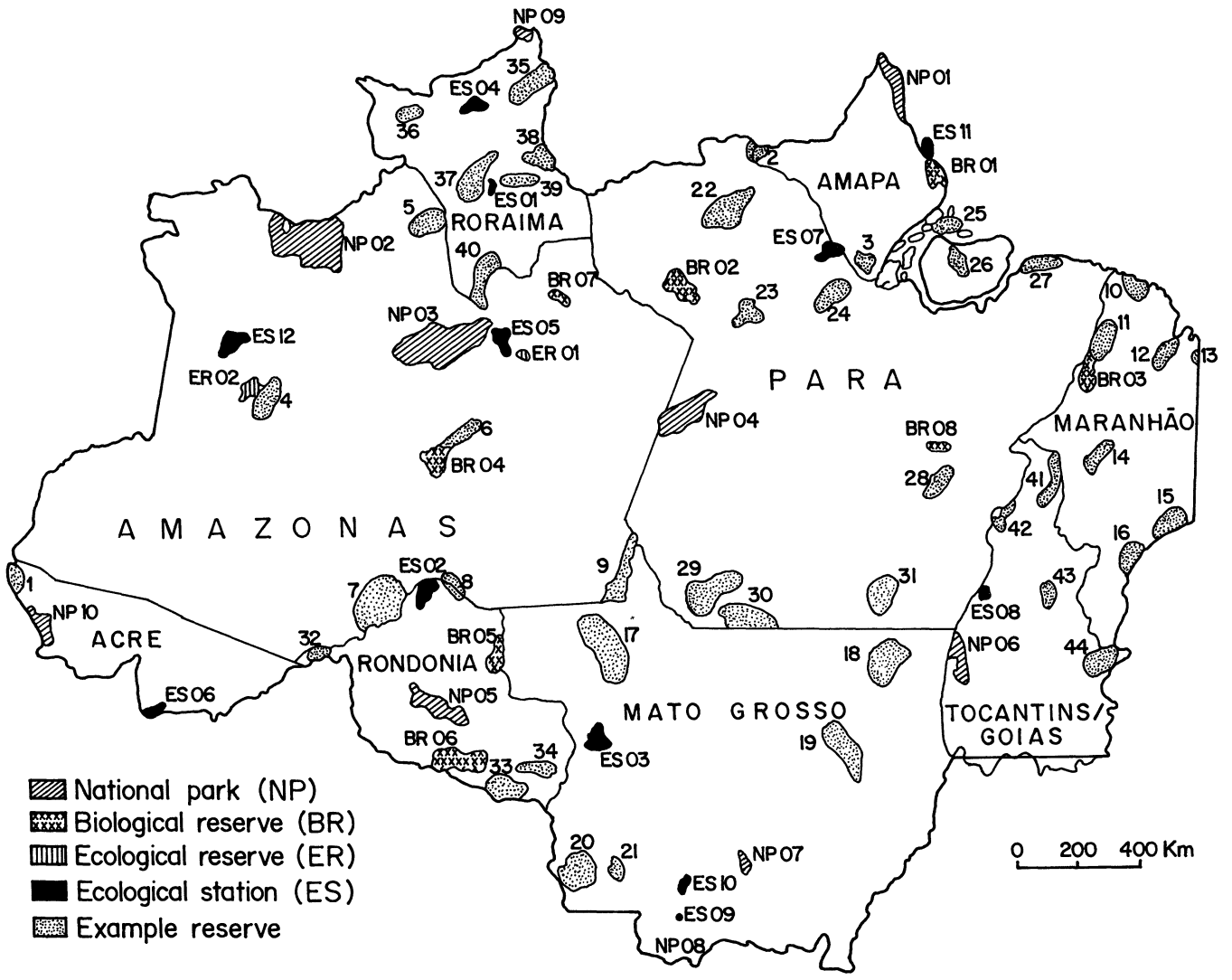

Figure 2. Existing protected areas (from Table 4, letters and numbers) and areas satisfying the criterion for protecting an example of each vegetation type within each state (from Table 5, numbers 1–44).

ha, or 3.3% of the region. In contrast, 25% of the original vegetation of the region was recommended for preservation in 1979 by the Interministerial Commission on Forest Policy in the original version of the draft law drawn up by the commission (Fearnside 1986). The areas in Table 3 refer to all types of vegetation, not only forests. Some discrepancies exist in the areas of conservation units measured from the maps (in Table 3) and those reported by other sources (IBAMA 1989, 1991).

The conservation situation would improve considerably if semi-protected areas were included. The term "semi-protected" is used here to refer to national forests, forestry reserves, extractive reserves, and indigenous areas. These units presently provide some inhibition of disturbance, but they lack legal requirements to prevent future exploitation and perturbation. Including semi-protected areas would increase the protected fraction of the Legal Amazon from 2.7 to 19.0% (Table 3). Incorporating indigenous and other semi-protected areas into a system of conservation units does not imply expelling the forest dwellers. On the contrary, not only do they have the right to inhabit their traditional homes, but their presence can potentially offer a better guarantee that the forest will remain standing than would transformation of these areas into parks without people, with protection against encroachment entrusted to IBAMA guards.

Commitments need to be negotiated with those responsible for these semi-protected areas (such as Amerindians, rubber tappers, and sectors of government tied to logging and forest management) to define the acceptable degree of disturbance and mechanisms for guaranteeing that these limits are not exceeded. At present, these areas cannot be considered protected. National

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Table 3. Protected and semi-protected areas in the Brazilian Legal Amazon.*

State	Terrestrial Area of State (10^3 km^2)	Protected Areas (10^3 km^2)					Semi-protected Areas (10^3 km^2)					Total of All Areas (%)
		Ecological Station	National Park	Biological Reserve	Ecological Reserve	Total (%)	National Forest	Forestry Reserve	Extractive Reserve	Indigenous Areas	Total	
Acre	154	984				4439 (2.9)			20,248	11,433	31,691	36,130 (23.5)
Amapá	142		4123	3969	548	8640 (6.1)			8052	9588	17,640	26,280 (18.5)
Amazonas	1568	4399	44,365	13,527	2057	64,348 (4.1)		36,980	3994	287,015	327,989	392,337 (25.0)
Maranhão	260			2936		2936 (1.1)				18,505	18,505	21,441 (8.2)
Mato Grosso	901	2225	2547			4772 (0.5)				111,285	111,285	116,057 (12.9)
Pará	1247		8206	3831	2016	14,053 (1.1)	3021	11,363		161,998	176,382	190,435 (15.3)
Rondônia	238	893	7176	8978		17,047 (7.2)			10,346	39,974	50,320	67,367 (28.3)
Roraima	225	5192			1156	7508 (3.3)				97,505	97,505	105,013 (46.7)
Tocantins/Goiás	273	370	4460			4830 (1.6)				23,415	23,415	27,875 (10.2)
Legal Amazon	5009	15,709	75,492	33,241	3761	128,203	3021	48,343	22,392	749,285	823,043	946,805
Percentage of area of Legal Amazon	100	0.3	1.5	0.7	0.1	2.6	0.1	1.0	0.4	15.0	16.4	18.9

**Areas measured from maps at a scale of 1:5,000,000 prepared by Conservation International (1990a, 1990b), with the exception of extractive reserves, which are from Fearnside (1989c). Areas do not include portions covered by water according to Brazil, IBGE & IBDF 1988. Not all indigenous areas listed have legal protection. All categories include all types of vegetation (not only forest); only intact natural vegetation is included. In the case of reserves not included on the Conservation International Map (Uatumã Biological Reserve, Sauim-castanheira Ecological Reserve, Caracaraí [Niquiá] Ecological Station, Coco-Javaes Ecological Station, Monte Roraima National Park), total area is used, possibly including water and nonnatural vegetation.*

Table 4. Vegetation types in protected areas by state in the Brazilian Legal Amazon.

State	Protected Area			Natural Vegetation Code[c] and Area (km^2)
	Code[b]	Type	Name	
Acre	ES06	ecological station	Rio Acre	Ab-0 (984)
	NP10	national park	Serra do Divisor	Aa-0 (372); Ab-0 (3083)
Amapá	BR01	biological reserve	Lago Piratuba	Da-0 (306); Pa-0 (3031); Pf-0 (473) Sp-0 (159)
	ES 11	ecological station	Maracá-Jipioca	Pa-0 (548)
	NP01	national park	Cabo Orange	Ds-0 (59); Pa-0 (2184); Pf-0 (1080); SO-0 (799)
Amazonas	BR04	biological reserve	Abufarí	Ab-0 (60); Da-0 (3312); Pa-0 (54)
	BR07	biological reserve	Uatumã	not included on Conservation International map [10,100]
	NP02	national park	Pico da Neblina	Da-0 (22); Dm-0 (3874); Ds-0 (2699); La-0 (597); LO-0 (13,672)
	NP03	national park	Jaú	Ab-0 (2699); As-0 (643); Db-0 (17,822); Ds-0 (378); Ld-0 (481); LO-0 (1248)
	NP04	national park	Amazônia	Db-0 (231)
	ER01	ecological reserve	Sauim-Castanheira	not included on Conservation International map [1]
	ER02	ecological reserve	Jutaí-Solimões	Aa-0 (98); Da-0 (945); Db-0 (1014)
	ES05	ecological station	Anavilhanas	Da-0 (449); Db-0 (481); Ds-0 (511)
	ES12	ecological station	Juami-Japurá	Da-0 (549); Db-0 (2286); LO-0 (123)
Maranhão	BR03	biological reserve	Gurupí	Db-0 (2936)
Mato Grosso	ES03	ecological station	Ioué	SN-0 (1712)
	ES09	ecological station	Taiamã	vegetation not available (143)
	ES10	ecological station	Serra das Araras	Sa-0 (513)
	NP07	national park	Chapada dos Guimarães	Sa-0 (820); SN-0 (119)
	NP08	national park	Pantanal Matogrossense	Sg-0 (852); SN-0 (754)
Pará	ES07	ecological station	Jari	Da-0 (7); Ds-0 (2010)
	NP04	national park	Amazônia	As-0 (75); Db-0 (5144); Ds-0 (2987)
	BR02	biological reserve	Rio Trombetas	Db-0 (795); Ds-0 (3036)
	BR08	biological reserve	Tapirapé	vegetation not available (182)
Rondônia	BR05	biological reserve	Jarú	As-0 (2398)
	BR06	biological reserve	Guaporé	Da-0 (295); Pa-0 (1560); Sa-0 (1388) SO-0 (145)
	ES02	ecological station	Cuniã	Ds-0 (192); SO-0 (701)
	NP05	national park	Pacaás Novos	Ab-0 (88); As-0 (2490); Ds-0 (363); Sa-0 (2105); SO-0 (2130)
Roraima	ES01	ecological station	Caracaraí	Ld-0 (475); LO-0 (111), plus the former Niquiá Ecological Station (no vegetation information available; not included on Conservation International map [2866])
	ES04	ecological station	Maracá	Dm-0 (564); Ds-0 (421); LO-0 (171)
	NP09	national park	Monte Roraima	not included on Conservation International map [1160]
Tocantins/Goiás	ES08	ecological station	Coco-Javaes	not included on Conservation International map [370]
	NP06	national park	Araguaia	Da-0 (57); Fs-0 (421); Sp-0 (3981)

[a] *Total areas by state differ slightly from totals in Table 3 because an adjustment for state areas has not been applied.*
[b] *Biological reserve = BR, ecological reserve = ER, ecological station = ES, national park = NP.*
[c] *Codes defined in Table 1.*

forests and forestry reserves, for example, are intended for future logging. The extractive reserves that have been created are justified primarily by their role in environmental conservation. The reserves represent an important initiative for maintaining the forest under the guardianship of its inhabitants. Care is needed, however, to avoid loss of the system's sustainability due to overly high expectations with respect to the capacity of these areas to absorb population or to produce wealth (Fearnside 1989*c*).

Most of the semi-protected vegetation is in indigenous areas, and, unfortunately, a large part of this land still lacks legal recognition and demarcation on the ground. Many indigenous areas included in Table 3 still are not legally recognized, and some of them have already been reduced by invasion or government decree.

Table 5. Example reserves for protection of currently unprotected vegetation types.

Reserve Number[a]	*State*	*Name*	*Vegetation Types*[b] *Example*
1	Acre	Extension of Serra do Divisor National Park	Db-0; Ds-0
2	Amapá/Pará	Serra do Tumucumaque	Dm-0 (Amapá); Dm-0 (Pará)
3	Amapá	Lower Jari	Db-0; Ds-0[c]
4	Amazonas	extension of Jutaí-Solimões Ecological Reserve	Aa-0[c]
5	Amazonas	Rio Demini	Lg-0
6	Amazonas	extension of Abufarí Biological Reserve	Pa-0[c]
7	Amazonas	Campos de Humaitá/ Campos de Estanho	Sa-0; SO-0; Sp-0
8	Amazonas/Rondônia	*várzea* of Rio Machado/Ji-Paraná	Aa-0 (Rondônia); Aa-0 (Amazonas)[c]
9	Amazonas	Rio Juruena	SN-0
10	Maranhão	mangroves of northern Maranhão	Pf-0
11	Maranhão	extention of Gurupí Biological Reserve	Ds-0
12	Maranhão	mangroves of São Luís	Pa-0; Pf-0
13	Maranhão	extension of Lençois Maranhenses National Park (off map)	SM-0
14	Maranhão	Rio Zutiua	Cs-0; SN-0
15	Maranhão	Boa Esperança	Sd-0
16	Maranhão	Rio Parnaíba	Sa-0; Sp-0
17	Mato Grosso	Aripuanã	As-0; Ds-0; ON-0; Sd-0
18	Mato Grosso	Serra do Roncador	SO-0
19	Mato Grosso	Upper Xingu/Rio Sete de Setembro	Fa-0; ON-0; Pa-0
20	Mato Grosso	Pontes e Lacerda	Fs-0; Sp-0; ST-0
21	Mato Grosso	Rio Jauru	Cs-0; Fs-0
22	Pará	Rio Cumina	Sd-0; SO-0
23	Roraima	Prainha	As-0; SO-0
24	Pará	*várzea* of Almeirim	Pa-0
25	Pará	Ilha Caviana	Da-0[c]; Pa-0; Sp-0
26	Pará	Ilha de Marajó	Da-0[c]
27	Pará	mangroves of Baía de Marajó	Pf-0
28	Pará	Serra do Carajás	As-0[c]; Dm-0
29	Pará	Serra do Cachimbo	Cs-0; ON-0; Sa-0
30	Pará	Rio Benedito	SN-0; SO-0
31	Pará	*cerrado* of Araguaia	Sg-0
32	Rondônia	Rio Abunã	Db-0
33	Rondônia	Upper Guaporé	Fs-0; Sp-0
34	Rondônia	Colorado d'Oeste	ON-0; SN-0
35	Roraima	Campos de Roraima	Sg-0; SN-0; Sp-0; Td-3; Tp-0
36	Roraima	parima refugium	rm-0
37	Roraima	northern extension of Caracaraí Ecological Station	As-0; La-0; Lg-0; ON-0
38	Roraima	Tacutu	Fs-0; SO-0
39	Roraima	eastern extension of Caracaraí Ecological Station	As-0; Lg-0
40	Roraima	Rio Jauaperi	Da-0; Db-0
41	Tocantins	Bico de Papagaio	As-0; Cs-0; SO-0
42	Tocantins	Rio Araguaia	Ds-0
43	Tocantins	central Tocantins	Sa-0; Sd-0; SN-0
44	Tocantins	*cerrados* of Rio Sono	Sa-0; Sg-0

[a] *Reserve numbers shown in Fig. 2.*
[b] *Codes defined in Table 1.*
[c] *These vegetation zones have some small area protected in existing reserves (< 0.5% of the area of the vegetation zone): Aa-0 in Amazonas; As-0 in Pará; Da-0 in Pará; Ds-0 in Amapá and Pa-0 in Amazonas. Two of these vegetation zones require additional reserves (example reserves nos. 43 and 44), and the others can be protected within the example reserves needed to protect vegetation zones currently with no area protected.*

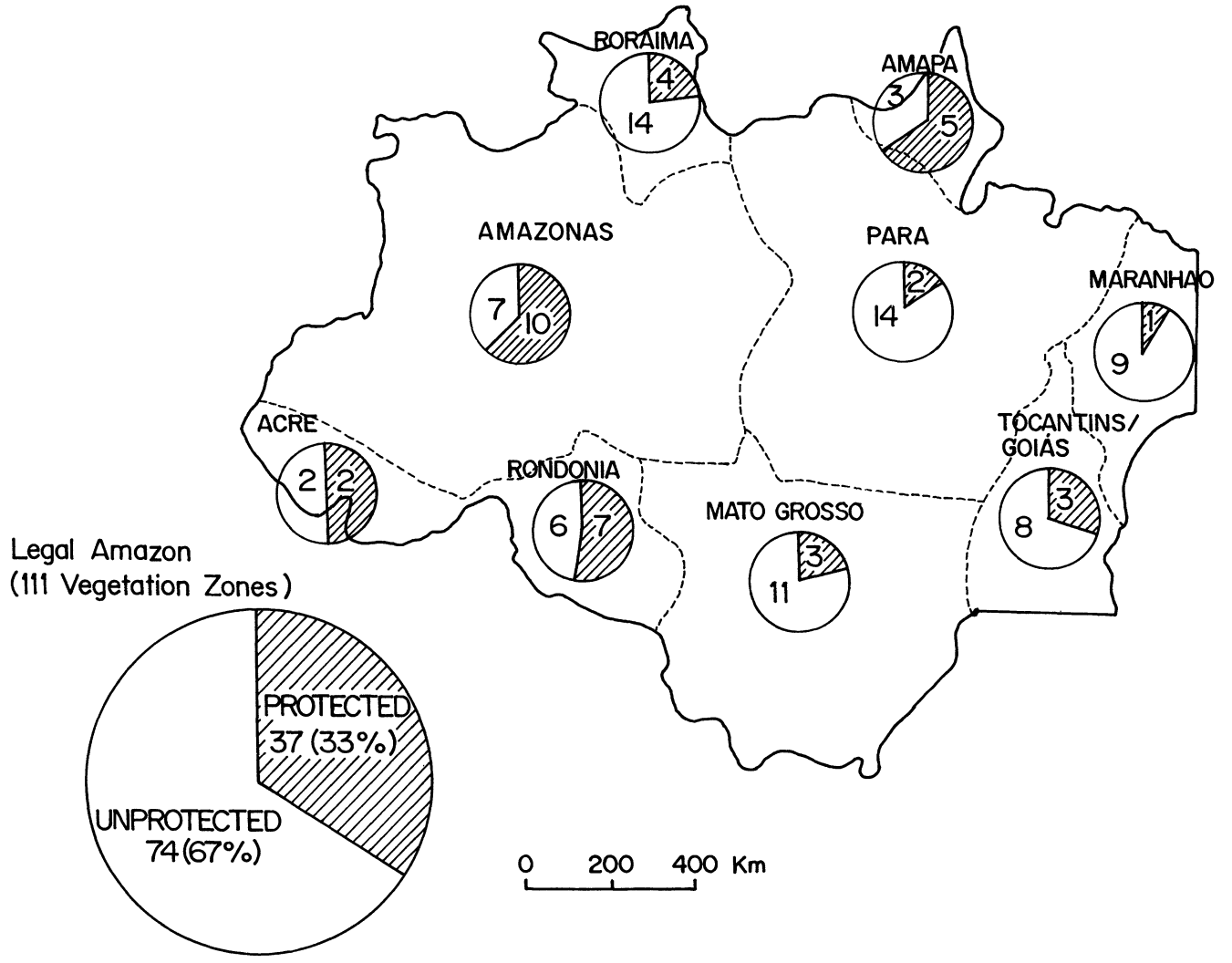

Figure 3. Number of protected and unprotected vegetation zones in the Brazilian Legal Amazon.

Example Reserves

Figure 2 shows areas that would satisfy the criterion of protecting at least some of each vegetation type within each state, assuming that already protected areas are maintained. The distribution of vegetation zones among existing protected areas is specified in Table 4. Examples of reserves that would cover the remaining vegetation zones are listed in Table 5. The dimensions of the areas indicated (Fig. 2) are modest. In a number of cases the vegetation in question exists in much larger areas. No attempt was made to establish criteria regarding the area of samples that should be protected. Where possible, the example reserves were drawn to include several of the missing vegetation zones in a single contiguous area. No attempt was made to locate the areas with reference to opportunities for habitat protection, such as Amerindian reserves. In some cases we avoided known conflicts with roads and development projects by indicating more remote areas of the same vegetation type, but we do not avoid all such conflicts. It is important to remember that where biologically important areas coincide with areas of extensive deforestation, any remaining scraps of forest should be protected quickly. But existing development projects in these areas should not necessarily be abandoned.

Table 1 defines the 28 types of natural vegetation on the Legal Amazon portion of the IBAMA map (IBGE & IBDF 1988) at a scale of 1:5,000,000. The area of natural vegetation of each type is presented by state in Table 6. The distribution of vegetation types in areas protected as biological reserves (BR), ecological reserves (ER), ecological stations (ES), and national parks (NP) in each state is presented in Table 7. The areas refer to present vegetation (in accordance with the map), which is different from original vegetation (shown in Table 2). Of the 28 vegetation types, 10 (36%) have no area protected in the entire Legal Amazon.

Because Amazonia is so vast, the species and other characteristics of the ecosystems change from one part

Table 6. Area of natural vegetation present in the Brazilian Legal Amazon (km^2).[a]

Category	*Code*[b]	*Acre*	*Amapá*	*Amazonas*	*Maranhão*	*Mato Grosso*	*Pará*	*Rondônia*	*Roraima*	*Tocantins Goiás*	*Total*
Dense forest	Da-0		9011	164,876			76,570	2704	3326	2610	259,097
	Db-0	16,408	2184	615,203	22,586		164,091	2066	10,248		832,786
	Dm-0		113	10,181			3418		20,661		34,373
	Ds-0	518	99,220	178,103	1988	23,154	413,345	14,607	83,692	3055	817,682
	Subtotal	16,926	110,528	968,363	24,574	23,154	657,424	19,377	117,927	5665	1,943,938
Non-dense Forest	Aa-0	10,591		65,748			805	2273			79,417
	Ab-0	114,380		211,052				41,064			366,746
	As-0			37,555		124,620	286,271	77,794	8430	1216	535,886
	Cs-0				3666	736	5386			115	9903
	Fa-0					3554					3554
	Fs-0					24,317		7718	1041	1328	34,404
	La-0			14,979					970		15,949
	Ld-0			37,405					10,967		48,372
	Lg-0			9663					9767		19,430
	LO-0			172,607					30,184		202,791
	ON-0					168,069	2991	4801	3045		178,906
	Pf-0		1823		2089		3894				7086
	SM-0				384						384
	SN-0			1082	6570	142,778	27,812	4781	904	14,465	198,392
	SO-0		4226	27,350		22,124	59,734	21,932	4286	6551	146,203
	Subtotal	124,971	6049	577,441	12,709	486,198	386,893	160,363	69,594	23,675	1,847,893
	Subtotal all Forests	141,897	116,577	1,545,804	37,283	509,352	1,044,317	179,740	187,521	29,340	3,791,831
Non-forest	Pa-0		15,157	12,778	2517	14,738	27,162	8690			81,042
	rm-0								390		390
	Sa-0			1531	55,758	167,534	5686	11,028		102,445	343,982
	Sd-0				15,771	10,840	1274			2234	30,119
	Sg-0					10,490	5057		15,481	7113	38,141
	Sp-0		10,038	5556	26,980	64,085	12,393	2664	8969	48,962	179,647
	ST-0					6599					6599
	Td-3								1550		1550
	Tp-3								10,671		10,671
	Subtotal	0	25,195	19,865	101,026	274,286	51,572	22,382	37,061	160,754	692,141
	Total	141,897	141,772	1,565,309	138,309	783,638	1,095,889	202,122	224,582	190,094	4,483,972

[a] *Areas measured from 1:5,000,000 vegetation map (IBGE & IBDF 1988). These areas do not reflect losses due to recent deforestation.*
[b] *Codes defined in Table 1.*

of the region to another, even within a given vegetation type. It is therefore important to adopt as a minimum goal protecting at least one example of each vegetation type within each of the region's states. As can be seen from Table 7, this implies that 111 locations should be protected in the region (often several locations can be lumped into a single reserve, as in the 35 existing protected areas and 44 example reserves in Table 5 and Fig. 2). Of the 111 vegetation zones only 37 (33%) have some part of their area protected to date, leaving 74 (67%) without protection (Fig. 3).

The percentage of each vegetation zone protected is also shown in Table 7. Because the areas protected are sometimes quite small, the combination of existing and example reserves considered here (Fig. 2) is only a starting point for a strategy to protect biodiversity in Brazilian Amazonia.

The states and the vegetation zones within them vary tremendously in size. The amount of land that should be protected in each vegetation zone in excess of minimum areas needed to maintain viable populations should be in some proportion to the size of the vegetation zones. Decisions on the size of new reserves need to be based on various factors not quantified in this paper, including the costs of establishing and maintaining protected areas in different locations, the merits of single large versus numerous small reserves, the limits of watersheds, and the defensibility of given locations against unauthorized access (Peres & Terborgh 1994).

We have focused on biodiversity as the rationale for protecting areas of natural vegetation. By storing carbon and recycling water, this vegetation also plays important roles in global and regional climate regulation. The priorities for conservation for climate regulation would be different, but establishing these priorities will depend on much of the information presented here.

Conclusions

Based on the criteria of our study, only one-third of the terrestrial vegetation zones present in the Brazilian Legal

Table 7. Area and percentage of protected vegetation zones in the Brazilian Legal Amazon.

Vegetation Type[a]		*Area Protected (km²) (%)*[b]									
Category Protected	*Code*	*Acre*	*Amapá*	*Amazonas*	*Maranhão*	*Mato Grossco*	*Pará*	*Rondônia*	*Roraima*	*Tocantins/ Goiás*	*Total*
Dense forest	Da-0	—	305	5,316	—	—	7	297	0	58	5983
			(3.38)	(3.22)			(0.01)	(10.98)	(0)	(2.22)	(2.31)
	Db-0	0	0	21,994	2872	—	5914	0	0	—	30,780
		(0)	(0)	(3.58)	(12.72)		(3.60)	(0)	(0)	(0)	(3.70)
	Dm-0	—	0	3902	—	—	0	—	565	—	4467
			(0)	(38.33)			(0)		(2.73)		(13.00)
	Ds-0	0	59	6614	0	0	7999	558	4954	0	17,184
		(0)	(0.06)	(2.03)	(0)	(0)	(1.94)	(3.82)	(5.92)	(0)	(2.10)
	Subtotal	0	364	34,826	2,872	0	13,920	855	5,519	58	58,414
		(0)	(0.33)	(3.60)	(11.69)	(0)	(2.12)	(4.41)	(4.68)	(1.02)	(3.00)
Non-dense forest	Aa-0	375	—	99	—	—	0	0	—	—	474
		(3.54)		(0.15)			(0)	(0)			(0.60)
	Ab-0	4100	—	2779	—	—	—	3296	—	—	10,175
		(3.58)		(1.32)				(8.03)			(2.78)
	As-0	—	—	648	—	0	75	4915	0	0	5638
				(1.73)		(0)	(0.03)	(6.32)	(0)	(0)	(1.05)
	Cs-0	—	—	—	0	0	0	—	—	0	0
					(0)	(0)	(0)			(0)	(0)
	Fa-0	—	—	—	—	0	—	—	—	—	0
						(0)					(0)
	Fs-0	—	—	—	—	0	—	0	0	430	430
						(0)		(0)	(0)	(32.38)	(1.25)
	La-0	—	—	601	—	—	—	—	0	—	601
				(4.01)					(0)		(3.77)
	Ld-0	—	—	485	—	—	—	—	476	—	961
				(1.30)					(4.34)		(1.99)
	Lg-0	—	—	0	—	—	—	—	0	—	0
				(0)					(0)		(0)
	LO-0	—	—	15,029	—	—	—	—	1296	—	16,635
				(8.71)					(4.29)		(8.05)
	ON-0	—	—	—	—	0	0	0	0	—	0
						(0)	(0)	(0)	(0)		(0)
	Pf-0	—	1547	—	0	—	0	—	—	—	1547
			(84.86)		(0)		(0)				(19.82)
	SM-0	—	—	—	0	—	—	—	—	—	0
					(0)						(0)
	SN-0	—	—	0	0	2592	0	0	0	0	2,592
				(0)	(0)	(1.82)	(0)	(0)	(0)	(0)	(1.31)
	SO-0	—	796	0	—	0	0	2993	0	0	3789
			(18.84)	(0)		(0)	(0)	(13.65)	(0)	(0)	(2.59)
	Subtotal	4475	2343	19,641	0	2592	75	11,204	1772	430	42,532
		(3.58)	(38.73)	(3.40)	(0)	(0.53)	(0.02)	(6.99)	(2.55)	(1.82)	(2.30)
	Subtotal all forests	4475	2707	54,467	2872	2592	13,995	12,059	7291	488	100,946
		(3.15)	(2.32)	(3.52)	(7.70)	(0.51)	(1.34)	(6.71)	(3.89)	(1.66)	(2.66)
Non-forest	Pa-0	—	5739	54	0	0	0	1569	—	—	7362
			(37.86)	(0.42)	(0)	(0)	(0)	(18.06)			(9.08)
	rm-0	—	—	—	—	—	—	—	0	—	0
									(0)		(0)
	Sa-0	—	—	0	0	1336	0	3513	—	0	4849
				(0)	(0)	(0.80)	(0)	(31.86)		(0)	(1.41)
	Sd-0	—	—	—	0	0	0	—	—	0	0
					(0)	(0)	(0)			(0)	(0)
	Sg-0	—	—	—	—	854	0	—	0	0	854
						(8.14)	(0)		(0)	(0)	(2.24)
	Sp-0	—	158	0	0	0	0	0	0	4064	4222
			(1.57)	(0)	(0)	(0)	(0)	(0)	(0)	(8.30)	(2.35)
	ST-0	—	—	—	—	0	—	—	—	—	0
						(0)					(0)
	Td-3	—	—	—	—	—	—	—	0	—	0
									(0)		(0)

Table 7. Continued

Vegetation Type[a]		*Area Protected (km²) (%)*[b]									
Category Protected	*Code*	*Acre*	*Amapá*	*Amazonas*	*Maranhão*	*Mato Grosso*	*Pará*	*Rondônia*	*Roraima*	*Tocantins/ Goiás*	*Total*
	Tp-3	—	—	—	—	—	—	—	0 (0)	—	0 (0)
	Subtotal	0 (0)	5897 (23.41)	54 (0.27)	0 (0)	2190 (0.80)	0 (0)	5082 (21.82)	0 (0)	4064 (2.53)	17,287 (0)
	Total	4,475 (3.15)	8604 (6.07)	54,521 (3.48)	2872 (2.07)	4782 (0.61)	13,995 (1.28)	17,141 (8.48)	7291 (3.25)	4552 (2.39)	118,233 (2.64)

[a] *Vegetation presently unaltered according to 1:5,000,000 vegetation map (IBGE & IBDF 1988). Codes defined in Table 1.*
[b] *Dash indicates that no vegetation of this type exists in the state; "0" indicates that vegetation exists but none is protected.*

Amazon are protected. Protecting an example of each type of vegetation within each state is recommended as a minimum goal. To protect all 111 terrestrial vegetation zones of the Legal Amazon, it would not be necessary to have a separate reserve for each because it is often possible to encompass several types in a single reserve. Our analysis indicates that 74 (67%) of the vegetation zones are unprotected. The situation is most critical in the contact areas between forest and *cerrado* in Maranhão, Tocantins, and Mato Grosso. In Maranhão, only one of 10 vegetation types is currently protected. The states with the fewest vegetation zones protected are precisely those that have already lost the largest percentages of their forest cover.

The areas we have identified as of high conservation priority are not the only areas in need of protection. Powerful political and economic forces in Brazil are trying to remove restrictions on development in all areas outside narrowly defined reserves. Some proposals would even revoke existing reserves to allow free exploitation of the entire region: The "Amazonian Code" proposed in July 1991 by Amazonas State Governor Gilberto Mestrinho says that "the areas of each state in the Amazon Region that, on the date of publication of this law, are under the effect of acts declaring permanent preservation will be the objects of revision, being submitted to new classification as specified in Article 18 of this Law [which states that all authority to create reserves will rest with the state legislatures]" (Mestrinho 1991: Chapter 5, Article 19). Recommendations based on our study emphatically do not imply that unrestricted development should be allowed in the remaining, unprotected areas.

As much area as possible needs to be set aside as quickly as possible for conservation purposes. There will be no second chance for many biologically important areas. Continuation of current trends in Amazonia would mean that areas that should be protected would soon be claimed by legal or illegal settlers. Deforestation can remove the possibility of future protection by removing the vegetation in question, but long before deforestation is complete, dramatic increases are expected in the political and financial costs of setting aside protected areas. This could make it impractical to create future reserves. The costs of procrastination are, therefore, very high.

The urgency of establishing protected areas before opportunities are lost requires that decisions be made now based on available information. It is too dangerous to postpone decisions on the grounds that more data must be collected. The dictum of Julius Caesar could not be more appropriate: Sometimes it is more important that a decision be made than that it be the best decision.

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