



Rich and Poor Ecosystems of Amazonia: An Approach to Management

E. F. Moran

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Edited by Toshie Nishizawa and
Juha I. Uitto

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The present book falls within the second programme, Integrated Studies of Ecosystems. This programme aggregates issues of environmentally sustainable development at the entry point of ecosystems and their ability to support, resist, or recuperate from the long-term impacts of major transformations. The programme has two tracks, one focusing on integrated studies of fragile ecosystems and vulnerable resources in given geographical zones; the other focusing on critical resources and their management.

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Acknowledgements ix

1 Introduction 1
Toshie Nishizawa and Juha I. Uitto

Part I: The ecological outlook

2 Ecological prospective for tropical Latin
America 13
Gilberto C. Gallopín and Manuel Winograd

3 Rich and poor ecosystems of Amazonia: An
approach to management 45
Emilio F. Moran

4 Archaeological perspectives on the potential
Amazonia for intensive exploitation 68
Betty J. Meggers

88. "Estimating reductions in the diversity of tropical species." In F.M. J.E.O. Wilson (eds.), *Biodiversity* (National Academy Press, Washington, -76.
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3

Rich and poor ecosystems of Amazonia: An approach to management

Emilio F. Moran

1 Introduction

The Amazon always brings out the grandiose vision in us. It is by any measure an enormously vast area. The drainage basin encompasses about 4 million km², an area the size of the continental United States. Contrary to the popular opinion, the Amazon Basin is not mostly tropical rainforest. It is made up of a patchwork of different vegetations, reflecting environmental conditions as well as past use and abuse. In it we find deciduous forests, seasonal forests, vine forests, palm forests, flooded forests, moist forests, well-drained and poorly-drained savannas, and xeromorphic scrub forests or *caatingas amazônicas*.

In this paper I will focus on two extremes of the environmental gradient in Amazonia. This gradient is based not only on the criteria of nutrient availability in soils and their pH, but relies also on assessment of other environmental and social processes (such as above-ground biomass and vegetation transformations by prehistoric populations) relevant to the future use and management of these areas. The two extremes chosen are the oligotrophic black-water river basins - of which the Rio Negro Basin is the best known - and the anthropogenic forests found associated with nutrient-rich soils in the

lower Xingú, lower Tapajós, and lower Tocantins basins and in portions of the state of Rondônia like the Guaporé valley.

This contrast departs from the traditional one commonly made between the *terra firme* (uplands) and *várzeas* (floodplains) of Amazonia. I do not dispute the validity and usefulness of the contrast between the floodplain and the uplands – a contrast that has served to highlight the differences between those areas enriched by Andean alluvial deposition and areas lacking these favourable conditions. However, this contrast has also hidden the heterogeneity present within the *terra firme*, an area that accounts for 98 per cent of the entire basin. As this paper hopes to show, the *terra firme* is very diverse in environmental conditions. The two extreme points of the gradient which I will discuss serve simply to suggest a more extensive exploration that makes more detailed discriminations within the *terra firme* (Moran, 1990, 1993). This heterogeneity has implications to the management of the region.

Within the *terra firme*, to which I will confine myself in this paper, annual precipitation varies from a low of 1,500 mm to a high exceeding 3,600 mm (Salati, 1985: 33), with considerable micro-ecological variation. The number of meteorological stations is still very small and the variability is probably even greater than figure 3.1 suggests.



Figure 3.1 Rainfall distribution patterns in Amazonia. (Source: Salati, 1985: 36.)

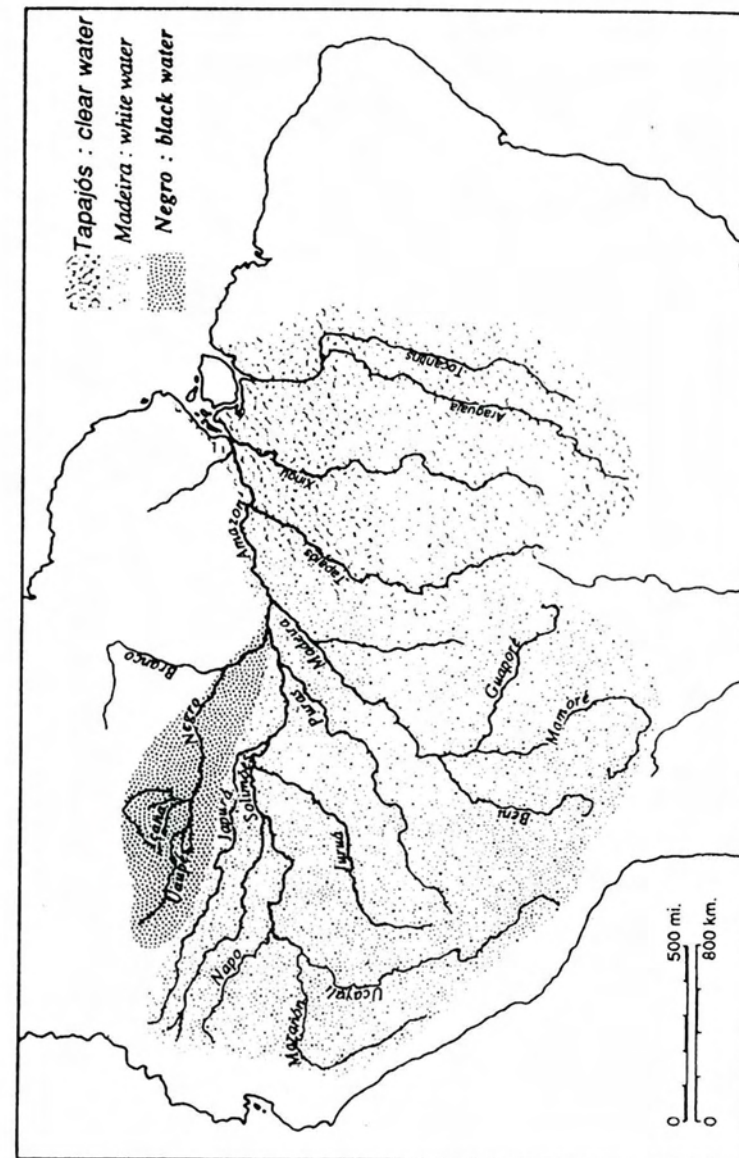


Figure 3.2 River "types" of Amazonia.

Average monthly temperatures do not fluctuate annually by more than 3°C, but the daily variation can be greater than 15°C.

An important ecological distinction was made long ago between the rivers of the Amazon (Sioli, 1951). Three types were distinguished: black-water, white-water, and clear- or blue-water rivers. See figure 3.2 for illustration of the areal extent of these three types of rivers. White-water rivers drain the Andean area and commonly, but not always, carry sediments of high fertility. Black-water rivers drain areas with white sand, podzolic soils, and are extremely acid and of poor optical quality owing to suspended undecomposed organic matter. Clear-water rivers drain areas of the Guiana and Brazilian plateaux and are of medium quality in terms of nutrients and acidity.

The areas drained by black-water rivers can be considered to fall at the poorest extreme of the ecosystems of Amazonia. They are dominated by the most nutrient-deficient and acid soils found in the basin. The forests have such a tight nutrient-cycling that hardly any nutrients escape the forested areas, and the river water has been described as being of near-distilled-water quality in terms of nutrients (Sioli, 1951). The productivity of black-water lakes is 15 to 19 times less than in várzea lakes and the fish show signs of nutrient deficiency in their vertebrae (Geisler and Schneider, 1976; Smith, 1979).

The extremely low levels of nutrients or oligotrophy lead to other responses that create additional difficulties for organisms exploiting such areas: organic matter decomposes more slowly because of the extreme acidity of the soils; native plants have evolved high levels of polyphenols and other toxic substances that appear to reduce nutrient loss through herbivory but which require specialized processing to detoxify the plant material. The extreme cycles of flood and drought have led to the selection of plants with highly specialized adaptations to these conditions, in the form of unusually high root biomass and leaves that are either leathery or spiny. The poor optical resolution of the rivers makes techniques like the use of bow and arrow in fishing less productive than elsewhere. These areas require careful description by ecologists and ethnographers because of their patchy nature and the coexistence of low above-ground biomass productivity and high biotic and abiotic diversity.

2 Characterization of the oligotrophic environment

Unlike other areas of terra firme, the characteristic vegetation of this habitat is *campina* or *caatinga amazônica* rather than tropical moist

or rain forest. Caatinga is a dwarfed scrub-forest vegetation of about 6 to 20 metres above ground level growing on hydromorphic quartzly sands (Klinge, 1978; Takeuchi, 1961). It is found chiefly in the Guianas and portions of the Rio Negro basin and its affluents (chiefly the Vaupés and the Içana). This type of vegetation develops in areas with a humid tropical climate where there is no dry season and which is dominated by podzolic soils or spodosols. The vegetation varies along a gradient from high caatinga to low caatinga or *bana*, which is the poorest of all. With increased oligotrophy, the herbaceous cover increases in dominance and the proportion of roots in total biomass increases. Figure 3.3 illustrates the interrelation between hydrology, soils, and vegetation in an area of the upper Rio Negro.

Leaves of caatinga vegetation are hard and leathery (sclerophyllous). Leaf area index is smaller in this type of vegetation (5.2) as compared with the mean of 8.0 in tropical forests, probably to reduce the effects of the drought stress period. Wood volume is less and the canopy is smaller than in areas less limited (Jordan, 1982: 395). Vines are uncommon, in contrast to epiphytes. In oligotrophic areas, there is a tendency for species dominance, in contrast to the pattern, more common in Amazonia, where dominance is rare in native forests. In a region near San Carlos de Río Negro in Venezuela, *Micrandra spruceana* and *Eperua leucantha* constituted 50.3 per cent of the biomass (Klinge, 1978: 260).

Caatingas are not restricted to the Amazon. In Sarawak this vegetation is known as *kerangas*, growing on poor soils where rice cultivation is not possible (Jacobs, 1988: 188). In other areas of Asia they are known as *padangs*. Areas with xeromorphic vegetation in the humid tropics have also been noted in Borneo, Sumatra, and Malacca. Richards (1952) compared the padangs of Malaysia to *wallaba* vegetation in the Guianas. In all these cases, these vegetations are associated with extremely leached white sandy soils. When cleared of their native vegetation, the areas take an uncommonly long time to return to their original state (perhaps as much as one hundred years), confirming the poverty of the environment (Jacobs, 1988: 189; Uhl, 1983; Uhl et al., 1982).

Low bana reaches a height of 3–7 metres, with dwarfed trees and bushes occurring mixed with grassy vegetation. In high caatinga the height may reach 20 metres, approximating the structure of upland tropical forest. High bana can be seen as a transitional zone between low bana and caatinga amazônica (Klinge, n.d.: 20). Biomass in caatinga is twice that of bana (i.e. 28 kg/m² vis-à-vis 10–17 kg/m²).

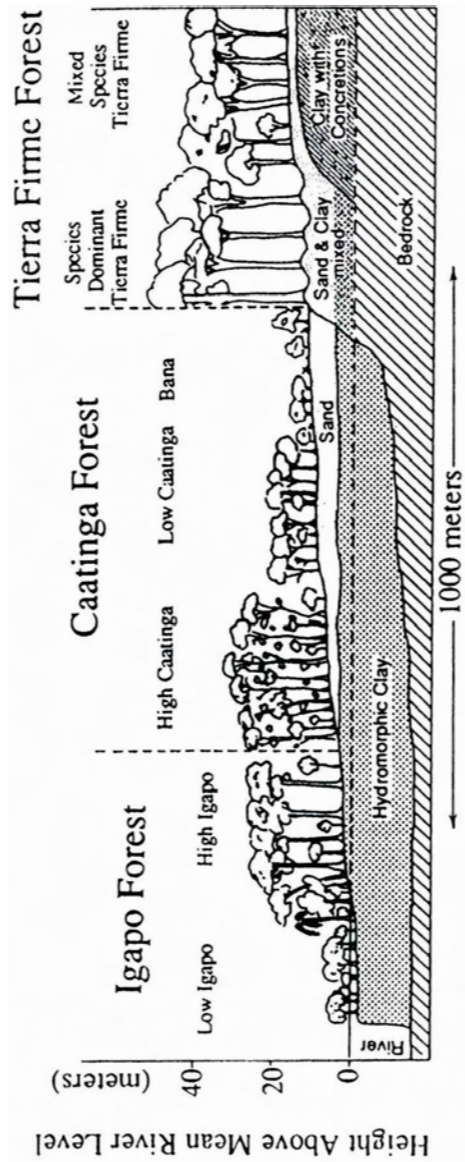


Figure 3.3 Hydrology, geology, soils, forests in the Rio Negro. (Source: Clark and Uhl, 1987: 5; Jordan, 1985.)

Table 3.1 Ecological characteristics of types of forest

	Bana & caatinga	Rio Negro upland forest	Other moist and rain forests
No. of tree spp. with 10 cm dbh/ha	18-69	80-100	80-100
No. of individual trees with 10 cm dbh/ha	39-173	650-800	600
Canopy height in metres	6-20	25-30	30-50
Basal area in m ² /ha 10 cm dbh	0.15-22	25-30	40-50
Above-ground biomass in metric tons/ha	170-335	320-340	400-700
Percentage of total biomass in roots	34-87	20-38	20

Source: Modified from Klinge, 1982 and Uhl and Murphy, 1981: table 3.

Other indices of the differences between bana/caatinga and upland tropical forests elsewhere in Amazonia clearly indicate the substantial differences between them (see table 3.1). Of particular note is the substantial increase in species diversity when moving from bana/caatinga to upland forests in the Rio Negro. The species diversity is comparable in upland forests of the Rio Negro to tropical moist and rain forests elsewhere in Amazonia. However, it is important to observe that the upland forests in the Rio Negro have a shorter canopy, a considerably smaller basal area, lower above-ground biomass, and a higher proportion of total biomass in the root layer than tropical moist and rain forests elsewhere in Amazonia. Thus, not all terra firme tropical forests are the same. The Rio Negro terra firme forests, because they are at the extreme end of the gradient of poverty, are more geared to nutrient conservation and recycling than they are to producing net yield available to herbivores or humans.

Also implicated in the presence of this type of vegetation are the hydrologic patterns. Medina et al. (1978) demonstrated that even with 3,600 mm of annual rainfall and rains of more than 200 mm each month, seasonal drought is common in these areas. By the time rainfall declines to the range of 200 to 300 mm in a month there is a high probability of wilting due to the high evapotranspiration (5.4-11.5 mm/day), high albedo, and the excellent drainage of the sandy soils. The water table is near the surface, due to an impermeable B horizon, characteristic of podzolic soils (Herrera, 1979). With every rain the water can flood an area immediately, and draining will occur only slowly over the next few days.

The soils are sandy and composed of near-pure quartz. They have

a high erosion potential. These soils are known variously as spodosols, podzolic soils, and hydromorphic podzols. They have a superficial layer with a great deal of undecomposed organic matter, pH below 4.0, and a diagnostic B horizon (i.e. a spodic horizon) of greyish colour of impermeable clays.

Further evidence for the oligotrophy of this environment is evident in the heavy investment in root biomass. Above-ground biomass is lower in this ecosystem but total biomass is comparable to other parts of terra firme. Roots constitute between 34 and 87 per cent of total biomass, as compared with 20 per cent in most areas of forested terra firme. Eighty-six per cent of the roots are found in the A horizon of the soils, and 70 per cent are considered extremely fine (Klinge and Herrera, 1978). In an experiment, 99.9 per cent of calcium and potassium was absorbed by the fine roots (Stark and Jordan, 1978). This is due to the mutualistic relation between mycorrhizae and the vegetation. In other areas of Amazonia the nutrient capture mechanisms are more porous and more nutrients escape from the immediate area of leaf-fall near a tree. The micro-organisms in the root layer incorporate the available nitrogen, the nutrient which seems most limiting in this ecosystem. Denitrifying bacteria are almost non-existent in this system, as compared to other areas of Amazonia. The poorer the ecosystem, the greater the development of the fine root layer, and the greater the presence of toxic substances which inhibit predation of leaves. Herbivore populations are very low in these areas, owing to the lack of palatable biomass. Research in Africa and in Venezuela confirms the presence of bacteriostatic and fungistatic substances like alkaloids and polyphenols in oligotrophic areas (McKey et al., 1978). These chemical defences are of considerable importance for research in both medicine and agriculture.

3 Characterization of eutrophic forests

One of the general characteristics of the upland forests found in Amazonian terra firme is their biotic diversity and environmental patchiness. Figure 3.4 illustrates just one type of patchiness present, in this case vegetational patchiness, in an eutrophic area of the lower Tapajós valley. One way in which human populations cope with extreme diversity is by simplifying the initial heterogeneity present, giving preference to resources to which they give particularly high value. Indeed, human beings do not simply adapt to the environment but also modify it so that its limitations are replaced with opportunities

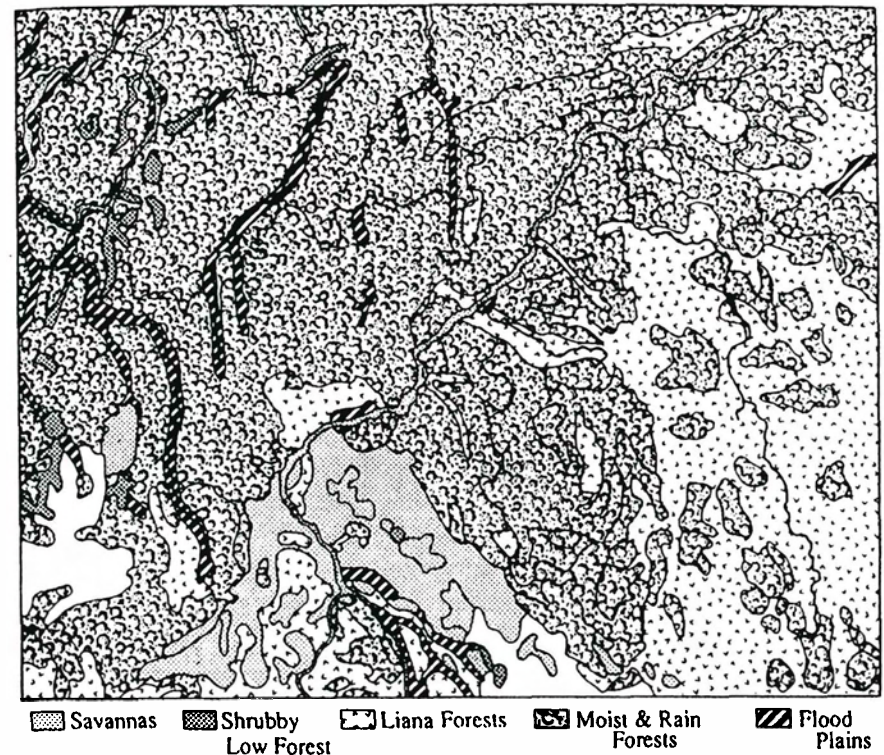


Figure 3.4 Patchiness in Amazonia, a Tapajós basin example. (Adapted from Prance, 1978: 210.)

for future use. As we will see in this section of the paper, prehistoric populations of terra firme brought about major transformations in the vegetation formations in the more productive areas of terra firme. These anthropogenic vegetations serve as indicators of areas of high potential for human occupation and agriculture. Indeed, there is much we can learn from indigenous peoples of Amazonia about how to manage the ecosystems.

The more favourable conditions of these eutrophic areas are reflected in the lower proportion of total biomass in the root component, with only about 20 per cent of the total, in contrast to 34–87 per cent of the total in the black-water basins (see table 3.1, p. 51). Thus, the above-ground biomass is nearly twice that of the black-water regions.

These forests' natural diversity has been simplified by management to the point where some of them have overwhelming dominance of

some species, particularly of some valuable palms. In areas that have not been notably modified by human management, one finds 80 to 100 tree species per hectare with 10 cm dbh (Black et al., 1950; Prance et al., 1976; Takeuchi, 1961; Uhl and Murphy, 1981). In a study by Uhl and Murphy, 67 per cent of the species were represented by fewer than four individuals. This diversity is reduced in areas that have been modified by prehistoric populations.

Soils in terra firme include some of the poorest and some of the richest soils in the world. The poorest we examined in the earlier section of this paper. The richest soils of terra firme are the alfisols and the mollisols. The alfisols are soils of medium to high fertility, resulting from basaltic intrusions, and are high in cation exchange capacity and of near-neutral pH. They occur in a highly dispersed pattern throughout the basin but are often associated with vine forests and with anthropogenic black soils. Areas like the Guaporé valley in Rondônia, the lower Tocantins and Xingú, and the north of Mato Grosso have sizeable areas of these good soils (Moran, 1990, 1993). Figure 3.5 illustrates visually the fertility of these soils in comparison to "average" soils of terra firme (the proverbial oxisols or latosols) and in contrast to the spodosols typical of the black-water basins with which we are contrasting the eutrophic areas. The soil samples for the eutrophic and average areas were taken by the author along the Trans-Amazon highway near Altamira, and were taken at a depth of 0–20 cm (i.e. fertility cores). The oligotrophic soil samples were taken by Rafael Herrera (1979).

At least 11.8 per cent of the terra firme forests are now thought to be anthropogenic in nature, resulting from prolonged management by prehistoric populations (Balée, 1989). The population did not eliminate diversity entirely in this process, as this would have been foolhardy and ineffective, but promoted, instead, islands of concentrated resources within a sea of diversity. They did this by creating favourable conditions for the dominance of species that they valued highly and with characteristics that facilitated their competitiveness over time in an environment where succession is remarkably vigorous. Among the vegetations that are likely to be anthropogenic in contemporary Amazonia one may cite palm forests, bamboo forests, Brazil nut forests, and vine forests.

Palms are excellent indicator species of archaeological sites. *Pupunha* (*Bactris gassipaes*), *inajá* (*Maximiliana maripa*), and *burití* (*Mauritia flexuosa*) have been used as indicative of prolonged human occupation sites (Balick, 1984; Boer, 1965; Heinen and Ruddle, 1974;

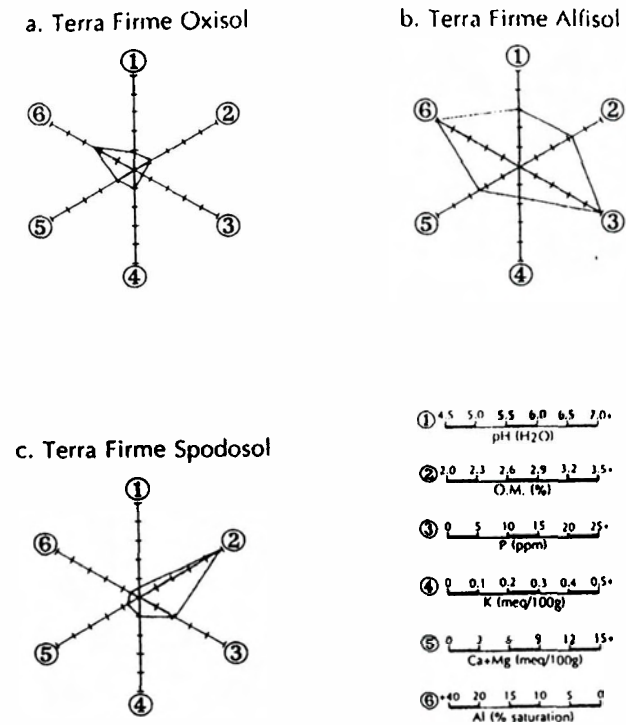


Figure 3.5 Comparison of terra firme soils.

Pesce, 1985). *Burití* is found most often in areas of flooded forest and várzea, in contrast to the other two. *Tucumã* (*Astrocaryum vulgare*), *caiaui* (*Elaeis oleifera*), and *babaçú* (*Orbignya phalerata*) are important, favoured species in the terra firme forests.

Boer (1965: 132) views *Astrocaryum vulgare*, or *tucumã*, as a species that "never is found in virgin" areas, but only in areas that have been extensively disturbed by human managers. The Urubú Ka'apor of the state of Maranhão value it as a tree that attracts tapir and cutias, making hunting easier and more productive. It is also valued for its fibres, which are used to make hammocks, child-carrying slings, and other articles of daily use (Balée, 1989).

Andrade (1983: 23) found an association between the presence of *Elaeis oleifera* and anthropogenic black soils in areas of the Madeira river and south of the city of Manaus. Its uses are similar to those of the African palm and it seems to have come originally from Central America.

Perhaps the best-known palm of the palm forests is *Orbignya pha-*

lerata or babaçú. It has been estimated that forests dominated by babaçú cover 196,370 km² in the Brazilian Amazon (May et al., 1985: 115). This degree of dominance is rare for any palm, and seems to be a result of its manner of germination (Anderson and Anderson, 1985). The babaçú palm lives about 180 years and its presence is indicative of human disturbance. Balée (1984: 94–5) found forest islands of babaçú of up to three hectares in areas occupied today by the Guajá, Tembê, and Urubú Ka'apor. Among the Suruí of Rondônia, areas near groves of babaçú are preferred as residential sites. Babaçú forests themselves do not occur on areas of high fertility, but they seem to occur near patches of high fertility.

Bamboo forests (*Guadua glomerata*) are important to indigenous populations because of their value in making flutes for rituals and arrows for hunting and fishing. Bamboo forests have been estimated to cover about 85,000 km² in the Brazilian Amazon (Braga, 1979: 55). Balée (1989) has noted that the Guajá occupy today areas of bamboo forest created earlier by the activities of the Guajajara in the area of the Pindaré river.

Forests dominated by the presence of the Brazil nut tree (*Bertholletia excelsa*) occupy approximately 8,000 km² in the lower Tocantins (Kitamura and Muller, 1984: 8) and have also been observed in Amapá, in the basin of the Jarí river, and in Rondônia, although their areal extent has not been mapped. Some observers have noted that these forests seemed to be associated with archaeological sites and with areas of anthropogenic black soils (Araújo-Costa, 1983; Simões and Araújo-Costa, 1987; Simões et al., 1973). The Kayapó at Gorotire plant Brazil nut trees because of their importance as food (Anderson and Posey, 1985; Posey, 1985). Besides its local food value, this tree is also an important economic resource for export (Larai and da Mata, 1968). Brazil nut trees live even longer than babaçú, and are important indicator species of anthropogenic forests.

Perhaps most extensive of all, after the babaçú palm forests, are the vine or liana forests (*matas de cipó*), estimated to occupy 100,000 km² in the Brazilian Amazon (Pires, 1973: 152). They occur in particular concentration in the lower Tocantins, Xingú, and Tapajós river basins (see the area of vine forests in figure 3.4). Vine forests have a lower basal area than presumably "virgin" forests of terra firme (18–24 *vis-à-vis* 40 m² per hectare, respectively), an unusually high density of woody vines, and a tendency towards dominance by a few species (Pires and Prance, 1985: 120–2).

In these vine forests one finds a concentration of resources that is

suggestive of complex, long-term management: food items, fruits that attract game, construction materials, medicinal plants, insect repellents, and firewood. The number of useful species is larger than in other types of upland forest. Observers have long noted the preference of farmers for vine forests (Moran, 1977, 1981; Sombroek, 1966: 195). Although no simple correlation between these forests and a particular soil order has been made, they seem to be more frequently associated with anthropogenic black soils (Heindsdijk, 1957; Smith, 1980) and with alfisols (Falesi, 1972; Moran, 1981). Balée (1989) found anthropogenic black soils in vine forests of Maranhão, of 39 cm depth, and with 31.8 meq/100 g of phosphorus – levels much higher than in adjacent soils. He also noted the higher pH (5.8) and the high concentration of calcium.

In contrast to the black-water regions of Amazonia, in these anthropogenic forests one finds an unusually high frequency of corn cultivation, in some cases leading to the near-total loss of bitter manioc cultivars and to the abandonment of manioc flour production. By contrast, in the black-water regions, one sees a predominance of extremely bitter varieties of manioc and a near-total absence of corn cultivation. One should note that in the white-water basins of the western Amazon, one also finds a low incidence of bitter manioc varieties and more corn cultivation. Corn is much more demanding of nutrients than can be sustained in many parts of Amazonia, particularly in the black-water regions.

4 Management of oligotrophic areas

There is much we can learn about the proper management of Amazonian ecosystems from the region's indigenous population, which coped with its limitations and in some cases rose above them by changing the composition of forest and soil. What we conclude from our examination of these two ecosystems is that native populations used both areas, but that they restricted their manipulations of the ecosystem to the "islands" of terra firme forest in the oligotrophic regions and focused on the eutrophic "islands" within the vaster nutrient-poor areas of terra firme.

Human populations have inhabited the upper Rio Negro for at least 6,000 years. Ceramics and anthropogenic soils have been identified in the Rio Negro, dated at 3750 BP (Clark and Uhl, 1987: 7; Saldarriaga and West, 1986; Sanford et al., 1985). The anthropogenic soils are found not in the caatinga areas but in upland tropical forests

growing on oxisols, suggesting a very ancient preference for the patches of tropical forest, rather than caatinga, for occupation and agriculture.

Populations of the upper Rio Negro practise slash-and-burn agriculture, clearing areas of between 0.5 and 2.0 hectares between September and November each year. It has been observed that contemporary native populations generally avoid locating their swiddens in areas of caatinga, which through ethno-ecological taxonomies are identified as inappropriate for agriculture (Hill and Moran, 1983). Clark and Uhl (1987) estimated that in the region near San Carlos de Río Negro, in Venezuela, only about 20 per cent of the soils were not spodosols. This extremely restricted availability of soils capable of supporting crops for even a couple of years runs counter to very old assumptions about the ease with which native populations could relocate in Amazonia and the lack of "environmental circumscription" in the basin (Carneiro, 1970). There have been no reports of nutrient-rich alfisols (*terra roxa estruturada eutrófica*) in the Rio Negro Basin. Galvão (1959: 24) noted another factor limiting the agricultural potential of the upper Rio Negro: the apparent avoidance of areas which required penetration into the forest and a preference for areas along river banks by horticultural populations. Chernela (1983) observed a similar preference among the Uanano, a Tukanoan population in the Vaupés, as have those who have studied the Bara Makú (Silverwood-Cope, 1972) and the Hupdu Makú (Reid, 1979). This tendency to limit territorial occupation to the river-banks may represent a compromise response to the poverty of the terrestrial ecosystem, the availability of restricted areas of fertile levees, and the importance of fisheries based on ancient territorial claims.

Similarly, flooded forests (*igapós*) are avoided for agriculture, given their importance for fisheries (Chernela, 1983; Clark and Uhl, 1987; Dufour, 1983). Many of the fish in Amazonian river channels enter the flooded forest during the rainy season to gain weight and to spawn (Goulding, 1980, 1981). When fishing gives poor results, the Wakuenai in Venezuela say that the fish are spawning and locate their swiddens distant from the flooded forests. Chernela (1982, 1986a) noted the same explicit avoidance of flooded forest for agriculture among the Uanano in Brazil.

The length of the cultivation period and the size of clearings is of special significance in these oligotrophic habitats. The smaller the area cleared, the easier it will be for seeds from the native vegetation

to recolonize the area. The length of the cultivation period affects the levels of nutrients available to the incoming seeds and the growth rate of secondary vegetation. In black-water ecosystems, the return of the original vegetation may take over a hundred years (Uhl, 1983; Uhl et al., 1982). Uhl et al. (1982: 319) found 271 seeds per m² in an area studied at the end of the cultivation cycle, 90 per cent of them secondary successional species. It is quite likely that secondary successional species are better adapted to low levels of nutrients and can thrive where domesticated plants cannot. Succession is much slower in black-water ecosystems: above-ground biomass after three years was only 870 g/m² compared to 2,000 g/m² in areas of oxisols on upland forest. It appears that oligotrophy, as well as the flooding, are responsible for this lower level of above-ground biomass production (Uhl et al., 1982: 320). After sixty years, the above-ground biomass is only 40 per cent of that of the original vegetation (Clark and Uhl, 1987: 12; Jordan and Uhl, 1978), compared to 90 per cent of above-ground biomass in eight years on ultisols in the Peruvian Amazon (Sanchez, 1976: 351).

One of the ways in which native peoples help accelerate the recolonization of cleared areas is by planting fruit trees in the swiddens. Not only does this increase the utility of the land, but it serves to attract birds and bats, which are the principal agents of primary forest seed dispersal in the humid tropics. In a controlled experiment, areas planted in this manner had nine times the number of seeds of native trees than an area which was not planted with fruit trees at the end of the cultivation cycle. The shade of the fruit trees serves to provide the needed shade to primary tree species of slow growth, and reduces leaching of nutrients.

The lack of a marked dry season in this region would lead us to expect that burns would be of poor quality. Generally, it is the quality of the burn that determines the yield of slash-and-burn cultivation in non-volcanic areas of the humid tropics (Moran, 1981). That is clearly the case in areas with high above-ground biomass. But in areas with lower biomass, high insolation, and high albedo resulting from reflection from the white sands, the biomass dries sufficiently to burn so well that, in fact, areas of xeromorphic vegetation tend to experience burns beyond the areas cleared. Clark and Uhl (1987) documented the problem of natural burns in this habitat, where hundreds of hectares can catch fire when twenty rainless days occur. The destructive impact of fire is a real threat in this ecosystem, in contrast

to other areas of the humid tropics, where fire rarely extends beyond the area cleared (or in areas scarred by logging activities). Planting follows, and is dominated by bitter manioc.

Dufour (1988) found more than a hundred varieties of bitter manioc among a Tukanoan population in the Colombian Vaupés. Very few varieties of sweet manioc were known and cultivated. Chernela (1986b) found that repeated efforts by Uanano peoples in the Vaupés of Brazil to introduce sweet cultivars of manioc failed and only bitter cultivars persisted, when she did a study of their manioc varieties. Bitter manioc resembles the native vegetation of black-water regions by its toxic quality, which serves to conserve nutrients for the plant through reduction of herbivory. Montagnini and Jordan (1983) found that insects consumed less than 3 per cent of the tissue of bitter manioc plants due to the cyanogenetic glucosides present.

Bitter manioc cultivation solves one of the great problems of Amazonian populations: how to cultivate soils that are extremely poor in nutrients, extremely acid, and have toxic levels of aluminium. Manioc, a plant that appears to have evolved in just such areas of South America, can produce impressive yields in areas where nothing else will grow (Moran, 1973). One of the few limitations to its cultivation is its inability to withstand water-logging, which explains why it is cultivated on higher ground. Manioc is even adapted to drought, during which it loses its leaves and goes into dormancy, gaining its leaves again with the return of soil moisture. Beans and corn, by contrast, are unable to produce a predictable crop in these nutrient-poor areas, and unable to cope with even short-term droughts. Galvão (1959: 24) noted that corn had been abandoned by the populations of the Içana and that it probably never had much importance in the Rio Negro Basin.

Bitter manioc produces the bulk of the calories for black-water basin populations. Dufour (1983) showed that among the Tukanoans she studied in Colombia, 70 per cent of the energy came in the form of manioc flour and manioc bread (*casabe* or *beijú*), tapioca, manioc beer, and other forms of prepared manioc. The energy efficiency of manioc is impressive: it yielded 15.2 calories for every calorie spent on its production. Seventy percent of the production costs occur during processing. Nevertheless, the oligotrophy of the black-water regions depresses the total yields. Yields vary between 3 and 8 tons per hectare, with a mean of 4.7 (Clark and Uhl, 1987). By comparison, the world mean is 8.4 tons per hectare, and reaches 12.7 tons in

Brazil. The relatively low mean harvests confirm the nutrient-poor conditions of the environment.

Clark and Uhl (1987: 19) estimated the fish productivity of the Rio Negro-Casiquiare-Guainía rivers to be between 6.6 and 13.2 kg/ha/year – one of the lowest values for any tropical basin. In Africa and Asia the mean values are 40–60 kg/ha/year and Goulding (1979) estimated the productivity of the Madeira River in Brazil at 52 kg/ha/year.

The lower mean productivity results, in large part, from the absence of some particularly large species like pirarucú or paiche (*Arapaima gigas*), aruanã (*Osteoglossum bicirrhosum*), several large species of the genus *Colossoma*, and several large catfishes or pimeloids (Goulding, 1979: 15). The absence of aquatic grasses in black-water rivers, an important food source for many of the larger fishes, influences the species composition of these rivers and favours smaller species. This is not to say that black-water rivers are species-poor. Goulding et al. (1988) have shown that the lower Rio Negro is among the most species-rich rivers in the world, with approximately seven hundred species. Fish species in the Rio Negro, however, are dominated by smaller species with a mean length of only 40 mm – with over one hundred species of less than 30 mm length (Goulding et al., 1988: 109).

Success in fishing in black-water ecosystems depends mostly on territorial control over catfishes and flooded forest, where the fish volume is greatest. The most successful method of fishing is through the use of large fixed traps which require considerable investment in their construction and maintenance. The importance of control over the best fishing spots is evident in such a situation, and reaches a considerable level of sophistication in the Rio Negro (Chernela, 1986a; Moran, 1990). Fish was found to be a part of meals in 78–88 per cent of cases sampled by Dufour (1987: 389).

5 Management of eutrophic areas

By contrast, management of the eutrophic areas of terra firme offers the challenge of diversity. This was handled by native populations by creation of “islands of resources.” They concentrated species of economic interest within close proximity to soils favourable for horticulture and favourable in locational factors, such as ease of river transportation, well-drained areas for habitational sites, and cool breezes to provide comfort and freedom from insects.

The creation of anthropogenic forests and soils solves two of the commonly mentioned problems posed by Amazonia: poor soils and species dispersal. This process need not have been conscious. The behaviour of ancestors could very well have been certified in myths and descendants continued traditions found to be favourable to their lifestyle.

For agriculture, the preferred areas were the vine forests, because of their association to alfisols. Near the villages, the population concentrated further resources by creating palm forests, bamboo forests, food/fruit-rich forests – and the garbage from their settlements built up over time anthropogenic soils which would serve in the future as usable soils in previously inferior areas from an agronomic viewpoint. This is equivalent to the population creating ecotones, or transitional areas, to favour high productivity.

In eutrophic areas, cultivation of grains and other nutrient-demanding plants is possible, although this will shorten the time before fertilization will be required. On the other hand, it makes no sense to build cities on top of these superb soils (as has been done in recent years, for example, at Tucumã, Pará) or to put them into the production of export and tree crops (as was the case in Rondônia with cacao). Agricultural zoning of these areas will need to achieve particularly high levels of sophistication, matching the quality of the soils to the products developed. Unfortunately, much of this will have more to do with market forces than with the micro-ecological characteristics of the areas.

The eutrophic areas of terra firme can be put to intensive use. Doing so should begin with attention to the processes of environmental modification undertaken by indigenous populations, and build on these efforts. The better soils can withstand cultivation for prolonged periods of time because of their fine structure and high initial cation exchange capacity. However, fertilization will be required for any form of continuous and intensive cultivation. The viability of continuous cultivation in these areas of terra firme is not an environmental issue *per se* but, rather, a political and economic one, of the government providing the conditions for access to fertilizers at competitive prices and of matching market demand to the products supplied by the areas put under cultivation. So far, for most of Amazonia, this has been poorly done. One of the few success stories has been the Japanese colony at the favourably located Tome-Açú, in which the inhabitants identified a low-weight/high-value crop early

on, and which invested in technical and human resources from the outset.

6 Conclusions

Black-water ecosystems such as those found in the Rio Negro, Vaupés, and Içana represent the poorest and most limited areas of Amazonia. Above-ground biomass is lower, litterfall is poor in nutrients, decomposition is slow due to the acidity of the soils and the water, and the drainage limitations resulting from the podzolic soils contribute to making these areas a true challenge to human populations.

Selection of particularly toxic varieties of bitter manioc and hierarchical control over fishing spots further adjusted native peoples to these poor areas of Amazonia. The areas are rich in endemic species and in toxic plants with secondary compounds with great promise for advances in medicine and pharmacology. More than any others they should be protected from large-scale development activities. These are important ethnic refuge areas, with low potential for intensification but high potential for specialized and more selective exploitation for genetic, pharmacological, and medical research. While the total biomass is less than elsewhere in Amazonia, the species diversity is as high, if not higher, than other phytogeographic areas of the Amazon Basin. The native populations of this region are particularly attuned to the limitations of this ecosystem and their expertise should guide land use and research in the years ahead. Their potential for medicine and pharmacology, in particular, should have highest priority, especially the caatinga and bana areas, which are too poor for most other economic uses. On the “islands” of terra firme forests, extensive forms of resource use and extraction may continue, but intensive use is out of the question except in very restricted areas.

By contrast, intensive agriculture in Amazonia is possible and should largely be restricted to the eutrophic areas, especially where there are anthropogenic forests and soils. These have demonstrated productivity and, under the right market conditions, are likely to be economical. In contrast to more virgin areas, use of these areas will have minimal significance in terms of species extinction and biodiversity, since these areas are already simplified versions of the original ecosystems, with a predominance of species of economic value. This strategy would, in turn, recommend that for the foreseeable future

large areas of the Amazon be protected from further clearing until such time as, through research and conservation, their potential can be better known.

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