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Brazilian rain forest colonization and biodiversity

Evaristo Eduardo de Miranda and Cristina Mattos
Environmental Monitoring Center (NMA), Brazilian Agency for Agricultural Research (EMBRAPA), Av. Dr. Júlio Soares de Arruda 803, 13085, Campinas/SP, Brazil

ABSTRACT

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This work explains the tropical rain forest's main characteristics, and the reasons why this ecosystem plays an important role in determining global biodiversity. The occupation process of the two Brazilian tropical rain forests (Atlantic and Amazon) are briefly described, with quantitative information on deforestation and its consequences. Human presence in these areas is millenary, and its role as a source of increase, decrease and maintenance of biodiversity are exemplified. Different kinds of man/forest interactions (such as those characterizing indigenous people, riverside communities, caboclos, rubber tappers and agriculturists) and their relation to biodiversity, are described. The future occupation of the Brazilian tropical rain forest supplanting past mistakes, especially in the Amazon, is proposed as a triple challenge. The first challenge is to stop the destruction of the still-intact forest, and to plan its rational occupation. An example of how this has been done by rubber tappers in the state of Acre, and how it affects wildlife and vegetation communities is given. The second challenge is to reduce the migration flow towards the economic frontier areas, and to propose to the thousands of agriculturists already installed there alternatives to reconcile economic development and environmental preservation. In this case, the situation of a colonization project in the state of Rondônia is described. The third challenge is to restore the biodiversity in the almost 400 000 km^2 of land that have been occupied and degraded for a long time, as in the state of Tocantins. An example of how scientific research contributes to meeting this challenge is described.

TROPICAL RAIN FORESTS AND BIODIVERSITY

Tropical rain forests: why so important?

Rain forests are among the most complex, sensitive, endangered and unknown ecosystems on Earth. Today, only about half of their original extent remains in large blocks throughout 37 countries in Latin America, Africa, Asia and Australia. They once covered some 16 million km^2, but human activities such as farming, logging, cattle ranching, large-scale development projects, and mining have reduced their area to less than 9 million km^2. About 7% of the world's landmass is still covered with this unique ecosystem (Corson, 1990).

Correspondence to: E.E. de Miranda, Environmental Monitoring Center (NMA), Brazilian Agency for Agricultural Research (EMBRAPA), Av. Dr. Julio Soares de Arrunda 803, 13085, Campinas/SP, Brazil.

Almost all the rain forests occur in the so-called intertropical or tropical zone of the globe, generally characterized by its main climatic aspect: high temperatures (Tricart, 1974; Demangeot, 1976). In this zone, thermal amplitude is daily exceptionally high and annually exceptionally low: 2 or 3°C over the year and 4 or 5°C over the day, with the mean temperature around 25°C (De Lemps, 1970). Some other important characteristics are the high humidity and plentiful rainfall — regularly more than 1500 mm $year^{-1}$ and non-seasonally distributed (Hallé et al., 1978). In these areas, climatically uniform with water, temperature and light suited to optimum plant growth throughout the year, without seasonal fluctuations, an evergreen, broad-leaved, vegetation flourishes.

This sort of forest has three main characteristics. First, lush vegetation: a dense and closed forest, with a high canopy that allows little light to reach the ground. Second, it has a rich flora with many examples of endemic species. This is a result of the climatic conditions favorable mainly to the trees, leading to intense competition, and also of climatic changes in the past, never as severe as in temperate latitudes — thus, the various species have had conditions to adapt themselves to the environment and to diversify. The third characteristic is stratification: ground plants, shrubs, vines, lianas, epiphytes and trees form a complex of layers ranging from a few centimeters to over 60 meters high — described by Alexander von Humboldt as "a forest above a forest" (De Lemps, 1970). This ecosystem differs from temperate forests not only in tree arrangement, but also in tree architecture: they are bigger, higher, the major part of their biomass is in stems and leaves, and they have superficial roots (Demangeot, 1976; Hallé et al., 1978).

Despite the lush vegetation, tropical rain forests often occur on poor and highly weathered soils. Seventy-five percent of the nutrients are in the plants, 17% in the decomposing matter and only 8% in the soil itself (Meirelles Filho, 1986). In this situation, these forests have evolved 'closed' nutrient cycles: anatomical, physiological, biochemical and ecological mechanisms guarantee little loss, little uptake from the sources and thus conservation of nutrients (Golley, 1983).

Controlled numerical experiments with complex models of the atmosphere have shown that tropical rain forests, as well as their destruction, may play an important role in determining the local and regional climate (Cutrim, 1990; Shukla et al., 1990). Biosphere–atmosphere interactions are significant within these areas. For instance: the incidence of sunlight is higher in the tropical zones than in any other place on Earth, and the vegetation contributes to its dissipation as water vapor, acting as a regulator of temperature and supplier of moisture — like an air conditioner. Lately, human activities such as deforestation and biomass burning have altered these interactions, and may cause worldwide climate changes that could affect the future habitability of our planet.

One striking aspect of tropical rain forests is the vast biological array of living organisms found there. These forests support more plant and animal species per unit area, as well as overall, than any other ecosystem on Earth. Current estimates of the total number of living species on the planet range from 5 to 30 million or more, of which only 1.4 million have been described by scientists (Wilson, 1988; Corson, 1990). More than two-thirds of these species come from tropical rain forests, basically because they are home to the most species-rich groups in the world — arthropods and flowering plants (Wilson, 1989).

Peru, in South America, for instance, contains around 30 000 species of plants (Itlis, 1988); Colombia, a country as big as New Mexico and Texas together, has more than 1550 bird species, i.e. twice the number found in North America from the Mexican border to the Arctic Circle (De Schauensee, 1964); a single river in Brazil harbors more species of fish than all rivers in the USA and ten 1-ha plots in Borneo contain 700 species of tree (Corson, 1990); the Amazon Forest is home to perhaps 80 000 plant species (including 600 kinds of palm alone) and millions of animal species, most of them insects (Colinvaux, 1989). A world record was established in 1988 by Alwyn H. Gentry, who identified about 300 tree species in each of two 1-ha plots in Iquitos, Peru (Wilson, 1989). Such great richness constitutes a constraint for the commercial exploitation of the forest: in 1 ha there are usually no more than two or three trees of the same species (De Lemps, 1970).

Besides sheltering native populations and providing habitat for millions of plant and animal species — which constitute an important genetic bank — tropical rain forests are also important because they supply a great variety of commercial and non-commercial products: timber (some highly prized woods such as teak, mahogany and rosewood); fuel wood; fruits, vegetables, nuts and spices; medicines (a quarter of all medically active substances come from tropical plants, and according to Caufield (1984) around 70% of the 3000 plants identified by the US National Cancer Institute as having anti-cancer properties are tropical rain forest species); and various industrial products such as oils, waxes, gums, resins, latexes, fibers, rubber, dyes, tanning agents, turpentine, lubricants, rattan and bamboo (Corson, 1990).

This richness and diversity has been threatened by man in three different ways: by destroying species individually; by destroying resources that they need to survive (such as habitat or food supply); and by introducing exotic species that kill or compete with the native species (Emmons, 1990). In the case of tropical rain forests, the destruction and the fragmentation of habitats through deforestation are the main causes of loss in biodiversity (Lovejoy et al., 1984). Deforestation reduces the area covered with forest and thus the number of habitats available in this ecosystem. This leads to a reduction in the number of species.

Deforestation is caused by three main factors: agricultural and livestock expansion (human population growth leads to expanded needs for crop and grazing lands), increased demand for commercial forest products (national economic development and international trade stimulate mainly timber harvesting), and increased demand for non-commercial forest products (fuel wood, fodder and others) (Gregersen et al., 1989). The causes vary from region to region. In Asia, for example, although timber harvesting is important, the major culprits are population growth and extensive agriculture; in America, beyond the above factors, mistaken governmental policies during recent years play a significant role; in Africa, the main causes are the uncontrolled population growth and nomadic agriculture (Siqueira, 1989). The rain forests have been globally destroyed not because of ignorance or stupidity but largely because of poverty and greed (Robinson, 1988).

The consequences of the eradication of tropical rain forests range from the local to the regional level: local scarcity of forest products, displacement of indigenous cultures, degradation of soils, siltation of waterways, disruption of water flow, local and regional climate change, and loss of biodiversity (according to Wilson (1989) 0.2 or 0.3% of all species in tropical rain forests are lost every year, a rate 10 000 times greater than the natural extinction rate).

Even though these consequences are starting to be studied, the amount of deforestation in tropical rain forests is still not known with accuracy. The estimates range from 110 000 km^2 (Wilson, 1989; Corson, 1990) to 204 000 $km^2\ year^{-1}$ (The World Resources Institute, 1990). Projections show that in 11 countries, much of the remaining forests will be cleared in less than 50 years (Gregersen et al., 1989).

Brazilian tropical rain forests

Around 57% of the tropical rain forests are in Latin America and 30% in Brazil. This country has two domains of tropical rain forest: the Atlantic Forest and the Amazon Forest (The World Resources Institute, 1990).

The Atlantic Forest, designated as one of the three top priority areas for conservation in the world, is the most deforested of them. It originally covered some 450 000 km^2 (5% of Brazil's national territory) along the Atlantic coast, from the state of Rio Grande do Norte in the northeast to the prairies of Rio Grande do Sul in the south. But since the year 1500, when the first Europeans reached these coasts, the forest has been constantly and indiscriminately altered or cleared. The early Portuguese pioneers chopped down the Brazil-wood to extract dye; later settlers cleared the forest to open the way for sugar cane and coffee plantations and for settlements; and in the last 50 years industrial activities, urbanization and road construction have reduced the forest to just 30 000 km^2, of which only 15 000 are considered as primary forest (Fundação SOS Mata Atlântica, 1988).

Today, 80 million people and a great part of the country's heavy industry are crowded in the area originally covered by the Atlantic Forest. Only a few remnants can be found in scattered patches throughout the southeast. In the north-east practically nothing remains. The demand for increasing amounts of raw materials and space, and the current rate of deforestation (around 4000 km^2 $year^{-1}$) can cause the total eradication of this forest by the year 2000 (Vieira and Meirelles Filho, 1989).

Despite the deforestation, the Atlantic Forest did keep a great diversity and even now shelters around 200 000 different species, many of them endemic (53% of the known trees, 40% of mammals and 80% of the non-human primates cannot be found anywhere else) (Fundação SOS Mata Atlântica, 1988).

Extinction is, however, a constant threat — 30% of the species are in danger of extinction. The primates golden lion tamarin (*Leontopithecus rosalia*), golden rumped tamarin (*Leontopithecus crysopygus*) and muriqui (*Brachyteles arachnoides*); the trees jacaranda (*Dalbergia nigra*) and Brazil-wood (*Caesalpinia echinata*); the birds red-tailed parrot (*Amazona brasiliensis*) and tinamou (*Tinamous solitarius*), are only some examples (Fundação SOS Mata Atlântica, 1988).

The Amazon Forest, however, is still almost intact (Table 1), and therefore attracts the attention of conservation groups that fear the threat of an uncontrolled and predatory human occupation. The term 'Amazonia' refers to an area that comprises 50% of Latin America (nine countries), and contains the largest continuous tropical rain forest in the world — the 6.5 million km^2 Amazon Forest. More than 50% of it (3.5 million km^2) are in Brazil alone. For planning purposes, the Brazilian government created 'Legal Amazonia', an area of 4 906 784 km^2 (57% of the national territory), legally defined and based on geographic, physiographic, social and political criteria, that includes nine states. It is an area with a continental aspect: within it, it would be possible to fit the European continent. Seventy percent of it corresponds to tropical rain forest (78% of the Brazilian forests) and the rest is savannah and other vegetal formations (Siqueira, 1989).

This region has been studied for a long time, since the early colonization in the sixteenth century, but it was only in the 1970s that the first systematic and homogeneous study was made — the governmental project RADAMBRASIL. The whole Amazon, along with the rest of the country, was surveyed by radar, and the final result included: 34 reports on natural resources (20 about the Amazon Region), and several cartographic products based on radar images (geology, geomorphology, pedology, vegetation, potential land use, agricultural suitability, subsidies for regional planning, hydric resources and relief evaluation maps).

This material showed some of the region's great diversity: different substrata, altitudes, soil types, climates and, consequently, forests. Today, satel-

TABLE I

Deforested area in Brazilian Legal Amazon from comprehensive Landsat MSS and TM surveys (Source: Fearnside et al., 1990). The values from 1978 to 1989 were obtained from recent studies by the National Institute for Space Research (Instituto de Pesquisas Espaciais (INPE) 1989, 1990), where 222 LANDSAT/TM images covering all of the forested portion of Brazilian Legal Amazon were interpreted manually on color composites of TM bands 3, 4 and 5 at a scale of 1 : 250 000 (Fearnside et al., 1990; Tardin et al., 1990). The values for 1990 come from a more recent survey (Agência Estado, 1991)

State	Deforested area in square kilometers, (% of area of state)				Area (km^2)
	January 1978	April 1988	August 1989	March 1990	
Acre	2206 (1.4)	7292 (4.7)	8836 (5.7)	9394 (6.1)	153698
Amapá	167 (1.0)	781 (0.5)	1016 (0.7)	1278 (0.9)	142359
Amazonas	1611 (0.1)	18559 (1.2)	21551 (1.4)	22084 (1.4)	1567954
Maranhão	6076 (2.3)	24451 (9.4)	30840 (11.9)	31952 (12.3)	260233
Mato Grosso	20005 (2.5)	71414 (8.9)	79594 (9.9)	83620 (10.4)	802403
Pará	16525 (1.3)	88531 (7.1)	99786 (8.0)	104688 (8.4)	1246833
Rondônia	4242 (1.8)	29678 (12.2)	31476 (13.2)	33152 (13.9)	238379
Roraima	132 (0.1)	2743 (1.2)	3621 (1.6)	3782 (1.7)	225017
Tocantins	3166 (1.2)	20959 (7.8)	22327 (8.3)	22915 (8.5)	269911
Legal Amazonia	54130 (1.1)	264408 (5.4)	299046 (6.1)	312864 (6.4)	4906784

lite images (from the American satellite LANDSAT or the European SPOT) confirm this diversity (John, 1989).

Formed 50 million years ago between two Pre-Cambrian shields, probably with the arrival of exogenous nutrients through trade winds, Amazonia is a vast sedimentary plain, covered by a forest that is not at all homogeneous. From 0 to over 3000 m altitude, one can find several different kinds of forest. The equatorial climate is permanently hot and humid, but annual precipitation ranges from 1200 to 3000 mm, with a brief dry season.

The forest functions in a complex way and plays a significant role in determining local and global environmental conditions (Molion, 1988; Shukla et al., 1990; Setzer and Pereira, 1991). It is a source of biogenic gases and aerosols, which because of the region's intense convective activity, can be rapidly mixed to higher altitudes where they impact global tropospheric chemistry, and thus may affect global climate (Harriss et al., 1988). Twenty percent of the world's fresh water cycles through the Amazon basin, that acts as supplier of heat and water vapor to the rest of the country and other parts of the globe. Numerical models have shown that the removal of the forest could cause a reduction in precipitation and evapotranspiration and an increase in surface temperature (Cutrim, 1990). Biomass burning and deforestation in the Amazon generates gases such as CO_2, CH_4 and other pollutants (CO and oxides of nitrogen) that may accelerate the greenhouse effect (Harriss et al., 1988).

The Amazon has a great potential for any kind of exploitation. Vegetal products: latex from *Hevea brasiliensis* (rubber), wax from *Copernica cerifera* (Portuguese: carnaúba), oils from *Orbignya martiana* (Portuguese: babaçú) and *Astrocaryum aculeatum* (Portuguese: tucumã), foods from *Euterpes oleifera* (Portuguese: açaí), *Bertholletia excelsa* (Brazil nut), *Bactris gasipaes* (Portuguese: pupunha) and many others (Balick, 1985), are only some examples of useful forest products, besides valuable hardwood trees that may be worth US$ 4000 each. Animal products: fishing (more than 2000 species of fish) and hunting. Minerals: some of the world's richest ore bodies are in the Amazon (iron, manganese, cassiterite, bauxite, gold, copper and nickel are some of the commercially exploited) (Berbert, 1989). Hydroelectric resources: about 45% of Brazil's hydroelectric potential are in the Amazon basin (Secretaria de Assessoramento da Defesa Nacional, 1989). Agricultural occupation: although the soils, as in other tropical rain forests, are poor, shallow and fragile — except in some wetlands along the Amazon, Solimões and Madeira rivers — the area is seen as the frontier for expansion of agriculture and cattle ranching.

This forest is the world's richest genetic bank, and for the last few years, has been the target of very controversial discussions about deforestation, biomass burning, global climate changes and biodiversity loss (Setzer and Pereira, 1991). A lot has been said, but very little attention has been given to the process that has brought about the present situation. Deforestation has its origin in local social relations and in the country's model for economic development. In the last decades, the region's population has grown to almost 20 million, big industrial and hydroelectric complexes have been constructed, agricultural projects have been implemented, and nothing indicates that this process will stop or even slow down in the future.

Before one tries to condemn or to justify the human occupation in the Amazon, it is necessary to know the whole process. Also, it should be remembered that the human presence in the past, present and future has always played an important role in determining the region's biodiversity. Man has been the cause, but could also be the solution to the Amazon's problems. Some aspects of this occupation will be presented next.

THE COLONIZATION OF THE BRAZILIAN AMAZON: WHO OR WHAT IS TO BLAME?

There is some controversy about the exact date when the first human populations penetrated to South America. Environmental conditions make the discovery of archaeological sites difficult, but some evidence shows that it happened some thousands of years ago (Meggers, 1979). The first human beings who arrived in the Amazon region, the Amerindians, became the main victims of colonization (Batista, 1976). When Portuguese colonizers arrived in Brazil in 1500, there were more than three million Indians (of which only 250 000 remain in the present) (Conselho Indigenista Missionário, 1986).

During the next four centuries the human occupation of the Brazilian Amazon proceeded in an irregular rhythm, with long periods of stagnation followed by brief periods of prosperity. It occurred basically through the river systems. The reduced local population was linked to the vegetal (rubber, wood, Brazil nut, and jute), animal (fish and wildlife) and mineral (small gold fields) extractive exploitation (Goodland and Irwin, 1975).

The most prosperous of these cycles occurred in the late nineteenth century — the rubber boom. Rubber reached high prices on the international markets, due to the development of the car industry and to the increased demand for insulating materials for the electrical industry. The Amazon, which at that time had the monopoly of the resin production, experienced great demographic and economic repercussions. While prices and production rose, waves of migrants moved to the area from other parts of the country, and even from other countries. Cities were constructed and population (rural and urban) grew. But prosperity did not last long. Brazil lost the monopoly and, around 1920, was supplanted by production in the Orient (Santos, 1980).

In the 1960s, a different phase in the occupation process began. The region suffered a great expansion of economic activities. The construction of Brasília (the capital of the country) and the linkage highway to Belém (BR-010) marked the beginning of this second phase, in which the high point of expansion was marked by the construction of roads, such as BR-364 (linking Mato Grosso to Rondônia and Acre) and the Trans-Amazon (BR-230).

Governmental fiscal incentive policies made 112 big projects of farming and cattle ranching viable between 1978 and 1988, which were linked to development policies supported by international loans — over 5 billion dollars of investment (Amazônia, 1989). The creation of an industrial and duty-free zone in Manaus (capital of the state of Amazonas) marked this second phase.

Extractive activities fell in relative importance and were replaced by the expansion of farming, and by the industrial exploitation and transformation of minerals — as in the case of the Grande Carajás Project. With international financing, big hydroelectric enterprises were constructed (such as Tucuruí in Pará, Balbina in Amazonas and Samuel in Rondônia), generating more than 4000 MW and, at the same time, severe environmental impacts.

The process once unleashed, attracted millions of small agriculturists without land, mainly from the south and southeast regions of the country (70% of the migration) (De Miranda, 1987). They moved to the agricultural frontier, conferring to the area a great dynamism marked by deforestation and burned-over land. In 1987, around 200 000 km^2 were burned in the region (Setzer and Pereira, 1991), although 75% of the Amazon soils are of low or very low fertility (Empresa Brasileira de Pesquisa Agropecuária, 1981). This occurred mainly in Pará, Mato Grosso and Rondônia states, where about 15% of the tropical rain forest was completely eradicated. Estimates of deforestation rates in Brazil's Amazon region over the last few years show that these states, crossed by important highways such as BR-364 and BR-010, have some of the highest percentages of deforested area (Table 1).

People migrated from other regions of the country to exploit the Amazon's gold reserves, estimated at 200 tons, in a large number of areas under rudimentary recovery (Portuguese: garimpo). The proliferation of these gold fields increasingly contaminated the rivers — such as the Madeira and Tapajós — with mercury. Mercury is used in the mining process as an amalgamate to separate the fine gold particles from other mineral components in the bottom gravel. In this process, 5–30% of the Hg is lost or directly discharged into the river, and 20% is released to the atmosphere (Malm et al., 1990). For each kilogram of gold, at least 1.32 kg of Hg is lost to the environment, contaminating the whole ecosystem (water, soil and sediments, air, fish and people) (Malm et al., 1990).

This process constituted a threat to local Indian communities. The region that, in the beginning of the century, had around 200 different Indian languages, witnessed the invasion of Indian reserves and the extermination of surviving tribes (Secretaria de Assessoramento da Defesa Nacional, 1989). Around 80 000 archaeological sites may be inundated in the next 20 years, 16 000 of them by hydroelectric plants already in construction or in operation. In the Xingu River Basin only, two hydroelectric plants that are planned to be built by the year 2010, threaten seven different indigenous populations (De Castro and De Andrade, 1988).

The mechanisms that gave incentive to this second phase in the occupation of the Amazon have increased its population to more than 20 million inhabitants. Fiscal and legal provisions encouraged deforestation by increasing the demand for farm, pasture and ranch land, thereby increasing deforestation at the frontier of settlement and accelerating the conversion of forest to farm land in already settled areas (Binswanger, 1989).

Today, three vectors of occupation remain in the Amazon. First, there are the big enterprises such as hydroelectric power stations and large farming projects, which were very important in the past decades but today fall in relative importance, since the Brazilian government suspended or extinguished subsidies for these activities in 1990 (Secretaria de Assessoramento da Defesa Nacional, 1990).

The second vector is represented by mineral exploitation. Large multinational and Brazilian (government and private) companies exploit mineral resources in several promising ore bodies, contributing to the region's occupation: Paragominas and Almeirim bauxite in Pará; Jari and Capim kaolin in Pará and Amapá; Azul manganese in Pará; Carajás nickel, gold and copper in Pará; Xingu cassiterite in Pará; and Surucucus cassiterite in Roraima (Berbert, 1989).

At the same time, thousands of prospectors have joined the gold rush to the jungle of western and northern Brazil and constitute an important part of the present occupation process. It is estimated that in Brazil more than 650 000 people are directly involved in mining (Malm et al., 1990). Gold fields proliferate rapidly and profusely in the area. Although not as intensively as during the eighties, gold seekers keep on taming the forest in search of minerals — particularly gold (in the Provinces of Tapajós, North of Mato Grosso, South of Pará, Amapá, Roraima and Rondônia) and cassiterite (in Rondônia, Amapá and Roraima) — with no respect for political or natural delimitations, Indian reserves or protected areas (Comissão da Ação pela Cidadania ao Estado de Roraima, 1989; Secretaria de Assessoramento da Defesa Nacional, 1989).

The third and main vector of occupation are the small agriculturists, without land, who migrate to the Amazon region attracted by the promises of plentiful and cheap land. These people leave the dry, overpopulated northeast and the farms in the South where machines have replaced manpower, and where the land has been successively divided into smaller properties, hoping to find a better life in government-sponsored colonization projects, and in public or private lands to which squatters go on their own initiative (Fearnside, 1985).

Given this present situation in the Amazon, Brazil is faced with the difficult task of defining a new phase of occupation that will supplant past mistakes. However, to define this new phase, it is important to understand not only the historical relations between man and the tropical rain forest, but also their consequences for biodiversity.

BIODIVERSITY AND THE COLONIZATION OF THE BRAZILIAN AMAZON

Human presence in the Amazon has been simultaneously a source of increase, decrease and maintenance of the biological diversity.

Biodiversity, or biological diversity, is a global resource made up of the great variety of living forms on Earth, both wild and domesticated. It can be understood in many different ways: genetic diversity (differences in genetic constitution among individual organisms), ecosystem diversity (distinctive assemblages of organisms that occur in different physical settings), and the most common measure, species diversity. One should never forget though, that man is part of the problems concerning biodiversity. This is a very complex matter and any generalization is dangerous. Very distinct situations coexist today in the Brazilian Amazon.

In the case of the indigenous populations, several studies have shown how certain tribes in this region have contributed, in a permanent way, to the partition and to the cultivation of vegetal species of their own interest, to the maintenance of a high polymorphism in their plantations, and to the management of several forest ecosystems (Posey, 1985; Taylor, 1988). Other studies indicate that this millenary influence has expanded to vast areas and could be the origin of some vegetation types considered natural until today (Ballée, 1988, 1989; Ballée and Campbell, 1990). Thus, the transformation of the Amazon forest by man was probably much greater than what was assumed to be the case until recently. This fact raises the first question, about the lack of knowledge and research on man/forest interactions in this region and their consequences.

Similar results, in terms of increasing biodiversity, have been observed in riverside populations and in some caboclo communities (mestizo populations descended from Indians, blacks and whites). In the state of Maranhão, along the eastern limits of the Amazon forest, on extremely poor soils, these communities have practiced, for over a century, an itinerant agriculture in small areas, besides hunting, fishing and the exploitation of forest products. They employ the traditional methods of shifting cultivation: after deforestation, the area is cultivated for a brief period (the soil tolerates the maximum of 2 years of cultivation) followed by a long fallow period. The non-eradication of the vegetation assures its reconstitution and the agriculturists take 15 years or more to come back to the same place. This agricultural practice generates a mosaic of forests, that differ in terms of phytodynamics or vegetal chronosequence, each one with its own characteristics in terms of faunal and floral communities. This spatial heterogeneity can be detected and monitored through satellite images. The diversity indexes of these areas are greater than the ones for original forests. At the same time man — like wild and domesticated animals — exploits the increase in primary productivity, cynegetic and energetic resources (De Miranda, 1985).

There are some cases in which the creation of reserves in these areas, with the consequent expulsion of the agriculturists–collectors and the return of relative homogeneity of the natural vegetation, is leading to a simplification of the ecological systems and to a loss of biological diversity. Several communities of caboclos in the wetlands of the Amazon River, have an extremely elaborate idea of the spatial and temporal partition of the natural resource supply, and they practice complex systems of exploitation and production, which guarantee the perpetuity of the ecosystems they use (Frechione et al., 1989).

This illustrates the complication of creating national parks and reserves as the only alternative to preserve these ecological systems, and the necessity of instruments and parameters to monitor the biodiversity in these areas of traditional occupation, many of them in places of high incidence of endemic species (Brown and Cardoso, 1989).

As the density of these populations living in the forest increases and their mobility decreases, the systems of production and exploitation tend to be simplified and to affect some aspects of the ecological systems. This is the case of rubber tappers in the state of Acre, in the western Amazon. The increase of population density and the intensification of land use has been feasible and compatible with the maintenance of the vegetal resources of the forest. On the other hand, animal communities, particularly vertebrates, have been subject to systematic, indiscriminate and quotidian hunting, that has led to local extinction of species, and still does, besides the consequent and dramatic reduction of the remaining populations (Nunes et al., 1990). How is it possible to keep the biodiversity of these traditional intensified agro–forestry systems, in the middle and long-term?

The migration of thousands of families of small agriculturists from the South, Southeast and Northeast Brazil to the Amazon has caused changes in the forest ecosystems, and the emergence of agroecosystems with a great spatial–temporal dynamism, and it has had complex environmental consequences. In the states of Rondônia and Mato Grosso, this colonization process has led, on the one hand, to the loss of biological diversity, stemming mainly from deforestation, eradication of habitats and disruption of traditional Indian, caboclo and rubber tapper production systems. On the other hand, it has caused an expansion of the total number of species, the emergence of interesting cases of sustainable land use for a high density resident population, the diversification of certain animal communities, etc. Because it is a recent process, diachronic comparisons are only now beginning to emerge, showing a more subtle picture than the one given in several articles that completely disapprove of the agricultural occupation of that region. Even the announced failure of the agriculturists, who after some years of cultivation sell their lands to exploit a new area, has proved to be, in many cases, part of a capitalization strategy (Lena, 1988). What is one to do with this reality? Even if the immigration of agriculturists into the agricultural frontier is reduced to zero, the thousands who are already there give us reason enough to look for new research alternatives for sustainable agro–forestry systems, that could be adapted to these settlers' socio–economic conditions.

Finally, there are in the Amazon hundreds of thousands of hectares that are completely deforested, as a result of an old agricultural occupation in the region of Belém (Pará state), along highway Belém–Brasília, and in the state of Mato Grosso, marked by extensive cattle ranching in large landholdings. Very little is said about these areas where deforestation is no longer carried out (since the forest that used to exist has already been eradicated), to which nobody migrates any longer (since all the land is owned and concentrated in the hands of few people), and where extensive production systems have left little space for new enterprises. Several of these big agricultural and agro-industrial projects are the result of an old fiscal incentive policy and now, without support, they tend to fail. Agrarian speculation dominates these rural landscapes in Tocantins, Mato Grosso and Pará (Instituto do Desenvolvimento Econômico-Social do Pará, 1987; Reydon and Herbers, 1989). They represent the largest loss of biodiversity in the Amazon, but it is not yet a permanent loss. The results of recent research show that these areas could have their biodiversity restored (Uhl, 1988; Uhl and Kauffman, 1990). In the first place, some of the remnant areas are more important for preservation than the vast areas of intact forest. Second, and more important, these degraded areas need a new agricultural transformation to recover their biological and production potentials. The ecological restoration of these regions, especially the degraded pastures and some old mining areas, is essential for the preservation of the rest of the Amazon forest. It represents the possibility of reducing the pressure on the untouched forest, generating a kind of buffer zone in the southern section of the Amazon River. Ecological studies, in this case more than in any other, should be inserted in the region's social and economic contexts. Finally, it is also in this region, where some scarce remaining areas of humid forest still are found, that preservation is very urgent and important.

OCCUPATION AND PRESERVATION: A TRIPLE CHALLENGE

In terms of biodiversity, the Amazon's future occupation presents a triple challenge. First: how is it possible to make sure that the more than 90% of intact forest does not suffer the same process of eradication, and that the people of the forest (rubber tappers, Indians, caboclos and riverside communities) are preserved? Second: how to administer the tense area of economic frontier, since the human contingent arrives continuously? How to reconcile economic development and environmental preservation in these areas? Third, and often forgotten: how is it possible to restore the biodiversity and the production potential of immense areas already devastated, around 400 000 km^2 of forest, savannah and field? Concrete examples of scientific research contributions toward meeting each of these challenges are described next.

An example of a preserved area — Acre

The best way to preserve untouched areas is not by turning them into reserves or parks, but by planning their rational occupation. The extractive reserves created in the state of Acre are an example of this kind of occupation.

Acre is located in the northern region of the country, in the western portion of the Brazilian Amazon, along the border with Peru and Bolivia. It has an area of 152 589 km^2 and holds a significant number of extractive communities (Menezes, 1989).

The term 'extractivism' means gathering and/or harvesting native products from natural ecosystems without destruction or real conversion of the original environment and, therefore, maintaining all or almost all of the pristine biodiversity (Dubois, 1989).

Extractive communities, especially rubber tappers, have lived in the forests of Acre collecting this product since the rubber boom in the nineteenth century (De Almeida, 1989). Although rubber production is no longer an important source of income to the country, and the extractive production has declined in terms of share of the total dollar value generated in the state, it is still of substantial economic importance and a very attractive development alternative compared to cattle or agriculture (Allegretti and Schwartzman, 1989). It is the main economic activity of these communities, which produce good rubber on a sustainable basis.

Today, the major part of Acre's original vegetation is still preserved (Table 1), but the state faces the possibility of a process of occupation similar to that in the state of Rondônia. The planned paving of highway BR-364 that crosses the state, and its prolongation to the Pacific Coast can cause, in the near future, an expansion of the agricultural frontier and the development of activities not always compatible with the original inhabitants' interests. The large-scale deforestation that would come with this process is totally incompatible with extractivism.

The Brazilian government is beginning to implement a new type of reservation — the extractive reserve — as a response to the massive deforestation and environmentally and socially disastrous development schemes in the Amazon (Fearnside, 1989a; Menezes, 1989). They are defined as forest areas inhabited by extractive populations granted long-term usufruct rights to forest resources which they collectively manage (Schwartzman, 1989). Thus, they may guarantee a sustainable system of life for extractive groups (Fearnside, 1989a).

Studies carried out by the Environmental Monitoring Center (NMA) gave rise to the creation of the Alto Juruá Extractive Reserve — one of the first of these reserves — in January 1990 in western Acre. It is an area of great ecological and social value: in about 5000 km^2 one can find fertile soils, many cases of endemic species, different vegetal and geomorphological formations (including bamboo forests), and a population of rubber tappers that has a reasonable rubber production (De Miranda et al., 1990a).

Besides vegetal extractivism, a sustainable activity that does not threaten biodiversity, these populations also practice animal extractivism. Fauna is not of secondary importance: fish and wild animals are the main source of proteins (contributing approximately 70% to their protein diet). The hunting is intense, conducted mainly while they are gathering latex, and has an impact on the animal communities. The most hunted vertebrate species are: agouti (*Dasyprocta* sp.), tinamou (*Crypturellus* sp.), paca (*Agouti paca*), nine-banded armadillo (*Dasypus novencinctus*), guan (*Penelope* sp.), naked-tailed armadillo (*Cabassous* sp.), common squirrel monkey (*Saimiri sciureus*), South American coati (*Nasua nasua*), spider monkey (*Ateles* sp.), capuchin monkey (*Cebus apella*), and howler monkey (*Alouatta seniculus*). Overhunting can lead to the reduction of these animal populations and to the extinction of some species locally, such as the capybara (*Hydrochaeris hidrochaeris*) and the tapir (*Tapirus terrestris*), reported to be currently rare in this region (Nunes et al., 1990).

In untouched areas, such as Alto Juruá, territorial planning prior to the arrival of colonization vectors is a fundamental step in order to preserve biodiversity.

One case of a frontier area — Rondônia

In the case of the agricultural frontier, at the same time that the migration flows should be reduced, alternatives to the thousands of agriculturists already installed there should be proposed. A good example of an alternative to reduce the environmental impact and to preserve biodiversity are the studies that have been done in agricultural colonization projects in the state of Rondônia.

Rondônia, in western Brazil, along the border with Bolivia, has been the main target of the uncontrolled migration flow to the Amazon region, and demonstrates clearly the dynamics and extension of the environmental impact of the agricultural colonization on the tropical rain forest.

The occupation of this state has always been connected to the highway BR-364, which goes from Cuiabá (Mato Grosso State) to Porto Velho (capital of Rondônia). During the 1970s, although not paved, this road was the main route to penetration to the state. Its reconstruction and paving in 1984 was the center of the Polonoroeste Project, a 1.5 billion dollar enterprise for regional development financed by the World Bank. It accelerated the migration to Rondônia. The state's population grew exponentially between 1980 and 1985 at a staggering rate of 14.8% a year, going from 500 thousand to over one million. The damage to the environment was also severe. Deforestation grew at higher rates than the population — 24.8% $year^{-1}$ from 1980 to 1985 (Fearnside, 1989b). Today it is one of the states with the most recent occupation in Brazil's Amazon region, and has the highest percentages of deforested area (Table 1).

In order to study the colonization of the Brazilian rain forest and the agricultural transformations in the Amazon, the NMA developed a research program in a colonization project implemented by the government in 1982 in the northeastern part of Rondônia — the Machadinho Project (today turned into the county Machadinho d'Oeste). A detailed description of the agriculturists and the agricultural practice in the 3000 plots of land was made: the settlers' origin, the effective rates of implementation and occupation, land use, the available resources to develop agriculture, the production systems in use, their sustainability and environmental impacts (De Miranda, 1987; Mattos et al., 1990a,b).

The results are a good example of the economic dynamics in the Amazon. In this area of 12 500 km^2, that in 1982 was completely untouched and covered with tropical rain forest, 30 000 people live today (8000 in urban and 22 000 in rural zones). A basic infrastructure has been created (primary school, hospital, bank, extension aid's office, etc.) and a local commerce has developed (supermarkets, pharmacies, sawmills, fuel stations and fish stores).

People usually think that this process of occupation is a threat to biodiversity. This is certainly the case when one considers the loss of habitats associated with the deforestation caused by settlers. But, at the same time, human occupation generates habitats and introduces new species in the area, with the practice of diversified agriculture and mixed crops. The list of the cultivated species in Machadinho is one example of man-generated biodiversity in agricultural projects, many of them with positive results in production, productivity and soil conservation (De Miranda, 1987). In 3000 plots of land 11 annual crops, nine perennial crops, 28 fruits, 18 horticultural plants are cultivated, besides over 50 different ornamental and medicinal plants (De Miranda, 1987). The list totals over 100 plant species!

Studies could show that, for small-scale agriculture such as that practiced in Machadinho, mixed crops (annual with perennial) are the best alternative for biodiversity preservation (De Miranda, 1987). The best systems of production could not be discovered in research centers, because the number of species that could be cultivated is very large, the perennials' growth is slow, the crops usually take over 10 years to start yielding and the possible combinations of species (mixed crops) are immense. That is why today researchers are trying to take advantage of the 15 years of experience in colonization to detect, based on the agriculturists' knowledge, the sustainable systems, so they can be improved and divulged on a regional level.

Some studies and actions in a degraded area — Tocantins

The third challenge in the Amazon, often forgotten, is represented by the almost 400 000 km^2 of forest, savannah and field that have been occupied and degraded for a long time, and are used today in a very extensive way. These areas demand strategies totally different from the other two mentioned above.

First, special attention should be paid to the remnants of preserved ecosystems, since they are the most threatened with extinction and the last testimony to these environments. Second, the degraded areas should be reincorporated into the productive process and should have their biodiversity restored. In this way, they could receive part of the migration flow that today moves towards the Amazon.

Several areas in the states of Mato Grosso, Pará, Tocantins and Maranhão are in this situation. To identify the potential areas for preservation, for restoration of biodiversity, and for the colonization process the NMA has developed a Geographic Information System (GIS) program.

One of the studies has been carried out in Tocantins state, in the central region of the country (De Miranda et al., 1990b). There, indiscriminate land occupation has led to an intensive degradation of fragile ecosystems, which in some cases are in an irreversible situation. There are also cases of unsuitable land exploitation due to an absence of planning (De Miranda and Santos, 1990). In an effort to slow down this process an automated cartographic data bank has been implemented, using GIS. Information about geology, geomorphology, vegetation, pedology, hydrography, environmental protection areas, stratification of agricultural areas, actual occupation, present urban area, county division, present road course and potential areas for preservation have been stored in 330 maps at the scale of 1:250 000. As a result of the weighing of seven information levels, an agroecological map has been generated (De Miranda et al., 1990b). With it, it is now possible to identify potential areas for preservation, in addition to those already delimited, and also indicate the appropriate regions for agricultural practices (based on sustainable land-use systems and actions for biodiversity restoration).

CONCLUSIONS

The colonization of the tropical rain forest goes on, worldwide, at an accelerated pace. Despite its multiform importance, demonstrated with quantified data in the present work, nothing indicates the reversal of this situation, even in the Amazon, which represents more than 30% of these ecosystems. The environmental consequences of this process, detailed in the text, acquires unprecedented dimensions. If recent research indicates man as the cause of a reduction in biodiversity, it also points to certain human communities as responsible for maintaining and even increasing biodiversity in the tropical rain forests, where they have been inhabitants for thousands of years. It is as well to remember that every crisis in the utilization of nature reflects a crisis in social relationships. It is urgent, in the case of the Amazon, to overcome the simplistic vision of a hypothetical man/nature relationship. What does exist are relations among men, through nature. Nature must be understood as the object and not the objective of social relationships.

This study illustrates how, in the Amazon, this has been historically translated into the coexistence, overlapping and confrontation of several societies and social groups, such as Indians, caboclos, rubber tappers, gold miners, small agriculturists, big farmers, industrialists and energy/mining industries, with complex and distinct consequences for the environment and biodiversity. Therefore, the solutions to these problems are not simple nor possible only on a regional scale. They require the participation of all of Brazilian society, and even of the international society, through programs in which the State should act according to permanent national interests and not only in the defense of private groups.

Today, there is a triple challenge to all those who are involved in and concerned with the preservation of man, nature and biodiversity in the Amazon. First, how to prevent the same eradication process — apparent in Rondônia, Mato Grosso and the South of Pará — of the 90% of intact forest still remaining? Second, how to manage the tense frontier — those areas where farming, cattle raising and mining meet the forest — given that the human contingent arrives continuously at the southern border of the Amazon Forest? And third, often forgotten, how to restore the biological potential and productivity of immense areas already devastated?

There are some examples to study, which have been presented here — the cases of the states of Acre, Rondônia and Tocantins. They show how science and technology can avoid a confused, uncontrolled and predatory occupation in the Amazon, reordering the colonization, development and preservation process, while at the same time restoring even lost biodiversity. We and our children should and can overcome these challenges.

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