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Deforestation and Land Use in the Brazilian Amazon

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Deforestation and Land Use in the Brazilian Amazon

Emilio F. Moran[1]

Deforestation in the Brazilian Amazon was less than 1% before 1975. Between 1975 and 1987 the rate increased exponentially. By 1985, world opinion and attention to the destruction of the richest biome on earth led to elimination of some of the major incentives that had fueled deforestation. Favorable credit policies for cattle ranchers, rather than population growth, explains the process of deforestation in the Brazilian Amazon. The paper suggests other actions that may be taken to reduce deforestation, and examines the rapid growth rates of secondary successional species in a colonization area.

KEY WORDS: Amazon Basin; deforestation; rain forests; colonization; ranching; logging; Brazil.

INTRODUCTION

The results of road-building, farming, ranching, and logging have been devastating to the tropical forests of the Amazon (Fearnside, 1982, 1987b; Browder, 1988; Mahar, 1988; Uhl and Vieira, 1989). Little deforestation had occurred in Brazil's Amazon before the 1970s. As of 1975, a total of only 3,000,000 hectares or about 0.6% of Brazilian Amazonia had been cleared. Between 1975 and 1987 the rate of deforestation steadily accelerated increasing to 12,500,000 hectares by 1980 (Mahar, 1988). Houghton has suggested that up to 40% of this amount were lands already deforested (Houghton, 1992). Both Booth (1989) and Setzer and Pereira (1991) have reported that up to 8 million hectares of previously uncut forest were burned in 1987—possibly the peak rate to date. The rate has declined to 1,800,000 hectares in 1989, to 1,380,000 hectares in 1990, and to 1,110,000 hectares in 1991 (Houghton, 1992). Rates of deforestation have declined since 1988 largely as a result of the economic recession and hyperinflation in Brazil.

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Concerns have focused on the effects of deforestation on biological diversity (Wilson, 1988), climate change (Dickinson, 1987; Shukla *et al.*, 1990; Aber and Melillo, 1991), and atmospheric trace gases (Dickinson, 1987; Andreae and Schimel, 1989; Crutzen and Andreae, 1990; Dale *et al.*, 1991). Attention has also been brought to tropical forests' contribution to the global carbon cycle (Detwiler and Hall, 1988). Moist forests of the tropics cover only about 11% of the Earth's land surface but are estimated to contain 41% of the global terrestrial biomass and over 50% of the world's species. The Brazilian Amazon contains 26.5% of the Earth's moist forests (Whittaker and Marks, 1975; Prance and Lovejoy, 1985; Silver, 1990). The continental size of the Amazon Basin and its high evapotranspiration rates make it a notable influence on world climate (Salati, 1985; Molion, 1987). It is believed that removal of Amazonian vegetation on a large scale will bring about sufficient changes in the region's hydrological cycle and climate such that the forests may not be able to re-establish themselves (Shukla *et al.*, 1990; cf. also Henderson-Sellers, 1987; Lean and Warrilow, 1989).

Monitoring the rates of deforestation has tended to focus on dimensions of the problem that serve to alert us to the scale of the problem, but which do not necessarily address land use and policy issues, other than the need to stop deforestation altogether. While no more salutary policy could possibly be implemented than a complete stop to deforestation in Amazonia, such an outcome is unlikely. A complete stop to deforestation is both impractical and insensitive to the demand for land by populations driven into those areas by lack of opportunity elsewhere (Janzen, 1988). Other strategies for reducing the rates of deforestation in the Brazilian Amazon are necessary, on both ecological and economic grounds. Reductions in deforestation are possible by a combination of approaches that take into account political and economic, as well as environmental considerations. Attention must be paid to the causes of deforestation, to intraregional differences in environmental conditions and land use patterns, and to the differential rates of secondary growth that may permit re-establishment of forest cover.

The causes of deforestation in Amazonia are distinctly different from those in Indonesia, and they vary significantly even within the Amazon Basin (Gillis, 1988; Repetto, 1988; Stern *et al.*, 1992; Kummer and Turner, 1992). Deforestation in Indonesia is directly caused by expansion of agriculture, with commercial logging an important contributing factor (Repetto, 1988; Collins *et al.*, 1991; Kummer, 1992). In Malaysia, 90% of deforested land has been converted to plantation agriculture, while in Thailand, it is difficult to find any one factor that accounts for most of the deforestation (Kummer, 1992; Hirsch, 1987).

Amazonian deforestation has transformed Brazil into the world's fourth major atmospheric carbon contributor, behind the United States, the Soviet Union, and China (Goldemberg, 1989, p. 39). Destruction of Amazonian forests is responsible for the equivalent of 7% of the total carbon dioxide emissions provoked by fossil fuel emissions (ibid.). Brazil contributes the lion's share of carbon emissions from deforestation with 336 million tons of carbon per year (ibid. p., 49; see also Table I). This is a very recent phenomenon. Salati and Vose (1984) noted that the Amazon Basin was a large system in equilibrium, but that signs were appearing of man-induced disequilibrium coming chiefly from deforestation. Their forecast has proven all too true.

Rates of deforestation escalated until Brazil was confronted in 1985 with the worldwide concern for deforestation in the Amazon Basin. Why did concern only start in 1985? When did the problem actually begin and why? Is it possible still to return the Basin to some balance between carbon released and carbon taken up by growing vegetation? What policies need to be put in place that take into account the social and economic realities of a nation like Brazil? These are some of the questions that this paper addresses. The paper also reports on analysis of deforestation processes between 1985 and 1991 along the Transamazon Highway combining satellite digital data and field studies. Remote sensing techniques have permitted the analysis of much larger areas than had been possible by reliance on field techniques alone.

THE CAUSES OF DEFORESTATION

Large-scale deforestation in the Amazon Basin did not begin in 1985 as media attention might suggest but, rather, with the construction of the Belém-Brasília Highway in 1958 (see Fig. 1). The objective of building Brasilia was to have the capital in a more central location that would encourage Brazilians to look away from the coastline which they had been hugging for 350 years and to begin the effective occupation of the vast interior of the country. The Belém-Brasília was the first of a series of highways that were to be built with the objective of "integrating" the Northern and Western states with the rest of the country (Mahar, 1979).

Occupation of land along the Belém-Brasília was slow at first and the road cut through a broad array of vegetation types, only a small part of which were tropical moist and rain forests. Most of them were savannas, scrub forests, and tropical deciduous forests. In the first 20 years, over 2 million people settled along this dirt road, which was paved only in 1973.

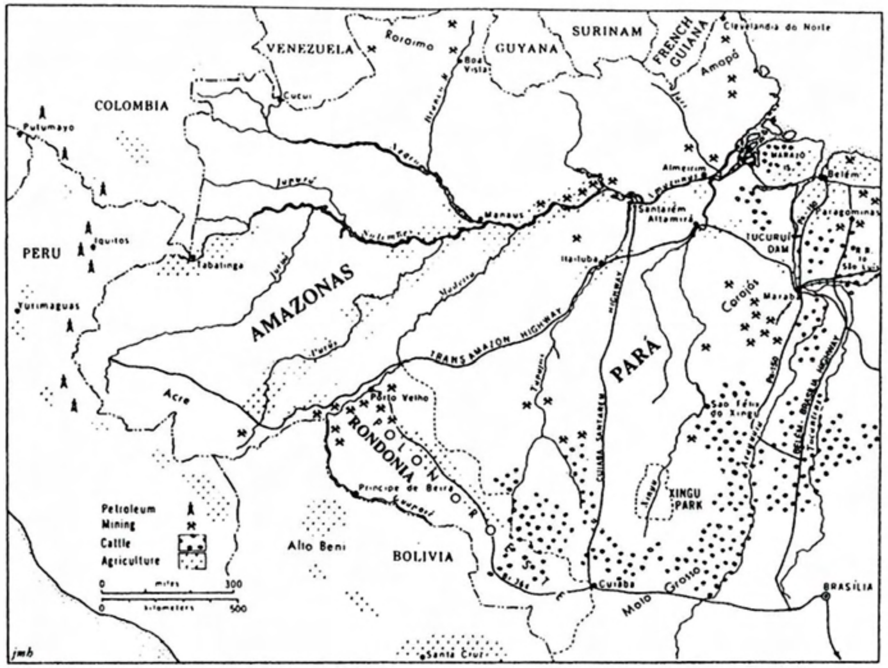

Fig. 1. Roads and economic activities in the Amazon Basin.

As we shall see later, it is land along this road that first attracted attention to the destruction of forest, especially through low-quality cattle ranches (Hecht, 1980). Cattle increased from near zero to over 5 million in the same 20-year time period (Mahar, 1988, p. 12). Even feeder roads near the Belém-Brasília Highway were quickly occupied and vast areas deforested. In an area of 4,700,000 hectares along the PA-150 highway, which runs parallel to the Belém-Brasília Highway, the cleared area jumped from 30,000 hectares in 1972 to 170,000 hectares in 1977, and to 820,000 hectares in 1985, with the leading cause being forest-to-pasture conversion (ibid., pp. 13-14).

Road-building became even more important with the announcement in 1971 by President Médici of a Program of National Integration (PIN) which would build north–south (Cuiabá-Santarem) and east–west (Transamazon) highways connecting the Amazon Basin internally and to the south of the country. Because the occupation of the Belém-Brasília had been seen as "disorderly," the military governments that ruled Brazil after 1964 planned a "directed" and highly orderly occupation of the land alongside the highways, with settlers from the northeast and southern Brazil. They had as a goal to move 100,000 families in the first 5 years, serviced by a hierarchical network of settlements and service communities (Moran, 1981; Smith, 1982).

The oil crisis affected the settlement and road-building plans of the Transamazon and Cuibá-Santarem highways too (see Fig. 1). After 1973, the costs of transportation increased so radically that construction of the planned communities almost stopped altogether, and only the main trunk of the highway was built—not the service roads going to the farms. This left most farmers stranded on their landholdings, unable to get their rice, corn, and other produce to market (Moran, 1976, 1981). It also reduced the incentives to deforestation in the area.

The changed costs of settling the Amazon with small farmers, and a change in Presidents, led to a policy shift in 1974—barely 3 years after the inception of the PIN. President Geisel announced that large-scale entrepreneurs would be more effective at developing the Amazon and land began to be parceled in large units to individuals and corporations. Instead of the 100,000 families foreseen by the Transamazon Settlement Scheme, only 6000 had come in the time period projected, and estimates are that small farmers accounted for less than 4% of total deforestation in the 1970s (Browder, 1988).

The contribution of small farmers to deforestation is probably higher in the Peruvian Amazon. According to Bedoya (1989), 38% of the cultivated land in Peru today is in the Amazon region and 20% of all individual farms are in that region—up from 10% just 10 years before. In Peru, the impact of cocaine production in the lowlands, under the protection of the Shining Path guerrillas, seems to be in part responsible for the high levels of agricultural activity and deforestation in the Peruvian lowlands. Cattle do not play as important a role in Peru as they do in Brazil (Hecht and Cockburn, 1989).

The priority in policy given to large-scale operators was not new. In 1966, a plan to encourage Brazilians to occupy the Amazon created a development agency (Superintendência do Desenvolvimento da Amazonia, or SUDAM) and a regional development bank (Banco da Amazonia, S.A., or BASA) through which individuals or firms could invest in projects within the Amazon region. It is important to remember that the area referred to as the Amazon includes large areas of savannas and other kinds of vegetation and even areas outside of the river drainage system. Through SUDAM and BASA it wass possible to have 50% of personal and corporate income tax liability invested in approved projects. Through these development projects, not only did one not pay taxes to the federal government but one received a 3 dollar rebate for every dollar invested from one's tax

liability—and got to keep all 4 dollars and capital gains tax-free. This sort of fiscal incentive was too much to pass up. Most of the deforestation in the southeastern portion of the Amazon Basin is traceable to this policy (Kleinpenning, 1975; Hecht, 1980; Fearnside, 1987a,b).

Not only was this tax holiday and subsidy attractive in its own right, but SUDAM allowed that a great majority of these projects be extensive cattle ranches. By late 1985 about 950 projects had been approved, of which 631 were cattle ranches (García Vásquez and Yokomizo, 1986, p. 51, in Mahar, 1988, p. 15). Cattle ranches currently cover at least 8.4 million hectares and average 24,000 hectares each (ibid., p. 16), some are as large as 560,000 hectares. These ranches employ few people, averaging one cowboy for every 300 hectares. A recent simulation of a typical 20,000 hectare ranch receiving a 75% subsidy demonstrates that livestock activities are profitable *only* when they receive the full array of tax holidays (Hecht *et al.*, 1988). Without them, they are not profitable and can achieve positive internal rates of return only through overgrazing. While overgrazing destroys their long-term viability, the favorable incentives to convert forest to pasture lead to clearing new forested areas rather than investing in recovery of areas already cleared. There can be little doubt that without the subsidies deforestation rates would have been much lower. The conversion of forest to pasture is not the result of local population pressure, as it is often assumed by scholars unfamiliar with the peculiar political economy of Brazil (Denevan, 1980). In fact, there is growing evidence that the conversion of forest to pasture leads to rural depopulation and urbanization in Amazonia (Mougeot and Aragon, 1981).

With the change of policy migrant flows were diverted to Rondonia. Occupation of this area was facilitated by the construction in 1968 of the Cuiabá-Porto Velho road which happened to be cut through some of the better soils available in the region. Rondonia is today the state with the highest proportion of deforested land (24%). *The average area deforested each year in Rondonia in the 1980s was equal to the total area deforested before 1980* (Mahar, 1988, p. 34). Deforestation in Rondonia is more clearly related to the increased pace of in-migration, which averaged 160,000 persons per year for the period 1984–88, as compared with 65,000 in the 1980–83 period, and 28,500 during 1968–78 (in contrast to a *total* population of 70,000 before 1968). Efforts to promote tree crops as a more environmentally-sound way of sustainable land-use have faltered. Favorable treatment of cattle ranching by banks and SUDAM has led to an increase in the total amount of land in pasture, 25.6% of the 1985 total, whereas land in perennial crops has remained stagnant at about 3.5% of the total. A great deal of the attention by scholars monitoring deforestation has focused on Rondonia (e..g., Tucker *et al.*, 1984; Woodwell *et al.*, 1986a,b). However,

Table I. Deforestation (in km^2) in the Brazilian Amazon

State (abbrev.) (NW-NE-SW-SE)	Total area in "Legal Amazonia"	Approximate original area of forest	Total area deforested by August 1989	Percentage of forest still intact	Totally protected areas 1990
Amazonas (AM)	1,567,954	1,540,000	21,551	99	70,000
Roraima (RR)	225,017	185,000	3,621	98	9,000
Amapá (AP)	142,359	112,000	1,016	99	10,860
Pará (PA)	1,246,833	1,140,000	139,604	88	17,300
Maranhão (MA)	260,233	163,000	88,664	46	3,410
Acre (AC)	153,698	153,000	8,836	94	6,820
Rondônia (RO)	238,379	214,000	31,476	85	17,380
Mato Grosso (MT)	802,403	417,000	79,594	81	2,620
Tocantins (TO)	269,911	40,000	22,327	44	6,000
Amazonian totals	4,906,787	3,964,000	396,689	90	143,390

it must be remembered that Rondonia is not "typical" in any meaningful sense, and that analyses of this region reflect particular circumstances, and what can happen when policy incentives that do not explicitly discourage deforestation and cattle ranches are implemented.

Land speculation is largely responsible for the loss of forests of Rondonia today (Mahar, 1988). Given the continued use of the standard that anyone clearing forested land has "improved" it and thereby gains the right to sell "the improvements," a brisk land market has developed. Average land prices have skyrocketed since 1983, leading to a frenzy of deforestation and real estate speculation—temporarily slowed down since 1989 by hyperinflation. It is possible to net the equivalent of $9000 from clearing 14 hectares of forest, planting pasture and a few crops for 2 years, and selling the "improvements" to a new settler (Mahar, 1988, p. 38). This is better than a farm laborer can hope to make under ideal conditions by a factor of four. The fact that the 25% capital gains tax on land sales is rarely collected is a strong incentive to engage in this sort of activity. If 14 hectares can net that kind of return in 2 years to a small operator, it is evident that such activity is highly attractive to average ranchers holding 10–20 thousand hectares. Rondonia is one of the few areas in Amazonia which is likely to continue to experience rapid deforestation even if fiscal incentives are removed because of the profits to be made from rising land prices. As we will see later in this paper, in the colonization region along the Transamazon highway, forest regrowth outpaced deforestation of mature forest by a factor of two between 1985 and 1991.

The two other sources of deforestation in the Brazilian Amazon are mining and timber activities. Mining activities do not seem to have had a major impact on the total area of forest cleared, although they are largely responsible for the exponential rise of malaria in the Basin. Brazil today accounts for 1 million out of a total 5 million official cases of malaria worldwide, and this figure is probably underreported. All reports from mining areas suggest that the number of positive cases is near 100%. Malaria affects not only miners but farmers and other inhabitants throughout the region. One recent large-scale mining project has begun to have a potentially devastating impact. Tax holidays were offered for the production of pig-iron in the Great Carajás region and plants were designed to operate based on locally-produced charcoal. Already the demand from the approved projects requires 1.1 million metric tons of charcoal annually, and is expected to double when projects under evaluation are approved by SUDAM (Fearnside, 1987b). Treece (1989) notes that 610,000 hectares of forest per year are used for charcoal smelting in the Greater Carajás projects alone.

The importance of timber exploitation in deforestation begins to be notable only in the 1980s. The most recent statistics indicate that four of the six states in the region depend on wood products for more than 25% of their industrial output (Browder, 1986, p. 65). In Rondonia and Roraima they account for 60% of the output. The number of licensed mills has increased more than eightfold since 1965 and the annual output per mill has doubled during the same period. The Amazon region of Brazil accounted in 1984 for 43.6% of national roundwood production, as compared with only 14.3% 10 years earlier (Browder, 1988, p. 249). The declining contribution of Asian forests to the world's demand for tropical wood products will lead to further increases in these activities in the 1990s (Repetto, 1988). This is one kind of land use which will have to be monitored from space, despite the inherent difficulties that presents. As Uhl and Vieira (1989) have suggested through field studies, selective logging has a devastating impact on the surrounding forest, leading to as much as 40% mortality.

DEFINING DEFORESTATION AS "A PROBLEM"

One can search deeply in the important book from the National Research Council *Ecological Aspects of Development in the Humid Tropics* (1982) for signs of concern over Brazilian deforestation, but none will be found. The book recommends protective action that would permit both conservation and development of the humid tropics—but no sense of alarm was felt in 1982. This is not surprising since, as noted above, the area deforested until 1975 was small and at the periphery of the Basin. Nor had some of the alliances been forged that would begin to give political clout to this issue.

Deforestation became of increasing concern beginning in the late 1970s, and this concern focused primarily on deforestation activities that had started after World War II in the Asian and African tropics. In those areas, much of the forest cover was gone by the 1970s and in the few remaining countries with significant areas of forest, the rates of deforestation were alarming (i.e., in the range of 2–3% annually).

The impact of the media can be seen in its changing attention to the topic of deforestation (see Fig. 2). Most of those who noticed what was happening to Amazonian forests were scientists who communicated with each other through scientific journals. The earliest clarion may have been the 1972 article in *Science* (Gómez-Pompa *et al.*, 1972) which questioned whether rain forests could re-establish themselves after deforestation, and warned of the danger of extinctions. Throughout the 1970s most of the attention given to rain forests was confined to periodicals such as *Science*, *Science News*, and *Scientific American*. A few conservation journals, such as *International Wildlife*, and *National Parks and Conservation Magazine* also alluded to the problem, but none of these were large circulation media (Anderson, 1990). Near the end of the 1970s the mainstream press began to take notice. A report by the Worldwatch Institute received attention from the *New York Times*, in the form of a 4-inch Associated Press story. The topic gained momentum a month later with a 15-inch article on the third page of the "Science Section"—a story that covered a research scientist's speech at an international conference on endangered species (March 29, 1979).

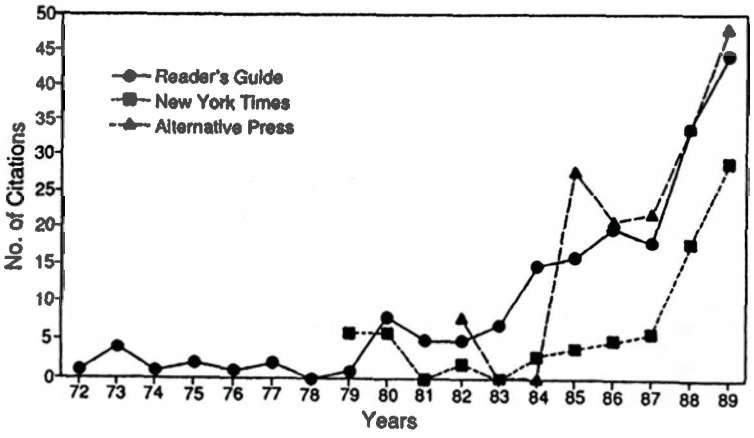

Fig. 2. Citations on rainforest destruction.

In July 1980, a 23-inch story in Section A of the *New York Times*, written by Tom Lovejoy of the Smithsonian, detailed the consequences of deforestation on biodiversity. Two major stories appeared 2 years later, one a 17-inch opinion piece in July by Norman Myers, and one in October of 14 inches which detailed efforts of 25 environmental organizations to persuade the World Bank to stop funding projects in Brazil that caused deforestation. The next month, a 23-inch story featured a study that pointed out that Indians used 85% of the plants in the rainforest. All these stories were in Section A of the *Times* (Anderson, 1990).

In 1985, the media momentum began to build up. Since that time, the number of articles has either remained steady or has increased, indicating that the issue of rain forest destruction is still high on the media's agenda, and thus in the public eye (Anderson, 1990). Part of the interest for the media was the dramatic consequences that began to be associated with tropical deforestation: that the Amazon was the "lungs of the world," contributing large net amounts of oxygen to our atmosphere; that the carbon dioxide released in burning contributed to global warming; that disruptions of the water cycle could alter world climate and reduce agricultural yields; and that native populations living in the forests would die from exposure to our diseases.

It took more than 15 years for the "lungs of the world" myth to be corrected. Rain forests contribute little net oxygen additions to the atmosphere through photosynthesis. However, the importance of oxygen was extremely effective in mobilizing public opinion. More accurate was the evidence for water moisture recycling in the Amazon and the consequences of disrupting the water cycle (Salati, 1985; Molion, 1987). These two arguments gained impetus when they gained a human face. Anthropologists and environmentalists have been able to show the devastating consequences of deforestation, land-grabbing, mining, and other development activities on the native people of Amazonia (Moran, 1976, 1981, 1983; Bunker, 1980; Hemming, 1985; Browder, 1986, 1988; Fearnside, 1987a; Mahar, 1988). The activism of a few native leaders in bringing the plight of their people before multinational banks, the executive and legislative branches of governments in Europe and the United States of America resulted in significant media attention that increased the capacity of environmental organizations to mobilize public support. Organizations like the National Council of Rubber Tappers, founded in 1985, formed alliances with international conservation organizations. Following the murder of Chico Mendes in December 1988, further coalitions were made.

Deforestation has also been connected to scientific concerns with the loss of biodiversity. Myers, one of the more effective advocacy scientists, has called the Amazon "the single richest region of the tropical biome" (1984,

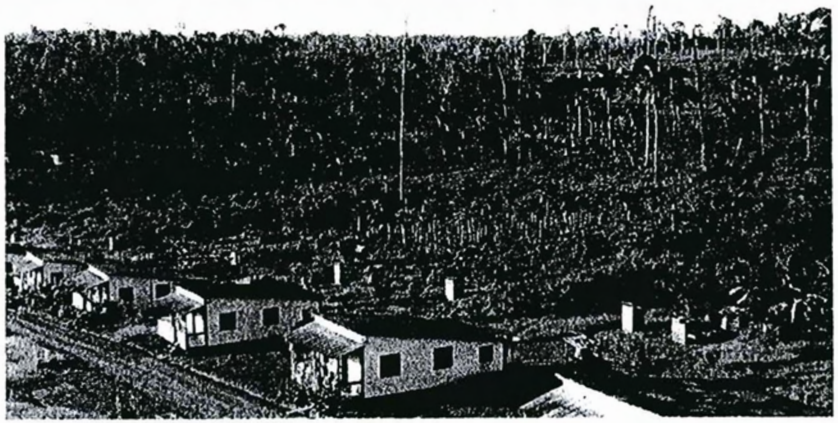

Fig. 3. Capital gains and property taxes are rarely collected—a practice that favors land concentration and undermines small farmers such as these.

p. 50). Humankind has been accused of destroying as-yet-undiscovered medicinal plants and pest-resistant genetic materials (Mahar, 1988, p. 5).

THE POLITICAL ECOLOGY OF DEFORESTATION

The politics of deforestation pit very diverse and increasingly well-organized and well-funded non-governmental conservation organizations (NGOs), in alliance with a diverse number of scientists in the biological and social sciences, against a highly nationalist Brazilian government which prefers to frame the confrontation in terms of territorial sovereignty over the Amazon. It is very difficult to predict which direction deforestation will take in the Brazilian Amazon. The rates have declined since 1988, after two decades of rapid increase. Under pressure from international NGOs (e.g., World Wildlife Fund, Nature Conservancy, Greenpeace, Environmental Defense Fund, Cultural Survival, to name but a few) Brazil has created a program called "Our Nature" which purports to deal with these concerns *internally*. As with earlier efforts, this organization was given a task far greater than the personnel were equipped to handle. The use of helicopters to identify illegal burning of forest, accompanied by fines, has

impressed some people in the Amazon, who now burn at night to avoid detection.

Recent economic analyses of deforestation suggest a number of steps that may be taken to reduce deforestation. Perhaps the most effective step has already been taken—to eliminate tax holidays and fiscal incentives to cattle ranches. Whether fiscal incentives remain unavailable to cattle ranchers or are reinstated will depend on continued pressure on lending institutions. Cattle ranching is an Iberian cultural tradition that enjoys considerable cultural preference, and bankers have been known to extend preferential credit to cattle ranchers over owners seeking to plant crops or agroforestry plantations even without federal credit subsidies. Incentives to ranching should be limited to transfer of technological expertise, especially more production-intensive methods that require less land than currently dominant extensive ranching. Scholars working elsewhere in the world have commented on the peculiar preference for cattle ranching in Latin America (cf. Scudder, 1981) when compared with practices in Asia and Africa.

Over the years, many scholars have suggested that an effective way to reverse the tendency toward latifundia in Latin America would be to tax landowners for their properties. In some countries, like Brazil, there are already laws in the tax code that charge 25% for capital gains on land sales (see Fig. 3). If collected, this tax could pay for the increased costs of expanding the staff needed to collect it. Unfortunately, it is rarely if ever collected. Even more effective would be to institute and collect an annual progressive property tax on landholdings. This tax could be eliminated for keeping forested land intact, in areas zoned for conservation especially where soils are poor or where biodiversity is high. These tax policies would reverse the current practice that favors deforestation as an "improvement." Favorable tax rates could be extended to those who bought degraded areas to reclaim them for farming, ranching, or forestry activities (Repetto and Gillis, 1988).

As the roads improve in the Amazon, there is evidence of growing activities by lumber companies (Fig. 4). The experience from other continents suggests that timber concessions should be of longer duration and be tied to regular monitoring of reforestation (Repetto and Gillis, 1988, p. 386). In an effort to stop deforestation, a number of scholars have rushed to suggest that road construction should be stopped (cf. Fearnside, 1989). More effective may be to stop roads which fail to present a clear environmental and social impact assessment, and those that fail to guarantee adequate policing of the areas made accessible by the road. Roads should not be initiated until indigenous land rights and biological reserves have been demarcated. Otherwise, the roads guarantee illegal entry and violence.

Fig. 4. Land use has gone from cash crops to cattle ranching and more recently to logging of hardwoods. Many roads are now created by loggers rather than government.

Greater support is needed for research that is appropriate to the region. Traditional methods of forest use, as practiced by indigenous Amazonians, have been characterized as low in impact (Hames and Vickers, 1983; Posey and Balée, 1989; Moran, 1990). This low impact results from the small areas that are cleared, and the common practice of shifting fields within 3 years. There is increasing evidence that indigenous Amazonians manage their fallows so that the process of ecological succession proceeds, but directed in such a way that the forest continues to yield useful products for as much as ten years (Denevan and Padoch, 1988; Posey and Balée, 1989). Forest management as practiced by indigenous Amazonians contrasts with the land use changes brought about by colonists coming into Amazonia since 1958, with the construction of the Belém-Brasília highway.

CHANGES IN LAND COVER, 1985–1991

Current ongoing research by anthropologists, geographers, and forest ecologists at Indiana University and Indiana State University, and Brazilian collaborators from the Brazilian Federal Agency for Agropastoral Research

(EMBRAPA) addresses these issues through multi-temporal analysis of Landsat satellite images and field verification. The long-term objective of this research is to discover areas that are experiencing rapid regrowth and then to find out through field studies what land use practices are responsible for favorable and unfavorable vegetation cover change. This approach is based on the assumption that local strategies have a greater potential of being used in the region, since they are products of the political economic and environmental setting within which they came about, rather than idealized solutions generated elsewhere. The research also aims to determine what the rates of regrowth are following deforestation.

Our research takes a more fine-grained view than is commonly undertaken in Landsat image analysis, concerned as we are with discovering approaches to restoration of deforested areas rather than with documenting the extent of deforestation *per se*. In such an approach, it is imperative that fields as small as one hectare be accurately identified. Thus, our preference is for thematic mapper (TM) over multispectral scanner (MSS) data, given the better resolution of TM data (30 m). The relatively large areas encompassed in the study and the need to interpret each site over a number of years, makes earth resources satellites the only reasonable choice. In view of these research requirements, the only two possible sensor choices are Landsat thematic mapper and SPOT. Although SPOT has the best resolution (20 m in multispectral mode and 10 m in panchromatic mode) it was determined that Landsat TM was the superior sensor to use for this research. The 30 m resolution of TM data permits observations with pixels of approximately .33 hectares, and the availability in TM data of two mid-infrared spectral bands facilitates vegetation cover analysis (see Fig. 5).

The steps followed in the analysis of the satellite data included the identification of discernible land cover classes of interest, the selection of representative samples or training sites for each class derived from fieldwork and other sources such as maps and aerial photography, the development of representative spectral statistics, and classification of the data. Ground information collected in summer 1992 was used to refine the accuracy of the spectral signatures in a supervised classification.

A portion of the moist forests and liana forests in the region near the city of Altamira, on the Xingú river, have been converted to agricultural areas. Very briefly, in the portion of the highway going from Altamira west toward Itaituba, to about km 70, in a total area of 267,378 hectares, the largest class is mature moist forest, which amounted to 64.26% of the total area in 1985. It declined by about 7% between 1985 and 1991 (see Table II). Cropland and pasture both increased but most of this area was deforested before 1985. While there were 19,000 hectares of mature forest cut in the period, secondary growth increased during the same period by 32,000

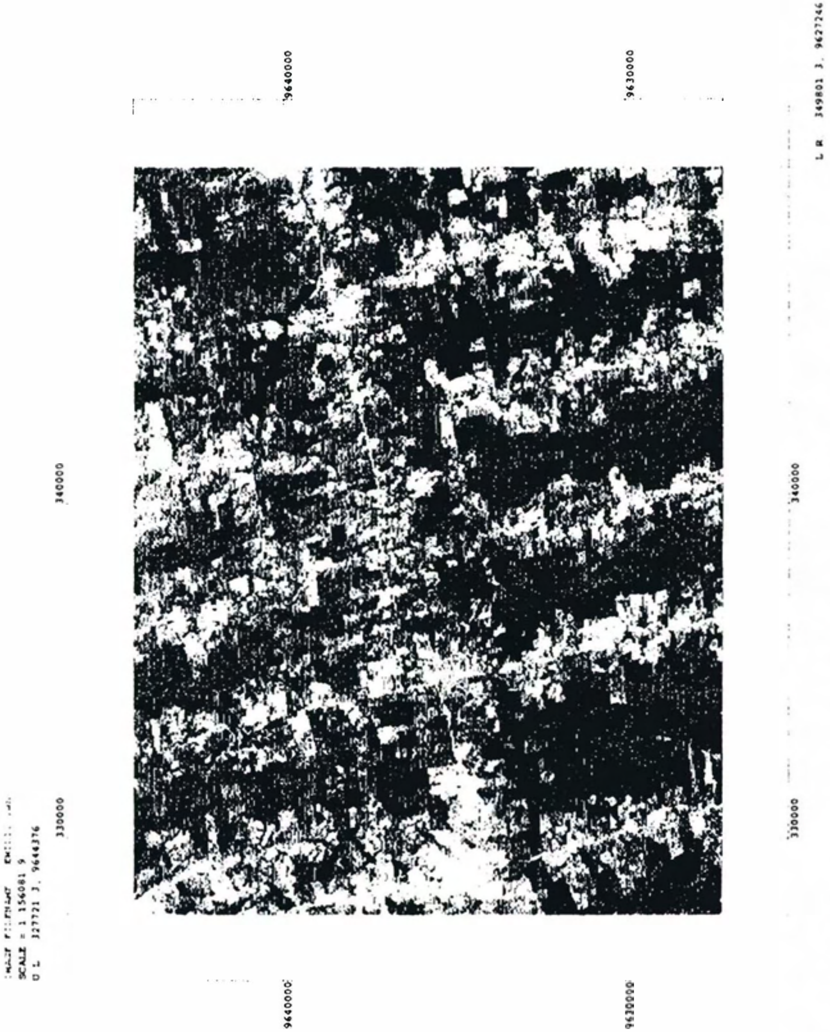

Fig. 5. Landsat thematic mapper view of deforestation and colonization near Altamira, Pará (Brazil). Darker areas are more vegetated, whereas lighter areas are more bare. Darkest areas are forest. Black areas are water.

Table II. Land Cover Changes: Altamira Area—1985–1991

	1985		1991		% change
	%	HA	%	HA	1985–1991
Water	5.23	13,984	5.27	14,091	.76
Wetland	.16	428	.17	455	6.31
Bare	13.19	35,267	1.38	3,689	−89.54
Crop	2.02	5,401	4.26	11,390	110.89
Forest	64.26	171,817	57.10	152,673	−11.14
Pasture	1.24	3,316	7.03	18,797	466.94
Initial SS	7.35	19,652	8.45	22,593	14.97
Inter. SS	5.26	14,064	11.84	31,658	125.10
Adv. SS	1.29	3,316	4.50	12,032	248.84
Totals	100.00	267,378	100.00	267,378	

hectares. This increase has not been reported before. Scholars using the coarser resolution Landsat multispectral scanner (MSS) data available between 1972 and 1983 had been unable to observe *any* non-forest area returning to forest (e.g. Woodwell *et al.*, 1986b). In this study, using the improved resolution of Landsat 4 and 5 it has been possible to accurately classify secondary growth of 0–5, 6–10, and 11–15 years since abandonment (a more detailed analysis of this data may be found in Moran *et al.*, in press).

These findings are consistent with other recent studies in tropical moist forests that show rapid rebounding of forest after cutting and burning, even after a few years of light grazing (Uhl *et al.*, 1982; Uhl and Jordan, 1984; Uhl *et al.*, 1988). Nearly all studies of succession (see references above) have focused on regions that are either extremely poor (i.e., the Rio Negro Basin with its depauperate spodosols or very poor oxisols) or poor (i.e., the Paragominas area oxisols). This study examined an area dominated by oxisols but with large patches of nutrient rich alfisols. In these areas, 6 years after a field is abandoned, vegetation has reached a height of 8 meters (Moran *et al.*, in press). Vegetation of over 15 years is spectrally similar to mature forest. It is also similar in total biomass and in water content. Total number of species present is similar for the first 15 years, although the species composition changes from year to year (cf. Moran *et al.*, 1993).

DEFORESTATION: THE HUMAN CONSEQUENCES

There is little disagreement that Brazilian government policies have encouraged the deforestation activities of both ranchers and farmers in the Amazon. Some of the policies could be changed at the stroke of a pen but their implementation is less likely. The institutional capacity to monitor and police compliance with conservation is not there. In areas of Peru, where anti-government guerillas effectively rule, it is difficult to imagine how the government can even enter some areas safely, much less be able to impose its will. In Brazil, the arm of the state reaches unevenly and ineffectively into the Amazon.

Despite the great difficulties in implementation, lack of action is likely to lead to even greater violence over access to resources, growing rates of migration to the frontier, exponential increase not only in malaria but in many other diseases, greater socio-economic inequality, and the long-term impoverishment of the Brazilian people.

Violence over land persists on the frontier and is likely to increase unless quick steps are taken to begin programs of land redistribution and agrarian reform throughout Brazil. Inequality of land distribution has increased over the last few decades in Brazil, "with 70% of Brazilian farmers now landless and 81% of the farmland held by just 4.5% of the population" (Stern *et al.*, 1992, p. 74). This general pattern applies to the Amazon as well. Hecht (1983) noted that farms with over 1000 hectares cultivated an average of only 26% of the property, while small farms cultivated an average of 50% of their holdings. The more extensive land use pattern associated with large landholdings and cattle ranching exacerbates deforestation by its emphasis on large areas and the removal of knowledgeable farmers and native peoples from the forested environment. The result is not only deforestation but also violence. NGOs estimate that over 800 persons were killed in 1989 in land-related conflicts (Hecht and Cockburn, 1989). Collecting existing tax levies might be one of the easiest ways to bring an end to this violence. The military might be charged with tax collection, to avoid tax collectors becoming victimized by well-armed farmers and ranchers. The laws exist but their application to locally influential persons is rare. Changing this situation will require the will of the state and mobilizing the armed forces to assure compliance. That this is a viable option is suggested by the recent military mobilization on Brazil's northern frontier.

Debt-for-nature swaps have a low potential for working in Brazil because of the concern of the Brazilian War College with the "internationalization" of the Amazon and presumed loss of sovereignty over national territory (Ferreira Reis, 1968; Game e Silva, 1991). While these views are not those of the average Brazilian, the views of the military have been influential in shaping Brazilian nationalism. More likely to work will be technical and scientific assistance in demarcating areas as Brazilian biological reserves, assistance in training forest rangers, and in the use of economical monitoring techniques. The rapidly growing conservation organizations within Brazil need help so that they can fight their own battles internally. The work of anthropologists and other social scientists investigating native systems of forest use and conservation needs research support (Posey and Balée, 1989; Moran, 1990). This work is consistent with technical recommendations favorably commending agro-forestry approaches to forest management and recognizes the importance of local ecosystems' variability (Denevan and Padoch, 1988).

The forces leading to deforestation vary from place to place within the Amazon. Ranching is dominant, but it is particularly significant in southeastern Amazonia. Mining, which was at first thought to have low impact, has grown in importance with the development of pig iron smelting and the design of smelters that consume locally-produced charcoal. Hydroelectric development has inundated significant areas of the region, and brought about relocation of both native and non-native populations. Colonization seems to have been a significant driving force in deforestation in Rondonia at the outset, replaced now by cattle ranching and land speculation. Global approaches that fail to take into account intra-regional diversity will miss the mark and propose inappropriate policies. Global effects have variable local causes that must be addressed if the effects are to be brought under control. Future research will need to be more sensitive to these internal differences in climate, soils, forest type, economic activities, and socio-economic and political forces interacting in the various parts of the Amazon. Toward achieving this goal, the use of satellite and radar data, in combination with field studies, promises to serve a useful role not only in monitoring rates of change in forest cover, but also in discovering local solutions to environmental problems of global import.

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