DEFORESTATION IN BRAZILIAN AMAZONIA

Philip M. Fearnside
Department of Ecology
National Institute for Research
in the Amazon (INPA)
C.P. 478
69.011 Manaus-Amazonas
BRAZIL

revised: Feb. 11, 1989

In press: In: G.M. Woodwell (ed.) The Earth in Transition: Patterns and Processes of Biotic Impoverishment. Cambridge University Press, New York.

ABSTRACT:

The extent and rate of rainforest clearing in Brazilian Amazonia provide ample cause for concern about the forest's future. While clearings are still small relative to the region's total area, the explosive surge of clearing in recent years has followed a pattern that would lead to disappearance of the forest within a few years if continued unchanged. Deforestation is concentrated in certain parts of the region, especially Mato Grosso, Rondônia, Acre and southern Pará.

Reasons dominating the deforestation process vary in different parts of Amazonia. Migration of small farmers is most important in Rondônia and eastern Acre; large cattle ranchers are the principal agents elsewhere. Deforestation for cattle pasture is used by speculators to secure their land claims. Positive feedback relationships linking roadbuilding to population increase, agricultural profits and speculative land values all lead to increased deforestation. Deforestation for low-yielding cattle pasture has also been a contributor to Brazil's high inflation, adding to the motivation for land speculation. These vicious cycles fuel accelerating deforestation.

Very little stands in the way of continued rapid clearing. Lack of sufficient capital and labor can temporarily slow the rate deforesters can realize their plans, but the deforestation process will run to completion unless fundamental changes are made in the structure of the system underlying forest clearing. While many events in Amazonian deforestation are beyond the government's control, key points within the government's domain include granting land titles on the basis of deforestation, programs of special loans and tax incentives for land uses requiring deforestation, and construction and improvement of highways. The frenzied rate of deforestation in the region today indicates the need for speedy government action to contain the process.

DEFORESTATION PATTERNS AND TRENDS

Brazil's Amazon forest is being destroyed at a galloping rate. The seemingly endless expanse of trees still existing cannot delay the forest's destruction by more than a brief moment in historical terms. It is of little importance whether twenty or sixty years pass before we come to the last tree. The essential point is the decision about what kind of world future generations will inherit: Will the Amazon forest survive?

The sharp disagreements concerning the area currently deforested in the Brazilian Amazon are partly rooted in limitations of existing data and, more importantly, in interpretation of these data. Both under and over statements of the extent of deforestation have resulted. Understatements have resulted from early studies of LANDSAT satellite images that suffered from the images being out-of-date and unreliable for areas deforested for more than a few years. In addition, the numbers were generally presented to emphasize the least alarming -- but also least important -- aspect of the results.

In 1980 Brazil's National Institute for Space Research (INPE) revealed a study of images of the Amazon taken in 1975 and 1978 (Tardin et al., 1980). This study created the widespread impression that only 1.55% of the Legal Amazon had been cleared, substantially underestimating the deforestation that had occurred up to that time -- a fact easily deduced from a comparison between results of the satellite study and what is known from direct ground observations. The Zona Bragantina in the state of Pará is the best example: the 30,000 km^2 surrounding the city of Bragança (Fig. 1) was completely deforested by the early 1900s by colonists furnishing food, charcoal and other products to the city of Belém (Egler, 1961; Sioli, 1973; Penteado, 1967). This area alone represents over three times the area indicated as deforested by 1975 in Pará[1]. Disturbed areas not completely deforested (such as forests where loggers have removed the more valuable trees) are not easily identified in LANDSAT studies even though more recent reports refer to "altered" instead of "deforested" areas. The areas that are disturbed but not yet deforested are at present relatively rare in the Amazon in comparison with other parts of the world, but this situation is rapidly changing as the pace of logging increases.

Although studies of LANDSAT images have underestimated the extent of deforestation in the Amazon, it is still true clearings represent only a fraction of the region's five million square kilometer total area. Despite Amazonia's vastness it is nonetheless finite and can therefore be destroyed. This becomes clear when one considers the rate of deforestation indicated by satellite data, instead of being concerned only with the area deforested at any given time.

The shape of the growth curve of the deforested area is crucial -- the most dangerous tendency is exponential increase. The best illustration is inflation. Who in Brazil ten or fifteen years ago would have imagined prices would be hundreds of times higher today? The difficulty of intuitively understanding exponential change is great, even for us living daily with a phenomenon such as inflation. Thus, for many people, it seems impossible the relatively small deforested area of the Amazon today could increase within a few years to the point of encompassing the whole region. This is precisely what would occur if deforestation were to increase in an uninterrupted exponential fashion, as inflation has. The same lack of understanding caused many people to be surprised when the forests in Brazil´s Central-South states disappeared in less than a generation.

To evaluate the growth curve of the deforested areas, it is necessary to measure them in successive years. In the case of the Amazon, data of this type are very scarce. One attempt (Fearnside, 1982) used information from LANDSAT images for three areas where the government settled small farmers and one area of large cattle ranches in Rondônia for the period 1973-1978. The data suggest the trend is better described as exponential rather than linear.

Available information for each state and territory is listed in Table 1 and graphed in Figure 2[1]. To better visualize the trends, the horizontal axes of the graphs begin in 1970. We know deforested areas were relatively small at that time based on the RADAMBRASIL Project´s mosaic of radar images taken in 1971-1972 (Brazil, Presidência da República, DNPM, Projeto RADAMBRASIL, 1973-1979). For purposes of comparison with later LANDSAT data we can consider the open area in 1970 negligible, taking into account the method´s inability to identify deforested areas under old second growth, as was apparent in the case of Pará´s <u>Zona Bragantina</u>. The fact that deforested areas really did exist in 1970 only increases the exponential rate implied by the graphs in Figure 2, where the open areas in 1970 are considered zero. The axes are presented in the graphs extending to the year 1990, to remind the reader the data already are out-of-date due to the extremely rapid pace of events.

The results presented in Figure 2 indicate explosive deforestation -- apparently exponential -- in Rondônia and Mato Grosso. In other states, the increase may not have been exponential; it is nevertheless very rapid. The deforestation rate in Rondônia declined slightly after 1985, partly as a result of migrants moving on to more distant frontiers in Acre and Roraima, and partly from a decrease in the number of migrants entering Rondônia from Mato Grosso. The increasing movement of migrants from Rondônia to Roraima -- one of the federative units with no recent data available -- means deforestation there has progressed further than the results in Figure 2 indicate.

Some satellite interpretation techniques have led to the opposite impression: that the areas deforested are much larger than those shown in Figure 2. An INPE study of areas burning in 1987 using the AVHRR sensor on the NOAA-9 satellite indicated 204,000 km^2 (20 million ha) burning in an area roughly corresponding to the Legal Amazon, of which 80,000 km^2 (8 million ha) were in the portion of the area classified as dense forest (Setzer *et al.*, 1988). Several reasons explain why these numbers are much higher than the 35,000 km^2 (3.5 million ha) calculated in Table 1 as the annual rate of deforestation in 1987. First, burning is not the same thing as deforestation: cattle pasture, secondary forest and especially *cerrado* (savanna) vegetation of Mato Grosso and Goiás are burned without adding to deforestation. Second, part of the area yielding the 204,000 km^2 value lies outside the Legal Amazon (the 427,331 km^2 that make up the non-Amazonian portions of Maranhão and Goiás), and these largely occupied areas are mostly pasture and *cerrado*. On the other hand, the inclusion of non-Amazonian areas is partly compensated by not including Roraima and Amapá, with a combined area roughly the same as the non-Amazonian portions of Maranhão and Goiás (areas north of the equator were not covered by the AVHRR image used). These two reasons account for the great difference between the 204,000 km^2 value for the Legal Amazon and the 80,000 km^2 value for dense forest. The difference between the 80,000 km^2 registered as burning in dense forest and the 35,000 km^2 annual deforestation calculated in Table 1 is probably in large part due to saturation of the sensor, or the phenomenon of triggering the heat measuring device to indicate that the whole of a picture element is burning when only a small fraction is, in fact, on fire. The AVHRR images used are composed of small squares or picture elements (pixels), each 1.1 km on a side. At a temperature of 825°K (602°C), a 1 m wide flame front only 30 m long is sufficient to trigger the sensor's 300°K threshold to indicate the entire 1.2 X 10^6 m^2 pixel as burning (Robinson, nd). Therefore, the pixels that are triggered when less than half of their area is burning will lead to an overestimate. In the INPE study, a correction factor of 70% was applied to compensate for partially burned pixels (A. Setzer, personal communication, 1988). However, it is difficult to derive a constant correction factor that adequately represents this effect because the relationship of area burning to the triggering of the sensor varies tremendously with fire temperature, and fire temperature varies with time of day and local conditions.

The best evidence that the measurements made of areas burning are overestimates of deforestation is the discrepancy between the burning estimate and an AVHRR measurement of deforested area made in Rondônia in the same year (1987). The AVHRR image interpreted by Jean-Paul Malingreau (personal communication, 1988) indicated that 36,900 km^2, or 15.1% of the state, had been deforested (see Table 1). The INPE study of burning indicated that 45,452 km^2 (18.7% of the state) was burning in 1987 (Setzer *et al.*, 1988: 28). Area deforested is cumulative since the beginning of occupation of the state, and is of necessity much larger than the area burned in any given year. Pastures can only be reburned every 2-3 years, since the settlers must maintain part of their pasture unburned in order to sustain their cattle while part of the lot is burned. If 18.7% of Rondônia were burning in 1987, this would imply that at least 40% of the state had been deforested by that year. The discrepancy between a value on the order of 40% and the 15.1% obtained for deforested area when sensing reflected solar radiation rather than the heat produced directly by the flames is of roughly the same proportion as the difference between the 80,000 km^2 and 35,000

km^2 estimates for the Legal Amazon.

It should be emphasized that even though the deforested area is less than the INPE burning study indicated, the rate of deforestation is extremely rapid and the areas affected are immense. Worse still, the 1987 AVHRR image for deforestation in Rondônia mentioned above indicate the beginning of clearing along the BR-429 Highway, penetrating the half of Rondônia represented by the Guaporé River valley, which until then was virtually untouched. No soils in the area are classified as good for agriculture (Fearnside, 1986a). This event is much more grave than would be the addition of the same amount of clearing to the already occupied areas along the BR-364 Highway. The danger is great that the BR-429 Highway will bring uncontrolled deforestation to the remainder of Rondônia.

An estimate for 1988 deforestation made by the World Bank (Mahar, 1988: 5) concludes that 12% of the region had been cleared by that year -- a higher percentage than the 8% value from the present study. The World Bank estimate is based on LANDSAT data, but the report does not specify the years of the images and the means of projection (since the report was released in June 1988 -- the beginning of the dry season -- all of its 1988 values are undoubtedly projections). Some of the values conflict with those obtained from recent LANDSAT studies: 12.8 % for Acre being higher and 9.6% for Pará being lower than those reported in Table 1. Qualitative assessment of a mosaic of 1986 and 1987 LANDSAT-TM images mounted by INPE (Brazil, Ministério da Ciência e Tecnologia, INPE, 1988) suggests that the 6.8% reported as cleared by 1988 in the state of Amazonas is much too high. Because of the vast size of Amazonas, this state alone accounts for more than half of the difference between the regional totals Mahar (1988) reports and those of the present study. Both the World Bank estimate and the present one lead to the same conclusion: the deforested area in Brazil's Legal Amazon is still relatively small, but is expanding explosively.

Data indicating that only a relatively small fraction of the region has been deforested so far are quite deceptive as an indication of the impact of deforestation in the affected zones. Deforestation is highly concentrated in a few foci of human activity. These foci are strongly affected, while many other areas are not significantly altered. The deforestation foci are concentrated along the Belém-Brasília Highway (which cuts through Pará, Maranhão and Goiás), in the states of Mato Grosso, Rondônia and Acre, in smaller areas along the Transamazon Highway in Pará, and in the SUFRAMA (Manaus Free Trade Zone Superintendency) Agriculture and Cattle Ranching District in Amazonas.

The spatial distribution of deforestation, when mapped in quadrats of one degree of latitude by one degree of longitude, shows clearly the concentration of deforestation in the areas mentioned above (Fearnside, 1986b). The routes of the principal highways in the region appear outlined in deforestation. The close association of deforestation with roads is a reflection of some of the principal causes of the current explosive trends, and is also an indication of what governmental actions would be most effective in reducing these rates.

MOTIVES FOR DEFORESTATION

The process of deforestation in Amazonia has two distinct components: the appearance of new deforestation foci, and the expansion of open areas inside already-existing foci. Within these foci are distinct influences from establishment of more properties and from the pattern of deforestation within already-occupied properties. The kind of increase in deforested areas, therefore, depends on the history of any given place as a focus of deforestation and on the dominant forces affecting clearing in the area.

The formation of new foci has been strongly influenced by governmental decisions over the past decades. Construction of the Belém-Brasília Highway (BR-010) in 1960, its improvement for year-round traffic in 1967, and its paving in 1974 were significant milestones in creating the Amazon's largest deforestation nucleus. The cleared area in this nucleus in southern Pará and in northern Mato Grosso enlarged significantly in recent years. Construction of the Cuiabá-Porto Velho Highway (BR-364) in 1967 initiated another focus, and its paving in 1984 brought even more rapid expansion.

Deforestation has been indirectly stimulated by the government through programs to attract new migrants from other parts of the country, along with establishment of settlements and improvement of access roads. These programs have multiplied as a result of the increase in federative units in Amazonia and the elevation of "territories" to the status of "states." The proliferation of new political units results from interior areas of the Amazon having almost always lent their support to incumbent governments, making it advantageous for any party in power to increase the political representation of these areas. The principal criterion for creating new territories and states is population increase, a factor leading directly to deforestation. In the early 1980s, for example, the governor of Rondônia launched a national media campaign to promote the "fertile land" there (which, in reality, represents under 10% of the area, almost all in already-occupied zones). The campaign was strongest just preceding transformation of that territory into a state in 1982. In 1983, the government of Roraima published paid advertizements in Brazilian newsmagazines stating: "thanks to its very rapid growth in the past four years, Roraima is almost ready to become the twenty-fourth state of Brazil." The text explained: "this dizzying expansion is due to the policy of attracting colonists. In four years -- 1979 to today -- the government of Roraima distributed no less than one million hectares of land to ten thousand families. With this, the population has more than doubled in this period" (Veja, 13 April 1983). In recent years the press has reported various government plans to create new federal territories in the southern, central and western parts of Pará and in the southwestern and western portions of Amazonas.

~~The paving of the Marechal Rondon or~~

Cuiabá-Porto Velho Highway (BR-364) in 1984, with financing from the World Bank, removed a great impediment to population flow to western Amazonia, thus increasing the probability heretofore untouched areas in the upper Rio Solimões (Upper Amazon) and Rio Negro drainage basins will be felled. Reconstruction and paving of BR-364 from Porto Velho (Rondônia) to Rio Branco (Acre) began in 1986, with financing from the Interamerican Development Bank. Disbursement of funds was suspended because of public concern in North America over the project's potential environmental impacts. Disbursements were resumed in 1988 coincident with announcement of the Brazilian government's "Our Nature" program establishing a series of committees and suspending for 90 days the export of logs and the approval of new ranching incentives. Opening Acre to rapid settlement can be expected to play a key role in bringing the Amazon as a whole into an accelerated phase of deforestation. Discovery of oil and gas fields in the Juruá and Urucú River valleys has added to the pressure for road construction in western Amazonas, which could become the next destination for the influx of migrants no longer finding land in Rondônia and Acre.

Migration to the Amazon has caused a rate of population increase far above the national average, reaching the highest values in places receiving the largest fluxes, such as Rondônia. The population of Brazil's Northern Region grew at 4.9% per year (continuous exponential rate) between the censuses of 1970 and 1980, compared with 2.5% per year in Brazil and 14.9% in Rondônia! In this state the deforested area increased at a rate of 37% per year between 1975 and 1980 (Fig. 2), indicating deforestation reached rates even higher than population growth. This suggests that the arrival of migrants explains only a part of the phenomenon of explosive deforestation.

Even so, the arrival of new inhabitants is fundamental. Deforestation patterns in 100-hectare lots in the Ouro Preto Integrated Colonization Project (PIC) in Rondônia are being observed as part of INPA's "Carrying Capacity Estimation of Amazonian Agro-Ecosystems Project." In eighteen lots that had only one owner over a 10-year period, the cumulative area deforested, on the average, increased linearly until the sixth year of occupation, after which it increased much more slowly (Fig. 3). The replacement of original colonists by new owners who bought lots second hand has a great impact on deforestation -- new owners increase the pace of deforestation after purchasing the lot. A comparison between 23 original colonists and 97 new colonists in the Ouro Preto PIC indicated that in the first four years after purchasing a lot, the new owner deforests, on the average, at an annual rate almost twice that of the original colonist (Fig. 4). Therefore, the process of replacing original colonists with new owners, already well on its way both in Rondônia and on the Transamazon Highway, contributes to accelerating deforestation in these areas.

Pasture plays a central role in accelerating deforestation, both for small colonists and for large land owners and speculators (Fearnside, 1983). Even in official settlement areas in Rondônia -- where almost all of the government effort in agricultural extension, credit, and advertizing is focussed on promoting perennial crops -- it is pasture that occupies the greatest area. For the small colonist, planting pasture is both a cause and a result of rapid deforestation. The colonist cutting forest for an annual crop can expect only one or two harvests before the decline in yields makes continued planting less attractive than the option of cutting a new area. When annual crop production is halted in any given field, the colonist is usually forced to choose between planting grass and temporarily abandoning the area to secondary forest. Other options, such as planting perennial crops, demand a much larger labor and capital investment. Pasture offers the advantage, in comparison with secondary forest, of producing some income, even if only a small amount, from the cattle raised by the colonist or from leasing the pasture. Much more important is the value that pasture grass adds to a lot´s price when the land is sold. Much of the money colonists receive as the fruit of their labors in the colonization areas comes not from agricultural production, but from the eventual sale of the lot for a higher price.

Real estate speculation is a major force driving deforestation in the Brazilian Amazon and pasture has a central role in this system: besides increasing land value of legalized lots, deforestation followed by planting pasture is the method most often used both by small posseiros (squatters), not always thinking of speculation afterwards, and by large grileiros (land grabbers), attracted primarily by speculative opportunities. The centuries-old legal practice in the Brazilian Amazon is to grant the right of possession to whoever deforests a piece of land (Fearnside, 1979a). Such rights of possession are eventually transformed into full rights of ownership. Pasture represents the easiest way to occupy an extensive area, thus considerably increasing the impact of a small population on deforestation.

Land speculation in the Amazon has yielded spectacular profits in recent years, far surpassing the income obtainable from agricultural production (Mahar, 1979; Hecht, 1985; Hecht et al., 1988a). Increase in land prices is linked to the function of real estate as protection against inflation. The prospect of reselling the land makes land buyers willing to pay prices far above those that expected production could justify. Land becomes something similar to gold or rare stamps, whose value is not based on utility as an input to production. Could it be that, in the future, the speculative value of land in the Amazon might crash, as sometimes happens with the prices of stocks? This is an important question, since the outlook for sustained production is very doubtful. The pastures being planted in Amazonia have dismal prospects for sustaining cattle production because of decline in the soil´s level of available phosphorus, soil compaction, and the invasion of inedible secondary vegetation (Fearnside, 1979b, 1980, 1985a; Hecht, 1981, 1984). Limited and poorly located deposits of phosphates (de Lima, 1976) make official plans for widespread fertilization of pasture unrealistic (Fearnside, 1986b).

Financial incentives also continue to contribute to the deforestation, despite the myth these incentives ceased to be important following the 1979 decision of the Superintendency for the Development of the Amazon (SUDAM) to stop approving incentives for new cattle projects in parts of the Amazon classified as "dense forest." New projects continue to be approved in the areas of "transition forest," located between the Amazon forest and the cerrado (Central Brazilian scrubland), contributing to intense deforestation in southern Pará and northern Mato Grosso. Old projects in dense forest continue to receive incentives for deforestation. The policy of denying new incentives to dense forest areas has not even always been followed: according to Fernando Campano (a member of the Consulting Council of SUDAM's Renewable Resources Department), a large cattle project was approved for Acre, completely within the supposedly-protected dense forest zone (F. Campano, statement at the Interciencia Association Symposium on Amazonia, Belém, October 1983). The Nossa Natureza ("Our Nature") program announced on 12 October 1988 does little to stem the flow of incentives: the program only suspends new incentives for ranching, and this only for a period of 90 days (later renewed for an additional 90 days). Generous governmental incentives make it possible for many projects to continue clearing pastures even after low beef production would have bankrupted any undertaking whose profits depended on agronomic results.

Deforestation for subsistence production is currently of little importance in the Brazilian Amazon when compared with other factors, but it may become more significant if population continues to grow. Because settlement schemes are almost always unsustainable, even more deforestation occurs as farmers and ranchers clear new areas when production ceases in already-cleared areas. Increasing output or sustainability of agricultural systems would not necessarily decrease deforestation rates, however, because very little clearing now occurring in Brazilian Amazonia is the handiwork of traditional farmers who limit their activities when subsistence demands are satisfied (Fearnside, 1987a).

Felling for commercial crop production occupies a larger area than subsistence agriculture, even for food crops such as rice, also planted for direct consumption. Loans from special financing programs have encouraged clearing, as happened in the colonization areas of the Transamazon Highway and Rondônia, for both annual and perennial crops. In assessing the motivation for the crops planted, or the pasture often replacing them, the speculative value of the land is inseparable from the value of the commercial production.

Inflation and deforestation for pasture are linked in a vicious cycle of positive feedback. Money invested in establishing and maintaining cattle ranches (including the vast pyramid of support activities) creates demand for products, but low pasture yields mean little is added to the marketplace for people to buy with the salaries they receive. Raising demand without increasing supply results in rising prices. Like any large investment that does not contribute to the economy, implanting vast areas of low-productivity cattle pasture is an inflationary factor (Fearnside, 1987b). Inflation, in turn, motivates speculation in Amazonian real estate -- investments that are protected by planting more pasture.

How can these processes of Amazon forest destruction be controlled? The miniscule amount of funds and personnel currently allocated to enforce environmental regulations indicates the Brazilian government is not taking deforestation control seriously. Infringement on parks and reserves is common whenever they stand in the way of new highways or other development projects (see Câmara, 1983; Fearnside and Ferreira, 1984; Werneck, 1983). The deforestation problem must be elevated to a higher position in the hierarchy of national priorites, but various obstacles would still remain even after the rationality of such a change is recognized.

One fundamental problem impeding deforestation control is the current distribution of the costs and benefits of forest destruction. The groups and individuals profiting from deforestation are generally not the same ones that pay the resulting environmental, social and financial costs. Profits are often channeled to beneficiaries outside the Amazon region. Besides this, the benefits are concentrated, while the costs are distributed among many: this is the classic formula of the "tragedy of the commons" (Hardin, 1968). Under these conditions, destruction continues to be completely rational in economic terms even if the total cost were much greater than the benefits. On the other hand, some costs are concentrated, with the benefits accruing to larger, more influential groups, as in the case of land seized from indigenous tribes.

Another factor that impedes controlling deforestation is the monetary nature of the benefits, while the costs, being environmental and human, are more difficult to quantify. The non-monetary costs, unfortunately, are no less real than the monetary ones (for a review of environmental impacts of deforestation, see Fearnside, 1985b).

The fact that felling forest brings immediate profits -- while many of the costs will only be paid by future generations -- is one of the most fundamental aspects of the problem. In the middle of the economic crisis Brazil faced in July 1983, Rondônia, Mato Grosso and Roraima were the only federative units whose monthly income from the Tax on Circulation of Merchandise (ICM) grew more than inflation. It is probably not a coincidence the ICM, considered one of the best indices of economic activity, has increased most where deforestation is most explosive. This encouraging picture of immediate profits, however, should be evaluated taking into account the heavy costs following massive deforestation.

The discount rate is a part of the very structure of decision-making that renders inviable many potentially renewable systems of resource management (Fearnside, 1989a). The discount rate -- the speed future profits and costs have their weights diminished in calculating the net present value of each option -- is an index that depends on the income potentially earned in alternative investments. No logical connection exists between the discount rate and the biological rates (such as the rate of growth of a tree in the forest) limiting the rate of return from sustained exploitation of biological resources (Clark, 1973, 1976; Fife, 1971). Rational use of the Amazon forest would generate only a slow return.

Human population growth in the Amazon region could also frustrate any policy designed to control deforestation. Population growth is attributed to two causes: reproduction above mortality rate, and entrance of new migrants. The flow of new migrants now greatly surpasses the impact of reproduction, but in the long term both must reach an equilibrium. The capacity of Amazonia to absorb population in a sustainable manner is very limited: the social problems motivating the rush of migrants to the region must be solved in the source areas themselves (Fearnside, 1986c).

The expulsion of small agriculturalists by land concentration both in the Amazon and outside it, together with the existence of a large landless rural population, makes finding a definitive solution to the deforestation problem extremely difficult. The land tenure system in Amazonia, based on deforestation, would have to be modified to make using the forest possible without clearing it. Since the tradition of legalizing land claims established by deforestation is an important factor in alleviating the impact of extreme social inequalities and the expulsion of rural populations, solutions for these problems would have to be implemented at the same time.

FUTURE PRESSURES FOR DEFORESTATION

What forces, besides the current ones, could influence Amazonian deforestation in the future? Commercial logging, until recently affecting a relatively small fraction of the region, is rapidly becoming a substantial source of disturbance. At the moment, world markets for tropical hardwoods are being supplied principally by forest destruction in southeast Asia (Myers, 1980a,b; Ranjitsinh, 1979).

The Asian tropical forests are dominated by a single family of trees, Dipterocarpaceae, and almost all produce high-quality lumber. Due to their more homogeneous character, the Asian forests are much more easily used for industrial purposes than is the Amazon forest. At the present pace, virtually all of Asia's tropical forests will be destroyed before the end of the century, and, according to tropical wood merchants, commercial volumes of hardwood from Asia could be insignificant by the early 1990s. This means large lumber firms, currently much more active in Asia than in tropical America, are likely to transfer their attention to Amazonia. Many forests intensively exploited by these firms are left in a heavily altered state with little chance of recuperation, even without having been cut down by clearcutting or burning. This form of destruction is likely to increase substantially in the Amazon. More advanced methods using a larger number of species to make fuelwood chips, pulp, plywood, particle board or other wood products would also increase the areas clearcut.

Another potential cause of large-scale destruction is the making of charcoal (Fearnside and Rankin, 1982). Wood is now being collected from native forest to supply a pig-iron industry in conjunction with the Grande Carajás Program. In 1986, seven pig-iron plants were approved for financial incentives from the Grande Carajás Program, with a combined annual demand for 705,000 metric tons (Brazil, Presidência da República, SEPLAN-PGC/SUDAM/CODEBAR, 1986: 3). In addition, two iron alloy plants requiring an annual total of 300,000 metric tons and two cement plants together requiring annually 82,000 metric tons were approved at the same time. Planned expansion to 20 pig-iron plants would bring the yearly total for charcoal demand to 2.4 million metric tons (Fearnside, 1988a, 1989b). Recent statements by the Grande Carajás Interministerial Commission concerning planned smelters imply a charcoal demand double this amount, enough to consume 1000 km^2 of surrounding forest per year. The Carajás iron deposit contains 18 billion metric tons of high grade (67% Fe) ore -- by far the world's largest and sufficient to sustain mining at current rates for at least 250 years (see Fearnside, 1986e). Only a tiny fraction is to be smelted in the area: the potential for expansion of smelting activity is limited only by the amount of available charcoal (i.e. by the amount of forest to be sacrificed). The first plant began operation on 8 January 1988. No environmental studies were done or impact statement prepared; it has not yet even been decided how much charcoal would be produced from plantations and how much harvested from native forest. Approval of the incentives, construction of the smelters and the beginning of operation all occurred after 23 January 1986, when environmental impact statements became a requirement in Brazil. The pig-iron program also illustrates several ways potential environmental impacts of major development projects escape the environmental review processes of multilateral lending agencies such as the World Bank, which financed the Carajás railway and mine (Fearnside, 1987c).

Many sources of forest loss are increasing in importance. Mining activity, with its associated population concentrations, should increase considerably in the future. The invasion of Amerindian reserves spearheaded by freelance gold prospectors ("garimpeiros") is already a major concern, the continuing officially-condoned assault on Yanomami tribal areas in Roraima being the best known case. Another growing factor is military bases with roads and settlements, especially in the Calha Norte Program along Brazil's borders with neighboring Amazonian countries (see Fearnside, 1989c). Yet another source of forest loss is hydroelectric development, plans for which imply flooding 2% of Brazil's Legal Amazon (Brazil, Ministério das Minas e Energia, ELETROBRÁS, 1987). The rapidly increasing rate of forest loss throughout the region means that vegetation replacing Amazonian forest is likely to become increasingly important in determining the global impact of deforestation.

VEGETATION REPLACING AMAZONIAN FOREST

Cattle pasture is the land use replacing almost all forest felled in Brazilian Amazonia. Small farmers often plant annual crops such as rice, maize and manioc (cassava) for one to three years before planting pasture, whereas large ranchers plant pasture directly after felling. The cattle pastures become degraded over the course of a decade or two, depending on the efforts undertaken by the land owner in combatting invading weeds and secondary forest vegetation. Small areas near dwellings or public roadways may receive special treatment beyond that justified by the beef produced if viewed as a return on investment in pasture maintenance. For larger areas, however, the poor prospects of degraded pastures often lead to effective abandonment (although land owners are often careful not to refer to their pastures as "abandoned" or as secondary forest).

Pasture degradation results from loss of soil fertility through erosion and leaching and from fixation of phosphorus in forms unavailable to plants. Soil compaction inhibits growth of pasture grasses. The decomposition of the unburned biomass from the original forest, and forest roots in the soil, removes this source of soil fertility after about a decade (Hecht, 1983). Measurements of pasture dry weight production over a two year period in Rondônia have shown a 12-year-old pasture produces at about half the rate of a 3-year-old pasture (Fearnside et al., nd).

The types of vegetation following the degraded pasture vary widely in different parts of Amazonia and in fields with different histories. Degraded pastures undergo a secondary succession quite distinct from that in shifting cultivation fallows. In succession after shifting cultivation, woody vegetation quickly recolonizes the sites (Uhl, 1987). The intensity of use greatly influences the species and rate of recovery. Stump sprouts are important in the case of first-cycle fallows if unburned or if burning is light. In Altamira (Pará) and Ouro Preto do Oeste (Rondônia), fields that were fallowed after burning the forest and a single crop of rice showed that a general relation exists between growth rate and soil quality. One would expect soil degradation from extended use with inadequate fallows would therefore lead to reduced rates of recovery, making a longer fallow necessary to achieve the same effect. The relatively fast biomass recovery on shifting cultivation sites (such as the fallows in Africa studied by Bartholomew et al., 1953, cited by Lugo and Brown, 1981, 1982) would reduce the contribution of Amazonian deforestation to the global greenhouse effect if these recovery rates applied to deforested areas in Brazil. Lugo and Brown (1981, 1982) have argued this is the case. Unfortunately, most deforestation in Amazonia is for cattle pasture, which regenerates much more slowly when abandoned. The large difference in biomass between forest and pasture means carbon release to the atmosphere from Amazonian deforestation could be a major contributor to the greenhouse effect over the coming decades (Fearnside, 1985c, 1986d, 1987d).

Secondary vegetation in abandoned pastures grows much more slowly if the pasture has been heavily used prior to abandonment. In Paragominas, (Pará), Uhl et al. (1988) found that eight years after abandonment (defined as the date of last weeding or burning), lightly used pastures (areas never weeded, with no or little grazing, and abandoned shortly after formation) had approximately twice the plant biomass as moderately used pastures (areas abandoned 6-12 years after formation, with grazing, weed cutting and burning every 2-3 years). The lightly used pasture sites had about 17 times more biomass than a heavily used site (an area undergoing bulldozing and windrowing after several years of maintenance under the "moderate use" techniques). Light, moderate and heavy use accounted for approximately 20, 70 and 10% respectively of the pastures in the Paragominas area.

Between Paragominas and Mato Grosso lies a wide strip where succession in abandoned pastures follows a different course. From Maranhão to the Marabá area in Pará pastures are often completely displaced after a few years by solid stands of babaçu (Attalea speciosa or Orbignya phalerata). These palms occur naturally in pure stands in parts of Maranhão outside of dense forest, and in the forest areas of Maranhão and central Pará are present at low density in the original forest. They are highly resistant to fire, and propagate quickly as the pastures are reburned. Their hard trunks have earned them the name of "quebra machado" (axe breaker), and have discouraged cutting them back. Although babaçu forms the basis of local industry in Maranhão (Hecht et al., 1988b), it is regarded strictly as a weed in Pará. Vast expanses of abandoned pastures in the Marabá area are virtually impenetrable stands of this palm; the problem is increasing 500 km further west in the Altamira area.

In Roraima the related inajá palm (Attalea regia) plays a role very similar to babaçu. Pure stands have taken over many pastures in the area of Mucajaí. Inajá palms invade only pastures planted in formerly forested areas -- not Roraima's extensive "natural" grasslands.

Some areas of very highly degraded pasture, are taken over by a low mint (Labiaciae), inedible to cattle. This has been the fate of pastures in areas near Altamira (Pará) that were cleared in the first four decades of this century (Fearnside, 1980).

It is possible the course of succession in degraded pastures could change to favor unpalatable grasses rather than woody secondary forest. Forest recovery in highly degraded pastures is extremely slow unless special countermeasures are taken, because repeated fire and hostile conditions present formidable barriers to tree seed dispersal and seedling establishment (Nepstad et al., nd). In some highly degraded pastures in Acre, for example, a grass known locally as "rabo de cavalo" Andropogon spp. dominates. In the Gran Pajonal region of Peru, Imperata brasiliensis dominates shifting cultivation successions (Scott, 1978). This is a less aggressive grass than its notorious relative, Imperata cylindrica, which dominates succession in southeast Asia (see UNESCO/UNEP/UN-FAO, 1978: 224). The tendency of woody species to dominate secondary succession in Amazonia is presently a major difference between South America and Asia, but nothing guarantees the woody successional path will always predominate in Amazonia. "Sapé" (Imperata brasiliensis) is frequent as the successional route in indigenous shifting cultivation fallows in dense forest areas near the cerrado edge in northern Mato Grosso (R.L. Carneiro, personal communication, 1986). Dense forest trees near the southern edge of their distribution may be closer to their limits of tolerence for water stress, making these trees more easily displaced by grass than is the case farther north. Widespread deforestation in the future is expected to lengthen the dry season because of reduced evapotranspiration (Salati et al., 1979; Salati and Vose, 1984). This change in precipitation patterns, especially during the periodic droughts naturally occurring even in the absence of massive deforestation, could alter successional patterns to favor a grassland or savanna dysclimax (Fearnside, 1985b). In addition to greater impact on the greenhouse effect, the shift to grass would further aggravate the disruption of the region's hydrologial cycle -- thereby forming a positive feedback loop that would continue to degrade the remaining remnants of forest (Fearnside, 1985b).

Fire entry into unfelled forest, which occurred on a large scale in Borneo during the 1982-1983 El Niño drought (Malingreau et al., 1985) could become an additional major factor hastening the demise of the remaining forest in Amazonia. Increased perturbation from selective logging, a practice already facilitating entry of fire into uncleared forest in Amazonia (Uhl and Buschbacher, 1985), could allow fire to deliver a coup de grace to the remaining patches of forest much more quickly than is commonly imagined.

CONCLUSION

Deforestation threatens to convert the remainder of Brazil's Amazon forest into degraded cattle pastures with little economic or other value. The successions following cattle pasture vary, but all compare poorly with the original forest in terms of biological richness and performance of the forest's environmental functions. Among the expected impacts of widespread conversion of forest to pasture are regional drying through reduced evapotranspiration and global warming through the greenhouse effect.

It is clear the range of problems that need to be solved to slow deforestation in the Amazon is enormous. Brazil must face all of these problems both present and future if destruction of the Amazon forest is to be avoided. Root causes of deforestation must be addressed, rather than restricting action to the more superficial symptoms.

Very little now stands in the way of massive increases in deforested areas. Limited amounts of capital, especially in Brazil's current economic crisis, can temporarily slow the rate deforesters are able to realize their plans, but the deforestation process will run to completion unless fundamental changes are made in the structure of the system underlying clearing.

Many events in the process of Amazonian deforestation are beyond government control. Decrees prohibiting deforestation, such as Law 7511 of 7 July 1986, have minimal effect on land clearing decisions made by farmers or ranchers living many kilometers from major roads and cities, and spread over a region as vast as Amazonia. Some key points in the system, however, are subject to government control. The granting of land titles, with its associated criteria of land "improvement" through deforestation, is entirely a government activity. The government also is responsible for the programs granting special loans and tax incentives for agriculture and cattle ranching activities requiring felling. Above all, only the government builds highways. Were the government to build and improve fewer highways in Amazonia, the vicious cycle of highway construction, population immigration, and deforestation would be broken.

Current deforestation rates indicate such changes would have to be made without delay. In the face of such a daunting array of problems, paralysis is frequent: either accepting destruction as inevitable, or considering as useless any action less extreme than a complete restructuring of society. Paralysis, whatever its rationalization, is the most certain path to a future without an Amazon forest.

ACKNOWLEDGMENTS

My research in Rondônia is funded by the Science and Technology Component of Projeto POLONOROESTE. J.G. Gunn, A. Setzer and S. Wilson provided useful comments on the manuscript. I thank the Sociedade Brasileira para o Progresso da Ciência (SBPC) for permission to use portions of the text translated from Ciência Hoje (Fearnside, 1984b), the Leeds Philosophical and Literary Society for permission to use Figures 3 and 4 (Fearnside, 1984a), and the Royal Swedish Academy of Sciences for permission to use Figure 2 (Fearnside, 1986d).

LITERATURE CITED

Bartholomew, W.V., J. Meyer and H. Laudelout. 1953. Mineral nutrient immobilization under forest and grass fallow in the Yangambi (Belgian Congo) region. Publication de l'Institut Nacional pour l'Étude Agronomique du Congo Belge. Série Scientifique No. 57. 27 pp.

Brazil, Ministério da Agricultura, Instituto Brasileiro de Desenvolvimento Floresal (IBDF). 1982a. Alteração da Cobertura Vegetal Natural do Estado de Mato Grosso: Relatório Técnico. IBDF, Brasília. 66 pp.

Brazil, Ministério da Agricultura, Instituto Brasileiro de Desenvolvimento Florestal (IBDF). 1982b. Alteração da Cobertura Vegetal Natural do Estado de Rondônia: Relatório Técnico. IBDF, Brasília. 68 pp.

Brazil, Ministério da Agricultura, Instituto Brasileiro de Desenvolvimento Florestal (IBDF). 1982c. Alteração da Cobertura Vegetal Natural do Estado do Acre: Relatório Técnico. IBDF, Brasília. 71 pp

Brazil, Ministério da Agricultura, Instituto Brasileiro de Desenvolvimento Florestal (IBDF). 1983a. Alteração da Cobertura Vegetal Natural do Território de Roraima: Anexo Relatório Técnico. IBDF, Brasília. 79 pp.

Brazil, Ministério da Agricultura, Instituto Brasileiro de Desenvolvimento Florestal (IBDF). 1983b. Alteração da Cobertura Vegetal Natural do Território de Amapá. (Relatório No. 3 Convênio IBDF/SUDAM), IBDF, Brasília. 47 pp.

Brazil, Ministério da Agricultura, Instituto Brasileiro de Desenvolvimento Florestal (IBDF). 1983c. Desenvolvimento Florestal no Brasil. PNUD/FAO/BRA-82-008, Folha Informativa No. 5. IBDF, Brasília.

Brazil, Ministério da Agricultura, Instituto Brasileiro de Desenvolvimento Florestal (IBDF). 1985. Monitoramento da Alteração da Cobertura Vegetal Natural da Área do Programa POLONOROESTE nos Estados de Rondônia e Mato Grosso: Relatório Técnico. IBDF, Brasília. 77 pp.

Brazil, Ministério da Ciência e Tecnologia, Instituto de Pesquisas Espaciais (INPE). 1988. Região Norte. (Mosaic of 1986 and 1987 LANDSAT-TM images). INPE, São José dos Campos, São Paulo.

Brazil, Ministério das Minas e Energia, ELETROBRÁS. 1987. Plano Nacional de Energia Elétrica 1987/2010: Plano 2010: Relatório Geral (Dezembro 1987). Centrais Elétricas Brasileiras S.A. (ELETROBRÁS), Rio de Janeiro. 269 pp.

Brazil, Ministério das Minas e Energia, Projeto RADAMBRASIL. 1973-1982. Levantamento de Recursos Naturais, Vols. 1-23. Departamento Nacional de Produção Mineral, Rio de Janeiro.

Brazil, Presidência da República, Secretaria de Planejamento (SEPLAN), Programa Grande Carajás (PGC), Companhia de Desenvolvimento de Barcarena (CODEBAR) and Ministério do Interior, Superintendência de Desenvolvimento da Amazônia (SUDAM). 1986. Problemática do Carvão Vegetal na Área do Programa Grande Carajás. CODEBAR/SUDAM, Belém. 117 pp.

Câmara, I. de G. 1983. Araguaia: Uma estrada contra o parque. Ciência Hoje 1(4): 67-68.

Clark, C.W. 1973. The economics of overexploitation. Science 181: 630-634.

Clark, C.W. 1976. Mathematical Bioeconomics: The Optimal Management of Renewable Resources. Wiley-Interscience, New York. 352 pp.

de Lima, J.M.G. 1976. Perfil Analítico dos Fertilizantes Fosfatados. Ministério das Minas e Energia, Departamento Nacional de Produção Mineral (DNPM) Boletim No. 39. DNPM, Brasília.

Egler, E.G. 1961. A Zona Bragantina do Estado do Pará. Revista Brasileira de Geografía 23(3): 527-555.

Fearnside, P.M. 1979a. The development of the Amazon rain forest: Priority problems for the formulation of guidelines. Interciencia 4(6): 338-343.

Fearnside, P.M. 1979b. Cattle yield prediction for the Transamazon Highway of Brazil. Interciência 4(4): 220-225.

Fearnside, P.M. 1980. The effects of cattle pastures on soil fertility in the Brazilian Amazon: Consequences for beef production sustainability. Tropical Ecology 21(1): 125-137.

Fearnside, P.M. 1982. Deforestation in the Brazilian Amazon: How fast is it occurring? Interciencia 7(2): 82-88.

Fearnside, P.M. 1983. Land use trends in the Brazilian Amazon Region as factors in accelerating deforestation. Environmental Conservation 10(2): 141-148.

Fearnside, P.M. 1984a. Land clearing behaviour in small farmer settlement schemes in the Brazilian Amazon and its relation to human carrying capacity. pp. 255-271 In: A.C. Chadwick and S.L. Sutton (eds.) Tropical Rain Forest: The Leeds Symposium. Leeds Philosophical and Literary Society, Leeds, U.K. 335 pp.

Fearnside, P.M. 1984b. A floresta vai acabar? Ciência Hoje 2(10): 42-52.

Fearnside, P.M. 1985a. Agriculture in Amazonia. pp. 393-418 In: G.T. Prance and T.E. Lovejoy (eds.) Key Environments: Amazonia. Pergamon Press, Oxford, U.K. 442 pp.

Fearnside, P.M. 1985b. Environmental Change and Deforestation in the Brazilian Amazon. pp. 70-89 In: J. Hemming (ed.) Change in the Amazon Basin: Man's Impact on Forests and Rivers. Manchester University Press, Manchester, U.K. 222 pp.

Fearnside, P.M. 1985c. Brazil's Amazon forest and the global carbon problem. Interciencia 10(4): 179-186.

Fearnside, P.M. 1986a. Settlement in Rondônia and the token role of science and technology in Brazil's Amazonian development planning. Interciencia 11(5): 229-236.

Fearnside, P.M. 1986b. Spatial concentration of deforestation in the Brazilian Amazon. Ambio 15(2): 72-79.

Fearnside, P.M. 1986c. Human Carrying Capacity of the Brazilian Rainforest. Columbia University Press, New York. 293 pp.

Fearnside, P.M. 1986d. Brazil's Amazon forest and the global carbon problem: Reply to Lugo and Brown. Interciencia 11(2): 58-64.

Fearnside, P.M. 1986e. Agricultural plans for Brazil's Grande Carajás Program: Lost opportunity for sustainable development? World Development 14(3): 385-409.

Fearnside, P.M. 1987a. Rethinking continuous cultivation in Amazonia. BioScience 37(3): 209-214.

Fearnside, P.M. 1987b. Causes of deforestation in the Brazilian Amazon. pp. 37-53 In: R.F. Dickinson (ed.) The Geophysiology of Amazonia: Vegetation and Climate Interactions. John Wiley & Sons, New York. 526 pp.

Fearnside, P.M. 1987c. Deforestation and international economic development projects in Brazilian Amazonia. Conservation Biology 1(3): 214-221.

Fearnside, P.M. 1987d. Summary of progress in quantifying the potential contribution of Amazonian deforestation to the global carbon problem. pp. 75-82 In: D. Athie, T.E. Lovejoy and P. de M. Cyens (eds.) Proceedings of the Workshop on Biogeochemistry of Tropical Rain Forests: Problems for Research. Universidade de São Paulo, Centro de Energia Nuclear na Agricultura (CENA), Piracicaba, São Paulo. 85 pp.

Fearnside, P.M. 1988a. Jari at age 19: Lessons for Brazil's silvicultural plans at Carajás. Interciencia 13(1): 12-24; 13(2): 95.

Fearnside, P.M. 1988b. An ecological analysis of predominant land uses in the Brazilian Amazon. The Environmentalist 8(4) (in press).

Fearnside, P.M. 1989a. Forest management in Amazonia: The need for new criteria in evaluating economic development options. Forest Ecology and Management 26 (in press).

Fearnside, P.M. 1989b. The charcoal of Carajás: Pig-iron smelting threatens the forests of Brazil's eastern Amazon region. Ambio (in press).

Fearnside, P.M. 1989c. Environmental destruction in the Brazilian Amazon. In: A. Hall and D. Goodman (eds.) The Future of Amazonia: Destruction or Sustainable Development. Macmillan, London, U.K. (in press).

Fearnside, P.M. and G. de L. Ferreira. 1984. Roads in Rondonia: Highway construction and the farce of unprotected reserves in Brazil's Amazonian forest. Environmental Conservation 11(4): 358-360.

Fearnside, P.M., N. Leal Filho, P.M.L.A. Graça, G.L. Ferreira, R.A. Custodio and F.J.A. Rodrigues. nd. Pasture biomass and productivity in Brazilian Amazonia. (in preparation).

Fearnside, P.M. and J.M. Rankin. 1982. Jari and Carajás: The uncertain future of large silvicultural plantations in the Amazon. Interciencia 7(6): 326-328.

Fife, D. 1971. Killing the goose. Environment 13(3): 20-27.

Hardin, G. 1968. The tragedy of the commons. Science 162: 1243-1248.

Hecht, S.B. 1981. Deforestation in the Amazon basin: magnitude, dynamics and soil resource effects. Studies in Third World Societies 13: 61-108.

Hecht, S.B. 1983. Cattle ranching in the eastern Amazon: environmental and social implications. pp. 155-188 In: E.F. Moran (ed.) The Dilemma of Amazonian Development. Westview Press, Boulder, Colorado. 347 pp.

Hecht, S.B. 1984. Cattle ranching in Amazonia: Political and ecological implications. pp. 366-398 In: M. Schmink and C.H. Wood (eds.) Frontier Expansion in Amazonia. University Presses of Florida, Gainesville, Florida. 502 pp.

Hecht, S.B. 1985. Environment, development and politics: Capital accumulation and the livestock sector in eastern Amazonia. World Development 13(6): 663-684.

Hecht, S.B., A.B. Anderson and P. May. 1988a. The subsidy from nature: Shifting cultivation, successional palm forests, and rural development. Human Organization 47(1): 25-35.

Hecht, S.B., R.B. Norgaard and G. Possio. 1988b. The economics of cattle ranching in eastern Amazonia. Interciencia 13(5): 233-240.

Lugo, A.E. and S. Brown. 1981. Tropical lands: Popular misconceptions. Mazingira 5(2): 10-19.

Lugo, A.E. and S. Brown. 1982. Conversion of tropical moist forests: A ~~critique. Interciencia 7(2): 96-98.~~

Mahar, D.J. 1979. Frontier Development Policy in Brazil: A Study of Amazonia Praeger, New York. 182 pp.

Mahar, D.J. 1988. Government Policies and Deforestation in Brazil's Amazon Region. Environment Department Working Paper No. 7, The World Bank, Washington, D.C. 42 pp.

Malingreau, J.P., G. Stephens and L. Fellows. 1985. Remote sensing of forest fires: Kalimantan and North Borneo in 1982-83. Ambio 14(6): 314-321.

Malingreau, J.P. and C.J. Tucker. 1988. Large-scale deforestation in the southeastern Amazon basin of Brazil. Ambio 17(1): 49-55.

~~Myers, N. 1980a. Conversion of Tropical Moist Forests. National Academy of~~

Sciences Press, Washington, D.C. 205 pp.

Myers, N. 1980b. The present status and future prospects of tropical moist forests. *Environmental Conservation* 7(2): 101-114.

Nepstad, D., C. Uhl and E.A. Serrão. nd. Surmounting barriers to forest regeneration in abandoned, highly degraded pastures (Paragominas, Pará, Brazil). In: A.B. Anderson (ed.) *Alternatives to Deforestation: Steps toward Sustainable Land Use in Amazonia*. Columbia University Press, New York. (in press).

Penteado, A.R. 1967. *Problemas de Colonização e de Uso da Terra na Região Bragantina do Estado do Pará*. Universidade Federal do Pará, Belém. 488 pp.

Ranjitsinh, M.K. 1979. Forest destruction in Asia and the South Pacific. *Ambio* 8(5): 192-201.

Robinson, J.M. nd. Fire from space: Global fire evaluation using IR remote sensing. *International Journal of Remote Sensing* (in press).

Salati, E., A. Dall'Olio, E. Matusi and J.R. Gat. 1979. Recycling of water in the Brazilian Amazon Basin: An isotopic study. *Water Resources Research* 15: 1250-1258.

Salati, E. and P.B. Vose. 1984. Amazon Basin: A system in equilibrium. *Science* 225: 129-138.

Scott, G.A.J. 1978. *Grassland Development in the Gran Pajonal of Eastern Peru: a Study of Soil-Vegetation Nutrient Systems*. Hawaii Monographs in Geography, No. 1. University of Hawaii at Manoa, Department of Geography, Honolulu, Hawaii. 187 pp.

Setzer, A.W., M.C. Pereira, A.C. Pereira Júnior and S.A.O. Almeida. 1988. *Relatório de Atividades do Projeto IBDF-INPE "SEQE" - Ano 1987*. Instituto de Pesquisa Espaciais (INPE), Pub. No. INPE-4534-RPE/565. INPE, São José dos Campos-São Paulo. 48 pp.

Sioli, H. 1973. Recent human activities in the Brazilian Amazon Region and their ecological effects. pp. 321-334 In: B.J. Meggers, E.S. Ayensu and W.D. Duckworth (eds.) *Tropical Forest Ecosystems in Africa and South America: A Comparative Review*. Smithsonian Institution Press, Washington, D.C. 350 pp.

Tardin, A.T., D.C.L. Lee, R.J.R. Santos, O.R. de Assis, M.P. dos Santos Barbosa, M. de Lourdes Moreira, M.T. Pereira, D. Silva and C.P. dos Santos Filho. 1980. *Subprojeto Desmatamento, Convênio IBDF/CNPq-INPE 1979*. Instituto Nacional de Pesquisas Espaciais (INPE) Relatório No. INPE-1649-RPE/103. INPE, São José dos Campos, São Paulo. 44 pp.

Uhl, C. 1987. Factors controlling succession following slash-and-burn agriculture in Amazonia. *Journal of Ecology* 75: 377-407.

Uhl, C. and R. Buschbacher. 1985. A disturbing synergism between cattle-ranch burning practices and selective tree harvesting in the eastern Amazon. *Biotropica* 17(4): 265-268.

Uhl, C., R. Buschbacher and E.A.S. Serrão. 1988. Abandoned pastures in eastern Amazonia. I. Patterns of plant succession. Journal of Ecology 76: 633-681.

United Nations Educational Scientific and Cultural Organization (UNESCO)/ United Nations Environmental Programme (UNEP)/ United Nations Food and Agriculture Organization (UN-FAO). 1978. Tropical Forest Ecosystems: A State of Knowledge Report. UNESCO, Paris. 683 pp.

Veja (São Paulo) 13 April 1983. "A fronteira do futuro." Advertizement from the Government of Roraima. pp. 95-97.

Werneck, H.F. 1983. A quem serve a nova reserva? Ciência Hoje 1(4): 68-69.

Woodwell, G.M., R.A. Houghton, T.A. Stone and A.B. Park. 1986. Changes in the area of forests in Rondonia, Amazon Basin, measured by satellite imagery. p. 242-257 In: J.R. Trabalka and D.E. Reichle (eds.) The Changing Carbon Cycle: A Global Analysis. Springer-Verlag, New York. 257 pp.

FIGURE LEGENDS

Fig. 1 -- Brazil's Legal Amazon region.

Fig. 2 -- Trends in deforested areas derived from satellite data. Growth is especially rapid in Rondônia and Mato Grosso. The beginning of the curves is shown as a broken line since LANDSAT data for 1970 do not exist (Updated from: Fearnside, 1986b). See Notes for data sources.

Fig. 3 -- Observed felling in Rondônia in a cohort of lots occupied by their original owners (Source: Fearnside, 1984a).

Fig. 4 -- Effect of colonist turnover on felling rates in Rondônia (Source: Fearnside, 1984a).

(1) Deforestation data references for Figure 2: All 1975 and 1978 data from Tardin et al., 1980 based on LANDSAT-MSS. All available data for Amapá and Amazonas are explained in Table 1. For the remaining states, values in Figure 2 exclusive of the last two years of data (which are presented in Table 1) are: Acre 1975 (1,166 km^2), 1978 (2,465 km^2); Goiás (Amazonian portion) 1975 (3,299 km^2); Maranhão (Amazonian portion) 1975 (2,941 km^2); Mato Grosso 1975 (9,781 km^2), 1978 (30,369 km^2). Pará 1975 (9,948 km^2), 1978 (24,949 km^2); Rondônia 1975 (1,217 km^2), 1978 (4,185 km^2); 1980 (7,579 km^2) based on LANDSAT-MSS (Brazil, Ministério da Agricultura, IBDF, 1982b); 1982 (11,400 km^2) based on AVHRR 1.1 km resolution data (Woodwell et al., 1986: 252); 1983 (13,955 km^2) based on LANDSAT-MSS (Brazil, Ministério da Agricultura, IBDF, 1985); Roraima 1975 (55 km^2).

TABLE 1 NOTES

Notes:

a.) Acre 1980 estimate from Brazil, Ministério da Agricultura, IBDF, 1982c based on LANDSAT-MSS. A value of 5,269 km^2 for 1985 deforestation in Acre (Malingreau and Tucker, 1988) was not used because only the eastern 2/3 of the state is covered by the AVHRR image interpreted by these authors.

b.) IBDF, Brasília (Estimate made using LANDSAT-TM).

c.) Tardin et al., 1980 (Estimate made using LANDSAT-MSS).

d.) Brazil, Ministério da Agricultura, IBDF, 1982b (Estimate made using LANDSAT-MSS).

e.) LANDSAT-MSS data for 1983 are available only for the western portion of Mato Grosso (227,996 km^2) interpreted for the POLONOROESTE Program (Brazil, Ministério da Agricultura, IBDF, 1985). The projection was made separately for the western and eastern portions of the state, using values for 1978 and 1980 for the eastern portion and 1980 and 1983 for the western portion. The 1978 and 1980 values for eastern Mato Grosso (24,084 km^2 and 40,700 km^2 cleared respectively) are approximations made assuming the same percentage deforested as in the state as a whole (Brazil, Ministério da Agricultura, IBDF, 1982a; Tardin et al., 1980). The 1980 western Mato Grosso value (12,086 km^2) was derived in the same way.

f.) Brazil, Ministério da Agricultura, IBDF, 1983c (Estimate made using LANDSAT-MSS).

g.) SUDAM, Belém (Estimate made using LANDSAT-TM).

h.) Malingreau and Tucker, 1988. Estimate made using AVHRR 1.1 km resolution data.

i.) Jean-Paul Malingreau, personal communication, 1988. Based on AVHRR 1.1 km resolution data.

j.) Brazil, Ministério da Agricultura, IBDF, 1983a. Estimate made from LANDSAT-MSS images, using 2 scenes from 1980, 6 from 1981 and 2 from 1982 (p. 33). The date is therefore considered as 1981, rather than the 1982 date assigned by IBDF (p. 74).

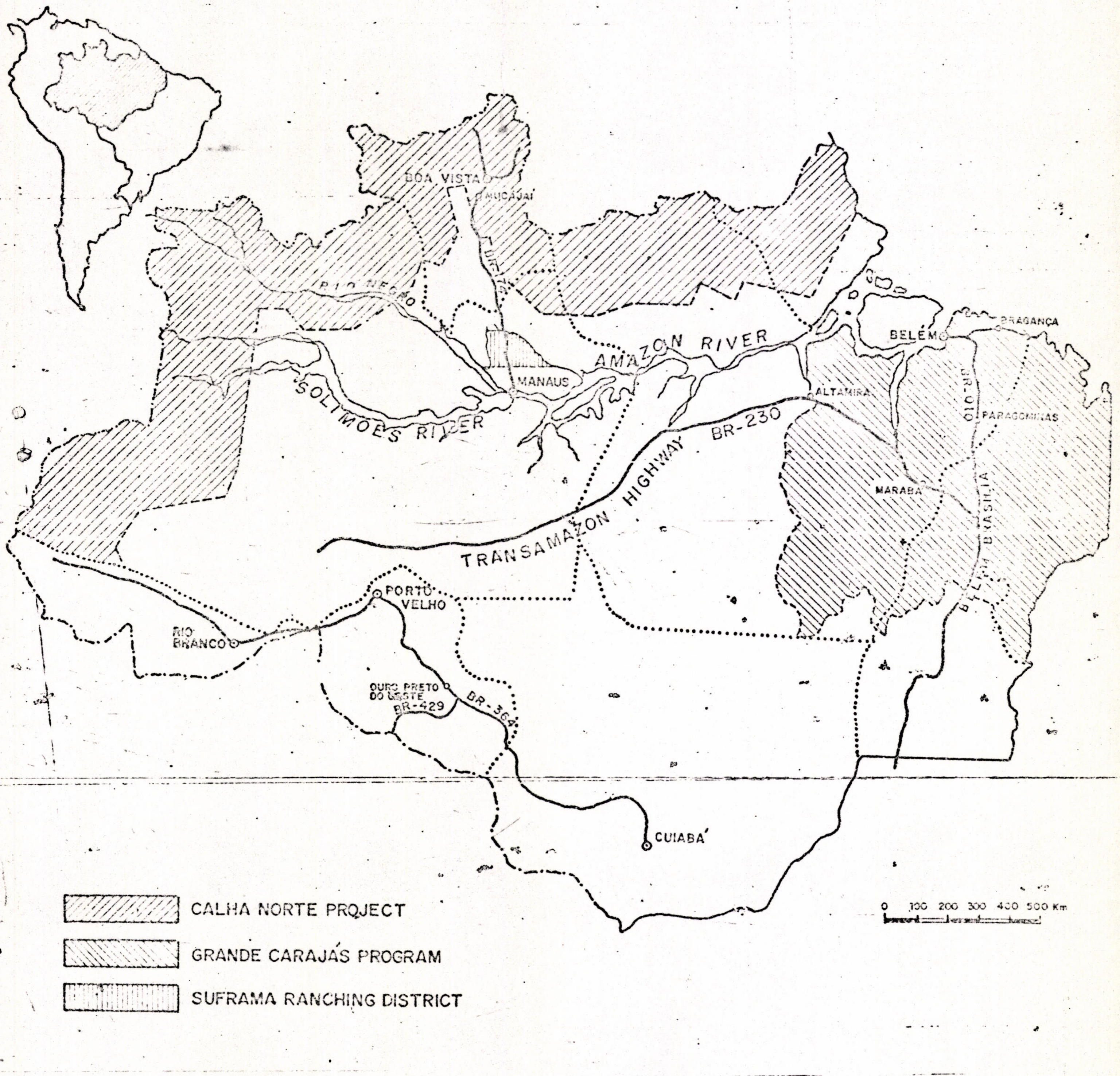

BOA VISTA
MUCAJAI
AMAZON RIVER
BELEM
BRAGANÇA
MANAUS
SOLIMOES RIVER
ALTAMIRA
PARAGOMINAS
BR-010
TRANSAMAZON HIGHWAY BR-230
MARABA
BELEM BRASILIA
PORTO VELHO
RIO BRANCO
OURO PRETO DO OESTE
BR-429
BR-364
CUIABA
0 100 200 300 400 500 Km
CALHA NORTE PROJECT
GRANDE CARAJÁS PROGRAM
SUFRAMA RANCHING DISTRICT

FIG. 1

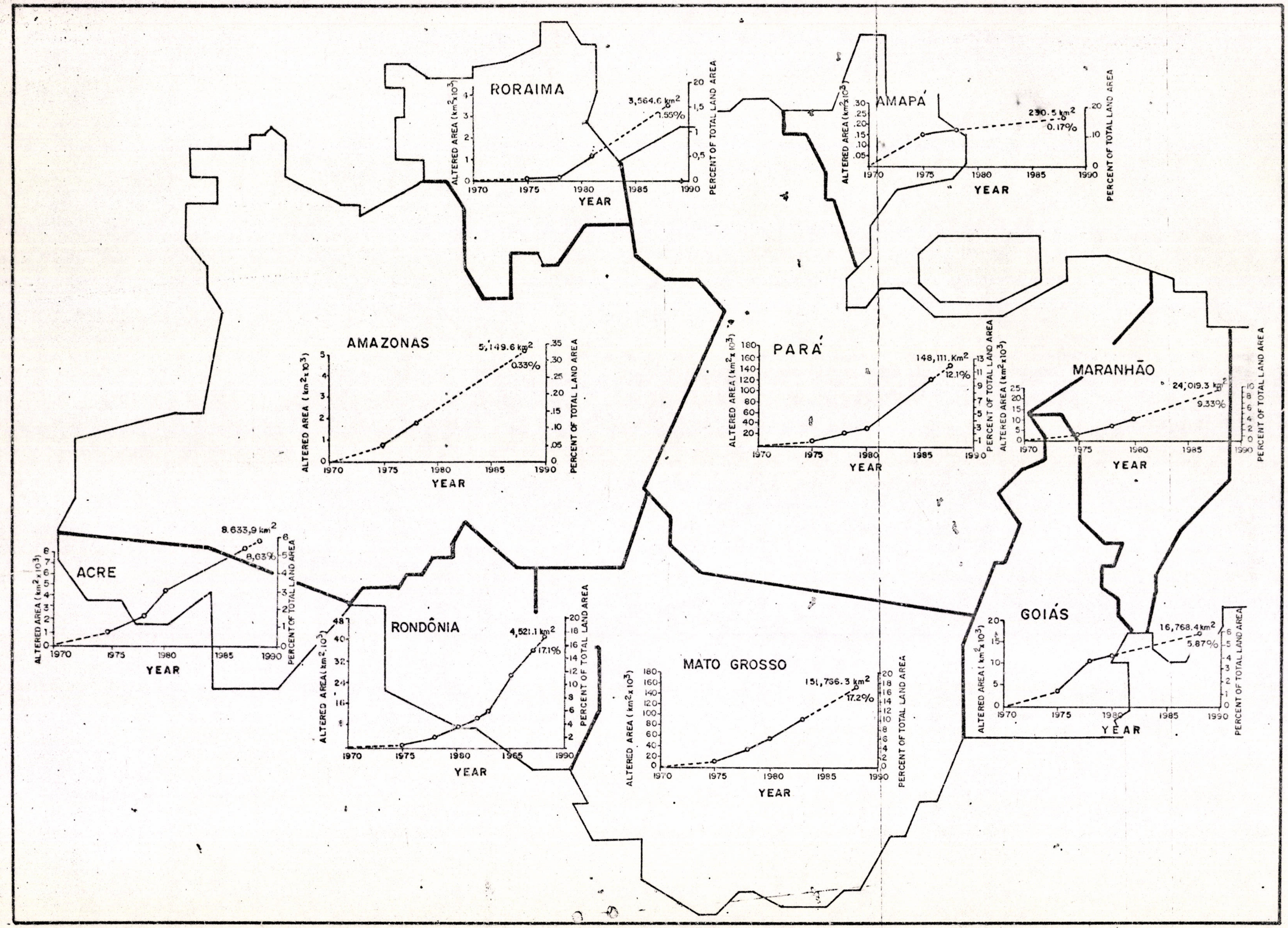
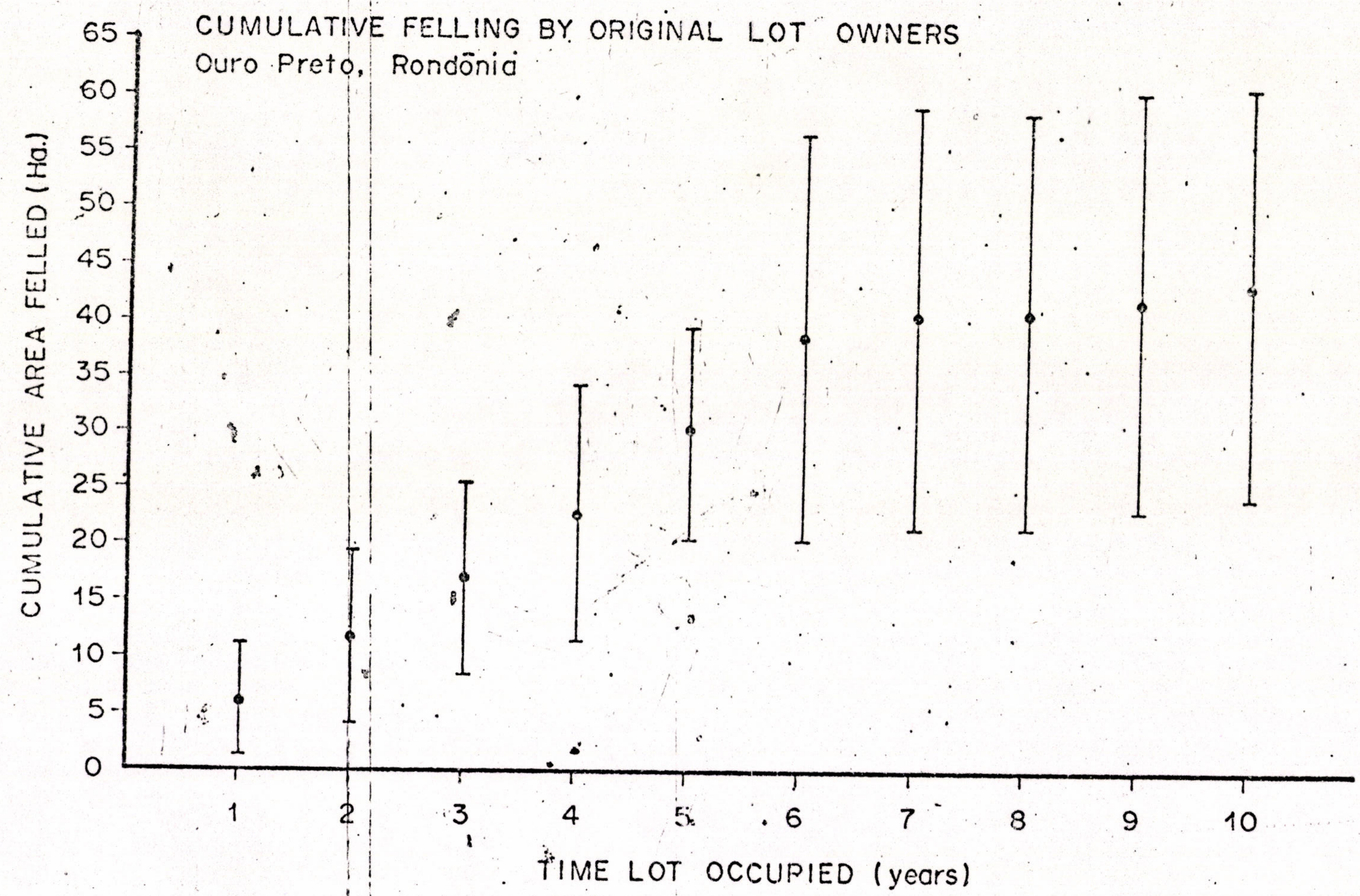

RORAIMA
3,564.6 km²
1.55%
AMAPÁ
230.5 km²
0.17%
AMAZONAS
5,149.6 km²
0.33%
PARÁ
148,111. Km²
12.1%
MARANHÃO
24,019.3 km²
9.33%
ACRE
8.633,9 km²
8.63%
RONDÔNIA
4,521.1 km²
17.1%
MATO GROSSO
151,736.3 km²
17.2%
GOIÁS
16,768.4 km²
5.87%
ALTERED AREA (km² x 10³)
PERCENT OF TOTAL LAND AREA
YEAR

FIG. 2

FIG. 3


CUMULATIVE FELLING BY ORIGINAL LOT OWNERS
Ouro Preto, Rondônia
CUMULATIVE AREA FELLED (Ha.)
65
60
55
50
45
40
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
TIME LOT OCCUPIED (years)

EFFECT OF COLONIST TURNOVER ON FELLING RATE
OURO PRETO – RONDÔNIA
1978 - 1981

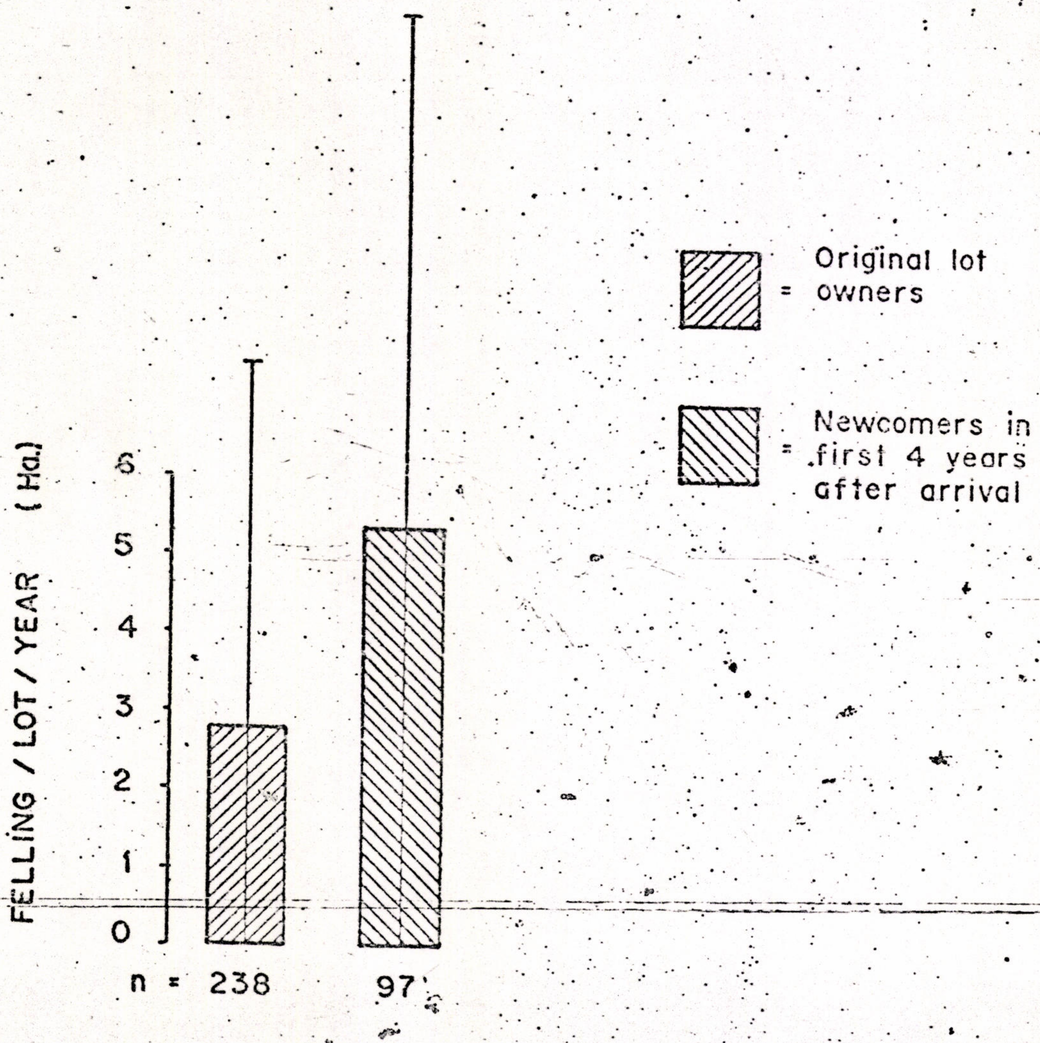


FIG 54

TABLE 1

DEFORESTATION IN BRAZIL'S LEGAL AMAZON REGION:

Two most recent satellite measurements for each state, with linear projection to 1988.

State	Land Area (km^2)	Year	Area clear (km^2)	Source	Year	Area Clear (km^2)	Source	Estimated area cleared by 1988 (km^2)	Estimated area cleared by 1988 (%)
Acre	152,589	1980	4,627	(a)	1987	8.133	(b)	8.634	5.7
Amapá	139,068	1975	153	(c)	1978	171	(c)	231	0.2
Amazonas	1,558,987	1975	784	(c)	1978	1,791	(c)	5,150	0.3
Goiás*	285,793	1978	7,209	(c)	1980	9,120	(a)	16,768	5.9
Maranhão*	257,451	1978	7,334	(c)	1980	10,671	(a)	24,019	9.3
Mato Grosso	881,001	1980	52,786	(d)	1983	89,903	(e)	151,766	17.2
Pará	1,227,530	1980	33,914	(f)	1986	119,561	(g)	148,111	12.1
Rondônia	243,044	1985	27,658	(h)	1987	36,900	(i)	41,521	17.1
Roraima	230,104	1978	144	(c)	1981	1,170	(j)	3,565	1.6
Total	4,975,567							399.765	8.0

* Only the portions of these states included in the Legal Amazon.