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Abstract

This paper presents quantitative evidence on the relationship between forest conversion and the productivity of agropastoral activities in the Legal Amazon. The extraction of timber products such as wood, fuelwood and charcoal is related to the process of agropastoral expansion in this region with the aim of providing physical coefficients to define intersectoral connections in Brazil's economy. The paper is organized as follows. Section I makes a geographical characterization of the original vegetation types of the region according to its principal geopolitical subdivisions. Section II presents evidence on deforestation rates and gross areas affected. Section III describes the principal sources of deforestation. Section IV describes sectoral activities and land occupation patterns distinguishing between "forested" and "non-forested" areas. Section V analyses major determinants of productivity in agropastoral activities following this broad vegetation distinction. Section VI provides gross estimates of wood removal associated with agropastoral expansion, and compares this with wood and fuel production figures. Conclusions are presented in Section VII.

I. Characteristics of the Original Vegetation Cover

To characterize the original vegetation cover of the Brazilian Amazon, it is necessary first to describe the geopolitical division of the region. Sixty percent of the Amazon tropical forest, which covers an area of approximately 5.5 million km², is located within Brazilian national territory, where it covers 3.55 million km², representing nearly forty percent of this territory (Figure 1). This area very nearly coincides with the area termed the North region of Brazil, which includes seven states: Rondônia (RO), Acre (AC), Amazonas (AM), Roraima (RR), Pará (PA), Amapá (AP), and Tocantins (TO) (Figure 2).[1]

The region known as the Legal Amazon refers to a geographic area of approximately 5 million km² defined for regional planning purposes which adds to the North region

[1] Reference is often made to the "old" North Region which excludes from the North region the state of Tocantins (TO), which was created in 1989. At least 84 percent of the Brazilian Amazon forests are located inside this region which is also referred to as Hylea Amazônica or "Classic Amazonia".

Figure 1 - Major Amazonian Ecosystems

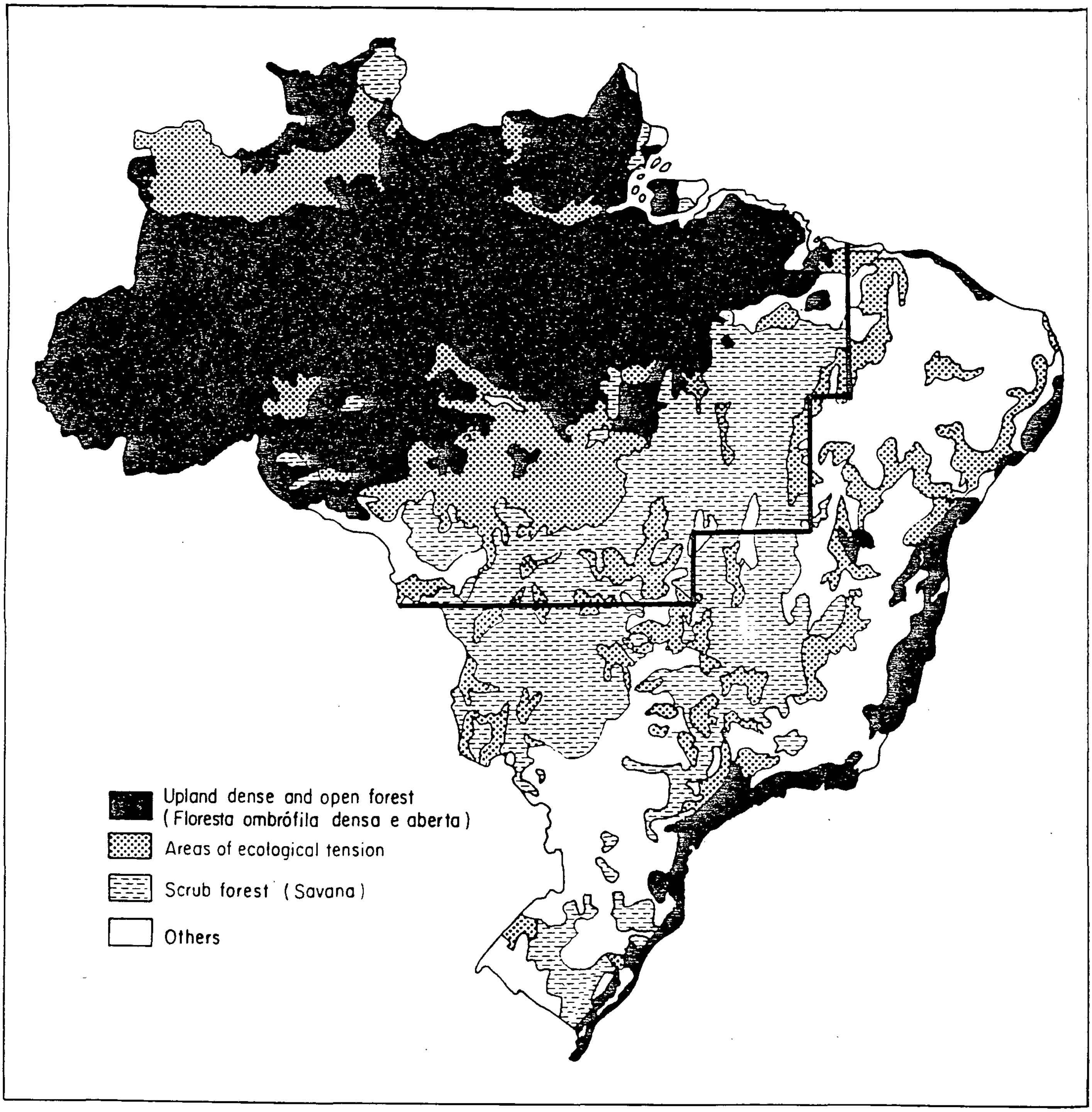
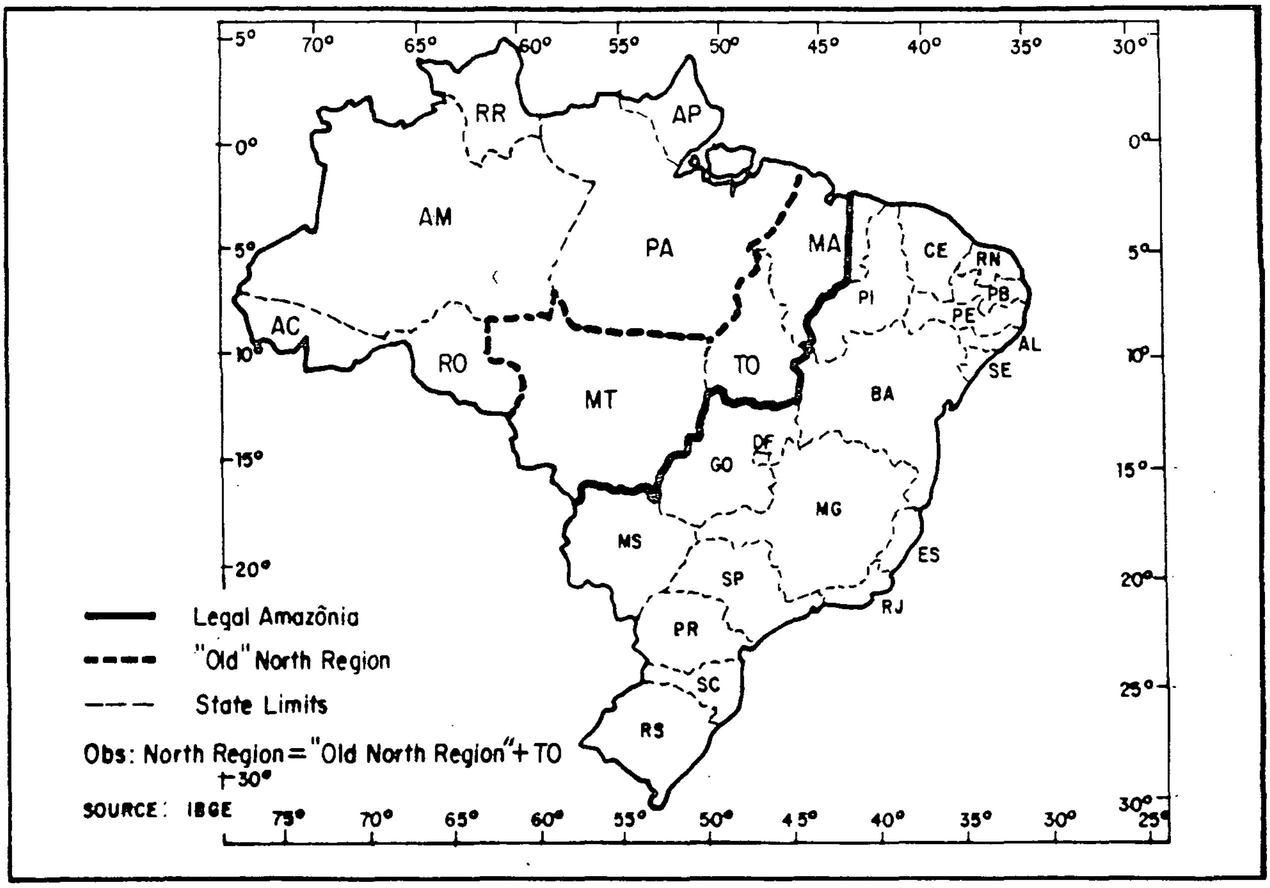


Figure 2 - Legal Amazõnia



those parts of the states of Mato Grosso and Maranhão which are located north of parallel 16 and west of meridian 44 (the area within solid black lines in Figure 1). It contains the entire area described as tropical forest in Brazilian segments of the Amazon river basin, but also contains significant areas of savanna and wetlands. This area totals about 58 percent of Brazilian national territory. For the purposes of this study - in which we intend to differentiate between land use and productivity in areas that were originally forested and those characterized by other vegetation types - we have determined to include the entire Legal Amazon region.[2]

The Legal Amazon is by no means a uniform forest biome. Though predominantly a tropical forest region, it comprises a complex mosaic of forest and savanna, inundated

2 In certain instances, it has been necessary for statistical reasons to restrict the area under analysis to the Classic Amazon states, with the addition of Mato Grosso alone. This is due to the recent division of Tocantins from Goiás, and the consequent difficulties of confining statistical analysis to those municipalities included within the Legal Amazon region in those cases where data is only tabulated on a state-by-state basis by the census bureau.

lowlands, and steppes. In simplified terms, the major vegetation types distinguished within this region are: closed and open tropical forests, seasonal open forests, savannas, campinaranas, ecological transition areas and wetlands.

By superimposition of municipal boundaries on vegetation mapping conducted on the basis of Radambrasil imagery (IBGE, c), we have been able to identify the percentage share of the geographic area of Amazonian municipalities categorized in each vegetation type.[3] Table 1 presents the geographic composition of the Legal Amazon according to major vegetation types by state. These are described below according to the Brazilian vegetation classification system (Velose et al., 1991).

CLOSED AND OPEN FORESTS include areas categorized as *Floresta Ombrófila Densa* and *Floresta Ombrófila Aberta*, respectively, ranging in vegetation composition with increased altitude. In lowland areas along watercourses, these forests contain hardwoods such as *Ceiba* and *Virola* species, interspersed with many palm varieties in the understory, particularly *Euterpe* and *Mauritia*. As the riparian areas are those initially settled, these forests tend to be modified and the more valuable wood species removed by the riparian extractivists. In the far more extensive upland segments of the Amazon basin, the principal characteristic of this formation is a multi-storied architecture, with emergent trees reaching as high as 60 metres, including such genera as *Parkia* and *Dinizia*. In other areas, these formations are clearer, due to high densities of bamboo, palms and vines. Some areas are now dominated by bamboo where the forest has been exploited for the noble hardwoods in the *Cedrela*, *Ocotea*, and *Aspidosperma* families. Other areas, such as central Maranhão and northern Tocantins have become dominated after initial clearing for cropland by palm forests made up of *Orbignya* species (babaçu). Closed and open forests jointly account for 68.6 percent of land area in the Legal Amazon region (see Table 1).

SEASONAL OPEN FORESTS unite areas categorized as *Floresta Tropical Caducifólia* in the Brazilian nomenclature, composed of deciduous vegetation that responds to pronounced dry and rainy seasons by loss of foliage in the unfavorable period. Fragments of these formations are found in southern Maranhão and Tocantins in submontane areas, which contain a range of valuable woods in families such as *Cedrela*, *Tabebuia* and *Jacaranda*, as well as in the Mato Grosso Pantanal depression. Together, these areas constitute only slightly over 3 percent of the Legal Amazon.

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[3] There were at the time of the most recent population census (1991) some 508 municípios (municipalities) in existence in the Legal Amazon region. Based on the administrative divisions in existence in 1980 and 1985, we have classified vegetation composition for 307 of a total of 336 geographic units to serve as a base for the analysis presented below. The difference in number is due to more recent subdivisions, and to exclusion of 50 municipalities in Mato Grosso whose vegetation composition is unclear.

Table 1 - Legal Amazon: Original Vegetation Cover by State (Area in 000 km^2)

Original Vegetation	RO		AC		AM		RR		PA		AP		MA		MT		GO		Amazon	
	Area	%	Area	%	Area	%	Area	%	Area	%	Area	%	Area	%	Area	%	Area	%	Area	%
Forests	222	93	153	100	1,265	82	150	66	1,167	95	110	79	142	52	332	55	59	21	3,600	77
• Dense	177	74	153	100	1,231	80	127	56	1,079	88	106	76	96	35	225	37	21	8	3,215	69
• Open	14	6	0	0	0	0	18	8	8	1	0	0	39	14	64	11	4	2	147	3
• Transition	31	13	0	0	34	2	4	2	80	7	4	3	7	2	44	7	33	12	238	5
Non-Forests	16	7	0	0	284	18	76	34	60	5	29	21	129	48	274	45	218	79	1,087	23
• Savannas	9	4	0	0	9	1	36	16	32	3	11	8	111	41	274	45	218	79	701	15
• Campinarana	0	0	0	0	258	17	39	17	0	0	0	0	0	0	0	0	0	0	298	6
• Wetlands	7	3	0	0	17	1	0	0	28	2	18	13	18	7	1	0	0	0	89	2
Total	238	100	153	100	1,550	100	225	100	1,228	100	139	100	271	100	606	100	277	100	4,687	100

Source: Reis (unpublished data).

SAVANNAS, commonly known as *Cerrado* in Brazil, are open hardwood forests that occupy a substantial portion of the central plateau region of the nation, which lies on the eastern fringe of the tropical forest in the Legal Amazon. Their characteristic pattern of open grasslands with torturously twisted trees arise due to seasonal rainfall (average six month dry season), poor, highly leached acid soils presenting serious aluminum toxicity, limiting their viability for forestry or agriculture. Nevertheless, large areas of *Cerrado* in Brazil have been adapted for mechanized soybean cultivation and pasture establishment and the region harbors a profuse wealth of plant and animal life that has only recently been the subject of research (Eiten and Goodland, 1979). *Cerrado* land area accounts for nearly 15 percent of the Legal Amazon. Wood extracted from this region contributes chiefly for fuelwood and charcoal manufacture.

CAMPINARANAS are open fields interspersed with forestlands which are subject to inundation during much of the year and are generally sparsely covered with vegetation due to extremely high rainfall and poorly drained hydromorphic or sandy soils. Covering a total of 6.4 percent of the Legal Amazon, *campinarana* occurs in greatest profusion in the upper Rio Negro region, where rainfall exceeds 4,000 mm annually, in low scrub forests characterized by the presence of endemic palms.

WETLANDS lie within the category of *Formações Pioneiras*, which refer to coastal lowlands and mangroves, as well as seasonally inundated alluvial areas within the Mato Grosso Pantanal, and *varzeas* throughout the Amazon basin, in total accounting for less than 2 percent of the Legal Amazon region.

ECOLOGICAL TRANSITION defines areas at the interstices of two vegetation groupings, which contain characteristics of both. In the Amazon region, these areas are typically found within forested areas where there exist enclaves of savanna, accounting for a total of 5.1 percent of the Legal Amazon.

For the purposes of the present study, the original vegetation types were grouped in two general categories: forests (including dense and open tropical forests, seasonal open forests and ecological transition areas) and non-forests (including savanna, campinarana, and wetlands). Table 1 presents the summary distribution of forest and non-forest landscapes in the Legal Amazon by state.

For comparative analyses of land use and productivity at the municipal level we have adopted more restrictive criteria to classify "forested" and "non-forested" areas. Thus, municipalities which contain forests in more than 75 percent of their territory are considered forested areas, and those having less than 25 percent of their territory in forests are considered non-forested areas. Those municipalities which remain between these two parameters were termed "intermediate" for classification purposes. Based upon these categories, Table 2 characterizes the distribution of municipalities and their geographic area within these ranges in the Legal Amazon.

Table 2 - Distribution of Legal Amazon Municipalities According to Forest Cover Classes (Percent)

Forest Cover Class	Number	Geographic Area	Area in Forests	Average Percent in Forests
0 - 25%	21.50	12.30	1.73	10.80
25 - 50%	7.49	9.13	4.77	40.14
50 - 75%	8.14	10.23	8.22	61.72
75 -100%	62.87	68.34	85.28	95.84
Total	100.00	100.00	100.00	76.80
Absolute	[307]	[4,687]	[3,499]	-

Source: IBGE

The resulting sample presents a thorough coverage of Amazonian municipalities in terms of both number and geographic area. The strata selected account for 260 (85 percent) of the 307 municipalities whose characteristics were analyzed for the Legal Amazon, and over 80 percent of regional land area. Moreover, the sample parameters assure a clear cut distinction between original vegetation types: on average, forested areas contain 96 percent of their area in forests while non-forested areas contain forest cover in only 11 percent of their area. It will thus be possible to uncover evidence of differentiation among these vegetation types regarding the economic variables of concern with a reasonable degree of statistical confidence.[4]

II. Evidence on Deforestation

The estimates of deforestation used in this study are based upon visual interpretation of anthropogenic activity from Landsat imagery, conducted by the Brazilian National Institute for Space Research (INPE).[5] In these estimates, the precision is greater in

4 Despite the robust nature of our sample and detailed physical data sources, it is important to caution that the agricultural census data correlated with proportional vegetation coverage at a municipal level is subject to error due to the impossibility of identifying specific crop or pasture lands that lie within original vegetation categories.

5 Figures in Table 3 come from 229 Landsat Thematic Mapper (TM, 30 meter resolution) images in a color composite of bands 3 (red), 4 (near infrared), and 5 (short wave infrared), at the 1:250,000 scale (except for 1975 and 1978, which uses 232 Landsat Multispectral Scanner - MSS - black and white images at the 1:500,000 scale). The advantages of Landsat TM images are their frequency of availability (16 days orbit) and their more adequate resolution, especially when compared with the 1.1 km resolution of NOAA Advanced Very High Resolution (AVHRR) which tend to overestimate the extent of deforestation.

forested areas, since other vegetation cover categories such as savannas or ecological transition areas pose major difficulties for the correct identification of anthropogenic activity. Table 3 presents estimates of deforested areas in the Legal Amazon from 1975 to 1991, by state.

The data in Table 3 show that up to the mid-seventies deforestation was practically restricted to the so-called *Zona Bragantina*, located on the eastern border of Pará with Maranhão and to the north of Tocantins. In the latter, due to the overwhelming predominance of savanna (Figure 1), deforestation figures for 1975 and 1978 probably underestimate the extent of deforestation along the Belém-Brasília corridor that was opened up during this period.

During the late seventies and throughout the eighties, deforestation rates within the region showed spectacular growth, most specifically, in northern Mato Grosso, following a northwest path of expansion toward the states of Rondônia and Acre, stimulated by the paving of highway BR-364. Broadly speaking, the expansion of frontier in this period took place in areas where the predominant original vegetation consisted chiefly of savannas and zones of ecological transition to tropical forest. The broadleaved high forests of Amazonas remained nearly intact, except in areas surrounding Manaus.

Table 3 - Deforestation in Legal Amazon States: 1975-1991

State	Geog. Area[a]	Deforested Share (percent)				Annual Growth (000 km^2)	
		1975	1978	1988	1991	1975-91	1988-91
Acre	154.7	.76	1.60	5.78	6.96	0.60	0.61
Amapá	142.4	.11	.12	.55	1.19	0.10	0.30
Amazonas	1568.0	.05	.11	1.26	1.48	1.40	1.15
Pará[b]	1246.8	3.89	4.52	10.39	11.87	6.22	6.15
Rondônia	238.4	.51	1.78	12.60	14.51	2.09	1.52
Roraima	225.0	.02	.06	1.22	1.87	0.26	0.49
M.Grosso[c]	802.4	1.15	2.49	8.91	10.78	4.83	5.00
Maranhão[b,c]	260.2	23.55	24.55	34.90	35.47	1.94	0.49
Tocantins[c]	269.9	1.26	1.14	7.79	8.44	1.21	0.58
AMAZON	4906.9	2.55	3.10	7.64	8.68	18.80	17.01

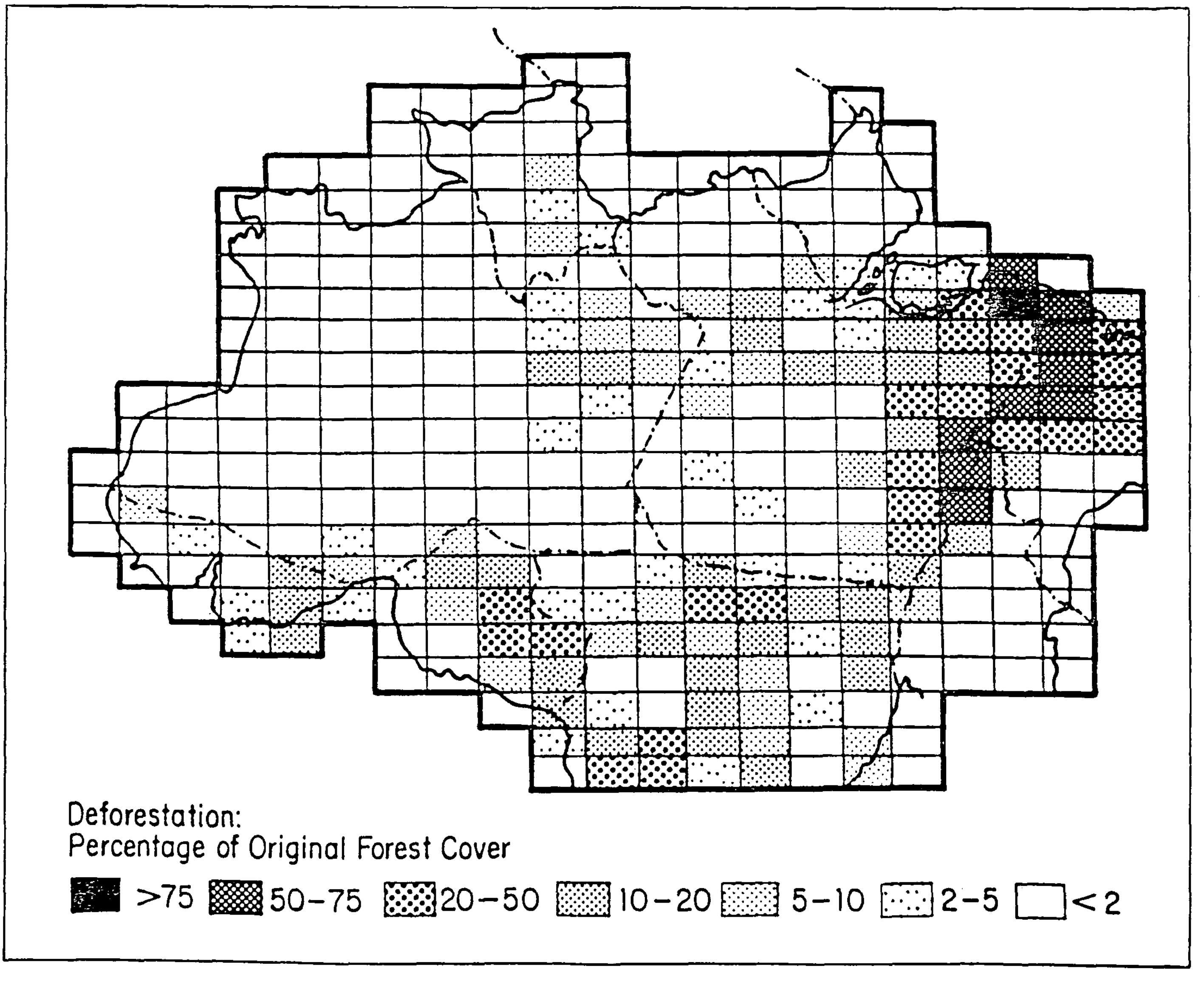
[a]Area in thousand km^2. - [b]Includes the "old deforestation" areas of the Bragantine Zone: 31,822 km^2 in Pará and 60,724 km^2 in Maranhão. - [c]Includes only portion of the state pertaining to the Legal Amazon region.

Source: INPE-1649-Rpe/103 for 1975 and INPE (1992) for the remaining years.

In more recent years, the process of deforestation experienced a slowdown in most states, except in the states of Pará, Mato Grosso, Amapá and Roraima where frontier expansion maintained an accelerated pace.

Despite the strong growth over the past two decades, in 1991 deforestation in the Legal Amazon was still mainly restricted to the peripheral areas in the eastern, southern, and southwestern borders of the region (Figure 3). This area, not coincidentally, also received a disproportionate share of economic activity, government investments and regional development incentives.[6]

Figure 3 - Satellite Images of Deforestation in Amazonia, 1989



6 See Serôa da Motta (1993) for a description of the policy instruments whose effects on deforestation were most pervasive in the Amazon region during this period.

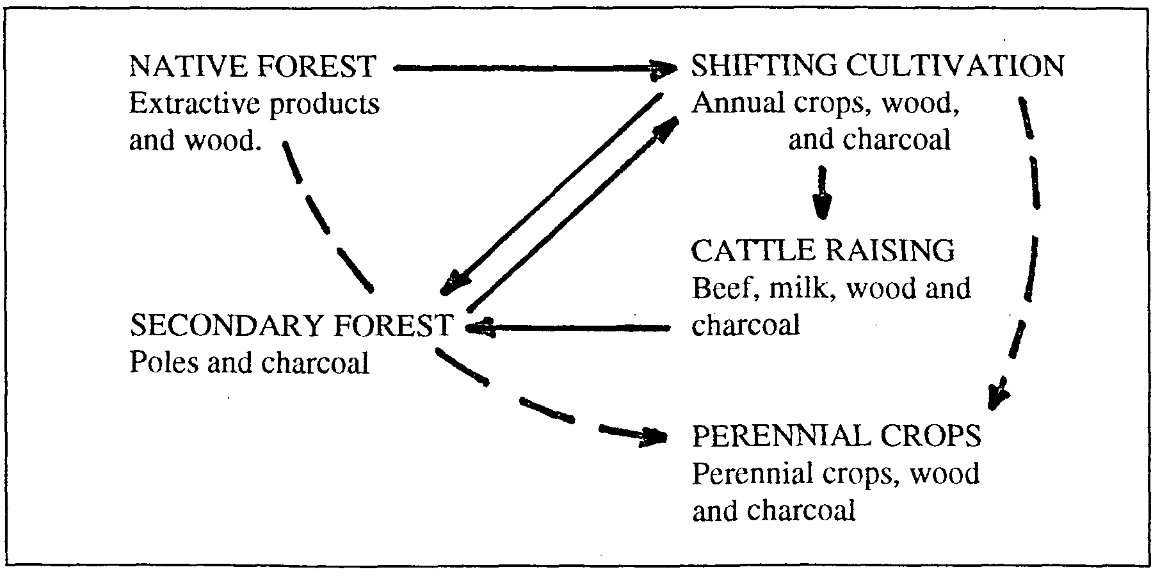
III. The Sources of Deforestation

This section characterizes the principal sources of deforestation in the Brazilian Amazon over the past two decades, with particular reference to the interlinkages between agricultural and forestry activities.

The accelerated deforestation in Brazilian Amazon in recent decades resulted from a multiplicity of factors which include road and railway construction, spontaneous and government directed colonization projects, timber extraction, charcoal production, subsidized agropastoral projects, hydroelectric facilities, mining (both placer and corporate), and uncontrolled forest fires associated with human activities.

The rapid expansion of the agropastoral frontier is probably the most important economic factor behind deforestation. Squatters who practice shifting cultivation are the leading agents in the conversion of forest lands to subsistence crops (rice, beans, maize, and cassava). Conversion to perennial crops (cocoa, coffee, pepper, orange, and bananas) or - as is more common - pastures, usually occurs in a second stage. Logging in Amazonia has generally been a by-product of clearing land for agricultural purposes. Mining and hydroelectric development, by contrast, played minor and indirect roles (Amelung, Diehl, 1992).

Despite the differences in time, location and site specific conditions, the typical process through which forestland is converted to agropastoral uses could be schematically described by the following flowchart:



Last but not least, it should be mentioned that the expansion of the agricultural frontier was decisively conditioned by the government's construction of roads, since the existence of a road network was a prerequisite for economic and demographic settlement of the so-called *terra-firme* (uplands between rivers that had previously served as principal transport corridors). The distribution of government subsidies through fiscal and credit mechanisms was another decisive factor for the profitability of certain agricultural activities, particularly cattle raising, which are considered economically unfeasible in the soil conditions prevailing in most areas of Amazonia (Hecht, 1985; Hecht et al., 1988; Mahar, 1989). Therefore, the government was a leading actor in the settlement of the region.

Due to the intricate relationship among these factors, it is very difficult to segregate specific causes of deforestation. The complex dynamics of the process makes almost impossible a rigorous identification of causes and consequences. Thus, sometimes, the profitability of cattle raising was the *primum mobile* of deforestation, though this activity arose subsequent to slash and burn agriculture.[7] In other instances, agricultural settlements were made possible by feeder roads built for logging, mineral extraction or hydroelectric facilities. Because of these complex dynamics it is better to talk of sources, rather than causes of deforestation.

The principal source of deforestation was decidedly agropastoral expansion. Table 4 presents evidence on the composition and growth of major agropastoral activities in the Legal Amazon according to IBGE Census data regarding rural establishments. The figures in Table 4 show, firstly, the small share of land used by rural establishments in the Legal Amazon: even as recently as 1985, more than 75 percent of the Amazon territory still remained in the public domain. Secondly, from 1975-1985 the region exhibited impressive rates of agropastoral expansion averaging nearly 4 percent annually. Thirdly, the data shows that a substantial proportion - more than 60 percent in 1985 - of the area in rural establishments is maintained under natural pastures and forests. Fourthly, planted pastures represent at least two-thirds of land effectively employed for agropastoral purposes,[8] far overshadowing annual crops (17 percent) or perennials (3 percent) in 1985. Planted pasture area increased in both absolute and relative terms over the decade, accounting for an ever larger proportion of land within agricultural establishments, attesting to the process of conversion described above.

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7 In some cases, shifting cultivators who arrived at a site were forced to abandon it after two or three years due to soil exhaustion, when they sold whatever rights they had to a rancher who then planted the already cleared areas with pasture grass. In other cases, ranchers allowed small farmers to plant annual crops on their lands with the provision that they sow pasture grass before the harvest, this being a nearly costless means to clear forests and establish pastures.

8 Land effectively employed for such purposes includes the following categories: annual and perennial crops, planted pastures, reforested and fallow lands.

Finally, the figures show the growing importance of fallow lands as croplands and pastures are abandoned due to soil exhaustion, increasing from less than 40,000 km² in 1975 to over 850,000 km² in 1985.

Table 4 - Legal Amazon: Agropastoral Land Use, 1975-1985

Land Area Used	Year			Annual Growth (thousand km²)		
	1975	1980	1985	75-80	80-85	75-85
In km² thousand	785.6	1,038.8	1,153.6	50.64	22.96	36.80
Share of Amazon (percent)	15.69	20.75	23.04	-	-	-
Out of which, percent in:						
• Annual crops	0.52	0.87	1.00	3.50	1.30	2.40
• Perennial crops	0.07	0.16	0.19	0.90	0.30	0.60
• Planted Pastures	1.43	2.67	3.82	12.41	11.52	11.97
• Planted Forests	0.02	0.05	0.04	0.30	-0.10	0.10
• Fallowlands	0.05	0.57	0.74	5.21	1.70	3.45
• Native Pastures	4.53	5.13	4.82	6.00	-3.10	1.45
• Native Forests	7.05	9.25	9.31	22.02	0.61	11.32
• Idle Productive	2.02	2.05	1.98	0.30	-0.70	-0.20
• Inappropriate	n.a.	n.a.	1.14	-	-	-

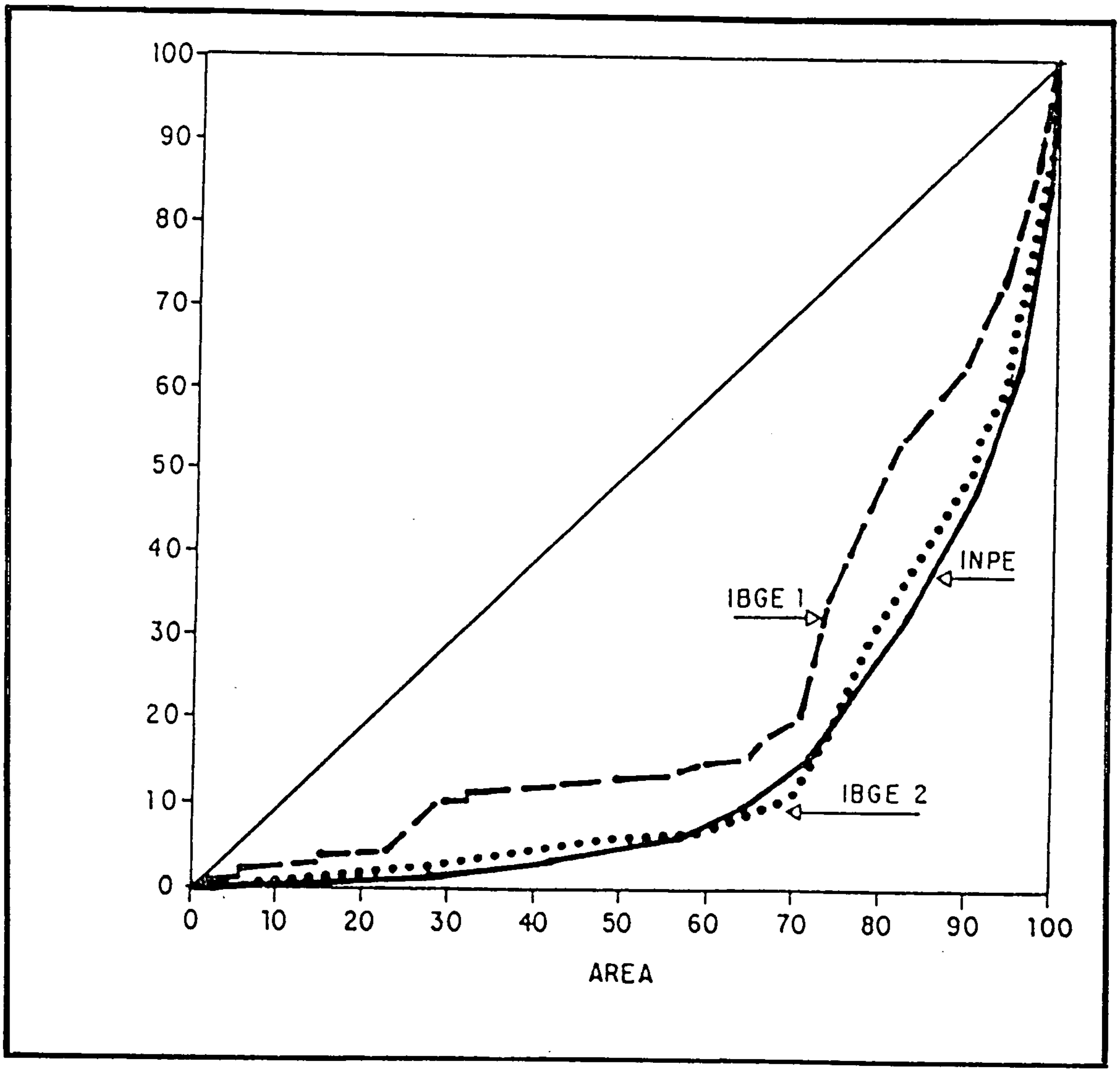
n.a. = not available.

Source: IBGE.

The relative importance of pasture lands suggests cattle raising is the main source of Amazon deforestation. Although the primacy of this source is evident from the statistics, figures could be biased to the extent that people tend to claim idle lands (whether deforested or not) as pastures to avoid any penalties for failure to make land improvements. This ploy is facilitated by the malleability of land requirements in extensive practices of cattle raising. Thus lands categorized as pastures are effectively used as a form of ensuring property rights, even though they may never have actually been used for grazing.

To conduct the detailed analysis presented here, we rely primarily on IBGE census data, which may be shown to represent adequate consistency with physical interpretation of deforested areas. We were able to compare deforestation estimates derived from satellite images by INPE with those obtained from agropastoral land uses surveyed by IBGE. Figure 4 compares Lorenz Curves for the geographic concentration of deforestation according to IBGE and INPE estimates for a sample of Amazon municipalities; the former with two alternatives, one including and the other excluding native pastures. The figure suggests that the IBGE estimate including native pastures does not correspond with the physical interpretation of cleared areas,[9] but that the estimate using plánted pasture areas closely accompanies the INPE observations.

Figure 4 - Geographic Concentration, INPE, IBGE 1 and IBGE 2 (Excluding Natural Pastures)



Unfortunately, neither INPE nor IBGE estimates allow the identification of specific sources of deforestation other than agropastoral activities. The only exception, in the case of INPE, is the contribution of large hydroelectric projects (namely Tucuruí, Samuel, Balbina, and Curua-Una) which in 1989 together amounted to 482,700 ha in area flooded for reservoirs, which only represents one percent of the Legal Amazon

9 For this study, the following classification was used: crop areas (both annual and perennial), planted pastures, fallowlands and idle productive lands are considered deforested areas, while native pastures, forests, and inappropriate areas are treated as forested. Native pastures is an ambiguous category since IBGE surveys can be referring in this case either to the original vegetation or to the characteristics of the (non-cultivated) secondary regrowth of vegetation in deforested areas.

territory. Individually, Balbina (AM) contributed with 239,900 ha, and Tucuruí (PA) with 192,600 ha (INPE, 1992), the other two reservoirs being of comparatively negligible scale.

In regard to timber extraction, the scanty evidence available refer to volumes of output and not to cleared areas. Table 5 demonstrates that the gross value of wood, fuelwood and charcoal extracted in the Legal Amazon during the 1975-1985 period represented a fairly constant share of total agropastoral output value of the region, exhibiting a slight increase from 32 percent to 39 percent of total crop output over the decade. There is a linear relationship between agropastoral output and timber extraction, although it is possible that more land has been cleared than converted to productive agropastoral uses at the frontier during the 1980s.[10] This evidence suggests that some logging and fuelwood consumption, although mainly a side-effect of the process of agricultural land conversion, may possess a dynamic of its own. Wood extraction over the past decade has remained a major contributor to rural income in the Amazon, accompanying the near tripling in real agricultural product.

Despite the growing importance of wood products to gross income, however, the probability that land initially logged over is then allowed to return to permanent forest use is quite small. Furthermore, researchers have found that the potential for recovery of original forest biodiversity after massive clearing and degradation is slim indeed (Uhl et al., 1990). There is no known natural forest concession in the Brazilian Amazon managed for sustained yield of timber. According to (Rankin, 1985), only a few hundred hectares in the entire region have been subject to sustained management and then only for experimental purposes. The concept of sustained management of non-timber forest products has become increasingly accepted.[11]

Use of wood for charcoal production, which relies mostly on waste from lumber mills, is also closely linked with agricultural land conversion. Over recent years there has been a considerable increase in charcoal production for iron smelting particularly in the Carajás railroad corridor in eastern Pará and northwestern Maranhão, a small portion of which may have been due to land clearing specifically for charcoal.

[10] It is important to discriminate the shares of this proportional growth due to changes in the relative prices of agricultural versus forest products and that due to actual growth in output. The decline in 1980 was possibly due to a drop in the relative prices of timber products as compared with crop values, since the growth in output of timber products has been fairly constant over this period.

[11] As of November 1988, there were over 22,000 km^2 in existing or proposed extractive reserves (Fearnside, 1989). Since that time, an additional 9,000 km^2 were added through establishment of the Chico Mendes reserve in Xapuri, Acre. The existence or proposal of extractive reserve establishment indicates that forest dwellers are already occupying these areas for non-timber forest product extraction. The extent to which such reserves constitute sustainable options for forest management in the Amazon remains an open question which we will not examine here.

Table 5 - Value of Timber Output Compared with Crop Value; North Region and Mato Grosso (constant 1980 US $ 000)

Year	(1) Wood[a]	(2) Crops[b]	(1)/(2)
1975	155,017	483,300	0.32
1980	183,811	724,752	0.25
1985	459,267	1,190,160	0.39

[a]Includes the sum of roundwood, charcoal and fuelwood value reported by agricultural establishments. - [b]Includes the sum of annual and perennial crop output value.

Source: IBGE, Statistical Yearbook (a, b, various years); Agropastoral Census (various years).

There are no significant commercial timber plantations in the Amazon region aside from the controversial Jari Florestal e Agropecuária enterprise planned for 100-200,000 ha *Gmelina, Pinus* and *Eucalyptus* (Rankin, 1985). Despite optimistic proposals for sequestration of carbon through massive tree planting schemes such as the program for environmental reforestation - FLORAM (Centro de Estudos Avançados, 1991), and for charcoal supply in the Carajás corridor,[12] it is unlikely that major reforestation efforts will prove to be economically viable in the near future in the Amazon. We have hence restricted the remainder of the discussion in this study to agropastoral expansion.

IV. Land Occupation Patterns and Original Vegetation Cover

This section analyzes the relationship between the original vegetation cover and major dimensions of land occupation patterns, including agropastoral land uses, the size distribution of establishments, and tenure patterns within the region. For this purpose, characteristics of agricultural establishments are compared between forested and non-forest areas, as defined in Section I, above.

Table 6 presents evidence on agropastoral land use for forested and non-forested municipalities. The figures show that patterns of occupation do not differ substantially beyond confirming that uncleared areas of rural establishments in forested municipalities tend to be mainly native forests, while uncleared ares are predominantly native pastures in non-forested municipalities.

[12] A proposal by Companhia Vale do Rio Doce to plant 1 million ha in eucalyptus was withdrawn from the Pilot Plan for Sustainable Development in the Amazon, at the insistence of environmental groups.

Table 6 - Legal Amazon: Agropastoral Land Use, 1985 According to Original Vegetation Cover

Agropastoral Land Use	Percent of Rural Establishment Area in Municipalities with Original Vegetation:		
	Non-Forested	Forested	Intermediate
• Annual crops	5.09	3.84	3.84
• Perennial crops	0.34	1.32	0.46
• Planted Pastures	11.43	18.04	15.72
• Planted Forests	0.04	0.21	0.55
• Fallowlands	3.01	4.07	4.07
• Native Pastures	41.58	5.63	28.55
• Native Forests	19.38	55.31	32.54
• Idle Productive	12.46	8.22	8.45
• Inappropriate	6.66	3.35	5.82
Total	100.00	100.00	100.00
As % Geog. Area	40.85	15.68	18.93

Forested (>75%) and non-forested (<25%) and intermediate (between 25% and 75%). Percent of geographic area refers to proportion of total area in municipality occupied by rural establishments.

Source: IBGE, Sinopse Preliminar do Censo Agropecuário de 1985.

The figures at the bottom of Table 6 show that the geographical density of rural establishments is significantly higher in non-forested municipalities (over 40 percent of total geographic area lies within agricultural establishments) than in forested municipalities (16 percent). It is possible to suggest that, due to the differential costs of clearing, non-forested areas have been the preferential direction for the advancement of the economic frontier. However, it also reflects the fact that forest municipalities tend on average to be far larger, and their settlement more recent, so that the land area so far dedicated to agriculture tends to be less.

The proportion of establishment area effectively in use for productive purposes (corresponding to the sum of area in crops, planted pastures, reforested and fallow) is greater in forested municipalities (27.5 percent) than non-forested (19.9 percent). This difference is primarily due to land area dedicated to planted pasture, somewhat higher in the forested municipalities. The probable rationale for the larger share of lands in production in forested municipalities is the need to convert native forests to pastures - which contrasts with the possibility of using native pastures in non-forested municipalities. Forest clearing for pasture may also reflect the previously described strategy to ensure property rights through "improvements".

In contrast to their inferior share of area dedicated to planted pastures, non-forest municipalities show a slightly higher proportion of farm area in annual crops. Likely reasons for this pattern of specialization include the greater adequacy of non-forested (chiefly savanna) soils for annual crops such as soybeans, once adequately fertilized and limed, as well as their better structure, suitable for mechanized tillage operations, which facilitate extensive agriculture.

Two other important dimensions of land occupation patterns are the size of rural establishments and their land tenure arrangements. These dimensions are especially important for their implications toward agricultural policy, in particular in those aspects related to agrarian reform and incentive mechanisms.

Table 7 presents cross-tabulations of land use patterns and the size distribution of rural establishments for the states of the "old" North Region and Mato Grosso.[13] For this purpose data on the size of area of rural establishment were grouped in three major categories: small (less than 100 ha); medium (between 100 and 500 ha); and large (area greater than 500 ha).

The Figures in Table 7 show that small establishments are specialized in crop production (13.8 percent of land area) while the medium and large operations are specialized in livestock ranching (between 13.6 and 14.7 percent of land area devoted to planted pastures). Nevertheless, even the smaller units occupy a substantial share of total area in planted pasture, nearly equivalent to that in annual crops, suggesting that livestock is an intrinsic aspect of agricultural production strategies among all strata of Amazon producers.[14] It is disturbing to note that large establishments not only occupy the vast majority of land within agricultural establishments in the Legal Amazon (73.6 percent) but are also those which proportionally show the least area proportionally devoted to forest reserves and the highest proportion of idle productive land.[15] Evidently, whatever policy hopes to deal with the problems caused by deforestation must address land concentration as well.

The tendency in areas of colonization has been toward aggregation of smaller units, due to colonist failure and speculation, but there is also some evidence of break-up among the large properties. At an aggregate scale, from 1975-1985, the distribution of land showed a slight improvement, with the smallest units increasing from 10 to 13.6 percent of total land in agriculture in the region, but also increasing in average size from 17 to nearly 24 ha. The average area in large properties declined, although their size (3,300 ha) remained over 100 times that of smallholders (Table 8).

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13 Unfortunately, these data are not available at municipal level, therefore precluding presentation of such tables for the entire Legal Amazon.

14 There are good reasons for the importance of cattle production to smallholders, which include their representing a form of savings that can be conveniently liquidated as need arises, and their relative ease of marketing unaffected by seasonal road conditions - when necessary, cattle can walk to market (Hecht, 1991).

15 As has been noted previously, however, the categories of native pasture, native forest and idle productive lands tend to overlap a great deal, thus distorting the capacity to characterize land use based on these data.

Table 7 - Agropastoral Land Use by Size Distribution in North Region and Mato Grosso, 1985 (Percent of Rural Establishment Area)

Agropastoral Land Use	Size of Rural Establishments		
	Small	Medium	Large
• Annual crops	10.16	5.10	2.04
• Perennial crops	3.63	1.48	0.27
• Planted Pastures	9.76	14.69	13.57
• Planted Forests	0.06	0.05	0.24
• Fallowlands	6.61	3.23	0.76
• Native Pastures	4.18	8.29	16.33
• Native Forests	55.73	60.21	38.39
• Idle Productive	9.87	6.97	28.41
Total	100.00	100.00	100.00
As % Geog. Area	12.4	14.0	73.6

"Small" refers to establishments less than 100 ha in size; "Medium" to those between 100 and 500 ha and "Large" to those over 500 ha. Percent of geographic area refers to proportion of total area in municipality occupied by rural establishments in size category.

Source: IBGE.

Table 8 - Size and Land Tenure Patterns of Rural Establishments in North Region and Mato Grosso, 1985 (percent share of area in rural establishments)

Land Tenure Arrangements	Size of Rural Establishments			
	Small	Medium	Large	Total
Owner	67	68	95	87
Renter	4	5	1	2
Sharecropper	2	2	1	1
Squatter	27	25	3	10
Total	100	100	100	100

Small refers to establishments less than 100 ha in size; Medium to those between 100 and 500 ha, and Large those over 500 ha.

Source: IBGE, b.

Land tenure patterns show that the majority of all lands are occupied by tenured owners (86.5 percent), and most of these lands lie within properties over 500 ha in size. In the smaller size categories, there are proportionally more squatters (25 to 27 percent) than renter or sharecropper categories, which are the least expressive in the Legal Amazon region, jointly accounting for only 3 percent of total land occupied (Table 9). The ready availability of land and the consequent lack of land markets in the region are the obvious explanation for the limited prevalence of renting or sharecropping, as well as for the considerable importance of squatting even in the medium size category. Since, in this context, land clearing is a legitimate mechanism to claim property rights on land, squatters have an incentive to deforest beyond what is required for immediate productive purposes, and then leaving this land fallow (Table 10).

Table 9 - Area and Number of Agropastoral Establishments in North Region and Mato Grosso, 1975-85

		1975	1980	1985
Large	Area (000 ha)	40,588	56,054	56,247
	Number	9,287	15,694	16,910
	Average Area (ha)	4,370	3,572	3,326
Medium	Area (000 ha)	7,807	11,875	13,944
	Number	52,256	72,313	89,645
	Average Area (ha)	149	164	156
Small	Area (000 ha)	5,658	8,185	11,057
	Number	331,567	381,937	466,982
	Average Area (ha)	17	21	24

Source: IBGE, b.

Table 10 - Agropastoral Land Use and Land Tenure in North Region and Mato Grosso, 1985

Agropastoral Land Use	Percent of Rural Establishment Area			
	Owner	Rentier	Sharecrop	Squatter
• Annual crops	3.79	15.94	6.67	5.32
• Perennial crops	0.93	0.98	5.65	1.44
• Planted Pastures	16.81	3.35	5.31	4.93
• Planted Forests	1.46	0.03	0.06	0.04
• Fallowlands	1.92	0.79	2.57	4.06
• Native Pastures	19.30	11.23	4.16	6.83
• Native Forests	44.43	64.86	73.90	70.51
• Idle Productive	11.35	2.82	1.69	6.87
Total	100.00	100.00	100.00	100.0
As % Geog. Area	86.5	2.0	1.14	10.4

Establishments whose tenure categories was not reported were eliminated from total.

Source: IBGE, b.

The characteristics of rural establishments are cross tabulated in Table 10 with major land uses within those establishments on a regional level. We observe here that property rights and associated economic incentives have played some role in directing economic activities toward specific land uses. Landowners are more likely to dedicate a significant share of land to planted pasture (16.8 percent), renters to annual crops (16 percent), while sharecroppers have more incentive to manage perennial crops than any other category of land occupant. These may not be sharecroppers in the traditional sense of sharing both in investment and output. Perennial crop operations are typically managed by hired laborers who earn a share of the crop as a payment. The distribution of land uses among native pastures, forests and idle productive land shows that all tenure categories retained over 75 percent of lands out of effective use in 1985, although the distribution among specific use categories differs somewhat.

With regard to the distribution of tenure categories among forest cover types, the only significant contrast is found in the significantly higher proportion of squatters in forested and intermediate areas of 15.7 percent and 11.8 percent, respectively, while this proportion was only 4.0 percent in non-forest municipalities. This reflects longer-term settlement patterns in non-forest areas, and the consequent aggregation of squatter units into titled properties, or recognition of land rights through agrarian reform processes.

V. The Determinants of Agropastoral Productivity

This section analyzes the determinants of factor productivity in major agropastoral activities in the Legal Amazon region. The ultimate objective is to obtain estimates of labor and land requirement coefficients for these activities taking account of structural characteristics of municipalities, including the structure of production, the vegetation cover, the size distribution of establishments, and land tenure conditions.

Unfortunately, data on labor employment are not distinguished by major agropastoral land uses. Total employment in agriculture by municipality was the only information available. In consequence, labor productivity is restricted to an aggregate measure defined as the relation between the real value of total output (including outputs from forest product extractivism, as well as from agriculture and stock raising) and the number of workers employed in rural establishments. Table 11 shows that labor productivity in 1985 was significantly higher in non-forested areas.

Data on land employment are distinguished according to major agropastoral uses, thus making it possible to define land productivity indices for major annual crops (rice, beans, maize, cassava, soybeans, and wheat), perennial crops (coffee, cacao, pepper, orange, banana, sugar cane), and for cattle raising.

Table 11 - Employment and Labor Productivity in Rural Establishments of Legal Amazon, 1985

	Output Value (Cr$ millions)	Employment (thousands)	Labor Productivity (Cr$ 1000/worker)
Non-Forested	2,990	748	3,994
Forested	5,097	2,990	1,704
All Areas	8,726	4,227	2,064
Figures do not add up due to elimination of "Intermediate" land cover class from this tabulation.			

Source: IBGE, b

For cattle raising, we define two alternative measures of range productivity, one including and the other excluding "native pastures" from the land area under consideration. In both of these measures, productivity is defined as the relation between size of cattle herd and the area of pastures. Figures in Table 12 show that, due to extensive cattle raising, productivity is obviously higher when natural pastures are excluded. Although not directly supported by the data presented in Table 12, our analysis suggests a relatively high comparative advantage of planted pastures in non-forested areas. The reason is probably due to the the more extensive use of natural pastures in non-forested areas, which supplement the smaller relative areas in planted pasture per animal unit. Time trends, however, show that these differences tend to decrease both in forested and non-forested areas, when measures are restricted to planted pastures, but increase when natural pastures are considered. An explanatory hypothesis could be the adoption of less extensive practices of cattle raising, as well as the effects of overgrazing. Note, however, that planted pasture productivity does not decline in forested areas.

Table 13 shows productivity measures for aggregate categories of agricultural products, divided into annual, perennial and total crops. Productivity is defined as the real value of output in each category (deflated by the price index of major crops in the same category) divided by the area of land employed in the respective category.

Table 12 - Cattle Herd, Pasture Area and Land Productivity in Cattle Raising in Legal Amazon, 1975-1985

		Non-Forested		Forested		All Areas	
		Incl.	Excl.	Incl.	Excl	Incl.	Excl.
Cattle herd (thousand)	1975	5,708	5,708	2,552	2,552	9,390	9,390
	1980	7,752	7,752	7,426	7,426	15,220	15,220
	1985	9,186	9,186	7,811	7,811	18,998	18,998
Pasture area (thousand ha)	1980	21,454	3,783	4,631	2,874	29,813	7,154
	1975	26,154	6,066	8,585	6,327	39,044	13,346
	1985	26,634	8,590	7,811	12,077	43,246	19,126
Productivity (herd/ha)	1980	0.27	1.51	0.55	0.90	0.31	1.31
	1975	0.30	1.28	0.62	0.95	0.39	1.14
	1985	0.34	1.07	0.65	0.85	0.44	0.99

Incl. = includes natural pasture; Excl.= Excluding natural pastures. For the definition of forested and non-forested areas, see text. Due to the "intermediate" category, figures of forested and non-forested areas do not add up to totals.

Source: IBGE, b.

Table 13 - Output, Crop Area, and Land Productivity for Major Categories of Agricultural Crops in Legal Amazonia, 1975-1985

		Non-Forested			Forested			All Areas		
		Temp	Perm	Total	Temp	Perm	Total	Temp	Perm	Total
Crop output (Cr$ million[a])	1975	582	111	736	1531	698	2098	2347	860	3132
	1980	1601	187	1908	3142	1550	4476	5223	1815	6970
	1985	2821	168	2989	3247	1850	5097	6543	2183	8727
Crop area (thousand ha)	1975	818	79	897	1506	237	1744	2599	341	2944
	1980	2052	144	2197	1931	581	2512	4354	781	5135
	1985	2656	170	2826	1988	705	2693	5015	934	5949
Productivity (Cr$ 000[a]/ha)	1975	711	1412	820	1016	1945	1203	904	2496	1064
	1980	780	1295	868	1627	2664	1781	1199	2324	1357
	1985	1062	986	1057	1633	2623	1892	1304	2336	1466

Temp. = Temporary crops; Perm. = Permanent crops. For the definition of forested and non-forested areas see text. Due to the "intermediate" category figures of forested and non-forested areas does not add up to totals. Differences in deflator explain the same problem for summation across crops. [a] Values are in 1985 constant Cruzeiros.

Source: IBGE, b.

Figures in Table 13 show that, for the Amazon region as a whole agricultural productivity increased over 4.9 percent p.a. in the 1975-1980 period, but this rate of increase slowed to 1.6 percent p.a. in the 1980-1985 period. The increase in productivity was especially strong for temporary crops in forested areas, where growth reached nearly 10 percent p.a. over the 1975-1980 period, undoubtedly reflecting opening up of inviolate frontier lands.

For individual crops, we define productivity as physical units of output per crop area. Estimates are presented in Table 14. Productivity was somewhat better for most subsistence and cash crops in forest areas, although soybeans performed slightly better in non-forest soils, where they have in consequence been planted on over double the area. Initial fertility after clearing of forest soils appears to have been an important factor, explaining a difference of nearly 10 tons per ha in sugarcane, and nearly 4 tons per ha in cassava. The exhaustion of these soils after continuous cropping would tend to result in a decline in these productivities over time.

Finally, Table 15 presents regression results which explain the differences of productivity among Amazonian municipalities based upon structural characteristics such as their structure of production, vegetation cover, size distribution of establishments, and land tenure conditions.

The dependent variable in all the regressions is the productivity of agriculture (including both annual and perennial crops), defined as the relation between the value of output and crop area, in 1985.

The explanatory variables in the regression are:

- the land/labor ratio measured by the relation between total employment of labor and total crop area in the municipality, introduced to capture the effects of diminishing returns in agricultural production;

- the average size of agricultural establishments, a measure of scale economies;

- the average size of cattle herd, measuring the importance of alternative employment of land and/or labor;

- integration to product markets, measured by the percent share of total production destined for industrial or commercial uses (as opposed to output consumed within the establishment) in the total value of output;

Table 14 - Productivity of Major Crops in Vegetation Zones, Legal Amazon, 1985

	Non-Forested Areas			Forested Areas			All Areas		
	Quant. (000 t)	Area (000 ha)	Prod. (t/ha)	Quant. (000 t)	Area (000 ha)	Prod. (t/ha)	Quant. (000 t)	Area (000 ha)	Prod. (t/ha)
Annual									
•Rice	1,063	830	1.28	1,045	827	1.26	2,333	1,822	1.28
•Beans	23	50	0.46	110	193	0.57	143	263	0.54
•Cassava	232	45	5.06	2,964	350	8.47	3,510	450	7.79
•Maize	272	254	1.07	461	589	0.78	825	952	0.87
•Sugarcane	1,178	21	54.80	247	6.8	36.39	1,597	34	46.92
•Soybeans	1,640	852	1.93	3	2.7	1.12	1,652	860	1.92
Perennial									
•Cocoa	0.1	0.15	0.68	34	61	0.56	35	63	0.56
•Coffee	13	13	1.00	81	82	1.0	104	103	1.01
•Cotton	1.3	7.8	0.16	0.26	1.7	0.15	1.8	11.3	0.16
•Banana	19	28	0.69	39	55	0.72	63	88	0.72
•Orange	76	1.25	61.0	166	3.5	48.0	274	5	52.3
•Pepper	0.019	0.1	0.19	29	22	1.34	30	22	1.33

Source: IBGE, b.

Table 15 - Regression for Agricultural Productivity in the Legal Amazon, 1985

	All Areas	Non-Forest	Forest	Intermediate
Constant	7.09** (0.22)	7.12** (0.74)	6.51** (0.73)	7.04** (0.44)
Labor/Land	0.30** (0.05)	0.15* (0.09)	0.41** (0.09)	0.09** (0.09)
Avg. Herd Size	-0.03 (0.03)	0.28 (0.18)	0.008 (0.04)	-0.09 (0.05)
Avg. Estab. Size	-0.005 (0.04)	-0.24 (0.19)	-0.003 (0.06)	0.02 (0.07)
Market Integr.	0.21 (0.16)	-0.49 (0.39)	0.52** (0.25)	0.77** (0.30)
Land Concentr.	-0.13 (0.70)	0.46 (1.07)	-0.48 (1.30)	-1.83 (1.35)
Share Squatters	-0.43** (0.16)	0.25 (0.47)	-0.53** (0.21)	-0.30 (0.32)
Dist. State Cap.	-0.15 (0.11)	-0.45** (0.22)	0.16 (0.15)	-0.34 (0.22)
Dist. Fed. Cap.	0.20** (0.05)	0.45** (0.19)	0.55** (0.11)	-0.06 (0.04)
Share of Forest	0.08 (0.11)	-1.10 (0.76)	-0.14 (0.65)	-0.03 (0.42)
Dens. Paved Rd.	3.33** (1.15)	14.66** (5.07)	3.71** (1.37)	3.35 (2.22)
Dens. Non-Paved	-0.87 (0.92)	1.37 (1.94)	-0.44 (1.19)	1.36 (2.30)
Dens. River	-2.00 (2.43)	1.35 (10.3)	-2.56 (2.92)	-3.12 (4.60)
R^2 adj.	0.34	0.34	0.29	0.54
RMSE	0.55	0.46	0.58	0.33
N.Obs.	304	66	190	46

Standard errors are in parentheses. RMSE = Root Mean Square Error. N.Obs. = sample size. Logarithms were taken in the cases of productivity, labor/land ratio, average herd size and average farm size; integration to markets, land concentration and squatters are percent shares; distances are in thousand km; and roads and rivers are geographical density (divided by geographical area of municipality).

Source: Authors' estimates.

- land concentration, measured by the percent share of large establishments (greater than 500 ha) in the total number of establishments in the municipality;

- the percent share of squatters in the total number of establishments, as a proxy for institutional conditions related to property rights in land;

- distance to State and Federal capital, expressed in thousand km, as proxies of access to local and national markets, respectively;

- vegetation cover summarized by the percent coverage of forests (including categories of dense, open and ecological transition) in the municipality;

- finally, transport conditions are represented by the proxies of geographical density of paved and non-paved roads, as well as by the geographical density of rivers (having class "A" navigability) .

All the variables refer to municipalities of the Legal Amazon, in 1985, and logarithms were taken in the case of productivity, land/labor ratio, average size of herds and average size of establishments.

Naturally, the model is not able to explain a large portion of the variance in cropland productivity, much of which has to do with soil and climatic conditions at an establishment level not measured by these variables. However, the effects of some variables are statistically significant. For the Amazon region as a whole, the labor/land ratio is the most important determinant of productivity. An increase of one percent in the labor/land ratio increases land productivity by 0.3 percent. However, there are significant differences in the value of this parameter between forested and non-forested areas.

Other important determinants of land productivity are the distance to the federal capital, the density of paved roads, and the share of squatters in the municipality. On the other hand, factors like the average size of herds, the average size of establishments, land concentration, and the share of crops marketed seem to have no clear effect on productivity.

The more distant from the federal capital the municipality is located, the higher productivity tends to be. Each additional thousand kilometers increases productivity by 0.2 percent. The reasons behind this geographic effect are not immediately obvious. Differences in the type or fertility of soil in more distant and recent settled areas is suggested as a possible explanation. On the other hand, it is interesting to note that distance from the state capital has the opposite effect, though estimates are not significant at reasonable levels of confidence. Probably, the latter distance is a proxy for the more profitable and/or productive crop mix of areas close to markets.

The higher the density of paved roads in the municipality, the higher are its productivity levels. Thus, each additional kilometer of paved road per square kilometer of geographical area leads to a 3.33 percent increase in producitivity. This is probably due to the fact that paved roads acts as a proxy for the more intensely urbanized areas, or for market integration. Note that the density of non-paved roads does not seem to have a significant effect on agricultural productivity, perhaps due to the fact that such roads are largely impassable in the harvest season.

Finally, the share of squatters in total rural establishments in the municipality has a strong negative effect on productivity. One additional percentage point of squatters leads to a decrease of 0.43 percent in productivity. A plausible hypothesis could be the incentives for the adoption of more extensive agricultural methods as a mechanism of granting property rights in larger tracts of land. Squatters also face institutional barriers to credit and tend to be located in areas least accessible to markets.

Results for forested and non-forested areas show important differences in the size and statistical significance of the effects of different factors. Firstly, the value of constants show that, independent of all other factors, productivity tends to be higher in non-forest areas, though the differences are not strongly significant. Secondly, the elasticity of output in relation to labor tends to be lower in these areas. In non-forest areas, moreover, the average size of herds (closely followed by average farm size) is the most important factor in the explanation of the variance of crop productivity (highest standardized estimates). We hypothesize that the importance of scale to agricultural productivity may be due to interactions that affect farmers' ability to use modern inputs. On the other hand, in non-forest areas, squatters and the degree of market integration are not significant factors for the explanation of productivity, in contrast to the forest areas. Finally, variables related to distance and transport condition show stronger effects in non-forest areas.

The differences above are probably related to soil conditions and, as a consequence, to the greater specialization of non-forest areas in cattle raising activities, as well as in less labor intensive agricultural crops. The technological characteristics of these activities tend to increase farm area with no increase on land productivity in agriculture; they also tend to reduce the linkage of farming activities to markets, thus decreasing the importance of the latter as a determinant of productivity. Furthermore, cattle raising tends to show a stronger complementarity to cropping activities and, finally, the less labor intensive techniques tend to reduce the elasticity of output to employment.

VI. Wood Removal

The average volume of timber per unit area in non-forest and forested municipalities has been estimated in cubic meter wood equivalent based on broad categories of vegetation from the specialized literature as shown in Table 16, below. For analytical purposes, we have taken estimates from the range of figures presented from forest inventories reported in the literature, and applied them to these broad vegetation types in the Legal Amazon to estimate total original standing wood volume, and total volume removed due to land use conversion from 1980-1985.

Table 16 - Estimated Timber Volume in Natural Forests, Legal Amazon

Inventory Source	Forest	Non-Forest
Radambrasil (IBGE, var.)[a]	107.6 m^3/ha	72.4 m^3/ha
FAO (1985)[b]	114.0 m^3/ha	63.0 m^3/ha
Brown et al. (1991)[c]	156.9 m^3/ha	n.a.
Estimated Average	133.9 m^3/ha	67.7 m^3/ha

[a]Data refer to total mean volume per ha of standing wood in commercial categories. Forested municipalities refer to the following map sheets: Belém, Araguaia/Tocantins, Macapá, Tapajós, Santarém, Tumucumaque, Rio Branco, Içа, Juruá, Porto Velho, Purus, Manaus, non-forested to: Boa Vista/Roraima, Pico da Neblina, Javari/Contamana, Guaporé, Juruema. - [b]Data refer to Radambrasil estimates for the North region, with forested municipalities represented by Broadleaved Forest (category NHCf) , with DBH>30 cm, and non-forested by productive woodlands of *Cerrado* formation (category NHO), with DBH>10 cm. - [c]Data refer to average volumes from a range of inventories carried out in the Latin American tropical forest area.

To derive an estimate of approximate wastage, Table 17 compares the average annual output volume of roundwood, charcoal and fuelwood production for 1980-1985 in wood equivalent volume with estimates of the areas cleared annually in each Amazon state.[16] According to previous studies, it has been estimated that the volume actually commercialized (VAC) as being about 25 m^3 per ha in the North region, or about 20 percent, considering extraction of 30 to 35 merchantable species. This is consistent with the average commercial utilization rate of 18.8 percent of deforested timber derived from the above analysis. However, the areas actually exploited tend to be limited to only five or six species, contributing between 5 and 10 m^3 per ha. This would tend to result in far lower estimates for wood utilization than those derived in Table 17. One explanation is the lack of consideration of fuelwood and charcoal in these market

16 Annual deforestation rates were derived using the formulation proposed in Serôa da Motta and May (1992), which calculates deforestation in inter-censal years due to agropastoral expansion as $[(A_{t+1} - F_{t+1}) - (A_t - F_t)]$, where A_t = area in agricultural establishments, and F_t = native forest area within such establishments.

figures, although these uses in some states are even more substantial than roundwood extraction.

Table 17 - Wood Removed due to Agropastoral Expansion and Commercial Timber Output in North Region and Mato Grosso, 1980-1985 average

	1980 - 1985 Average			Timber Equiv. (000m^3)	Timber Removed (000 m^3)	Utilization Rate
	Roundwood (1000 m^3)	Fuelwood (1000 m^3)	Charcoal (t)			
Acre	171.0	1,250.4	2,342	864.9	1,807.4	47.9 %
Amapá	594.2	312.6	710	756.1	8,214.5	9.2 %
Amazonas	739.2	3,346.1	5,646	2,457.4	n.a.	n.a.
Pará	13,087.7	4,454.9	25,335	15,517.9	67,104.9	23.1 %
Rondônia	787.6	118.8	3,096	871.8	14,693.4	5.9 %
Roraima	40.6	64.0	35	72.9	n.a.	n.a.
Mato Grosso	750.7	3,310.0	706	2,411.3	30,333.2	7.9 %
Total	16,171.0	12,956.8	37,869	22,952.3	122,153.4	18.8 %

It is estimated that 1 metric ton charcoal = 8.0 m^3 timber equivalent. Fuelwood, measured in steres (1 m^3 stacked wood), is adjusted as 1 m^3 fuelwood = 0.5 m^3 timber equivalent. n.a. = agricultural establishment land use shows increase in forested areas, inconsistent with timber extraction statistics.

Source: Authors' estimates, based on data in Tables 1 and 16, IBGE, 1980 and 1985 Agricultural Census: annual change in native forest in agricultural establishments; 1980-1985 Statistical Yearbooks: timber extraction volumes.

VII. Conclusions

This study has provided preliminary sub-regional estimates of land use change due to agropastoral expansion in the Legal Amazon region, and of the relationship between these changes and both agricultural productivity and timber removal. To the extent feasible, the research has further disaggregated this analysis to characterize the form of occupation of areas originally forested and of non-forested areas, defined acccording to Brazilian vegetation formations predominant in the Legal Amazon, on a municipal level. Although this unique data source provides a more comprehensive picture of the sources of land use change, it is impossible to correlate vegetation characteristics with types of establishments and specific land uses on the basis of municipal census data. To further refine these estimates would require a survey of individual properties and their precise land use structure in relation to original vegetation cover characteristics.

For the Legal Amazon region as a whole, we have found that agricultural occupation rates are significantly higher in the non-forested areas, a tendency which is reinforced by the difficulties of settlement in the dense tropical forest. Nevertheless, crop productivities are higher in the forest municipalities, at least during the period of initial settlement. This attraction is offset by the labor requirements of land clearing and the far more difficult access to markets. This can explain the conversion of croplands to pastures and secondary forests after initial occupation. Planted pastures in the non-forest areas appear more productive than in forest lands, but this is primarily due to the extensive use of native pastures, more prevalent in these areas.

Wood removal rates associated with agropastoral expansion are on the whole quite inefficient, averaging only about 19 percent of estimated timber volume removed by land clearing, even when fuelwood and charcoal production is included in the estimate. Of total timber marketed in the region, the share of roundwood in total wood volume is about 70 percent. However, this proportion is far greater in forested than non-forest areas. In the latter, a considerable share of timber extracted for commercial purposes is destined for fuel. With the growth of the steel industry in the eastern Amazon, the tendency for diversion of timber to fuel will increase, particularly given the improbability of investments in reforestation for charcoal production.

References

Amelung, T. and M. Diehl (1992), Deforestation of Tropical Rain Forests - Economic Causes and Impact on Development. Kieler Studien, 241. Tübingen: J.C.B. Mohr.

Brown, S., A. Gillespie and A.E. Lugo (1991), Biomass Estimation Methods for Tropical Forests with Applications to Forest Inventory Data. Forest Science 35(4):881-889.

Centro de Estudos Avançados (1991), Projeto Floram. Universidade de São Paulo, São Paulo.

Eiten G. and R. Goodland (1979), Ecology and Management of Semi-Arid Ecosystems in Brazil. In: Walker, B.H., (ed.), Management of Semi-Arid Ecosystems. Amsterdam: Elsevier.

FAO (1985), Forest Resources of Brazil. Food and Agriculture Organization of the United Nations, Rome.

Fearnside, P. (1989), Extractive Reserves in Brazilian Amazonia. BioScience 39(6):387-393.

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. (1991), Sacred Cow in Green Hell. The Ecologist, March.

Hecht, S.B., Norgaard, R. and G. Possio (1988), The Economics of Cattle Ranching in Eastern Amazon. Interciencia 13(5):233-240.

IBGE (a, various years), Anuário Estatístico. Brazilian Institute for Geography and Statistics, Rio de Janeiro.

IBGE (b, various years), Censo Agropecuário, 1975, 1980, 1985. Brazilian Institute for Geography and Statistics, Rio de Janeiro.

IBGE (c, 1974-82) Radambrasil. Brazilian Institute for Geography and Statistics, Rio de Janeiro.

INPE (1992), Deforestation in Brazilian Amazonia. National Institute for Space Research. São José dos Campos, São Paulo.

Mahar, D. (1989), Government Policies and Deforestation in the Brazilian Amazon. The World Bank, Washington, D.C.

Rankin, J. (1985), Forestry in the Brazilian Amazon. In: G.T. Prance and T.E. Lovejoy (eds), Amazonia. Oxford: Pergamon.

Serôa da Motta, R. (1993), Policy Issues Concerning Tropical Deforestation in Brazil. Kiel Working Paper No. 566. Kiel Institute of World Economics, Kiel.

Serôa da Motta, R. and P. H. May (1992), Loss in Forest Resource Value Due to Agricultural Land Conversion in Brazil. Texto para Discussão, n. 248, IPEA, Rio de Janeiro.

Uhl, C., D. Nepstad, R. Buschbacher, K. Clark, B. Kauffman and S. Subler (1990), Studies of Ecosystem Response to Natural and Anthropogenic Disturbances Provide Guidelines for Designing Sustainable Land-Use Systems in Amazonia. In: Anderson, A. Alternatives to Deforestation in the Amazon. New York: Columbia University Press.

Veloso, H.P., A.L. Rangel F. and A.C. Alves Lima (1991), Classificação da Vegetação Brasileira, Adaptada a um Sistema Universal. Brazilian Institute for Geography and Statistics, Rio de Janeiro.