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Logging impacts and prospects for sustainable forest management in an old Amazonian frontier: the case of Paragominas

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ABSTRACT

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The Brazilian wood industry is highly mobile. Over the past 20 years the eastern Amazon developed from a logging backwater to the principal hardwood processing center in Brazil. This occurred because of a decline in hardwood stocks in the south of Brazil coupled with the development of good transport, energy, and communications systems in eastern Amazonia.

We studied the structure and economy of the wood industry along a 340 km stretch of the Bélem–Brasília Highway in eastern Amazonia. Of the 238 sawmills present in this study region in late 1989, 79% were installed in the 1980s. Ninety-seven percent of the mill owners came from outside Amazonia. Most (63%) of the mill establishments were vertically integrated, engaging in both forest mill processing and forest logging.

Logging establishments realize substantial profits. A typical sawmill with one band saw produces, on average, 4300 m^3 of sawnwood $year^{-1}$ from 9200 m^3 of roundwood. The value of this sawn production is estimated at $670 800 or $156 m^{-3}. Production costs are $116 m^{-3} giving an annual mill profit of $170 000. For firms engaged in both logging and processing activities, annual profits were estimated at $217 000 (profit margin, 32%) or $900 ha^{-1} logged.

An average of six trees were harvested per hectare in logging operations ($n=3$ study areas) and the volume yield averaged 38 m^3 ha^{-1}. Damages to the forest during logging are significant. Twenty-seven trees greater than or equal to 10 cm dbh are severely damaged for each tree harvested. This damage occurs in the opening of approximately 40 m of logging road and 600 m^2 of canopy per tree harvested. Vines are favored by these open conditions and forest fires are possible.

Forest management is technically feasible but economically unattractive. Natural regeneration is abundant on logged sites: 4300 seedlings and saplings of economic species were registered per hectare. Stocking of larger trees of economic species with good form is also adequate: 16 trees ha^{-1} greater

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than or equal to 30 cm dbh. This residual stock could be favored by vine cutting and refinement thinnings at an estimated cost of \$180 ha^{-1}. Although these treatments result in increased growth rates, the projected return on management investments is low. Nonetheless, given the robust profits in the wood sector, profit margins would remain well above 20% if management were mandated by law.

At present the biggest impediment to forest management in the eastern Amazon is the undervaluing of the timber resource. Ranchers, who own most forest land, sell harvest rights to loggers at low prices — \$50–\$150 ha^{-1}. After the logging teams extract the timber, these same ranchers are left with badly damaged forest tracts. With careful extraction and management procedures, harvests could be accomplished on a 30- to 40-year rotation and forest integrity could be maintained. Ranchers, insofar as they control the forest resource, have the power to guarantee its wise use. They could do this by supervising harvest operations on their lands to reduce damage and by raising the price of their timber and using this additional revenue to finance simple silvicultural operations.

INTRODUCTION

For more than three centuries logging was restricted to the floodplain forest bordering Amazonia's major rivers (Rankin, 1985). But the construction of strategic access roads into Amazonia coupled with the depletion of hardwood stocks in the south of Brazil have transformed Amazon logging from a minor activity to a major growth industry. For example, in the 12 year period, 1976–1988, the total roundwood production in the south of Brazil decreased from 15 million m^3 year^{-1} to 7.9 million m^3 year^{-1} (FIBGE, 1988). During this same period, roundwood production in the north (Amazonia) increased from 6.7 to 24.6 million m^3 year^{-1} (54% of Brazil's total). Meanwhile, the anticipated exhaustion of tropical hardwood stocks in Asia, which currently supply the bulk of the international lumber market (Nectoux and Kuroda, 1989; Bee, 1990), could catalyze the opening of new markets for Amazonian wood. Brazil, which possesses almost one-third of the world's rainforest area, is well positioned to dominate the tropical timber trade in the twenty-first century.

Eighty-seven percent of all roundwood production in the Brazilian Amazon occurs in the eastern Amazonian state of Pará (Fig. 1). Pará is a natural place for a burst of logging activity because it is adjacent to Brazil's wood-hungry northeast with its burgeoning population and paucity of wood resources.

The expansion of the sawmill industry in the eastern Amazon has provoked a profound change in the way that the forest is viewed. In the 1960s and 1970s forested land in this region was held in low esteem, frequently selling for a few dollars per hectare. Speculators and colonists hacked down the forest as quickly as possible in a race to lay clear claim to large land parcels (Hecht et al., 1988). With the rapid expansion of the logging industry in Amazonia, the forest is now accorded a market value. Nowhere in Amazonia is this sense of value more evident than in the Paragominas region where hundreds of sawmills whir day and night processing the region's bounty.

In this paper we will first characterize the structure and economics of the

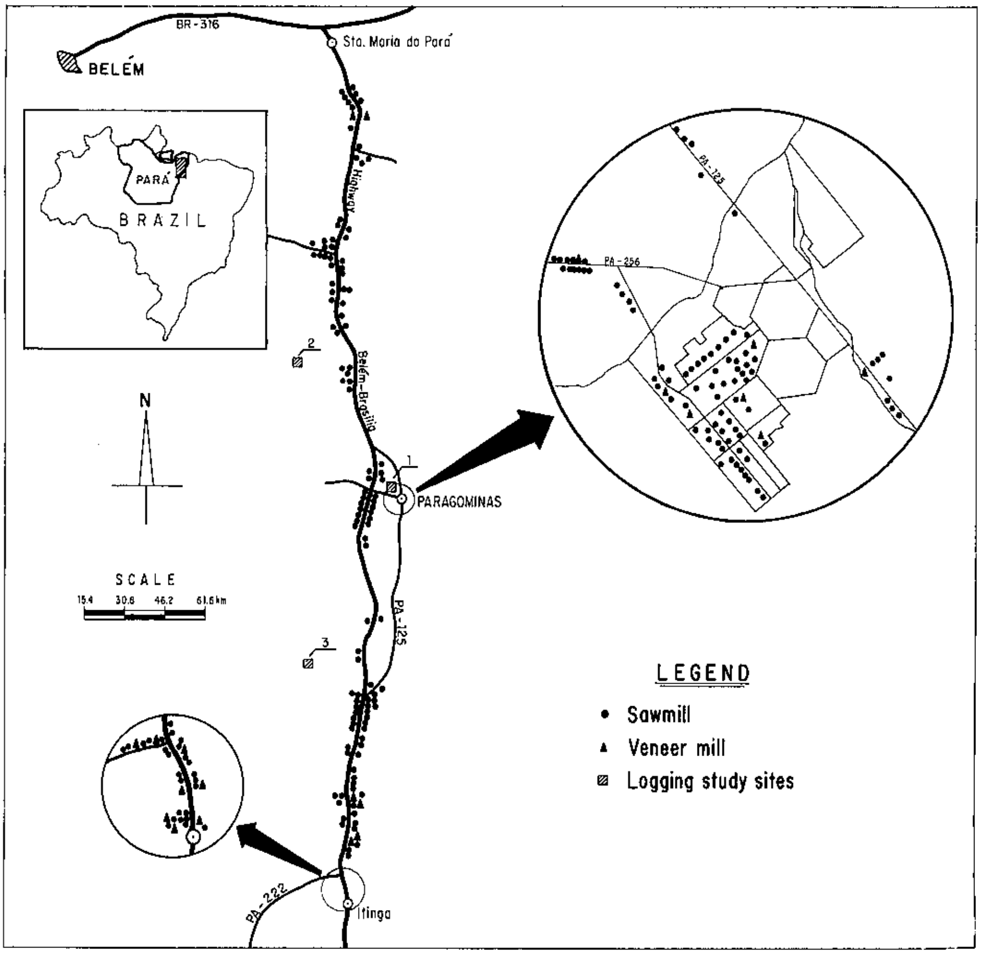

Fig. 1. The study region, extending from Santa Maria de Pará to Itinga, Pará, showing the location of sawmills and the three logging study sites.

wood industry in the Paragominas region of eastern Amazonia. We will then consider the impacts of the wood industry on humans and on the forest. Finally, we will combine our economic, biological and social information to evaluate the impediments to and prospects for sustainable forest management for timber production in eastern Amazonia.

THE STUDY REGION

In eastern Amazonia, the spatial distribution of the logging industry is determined in large part by the location of major highways. We studied a 340 km stretch of the Belém–Brasília Highway centered on the municipality of

Fig. 2. Landsat photo (1:250 000) showing pasture clearings, logged areas, and virgin forest bordering the Belém–Brasília Highway in the municipality of Paragominas, Pará.

Paragominas (3°S, 50°W) (Fig. 1). Wood industries are located in cities and towns along this highway with the highest concentration of mills in the city of Paragominas.

The vegetation of the Paragominas region is evergreen, lowland rainforest with a canopy height of 25–40 m and an aboveground biomass of approximately 300 t ha^{-1} (Uhl et al., 1988). The terrain is rolling and the soils are oxisols and ultisols. Rainfall is seasonal, totaling about 2000 mm $year^{-1}$. Forest logging is concentrated in the 7 month dry season extending from June to December. Because of the central role of Paragominas in the region's economy, we refer to our study area as the 'Paragominas region' throughout this paper.

When the Belém–Brasília Highway was laid down across this region in the early 1960s, the area was sparsely settled but by the end of that decade a giant land-use experiment was under way — forest was being replaced with cattle pastures. The initial results of this experiment were promising but by the late 1970s most pastures were in poor condition. To make matters worse, the attractive lines of credit that were available initially were withdrawn as Brazil's economic crisis deepened. As the ecological and economic prospects for ranching worsened, the logging industry began to expand.

At first, in the early 1970s, loggers harvested only a few high-value species and forest impacts were small. This type of highly selective, non-mechanized logging is typical of new Amazonian frontiers and was characterized by Uhl et al. (1991) for the region along Pará Highway 150, 200 km to the west of Paragominas. Loggers hand-cut narrow paths into the forest to the choice trees, following a path of least resistance. The boles are hand-winched onto lorries and transported to small processing mills. Now, 20 years later, more than 100 species of trees are harvested; bulldozers open up wide swaths through the forest and drag boles out to landings that serve as staging areas for the loading and transport of logs to mill. This more intensive logging significantly alters forest cover as can be verified in recent Landsat photos (Fig. 2). Logged areas leave a characteristic spray of white points (the landings) embedded in light grey hues (fragmented forest canopy) in contrast to the darker, more uniform grey signature of virgin, closed-canopy forest. In two decades the character of logging has changed dramatically: the wood industry is now a dominant economic force in the Paragominas region and logging is intensive and potentially destructive.

METHODOLOGY

Characteristics and economics of the wood industry

We mapped the locations of all sawmills in the study region defined by the 340 km stretch of the Bélem–Brasília Highway extending from Santa Maria do Pará in the north to Itinga in the south (Fig. 1). We also applied questionnaires at each mill to determine: (1) mill history (year of mill establishment, origin of the mill and owner, previous work of owner, etc.); (2) mill productivity (m^3 of wood processed $month^{-1}$, percent of total roundwood transformed into sawn products, secondary wood processing, etc.); (3) raw material supply (ownership of forest land, involvement in forest extraction, distance between mill and extraction areas); (4) types of sawn products produced (standard dimension boards, moulding, flooring, etc.); (5) mill investments (machinery, infrastructure, land, forest management, etc.).

We conducted more detailed interviews on the costs and profits of forest logging and wood-processing activities with five forest extraction crews and 33 mill owners in the city of Paragominas (21 mills with one band saw, six mills with two or more band saws and six veneer mills). Mill owners chosen for these more detailed interviews were those that demonstrated an openness to sharing economic information in the first, more general, questionnaire.

Impacts of wood industry on humans

We conducted interviews in the households of 112 sawmill workers in the main working class neighborhood in the city of Paragominas. The neighborhood was first mapped. Then, we selected households at random for study. Household heads were questioned concerning: (1) past history (age, schooling, origin, past work, number of migrations prior to arriving in Paragominas, reasons for migrations, etc.); (2) familial responsibilities (family size, family work force, family expenses); (3) work status (job classification in mill, salary, number of different mills worked in, union membership, etc.).

Impacts of wood industry on the forest

Extraction yields and logging damage

We studied logging yields, logging damages, and the vegetation characteristics of logged forests in three logging sites along the Bélem–Brasília Highway (Fig. 1). After a general reconnaissance of each site, we selected a representative area and mapped all logging roads. Along the logging roads, we identified all harvested trees and estimated their volume by multiplying the lengths of the boles by their average basal areas (acquired by measuring bark-free log diameter at the base and at the top of each log). Damage to non-harvested trees was assessed by randomly establishing 60 or more 10 m×30 m plots in each study site. All damaged trees greater than or equal to 10 cm dbh in these plots were identified, measured for diameter, and classified by damage type. Bark-free volume of all damaged trees was estimated using equations presented in Silva and Araujo (1984) and Silva et al. (1984).

Canopy opening attributable to logging was assessed in six to eight 300-m transects, spaced at regular intervals in both the logged and non-logged portions of each of the three study areas. Canopy cover was classified at 2-m intervals along each transect as present or absent by sighting along a small pointed stick.

Stocks of economic species remaining after logging

To assess the stock of timber-producing trees present in the study areas after logging, we identified and measured the diameter of all trees greater than or equal to 30 cm dbh in two 20 m×1000 m transects in each of the three study areas. Species encountered in these transects were classified into three wood-quality groupings: (1) species with present value (accepted by the region's sawmills); (2) species with future value (wood used for rough construction but generally not sawn at present); (3) species with wood having no known present construction use and little prospect for future use. The physical condition of all trees in the first two wood categories was evaluated considering bole form, bole length, bole defects, completeness of crown, and vine loading.

Characteristics of plant regeneration in forests after logging

We did a general assessment of seedling and sapling stocking by placing ten 5 m×5 m plots at 200-m intervals along the two 1000-m transects in each study area (see above). We identified and determined the height of all individuals greater than or equal to 10 cm tall in these plots. We also characterized regeneration in the forest zones most directly affected by logging — logging roads and canopy openings — and compared this with forest patches not directly affected by logging. This more detailed assessment was done in a portion of Area 1 that had been logged 2 years previously. Five plots, 6 m×15 m each, were established at 100-m intervals along each of two logging roads. Additional plots, also 6 m×15 m, were placed in the logging openings and closed forest patches adjacent to these road plots. In these plots, we identified and measured the height of all timber species greater than or equal to 1 m tall. In smaller plots (1 m×15 m), nested within each 6 m×15 m plot, we tallied all plants greater than or equal to 1 m tall, including shrubs and vines.

RESULTS AND DISCUSSION

Structure and economics of the wood industry

Characteristics of the wood industry

Of the 238 sawmills present in the study region in late 1989, 79% were installed in the 1980s with the remainder having been constructed in the 1970s (Fig. 3a). Only 11 mills had ceased to function and new mills were still being constructed in the early 1990s.

The majority (75%) of the mills were not transferred from other regions

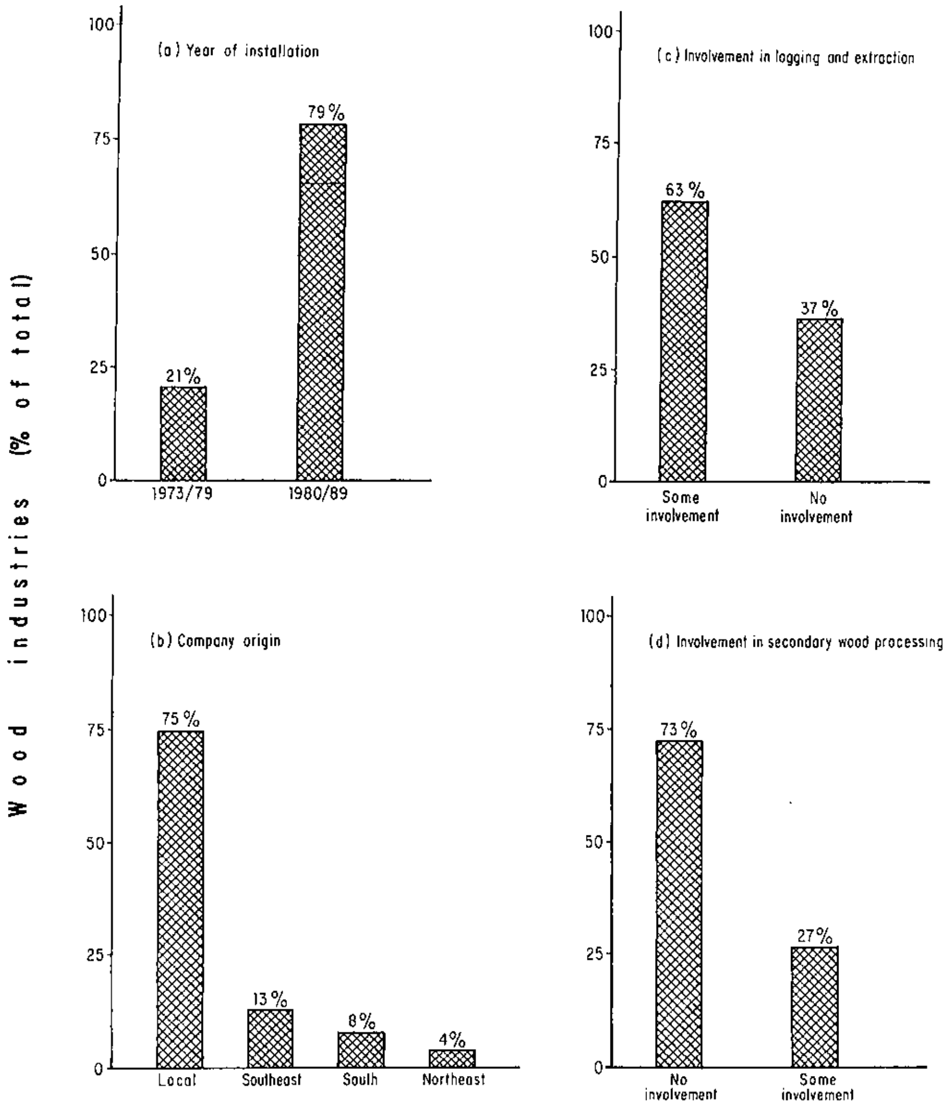

Fig. 3. Characteristics of the sawmill industry in the Paragominas region of Pará considering: (a) year of installation, (b) origin of the mills, (c) involvement in forest extraction, and (d) involvement in secondary wood processing.

but, rather, were new businesses begun along the Belém–Brasília Highway (Fig. 3b). Of the firms that were transferred, most were veneer mills with their main offices in the south and southeast of Brazil.

Only 3% of the sawmill owners were from Pará State; half were from the southeastern state of Espirito Santo (a major logging center in the 1960s and 1970s), and the remainder were from the south and northeast of Brazil. Most mill owners had previous experience in the wood sector — 40% had owned a sawmill previously and another 40% had been involved in logging or wood-processing activities.

Most (63%) of the region's sawmills are vertically integrated in so far as they extract timber from the forest as well as saw logs in their mills (Fig. 3c). The distance between forest logging sites and the mills ranged from 20 to 150 km in 1990 with the mean distance standing at 80 km (SD=39). Most mills (61%) were processing wood extracted exclusively from forest tracts owned by ranchers, whereas 15% of the mills processed wood just from their own holdings. The remaining 24% of the mills were processing wood coming both from their private holdings and ranchers' lands. Although some ranchers engaged in logging, most ranchers sold logging rights to sawmills and independent loggers. The average price for logging rights in 1990 was \$70 ha^{-1} (SD=28) for forest tracts about 80 km from Paragominas.

The majority (73%) of mills produce standard dimension boards, using the sawing scraps to make moulding. Secondary processing (e.g. to make doors, windows, flooring) was practiced in 27% of the mills (Fig. 3d). In these mills, generally less than half of the sawn volume undergoes secondary processing. Approximately 90% of the sawn wood produced in the Paragominas region is sold within Brazil, the majority going to the northeast and south.

Economics of the wood industry

Logging and transport activities in the Paragominas region are lucrative. These activities are concentrated in the period June–December. Bulldozers are used to open up a coarse network of roads and loading zones (Fig. 4). Then, woodsmen with chainsaws cut down the trees of economic interest and bulldozers drag the boles to the loading zones where they are sectioned into 6–8 m lengths and mechanically loaded onto flatbed lorries.

Timber extraction yield. The average number of trees harvested per hectare in the three study sites ranged from 2.9 (Site 1) to 9.3 (Site 3) (mean of three sites, 6.4), and volume yields ranged from 18 to 62 m^3 ha^{-1} (mean 38; SD=18) (Table 1). Within individual sites, the number of trees and volume harvested per hectare were also extremely variable. For example, in Area 2 (Fig. 4) some hectares had no harvestable trees while others had as many as 20. While extraction yields vary greatly, logging crews that we interviewed concurred that typical extraction yields for the region generally range from 20 to 50 m^3 ha^{-1}.

Harvested trees were large: the average stump diameter ranged from 73 to 75 cm ($n=3$ study sites); average bole length was between 16 and 20 m; average volume per tree ranged from 5.2 m^3 to 6.4 m^3 (Table 1).

The number of species extracted per study site ranged from 43 to 57, and the total number of species extracted, considering all three sites together, was

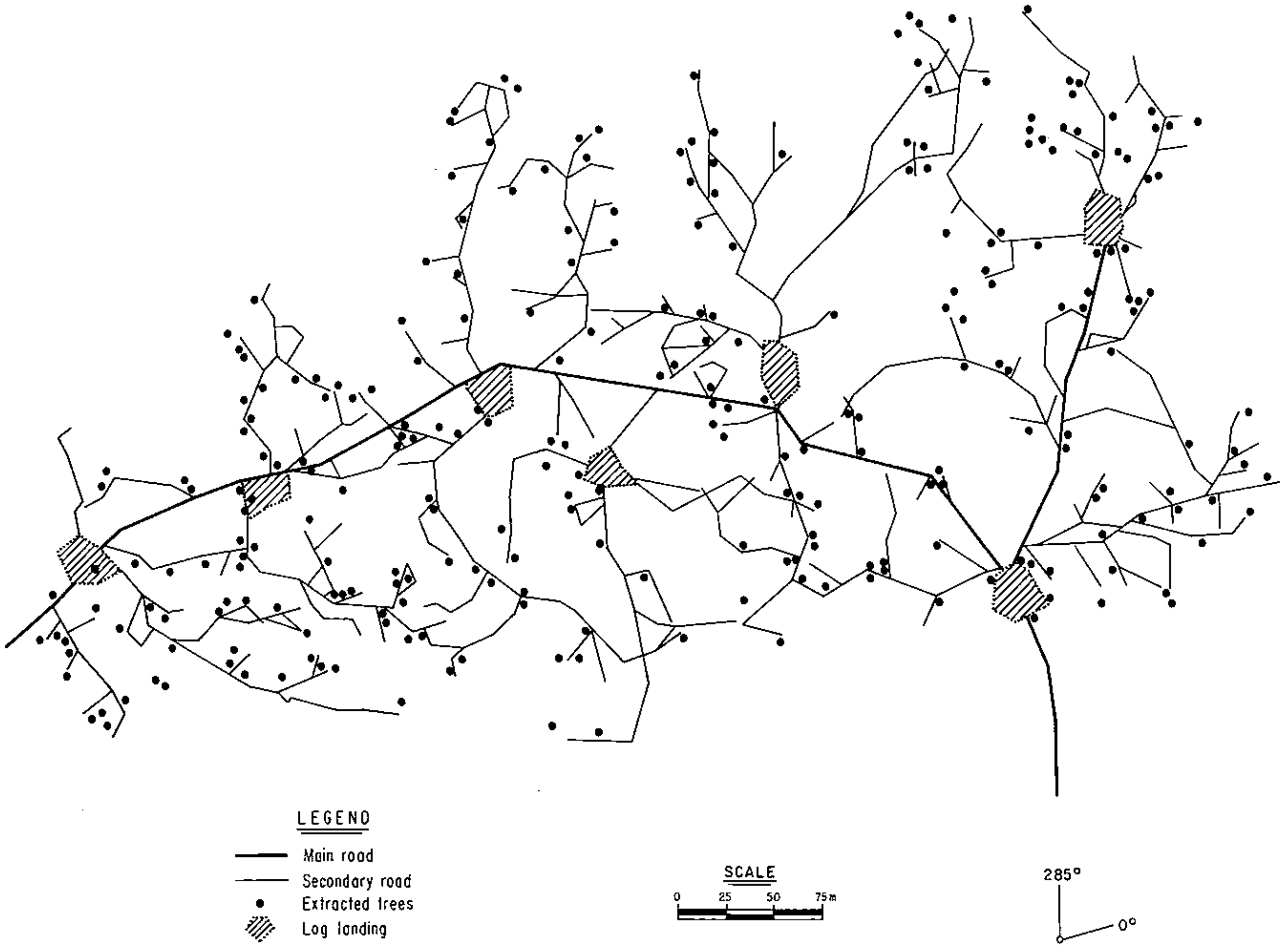

Fig. 4. A scale map of the Area 2 logging site showing locations of logging roads, log loading zones, and extracted trees.

TABLE 1

Characteristics of timber harvest in three logging operations in the Paragominas region of eastern Amazonia

	Area 1	Area 2	Area 3	Average
General characteristics				
Size of study area (ha)	115	37	16	56
No. of trees harvested ha^{-1}	3	7	9	6.4
Volume[1] (m^3) harvested ha^{-1}	18	35	62	38
No. of species harvested	57	55	43	52
Size of harvested trees				
$\bar{X}$ diameter (cm dbh) of harvested trees (SD)	75 (20)	73 (18)	73 (20)	74
$\bar{X}$ bole length (m) (SD)	18.4 (5.0)	16.5 (3.9)	20.5 (4.3)	18
Volume (m^3) per harvested tree (SD)	6.1 (3.9)	5.2 (3.5)	6.4 (4.7)	5.9
Largest tree harvested (cm dbh)	161	170	150	160
Smallest tree harvested (cm dbh)	40	39	40	40

[1] The volume is the 'real volume' and not the 'Francon volume' used by loggers in the Paragominas region. The Francon volumes are 14 m^3, 27 m^3 and 48 m^3, respectively, for Areas 1, 2, 3.

84 (Table 2). Of these 84 species, 23 occurred in all three sites, 20 occurred in two sites, and 41 occurred in just one site. The 23 species occurring in all three sites comprised 524 individuals or 71% of the total trees harvested.

The most extracted species in each of the three study areas was *Manilkara huberi* ('maçaranduba'), with a harvested density of 0.6 individuals ha^{-1} in Area 1, 1.5 ha^{-1} in Area 2, and 3.5 ha^{-1} in Area 3 (Table 2). Considering all three sites together, 28% of all harvested trees were 'maçaranduba'. The next most harvested species was *Hymenaea courbaril* or 'jatoba', representing 5.2% of all harvested individuals, followed by *Caryocar villosum* or 'piquia' (3.3%) and *Copaifera duckei* or 'copaiba' (2.8%). Together, these four species accounted for 35% of the volume harvested in the three study areas.

Cost and profits in logging and wood processing activities. A typical logging unit consists of 13 men equipped with two chainsaws, one bulldozer, one log loader, and three lorries. The average production of such a unit during one logging season (7 months) was estimated to be 9200 m^3 ($SD=2130$; $n=16$) or 1314 m^3 $month^{-1}$ (Table 3). The total value of this production was approximately $253 000. The costs of logging were estimated at $114 190 and include the purchase of logging rights (15%), salaries and benefits (20%), food (5%), fuel (9%), taxes (12%), equipment maintenance (17%), and depreciation (22%) (Table 3). The cost to transport logs from the forest to the mill was estimated at $75 761 and includes salaries (15%), fuel (24%), maintenance (20%), and depreciation (41%) (Table 3). Summing logging and transport costs (Table 3) reveals that: (1) approximately $22 are spent

TABLE 2

The identified species extracted in three logging operations in the Paragominas region of eastern Amazonia[1]

Species	Area 1		Area 2		Area 3	
	No. ha^{-1}	Vol ha^{-1}	No. ha^{-1}	Vol ha^{-1}	No. ha^{-1}	Vol ha^{-1}
Anacardium giganteum Hanc. ex Engl.	0.01	0.04	0.16	1.03	0.06	0.45
Apeiba burchelii Sprague	–	–	0.05	0.15	0.13	0.33
Licania kunthiana (Hook) F.	–	–	0.32	1.86	–	–
Apuleia molaris Spruce	–	–	0.03	0.13	–	–
Astronium lecointei Ducke	0.13	1.02	0.05	0.24	0.25	1.80
Bagassa guianensis Aubl	0.07	0.44	0.05	0.31	0.13	0.41
Bowdichia nitida Spruce ex Benth	0.02	0.08	0.16	0.47	0.06	0.89
Brosinum acutifolium Huber	0.03	0.20	0.03	0.13	–	–
Caraipa grandiflora Mart.	0.01	0.02	0.03	0.08	–	–
Caryocar villosum (Aubl) Pers.	0.10	0.91	0.24	1.87	0.31	3.36
Caryocar glabrum (Aubl) Pers.	0.01	0.06	0.03	0.11	–	–
Chimarhis turbinata DC.	–	–	–	–	0.06	0.29
Copaifera duckei Dwyer	0.12	0.66	0.19	0.64	0.25	1.59
Cordia bicolor A. DC.	0.10	0.32	–	–	–	–
Cordia goeldiana Huber	0.01	0.06	–	–	0.06	0.34
Couratari oblongifolia Ducke ex Kunth	–	–	0.08	0.57	0.06	0.57
Didymopanax morototoni (Aubl) Dc et Pl	0.01	0.03	0.03	0.09	0.06	0.28
Dinizia excelsa Ducke	–	–	0.03	1.03	0.13	1.79
Diplotropis purpurea (Rich) Amsh	–	–	0.03	0.09	–	–
Dipterix odorata (Aubl) Willd.	0.07	0.48	0.27	1.41	0.06	0.20
Euxylophora paraensis Hub.	–	–	0.05	0.17	0.76	4.23
Franchetella anibifolia Radlk	–	–	0.05	0.26	–	–
Goupia glabra Aubl	–	–	–	–	0.06	0.97
Guarea kunthiana A. Juss	0.02	0.03	–	–	–	–
Hymenaea courbaril L.	0.44	3.25	0.26	1.45	0.32	4.78
Hymenaea parvifolia Huber	–	–	0.05	0.16	–	–
Hymenolobium excelsum Ducke	0.02	0.15	0.03	0.09	–	–
Hymenolobium nitidum Benth	0.01	0.07	0.54	0.25	–	–
Hymenolobium petraeum Ducke	0.01	0.14	0.08	0.61	0.32	3.85
Hymenolobium sericeum Ducke	–	–	0.38	2.01	0.06	0.24
Inga heterophylla Willd.	0.01	0.02	–	–	–	–
Laetia procera (P et E) Eichl	0.03	0.09	0.05	0.17	0.06	0.20
Lecythis lurida (Mierse) Mori	0.01	0.03	0.43	1.89	0.50	2.89
Lecythis pisonis Huber	0.02	0.06	–	–	0.06	0.17
Manilkara huberi Standl	0.55	2.96	1.48	7.20	3.53	21.71
Micropholis sp.	–	–	0.11	0.54	–	–
Nectandra cuspidata Nees	0.01	0.02	–	–	–	–
Ocotea sp.	–	–	–	–	0.06	0.12
Parkia multijuga Benth	0.14	1.08	0.11	0.44	0.13	0.80
Parkia sp.	0.02	0.19	0.08	0.62	–	–
Peltogyne venosa (Spruce ex Benth) M.F. Silva	0.02	0.12	0.03	0.19	0.06	0.27
Piptadenia comunis Bth.	0.07	0.26	0.16	0.83	0.06	0.96
Piptadenia psilostachya	0.03	0.17	0.19	0.86	0.13	0.83
Pithecellobium pedicellare (DC) Bth.	0.03	0.16	–	–	–	–

Species	Area 1		Area 2		Area 3	
	No ha^{-1}	Vol ha^{-1}	No ha^{-1}	Vol ha^{-1}	No ha^{-1}	Vol ha^{-1}
Planchonella pachycarpa Pires	–	–	0.03	0.11	–	–
Platymiscium ulei Harms	0.03	0.14	–	–	0.19	0.90
Pourouma guianensis Aubl	–	–	–	–	0.06	0.19
Pouteria guianensis Aubl	–	–	0.22	0.95	–	–
Protium paraense Cuart	0.02	0.08	0.11	0.54	0.06	0.34
Qualea paraensis Ducke	0.05	0.40	0.05	0.45	0.06	0.56
Richardella macrocarpa (Hub) Aubr	–	–	–	–	0.38	1.70
Sclerolobium paraense Huber	0.02	0.05	0.16	0.82	0.19	0.67
Simaruba amara Aubl	0.01	0.04	0.08	0.31	–	–
Sterculia pruriens (Aubl) Schum	0.05	0.15	–	–	0.06	0.32
Symphonia globulifera L.F.	–	–	0.03	0.16	–	–
Tabebuia insignis (Miq) Sandw	0.11	1.21	0.05	0.40	–	–
Tabebuia serratifolia (Vahl) Nicholes	0.07	0.45	–	–	–	–
Tachigalia myrmecophyla (Ducke) Ducke	0.07	0.22	0.16	0.74	0.06	0.15
Taralea oppositifolia Aubl	–	–	0.11	0.44	–	–
Terminalia guianensis Eichl	0.08	0.44	0.08	0.44	0.06	0.86
Tetragastris altissima (Aubl) Swart	0.04	0.08	–	–	–	–
Trattinichia rhoifolia Willd.	0.01	0.03	–	–	–	–
Vataireopsis iglesiasii Ducke	–	–	0.03	0.25	–	–
Unidentified species	0.29	1.71	0.36	1.62	0.44	1.89
Total	3.0	18.1	7.3	35.2	9.3	61.9

[1] An estimated 20 additional species were extracted but these were only identified by common name.

for each cubic meter harvested ($206 247/9200 m^3 equals $22.42 m^{-3}); (2) the net profit from harvest and transport is approximately $47 000 during the 7 month logging season.

Wood processing in the mills is also lucrative. A sawmill with one band saw produces, on average, 4300 m^3 of sawnwood $year^{-1}$ (SD=858). Processing efficiency is 47% (2.13 m^3 of roundwood produce 1 m^3 of sawnwood). The value of production for such a mill is estimated at $670 800 or $156 m^{-3} of sawnwood produced (Table 4). The cost to produce this wood is approximately $500 800, with the principal expenses being raw material purchase (51%), salaries and benefits (19%), and taxes (20%) (Table 4). Production costs per m^3 of sawnwood are approximately $116 ($500 806/4300 m^3). Subtracting the value of the processed wood ($670 800) from the total cost of production ($500 806) reveals an annual sawmill profit of approximately $170 000.

In cases where the sawmill establishment engages in forest logging as well as sawing (true for 63% of the firms in the Paragominas region), profits are estimated at $217 000 $year^{-1}$ (the sum of logging profits, $46 754, and sawing profits, $169 994) and the profit margin would be 32% ($217 000/ $670 800). The forest area required to generate this annual profit is 242 ha,

TABLE 3

Estimates of logging and transport costs during one logging season in the harvest of 9200 m^3 of roundwood in the Paragominas region of eastern Amazonia[1]

Category	Cost (US$)
Costs of logging:	
Logging rights[2]	$16940
Salaries[3]	$14840
Worker benefits[4]	$8607
Food[5]	$6000
Fuel[6]	$10262
Forest tax[7]	$14168
Equipment maintenance[8]	$19000
Depreciation[9]	$24373
Total logging costs	$114190
Costs of transport:	
Salaries[10]	$7140
Worker benefits[11]	$4140
Fuel[12]	$18280
Maintenance[13]	$15000
Depreciation[14]	$31200
Total transport costs	$75761
Capital investment costs[15]	$16296
Costs of logging and transport	$206246
Value of production[16]	$253000
Net profit	$46754

[1] All Cruzeiro values were converted to US dollars using the official exchange rate. Cost estimates in this table are based on interviews conducted in 1989 at 11 wood establishments engaging in logging and with five independent logging teams. Production 9200 m^3 (SD=2130) is expressed in real volume. The logging season has a duration of 7 months (210 days) but because of rest time, rains, and mechanical failures, the actual number of work days is approximately 140.

[2] Forest logging rights sold for $70 ha^{-1} (SD=28) in 1990. Given an average extraction intensity of 38 m^3 (Table 1) and an average annual mill consumption of 9200 m^3 for a typical mill with one band saw, approximately 242 ha of forest must be harvested year^{-1} (9200 m^3/38 m^3=242) to supply mill needs at a cost of $16 940.

[3] Salaries are for ten people during 7 months as follows: bulldozer operator — $2240; loglifter operator — $1960; two chainsaw operators — $1120 each; four field hands and one cook — $840 each; one foreman — $4200.

[4] Workers benefits are 58% of salary and include social security, retirement, and health and accident insurance. These employer obligations are not always fulfilled.

[5] Food costs for the logging team (ten people), as well as the three truckers that transport logs to the mill, are estimated at $6000 for the 7 month harvest season.

[6] We estimated that a bulldozer consumes about 110 l of diesel day^{-1} (SD=31)×140 days of work during harvest season, i.e. 15 400 l. A loglifter consumes 70 l of diesel day^{-1} (SD=17)×140 days=9800 l. Hence, the total price of diesel fuel is estimated at $7560 (25 200 l at $0.30 l^{-1}). Gasoline consumption by the two chainsaws is estimated at 8.6 l day^{-1} (SD=0.4)×140 days: 1204 l at $0.50 (price per liter)=$602. Combined consumption of lubrication oil by the bulldozer, log lifter and chainsaws during the logging season was estimated to be 750 l×$2.80 l^{-1}=$2100. Therefore, total fuel-related expenses come to approximately $10 262.

given an average extraction intensity of 38 m^3 ha^{-1} (Table 3). Hence, each hectare of forest generates a profit of about \$900 divided between logging (\$197 ha^{-1}) and processing (\$702 ha^{-1}) activities.

Initially, sawmill owners used their profits to pay for the machinery and infrastructure and the development of their mills. The estimated value of these investments was \$170 000 (Table 4, Footnote 10). Later, mill owners invested in logging equipment — bulldozers, trucks and loglifters — at an estimated cost of \$400 000 (Table 3, Footnotes 9 and 14). More recently, these lumbermen have also begun investing in wood-procesing equipment (planers, lathes, etc.) and in the purchase of virgin forest tracts. At present, an estimated 18% of the municipality of Paragominas is owned by lumbermen (M. Uzeda, personal communication, 1992).

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[7] IBAMA, The Brazilian Institute of the Environment, charges a tax of \$2.00 for each m^3 of bole wood extracted. IBAMA uses the Francon volume measure (77% of the 'real' volume) in assessing this tax.

[8] Maintenance costs were provided by five sawmills that systematically monitored these costs for bulldozer (\$11 200 $year^{-1}$), loglifter (\$7000 $year^{-1}$), and two chainsaws (\$800 $year^{-1}$).

[9] Chainsaws cost \$700 new and are used for 3 years after which they have a value of \$140. Annual depreciation is \$373 (((\$700–140)/3 years) × two chainsaws). Bulldozers cost \$120 000 new and are used for 7 years after which their value is reduced to \$24 000. Annual depreciation is \$13 714 ((\$120 000–24 000)/7 years). Loglifters cost \$90 000 and are used for 7 years after which their value is \$18 000. Annual depreciation is \$10 286 ((\$90 000–18 000)/7 years).

[10] Three drivers are necessary for log transport during 7 months. The total salary per driver is estimated at \$2380.

[11] Worker benefits are approximately 58% of salaries (see above) or \$1380 per driver.

[12] Considering that 9200 m^3 of roundwood must be transported, and that, on average, 13 m^3 (SD=2.7) are transported per trip, and that the average round-trip distance between mill and forest is 160 km, the number of trips necessary between mill and logging site is estimated at 708 (9200 m^3/13 m^3) for a total travel distance of approximately 113 280 km (708 trips × 160 km). Average diesel consumption is 0.5 l km^{-1} × 113 280 km = 56 640 l × \$0.30 (price per liter) = \$16 992. A complete oil change (20 l) is necessary every 5000 km necessitating 23 changes during logging season. The cost of oil is \$2.80 l^{-1} × 23 changes × 20 l per change is \$1288.

[13] Data from five mills that had systematically recorded truck maintenance costs.

[14] Logging trucks cost approximately \$65 000 new and are used for 5 years after which they have a sale value of \$13 000. Annual depreciation per truck is \$10 400 ((\$65 000–13 000)/5 years).

[15] The annual cost of having capital tied up in machinery is estimated at \$16 296. This estimate assumes: (1) the mill owner uses his own capital for equipment purchases; (2) the total investment for equipment is \$406 400 (see Footnotes 9 and 14); (3) a 6% rate of return on investments; (4) investment periods in accordance with the useful life of each item of equipment.

[16] The average harvest per logging season was 9200 m^3 ($n=16$). We divided this harvest into four price groupings: (1) high value (\$50 m^{-3}, SD=13) — 10% of total harvest; (2) medium value (\$32 m^{-3}, SD=13) — 50% of total harvest; (3) low value (\$20 m^{-3}, SD=8) — 10% of total harvest; (4) very low value (\$15 m^{-3}, SD=5) — 30% of total harvest.

TABLE 4

Estimates of annual operating costs and profits for a typical sawmill in the Paragominas region of eastern Amazonia[1]

Production (m^3)[2]	\$4300
Value of production[3]	\$670800
Production costs:	
Raw material[4]	\$253000
Processing costs:	
Salaries[5]	\$47568
Worker benefits[6]	\$27590
Energy[7]	\$9823
Fuel[8]	\$3000
Maintenance[9]	\$13020
Depreciation[10]	\$15526
Telephone[11]	\$3500
Office supplies[12]	\$1700
Owner salary[13]	\$18000
Car[14]	\$3650
Taxes[15]	\$98272
Capital investment costs[16]	\$6157
Total costs	\$500806
Net profit	\$169994
Profit margin	25%

[1] Our 'typical sawmill' has one band saw (true of 78% of the 238 mills visited in this study). Cost estimates are based on interviews in 33 sawmills in the town of Paragominas.

[2] Production for mills with one band saw ranged from 2500 to 6000 m^3 (mean 4300 m^3, SD=858).

[3] Production value was determined by estimating the volume of sawnwood produced in four price groupings: (1) high value (280 m^{-3}, SD=42) — 430 m^3 produced×\$280=\$120 400; (2) medium value (\$180 m^{-3}, SD=29) — 2150 m^3 produced×\$180=\$387 000; (3) low value (\$140 m^{-3}, SD=17) — 430 m^3 produced×\$140=\$60 200; (4) very low value (\$80 m^{-3}, SD=14) — 1290 m^3×\$80=\$103 200.

[4] An estimated 2.13 m^3 of bolewood (real volume) were required to produce 1 m^3 of sawnwood necessitating the acquisition of 9200 m^3 of bolewood to satisfy the annual raw material needs of the mill. A breakdown of roundwood cost by quality type is provided in Footnote 16, Table 3.

[5] A typical mill is staffed by 22 non-specialized laborers each receiving \$1344 $year^{-1}$ together with six specialized workers, including, band saw operators and office funcionaires, each receiving \$3000 $year^{-1}$.

[6] Insurance, health, retirement, and vacation payments for employees sum to 58% of salaries. These worker compensation stipends are not always paid.

[7] Most mills depend on electricity for operation at an estimated cost of \$9823 $year^{-1}$ (SD=2630).

[8] A loglifter is necessary to set logs in position for sawing. Daily fuel consumption is 40 liters×250 days work $year^{-1}$×\$0.30 (price per liter of fuel)=\$3000.

[9] Annual maintenance of loglifter, including repairs and parts was estimated at \$8000. Replacement of saw blades (26 band saws (\$150 each) and 16 circular saws (\$70 each)) was estimated at \$5020.

Importance of logging to the regional economy. The 238 wood-processing firms operating in the Paragominas region in 1990 processed an estimated 2 578 120 m^3 of roundwood into 1 225 700 m^3 of sawn products (Table 5). Assuming an average roundwood yield of 38 m^3 ha^{-1} in logging operations (Table 1), an estimated 67 845 ha of forest were logged in 1989–1990 or 285 ha per industry.

The gross revenues generated by the logging industry in the Paragominas region in 1990 can be estimated by combining the gross income of a typical sawmill with a production of 4300 m^3 of sawnwood $year^{-1}$ valued at $670 800 (Table 4) with the total volume of sawnwood produced in the region (Table 5). The result is $191 million (1 225 700 m^3/4300 m^3 × $670 800). Assuming a profit margin of 32% (typical of mills engaging in both logging and processing activities), the composite profits of these 238 mills would be approximately $62 million.

With gross annual receipts of some 190 million dollars, the wood industry dominates the economy of the Paragominas region. Ranching, the principal development activity since 1965, responsible for the deforestation of some 25% of the Paragominas region, has an estimated gross annual revenue that is only 10–20% that of the wood industry (Mattos et al., 1992).

Economic links between logging and ranching. Logging revenues play an im-

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[10] A band saw/'destopadeira' costs $42 000 new and is used for 15 years, after which it retains a value of $4200. Annual depreciation is $2520 ($42 000–4200/15). A 'conjunto de afiação e guincho' costs $9900 new and is used for 7 years, retaining a value of $990. Annual depreciation is $1273 ($9900–990/7). A circular saw costs $2300 new and is used for 10 years retaining a value of $230. Annual depreciation is $207 ($2300–$230/10). A log turner costs $3000 new and is used for 10 years, retaining a value of $600. Annual depreciation is $240 ($3000–$600/10). A logloader costs $90 000 new and is used for 7 years, retaining a value of $18 000. Annual depreciation is $10 286 ($90 000–18 000/7). The cost to construct a large mill shed and an office is $25 000 and the use period is estimated at 20 years with a residual value of $5000. Annual depreciation is $1000 ($25 000–5000/20).

[11] Annual telephone costs estimated at $3500 (SD=789).

[12] Office supplies estimated at $1700 (SD=417).

[13] Owner salary estimated at $18 000 (SD=3450).

[14] Office vehicle costs calculated as: (i) gas consumption — 1500 l $year^{-1}$ (SD=549) × $0.50 l^{-1}=$750; (ii) maintenance — $1700 $year^{-1}$ (SD=785); (iii) depreciation — value of new car=$12 000, use period=6 years, residual value=$4800, annual depreciation=$1200 ($12 000–4800/6).

[15] Taxes are calculated in relation to sawnwood production and are as follows: (i) ICMS (12%)=$80 496; (ii) Finsocial (2%)=$13 416; (iii) PIS (0.65%)=$4360.

[16] The annual cost of having capital tied up in machinery and infrastructure is $6157. This estimate assumes: (1) the mill owner uses his own capital for equipment and infrastructure purchases; (2) the total investment for equipment and infrastructure is $172 000 (Footnote 10); (3) a 6% rate of return on investments; (4) investment periods in accordance with the useful life of each item of equipment.

TABLE 5

Estimate of consumption of roundwood and production of processed wood by the 238 mills operating in the Paragominas region of eastern Amazonia in 1989–1990

Type of wood-processing industry	Number	Consumption of roundwood per mill year^{-1} (m^3)	Total consumption of roundwood year^{-1} (m^3)	Prod. of processed wood per mill year^{-1} (m^3)	Total prod. of processed wood year^{-1} (m^3)
1 band saw	196	9200	1803200	4300	842800
2–3 band saws	24	17450	418800	8200	196800
4–7 band saws	5	42130	210650	19800	99000
Veneer mill	13	11190	145470	6700	87100
Total	238		2578120		1225700

portant role in subsidizing ranching. By the time loggers arrived in force at Paragominas in the 1980s, most land, cleared and forested alike, was in large holdings controlled by ranchers and land speculators who had moved to the region in the previous two decades. As their forest tracts gained value, ranchers became increasingly interested in logging. This interest stems, in large part, from the vital role that timber sales can play in revitalizing degraded pastures. The cost for pasture reformation in 1990 was \$260 ha^{-1} (Mattos et al., 1992).

When ranchers sell forest extraction rights to loggers, they receive, on average, \$70 ha^{-1}. Hence, almost 4 ha are logged to pay for restoration of 1 ha of degraded pasture. When ranchers conduct the logging operations themselves, they realize an estimated profit of \$200 ha^{-1} (Table 3) and are able to restore almost 1 ha of degraded pasture land for each hectare of forest that they log.

The sudden valuation of Amazon forest timber, in effect, extends the ranching trial period in the eastern Amazon. Large ranchers, with appreciable areas in forest who are willing to participate in the timber extraction process, now have an additional period of subsidies before they will have to stand on their own. This is the third time that ranching has been subsidized in eastern Amazonia. The first subsidy came with the initial forest felling when the nutrients embodied in the forest biomass were liquidated to help pasture grasses establish (Buschbacher et al., 1988). The second subsidy was from the government in the form of capital for ranch infrastructure establishment (Browder, 1988). This third subsidy, to restore degraded pastures, like the first subsidy, comes from nature and, although it is assumed to be free, there are costs involved.

Impacts of the wood industry on humans and the forest resources

Social impacts

The 112 mills in the vicinity of Paragominas (i.e. those in the town itself and those located along the Belém–Brasília Highway on the outskirts of the town) (Fig. 1) generate approximately 5750 jobs distributed among sawmill employees, truckers, forest timber extractors, and odd-job laborers. Overall, we estimate that 56% of the urban population of Paragominas depends directly on the wood industry for sustenance. Considering that these 112 mills log approximately 32 000 ha of forest each year, each employee in the industry depends on approximately 5 ha of forest year^{-1} for sustenance.

In household interviews in the mill neighborhood we found that most sawmill workers had come to Paragominas from other municipalities within Pará or from other states (e.g. 41% were from the poverty-stricken state of Maranhão). Fifty-five percent of the interviewees had arrived within the last 5 years. The great majority (90%) of these mill workers had migrated from the rural zone, having left farming for urban wage labor in hopes of a better life.

But mill salaries are low, \$112 month^{-1} ($n=87$; SD$=43$). Three-quarters of the families interviewed used more than 66% of their salaries in the purchase of food and 11% used more than 90% in food purchase (Fig. 5a). Furthermore, owing to the non-specialized nature of the work, there was no apparent relationship between years of work in sawmill service and earning power (Fig. 5b).

Given the importance of wood in the regional economy, the timber industry could generate significant tax revenues that could improve the quality of life of the regional inhabitants. For example, the 238 mills in the Paragominas region should have jointly produced approximately \$28 000 000 in taxes (14.6% of gross receipts) (Table 4) in 1990. If half this money were retained in the region, there would be \$200 per person year^{-1} available for social services or approximately \$1000 per family of five.

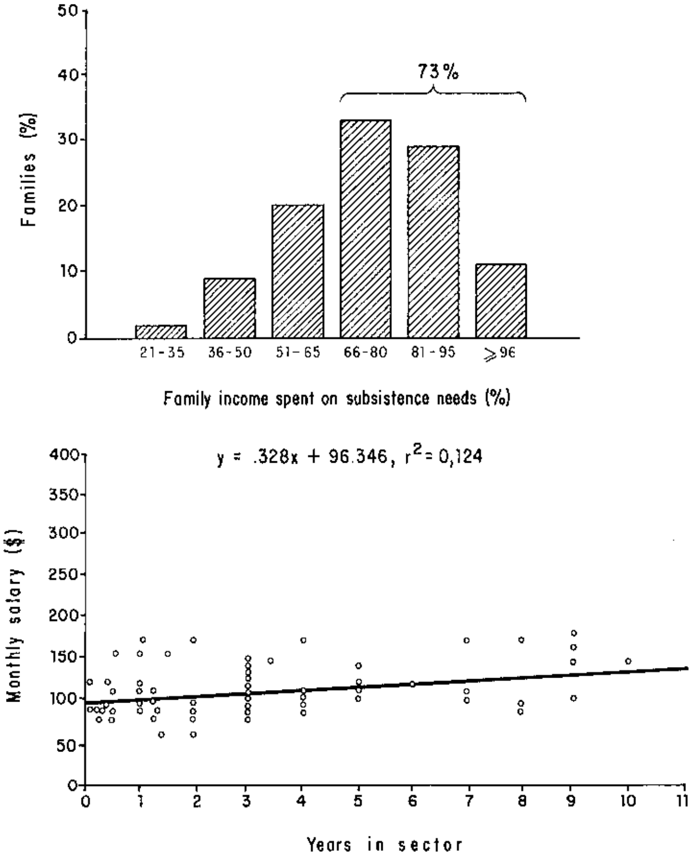

Fig. 5. (a) Percentage of salary spent to meet basic necessities of food, clothing, and shelter for sawmill workers in Paragominas, Pará; (b) relationship between salary and years of work in sawmills in Paragominas, Pará.

Impacts of wood industry on the forest

Logging damages. A considerable amount of damage occurs in the opening up of logging roads and the felling and extraction of trees in tropical forests (Burgess, 1971; Jonkers, 1988; Hendrison, 1990). While an average of 6.4 trees were extracted ha^{-1} in our three study sites, almost 150 trees ha^{-1} greater than or equal to 10 cm dbh were severely damaged (Table 6). This represented an estimated 27%, 35%, and 43% of all trees greater than or equal to 10 cm dbh present in Areas 1, 2, and 3, respectively. Almost half (mean, 48%; SD = 5; $n = 3$) of the damaged trees were uprooted, 41% had broken stems, and the remaining 11% suffered severe bark damage. The average size of damaged trees was 20 cm dbh (range 10–93).

Tree damage was not proportional to the volume felled. For example, the harvesting of 18 m^3 damaged 5 m^2 of basal area in Area 1, but in Area 3, when more than three times this volume was extracted, basal area damage increased by only 50%. Higher yields, therefore, caused substantially less damage m^{-3} extracted (see Jonkers, 1988 for a similar finding).

Many of the damaged trees were of potential economic interest (Fig. 6). For example, 32% of the damaged individuals were of species being sawn in the Paragominas mills. An additional 44% of the damaged individuals were of species used in rural construction, although not generally sawn at present. The remaining 24% of the damaged trees belong to species having no present or potential wood-related importance. In terms of volume, 85% of the total

TABLE 6

Damage caused in wood extraction in three logging operations in the Paragominas region of eastern Amazonia

	Area 1	Area 2	Area 3	Average
Number of trees harvested ha^{-1}	2.9	6.9	9.3	6.4
Damage caused in logging:				
Trees ≥ 10 cm dbh damaged (no. ha^{-1})	121	130	193	148
Basal area ≥ 10 cm dbh damaged (m^2 ha^{-1})	5.0	6.6	7.6	6.4
Volume ⩾ 10 cm dbh damaged (m^3 ha^{-1})	47	63	77	62
Canopy opening[1] (m^2 ha^{-1})	2500	4500	4400	3800
Damage indices:				
Trees damaged per tree extracted	41	19	20	27
m^3 damaged m^{-3} extracted	2.6	1.8	1.2	1.9
m logging road opened per tree extracted	37	38	43	39
m^2 road and patio opened per tree extracted	186	219	249	218
m^2 canopy opening per tree extracted	862	652	473	663

[1] Considering only canopy openings caused by logging activities.

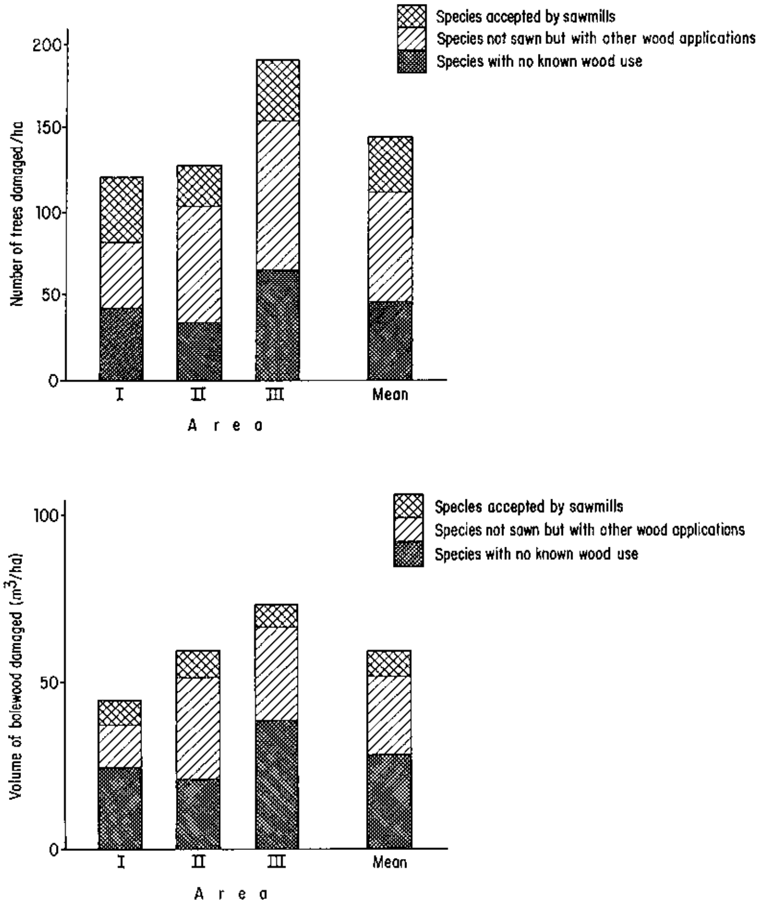

Fig. 6. The estimated number (top) and volume (bottom) of trees damaged per hectare in Area 1 (2.9 trees harvested ha^{-1}), Area 2 (6.9 trees harvested ha^{-1}) and Area 3 (9.3 trees harvested ha^{-1}) in the environs of Paragominas, Pará.

damaged volume has some wood use (49% as sawn timber and 36% in other applications).

Canopy cover in the three logged sites ranged from 40 to 47% (mean, 45; SD=8; n=3). By contrast, average canopy cover in the three control (non-logged) areas, associated with each logged site, averaged 82% (SD=11). Hence, logging decreased canopy cover by an average of 37% in the three study sites. The large canopy openings associated with logging favor the growth of vines.

Logging damage indices (Table 6) reveal that a substantial trade-off is involved in forest extraction. Almost 2 m^3 of wood are destroyed for each m^3 harvested. This damage occurs in the opening of approximately 40 m of logging road per tree harvested resulting in 218 m^2 of scraped ground surface per harvested tree and 663 m^2 of open canopy per harvested tree. By contrast, natural tree falls in this region usually result in canopy openings less than half this size (between 150 and 300 m^2).

Regeneration in logged forest. There was an abundance of seedlings and saplings greater than or equal to 10 cm tall present in the ten 5 m×5 m regeneration study plots established in each of the three logged forest sites, but most of these plants (86%; SD=5; $n=3$) had no known potential wood value. For example, treating all three sites together, there were, on average, 2.7 non-timber seedlings and saplings and 1.6 vines m^{-2} for a total density of 4.3 non-timber-producing plants m^{-2} compared with only 0.43 plants of sawable species m^{-2} and 0.25 plants of 'other wood-use species' m^{-2}. Even so, this gave an estimated total of 0.68 (SD=0.13; $n=3$) seedlings and saplings of species with present or future wood uses m^{-2} or 6800 individuals ha^{-1}.

We observed that regeneration was vigorous in both roads and in the gaps where trees had been felled in the portion of Area 1 subjected to logging 2 years previously. There were an average of 4.5 plants m^{-2} greater than or equal to 1 m tall in plots established on the abandoned logging roads, 2.4 plants m^{-2} in the gaps resulting from tree harvest, and 1.6 plants m^{-2} in unlogged forest patches (Fig. 7). Hence, plant density was almost two times greater in abandoned logging roads than in logging gaps (see Jonkers (1988) for a similar finding). Colonizing plants in the roads had established from seed (82%) or via sprouting (18%).

Most of the plants tallied in this survey, irrespective of microhabitat, were of no economic value (i.e. 92% in roads, 91% in gaps, and 91% in forest), given present-day criteria. Nonetheless, owing to the high density of plants, there were still 0.3 individuals of economic species greater than or equal to 1 m tall m^{-2} in the roads, and 0.2 m^{-2} in the gaps.

The number of economic species per plot (6 m×15 m) was similar among the three microhabitats ranging from 7.3 (SD=2.8; $n=10$) in the gaps to 8.7 (SD=3.7; $n=10$) in the forest. Species dominance was most pronounced in the road and gap sites, though. For example, 48% of the economic individuals in the road plots were *Jacaranda copaia*. In gaps, *Jacarandra copaia* comprised 40% of all individuals. Meanwhile, *Jacaranda copaia* represented only 1% of the individuals in the forest plots.

Height growth was good in both road and gap plots (usually greater than 1 m $year^{-1}$). Along the road, the best growth was for *Ocotea c.f. glandulosa* (mean 4.1 m for the entire 2 year period; SD=0.7; $n=7$). *Pithecellobium pedicellare* showed the best growth in the gap plots (mean 4.6 m for 2 years; SD=1.2; $n=5$).

Natural stocking of economic species present after logging. Given the high damage associated with logging in Paragominas, what is the potential timber-producing power of the post-logged forest? In our survey of all trees greater

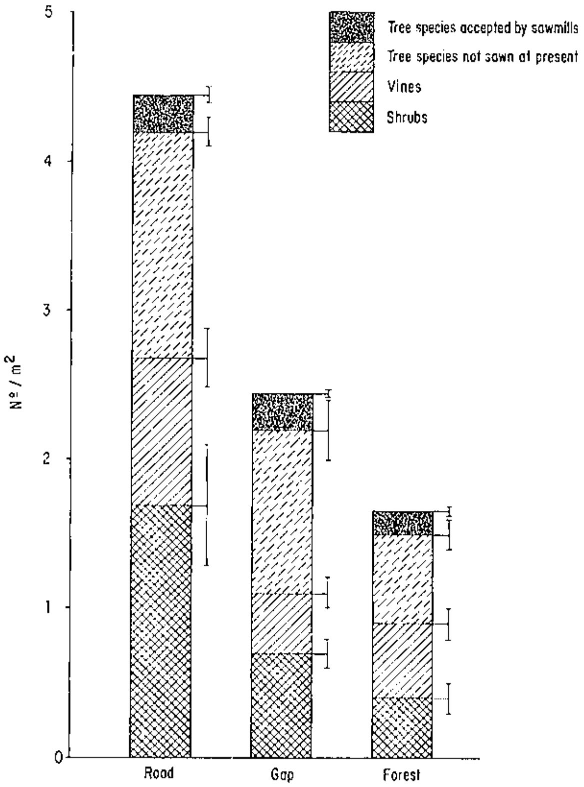

Fig. 7. The density (number per m^2) of trees, shrubs, and vines regenerating on logging roads, in forest gaps created by tree felling, and in patches of non-logged forest 2 years following logging in Area 1 near Paragominas, Pará.

than or equal to 30 cm dbh in two 20 m×1000 m transects in each of the three logged sites we found, on average: 16 trees ha^{-1} that had good form, were defect-free and are presently accepted at sawmills of the eastern Amazon; 17 individuals ha^{-1} that were of potential use but that are not sawn at present in the eastern Amazon; and 22 individuals ha^{-1} that were of no use either because of severe defects or because of inferior wood properties. Hence, of a total of 55 trees ha^{-1} greater than or equal to 30 cm dbh present in the logged forest, 60% have present or potential future uses. In volumetric terms, we found an average of 27 m^3 ha^{-1} of wood in the sawable category with 33 m^3 ha^{-1} of wood in the future-use category and 40 m^3 ha^{-1} with no known potential wood-related uses (Table 7).

Economic feasibility of forest management at Paragominas

Feasibility of forest management at the level of the sawmill

Combining information on mill profits, management costs, and forest response to management allows an assessment of the economic viability of

TABLE 7

The intensity of logging and the density of trees, by wood-use class, greater than or equal to 30 cm dbh remaining after logging in the Paragominas region of eastern Amazonia

Area	Intensity of exploitation		No. and vol. of trees greater than 30 cm dbh after logging			
			Sawn at present[1]	Potentially useful	Without wood uses[2]	Total
1	No. trees extr. ha^{-1}	3	13	14	17	44
		18	19	19	27	65
2	No. trees extr. ha^{-1}	7	19	16	32	67
	Vol. trees extr. ha^{-1}	35	31	27	42	111
3	No. trees extr. ha^{-1}	9	15	23	19	57
	Vol. trees extr. ha^{-1}	62	29	55	40	124
Average	No. trees extr. ha^{-1}	6.4 (3.3)	16 (3.0)	17 (4.7)	22 (8.1)	55
	Vol. trees extr. ha^{-1}	38 (22)	27 (6)	33 (19)	40 (13)	100

[1] Includes only individuals that are sawn at present and that had good form and boles free of defects.
[2] Includes individuals that were deformed or damaged or that belonged to species that have no known potential wood uses.

management. The most fundamental timber management measures that could be taken at Paragominas to increase timber production are: (1) pre-harvest stand inventory to determine the location of desirable trees and plan the felling directions and skidder pathways to minimize logging damage; (2) vine cutting — 1 year prior to harvest to reduce felling damage and reduce competition for light; (3) general stand refinement and liberation thinning together with vine cutting to open up growing space for desirable trees at 1, 10 and 20 years following logging. The costs of these management measures are estimated, in very general terms, at about $180 ha^{-1} and divided as: (1) pre-harvest stand inventory ($20 ha^{-1}); (2) pre-harvest vine cutting ($25 ha^{-1}); and three post-harvest thinnings ($45 ha^{-1} each) (P. Barreto, unpublished data, 1991) (see also DeGraaf, 1986; Jonkers, 1988; Hendrison, 1990).

A typical mill with one band saw that also engages in logging would need to manage 242 ha year^{-1} to supply its raw material needs (Table 3, Footnote 2) at a total estimated cost of $43 560 (242 ha × $180 ha^{-1}). The actual cost over the first 2 years of management (the year prior to logging and the first year following logging) would be $90 with additional investments made after 10 and 20 years. However, for mills truly engaged in managing forest estates, investments would be required in recently logged, 10-year-old and 20-year-old parcels each year. Hence, although not applied to the same parcel, an average of $180 ha^{-1} would be spent on 242 ha of forest land each year. Given an annual mill profit of approximately \$217 000 (Tables 3 and 4), these management costs would consume 20% of total profits or 7% of total annual receipts. Even if no benefits accrued from management, profit margins would only be shaved from 32% to 25% given a management investment.

However, simple forest management techniques do result in increases in volume accumulation. For example, when vine cutting and girdling of non-economic species are done following unplanned logging operations, commercial trees greater than or equal to 30 cm dbh achieve long-term annual diameter increments of 0.6–1.0 cm compared with 0.1–0.4 cm year^{-1}, typical of untreated stands (DeGraaf, 1986; Jonkers, 1988). Our projections, based on the post-harvest stand characteristics of our three forest study sites (Fig. 1), and given 2% annual mortality and annual growth increments of 0.8 (managed stands) and 0.3 (unmanaged stands), reveal that the difference in accumulated bole volume between managed and non-managed stands, considering just commercial species greater than or equal to 30 cm dbh, will be 22 m^3 after 35 years (P. Barreto, unpublished data, 1991). Moreover, these simulations reveal that there would be an adequate timber stocking for future harvests.

If a pre-extraction inventory and vine cutting are added to the management program, logging damage might be reduced by as much as 50% (Marn and Jonkers, 1982; Appanah and Putz, 1984; Hendrison, 1990). Hence, we might expect that, in the case of our three study areas, some 24 individuals ha^{-1} greater than or equal to 10 cm dbh presently valued for their wood would be spared damage (P. Barreto, unpublished data, 1991). Given our assumptions for growth (0.8 cm year^{-1}) and annual mortality (2%) for managed stands, this additional stock would increase the volume accumulated by commercial trees greater than or equal to 30 cm dbh by an average of 10 m^3 after 35 years.

If we add the additional 10 m^3 gained with planned extraction to the 22 m^3 resulting from vine cutting and thinning treatments, the total difference in volume accumulated between managed and non-managed stands is projected at 32 m^3. Meanwhile, non-managed stands in our simulations have about the same volume of commercial wood after 35 years as that present just after harvest. This is due to tree attrition and slow growth rates. More than a decade of research in tropical forests in Suriname (DeGraaf, 1986; Jonkers, 1988; Hendrison, 1990), likewise, reveals that volume accumulation of commercial species in logged stands that are not managed is extremely low (0–0.25 m^3 ha^{-1} year^{-1}). Timber harvest rotation times for non-managed stands are projected to be well beyond 50 years.

There is no straightforward way to calculate the return on forest management investments. At one extreme, the return might be regarded as the value of the extra wood volume generated by management as it stands in the forest. At present, loggers pay \$1–3 m^{-3} for the right to extract standing timber. Given a management cost of about \$5 associated with each m^3 of accumulated wood (\$180/32 m^3), a \$1–3 return after 35 years is clearly unattractive. At the other extreme, one might consider the return on the management investment to be the value of the wood volume resulting from management after it is sawn. In this case, given a net profit of \$23.60 for each m^3 roundwood that is processed (Tables 3 and 4), the final value of the extra wood volume generated by management would be \$755 (32 $m^3 \times$ \$23.60). Considering the time pattern of the management investments, the return on investment would be 4.9%. While neither of these accounting approaches is entirely satisfactory, our analysis reveals that: (1) simple management approaches could lead to substantial increases in commercial volume accumulation, and (2) profits of mill establishments are adequate to cover management costs.

Forest management — a regional perspective

In conclusion, we will use the data from this study to evaluate the future sustainability of logging in the Paragominas region. This activity has been under way for 20 years. During this period we estimate that 19.48 million m^3 of roundwood have been extracted from the region's forest (Table 8). The area of forest supplying this wood is estimated at 512 753 ha (19 484 627 ha/ 38 m^3).

Knowing the remaining forest area available to lumbermen and the wood present in this forest allows an estimate of the number of years of log supply, assuming no reharvesting of previously logged areas. For this exercise, we consider that the forest available to the sawmill industries is that flanking a 300 km stretch of the Belém–Brasília Highway between Santa Maria and Itinga to a distance of some 100 km on either side of the Highway (Fig. 1), for a total area of 60 000 km^2. Approximately 65% of this area (39 000 km^2) is still virgin forest (SUDAM, 1988) (O. Watrin, personal communication, 1990). At present, the 238 mill establishments that operate in this region, exploit an estimated 678 km^2 of forest per year (Table 8). Hence, the region might supply the logging industry at its present rate of consumption for some 58 years (39 000 km^2/678 km^2 $year^{-1}$).

These numbers take on additional relevance when considered in the context of forest management at the level of individual industries. The average area of forest exploited per mill $year^{-1}$ is 285 ha, considering all mills together (67 845 ha/238 mills) (Table 8). Assuming a rotation period of 35 years, each mill would need almost 10 000 ha of forest to guarantee sustainable production, and the 238 firms present in 1990 would require a total of 23 740 km^2. This represents 61% of the estimated virgin forest estate in the study rectangle. The number of mills that could be theoretically accommodated in this region under sustainable management might, thus, approach 400 (39 900 km^2/100 km^2 per mill=390), although a number well shy of this would be wise, given the importance of conserving areas of high biodiversity

TABLE 8

Volume of roundwood harvested and processed wood produced by the mills in the Paragominas region of eastern Amazonia from 1970 through 1990

Year	Number mills functioning	Vol. processed wood prod. (m^3)	Vol. roundwood harvested (m^3)[1]	Area exploited (ha)[2]
1970	2	8600	18300	482
1971	2	8600	18300	482
1972	2	8600	18300	482
1973	5	21500	45750	1204
1974	9	38700	82350	2167
1975	12	51600	109800	2889
1976	12	51600	109800	2889
1977	21	90300	192100	5055
1978	32	137600	292750	7704
1979	47	202100	428495	11276
1980	67	283800	599184	15768
1981	82	356900	751917	19787
1982	98	430000	903940	23788
1983	110	516000	1087120	28608
1984	136	645000	1355910	35682
1985	154	791200	1663176	43768
1986	189	946000	1992900	52445
1987	215	1075000	2259390	59458
1988	225	1140500	2398905	63129
1989	238	1225700	2578120	67845
1990	238	1225700	2578120	67845
Total		9255000	19484627	512753

[1] Considering that 2.13 m^3 of roundwood are required to produce 1 m^3 of sawnwood and 1.67 m^3 of roundwood render 1 m^3 of sheet veneer.
[2] Considering that 38 m^3 are harvested ha^{-1}.

and because not all areas of the forest estate are capable of sustainable timber production.

While these projections and estimates reveal that forest management for timber production might be good for the landscape and the regional population as well as the industry over the long haul, there are three impediments to management. First, there is little knowledge or experience in management and without technical assistance management attempts will be misguided and perhaps even damaging. Second, the returns on management investments do not compare well with other investment options at the moment. Third, virgin forest is cheap — virgin forest land in the study region was selling for \$50–150 ha^{-1} in 1991. Rather than invest \$180 ha^{-1} in management over 35 years, the lumberman in need of roundwood will buy virgin forest tracts for \$100 and harvest them immediately. If forest tracts were harvested once and then left for 70 years to recover, it is possible that management would be unnecessary. The lumberman might return each 70 years to remove 25–35 m^3 of accumulated hardwood volume. But in practice, the tendency in the Paragominas region has been for loggers to make repeated incursions into the forest. This occurs because the number of species with economic value has been expanding rapidly.

At least three economic tools could be employed to promote management. First, management could simply be mandated by law. In this case, mill profit margins would decline but still remain robust (above 20%). Second, management costs could be passed on to the consumer as a 7% increase in product price (ecology tax). Third, commercial tax revenues (ICMS) could be reduced from 12% of total mill receipts to 5%. The tax savings (about $45 000) for a typical mill would be enough to cover management costs. These economic measures would have to be coupled with strict enforcement efforts.

Although our discussion of management has centered on the wood industry and the government, ranchers might also play a key role in promoting forest management. Indeed, because ranchers control approximately 80% of the forest estate in the study region, it is directly in their interest to use this forest resource wisely. But, as a group, ranchers have little understanding of the value of their forest holdings and the damages which occur during logging. They sell logging rights cheaply and seldom evaluate the impacts of the logging operations. In practice, ranchers could easily regulate extraction practices on their properties. Moreover, considering the high profits of the mills, ranchers could charge more for their wood resources and, then, use these 'extra' revenues to institute simple management measures like site inventories, vine cutting, and liberation thinnings. With reduced damages and improved wood accumulation rates resulting from management, ranchers would stand to gain and the forest would be used in a more productive fashion.

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NOTE ADDED IN PROOF

Shortly after concluding our economic analysis of the Paragominas logging sector, Brazil entered into a severe recession which continues at the time of this writing (September 1992). Because capital is scarce at present, construction starts have declined as has the price of sawnwood. Meanwhile, mill operating costs have increased. As a result, profit margins of many mills sank to below 15% in 1991. Nonetheless, the 80-odd sawmill establishments in the city of Paragominas continue to function. Not a single one has closed. The ability of the industry to weather a severe economic crisis might be viewed as an indicator of its robustness.

Finally, given the large annual fluctuations in mill profit margins in Brazil's unstable economy, and given our conclusion that the return on forest management investments will probably be low in the foreseeable future, it would seem inappropriate to mandate that mill establishments shoulder management costs, unless steps are taken to assure stable wood product prices.

REFERENCES

Appanah, S. and Putz, F.E., 1984. Climber abundance in virgin dipterocarp forest and the effect of pre-felling climber cutting on logging damage. The Malays. For., 47: 335–342.

Bee, Ooi Jin, 1990. The tropical rain forest: patterns of exploitation and trade. Singapore J. Trop. Geogr., 2: 117–142.

Browder, J.O., 1988. Public policy and deforestation in the Brazilian Amazon. In: P. Repetto and M. Gillis (Editors), Public Policy and the Misuse of Forest Resources. Cambridge University Press, New York, pp. 247–297.

Burgess, P.F., 1971. The effect of logging on hill dipterocarp forests. Malay. Nat. J., 24: 231–237.

Buschbacher, R., Uhl, C. and Serrão, E.A.S., 1988. Abandoned pastures in eastern Amazonia. II. Nutrient stocks in the soil and vegetation. J. Ecol., 76: 682–699.

De Graaf, N.R., 1986. A silvicultural system for natural regeneration of tropical rain forest in Suriname. Agricultural University, Wageningen, The Netherlands, 250 pp.

FIBGE (Fundação Instituto Brasileiro de Geografia e Estatística), 1988. Produção e rendimento total do Estado do Pará. Delegacia do Pará, Belém, Pará.

Hecht, S., Norgaard, R. and Possio, G., 1988. The economics of cattle ranching in eastern Amazonia. Interciencia, 13: 233–240.

Hendrison, J., 1990. Damage-controlled logging in managed tropical rain forest in Suriname, Agricultural University, Wageningen, The Netherlands. 204 pp.

Jonkers, W.B.J., 1988. Vegetation structure, logging damage and silviculture in a tropical rain forest in Suriname. Agricultural University. Wageningen, The Netherlands, 172 pp.

Marn, H.M. and Jonkers, W.B., 1982. Logging damage in tropical high forest. In: P.B.L. Srivastava et al., (Editors), Tropical Forests — Source of Energy through Optimization and Diversification. Proceedings of an International Conference held 11–15 November 1980 at Penerbit University Pertanian, Serdang, Selangor, Malaysia, pp. 27–38.

Mattos, M., Uhl, C. and Gonçalves, D., 1992. Perspectivas econômicas e ecológicas da pecuária na Amazônia Oriental nos anos 90. Instituto de Desenvolvimento Econômico e Social do Pará. Para Desenvolvimento, in press.

Nectoux, F. and Kuroda, Y., 1989. Timber from the South Seas: an analysis of Japan's tropical timber trade and environmental impact. A World Wildlife Fund International Publication. World Wildlife International, Gland, Switzerland, 134 pp.

Rankin, J.M., 1985. Forestry in the Brazilian Amazon. In: G.T. Prance and T.E. Lovejoy (Editors), Amazonia, Key Environment Series. Pergamon Press, Oxford, UK, pp. 369–392.

Silva, J.N.M., 1989. The behavior of the tropical rain forest of the Brazilian Amazon after logging. PhD. Dissertation. University of Oxford, UK.

Silva, J.N.M. and Araújo, S.M., 1984. Equação de volume para árvores de pequeno diámetro na Floresta Nacional do Tapajós. In: Boletim de Pesquisa Florestal Número 8/9. Empresa Brasileira de Pesquisa Agropecúaria, Centro de Pesquisa Agropecúaria do Tropico Umido, Belém, Pará, Brazil, pp. 16–25.

Silva, J.N.M., de Carvalho, J.O.P., Lopes, J. do C.A. and de Carvalho, M.S.P., 1984. Equações de volume para a Floresta Nacional de Tapajós. In: Boletim de Pesquisa Florestal Número 8/9. Empresa Brasileira de Pesquisa Agropecúaria, Centro de Pesquisa Agropecúaria do Trópico Umido, Belém, Pará, Brazil, pp. 50–63.

SUDAM, 1988. Programa de monitoramento da alteração da cobertura vegetal primitiva do Estado do Pará. SUDAM, Belém, Pará.

Uhl, C., Buschbacher, R. and Serrão, E.A.S., 1988. Abandoned pastures in eastern Amazonia. I. Patterns of plant succession. J. Ecol., 76: 663–681.

Uhl, C., Verissimo, A., Mattos, M., Brandino, Z. and Vieira, I., 1991. Social, economic, and ecological consequences of selective logging in an Amazon frontier: the case of Tailândia. For. Ecol. Manage., 46: 243–273.