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Extraction of a high-value natural resource in Amazonia: the case of mahogany

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Abstract

Mahogany, *Swietenia macrophylla* King, is by far the most valuable timber species in the Brazilian Amazon: 1 m^3 of export-quality sawn wood was valued at about $700 in the early 1990s. We studied the structure and economy of the mahogany companies operating in southern Pará State, the major mahogany processing center in the Brazilian Amazon. Of the 86 mills in operation in this region, 24 specialized in mahogany and were responsible for processing 90% of the mahogany harvest. Many of these mahogany mills (60%) were established in the 1980s. By the early 1990s, most (91%) were vertically integrated—participating in forest logging, log transport, mill processing, and marketing.

Mahogany companies achieved good profits in the early 1990s. A typical mill with one band saw produced, on average, 4500 m^3 of sawn wood $year^{-1}$ from 9900 m^3 of roundwood. The value of this sawn wood was approximately $3 000 000; annual profits for such a company were approximately $800 000.

In three logging operations that we studied, an average of 5 m^3 of mahogany logs were extracted per hectare; this is equivalent to the extraction of about one mahogany tree per hectare. However, future cuts of mahogany are in doubt: in surveys of recently logged sites we encountered, on average, only 0.25 mahogany trees of at least 30 cm diameter at breast height (dbh) per hectare and no trees between 10 and 30 cm dbh. Mahogany seedlings were also rare.

Logging damage can be great on a local scale. Thirty-one trees at least 10 cm dbh were severely damaged for each mahogany tree harvested; approximately 1100 m^2 of forest ground surface were scraped clean or trampled for each mahogany tree removed. However, because mahogany trees are usually distributed in widely scattered patches only a small fraction of the region's forest has been directly disturbed by this logging. Nonetheless, the specific effect on *Swietenia macrophylla*—its population numbers and genetic structure—may be significant. Moreover, mahogany logging indirectly contributes to regional deforestation. Logging companies have opened up some 3000 km of logging roads in southern Pará and mahogany logging has been documented in each of the region's 15 Indian Reserves. After logging, there is a growing trend to convert forests to cattle pasture, in part perhaps, because the prospects for future mahogany harvests do not appear to be good. We conclude our paper with a discussion of initiatives in the policy, business, and technical sectors aimed at promoting the sustainable management of mahogany forests in the Brazilian Amazon.

Keywords: Swietenia macrophylla; Mahogany; Amazonia; Logging; Forest management

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1. Introduction

Sawmills in the Brazilian Amazon are involved in the processing of more than 300 tree species (Martini et al., 1994). The majority of these woods (over 90%) were valued at less than \$300 m^{-3} in sawn form in 1992 but a few species were highly valued. Among the select group of valuable species, mahogany (*Swietenia macrophylla* King) topped the list, selling for approximately \$700 m^{-3} for export grade sawn boards in 1992. *Swietenia macrophylla* is prized for its attractive color, durability, dimensional stability, and workability; it is used for decorative woodwork, furniture, door and window frames, shingles, beams, and veneer (Lamb, 1966).

This species occurs in a broad swath extending from Mexico through Central America and across the southern Amazon of Bolivia and Brazil (Rodan et al., 1992). In the Brazilian Amazon, it occurs in patches from the State of Acre through Amazônia, Rondônia and Mato Grosso to Pará State in the eastern Amazon (De Barros et al., 1992).

Swietenia macrophylla has been cut for local building needs for many years in the Brazilian Amazon but significant commercialization of this species did not begin until the 1960s with the building of highways into the southern Amazon. The availability of government credit for wood export activities also encouraged logging (Browder, 1987). Declines in *S. macrophylla* supplies in Central America has meant that the demand for this species has been high in Amazonia in recent decades (Rodan et al., 1992).

From 1971 to 1992, Brazil exported an estimated 3 310 000 m^3 of sawn *S. macrophylla* (Funatura, 1992). The United Kingdom and the United States were the principal buyers: from 1978 to 1992 these two countries imported 35% and 40%, respectively, of Brazil's total *S. macrophylla* exports (Funatura, 1992).

At a national level, *S. macrophylla* represents only a small fraction (approximately 0.3%) of the value of Brazil's exports (Hahn, 1991). In contrast, in the state of Pará, source of 64% of all the *S. macrophylla* exported from Brazil, exports of this species represent 5% of the total export value (Associação dos Exportadores de Madeira do Para e Amapa, internal records).

There is now concern that *S. macrophylla* is threatened by undisciplined logging activities (Rodan et al., 1992). Indeed, two relatives of *S. macrophylla*, *Swietenia mahogany* and *Swietenia humilis*, are presently listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (Rodan et al., 1992). There is now growing pressure to add *S. macrophylla* to CITES, Appendix II. This would mean that *S. macrophylla* could only enter international markets after the government of the producer country had determined that trade would not lead to significant population reductions of this species. Meanwhile, some environmental groups have called for an international boycott of *S. macrophylla*. Brazil has been at the center of this debate because it is the major supplier of *S. macrophylla* for the international market and because it still has considerable stocks of this species.

This paper has three objectives. First, we present an economic analysis of *S. macrophylla* (referred to simply as 'mahogany' throughout the remainder of this paper) logging and processing in southern Pará State. Second, we evaluate the ecological and social impacts of mahogany logging in this region. Finally, we consider the obstacles to, and potential for, sustainable management of mahogany in the Brazilian Amazon.

2. The study region

Up to the middle of the 1800s, the south of Pará was occupied almost exclusively by Indians (Schmink and Wood, 1992). Then, rubber was discovered and whites began to settle in the region. After the market for rubber collapsed in the early 1900s, economic activity was restricted to the occasional sale of Brazil nuts, exotic woods, and oils. In the 1960s, the region again attracted

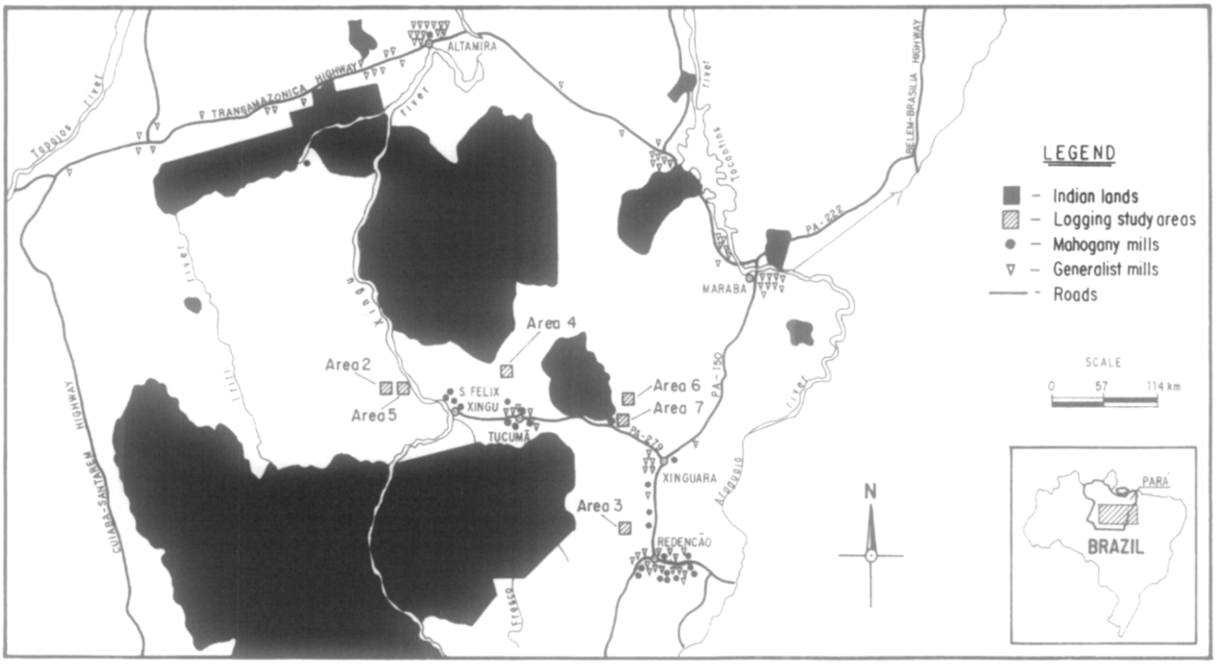

Fig. 1. The location of the study areas, Indian Reserves, and wood companies in the mahogany belt in southern Pará State, Brazil.

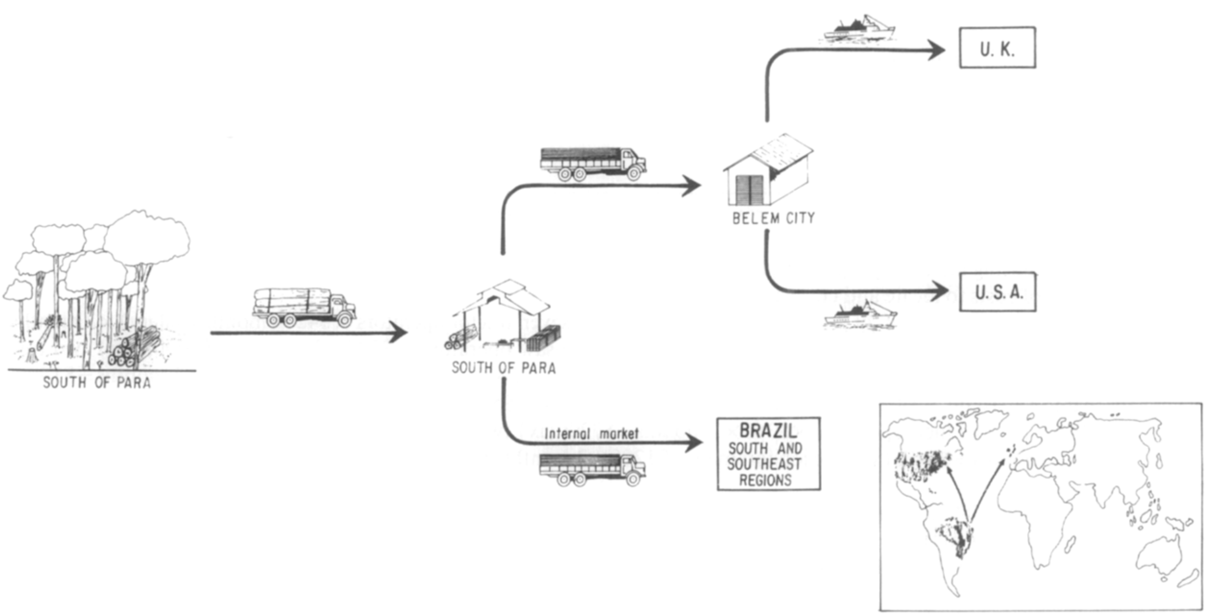

Fig. 2. Schematic representation of the steps involved in extraction, processing, and commercialization of mahogany in southern Pará State, Brazil.

Table 1
Costs to extract and transport 5500 m^3 of mahogany in a typical logging operation in southern Pará State, Brazil, 1992

Category	Cost[a] ($)
Logging rights[b]	220,000
Cost m^{-3} of mahogany roundwood	40
Reconaissance and tree felling[c]	25,240
Cost m^{-3} of mahogany roundwood	4.60
Extraction of logs from the forest	
Wages[d]	25,740
Benefits[e]	14,929
Food[f]	6,480
Fuel[g]	19,491
Air shuttle[h]	7,600
Machine maintenance[i]	28,000
Machine depreciation[j]	28,831
Extraction total	131,071
Cost m^{-3} of mahogany roundwood	23.80
Transport of logs to the mill[k]	
Road construction[l]	110,000
Wages[m]	12,080
Benefits[n]	7,006
Fuel[o]	20,917
Machine maintenance[p]	14,400
Machine depreciation[q]	16,780
Freight[r]	236,500
Transport total	417,683
Cost m^{-3} of mahogany roundwood	75.90
Taxes on logs[s]	16,500
Cost m^{-3} of mahogany roundwood	3.00
Cost of capital[t]	25,185
Cost m^{-3} of mahogany roundwood	4.60
Total cost	835,679
Total cost m^{-3}	152

[a] All cost estimates in Tables 1, 2, and 3 were provided in cruzeiros and then converted to US dollars using the official exchange rate.

[b] The cost of purchasing mahogany logging rights was \$40 m^{-3}.

[c] The full details of costs to locate and cut mahogany are provided in Table 2.

[d] The extraction team consisted of 29 people divided as follows: (i) seven tractor operators ×\$420 (monthly salary)×2 months (total job time)=\$5880; (ii) two tractor assistants and three chainsaw operators ×\$300×2 months=\$3000; (iii) two tree finders and three assistants to chainsaw operators ×\$260×2 months=\$2600; (iv) one mechanic ×\$700×2 months=\$1400; (v) one mechanic's assistant ×\$450×2 months=\$900; (vi) one welder ×\$500×2 months=\$1000; (vii) two drivers ×\$400×2 months=\$1600; (viii) one fuel supervisor ×\$360×2 months=\$720; (ix) two cooks ×\$400×2 months=\$1600; (x) one cook's helper ×\$320×2 months=\$640; (xi) one job foreman ×\$1200×2 months=\$2400; (xii) two assistant supervisors ×\$1000×2 months=\$4000.

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

[f] Food costs during 2 months for the logging team of 29 people, as well as 14 workers involved in transport and 10 independent truckers (total of 53 people).

[g] Estimated diesel consumption over the 2-month extraction period was 9000 l for each of two skidders, 7800 l for each of five D-6 bulldozers, 2760 l for one road grader, 1200 l for each of two logging trucks, and 840 l for each of two pickup trucks. Total diesel consumption was 63840 l×\$0.28 (price per liter)=\$17875. Estimated gasoline consumption was 120 l for each of three chainsaws ×\$0.44 l^{-1}=\$158. Estimated lubricating oil consumption for all machines was 540 l×\$2.70=\$1458.

attention: roads were put in, forging links with Brazil's Central West and Northeast, and government subsidies were provided to attract ranchers and colonists. At the same time, the subsoil in some parts of the region was found to be rich in iron, tin, and gold; growing on top of this soil was mahogany, a tree of extraordinary value.

Mahogany is a canopy tree, 30–40 m tall, that grows well on a wide range of soils (Lamb, 1966; Snook, 1992). The vegetation in Pará's mahogany zone is evergreen forest intergrading with open Cerrado to the south. Soils are generally red-yellow podzolics. Annual rainfall ranges from 1500 to 2000 mm, with a period of less frequent rains from June to October.

When the first modern mahogany loggers arrived in southern Pará in the early 1960s, large mahogany trees were cut in close proximity to rivers and floated to Belém (Schmink and Wood, 1992). By the early 1970s, mahogany logging had spread northward up Pará Highway 150 and sawmills began to be established in the towns of Redenção, Rio Maria, and Xinguara (Fig. 1). By

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[h] To transport the workers, food, fuel, and parts to the harvest site, 38 h of flight time were required ×\$200 h^{-1}=\$7600.

[i] Maintenance for all machines, including the replacement of tires and parts was estimated at \$14000 $month^{-1}$ by the job foreman based on 4 years of experience (\$14000×2 months=\$28000).

[j] Depreciation is based on estimates of machine purchase price, operating life, and salvage value. Bulldozer (D-6) price=\$100000; operating life 60 months; salvage value \$20000; depreciation \$1333 $month^{-1}$ (\$100000–\$20000/60 months); total depreciation \$1333×5 tractors×2 months=\$13330. Road grader (caterpillar) price \$140000; operating life 60 months; salvage value \$28000; depreciation \$1867×2 months=\$3733. Skidder price \$120000; operating life 60 months; salvage value \$24000; depreciation \$1600×2 skidders×2 months=\$6400. Logging truck price \$68000; operating life 50 months; salvage value \$13600; depreciation \$1088×2 trucks×2 months=\$4352. Ford pickup truck price \$26000; operating life 80 months; salvage value \$5200; depreciation \$260×2 months=\$520. Toyota pickup price \$20000; operating life 80 months; salvage value \$4000; depreciation \$200×2 months=\$400. Chainsaw price \$720; operating life 36 months; salvage value \$144; depreciation \$16×3 saws×2 months=\$96.

[k] Transport was divided into two phases: (1) transport the logs approximately 50 km from the interior of the forest to the intersection with the Morada do Sol road; (2) transporting the logs approximately 270 km from the intersection of the Morado do Sol road to the mill in Tucumã.

[l] The company constructed a 100 km of feeder roads from the forest extraction sites to the main north–south road (Estrada do Sol). The cost of constructing the road (12 m wide) was approximately \$4000 km^{-1} (data from job foreman who supervised the construction of 550 km of forest roads from 1987 to 1992). Given that the 100 km of feeder roads accessed a forest tract containing approximately 20000 m^3, the cost of this road construction m^{-3} of wood extracted is \$20 (\$400000/20000 m^3). Hence, the road cost attributable to the 5500 m^3 extracted in 1991 was \$110000.

[m] Fourteen people worked for a 2-month period to conduct the first phase of transport. The team was divided into: two log-lift operators (\$420 individual monthly salary), two log scalers (\$400 salary), five truck drivers (\$420 salary), one chainsaw operator (\$300 salary), two mechanics (\$600 salary), and two cooks (\$400 salary).

[n] See Note e, this table.

[o] Estimated diesel consumption over the 2-month extraction period was 11500 l for each of the five logging trucks and 5400 l for each of the two log-lifters×\$0.28 (price per liter)=\$19124. Estimated gasoline consumption was 240 l for the chainsaw×\$0.44 l^{-1}=\$106. Estimated lubricating oil consumption for all machines was 625 l×\$2.70=\$1687.

[p] Maintenance costs are based on information provided by the job foreman.

[q] Depreciation is based on estimates of machine purchase price, operating life, and salvage value. Log transport trucks (Mercedes Benz 22-20) price \$68000; operating life 50 months; salvage value \$13600; depreciation \$1088×2 months×5 trucks=\$10880. Log lifter price \$110000; operating life 60 months; salvage value \$22000; depreciation \$1467×2 months×2 log lifters=\$5868. Chainsaw price \$720; operating life 36 months; salvage value \$144; depreciation \$16×2 months=\$32.

[r] In the second phase of the log transport operation, independent truckers received \$43 m^{-3} to transport wood 270 km down the Morada do Sol road to the mill in Tucumã. This value was typical for the region at the time of this study.

[s] The tax on harvested roundwood is \$3.00 m^{-3}.

[t] The cost of having capital tied up in machinery is estimated at \$62962 $year^{-1}$. This estimate assumes: (1) the mill owner uses his own capital for equipment purchases; (2) the total investment for equipment is \$1624880 (footnotes j and q); (3) an 8% rate of return on investment; (4) investment periods in accordance with the useful life of each item of equipment. Note: mahogany logging is restricted to the 5-month dry season. Therefore, given a 2-month operation, the cost of capital is \$28185 or 40% of the annual cost of capital.

Table 2
Costs to locate and cut 1200 mahogany trees in a typical logging operation in southern Pará State, Brazil, 1992

Category	Cost[a] ($)
Salaries for scouts[b]	6600
Salaries for cutters[c]	8550
Food[d]	3300
Fuel[e]	1845
Maintenance[f]	885
Machine depreciation[g]	240
Cost of capital[h]	50
Air transport[i]	3300
Landing strip[j]	470
Total	25240

[a] All cost estimates were provided in cruzeiros and then converted to US dollars using the official exchange rate.
[b] Ten scouts worked for 3 months to locate the 1200 trees at a monthly salary of $100 with a $3 bonus for each mahogany tree that was located.
[c] Five chainsaw operators (salary $150 per month) and five assistants ($100 per month) required 3 months to cut the 1200 mahogany trees. The crews received an additiona $4 bonus for each tree felled.
[d] All food for the scouts and cutting crews was purchased in Tucumã, flown to the forest, and dropped into forest clearings. Most meat was supplied by hunting.
[e] Each of the five chainsaws used approximately 225 l of fuel ($0.44 l^{-1}) and 100 liters of oil ($2.70 l^{-}) during the 3-month harvest period.
[f] Chainsaw maintenance included the purchase of 25 chains ($28 each), 40 round files ($3.80 each), and 10 flat files ($3.30 each).
[g] The purchase price of a chainsaw was $720; the operating life was 36 months; the residual value after 36 months of use was $144. Hence, the monthly depreciation was $16 ($720−$144)/36) and total deprecitation cost for all five chainsaws over the 3-month harvest period was $240.
[h] The cost of having capital tied up in chainsaws is estimated at $50. This estimate assumes: (1) the total investment for equipment was $3600 (price of five chainsaws); (2) a 8% annual rate of return on investment; (3) a chainsaw operating lifetime of 36 months.
[i] All air transport was by single engine plane (500 kg capacity). Two flights were required to perform the initial reconnaissance of the area. Six additional flights were necessary to transport the 20 workers and equipment. Finally, three additional flights were required to transport food and fuel during the 3-month work period. The total cost was $3300 (11 flights × 1.5 h per round-trip flight × $200 h^{-1}).
[j] A 600 m × 30 m landing strip was cleared out of forest as a staging area for the extraction. Seven days were required to make the strip. Construction cost is estimated based on values in Table 1 for bulldozer operation and salaries for operator and assistant.

the end of the 1970s, mahogany trees were becoming scarce in the vicinity of Pará Highway 150 and logging shifted to accompany the opening of Pará Highway 279 (Fig. 1). In the period from 1970 to the early 1990s, the distance between logging areas and sawmills grew from only a few kilometers to more than 500 km. Present-day logging activities are increasingly concentrated in the region between the Xingu and Iriri Rivers (Fig. 1).

3. Methodology

3.1. Economic analysis of mahogany companies

3.1.1. Mahogany logging and transport

Before mahogany can be processed, the trees must be located in the forest and then cut, skidded, and transported to mills. We studied these activities for one typical logging operation (Area 1, Fig. 1). The team that we chose used the skidders and log-loaders commonly in operation in the region. We interviewed the production foreman together with 25 members of the logging team, including eight woodsmen, four chainsaw operators, three chainsaw assistants, three heavy machinery operators, four truck drivers, two wood scalers, and one cook. The oral questionnaires administered to the woodsmen and chainsaw teams were aimed at determining the number of trees located (woodsmen) and cut (chainsaw team) per unit time and costs of these activities. In our interviews with heavy equipment operators, we gathered information on the types of machinery used, number of trees extracted per unit time, fuel consumption, machine maintenance costs, and salaries. We questioned truck drivers concerning fuel consumption maintenance costs, wood volumes transported per unit time, and salaries. Questions directed at the wood scalers focused on the volumes of wood extracted per unit time. The cook furnished information on the types and quantities of food consumed. Finally, the foreman provided additional information on production and overall costs.

We built redundancy into the questioning of the different actors as a means of checking responses. We also compared the time and cost estimates secured in this intensive interview process with numerous spot checks with other extraction crews in an effort to identify possible problems in the data.

3.1.2. Mahogany processing and commercialization

We administered questionnaires to representatives of 66 of the 86 wood companies in the study region (Fig. 1). In case of the 20 wood companies where formal interviews could not be arranged, we ascertained that mahogany processing was small or non-existent. The questionnaires were designed to provide data on company age, mill type, equipment, annual production, species sawn, wood sales, and degree of vertical integration. In five of the wood companies that processed mahogany exclusively, we also gathered data on costs of wood processing, transport, storage, and export.

3.2. Logging yields and damage associated with mahogany logging

We also studied logging yields and logging damage in Area 1 and in two other sites (Areas 2 and 3, Fig. 1). Areas 1 and 2 (Fig. 1), located north of Tucumã, appeared to be typical, in terms of forest structure and mahogany abundance, of the forest in the Upper Xingu Basin. Area 3, located south of Tucumã (Fig. 1), was one of the few remaining remnants of unlogged forest in that region. Loggers consistently reported that the forest in the vicinity of Area 3 was unusually rich in mahogany.

After a general reconnaissance of the three logging sites, we selected a representative area (about 100 ha) in each and mapped all logging roads, skid trails, and cut mahogany trees. We estimated the volume of all felled mahogany trees by multiplying the length of the bole by the average basal area (determined by measuring bark-free log diameter at the base and the top of each log). The total area of each extraction site was estimated using a variation of the Point Quarter method (Brower and Zar, 1984) and by planimetry using site maps.

Using information on the area of roads, skid trails, and log landings in each extraction site and the pre-harvest density of trees in the forest, we were able to estimate the number of trees of at least 10 cm diameter at breast height (dbh) damaged due to machine movements. Area estimates of roads and log landings included the edge zones where soil and debris were piled. We estimated the damage associated with the felling of the mahogany trees by noting all damaged trees in 40 tree felling openings (ten in Area 1 and 15 in each of Areas 2 and 3). The damaged trees were classified by damage type (i.e. uprooted, broken crown, or severe bark scaring). The area of each mahogany opening was also estimated by establishing a central point in each gap and measuring, at intervals, the distance and compass degrees to the gap edge. These measurements were used to construct a scale map of each gap and the area was determined by planimetry.

3.3. Characteristics of the post-logged forest

3.3.1. Stocks of other timber species remaining after mahogany logging

We identified and measured the dbh (or in the case of trees with buttresses, diameter above the buttresses) of all trees of at least 30 cm dbh in two parallel 20 m × 1000 m plots, spaced approximately 400 m apart, in Areas 1, 2, and 3; trees of 10–30 cm dbh were tallied in a 10 m × 1000 m plot nested in each of the larger plots. All trees encountered in these plots were classified into three quality groupings: (1) species with present value (accepted by some Amazonian sawmills; (2) species with future value (wood used for rural construction but generally not sawn in Amazonia at present); (3) species with no known construction use. The physical condition of all individuals in the first two categories was evaluated considering bole length, bole form, and crown form.

3.3.2. Prospects for future mahogany harvests

We tallied all mahogany seedlings and saplings (1–9.9 cm dbh) in ten 10 m × 20 m subplots located at 100 m intervals in each of the 20 m × 1000 m plots in Areas 1, 2, and 3.

We directed a second round of regeneration sampling at old treefall openings created by past mahogany cutting. We did this by locating a total of 69 mahogany gaps in four areas that were logged between 1979 and 1988 (Areas 4–7, Fig. 1). In each gap opening we established one 5 m × 15 m plot, extending from the stump of the cut tree toward the remnants of the downed crown. All mahogany seedlings (over 25 cm tall) and saplings were tallied and measured for height in each plot.

3.4. Social consequences of mahogany logging

Based on an analysis of Landsat images, informal interviews, and extensive travel in the study region, we assembled a working map of the road system built by loggers. The lands surrounding this road network are being claimed by small farmers and large land holders. We studied the process of land settlement by small farmers along a 70 km stretch of one logging road, Morada do Sol, that ran north from the town of Tucumã (Fig. 1). First, we made a field map of all properties along this road; then we randomly selected 62 families (20% of all households) and interviewed each concerning family history, property size, and land uses. To understand the role of the larger land-holders in post-logging settlement activities, we conducted additional interviews at 20 properties greater than 1000 ha located in the vicinity of the Morada do Sol road.

Finally, we evaluated the impact of mahogany logging on Indians by visiting Indian Reserves where mahogany logging had taken place and by consulting research documents.

4. Results and discussion

4.1. Economic analysis of mahogany companies

Fig. 2 provides a schematic view of mahogany logging, processing, and commercialization activities as they were occurring in the early 1990s in the study region. Mahogany was first extracted from the forest and transported several hundred kilometers, on roads built by logging companies, to sawmills located in the towns of Tucumã and Redenção. After processing, the mahogany destined for export was transported 700–1000 km by truck to the port of Belém, where it was graded and loaded on ships destined principally for the US and UK. The remaining production was trucked to the south of Brazil for domestic uses.

We divide our analysis of mahogany company costs and returns into six phases: (1) purchase of logging rights; (2) forest reconnaissance and tree felling; (3) extraction of boles from the forest; (4) transporting logs to the mill; (5) processing; (6) commercialization. Frequently, all six steps are coordinated by individual vertically integrated companies.

4.1.1. Purchasing logging rights

Mahogany loggers frequently purchased logging rights from land holders of the parcels being logged. Based on interviews with sawmill owners, we estimate that logging fees were paid on about 70% of the mahogany harvested between 1990 and 1992. These fees, paid on a cubic meter basis, varied from \$15 to \$70 m^{-3} (mean ± SD \$40 ± 12.6 m^{-3}; $n=9$; Table 1) in 1992. The total cost of purchasing logging rights for the logging operation that we studied was \$220 000 (5500 m^3 × \$40 m^{-3}; Table 1). Logging fees were usually not paid on remote government lands or sparsely settled Indian lands.

4.1.2. Reconnaissance and tree felling

Forest tracts containing mahogany were frequently located using small airplanes: pilots searched for mahogany in low-lying terrain, distinguishing it from other species by its large, shiny, light-green crown. Once mahogany-rich zones were detected, woodsmen entered to locate the trees. They cut trails through the forest using a system of arrows and notchings to signal tree locations to the chainsaw operators that followed them. These reconnaissance and cutting activities occurred during the rainy months, March through May; the boles were extracted and transported to the mills during the dry season, from June through November.

The extraction team that we observed required approximately 3 months to locate and cut 1200 mahogany trees (5500 m^3). The cost was approximately \$25 000, or \$4.60 m^{-3}, divided between salaries (60%), air support (13%), food (15%), fuel (7%), and miscellaneous costs (7%) (Table 2). Mahogany stocking will influence these costs: in areas where mahogany is more or less abundant than the case considered here, costs per cubic meter should decrease, or increase, accordingly.

4.1.3. Extraction of logs from the forest

After the trees had been felled, D-6 bulldozers opened roads and log landings. Then, rubber-track skidders were guided by woodsmen to the felled trees to drag the boles (10–20 m long) to log landings. Once at the landings, the boles were cut into 4–7 m sections, appropriate for transport.

Approximately 2 months were required to skid the 1200 trees (5500 m^3) in the extraction operation that we studied. The total cost was approximately \$131 000 or \$23.80 m^{-3} divided among salaries and benefits (31%), machine maintenance (21%), depreciation (22%), and miscellaneous costs (26%) (Table 1).

4.1.4. Transportation of logs to mills

The mean (± SD) distance from extraction areas to the processing mills in the study region was 245 ± 130 km ($n=19$). For the extraction

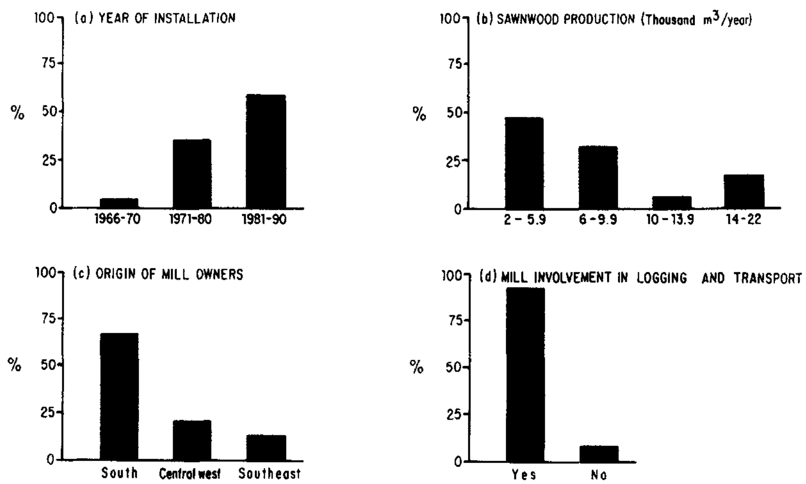

Fig. 3. Characteristics of the mahogany industries in southern Pará State, Brazil, considering: (a) year of installation; (b) annual production of sawn wood; (c) region of origin for mill owners; (d) mill involvement in forest extraction.

Table 3
Estimates of costs and profits (in dollars) for small and large mahogany companies in southern Pará State, Brazil, 1992

Category	Small mahogany company[a] (4500 m^3 $year^{-1}$)	Large mahogany company[a] (15 000 m^3 $year^{-1}$)
Receipts		
Value of production[b]	3 122 100	10 407 000
Value of processed mahogany (m^{-3})	694	694
Costs		
Harvest and log transport to mill[c]	1 504 800	5 016 000
Cost of processed mahogany (m^{-3})	334	334
Processing[d]	237 600	792 000
Cost of processed mahogany (m^{-3})	53	53
Commercialization		
Transport from mill to port[e]	148 500	495 000
Port infrastructure[f]	67 000	105 000
Transport to docks[g]	13 800	45 000
Dock fees[h]	108 000	360 000
Commercialization total	337 000	1 005 000
Cost of processed mahogany (m^{-3})	75	67
Taxes[i]	163 350	544 500
Cost of processed mahogany (m^{-3})	36	36
Total costs	2 242 750	7 357 500
Cost of processed mahogany (m^{-3})	498	490
Profits		
Net profit	879 350	3 049 500
Net profit of processed mahogany (m^{-3})	195	203

[a] The average annual sawn wood production for mills with one band saw was approximately 4500 m^3 (mean 4417; $n=17$; SD 1459); average production for large mills (with two or more band saws) was 15 000 m^3 (mean 14958; $n=7$; SD 2058).

[b] Minimum official prices for mahogany for exports are based on the following quality classes: (1) 'fas' \$670 m^{-3} (represents 50% of marketed volume); (2) 'select' \$570 m^{-3} (20% of marketed volume); (3) 'better common' \$505 m^{-3} (20% of volume); (4) 'nos 1 and 2 common and shorts' \$400 m^{-3} (10% of volume). Interviews with five owners of mahogany industries involved in exporting revealed that these minimum prices ran about 15% below actual prices. Hence, we adjusted the sale price accordingly (i.e. fas \$788 m^{-3}, select \$670, better common \$594; nos 1 and 2 common and shorts \$470.

[c] Given that 2.2 m^3 of mahogany roundwood produced 1 m^3 of sawn wood, the small mill would require approximately 9900 m^3 of roundwood, and the large mill approximately 33 000 m^3. The cost of mahogany extraction and transport was \$152 m^{-3} (Table 1). Hence, the cost to get the mahogany logs to the mill is estimated at \$1 504 800 for the small mill (9900 m^3×\$152 m^{-3}) and \$5 016 000 (33 000 m^3×\$152 m^{-3}) for the large mill.

[d] The cost to process 2.2 m^3 of mahogany roundwood (yielding 1 m^3 of sawn wood) was approximately \$24 m^{-3} ($n=5$ mill owners, SD 6.2). This cost includes allocations for salaries, worker benefits, energy, fuel, maintenance, depreciation, telephone, office supplies, as well as the cost of capital. Hence, the processing cost for the small mill was \$237 600 (9900 m^3×\$24); processing cost for the large mill was \$792 000.

[e] Mahogany destined for export was transported from southern Para to the port city of Belém (about 1000 km distance) at a cost of \$33 m^{-3} ($n=5$ companies; SD 7.5) or \$148500 for the small mill (4500 m^3×\$33) and \$495 000 for the large mill.

[f] The mahogany wood companies maintain offices and warehouses in Belem. The cost of maintaining this infrastructure was estimated at \$67 000 for small companies and \$105 000 for big companies.

[g] The cost to transfer wood from warehouses in Belem to the port (approximately 10 km) was approximately \$3 m^{-3} ($n=5$ industries; SD 1.2). Hence, for the small mill, this cost would be \$13 500 (4500 m^3×\$3 m^{-3}), and for the large mill, \$45 000.

[h] There was a port tax of \$12 m^{-3}. The cost for loading the wood on ships was also \$12 m^{-3} ($n=5$ industries; SD 4.7) and included the costs of weighing, stacking, and storing the wood. Hence, total dock and loading fees were \$24 m^{-3} or \$108 000 for a small mill (4500 m^3×\$24 m^{-3}) and \$360 000 for the large mill.

operation that we monitored, the distance from forest to the mill was 320 km and the total transport cost for the 5500 m^3 of mahogany logs was approximately $418 000 or $76 m^{-3} (Table 1). This included freight fees (57%), cost of road construction (26%), salaries and benefits (5%), fuel (5%), and maintenance and depreciation (7%). Hence, the cost to transport 1 m^3 of wood was $0.24 km^{-1} or $76 per 320 km.

4.1.5. Mahogany processing

We recorded 86 mills operating in the study region in 1992 with most mills concentrated in the towns of Tucumã and Redenção. Of these, 24 specialized in mahogany processing (Fig. 1). These 24 were responsible for about 90% of all mahogany processing in southern Pará

We focused our analysis on these 24 mills that specialized in mahogany processing. Fourteen of these mills were established in the 1980s, with another nine starting in the 1970s and just one mill operating in the 1960s (Fig. 3(A)). These mahogany mills were family operations. Their owners came to Amazonia from southern Brazil (Fig. 3(C)). Forty-seven percent of the mills produced 2000–6000 m^3 of sawn wood $year^{-1}$: 37% produced 6000–10 000 m^3 $year^{-1}$, and 16% produced more than 10 000 m^3 $year^{-1}$ (Fig. 3(B)). Approximately 88% of total production was sawn boards, with the remaining 12% veneer destined for plywood and furniture facing.

The equipment used in both small and large mills was the same; the difference was that small mills had one band saw, whereas large mills had two or three band saws. We estimate that approximately $24 ± 6.2 were spent in the processing of each cubic meter of mahogany roundwood ($n=6$). This included the costs of salaries, worker benefits, energy, fuel, maintenance, depreciation, infrastructure, office supplies, and communication (Table 3). This agrees with results from a more intensive study of mill operating costs (Verissimo et al., 1992) conducted in the same state. Hence, the milling cost to produce 1 m^3 of mahogany boards was estimated at $53 (2.2×$24).

4.1.6. Mahogany commercialization

We estimate that 70% of the total mahogany sawn wood production of the 24 mahogany mills went to the export market. Some large mills exported all of their production. Sixty-five importing companies purchased this mahogany, but here too, a few large companies dominated: five importers received 60% of Pará's total mahogany exports in 1992.

The commercialization cost for mahogany destined for export ranged from $67 to $75 m^{-3} of sawn wood (Table 3). Approximately 45% of this cost was a freight fee to transport the sawn wood from the mills in southern Pará to the port of Belém and the remainder was for local transport, dock, and shipping fees (Table 3).

4.1.7. Profitability

We now combine the cost information detailed above and in Tables 1 and 2 with information on the value of mill production (Table 3) to estimate the profits of mahogany companies. We consider a typical small mill (one band saw: production of sawn boards 4500 m^3 $year^{-1}$)

[i] Wood destined for the export market was taxed at 6% of the minimum official sale price. For a 'small' company producing 4500 m^3 of sawn mahogany, we calculate the tax as follows: (1) 450 m^3 (10% of production)×$400 m^{-3} (official price for shorts and common)×0.06=$10 800; (2) 900 m^3 (20% of production)×$505 m^{-3} (official price for 'better common')×0.06=$27 270; (3) 900 m^3 (20% of volume×$570 m^{-3} (official price for select)×0.06=$30 780; (4) 2250 m^3 (50% of volume)×$700 m^{-3} (price for fas)×0.06 (tax for export)=$94 500. The total tax for this small mill comes to $163 350. A similar procedure was used for the big mill. Note: at the time of this writing there was a judicial dispute between the wood sector and the Pará government. The state was mandating a 10.5% tax on sawn wood. We applied a 6% tax in this analysis because that is what mills were actually paying in the early 1990s. If the tax rate was 10.5%, the tax would climb from $36 to $63 m^{-3}.

and a typical large mill (three band saws: production of 15 000 m^3 $year^{-1}$). Most of the mills specializing in mahogany had just one band saw but three companies, each with three band saws and an average annual production of approximately 15 000 m^3, were responsible for one-third of all mahogany processing in Pará in 1992.

Since most mahogany mills (91%; Fig. 3(D)) engaged in forest extraction, we consider that the mills in our example do their own extraction. The cost to cut, extract, and transport mahogany logs to the saw mill gate was approximately \$152 m^{-3}, divided among purchase of logging rights (\$40 m^{-3}), reconnaissance and tree felling (\$4.60 m^{-3}), extraction (\$23.80 m^{-3}), transport of logs to the mill (\$76 m^{-3}—assuming that the forest is 320 km from mill), taxes (\$3.00 m^{-3}), and capital investment cost (\$4.6 m^{-3}) (Tables 1 and 2). The logging and transport cost per cubic meter of processed wood was \$334 (2.2 $m^3 \times$\$152). The remaining costs include processing (\$53 m^{-3}), commercialization (\$75 m^{-3}), and taxes (\$36 m^{-3}). Therefore, the total cost of producing 1 m^3 of sawn mahogany was approximately \$498 and \$490 m^{-3}, for the small and large mill, respectively (Tables 1, 2, and 3).

The average output of the small mill was 4500 m^3 of sawn mahogany per year, with gross returns of approximately \$3 122 100 or \$694 m^{-3} of sawn mahogany. Annual profits were approximately \$879 000 or \$195 m^{-3} of sawn mahogany (Table 3). In the case of the large company, the average estimated total return was \$10 407 000 with costs of \$7 357 500 and final profits, approximately \$3 050 000, or \$203 m^{-3} of sawn mahogany (Table 3).

Most (88%) of the 24 mahogany mills in the study region had invested at least some of their profits in other economic activities in the region (e.g. ranching, cacao plantations, automobile dealerships, soft drink distributors, and shipping companies).

Timber harvesting and processing have been shown to be lucrative in other regions of the eastern Amazon (Uhl et al., 1991; Verissimo et al., 1992). Wood companies outside the mahogany belt rely on dozens of moderate and low value species. The exceptionally high value of mahogany places wood industries that specialize in this species in a class apart: net returns per cubic meter of sawn wood are several times greater than that recorded for mills in other regions.

4.1.8. Factors that cause variation in profitability

Three factors exert a strong influence on the profits of mahogany companies: transport costs, logging fees, and market prices for processed mahogany boards. Transport costs differ among the operations that we examined because transport distances from forest to mill varied by more than ten-fold (from 50 to over 500 km). In general, the more distant the extraction site from the mill, the higher the transport cost. In contrast, the cost of purchasing logging rights usually declines with distance from the mill. Hence, while operators extracting mahogany at 500 km will have greater transport costs, they often do not have to purchase logging rights because the land is unoccupied or because the native inhabitants are ill-equipped to bargain with loggers.

Two examples are helpful here. First, consider an operation just 50 km from the processing center of Tucumã (Fig. 1). In this case, the transport cost would be roughly \$12 m^{-3} (the cost of transportation being \$0.24 m^{-3} km^{-1}; thus 50 km$\times$\$0.24 m^{-3}) or 15% of the base case given in Table 1. Meanwhile, the cost of purchasing logging rights is generally higher than average—about \$70 m^{-3}—for such 'close' sites. Hence, the total reconnaissance, cutting, extraction, and transport cost in this case would be \$117 m^{-3} (including taxes and costs of capital, Table 1), or 23% less than our base scenario (\$152, Table 1). Therefore, profits per cubic meter of processed mahogany would increase by \$35 in this example.

Now, consider the other extreme, an extraction operation located 600 km from the mill. In this case, the transport cost would be approximately \$144 m^{-3} (600 km$\times$\$0.24 m^{-3}). However, at this distance the forest frequently is unoccupied, and so there would be no logging fee. Hence, the final cost of extraction would be \$180, or 18% above the base scenario. In this case, profits per cubic meter of sawn wood would be \$28 less than the base scenario. These examples help to explain why profits margins may vary among companies and even within companies from year to year and also why mahogany can be extracted at such great distances.

Finally, fluctuations in the market price of mahogany contribute to annual variation in industry profits. For example, in the 5 year period from 1988 through 1992, the weighted market value of 1 m^3 of mahogany boards, considering the four value classes ('fas', 50% of production; 'select', 20%; 'better and common', 20%; 'nos. 1 and 2 common', 10%) ranged from \$530 to \$750 m^{-3}. Considering that the total cost to extract, process, and market 1 m^3 of sawn mahogany was approximately \$498 (Table 3) in 1992, the profit per cubic meter of sawn mahogany may have varied by up to tenfold between 1988 and 1992 from \$32 (\$530 – \$498) to \$252 (\$750 – \$498). Hence, while mahogany companies can realize substantial profits, the margin of profit fluctuates widely.

4.2. Logging yields and damage associated with logging

Mahogany trees are not distributed uniformly over the landscape. Also, the density of mahogany stems in those forest tracts where mahogany is present varies greatly. For example, there was a seven-fold difference in large mahogany tree density in the three extraction sites that we studied (Table 4).

Considering Sites 1, 2, and 3 together, an average of one mahogany tree was extracted per hectare; the average volume extracted per hectare was 5 m^3, varying from 1.3 m^3 (Area 1) to 11.3 m^3 (Area 3) (Table 4). The average diameter of the harvested trees was 75 ± 21.2 cm dbh (range 36–155 cm; $n = 245$) and the average volume per tree was 5.4 ± 3.7 m^3. These averages and ranges are typical for other mahogany extraction areas in the Brazilian Amazon (De Barros et al., 1992).

Damage to the vegetation was caused during the felling of mahogany trees and in the opening of skid trails, logging roads, and log landings (Fig. 4). For each mahogany tree harvested, 58 m of logging road was opened, equivalent to 583 m^2 of scraped ground and debris surface per harvested tree. In addition, for every harvested tree, the skidder traversed, on average, 125 m of forest affecting approximately 493 m^2 of forest understorey. Finally, an average of 368 m^2 of forest canopy was eliminated with the extraction of each tree.

Damage indices (Table 4) reveal that 31 trees were damaged for each mahogany tree extracted (average of Sites 1, 2, and 3). The majority of these damaged trees (68%) were pushed over; 29% suffered trunk breakage or significant crown loss; and the remaining 3% experienced extensive bark removal. Expressing damage in volumetric terms, approximately 3 m^3 of wood were severely damaged for each cubic meter of mahogany extracted (Table 4). The most lightly harvested site (Area 1 with 1.5 m^3 removed ha^{-1}) had the highest damage ratio (4.8 m^3 damaged m^{-3} harvested). By contrast, in Area 3, where 11.4 m^3 ha^{-1} was harvested, only 1.5 m^3 was damaged per cubic meter harvested.

Two points must be considered in interpreting these damage data. First, these estimates do not include the damage caused in the construction of feeder roads that link extraction sites to main roads. Frequently, several or even tens of kilometers of feeder roads separate the forests tracts that contain mahogany. We were not able to accurately estimate this component of logging damage, but judge that the inclusion of these feeder roads in our analysis would increase, perhaps markedly, the estimates of the number of trees and volume damaged per mahogany tree harvested. Second, while reports that a certain number of trees or certain volume is damaged for each unit harvested provide a useful benchmark, such ratios do not say anything about how the forest as whole is affected by mahogany logging. Because mahogany trees are usually distributed in widely scattered patches, only a small fraction of the region's forest has been directly disturbed by this logging. Hence, we believe that the direct impact of mahogany logging on the structure and function of the regional forest ecosystem has been small. Nonetheless, the species-specific impact on *Swietenia macrophylla*—its population numbers and genetic variation—may be significant.

Table 4
Forest characteristics and logging damage in three mahogany extraction areas in southern Pará State, Brazil

	Area 1	Area 2	Area 3	Mean
General characteristics of extraction site				
Size of extraction area (ha)	166	114	74	118
Basal area (m^2 ha^{-1} for trees ≥ 10 cm dhb)	17.4	12.7	10.3	13.5
No. trees extracted ha^{-1}	0.3	0.5	2.1	1.0
Volume (m^3) extracted ha^{-1}	1.3	2.5	11.4	5.0
Size of harvested trees				
Mean diameter (cm dbh) of harvested trees (SD)	72 (21.4)	82 (24.8)	72 (18)	76
Volume (m^3) per harvested tree (SD)	4.7 (2.7)	5.9 (4.2)	5.7 (4.2)	5.4
Largest tree harvested (cm dbh)	111	155	142	136
Smallest tree harvested (cm dbh)	44	45	36	42
Damage caused in logging				
Trees ≥ 10 cm dbh damaged (no. ha^{-1})	12.8	13.5	30.6	19
Volume ≥ 10 cm dbh damaged (m^3 ha^{-1})	6.3	5.7	17.6	9.9
Damage indices				
Trees damaged per tree extracted	43	32	15	30.7
m^3 damaged m^{-3} extracted	4.8	2.3	1.5	2.8
m^2 logging road opened per tree extracted	873	605	270	583
m^2 skid trail opened per tree extracted	777	455	246	493
m^2 canopy opened per tree extracted	435	344	324	368
Total area (m^2) affected per tree extracted	2085	1404	840	1443

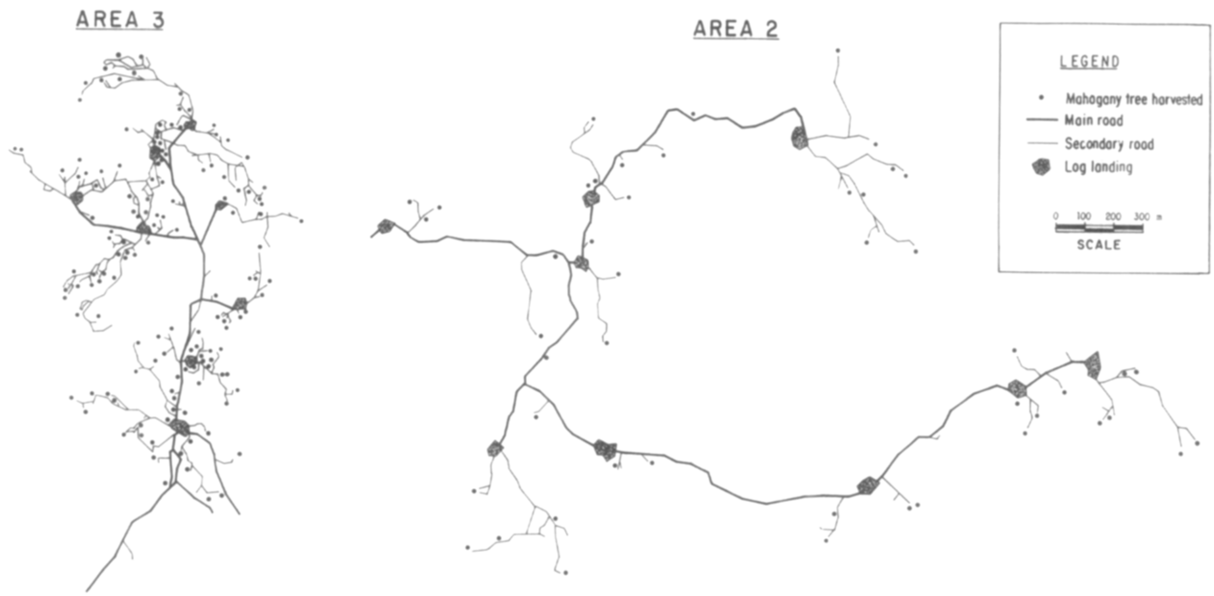

Fig. 4. A scale map of Area 2 and Area 3 mahogany logging sites in southern Pará State, Brazil, showing locations of logging roads, log landings, and cut trees.

4.3. Characteristics of the post-logged forest

4.3.1. Stocks of timber species remaining after mahogany logging

We found an average of 53 trees ha^{-1} with dbh of at least 30 cm in our three study sites (Areas 1, 2, and 3; Table 5). Of this total, 13.4 individuals ha^{-1} had good form and were of species processed by mills in other regions of Amazonia, and 4.5 individuals ha^{-1} had good form and belonged to species with potential wood use. However, there were only 0.25 mahogany trees ha^{-1} of at least 30 cm dbh. The remaining 35 trees ha^{-1} were of no use to the wood companies, either because of severe defects or because of inferior or unknown wood properties. Expressed in volumetric terms, there were, on average, 31.3 m^3 ha^{-1} of wood at least 30 cm dbh in the sawable category (only 0.3 m^3 of this being mahogany), 13.1 m^3 ha^{-1} in the potential-use category, and 51.3 m^3 ha^{-1} without wood-related uses (Table 5). These volumes are low compared with volumes left after selective logging further to the north in Pará State (Uhl et al., 1991; Verissimo et al., 1992).

In the smaller diameter classes (10–29.9 cm dbh), there were, on average, 34 ± 7.4 trees ha^{-1} with present or potential value in the sample plots. Not one mahogany tree was found in these plots (total sample area 6 ha). There were also 175 ± 22.2 trees ha^{-1} in this 10–29.9 size category with no known wood-related uses. Expressed as wood volume, there were 8 ± 1.6 m^3 ha^{-1} between 10 and 29.9 cm dbh, with present or potential value and 33 ± 5.2 m^3 ha^{-1} with no apparent potential to produce sawn wood.

4.3.2. Prospects for future mahogany harvests

The prospects for a second mahogany harvest in our three study areas do not appear to be good. The average volume of mahogany trees at least 30 cm dbh for the three areas was only 0.3 m^3 ha^{-1} (Table 5) or 6% of the average volume present just prior to harvest (Table 4). The apparent absence of mahogany between 10 and 30 cm dbh also puts future harvests in doubt. Furthermore, we failed to find any saplings (1–10 cm dbh) in the sixty 10 m×20 m plots spread at 100 m intervals in the 1000 m×20 m plots in Areas 1, 2, and 3.

Surprised by the lack of regeneration in our study sites, we decided to visit four sites where mahogany had been extracted in the recent past (Sites 4, 5, 6, 7; Fig. 1). We found mahogany regeneration in 21 of the 69 mahogany gaps (plot area 75 m^2 per gap) that we sampled. The average number of mahogany treelets per plot was 0.46 ± 0.28 or 0.006 m^{-2}. The vegetation was dense in these gaps and the mahogany treelets that were present were no bigger than the sur-

Table 5
The density and volume of trees by wood-value classes in three mahogany extraction areas in southern Pará State, Brazil

	Number of volume of trees ≥ 30 dbh present after mahogany logging									
	Swietenia macrophylla		Individuals with present-day wood uses[a]		Individuals with wood of potential use[b]		Individuals without wood use[c]		Total	
	No. ha^{-1}	Vol. ha^{-1}	No. ha^{-1}	Vol. ha^{-1}	No. ha^{-1}	Vol. ha^{-1}	No. ha^{-1}	Vol. ha^{-1}	No. ha^{-1}	Vol. ha^{-1}
Area 1	0	0	23.6	60.7	3.0	6.5	51.5	78	78.1	145.2
Area 2	0.5	0.5	5.7	10.9	7.2	25.4	31.1	41.2	44.5	78
Area 3	0.25	0.4	11	21.6	3.5	7.4	23	34.8	37.7	64
Mean	0.25	0.3	13.4	31	4.5	13.1	35.2	51.3	53.4	95.8

[a] Includes only individuals of species that are sawn at present in the eastern Amazon and that had good form and defect-free boles.
[b] Includes defect-free individuals of species that could be sawn if a market existed.
[c] Includes individuals that were deformed or damaged or that belonged to species that have no known potential wood uses.

Table 6
Presence of *Swietenia macrophylla* regeneration in 1991 in openings created during mahogany extraction events from 1981 to 1987 in southern Pará State, Brazil

Study area no.	Year of extraction	No. of gaps sampled	Mean number mahogany plants per 75 m^2 plot (SD)
4	1981	40	0.68 (0.009)
5	1988	15	0.46 (0.006)
6	1987	4	0.0 (0.0)
7	1987	10	0.7 (0.009)

rounding regeneration. Hence, it is doubtful if the mahogany treelets that we found will grow to be adult trees.

The poor representation of mahogany in the sapling and seedling size classes is somewhat surprisingly given that adult mahogany trees produce thousands of wind-dispersed seeds each year (Lamb, 1966). The scantiness of mahogany regeneration in extraction openings in Areas 4–7 may be associated, in part, with the scarcity of mature mahogany trees after logging. Studying natural regeneration of mahogany in Mexico, Snook (1993), attributed poor regeneration to the absence of large seed trees and also to the absence of large, light-rich openings. Poor mahogany regeneration has also been observed in Central America and in various countries of Amazonia (Lamb, 1966; Johnson and Chaffey, 1973).

In summary, based on our limited sample, it appears that mahogany may be rare in both small (sapling) and intermediate (10–50 cm dbh) size classes in logged forest in southern Pará. Hence, it might be many years (easily more than 100) before a second mahogany cut could be possible. The scarcity of mahogany in the middle size range suggests that mahogany populations are not replacing themselves. Mahogany requires large, well lit openings to grow well. The relatively small (200–400 m^2) and widely scattered (average of 1 ha^{-1}) openings created in mahogany logging may not be adequate to permit the natural regeneration of this species. Indeed, it may be that the present-day cohort of large mahogany trees established after large-scale disturbances, such as fire, several hundred years ago and have not been able to effectively reproduce since that time (see Gullison and Hubbell (1992) for a discussion of the disturbance ecology of mahogany).

4.4. Social consequences of mahogany logging

4.4.1. Mahogany logging as a catalyst for deforestation

When examining government maps, it appears that the zone of mahogany occurrence in the south of Pará State is a vast expanse of intact forest (Fig. 1). However, there is a network of logging roads that criss-cross this region. We estimate that some 3000 km of roads have been constructed by loggers. Many of these roads radiate out from the town of Tucumã.

In addition to providing loggers with access to mahogany stocks, these roads offer entry points for settlers seeking land. For example, from 1985 to 1992, human colonists pushed steadily northward from Tucumã in annual increments of 25–50 km along the principal logging road, Morada do Sol (Fig. 5). At least two mahogany companies were involved in building this road.

The land bordering the first 70 km of this road was occupied by immigrants, each staking a claim to 50–100 ha. Sixty percent of the colonist families we interviewed ($n=62$) came from Brazil's central west region, while 34% were from the northeast; none were from Amazonia. These colonists were practicing slash-and-burn agriculture and many (85%) had established small pastures. Forty percent of the land in these small holdings was deforested within the 7 year period, 1985–1992.

The land bordering the road from km 70 to the beginning of the Apyterewa Indian Reserve at km 120 (Fig. 5) was claimed by two mahogany com-

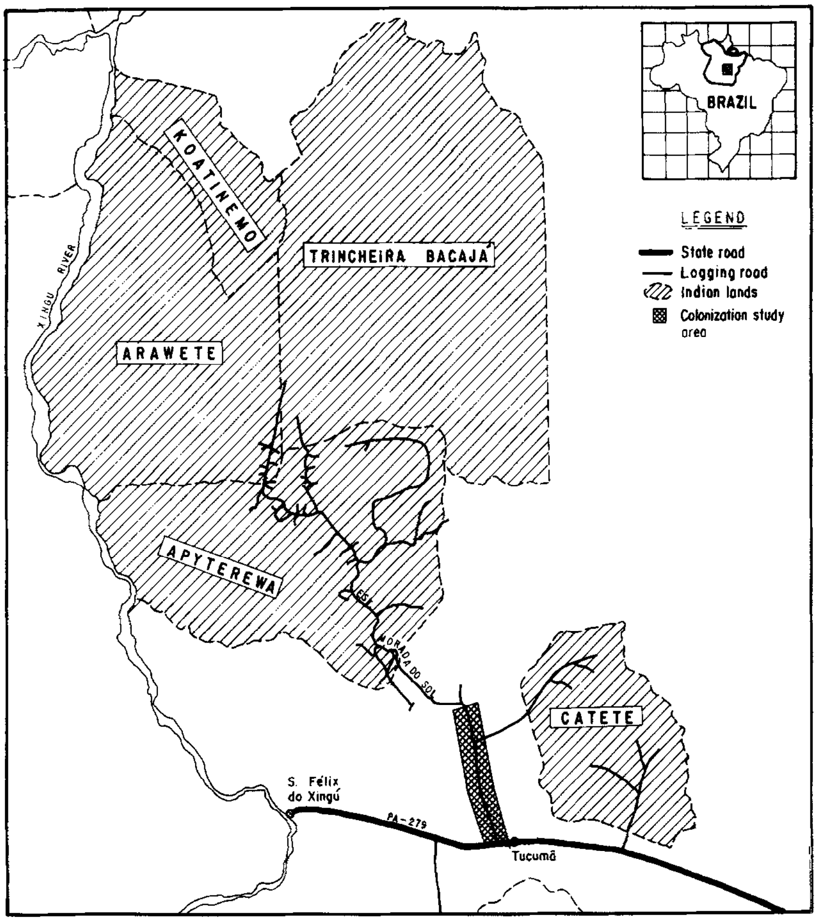

Fig. 5. Location of the road, Morado do Sol and the colonist lots bordering this road in southern Pará State, Brazil.

panies. Beyond km 120, the road traversed the Apyterewa Indian Reserve and then penetrated the reserves of the Arawetê and Trincheira Bacajá Indians. Mahogany was extracted from these lands from 1987 to 1992 by two other mahogany companies, one of which claimed 70 000 ha in the vicinity of km 180.

There was some indication that mahogany companies laying claim to lands, 150–200 km from their processing mills, were inclined to convert part of the forest to cattle pasture after mahogany extraction. This is perhaps, in part, because the timber species remaining in the forest are valued at only about 20% of mahogany. It is not economically feasible, at present, to extract these comparatively low value species much beyond 75 km of Tucumã. Furthermore, conversion of forest to pasture continues to be an effective way to lay claim to land in this region. Finally, ranching may prove to be a lucrative land use, particularly with the introduction of improved forages and better approaches to herd management (Mattos and Uhl, 1994).

The fate of forested land beyond 200 km of Tucumã is less clear. In some cases, large companies have made land claims. In other cases, mills harvest the mahogany and abandon the area. The alleged reason is that land titling fees and land taxes are too high to justify occupation of these lands.

In summary, there are indications that, within a 200 km radius of the mahogany processing center of Tucumã, mahogany logging is the first step in a colonization process involving slash-and-

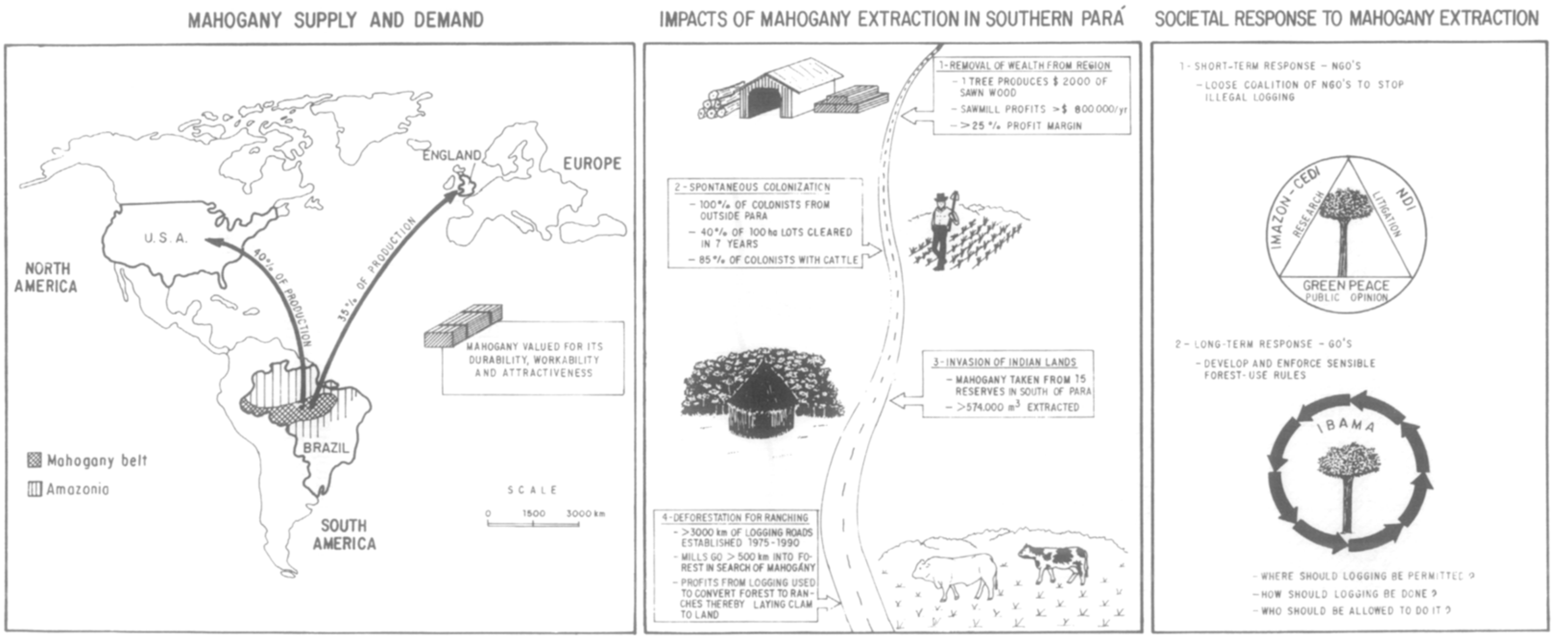

Fig. 6. Summary of the causes and consequences of mahogany logging and societal response to this activity. Left, foreign demand creates market for mahogany; center, industry profits are robust but logging affects Indian cultures and leads to deforestation; right, in absence of government presence, national and international NGOs seek to promote sustainable mahogany logging.

burn agriculture and ranching. The near-term fate of the more distant forest tracts (200–600 km), now supplying most of the mahogany reaching the Tucumã mills, is still conjectural. It may be that another Tucumã-type logging town will spring up in the midst of this logging territory.

4.4.2. Impacts of mahogany logging on Indians

Some 120 Indian groups speaking 45 different languages occupy an estimated 472 100 km^2, divided into 160 reserves spread across the southern flank of the Brazilian Amazon (Heringer, 1993). Indeed, about one-third of mahogany's range in Amazonia coincides with Indian lands. In Pará alone, there are 15 Indian Reserves occupying 162 430 km^2 (Fig. 1).

The first reported incidence of commercial mahogany extraction on Indian lands dates to 1975, but it was in the 1980s that this extraction increased significantly (Centro Ecumênico de Documentação e Indormação (CEDI), 1993). With the help of the Federal Agency for Indian Affairs (FUNAI), the Kayapo Indians were the first to sell logging rights. Of 257 documented cases of mahogany extraction on Indian lands in the Brazilian Amazon between 1975 and 1992 reported by CEDI (1993), 26 were arranged through the mediation of FUNAI and 99 were the result of direct negotiations between Indians and loggers. In the remaining 132 cases, mahogany was apparently extracted without Indian consent.

We found that 45% of the mahogany extractors that we interviewed in southern Pará (n=24) in 1991 were extracting mahogany from Indian lands. By the end of 1992, mahogany extraction had occurred in all 15 reserves in southern Pará (CEDI, 1993; Heringer, 1993). The total volume of mahogany extracted from these reserves, up to 1992, was at least 574 000 m^3 (Heringer, 1993).

Because of the great cultural diversity of Indians in the region, some groups have been keen to sell logging rights to the mahogany companies (e.g. Kayapo), while others have shunned the loggers. Although it appears inevitable that all these Indian groups will eventually be introduced to modern Brazilian culture, the advance of mahogany loggers into Indian lands jeopardizes a planned and sensitive cultural transition.

4.5. *Prospects for sustainable mahogany production*

We pointed out that mahogany trees were scarce in the medium and small size classes in our study areas. This suggests that the prospects for a future mahogany harvest are poor unless steps are taken to encourage the regeneration of this species. There are three strategies that have been considered: (1) adopt measures to increase natural regeneration of mahogany; (2) plant mahogany in logged forest; (3) establish plantations of mahogany in open areas.

Specific steps could be taken to increase the natural regeneration of mahogany. For example, large seed trees could be left in areas opened during logging (e.g. in the vicinity of log landings). Additionally, felling could be concentrated at the end of the dry season (September through November), just after seed drop (July and August) rather than prior to fruiting. Perhaps the best approach of all would be to enter mahogany stands several years prior to the cut to poison girdle trees in the vicinity of the large mahogany trees targeted for harvest. The increased light afforded by the death of these neighboring trees together with several years of seed rain from the big mahogany trees might ensure the establishment of a vigorous cohort of mahogany seedlings and saplings by the time the harvest occurs.

Even if such measures were successful, the cutting cycle would be long because of the seeming absence, at present, of mahogany trees between 10 and 50 cm dbh. If we assume a diameter increment of 0.8 cm year^{-1} (Gullison and Hubbell, 1992) and reliance on seedling regeneration for the next cut, a second harvest of mahogany might not be possible for another 80–100 years.

A more direct way to increase mahogany regeneration is to plant mahogany seedlings in the forest (i.e. enrichment planting). Four large mahogany companies in southern Pará have been introducing mahogany seedlings into their forest holdings following mahogany extraction. This is done by opening up 2–3 m wide swaths through the forest (10 swaths ha^{-1}) and planting mahogany seedlings every 10 m along these swaths. The total area planted by the four companies by 1992 was reported to be about 4000 ha. The effectiveness of enrichment planting, however, has not been demonstrated since growth has been slow in these line plantings (height growth less than 50 cm $year^{-1}$), perhaps owing to inadequate light levels (J. Zweede, personal communication, 1993).

A third option to encourage mahogany production is to plant mahogany seedlings in cutover areas (e.g. abandoned pastures). In 1992 one of the mahogany companies that had disappointing results with enrichment planting began to plant mahogany at a spacing of 7.5 m × 7.5 m in cleared areas together with corn. Mahogany trees in these open areas were 2.5–3 m tall after one year, and the owner reported that receipts from the corn harvest covered the cost of the mahogany planting (A. Malinski, personal communication, 1993). However, mahogany grown in plantations in other regions frequently suffers from attacks of *Hypsipyla grandella*. This insect kills the terminal bud and causes mahogany to lose form. Hence, although the initial performance of plantation-grown mahogany in southern Pará has been encouraging, much more time is needed to evaluate such initiatives.

5. Conclusion

In the early 1990s mahogany was by far the most valuable timber species in Amazonia. As a result, company profits were frequently large. Meanwhile, most of the demand for mahogany boards came from the United States and the United Kingdom (Fig. 6, left).

It appears that the mahogany trees remaining in the forest of southern Pará will be removed over the next several decades. The direct impacts of this harvest on forest ecosystems will probably be small—well within the bounds of natural perturbations. However, the specific effects on mahogany—its genetic structure and population size—may be significant. Moreover, the indirect impacts of mahogany logging are already noteworthy. The establishment of logging roads in this forest region is leading to haphazard settlement. Areas of logged forest are being converted to pasture before a systematic study of the wisdom of this conversion has been carried out. Loggers have also become the agents that frequently make initial contact with Indians and they are ill-equipped to assume this role (Fig. 6, center). Through all this, it is clear that the Brazilian government has had no coherent policy to assure that mahogany is harvested in a sustainable manner.

In the absence of government action, non-governmental organizations, both national and international, have been working together in novel ways to promote sustainable forestry practices in this region. Brazil's Greenpeace office, using information from two research-oriented NGOs, Instituto do Homem e Meio Ambiente da Amazônia (IMAZON), and CEDI and legal guidance from a litigation-oriented NGO, Núcleo de Direitos Indigenas (NDI), developed a campaign designed to keep mahogany loggers out of Indian Reserves and to require more sustainable extraction practices (Greenpeace Brasil, 1992) (Fig. 6, right). The US-based Natural Resources Defense Council (NRDC) spearheaded a campaign to have *S. macrophylla* listed on CITES, Appendix II, a move that would improve monitoring of the international trade of Amazonian mahogany. Finally, there is increasing interest in green labeling programs, also promoted by NGOs, designed to assure consumers that the wood they buy is coming from sustainably managed forests. To date, the Brazilian government has been lethargic in the face of these NGO initiatives, although it is hoped that IBAMA (Federal Institute of the Environment) will assume its role of land steward in the mahogany belt (Fig. 6, right). If the Brazilian government fails to act, it is likely that much of the Pará's public forest land bounded by Highway (Fig. 1) will be taken over in a haphazard fashion by private interests during the next few decades. However, the Brazilian government could establish an unambiguous presence in this region. Forests with forestry potential could be designated as working forests and effective licensing and concessionaire arrangements could be established. Indian groups, also could play a pivotal role in the development of sustainable land-use strategies for this region, insofar as they have knowledge of the biota and a long-standing commitment to their homelands.

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Note added in proof

Since the conclusion of this study in 1992 the debate over the merits and consequences of mahogany logging in Amazônia has continued. In November 1994 a proposal to list mahogany in Appendix II of CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) fell six votes short of the two-thirds majority needed for approval. Brazil and Bolivia, the principal producers of mahogany, voted against listing.

Meanwhile, the Brazilian government has not provided a concrete plan for the regulation of mahogany logging, and conflicts continue between loggers, Indians, and evironmentalists. As a result of one such conflict, the federal judiciary has temporarily prohibited logging in several Indian reserves in the southern Pará.

Through all this, the export of mahogany continues be extremely lucrative. There was a real price increase of about 15% for export quality sawn boards from 1992 to 1994.

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