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

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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 Tucuma and Redencao. 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 descined principally for the US and UK. The remaining production was trucked to the south of Brazil for domestic uses.

We devide our analysis of mahogany company costs and returns into six phases: (1) purchase of logging rights; (2) forest reconnaissance and free 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 fequently 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 /m³ (mean~SD \$40+/-12.6 /m³; n=9; Table 1) in 1992. The total cost of purchasing loggig rights for the logging operation that we studied was \$220 000 (5500 m³ x \$40 /m³; Table 1). Logging fees were usualy not paid on remote government lands or sparsely settled Indian lands.

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 enterd to locate the trees. They cut trails through the forest using a system of arrows and notchings to signal tree locations to 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 seasen, from June through November.

The extraction team that we observed required approximately 3 months to locate and cut 1200 mahogany trees (5500 m³). The cost was approximately \$25 000, or \$4.60 /m³, decided 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, rubbertrack skidders were guided by woodsmen to the felled trees to drag rhe boles (10-20 m long) to log landings. Once at the landings, the boles were cut into 4-7 m sections, appropriate for transport.

Approximatily 2 months were required to skid the 1200 trees (5500 m³) in the extraction operation that we studied. The total cost was approximatily \$131 000 or \$23.80 /m³ decided 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 operation that we monitored, the distance from forest to the mill was 320 km and the total transport cost for the 5500 m³ of mahogany logs was approcimatily \$418 000 or \$76 /m³ (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 m³ of wood was \$0.24 /km or \$ 76 per 320 km.

4.1.5. Mahogany processing

We recorded 86 millls operating in the study region in 1992 with most mills concentrated in the towns of Tucuma and Redencao. Of these, 24 specialized in mahogay processing (Fig. 1). These 24 were responsible for about 90% of all Mahogany processing in southern Para.

We focused our analysis on theses 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 m³ /year, and 16% produced more than 10 000 m³ of sawn wood /year. 37% produced more than 10 000 m³ /year (Fig. 3 (B)). Approximately 88% of total production was sawn boards, witz the remaining 12% veneer destined for plywood and furniture facing.

The equipment used in both small and large mills was the same; the differerence was that small mills had one band saw, whereas large mills had two or three band saws. We esitmate that approximatily \$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 m³ of mahogany boards was estimated at §53 (2.2x\$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 productions. 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 commercializaton cost for mahogany destined for export ranged from §67 to $75 /m³ of sawn wood (Table 3). Approximatily 45% of this cost was a freight fee to transport the sawm 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 abave 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 m³ /year) and a typical large mill (three band saws: production of 15 000 m³ /year). 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 m³, 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 transpoort mahogany logs to the saw mill gate was approximatily $152 /m³, dicided among purchase of logging rights ($40 /m³), reconnaissance and tree felling ($4.60 /m³), extraction ($23.80 /m³), transport of logs to the mill ($76 /m³- assuming that the forest is 320 km from mill), taxes (§3.00 /m³), and capital investment cost (§4.6 /m³) (Tables 1 and 2). The logging and transport cost per cubic meter of processed wood was §334 (2,2 m³ x $152). The remaining costs include processing ($53 /m³), commercialization ($75 /m³), and taxes (§36 /m³). Therefore, the total cost of producing 1 m³ of sawn mahogany was approximatily §498 and §490 /m³, for the small and large mill, respectively (Tables 1, 2, and 3).

The average output of the small mill was 4500 m³ of sawn mahogany per year, with gross returns of approximately $3 122 100 or $694 /m³ of sawn mahogany. Annual profits were approximately $879 000 or $195 /m³ of sawn mahogany (Table 3). In the case of the large campany, the average estimated total return was 4500 m³ of sawn mahogany. Annual profits were approximately $879 000 or $195 /m³ 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 /m³ 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 industies that spacialize 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 amomg the operations that we examined bacause 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 illequippet to bargain with loggers.

Two examples are helpful here. First, consider an operation just 50 km from the processing center of Tucuma (Fig. 1). In this case, the transport cost would be roughly $12 m³ (the cost of transportation being $0.24 m³ /km; thus 50 km x $0.24 m³) or 15% of the base case given in Table 1. Meanwhile, the cost of purchasing logging rights is generally higher then average – about $70 /m³ - for such “close” sites. Hence, the total reconnaissance, cutting, extraction, and transport cost in this case would be $117 /m³ (including taces 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 x $024 /m³). 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 then the base scenario. These examples help to explain why profits margins may very 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 1m³ 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 /m³. Considering that the total cost to extract, process, and market 1 m§ 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, the profit per cubic meter of sawn mahogany may have varied by up to tenfold between 1988 and 1992 from $32 ($530 - $398) 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 exaple, 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 m³, varying from 1,3 m³ (Area 1) to 11.3 m³ (Area 3) (Table 4). The average diameter of the harvested trees was 75+/-3.7 m³. There 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 m² of scraped ground and debris surface per harvested tree. In addition, for every harvested tree, the skidder traversed, on average, 125 m of forest affecing apporoximately 493 m² of forest understorey. Finally, an average of 368 m² 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 m³ of wood were severely damaged for each cubic meter of mahogany extracted (Table 4). The most lightly harvested site (Area 1 with 1.5 m³ of removed /ha) had the highest damage ratio (4.8 m³ damaged /m³ harvested). By contrast, in Area 3, where 11.4 m³ /ha was harvested, only 1.5 m³ was damaged per cubic meter harvested.

Two points must be considered in interprating 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 dammage, but judge that the inclusion of these feeder roads in our analysis would increase, perhaps markedly, the estimates of the mumber 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 useful benchmark, such rations 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. Hince, 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 (m²/ha for trees min. 10 cm dhb)	17,4	12,7	10,3	13,5
No trees extracted /ha	0,3	0,5	2,1	1,0
Volume (m³) extracted /ha	1,3	2,5	11,4	5,0
Size of harvested trees				
Mean deameter (cm dbh) of harvested trees (SD)	72 (21,4)	82 (24,8)	72 (18)	76
Volume (m³) 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 min. 10 cm dbh damaged (no./ha)	12,8	13,5	30,6	19
Volume min 10 cm dbh damaged (m²/ha)	6,8	5,7	17,6	9,9
Damage indices				
Trees damaged per tree extracted	43	32	15	30,7
m³ damaged /m³ extracted	4,8	2,3	1,5	2,8
m² logging road opened per tree extractet	873	605	270	583
m² skid trail opened per tree extractet	777	455	246	493
m² canoopy opened per tree extracted	435	344	324	368
Totas area (m²) affected per tree extracted	2085	1404	840	1443

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 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 had good form and were of species processed by mills in other regions of Amazonia, and 4.5 individuals /ha had good form and belonged to species with potential wood use. However, there were only 0.25 mahogany trees /ha of at least 30 cm dbh. The remaining 35 trees /ha were of no use to the wood companies, either because of severe defects or because or inferior or unknown wood properties. Expressed in volumetric terms, there were, on average, 31.3 m³ /ha of wood at least 30 cm dbh in the sawable category (only 0.3 m³ of this being mahogany), 13.1 m³ /ha in the potential-use category, and 51.3 m³ /ha without wood-related uses (Table 5). These volumes are low comperad with volumes left after selective logging further to the north in Pará State (Uhl et al., 1001; Verissimao et al., 1002).

In the smaller diameter classes (10-29.9 cm dbh), there were,on average, 34 +/- 7.4 trees /ha 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 in this 10-29.9 size category with no known wood-related uses. Expressed as wood volume, there were 8 +/- 1.6 m³ /ha between 10 and 29.9 cm dbh, with present or potential v alue and 33 +/- 5.2 m³ /ha with no apparent potential to produce sawn wood.

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 min. 30 dbh present after mahogany logging									
	Swietenia macrophylla		Individuals with present-day wood uses°		Individuals with wood of pootintiol use²		Individuals without wood use³		Total	
	No. /ha	Vol. /ha	No. /ha	Vol. /ha	No. /ha	Vol. /ha	No. /ha	Vol. /ha	No. /ha	Vol. /ha
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

° Includes only individuals of species that are sawn at present in the eastern Amazon and that had good form and defect-free boles.
² Includes defect-free individuals of species that could be sawn if a market existed.
³ Includes individuals that were deformed or damaged or that belonged to species that have no known potential wood uses.

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 m³ /ha (Table 5) or 6% of the average volume present just prior to harvest (Table 4). The apparent absence of mahogany between 10 and 39 cm dbh also puts future harvests in doubt. Furthermore, we failed to find any saplings (1-10 cm dbh) in the sixty 10 m x 20 m plots spread at 100 m intervals in the 1000 m x 20 m plots in Areas 1, 2, and 3.

Surprised by the lack of regegeration in our study sites, we decided to visit four sites where mahogany had been extrected in the recent past (Sites 4, 5, 6, 7; Fig. 1). We found mahogany regegeration in 21 of the 69 mahogany gaps (plot area 75 m² per gap) that we sampled. The average number of mahogany treelats per plot was 0.46 +/- 0.28 or 0.006 /m. The vegetation was dense in these gaps and the mahogany treelets that were present were no bigger than the surrounding regeneration. Hence, it is doubtful if the mahogay treesets 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 (Lamg, 1966). The scantiness of mahogany regeneration in extraction openings in Areas 4-7 may be associated, in part, with the scarcity of nature mahogany trees after logging . Studying natural regegeration of mahogany in Mexico, Snook (1993), attributed poor regeveration 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 intermadiate (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 mahogay populations are not replacing themselves. Mahogay requires large, well lit openings to grow well. The relatively small (200-400 m²) and widely scattered (average /ha) openings created in mahogany logging may not be adequate to permit the natural regenaration of this species. Indeed, et 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 effectevely reproduce since that time (see Gullison and Hubbell (1992) for a discussion of the disturbance ecology of mahogany).

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 m² 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)

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 netword of logginng roads that some 3000 km of roads have been constructed by loggers. Many of these roads radiate out from the town of Tucuma.

In addition to providing loggers with access to mahogany stocks, these roads offer entry points for settlers seeking land. For example, from 1985 ro 1992, human colonists pushed steadily northward from Tucuma in annual increments of 25-50 km along the prinipal logging road, Morada do Sol (Fig. 5). At least two mahogany companies we interviewed (n=62) came from Brazil´s central west region, while 35% were from the northeast; none were from Amazonia. These colonists were practicing slach-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 companies. Beyond km 120, rhe road traversed the Apyterewa Indian Reserve and then penetrated the reserves of the Araweté 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 enclined 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 ecomonically feasible, at present, to extract these comparatively low value species much beyond 75 km of Tucuma. Furthermore, conversion of forest to pasture continues to be an effective way to lay claim to land in this rigion. 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 forsted land beyond 200 km of Tucuma 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 Tocuma, mahogany logging is the first step in an colonization process involving slach-and-burn agriculture and ranching. The near-term fate of the more distant forest tracts (200-600 km), new supplying must of the mahogany reaching the Tucuma mills, is still conjectural. It may be that another Tucuma-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 455 different langueges occupy an estimated 472 100 km², divided into 160 reseves spread across the southern flank of the Braazilian Amazon (Heringer, 1993). Indeed, about one-third of mahogany´s range in Amazonia coincides with Indian lands. In Pará alone, there are 15 Indian Reseves occupying 162 430 km² (Fig. 1).

The first reported incindence of commercial mahogany extraction on Indian lands dates to 1975, but it was in the 1980s that this extraction increased siginficantly (Centro Ecumênico de Documentacao Informacao (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 ducumented cases of mahogany extraction on Indian lands in the Brazilian Amazon between 1975 and 1992 reported by CEDI (1993), 26 were arranged through the madiation of FUNAI and 99 were the result of direkt negotiations between Indians and loggers. In the remeining 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 m³ (Heringer, 1993).

Because of the great cultural diversity of Indians in the regon, 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.