Final Technical Report

Ecology and silviculture of mahogany (*Swietenia macrophylla* King) in the state of Pará in the Brazilian Amazon.

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Executive Summary

Mahogany is the most valuable timber species in tropical America. Almost all mahogany production is from natural forests, and the industry plays an important role in regional economies. There is no silvicultural system for mahogany in the Amazon and logging has been accused of causing the local extinction of mahogany.

The project sought to quantify the effect of logging on mahogany populations, to identify the life-stage limiting mahogany regeneration and assess the conditions necessary for successful mahogany regeneration. Once this research had been completed, the project aimed to design a silvicultural system that would ensure that mahogany could be sustainably managed. The final project aim was to disseminate findings to policy makers, the international community and the timber industry.

To achieve these aims, the project research activities included:

- 100% inventory and mapping of all mahogany stems ≥ 15 cm diameter at breast height in nearly 1200 hectares of logged forests.
- Regeneration sampling in 60 hectares of the same forests.
- A study of seed and seedling dynamics in three previously logged areas.
- An experimental investigation of the effect of canopy openness and topographic position on mahogany seedlings.
- Holding workshops, discussion meetings and other dissemination activities.

The proposed development of a silvicultural system proved impossible to achieve.

The principal project outputs were:

- Mahogany populations recover after conventional logging, but in the absence of silvicultural intervention, prospects for a sustained yield are limited.
- Low seed production and high post-dispersal seed predation are major factors limiting mahogany regeneration.
- High levels of canopy openness are required for rapid seedling growth and high survival of mahogany. Edaphic factors were not found to be important.
- The project held maturity workshops in both Brazil and the UK, worked closely with local mahogany producers and trained several Brazilian foresters in a range of forestry techniques.
- The project is publishing the results in peer-reviewed scientific journals.

The project contributes to DFID's development goal ('*Livelihoods of poor people improved through sustainably enhanced production and productivity of forest resource systems*') by ensuring that local producers, policy makers, forest managers, environmental NGOs, and the international scientific community are able to address the issue of the sustainable management of mahogany forests from a sound scientific basis.

Background

Mahogany (*Swietenia macrophylla* King) is one of the world's most valuable timbers. It has a huge geographical range in the Neotropics, from Mexico, through to the Bolivian and Brazilian Amazonian regions (Lamb 1966; Styles 1981). In Brazil it occurs in an arc running across the southern Amazonian rain forests (Barros et al. 1992; Lamb 1966), in the states of Pará, Mato Grosso, Rondônia, Acré and in the south of (Barros et al. 1992). It is found in the south of the State of Pará, where it typically occurs on the poorly drained soils near streams (Grogan 1996).

In Pará, the timber trade is second only to mining in income generation, and exports of mahogany alone account for 5% of the state's export earnings (Verissimo et al. 1995). Pará produces 64% of all mahogany exported from Brazil (Verissimo et al. 1995). Within Brazil, Pará is the focus for conservation and management of natural mahogany forest, because it is in this state where most of the natural reserves are located.

There is growing concern over the effects of mahogany logging. Current logging practices, which typically remove approximately 95% of commercial sized trees, almost certainly deplete the genetic variability of the species (Newton et al. 1996; Snook 1996). Logging of mahogany may be leading to its commercial extinction: the volume exported from Brazil has fallen from 237,477 m^3 in 1987 (164,539 m^3 or 69% from Pará) to 93,051 m^3 in 1995 (62,872 m^3 or 68% from Pará) (Carvalho 1996). From evidence in Bolivia and Mexico, (Dickinson and Whigham 1999; Gullison et al. 1996; Snook 1996) it is claimed that there is little or no regeneration after logging. The only published study to date on post-logging regeneration in Brazil reached similar conclusions (Verissimo et al. 1995). However, even basic inventories are lacking for mahogany over most of its range (Gullison et al. 1996; Snook 1996). The social effects of mahogany logging on indigenous people may be catastrophic, and are alleged to include assassination, prostitution, spread of disease and alcohol and drug related problems (Watson 1996). It is widely reported that 80% of all Brazilian Amazon mahogany log production is illegal.

In 1992 and again in 1994, these concerns led to proposals that mahogany should be placed on Appendix II of CITES (Rodan and Campbell 1996; Rodan et al. 1992; Snook 1996). These proposals were unsuccessful, however, it is likely that they will resurface in the near future. If mahogany were to be listed on Appendix II a scientific authority of the Brazilian State would need to be able to assess whether international trade in mahogany would be detrimental to the survival of that species. Prior to this project there was insufficient information available for an informed decision to be made.

In August 1996, the Brazilian government declared a two-year moratorium on the felling of mahogany. This was renewed in 1998 and again in 2000, for a further two year period. There were a number of reasons for this policy, including the belief that logging might be leading to the extinction of mahogany in Brazil. This project aimed to provide a sound scientific underpinning for these far-reaching natural resource management decisions.

At present, therefore, mahogany logging has very little benefit for wood based industries, the indigenous communities on whose land much of the remaining mahogany stocks occur, and from local populations dependant on the mahogany trade. Were a system for the sustainable management of mahogany to be developed this could have significant benefits:

1. As once of the most prized products from natural tropical rain forest it could provide a powerful incentive for the conservation of this valuable ecosystem that can provide a greater source of income than the conversion of forest to other land-uses. Unlike many other high value products gathered from natural forest, mahogany is unlikely to be suitable for cultivation in the near future. Mahogany has failed to thrive as a plantation crop across much of the tropical world, principally due to damage by the shoot-borer

Hypsipyla (Newton et al. 1993) (*H. grandella* in the Neotropics and *H. spp.* in the Old World). It seems unlikely that, in the near future, plantation-grown mahogany will replace timber sourced from natural forest.

2. Sustainable management of natural forest will provide long-term employment for local communities.

Mahogany is a strongly light demanding climax species (Gullison et al. 1996). In mahogany forests, population size class distributions typically show a unimodal peak in the large size classes (Gullison et al. 1996; Snook 1993), which has been interpreted as evidence that natural mahogany regeneration has occurred as infrequent, even-aged cohorts. Observations of seedling ecology from Mexico and Belize are consistent with the theory that mahogany regenerates as a result of periodic catastrophic disturbances, such as hurricanes, fires, blowdowns, drought, fire or on abandoned agricultural fields (Lamb 1966; Snook 1993; Snook 1996). Seeds dispersed by those adult mahogany trees that have survived may find optimum conditions for establishment in the open and relatively competition-free conditions created by these types of disturbance (Lamb 1966; Snook 1996). However, it is also recognised that while there is a strong observational basis for the understanding of the ecology of populations at the north end of its range, little is known about the ecology of Amazonian populations (Gullison et al. 1996). In Bolivia, little regeneration was found in 4 out of 5 studied forests, although only saplings (individuals >2.5cm dbh), not seedlings, were enumerated (Gullison et al. 1996). Regeneration of mahogany in Bolivian forests was conjectured to occur after occasional logjam-induced flooding (Gullison et al. 1996). Initial results from a project currently in progress in Pará suggest that here at least, mahogany seedlings may establish in the gaps created by adult tree extraction (Grogan 1996). Mahogany here is believed to produce seed annually, and the seed has high viability (Grogan 1996).

The demand for this research was identified by research staff at EMBRAPA-CPATU, in consultation with AIMEX. The President of IBAMA (then Raul Jungmann) wrote to Jeff Burley, Director of the Oxford Forestry Institute in 1995 requesting that we carried out this research. On a global scale, the need for increased knowledge of mahogany ecology and silviculture has frequently been stressed, exemplified by two recent conferences:
1) Linnean Society of London, 1994: "Mahogany: the future for the genus *Swietenia* in its native forests,"
2) International Institute of Tropical Forestry, 1996: "Big-leaf mahogany: genetic resources, ecology and management."

Project Purpose

The project sought to improve understanding of the population dynamics, regeneration ecology and the consequences of commercial exploitation of mahogany, the most valuable timber species in tropical America. We sought to develop a silvicultural system likely to achieve ecologically sustainable mahogany production.

Specifically, the project was designed to address the following key issues:

- In order to manage natural populations of mahogany in Pará, information is needed on the population size class distribution, growth and yield in both undisturbed and logged forest. This was addressed by quantifying mahogany stocking, diameter distributions and the dynamics of seedling populations (Output 1).
- To understand the apparent lack of mahogany regeneration, and also to develop a silvicultural system for mahogany, knowledge of the regeneration requirements of mahogany seedlings was necessary. The responses of mahogany seedlings to topographical location and canopy disturbance are quantified (Output 2).

- There is an urgent need for silvicultural techniques that will ensure sufficient mahogany regeneration and yield. A silvicultural system was to be developed and implemented (Output 3).
- It is of central importance that the above findings are transmitted to the international community (to inform the current debate about mahogany), to policy makers, and to the local mahogany producers, to provide a sound basis for future changes in logging practices. This will be achieved by the publication of scientific papers (Outputs 1-3) and by the production of a pamphlet, conducting a workshop and holding field days (Output 4).

Research Activities

Output 1. Mahogany stocking, diameter distributions and the dynamics of seedling populations in logged and unlogged forests.

The research activities associated with Output 1 were conducted in two separate forests in the south of Pará state, separated by over 340 km. Pataua forest lies at 5º42' S and 48º56' W. It was logged for mahogany in 1984 and for 21 other species afterwards. The second forest, Fazenda Mogno II (7°06' S and 50°16' W) has logging coupes that were logged in successive years from the late 1980s onwards. Three of these logging coupes were used. The first (265 ha) was logged for mahogany and 10 other species in 1989. The second coupe (297.5 ha) was logged for mahogany and two other species in 1992. The third was 297.5 ha in size and was logged for mahogany and 3 other species in 1996. Both forests are c. 3000 ha in total size, with c.90% of the area as managed natural forest.

1.A. Seedling populations located and measured over three years.

Eight mahogany trees and eight mahogany stumps were selected in Pataua forest, and similarly in coupes logged in 1989 and 1992 at Fazenda Mogno II. Trees were between 35 and 95 cm dbh. At each of these, 50 m long transects were laid out in each of the cardinal bearings. Transects were 0.5 m wide at the base of the tree or stump, and opened by 4° (transect area = 199 m^2, area measured per tree/stump = 795 m^2). All seed and seedlings within the transect were mapped. Seedling height was measured, and canopy openness was measured with a canopy scope (Brown et al. 2000) above both seed and seedlings. Canopy scope measurements were also taken every 10 m along each transect to describe the canopy conditions of the measured area. All were re-measured two – four times a year for three years at Pataua and two years at Fazenda Mogno II. The same parameters were measured on each re-measurement with the addition of recording of cause of death of dead individuals where it could be ascertained. The fruit production of all study trees was quantified by careful examination of the crown of each tree through binoculars prior to seed dissemmination.

1.B. Mahogany stocking and size class determined, phytososiological survey conducted.

Inventory and mapping of mahogany was conducted at the two previously logged mahogany forests in the south of Pará State. In Pataua forest, an area of 300 ha was inventoried and mapped. All mahogany trees ≥ 15 cm diameter at breast height (dbh) or 30 cm above buttresses if higher were measured and mapped. Stumps of all logged species were identified, measured and mapped. The courses of the many seasonal streams that dissect the area were also mapped. Mahogany trees were re-measured in 1999 and 2000. At Fazenda Mogno II the three logging coupes were inventoried and mapped in the same way. The 1989 and 1992 logging coupes were first measured in 1999 and the mahogany trees remeasured in 2000. The 1996 coupe was mapped and measured in 2000.

The density of mahogany regeneration was measured in each of these logging coupes in 2000. All mahogany stems < 10 cm dbh were mapped and measured (diameter if ≥ 1 cm dbh, height if ≤ 3 m) in 15 transects 1000 long by 10 m wide (total 15 ha per logging coupe).

In each of the inventoried areas, a phytosociological survey was conducted in 2000. Random points were selected along cut-lines and a 20 m x 10 m plot installed at each. All trees ≥ 10 cm dbh were identified to vernacular name by experienced Embrapa Amazônia-Oriental tree spotters and the dbh measured. Plots were added to the sample until 1100 trees had been measured.

Output 2. Mahogany seedling ecology studied.

Mahogany is reputedly a highly light-demanding species (Lamb 1966; Snook 1993). In addition, results from Output 1 (below) had shown clear evidence that mahogany trees are usually found in low-lying parts of the forest landscape, in the vicinity of seasonal streams. An experiment was installed at Pataua forest to determine the importance of light conditions and topographic position on mahogany seedling regeneration.

A range of canopy conditions were created by felling trees. There were four canopy treatments: control (closed canopy, no manipulation), small, medium and large gaps. These were created in two topographical locations: in valley-bottoms (within 5 – 15 m of seasonal streams) and on ridges. The experiment was replicated at four different sites within the Pataua forest, although due to lack of space, the large gap treatment was repeated at only two of the sites. Fifty mahogany seeds were sown into a plot at the centre of each gap at a spacing of 50 x 50 cm in June 1998. Seedling height, mortality and *Hypsipyla* attack were measured for 26 months.

The canopy openness of each plot was estimated by taking hemispherical photographs in the centre of each plot using a Nikon 8 mm fisheye lens (180° field of view) at a height of 1 m above ground level. The lens was held horizontal with a gimbal. Images were scanned with an Olympus E6-10 scanner (version 1.20) and associated software and were analysed using HemiView© version 2.0 (Delta-T Devices Ltd.). Light was measured in a subset of the plots, at a height of 1 m using quantum sensors (SKP215, Skye Instruments Ltd.) attached to a data logger (version 2.01, Delta-T Devices Ltd.) and programmed to take readings every 10 seconds, stored as by the logger as 10 minute averages.

Soil matric potential was measured within one replicate of each plot type. An equitensiometer (type EQ-1, Delta-T Devices Ltd.) was buried at each site with the sensor head measuring at a depth of 15-20 cm in a hole created at an angle of 45° by an auger of the same diameter. The equitensiometers were connected to data loggers and programmed to take readings every four hours. Ten days data was recorded from each plot in both wet and dry seasons, over two years.

Soil samples were collected from a depth of 0 – 30 cm at each plot. These samples were dried and subjected to particle size distribution analysis at the Embrapa Amazônia-Oriental Soil Laboratory.

Output 3. Initial effects of silvicultural treatment on regeneration characterised.

As a result of continued bureaucratic and logistical constraints (Appendix 1), it proved impossible to start the research activities associated with this Output. These activities have now been incorporated into the Embrapa Amazônia-Oriental mahogany project, so there remains the possibility that this research will start in the near future.

Output 4. Information on the management and ecology of mahogany disseminated.

Two maturity workshops have being organised, one in Belém, Pará, Brazil, the other in Oxford, UK. A pamphlet on the ecology and management of mahogany is being prepared, in Portuguese, in Brazil.

Outputs

Output 1. Mahogany stocking, diameter distributions and the dynamics of seedling populations in logged and unlogged forests.

1.A. Seedling populations located and measured over three years.

- *Key Issue: what are the limiting phases in mahogany regeneration?*
- *Output response: low seed production and high levels of post-dispersal seed predation limit mahogany regeneration in forests in the south of Pará.*

Studies of seed were not included amongst activities for Output 1.A in the project logical framework. At the inception of fieldwork, the importance of considering the fate of mahogany seed should as part of the Output became immediately obvious. Mahogany produced seed in all forests in every year. However, not all trees reproduced each year, and the proportion of trees producing seed was highly variable (Table 1). The number of fruit produced was small, and even the maximum number of fruit recorded on a single tree (67) was a fraction of that reported from fecund mahogany trees in other forests, were many hundred fruits are often produced (Camara and Snook 1998; Gullison et al. 1996).

	Year					
	1998		1999		2000	
Forest	% trees fruiting	Mean # fruit	% trees fruiting	Mean # fruit	% trees fruiting	Mean # fruit
Pataua	50	4.3	25	3.5	38	2.0
Fazenda Mogno II – 1989 coupe			63	3	88	7.9
Fazenda Mogno II – 1992 coupe			50	8.3	88	14.7

Table 1: Proportion of trees fruiting and mean fruit production of fruiting trees in two logged forests in Pará.

Mahogany disseminates in the early - mid dry season (June – August), but most seed begins to germinate at the start of the following wet season (October - November). During the months that seed lies dormant on the forest floor we found that rodents eat the vast majority. The rodent was identified as *Proechimys* cf. *guyannensis*-group. There are no previously published reports of significant rodent predation of mahogany seed On a forest-wide basis, 40-87% of all seed was eaten by rodents (mean across all forests and years = 67%) and only a tiny fraction germinated (5%).

Figure 1: *Proechimys* cf. *guyannensis* filmed by a camera trap eating mahogany seed.

Despite its light demanding reputation, mahogany seedlings were not consistently found to occupy the more illuminated parts of the study transect: indeed in two of the three study areas, seedlings were concentrated in the areas of transects with more closed canopy (Table 2). This suggests that seedling density is not limited by canopy gaps.

	Transect	seedlings	*P*
Pataua	3.9	1.6	0.04
Fazenda Mogno II – 1989 coupe	2.0	4.9	0.0004
Fazenda Mogno II – 1992 coupe	6.8	5.4	0.04

Table 2: Mean canopy scope scores of transects for those trees with seedlings and mean canopy scope score of seedlings at each tree. Differences between canopy scope scores were tested with a paired Student's T test.

- *Key issue: what are the consequences of recruitment limitation for the sustainable management of mahogany?*
- *Output response: Conventional shelterwood systems for sustainable management of mahogany may often fail in the south of Pará because recruitment is of seed-limited.*

Tropical shelterwood systems are based upon opening the forest canopy in order to release existing seedling populations (advance regeneration) into rapid height growth. It is vital that desirable species are present in the seedling bank as the canopy is opened, because the composition and size structure of natural regeneration at the time of canopy opening largely determines the composition of the resulting vegetation (Brown and Jennings 1998). In the case of mahogany, a straightforward shelterwood system would be of limited success (and see Table 4 below) because of the paucity of advance regeneration. The research conducted for this output identified a clear limitation to mahogany regeneration, namely the survival of seed. A silvicultural system for mahogany should address this constraint. One possible solution would be to collect seed from the forest in the middle of the dry season before felling, and then broadcast the seed at the beginning of the following wet season in areas of the forest that would be opened up by subsequent felling.

1.B. Mahogany stocking and size class determined, phytososiological survey conducted.

- *Key issue: do conventional logging practices cause the local extinction of mahogany?*
- *Output response: mahogany is still present in logged forests, and often in relatively high numbers. Logging can however cause a dramatic shift in the size structure of the population.*

Mahogany trees were found in all logged areas. Density of mahogany was an order of magnitude lower at Pataua than at Fazenda Mogno II, but because this was also the case for stumps, this indicates that Pataua was always a low-density population (Table 3). The ratio of stems to stumps was between 40-170%, indicating that current populations are a relatively high proportion of the stems that were felled. In tropical rain forests, such stem densities are not unusual for many species, even in unlogged forests. The assertion that logging causes the local extinction of mahogany (Snook 1996) can not therefore be supported by this Output. Not only is mahogany still present after conventional logging, but within a few years of logging, it may exist at levels comparable with the number of trees felled. We conclude that the species is not endangered by logging. During the entire period of fieldwork, with the exception of ornamental urban plantings, mahogany trees were never seen on non-forested land. Habitat loss would therefore appear to be a more serious threat to the species than is logging.

Forest	Year Logged	Stem density (# ha^{-1})	Stump density (# ha^{-1})
Pataua	1984	0.06	0.03
Fazenda Mogno II	1989	0.79	1.41
	1992	0.40	0.42
	1996	0.35	0.85

Table 3: Densities of mahogany stems ≥ 15 cm dbh and of stumps in logged forests in Pará.

- *Key issue: what are the prospects for sustainable management of mahogany in forests already logged by conventional methods?*
- *Output response: in the absence of silvicultural intervention, future harvests will usually be poor.*

Analysis of these conventionally logged forests to assess their potential for future sustainable timber production requires a more detailed examination of the data. Brazilian forest law sets a minimum felling diameter of 45 cm dbh. The density of commercial – sized trees is low in all sites (Table 4). Brazilian forest law also specifies a minimum cutting cycle of 30 years. It will therefore be many years before these forests could legally be logged again, and so considerable stem ingress into the commercial – size class is to be expected.

The density of regeneration (stems ≤ 10 cm dbh) varied by nearly two orders of magnitude (Table 4). Stems in the larger regeneration class (≥ 2.5 ≤ 10 cm dbh) were scarce. These results indicate that the long-term prospects for sustainable mahogany production in these areas are patchy in the absence of silvicultural intervention.

		Density (# ha^{-1})			
Forest	Year Logged	< 1 cm	≥1≤2.5 cm	≥2.5≤10 cm	≥ 45 cm
Pataua	1984	0.53	0.13	0	0.03
Fazenda Mogno II	1989	18.1	0.59	0.37	0.12
	1992	58.2	0.53	0	0.10
	1996	5.9	1.8	0.27	0.08

Table 4: Density of different sized mahogany stems (in cm dbh) in logged forests in Pará.

- *Key issue: where does mahogany occur in the forest landscape?*
- *Output response: most mahogany stems are found in low-lying areas, close to seasonal streams.*

The spatial pattern of mahogany occurrence within the forest can potentially reveal important information on habitat requirements, which it may be necessary to incorporate into silvicultural systems. Mapping of mahogany trees and stumps revealed that the majority of mahogany trees occur in low-lying parts of the forest landscape, in the vicinity of seasonal streams (Figure 2). Analysis of this trend using GIS software revealed highly statistically significant relationships between streams and mahogany presence in all inventoried areas (Table 5).

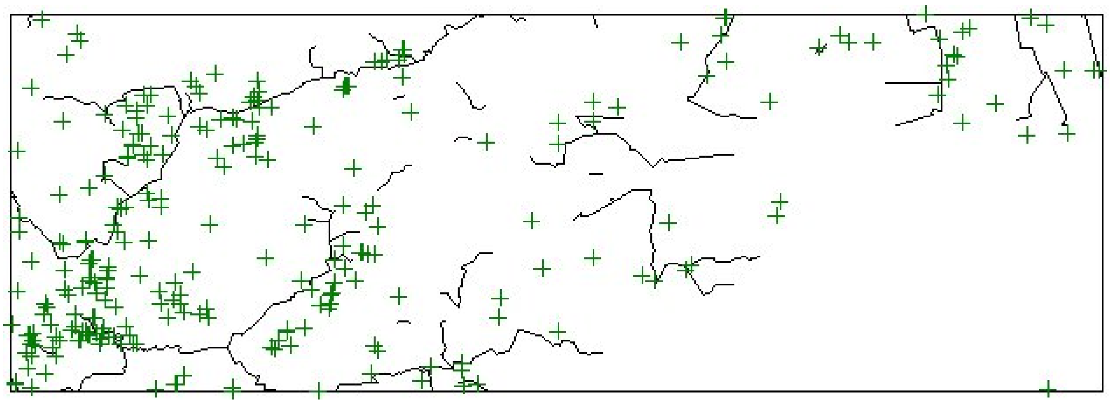

Figure 2: Locations of all mahogany trees (>15 cm dbh), stumps and seasonal streams in a 297.5 ha plot the coupe logged in 1992 in Fazenda Mogno II.

The results from Output 1.B form part of the M.Sc. thesis of a Brazilian student, who will submit in February 2001. Papers arising from this Output are in an advanced stage of preparation, and we anticipate that they will be submitted for publication by April 2001 (logical framework activity 1.B.2).

Distance of trees from seasonal streams (m)	χ^2 values		
	Fazenda Mogno II 1989	Fazenda Mogno II 1992	Pataua
5	77.96	30.02	14.25
10	124.08	29.64	14.40
20	180.52	27.88	30.62
30	159.42	30.34	29.29
40	123.20	18.79	35.04
50	126.61	12.22	33.04
60	110.00	6.76	28.28
70	101.56	4.44	23.24

Table 5: χ^2 values for the comparison of the observed and expected frequencies of mahogany trees within specified distances from seasonal streams. All exceed the critical χ^2 value (p = 0.05)

Output 2. Mahogany seedling ecology studied.

- *Key issue: What topographic and canopy conditions are necessary for successful performance of mahogany seedlings?*
- *Output response: Mahogany seedling growth is significantly increased, and mortality reduced, in large canopy gaps. Topographic and edaphic factors were not found to be important.*

Mean composition of valley-bottom soils was 41% sand, 44% silt and 15% clay; corresponding values for ridge soils was 51% sand, 33% silt and 16% clay. There was no significant difference in soil particle size distribution between the two topographical treatments (Chi-squared test: $\chi 2 = 2.71$, df = 2, P = 0.263). Wet season soil matric potentials showed little variation with either topographic position or canopy openness. In the dry season, valley-bottom soils remained humid, whereas ridge soils dried out considerably, but there was no consistent pattern of soil matric potential with canopy openness (Table 6).

Canopy manipulation provided a range of canopy conditions above the plots and there was no significant difference in the canopy conditions between valley-bottom and ridge sites (Figure 2). Canopy openness estimated from by hemispherical photography was a good predictor of light conditions (Photosynthetically Active Radiation (mol m^2 day^{-1}) = 6.7 Ln(% openness) – 6.8, $R^2 = 0.95$, $p < 0.001$).

Mahogany seedlings showed a marked and highly significant response to canopy openness (two-way ANOVA, $p < 0.001$), but none to topographical position ($p = 0.71$). Seedlings growing in the control plots had achieved a mean height of 25 cm after 26 months, whereas those in the large gaps averaged 177 cm in height (Figure 2). Mortality was higher in under a closed forest canopy but declined with increasingly open conditions (two-way ANOVA, p = 0.001, Figure 3), and showed no response to topographic position ($p = 0.78$).

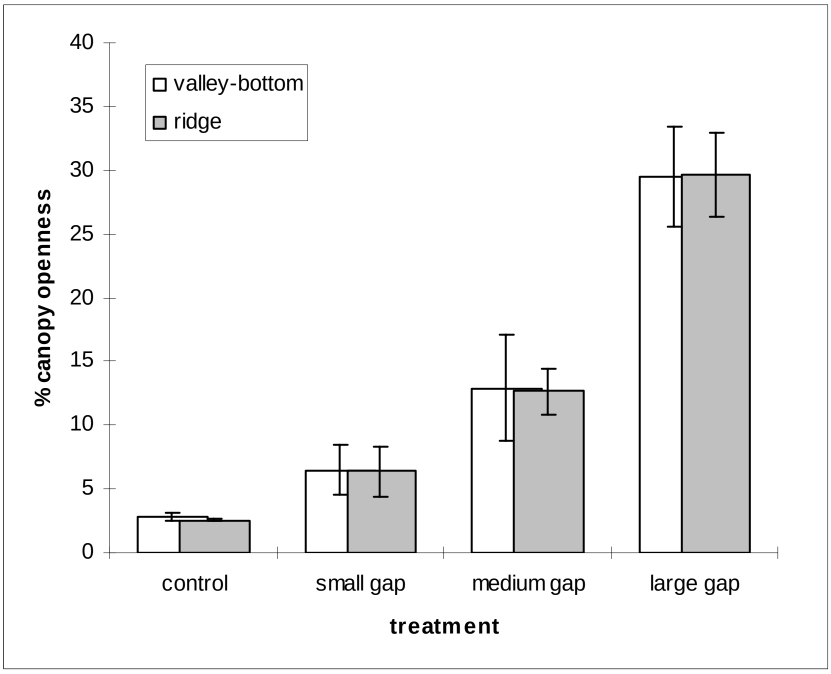

Figure 3: Canopy openness above experimental seedling plots, measured by hemispherical photography.

	Wet season		Dry season	
	Valley-bottom	Ridge	Valley-bottom	Ridge
Control	-0.04 (0.003)	-0.02 (0.006)	-0.04 (0.004)	-0.35 (0.067)
Small	-0.02 (0.014)	-0.03 (0.006)	-0.06 (0.003)	-0.18 (0.104)
Medium	-0.02 (0.003)	-0.03 (0.007)	-0.04 (0.004)	-0.24 (0.224)
Large	-0.02 (0.006)	-0.02 (0.009)	-0.05 (0.004)	-0.46 (0.026)

Table 6: Mean soil matric potential (MPa) of experimental plots in wet and dry season. Average of 10 days data for each site in each season, the standard error about the mean is included in parentheses.

By the end of the experiment, the only seedlings that had reached sufficient size to be affected by *Hypsipyla* were in the large gaps, and attack rates were not different in the different topographical positions. Given the minor relevance of *Hypsipyla* in the context of this experiment, population studies on *Hypsipyla* were not attempted (see logical framework, activity 2.2).

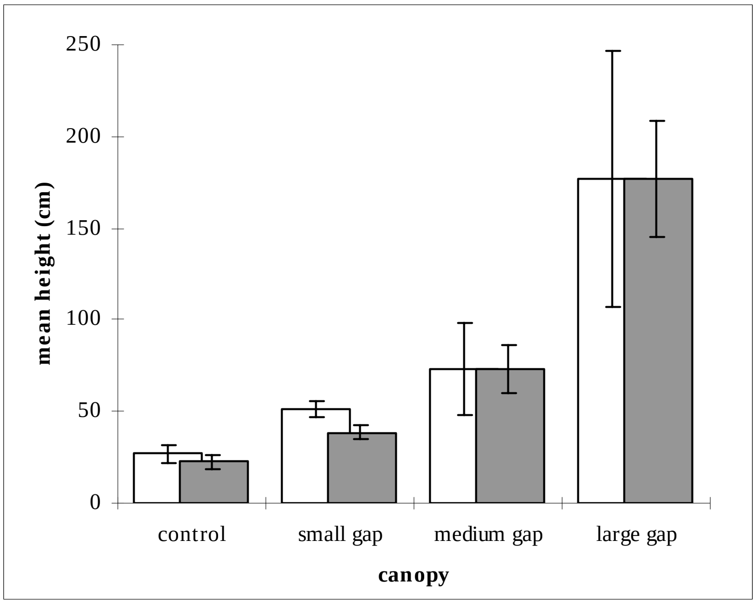

Figure 4: **Mean height of seedlings of *Swietenia macrophylla* 26 months after sowing in a range of canopy conditions in valley-bottom (open) and ridge sites (filled). Bars indicate the 95% confidence limits.**

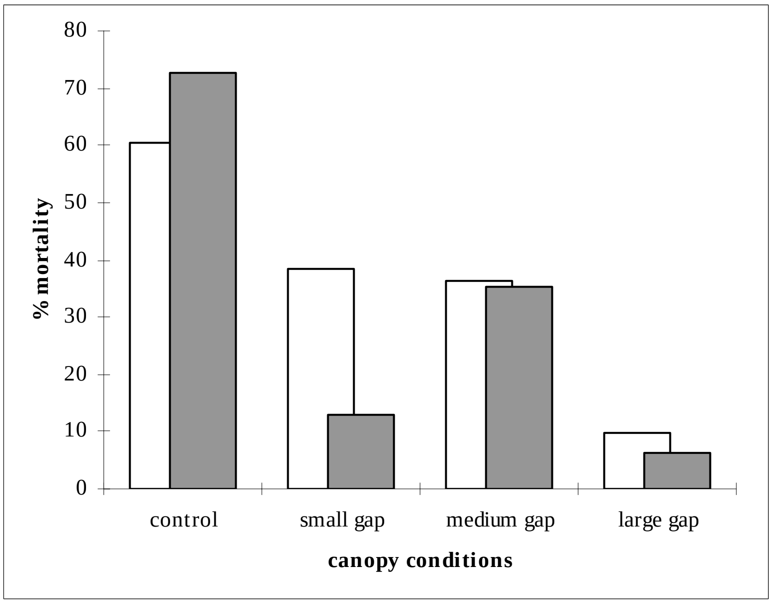

Figure 5: Mean % mortality of seedlings of *Swietenia macrophylla* 26 months after sowing in a range of canopy conditions in valley-bottom (open) and ridge sites (filled).

Papers on the ecology of mahogany regeneration are in an advanced stage of preparation, and are expected to be submitted for publication before the end of 2001 (logical framework activity 2.4).

Output 3. Initial effects of silvicultural treatment on regeneration characterised.

None of the research activities associated with this output were achieved. In brief, the project was forced to change from the unlogged forest identified in the contract document to another when the first was sold. This second forest was the Área Indígena do Xikrin do Cateté. In essence, despite persistent efforts on behalf of the researchers, the excessive legal and bureaucratic problems associated with entering into multi-party research agreements in Brazil have not, to date, been resolved. A detailed history of these problems is supplied in Appendix 1.

Output 4. Information on the management and ecology of mahogany disseminated.

Through working closely with local timber producers and through the maturity workshops we have disseminated the results and conclusions of this project to both local timber producers, the scientific community, policy makers and environmental NGOs.

Other, specific dissemination activities included:

- Maturity workshop (September 2001, Belém, Brazil).
- Maturity workshop (April 2001, Oxford, UK).
- Discussion meetings between project researchers and timber companies.
- Catalysing the creation and progress of an Embrapa Amazônia-Oriental mahogany research project. Details of this project are available on request from José do Carmo Alves Lopes (Embrapa Amazônia-Oriental, e-mail:- carmo@cpatu.embrapa.br).
- Pamphlet in Portuguese (in preparation).
- Policy Brief.
- One Brazilian student is completing an M. Sc. Based on Output 1 of the project (submission date: February 2001).
- Five Brazilian foresters and three rural technicians have received training on forest inventory, mapping and regeneration sampling techniques.
- Three Brazilian forestry students and six Oxford undergraduates trained in tropical rain forest ecological techniques.
- Research seminar to the Department of Plant Sciences, University of Oxford, UK.
- Lectures to both Masters and Undergraduate degree students in the Department of Plant Sciences, University of Oxford, UK.
- Lectures to both Masters and Undergraduates degree students at Buckinghamshire Chilterns University College, High Wycombe, UK.

The lack of progress on Output 3 (silvicultural experiment) precluded carrying out the proposed training courses (logical framework activity 4.5).

Contribution of Outputs

The outputs mentioned above will contribute towards DFID’s developmental goal:

- *Livelihoods of poor people improved through sustainably enhanced production and productivity of forest resource systems.*

by ensuring that the local producers, forest managers, environmental NGOs and policy makers are able to address the issues of sustainable management of mahogany forests from a sound scientific base.

Promotion of the project outputs has been achieved through working closely with local mahogany producing industry and the other Outputs described in *Output 4* above.

Undoubtedly, the impossibility of achieving the silvicultural experiment (Output 3) has reduced the project's impact on improving local capacity to implement mahogany-specific sustainable management techniques. Attempts to progress these research activities will continue under the Embrapa Amazônia-Oriental mahogany project, which was catalysed by the FRP project. The Embrapa Amazônia-Oriental mahogany project will press forward the development benefit of the project by continuing to work closely with mahogany producers in Brazil. Embrapa has already obtained funding for this work from a number of sources.

Publications

Jennings, S.B., Brown, N.D., Whitmore, T.C., Silva, J.N.M., Lopes, J. do C. A. & Baima, A.M.V. (2000). To conserve rainforest, we have to help local people live sustainably. *Nature* **405**: 507 (peer reviewed paper)

Jennings, S.B., Clements, T., Brown, N.D., Whitmore, T.C., Lopes, J. do C. A. (in prep.). Spatial variation in population densities of a spiny rat (*Proechimys* cf. *guyannensis*-group), a major seed predator of Mahogany (*Swietenia macrophylla* King) in the Brazilian Amazonian.

Brown, N.D., Jennings, S.B., Whitmore, T.C., Lopes, J. do C. A. (in prep.). Landscape-scale distribution of mahogany *Swietenia macrophylla* King) caused by multiple ecological interactions.

Future dissemination through publications is dealt with under the appropriate Outputs above.

Internal Reports:

Lopes, J. do C. A. & Jennings, S.B. (1998). ECOLOGIA DA REGENERAÇÃO DO MOGNO (*Swietenia macrophylla* King). Unpublished report submitted to AIMEX, Belém, Brasil.

Whitmore, T.C. & Brown, N.D. (1998). Visit report, September 1998. Unpublished internal project report, UK.

Lopes, J. do C. A. & Jennings, S.B. (1999). Ecologia da regeneração natural, estrutura e potencialidade de produção do mogno (S*wietenia macrophylla* King) em floresta natural no Estado do Pará. Unpublished report submitted to AIMEX, Belém, Brasil.

Whitmore, T.C. & Brown, N.D. (2000). Visit report, August 2000. Unpublished internal project report, UK.

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