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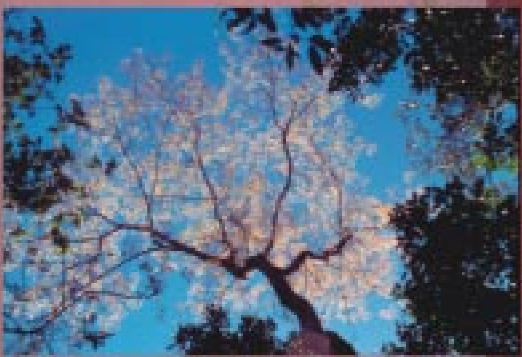
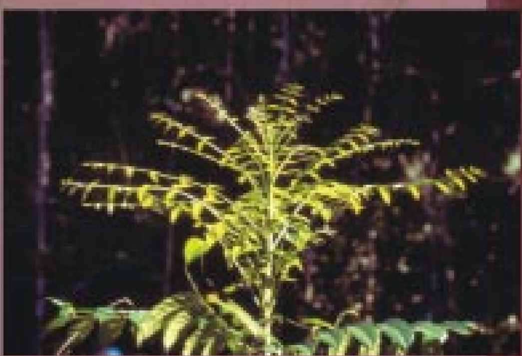
Ecology and Perspectives on Management





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The Institute of People and the Environment in the Amazon

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SUMMARY

Mahogany's extraordinary commercial value has fueled intense extraction pressure across its natural range in Brazilian Amazonia since the early 1970s. As the logging industry approaches the last natural stands of mahogany in south Pará, southeast Amazonas, and Acre, Brazilian regulatory agencies have responded to public concerns about mahogany's commercial future by 1) steadily reducing export quotas since 1990, 2) freezing authorization of new forest management plans for mahogany since 1996, and 3) prohibiting the transport, processing, and commercialization of mahogany within Brazil following detection of widespread illegal logging practices in south Pará in October 2001. Assuring mahogany's future as a renewable natural resource and national patrimony now requires translating available technical information into rational forest management guidelines that are concordant with public interests, affordable to industry, and enforceable by federal and state regulatory agencies.

This book provides a descriptive account of mahogany across its natural range in South and Central America, with emphasis on recent research conducted in Brazil. Mahogany is a large tree that occurs at low densities (generally less than 1 adult tree per hectare) in seasonal primary forests, often clustered together in groups along watercourses or in highly disturbed transition zones between forest types. Mahogany occurs under widely ranging climatic, hydrologic, edaphic, and competitive circumstances across its vast natural range. Said to require large-scale catastrophic disturbances to regenerate in Central America and Bolivia, it has also been shown capable of successful recruitment following small-scale disturbances in south Pará. Its wind-dispersed seeds are highly germinable but disperse relatively short distances. Seedlings are hardy and grow rapidly where light levels are high and soils are fertile. Diameter growth rates by juveniles and adult trees (larger than 10 cm diameter at breast height, or dbh) may exceed 1 cm/year for many years or decades. However, a natural predator – the shootboring moth, *Hypsipyla grandella*, which feeds on growing plant stem tissues – may limit population densities in natural forests and is generally too costly to control in plantations.

In south Pará, mahogany population structures in natural forests were robust before logging, with sufficient juvenile trees to provide second harvests after approximately 30 years. However, minimum diameter cutting limits were rarely respected during selective logging operations, and logging roads opened for mahogany's extraction frequently led to land-use conversion to pasture or small-holder agriculture. Where forest cover persists, mahogany's regeneration in logging gaps is generally poor. This may be attributed to low pre-harvest seed production, low post-harvest seed availability due to tree felling before seed dispersal, and or competing vegetation suppressing mahogany seedlings and saplings during the years following extraction.

Natural forest management recommendations for mahogany derived from ecological studies in south Pará include: planned harvests to reduce damage to residual stands, strict adherence to minimum diameter cutting limits (recommended 55 cm dbh), selection criteria for seed-tree retention, directional felling, and seed collection from felled trees for redistribution in logging gaps. Instead of relying on naturally occurring

seedling regeneration, which is rare in natural forests, collected seeds should be planted at low density in enlarged and treated (cleaned) treefall gaps to ensure establishment of the next generation of harvestable trees. Planted seedlings will require tending at 1- to 5-year intervals through the first decade, and then again after 25 – 30 years when today's juvenile trees (25 – 55 cm dbh) are harvested. A second round of enrichment plantings should accompany the second harvest, and so on through successive 25- to 30-year rotation periods.

To improve control over mahogany's exploitation across Brazilian Amazonia we recommend the following: 1) a comprehensive national inventory of logged and unlogged forests within mahogany's natural range to assess historical and surviving merchantable stocks; 2) improvement of regulatory control relating to forest management plans, including georeferenced tracking by satellite of source and transport of unsawn logs; and 3) encouragement of independent certification mechanisms that could confer legitimacy to Brazilian mahogany production.

INTRODUCTION

Bigleaf mahogany (*Swietenia macrophylla* King, Meliaceae) is the world's most valuable tropical timber species – in 2001, a cubic meter of first-quality sawn mahogany was sold for US$1200 at port in Belém (FOB price). Mahogany's extraordinary value has fueled intense extraction pressure during recent decades throughout its natural range in tropical America from Mexico to Brazil (Rodan *et al.* 1992, Veríssimo *et al.* 1995, Snook 1996, Lugo 1999). Between 1971-1992, an estimated 4 million m^3 (cubic meters) of sawn mahogany were exported from Brazil, 75% of this to the United States and England. Total production from Brazil during this period is estimated at 5.7 million m^3 of sawn timber[1], assuming that approximately 1.7 million m^3 were consumed by the domestic market. Considering an average value of US$700/$m^3$, mahogany generated approximately US$3.9 billion of revenue during this period.

Mahogany's enormous commercial importance combined with its ecological vulnerability have generated controversy over its conservation and sustainable use. Basic to resolving this debate is improved understanding of mahogany's life history characteristics, especially regeneration patterns, throughout its natural range. For example, research in Central America and Bolivia has shown that mahogany regenerates after catastrophic disturbances like hurricanes, fires, and floods (Stevenson 1927, Lamb 1966, Gullison & Hubbell 1992, Snook 1993, Gullison *et al.* 1996). On the other hand, recent field studies in the Brazilian Amazon indicate that regeneration may occur following smaller-scale disturbances such as natural tree-fall gaps in closed forest (Grogan 2001).

Industrial exploitation of mahogany was one of the most controversial conservation issues of the 1990s, principally within context of the Convention on International Trade in Endangered Species (CITES). Some consumer nations and environmental groups supported mahogany's inclusion on Appendix II of CITES as a species whose continued trade at current levels could threaten it with extinction, a measure which would have restricted predatory extraction (Rodan *et al.* 1992, NRDC 1994, Bass *et al.* 1999). In opposition, producer nations and logging industry advocates argued that available scientific information was insufficient to prove mahogany's decline towards extinction. They argued as well that existing trade regulatory mechanisms were adequate to assure mahogany's conservation and management (Figueroa Colón 1994). Brazil found itself at the center of this debate for being the primary producer nation harboring much of the last natural populations of mahogany in unlogged primary forests.

In Brazil, mahogany's exploitation has frequently been associated with predatory and illegal logging practices. The Brazilian federal government has attempted to restrict illegal practices by halting issuance of new management concessions for mahogany since 1996. As well, total annual allowable export volumes have declined steadily since the early 1990s. Most recently, in 2001, Ibama, the national environmental regulatory agency,

1 Equivalent to 12.6 million cubic meters of mahogany in logs considering an average conversion factor of 45% from log to sawn wood.

suspended all remaining management plans for mahogany after field reviews demonstrated widespread technical inadequacy and fraud. Stockpiled mahogany logs harvested during the 2001 dry season were impounded (Ibama 2001a, b, c).

As the industrial logging sector approaches the last remaining stands of unlogged mahogany in primary forests of Brazil, Bolivia, and Peru, it is important to accurately describe mahgoany's current status and to outline possible strategies for its sustained-yield management and conservation. The objective of this report is to summarize the state of current knowledge about the ecology and management of mahogany in Amazonia. We review the scientific literature and recent research on mahogany life history in natural forests and plantations, first providing a descriptive overview of mahogany across its tropical American range and then summarizing available information from the Brazilian Amazon, where most internationally traded natural supplies originate. We describe possible natural forest and artificial management systems derived from biological understanding of mahogany life history, and options for conservation of this most valuable natural resource and national patrimony. Finally, we close by proposing measures that would improve control of mahogany's exploitation and commercialization in Brazil.

MAHOGANY: GENERAL CHARACTERISTICS

Description

Mahogany is an emergent tree that may grow to enormous stature, attaining stem diameters as large as 3.5 m with crowns rising as high as 70 m tall (averaging 30 – 40 m) and stretching up to 40 – 50 m across (Williams 1932, Lamb 1966, Pennington & Sarukhán 1968). Solid clean boles may rise 20 – 25 m before branching and, in Central America, present deeply furrowed, black bark that offers excellent fire resistance. Buttresses are common and may reach 5 m above the base of the tree (Lamb 1966, Chudnoff 1979).

Natural Range

Mahogany's natural range stretches from Mexico at 23º N of the equator down the Central American Atlantic coastal strip into South America, continuing in a broad southeasterly arc from Venezuela through the Colombian, Ecuadorian, Peruvian, Bolivian, and Brazilian Amazon regions to points as far south as 18º S (Lamb 1966, Pennington *et al.* 1981) (Figures 1 & 2). Its distribution generally corresponds to forests classified as 'tropical dry', with annual temperature averages of greater than or equal to 24º C, 1000 – 2000 mm annual precipitation, and a year-round rainfall-to-evapotranspiration ratio of 1.0 – 2.0 (Holdridge 1967). It also grows in humid and subtropical zones, at elevations ranging from sea level in Central America up to 1400 m in the Andean foothills of Ecuador, Peru, and Bolivia, in a wide variety of soil types – derived from alluvial, volcanic, metamorphic, and calcareous materials – and soil conditions – deep, shallow, acid, alkaline, well-drained, and gleyed (Oliphant 1928, Stevenson 1928, Williams 1932, Lamb 1966, Negreros-Castillo 1991, Snook 1993, Gullison *et al.* 1996).

Distribution and Density Patterns

Mahogany was earliest known as a riverine species growing along coastal riverways on the Atlantic seaboard of British Honduras (now Belize) in Central America (Swabey 1941, Lamb 1966, Weaver & Sabido 1997). Lamb (1966) described *caobal* forest associations (*caoba* being the Spanish word for mahogany) with highest densities of mahogany on deep, well-drained river valley soils and moist slopes just above them. Descriptions from South America emphasize mahogany's association with river floodplains in the upper reaches of the western Amazon Basin. From Ecuador, Peru, Bolivia, and Brazil observers have described its tendency to grow at highest densities

Figure 1. *Mahogany's natural range across Central America. Based on Lamb (1966).*

Figure 2. *Mahogany's natural range in South America. Based on Lamb (1966) and on the authors' field observations.*

on drier, firmer soils slightly above seasonally inundated floodplains, where floods occur infrequently (Williams 1932, Hoy 1946, Irmay 1949, Lamb 1966, White 1978, Gullison & Hubbell 1992). Gullison *et al.* (1996) found aggregations of mature trees along river courses as well as perched atop steep erosion gullies in floodplain ecosystems of lowland Bolivia.

Non-riverine associations have also been described. Moving into interfluvial and upland ecosystems in Belize, mahogany characteristically occurs at highest densities in transition zones where different vegetative communities grade into each other, on soils with medium to good drainage. Examples include the *sequelar*, between savanna and forest, and *botanal-escobal* palm associations on well-drained soils that are transitional communities between wooded swamps and upland climax vegetation (Lamb 1966). Negreros-Castillo (1991) reported from Mexico's Yucatan Peninsula, where subsurface water flow characterizes an essentially flat landscape (Snook 1993), that mahogany grows in topographical depressions where poorly drained acid soils accumulate, as well as on well-drained alkaline soils above them. In general, drier, more disturbance-prone areas tend to have higher stockings than wetter, more stable environments (Lamb 1966).

Mature trees are typically found scattered through the forest matrix at densities of less than 1 per hectare. These tend to grow in aggregations of several tens to hundreds of trees, often with expanses of "empty" forest separating aggregations. Highest densities have been reported from Central America: in the Petén district of northern Guatemala densities of 12 trees/ha were once found over large areas. Limited areas with extremely high densities – 55 to 70 trees per hectare – have been described in Panama, Nicaragua, Guatemala, Belize, and Mexico (Lamb 1966). Gullison *et al.* (1996), working in the floodplains of lowland Bolivia, reported that mahogany occurs in forest areas up to several hundred hectares in size, with 0.1 – 0.2 merchantable (larger than 80 cm dbh) trees/ha and comparable densities of sub-merchantable stems. Outside these areas mahogany may not reappear for distances up to 10 km. On similar landscapes, Quevedo (1986) and Saa *et al.* (1996) recorded similar distribution patterns, with densities up to 7 mahogany trees/ha within aggregations separated by 300 m or more of uncolonized forest.

Regeneration and Growth

Commonly classified as a pioneer, large-gap, or late secondary tree species (*sensu* Budowski 1965, Denslow 1987, Swaine & Whitmore 1988), mahogany regenerates in forest gaps following canopy disturbance. Winged seeds are produced in woody capsules held above the crown, with up to 600 fruit capsules and 30,000 seeds produced by individual trees in a single year (Pennington *et al.* 1981, Gullison *et al.* 1996) (Figures 3 & 4). Most seeds disperse within 80 m of parent trees during the late dry season (Gullison

Figure 3. *Mahogany fruit capsules.*

Disturbance scenarios known to favor mahogany include hurricanes, fires, floods, agricultural clearings, abandoned loading yards and roadsides associated with timber extraction, and treefall gaps (Wolffsohn 1961, Lamb 1966, Snook 1993, Gullison *et al.* 1996, Grogan 2001). Lamb (1966) noted that light conditions in hurricane-damaged forests were suitable for mahogany regeneration, and concluded that seedlings growing vigorously after the 1942 hurricane in Belize began as advance regeneration. In Quintana Roo, Mexico, Snook (1993) documented size class frequency distributions of mahogany stands ranging from 15 – 75 years old. These indicated regeneration associated with hurricane and fire disturbances occurring across large areas, with differential growth rates spreading pulsed *et al.* 1996). Seed germination occurs rapidly in the forest understory after the onset of wet season rains (Morris *et al.* 2000), with delayed germination in the drier environments of open gaps after disturbance (Grogan 2001). Seedlings and saplings (Figures 5 & 6) are strongly heliotrophic, requiring high light levels associated with overhead canopy openings for prolonged rapid vertical growth (Stevenson 1927, Lamb 1966, Gullison & Hubbell 1992, Gullison *et al.* 1996, Grogan 2001). Average diameter increment rates reported for trees larger than 10 cm dbh in natural forests range from 0.26 – 1.09 cm/yr, with individual trees capable of annual diameter growth exceeding 2 cm/yr over two to several years (A. Lamb 1945 in Lamb 1966, Snook 1993, Gullison *et al.* 1996, Grogan 2001).

Figure 4. *Mahogany seeds.*

Figure 5. *Mahogany seedling.*

Figure 6. *Flushing mahogany sapling.*

recruitment through contiguous 10-cm size classes over time. Gullison *et al.* (1996) described population structures of trees larger than 60 cm dbh in Bolivia as unimodal, suggesting single-aged cohorts established after large-scale disturbance events which differences in growth rates had spread through a range of size classes. They attributed even-aged population structures to regeneration opportunities pulsed at long intervals between landscape-scale flooding events, which open growing space at large spatial scales through overstory mortality. As well, large stems growing above erosion gullies on high terraces suggested that a single massive disturbance event in the distant past was responsible for a single cohort of adult trees.

Management and Silviculture

Regeneration failures

Regeneration failure by mahogany following logging has been reported in the literature (Stevenson 1927, Lamb 1966, Quevedo 1986, Snook 1993, Veríssimo *et al.* 1995, Gullison *et al.* 1996, Saa *et al.* 1996, Dickenson & Whigham 1999, Grogan *et al.* in press) and offered as evidence that low-impact logging practices (Gullison & Hardner 1993, Whitman *et al.* 1997) lead to mahogany's local and regional extirpation (Snook 1996). Based on these findings, Snook (1993) recommended silvicultural treatments for mahogany mimicking regeneration conditions following catastrophic disturbances: creation of large clearings with removal of advance regeneration, accompanied by soil scarification, removal of secondary vegetation (for example, through controlled burning or cleaning), and retention of seed trees. From similar findings, Gullison *et al.* (1996) recommended retention of large seed trees in areas appropriate for seedling regeneration, adjustment of harvest schedules to a monocyclic system with rotations of 100 or more years (considering observed mean annual diameter increments), and inclusion of secondary species in harvest plans to improve financial viability.

Silviculture based on natural regeneration

Earliest silvicultural experiments with mahogany were implemented by the British Honduran Forest Department in the 1920s. Shelterwood systems opening growing space at ground level with partial retention of overhead canopies successfully established abundant seedling regeneration, but growth rates were slowed by high shade. As well, many stems freed by cleaning from competing vegetation and vines were attacked by the mahogany shootborer (*Hypsipyla grandella*, Lepidoptera: Pyralidae), a nocturnal moth whose larval instars feed on the growing apical leader, disabling it and destroying growth form (Stevenson 1927, Lamb 1966; see also Negreros-Castillo & Mize 1993, Negreros-Castillo & Hall 1996). Because of the shootborer's impact in open growing conditions, enrichment efforts turned to secondary vegetation on abandoned agricultural land.

Agroforestry systems

In *taugnya* systems, mahogany was planted at regular spacing among food crops like corn after forest felling and burning. These systems returned promising short-term height and diameter growth (Lamb 1966). Experimental enrichment plantings in moist secondary forests near Veracruz, Mexico indicated that seedling height growth correlates positively with degree of canopy opening (Ramos & del Amo 1992). However, plantation management of mahogany in the American tropics has proven largely unsuccessful because of the shootborer, which repeatedly infests high-density stands, damaging growing stems and reducing timber value (Newton *et al.* 1993, Mayhew & Newton 1998). Many authors have observed that planting at low densities in secondary vegetation reduces shootborer attack rates (Stevenson 1927, Swabey 1941, Marie 1949, Brienza 1980, Yared & Carpanezzi 1981, Oliveira 2000).

MAHOGANY IN THE BRAZILIAN AMAZON

Natural Range

In Brazil, mahogany occurs in natural forests covering an estimated 1.5 million km^2 along the southern and southeastern rim of legal Amazonia. Its range extends as far north and east as the Transamazon Highway (BR-230) at Altamira and the Tocantins River valley east of Marabá. From these limits mahogany occurs in a broad southwesterly swath across northwest Tocantins, south Pará, north Mato Grosso, southeast Amazonas, and most of Rondônia and Acre (Lamb 1966, Contente de Barros *et al.* 1992). Regions of highest landscape-scale density before the onset of industrial logging in the early 1970s were southeast Pará between the Xingu River and forest-cerrado transition zones along the PA-150 from Xinguara to Redenção; and across northern and central Rondônia. In southeast Pará densities approached 3 trees/ha larger than 10 cm dbh within local areas before logging (Veríssimo *et al.* 1995, Baima 2001, Grogan 2001, Jennings & Brown 2001). Outside these regions densities are (or were, before logging) much lower, on the order of 1 tree in 5 to 20 hectares.

Brief History of Extraction

Little is known about the history of mahogany's extraction in the alluvial lowlands of western Amazonia. Commercial exploitation along Peruvian tributaries of the Solimões River had begun by the first decade of this century, and accelerated to industrial scales by the 1920s with the construction of sawmills in Iquitos (Hoy 1946, Lamb 1966). Difficult access to *terra firme* forests limited early logging to the vicinity of larger rivers, with trees felled and rolled or dragged to the nearest flowing water for floating downstream for processing.

Acre

Mahogany's exploitation in Acre occurred in two phases. First, in the 1930s and '40s, logging was concentrated along the margins of major western rivers – for example, the Juruá, Tarauacá, Envira, and Purus Rivers. During this phase, riverside trees were felled and floated out in timber rafts for processing in Manaus and Belém. The second phase began in the late 1970s in the eastern portion of the state with the influx of immigrants arriving by the improved Porto Velho landbridge. Mahogany logged and processed in the eastern portion of the state was consumed locally or exported overland to the port of Paranaguá (Paraná) and São Paulo.

Pará and Mato Grosso

By the early 1940s mahogany was known to grow in forests as far east as the Tocantins River (Froes 1944, Lamb 1966), but exploitation in the state of Pará was delayed by access and transport difficulties. Construction of the Belém-Brasília and Transamazon highways in the mid 1960s opened this region to a broad spectrum of socioeconomic interests, including the logging industry. The first wave of mahogany exploitation occurred along the Araguaia River and its tributaries. By the early 1970s these supplies had been exhausted and the mahogany frontier shifted west to forests adjacent to the new state highway (PA-150). As commercial stocks were liquidated through the late 1970s and early 1980s the logging frontier shifted again west along the unpaved PA-279 towards São Felix do Xingu on the Xingu River (Schmink & Wood 1992, Veríssimo *et al.* 1995).

Through the 1980s the mahogany-rich south- and northeast corners of Pará and Mato Grosso were parceled up by independent and industrial-scale loggers exploiting untitled federal forests (*terra devoluta*) and Indigenous Areas through a variety of access arrangements, both legal and illegal, by both consent and coercion. New areas rich in mahogany were located by spotters criss-crossing the landscape in small planes. The frontier moved steadily west on a broad north-south front, crossing the Xingu River, removing commercial stands of mahogany from there west to the Iriri River, and then, in recent years, beyond into southwest Pará (the region surrounding Novo Progresso along the unpaved Cuiabá-Santarem highway) and southeast Amazonas. Throughout this period mahogany's removal continued within the "Middle Land" between the Iriri and Xingu Rivers, as loggers returned in search of trees deemed inaccessible or sub-merchantable during the first wave of extraction. In many cases this second cut removed trees smaller than 45 cm dbh (Greenpeace 2001).

Rondônia

Mahogany exports from Pará were matched in the early 1980s by a spectacular boom from Rondônia, where colonization projects along the southern Transamazon highway, the BR-364, provided access to vast tracts of mahogany forests within a few short years. Until 1980 mahogany stumpage had been purchased piecemeal by independent loggers from agriculturists holding 100-ha parcels of land. An export subsidy program underwritten by the Brazilian Finance Ministry fueled a "mahogany rush" by large-scale exporting companies on *terra devoluta* and in protected and Indigenous Areas from 1980-1985, during which Rondônia's commercial stocks of mahogany were essentially liquidated (Browder 1986, 1987, CEDI 1992).

Distribution Patterns

Mahogany's distribution within Brazil roughly correlates with *terra firme* forests on undulating terrain of the Brazilian Shield and the upper reaches of the western alluvial basin. In southeast Pará, three distribution patterns occurred before logging: 1) along the margins of aseasonal rivers flowing east and west towards the Araguaia and Xingu Rivers, respectively; 2) along or near seasonal streams on gently undulating landscape between aseasonal rivers; and 3) on rocky slopes to the tops of isolated "inselberg" mountains or mountain ranges (Grogan 2001).

Mahogany was common in Xingu River Basin liana forests (Pires & Prance 1985). Moving west of the Xingu and Iriri Rivers across Pará into steeper terrain receiving higher annual rainfall, mahogany occurs at lower densities in larger-statured, more species-rich forests. No clear physiographic associations have been described for this region, nor for Rondônia, where mahogany reportedly occurred at high densities on rich *terra roxa* soils (alfisols). Moving further west into Acre, mahogany occurs at low densities along the margins of aseasonal rivers draining the Andean highlands of Peru and Bolivia, and on the highly dissected landscape between rivers. Densities fall approaching the state's western region where annual rainfall totals rise, and on relatively flat landscape characterizing the state's eastern margins.

Mahogany's strong correlation with low ground adjacent to seasonal streams in southeast Pará has been attributed to 1) increased disturbance frequencies associated with alternating excess and deficit water cycles on low ground through wet and dry seasons; and 2) optimal seedling growth rates in nutrient-enriched low-ground soils compared to nutrient-impoverished soils on high ground (Grogan 2001).

Demography and Growth

On the seasonally dry landscape of southeast Pará (distribution type 2 described above), size class frequency distributions of trees larger than 10 cm dbh coupled with spatial, growth, and mortality data indicate that recruitment of new individuals occurs within local aggregations of adult trees at shorter time intervals and at smaller spatial scales than predicted by research from Central America and Bolivia (Grogan 2001; see Snook 1993, Gullison *et al.* 1996). Catastrophic disturbances such as hurricanes and floods have not been documented from mahogany's Brazilian range, though a growing body of evidence suggests that region-wide fires may be associated with mega-El Niño Southern Oscillation events occurring at centuries-wide intervals (Meggers 1994).

Size class frequency distributions of trees larger than 10 cm dbh within this region indicate that trees smaller than 55 cm dbh may represent up to 50% of total stems before selective logging (Figure 7). That is, substantial numbers of sub-merchantable trees may survive in standing logged forests. With appropriate silvicultural treatments, these trees could represent a future second cut. However, most forests logged for mahogany in this region have been converted to pasture (Figure 8), agriculture, or subjected to uncontrolled burns (Grogan 2001).

Figure 7. *Size-class frequency distribution for mahogany stems larger than 20 cm dbh in 1035 hectares in south Pará. (Source: Grogan 2001)*

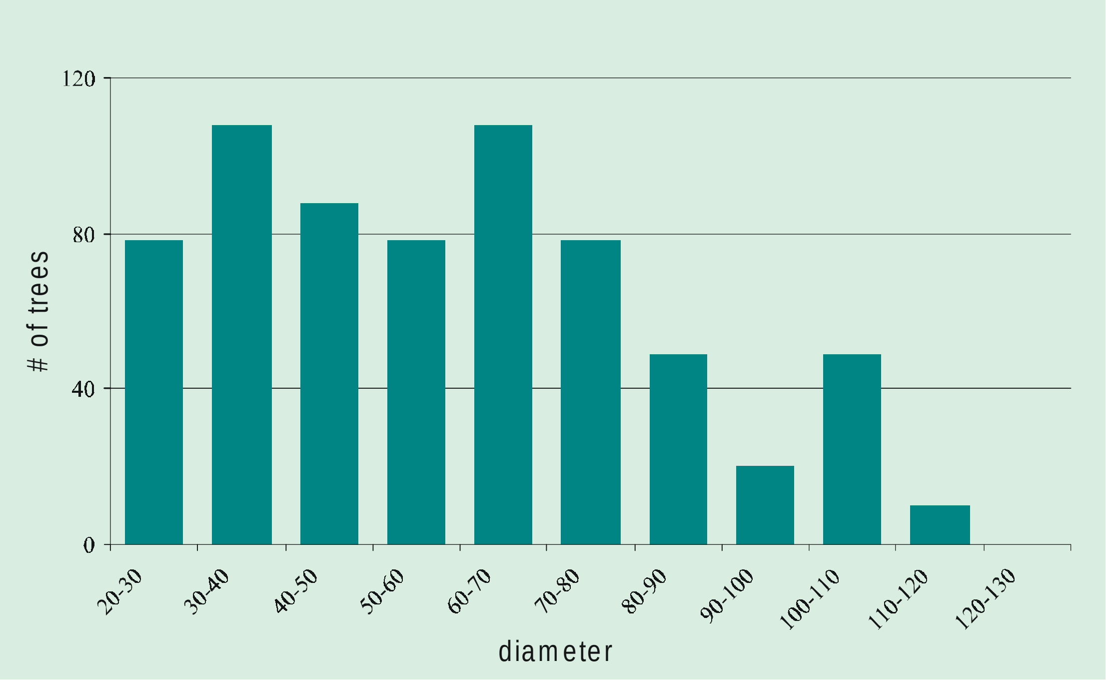


Figure 8. *Overhead view of south Pará landscape showing seasonal drainage courses where mahogany occurred at highest densities.*

Commonly thought to be absent in closed forest, these small trees are frequently missed by woodsmen (*mateiros*) exploring primary forest for mahogany because search images of bark and crowns differ greatly for small (sub-merchantable) and large trees (Grogan 2001). In regions where mahogany's landscape-scale densities decline (southwest Pará, southeast Amazonas, Acre), reports that small size classes are rare or absent from populations must be viewed with caution, considering how difficult small trees are to locate in highly diverse, tall closed forest. Just because only large trees are being found and harvested does not necessarily mean that these represent single-aged cohorts recruiting episodically after large-scale catastrophic disturbances as documented in Mexico and Bolivia by Snook (1993) and Gullison *et al.* (1996).

Reproduction and Regeneration

Rates and annual patterns of fruit production at individual tree and population levels are poorly understood. In southeast Pará, fecundity rises as a function of stem diameter, as reported from Bolivia by Gullison *et al.* (1996) and Mexico by Camara & Snook (1998). However, fruit production rates are highly idiosyncratic – not all large trees produce abundant fruit crops, some small trees are among the most fecund individuals, and inter-annual production varies widely at both individual and population levels. For these reasons, rates of seed availability for dispersal are highly unpredictable at a given tree of any size in any given year (Grogan 2001).

Seed dispersal and germination

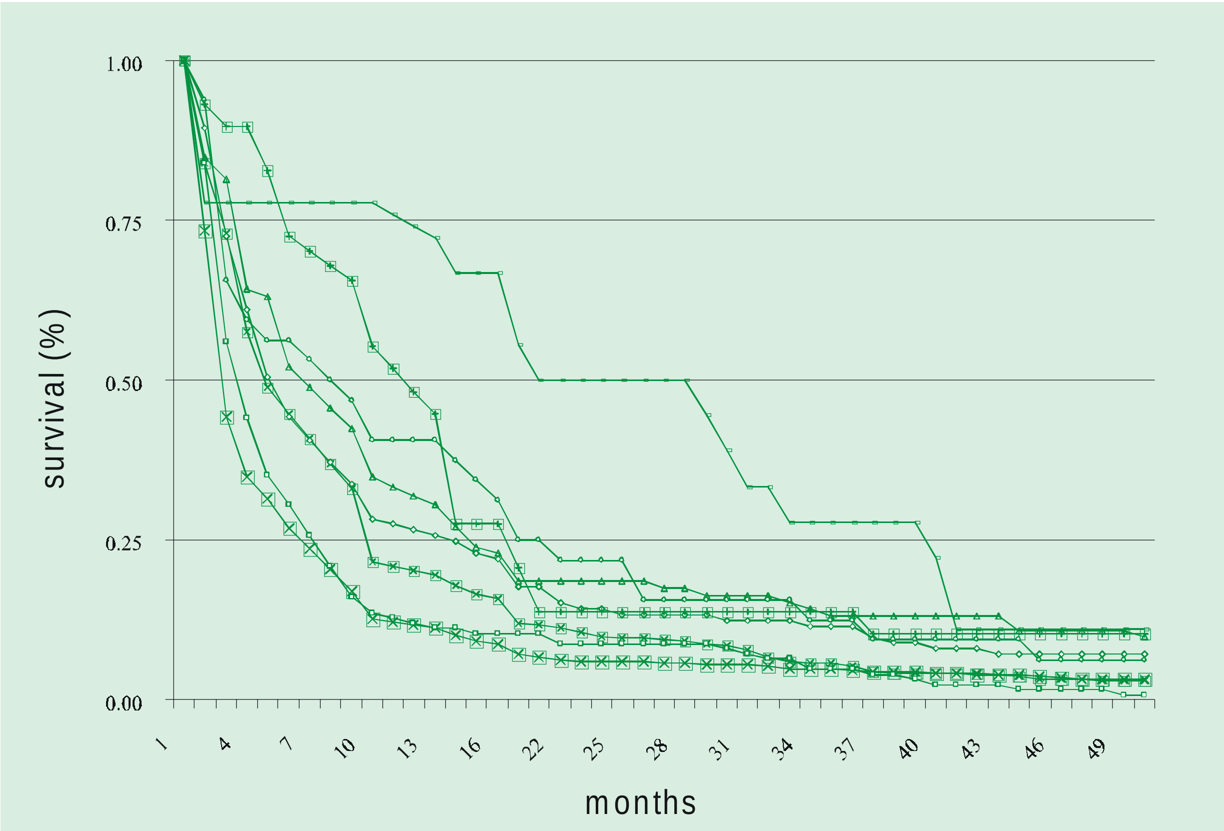
Prevalent dry season winds blow east to west across southeast Pará, and most seeds disperse within 100 m to the west of parent trees before the onset of wet season rains. Between 60 – 70% of seeds are viable at the time of dispersal. Seed survival on the ground until germination depends on length of time before the onset of wet season rains and the temporal pattern of early season rainfall (Grogan 2001). While up to 50% of seeds in experimental plots may be lost to animal and insect predators and to fungal pathogens, systematic foraging patterns and or losses were rare in lightly logged forest compared to predation rates by spiny rats (*Proechimys* spp.) reported from heavily logged forests (Clements 2000, Grogan 2001, Jennings & Brown 2001).

Germination rates by surviving seeds are fastest in shaded, moist forest understory conditions (Morris *et al.* 2000). Delayed germination in gaps where daily sun exposure dries leaf litter and seeds after early wet season rains means that exposure to predators and pathogens is prolonged, increasing seed mortality rates (Grogan 2001).

Growth by juveniles and adult trees

After germination, most seedling mortality is attributable to forest pathogens, insect predators, falling debris, and dry season moisture stress. Seedlings may establish at densities averaging 1 per m^2 within 50 m radius of parent trees producing heavy fruit crops (Grogan 2001). Though seedlings establishing in the forest understory grow little, rare individuals may survive many years in understory shade (Figure 9) (Gullison & Hubbell 1992). However, after one to two years of suppression, these seedlings may lose their ability to rapidly accelerate vertical growth rates following overhead canopy disturbances which elevate ground-level light availability (Grogan 2001).

Figure 9. *Survivorship by naturally established seedlings around eight parent trees in south Pará between 1995-2000. Each line represents seedlings associated with a single tree. (Source: Grogan 2001)*

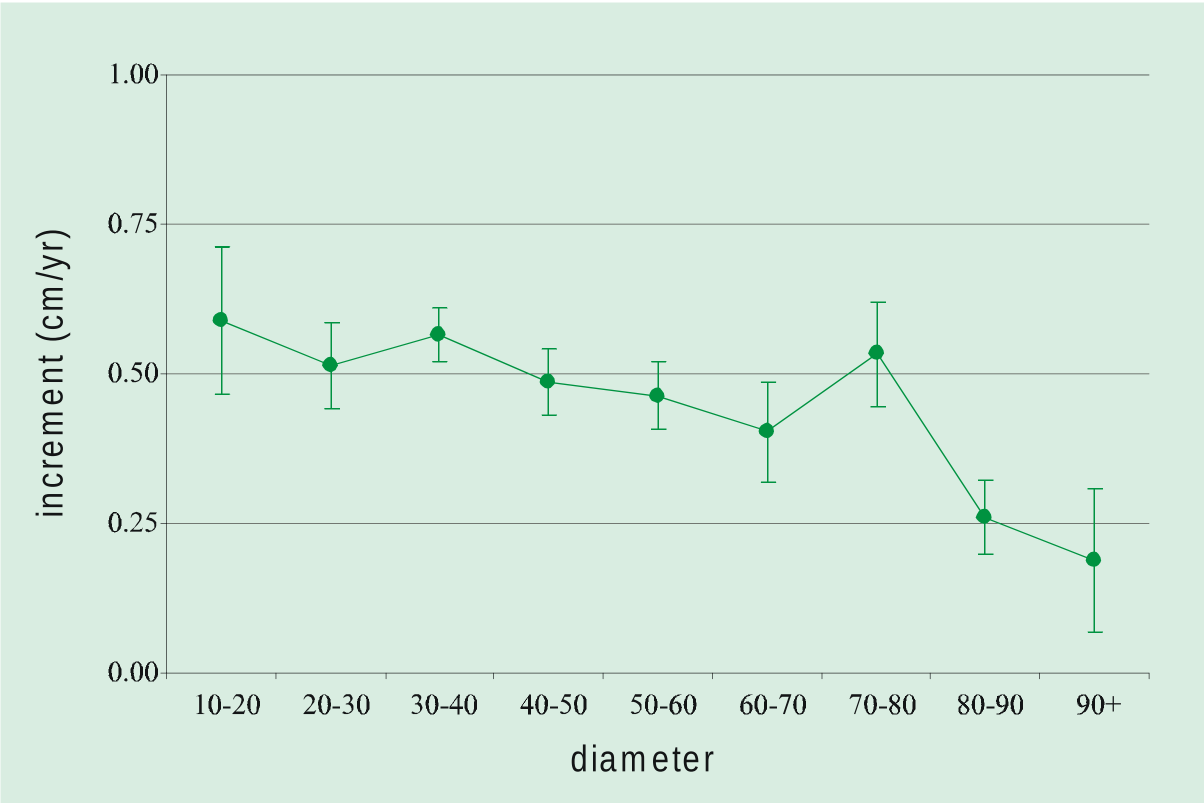


Vigorous early seedling growth requires higher light levels than are available under average forest understory conditions. Saplings taller than 50 cm height and poles 5 – 10 cm dbh are rare in primary forest, occurring only in large or small canopy gaps within dispersal distance of parent trees. In ideal growing conditions in canopy gaps with fine-textured, well-draining, nutrient-rich soils, annual seedling and sapling growth rates exceeding 3.5 m height and 3 cm dbh have been recorded (Lopes *et al.* 2000, Grogan 2001).

In southeast Pará, early growth rates correlate positively with soil nutrient status. Experimental studies have shown seedling growth rates in low-ground hydromorphic soils where adult trees cluster to exceed growth rates in high-ground dystrophic soils where adults are rare. This indicates that enriched soil nutrient status in low-ground soils may influence recruitment rates along with light environment and level of competition. Indeed, zones of high-nutrient soils within the seasonally dry landscape are thought to harbor merchantable trees at highest densities, especially slightly elevated areas surrounding first-order streambeds where aboveground streamflow originates (*cabeceiras*). As soil fertility declines moving away from streambeds, the scale and intensity of canopy disturbance required for successful recruitment by mahogany likely increases (Grogan 2001). These results echo observations from the lower Araguaia River basin by Sombroek & Sampaio (1962), who reported that mahogany occurred most commonly in areas with poor drainage (low ground) on yellow podzols (ultisols) with high base saturation and exchangeable bases (primary nutrients).

Recent field studies permit preliminary projections of mahogany's long-term development patterns. Diameter increment data from southeast Pará for trees larger than 10 cm dbh demonstrate average population-wide growth rates ranging from 0.49 – 0.79 cm/year among four study sites (Figure 10). Potential or optimal growth rates represented by mean values for the fast-growing quartile by 10-cm size class exceeded 1 cm/year for nearly all size classes below 70 cm dbh at all sites, indicating that merchantable trees 55 cm dbh may require 50 to 60 years to attain that size (Grogan 2001).

Figure 10. *Annual diameter growth by 214 trees by diameter size class at one site in south Pará, 1996-1999. Error bars indicate one standard error. (Source: Grogan 2001)*



Post-Logging Regeneration

Mahogany saplings and poles tend to occur in logged forest where canopy disturbance is widespread, along skidtrails and access roads, and around the perimeters of persistent ponding water where logging roads impede drainage. However, Veríssimo *et al.* (1995) found mahogany seedlings in only 30% of 69 plots placed in gaps created by mahogany's extraction at four sites in southeast Pará, and none of these appeared to be growing vigorously. Grogan *et al.* (in press) found seedling and sapling regeneration in 65% of 40 treefall gaps opened by mahogany's removal in surveys conducted two to three years after logging. Four of these gaps accounted for 55% of all individuals tallied, while the remaining 22 gaps with regeneration averaged only 2.6 seedlings and saplings in area averaging 535 m^2 per sampled gap. Secondary vegetation was filling all gaps, and most mahogany regeneration appeared to be suppressed by shade cast by taller woody competition. Jennings & Brown (2001) reported scarce or absent seedling, sapling, and pole regeneration at two sites in southeast Pará 8 – 13 years after logging.

The basic facts of mahogany life history help explain why regeneration is rare or absent after logging in southeast Pará and in regions outside Brazil (Stevenson 1927, Lamb 1966, Quevedo 1986, Snook 1993, Gullison *et al.* 1996, Grogan *et al.* in press). Low stocking or the absence of saplings and poles within aggregations of adult trees in primary forest indicates that conditions necessary for recruitment – abundant seeds, high light levels, available soil nutrients, and reduced above- and belowground competition – occur rarely, whether at intervals several years to many decades apart, or at spatial scales from hundreds of square meters to hundreds of hectares in extent. Treefall gaps created by mahogany's extraction may not provide necessary conditions for sustained growth by seedlings, either because the gaps are too small (Snook 1993, Gullison *et al.* 1996) or because they are opened at sites where growing conditions are not ideal. The likelihood that seeds are abundantly available in logging gaps is reduced by the fact that few trees produce large seed crops in any given year; indeed, some large trees rarely produce fruit at all. Since trees smaller than the legal minimum diameter cutting limit of 45 cm dbh are commonly logged from primary forests, low fecundity by young adult trees guarantees that few seeds will be available for their potential replacement (Grogan 2001).

Current logging practices dictate that most trees are felled in the late rainy season or early dry season, before seeds disperse (Veríssimo *et al.* 1995). Where logging occurs before seeds disperse, seedlings established in the forest understory during the years previous to extraction will be in short supply due to high mortality rates in understory shade. Growth response ability by previous years' seedling survivors to suddenly elevated light levels in treefall gaps may be compromised by prolonged suppression in understory shade. Where logging occurs after seed dispersal, increased seed mortality rates can be expected in gaps compared to the forest understory due to delayed germination (Grogan 2001).

Finally, many tree crowns are felled away from the zone of highest seed and seedling density west of parent trees, leaving most potential regeneration in understory shade. Collateral damage to seedling crops caused by falling trees and logging equipment may further reduce seedling numbers.

Low rates of post-logging regeneration documented years after extraction are therefore not surprising when we examine the many factors limiting seedling establishment at a given tree in a given year. Successful regeneration and recruitment following logging will require two types of silvicultural interventions: first, seed dispersal (or seedling, if outplanting) to appropriate growing sites; and second, tending operations in subsequent years to maintain growth rates as canopy gaps close. These treatments will be discussed below in the section on management practices.

Enrichment Planting in Natural Forests and Plantations

Enrichment plantings of mahogany in secondary or logged forest in Brazil have seen mixed results. At Belterra near Santarém, Pará, Yared & Carpanezzi (1981) reported high seedling survivorship and growth rates four years after outplanting at 4 to 6 m spacing into logged forest where all trees smaller than 25 cm dbh had been cut. No shootborer attacks were observed, attributed to protection afforded growing mahogany seedlings by secondary vegetation. Brienza (1980) also documented shootborer attack rates of 0% on seedlings planted into secondary vegetation, compared to 54% in open fields near Capitão Poço, Pará. In a *taugnya* system in the Tapajós region, Brienza *et al.* (1983) recorded 82% shootborer attack rates after two years. In Acre, Oliveira (1996, 2000) planted mahogany into logging gaps and skidtrails after clearing by chainsaw. Declining shootborer attack rates over time were attributed to increasing protection provided mahogany seedlings by regenerating secondary vegetation. Extensive line plantings in logged forests in southeast Pará returned poor results due to inadequate light availability in partial overstory shade (Veríssimo *et al.* 1995).

Plantation management in southeast Pará, where thousands of hectares of mahogany have been planted in pure stands since the early 1990s, has been unsuccessful due to shootborer infestation, fire, and poor site selection on a landscape where mahogany grows poorly on high ground characterized by nutrient-impoverished soil (Grogan 2001). Experimental plantations have been established in east Pará, north of mahogany's natural range in the Brazilian Amazon, examining resistance of mahogany seedlings from different regions in Brazil to the mahogany shootborer. As well, protection offered to mahogany seedlings by closely related exotic species (*Toona ciliata* or Australian cedro) that are toxic to the shootborer is being tested, and protection from the shootborer when mahogany is planted at wide spacing in mixed-species systems (A. Terezzo, *personal communication*; see Costa *et al.* 2000, Ohashi *et al.* 2000). Anecdotal reports indicate early success intercropping mahogany in high-input (fertilizer) black pepper plantations near Paragominas, Pará.

MANAGEMENT AND CONSERVATION OF MAHOGANY IN THE BRAZILIAN AMAZON

In this section we focus on technical aspects of mahogany's management and conservation in Amazonia. It is important to emphasize that successful management and conservation will require market pressure (for example, demand for certified wood) and rigorous control mechanisms. In the absence of efficient control, mahogany's extraordinary value – determined by international demand – has only encouraged short-term profit-taking. Here we discuss the history of and possibilities for control of mahogany's exploitation.

Remaining Commercial Stocks

In order to design effective conservation and management strategies for mahogany it is essential to assess remaining natural stocks. The Brazilian government convened a Working Group on Mahogany in 1998 at which a national inventory to evaluate commercial stocks was approved. However, this initiative has yet to be realized, and information regarding available stocks remains scarce and unreliable.

It is difficult to quantitatively assess the status of remaining Brazilian mahogany stocks for several reasons. First, mahogany's vast range across remote stretches of the Amazon Basin make region-wide inventories logistically challenging and costly. Second, scant information about historical distribution and density patterns combined with unreliable information from the logging industry about volumes extracted from any given locale or region means that no basis exists for comparing logged volumes with historical stocks to estimate remaining supplies. Third, changes in land-use following mahogany's extraction – for example, forest conversion to pasture and agriculture, or forest degradation by periodic dry season fires (see Cochrane et al. 1999, Nepstad et al. 1999) – occur at scales too large and variable to accurately quantify. Finally, little is known about how surviving trees (usually smaller than 40 cm dbh) and potential regeneration (seedlings and saplings established before or after logging) fare in logged-over forests.

Contente de Barros *et al.* (1992) attempted to quantify remaining harvestable volumes of naturally occurring mahogany in Brazil. They estimated that 16 – 21 million m^3 of commercial stocks remained in 500,000 km^2 of forests outside Indigenous and other protected areas. This stock, according to the authors, is sufficient to provide 500,000 m^3 per year over a period of 32 – 42 years. They estimated as well that an additional 13.7 million m^3 of mahogany remained in approximately 340,000 km^2 within Indigenous and protected areas.

Though an important contribution, this unpublished report suffered serious methodological flaws. Its conclusions were based on data sources that were out of date at the time of writing. In fact, a significant portion of forests within mahogany's natural range had been subjected to predatory logging, fire, and or conversion to other uses, principally pasture, by 1992. Another problem with this report is that inventory data sources, including Radambrasil, were not suited to region-wide extrapolation or were not comparable due to differences in objectives and methods. Finally, mahogany populations occurring within Indigenous Areas and conservation areas have not escaped loggers' attentions. Except in remote pockets of forest within Indigenous Areas, commercial stands of merchantable mahgoany will not persist many years longer in south Pará. Indeed, the current second wave of extraction within the so-called Middle Land between the Xingu and Iriri Rivers is removing nearly all surviving accessible trees larger than 45 cm dbh.

The frontier for mahogany extraction is presently centered in southwest Pará along the Cuiabá-Santarém highway and in southeast Amazonas. After these stocks have been exhausted, the final frontier for mahogany in Brazilian Amazonia will be in the western state of Acre. In order to accelerate the inventory process, it is important that alternative methods for identifying intact and logged populations be developed. For example, it is probable that logging companies specializing in mahogany already possess empirical inventories delineating areas of occurrence and remaining stocks. During the exploration phase, these companies conduct aerial surveys from small planes over unlogged forests, identifying mahogany trees by their shiny leaves and by their irregular crown outlines generally occurring on low ground. This expertise could be incorporated into rapid inventories at regional scales. Satellite images could be used to map logging roads and loading patios to indicate areas already exploited. More detailed inventories could be conducted within regions where remaining stocks are concentrated.

Management of Mahogany in Primary Forests

In this section we present recommendations for managing mahogany in natural forests. Before doing so, however, it is important to point out that management plans for mahogany could encounter legal problems associated with Permanent Preservation Areas (PPAs) as designated by the Brazilian Forest Code. Most merchantable mahogany trees occur along the margins of rivers and seasonal streams defined as PPAs. These areas were originally excluded from production activities except those benefitting the public interest. The current Provisional Measure (*Medida Provisória*) regulating the Forest Code's implementation states that vegetation within PPAs can be exploited under certain circumstances. Management activities are possible within PPAs when such use conveys benefits to broad social interests and utilization is "eventually discontinued, with minimal impact on vegetation" (article 4, paragraph 3 of Provisional Measure 2166-67, August 2001). Even so, regulations specifying management practices within PPAs have not yet been formally enacted. In the meantime, the lack of clear guidelines to production activities within PPAs and the limited number of cases involving interpretation of the current Provisional Measure could complicate management of mahogany in natural forests. We suggest that technical recommendations presented below could serve as a reference for future regulations specifying management practices for this species.

The basic premise underlying sustained-yield forest management is that harvested timber volumes must be replaced during the length of the cutting cycle by growth of sub-merchantable trees – those too small to remove at the time of first harvest – and by recruitment into pole and sub-merchantable size classes of new individuals from seeds and seedlings, whether naturally or artificially occurring (that is, through enrichment planting). Management recommendations presented here are derived from field studies conducted in south Pará and Acre since 1995 (see Grogan 2001, Baima 2001). As discussed previously, remaining forests with intact mahogany populations are located principally in Acre and in restricted areas within southeast Amazonas and southwest Pará. Management of these remaining stocks will require careful extraction of mature trees combined with silvicultural treatments to stimulate growth by sub-merchantable trees and seedling regeneration as summarized in Table 1.

Table 1. *Management procedures for mahogany and projected harvest lengths.*

Target population of treatments	Year of intervention	Treatments	Time until harvest relative to year zero (years)
Trees > 55 cm dbh: 1st harvest	0	- Plan logging. - Respect minimum diameter cutting limit. - Select seed trees and collect seeds.	0
Trees > 25 cm dbh: 2nd harvest	0	- Cut vines from sub-merchantable mahogany trees. - Thin competing crowns.	~ 30
Seedlings: 3rd harvest	0 ~ 1, 3, 6, 10, 30	- Establish artificial regeneration through enrichment plantings in logging gaps. - Accelerate growth by natural regeneration in logging gaps. - Clean around planted regeneration, cut vines.	~ 60
Seedlings: 4th harvest	~ 30 ...	- Establish artificial regeneration through enrichment plantings in logging gaps. - Clean around planted	~ 90

Procedures for harvesting merchantable trees (1st harvest)

The management plan. Planned extraction should include mapping of all merchantable trees and pre-harvest design of road and skidding networks, reducing costs and damage inflicted on forest structure (that is, through reduction in forest area opened by roads, eliminating unnecessary forest clearings, reducing the number of injured or killed juvenile trees, and minimizing damage to surface drainage systems). As well, reduced forest canopy opening lowers the risk of post-harvest forest fires (Holdsworth & Uhl 1998).

Respect minimum diameter cutting limits and seed tree selection criteria. Only trees larger than 55 cm dbh should be harvested. Small trees should be retained to grow to merchantable size for removal during the second cut. Large hollow unmerchantable mahogany trees may be perfectly healthy otherwise and capable of producing high-quality seeds. Because landscape-scale densities are low in Acre compared to southeast Pará, seed trees may need to be retained in groups to maintain reproductive capacity. Complete removal of merchantable mahogany outside groups of trees designated for retention should be considered, coupled with enrichment plantings detailed below. Seed trees should be retained as sources for seed collection and re-distribution across management areas, not for purposes of natural regeneration through dispersal. This is because the seed shadow downwind of any given tree is small relative to the total area requiring seeds after logging.

Directional felling and seed collection. Where possible, trees should be felled directionally to open canopy gaps where seeds and seedlings are most likely to occur naturally, that is, in the direction of prevailing dry season winds. If felling occurs before seed dispersal, undehisced fruit should be removed from crowns for seed collection.

Treatments for sub-merchantable trees (2nd harvest)

Thinning competing crowns and vine-cutting. At the time of first harvest (year 0 in Table 1), vines and neighboring tree crowns competing for canopy space with sub-merchantable mahogany trees (those 25 – 55 cm dbh) should be cut and thinned. Preliminary results from south Pará indicate that suppressed trees are capable of accelerating diameter increments in response to canopy thinning operations within two years after treatment (Grogan, unpublished data). These trees can be harvested approximately 30 years following the first cut.

Treatments for establishing the 3rd harvest

These treatments are designed to establish mahogany regeneration representing the third cutting cycle, approximately 60 years after the first harvest. At the time of first harvest the following treatments should be implemented:

Opening clearings for natural regeneration. Canopy gaps should be opened downwind of logged and surviving mahogany trees where seeds are likely to disperse. Prior knowledge of fruiting rates and patterns by individual trees could indicate trees with highest fecundity for treatments; or, gaps could be opened wherever trees are confirmed to fruit heavily.

Enrichment planting. Seeds (or seedlings) should be planted directly into artificial gaps opened where site quality increases the likelihood of sustained growth and recruitment. These could be in *cabeceiras*, or along the banks of higher-ordered seasonal streams where advance regeneration is not dense with vines, bamboo, or babaçu (*Attalea speciosa*, Palmae). Planting densities should be low to avoid build-up of resident shootborer populations; for protection from the shootborer, seedlings should grow within a matrix of secondary vegetation. Site preparation should include soil scarification and burning within gaps to enrich soils and reduce above- and belowground competition (Grogan 2001). Burns should be strictly monitored to avoid escaped forest fires.

Silvicultural treatments. Periodic silvicultural treatments will be necessary during the first 10 years following outplanting. The precise sequence of tending operations (principally cleaning around growing saplings and poles and occasional gap enlargement) will depend on local site conditions and should be determined experimentally. We anticipate tending operations 1, 3, 6, and possibly 10 years following establishment.

At the time of the second cut approximately 30 years following the first harvest, individuals established through enrichment plantings in year 0 will likely require tending operations to stimulate growth rates. In this case, thinning operations and vine cutting are equivalent to those described above for sub-merchantable trees. Harvest of this generation of trees should occur approximately 30 years after tending during the second cut, or 60 years after the first cut.

Management of Mahogany in Logged Forests

Unlogged commercial stands of mahogany are rare east of the Iriri River in southeast Pará, whether on *terra devoluta*, within Indigenous Areas, or within nominally protected areas. Mahogany's extraction across this vast region since the early 1970s was essentially a mining operation, removing all trees of commercial value (Veríssimo *et al.* 1995). A second wave of extraction targeting lesser-value species beginning in the 1990s removed most surviving merchantable mahogany trees.

Forests logged during the first wave of mahogany extraction should retain sub-merchantable trees at densities sufficient to consider silvicultural interventions (Baima 2001, Grogan 2001, Jennings & Brown 2001). Management options outlined here consider surviving mahogany populations where forests have been logged only once. These practices include treatments favoring second- and third-rotation trees.

Treatments for sub-merchantable trees (2nd harvest)

Thinning competing crowns and vine-cutting. These treatments should free mahogany trees of intermediate size (25 – 55 cm dbh) from competition by neighboring crowns and vines, as described in Table 1. This stock could be harvested approximately 30 years following treatment.

Treatments for establishing the 3rd harvest

Treatments described for natural forests are appropriate for establishing trees to be harvested during the third cutting cycle. However, in regions where mahogany has already been logged once, enrichment planting should occur in logging gaps created by extraction of secondary timber species and by removal of intermediate sized surviving mahogany trees with low growth potential (for example, with damaged crowns). Removal of secondary species serves the dual purpose of opening growing space for outplanted mahogany and subsidizing treatment costs (Snook 1993, Gullison *et al.* 1996). Where logging secondary species is not economically viable, it may be necessary to open growing space by felling non-commercial trees. In this case, incentives for loggers and landowners interested in forest management are greatly reduced, as they are forced to return to previously logged forests to implement silvicultural treatments without benefit of short-term returns on their investment.

Plantations

In southeast Pará, a substantial portion of the landscape is unsuitable for plantation establishment, particularly nutrient-impoverished soils on high ground between seasonal streams. Only costly fertilizer inputs can correct soil nutrient deficiencies. Low ground nearest streams is also unsuitable for mahogany in plantations due to increased swampiness after forest clearing. Best seedling performance in plantations as currently practiced is restricted to slightly elevated ground set somewhat back from streams (Grogan 2001).

Best performance in artificial systems may be achieved where secondary vegetation is felled and burned, mimicking small-holder agricultural establishment, and seedlings are outplanted into heavy debris. Ash inputs and partial protection from the shootborer afforded by dense regenerating secondary vegetation enable mahogany to grow robustly under these conditions. Woody regrowth rapidly restores canopy shade, reducing weedy groundcover and lowering fire susceptibility. Outplanting density should be low, approximately 50 planting sites per hectare at 15 m spacing to reduce mahogany shootborer attack rates.

Mahogany is a poor candidate for reforestation efforts on degraded soils (e.g., in pastures or abandoned pastures). It competes poorly belowground with grasses, and grows poorly in nutrient-impoverished soils (Grogan 2001). As well, fire is a constant threat in these systems. However, mahogany may grow vigorously enough to overcome repeated shootborer infestations when inter-planted into agricultural systems on short rotation cycles (one to five years) where fertilizer inputs are high (e.g., in black pepper plantations).

Conservation

Forest management could contribute to conservation by maintaining reproductively viable populations across mahogany's natural range. Additional measures recommended to strengthen conservation of mahogany in Brazil include:

Designate new protection areas for mahogany. This would assure conservation of representative phenotypes and genotypes across mahogany's Brazilian range. These might include, for example, isolated populations on scattered mountain outcrops (inselbergs) in southeast Pará, and small patches of logged populations in forest types that are currently unprotected.

Protect existing conservation units against further exploitation. Mahogany's extraordinary value renders merchantable quantities in protected areas vulnerable to illegal exploitation. Without active federal or state protection combined with heavy and enforced penalties for unlawful extraction, mahogany's disappearance as an adult tree from any landscape is inevitable.

Enforce retention of Legal Reserves on private properties. Across mahogany's natural range in Brazil a significant portion of the forested landscape is being converted to other uses without precautions taken to conserve faunal and floral communities that are unique to each region and locality. Some of these forests contain sub-populations of mahogany trees that survived the first wave of logging as well as isolated individuals at inaccessible locations (for example, on the steep slopes of inselberg mountains in southeast Pará). These populations could be protected by properly enforcing legislation mandating retention of Forest Reserves within private landholdings.

Invest in research towards improved management and conservation. Silvicultural techniques for managing trees in natural or artificial settings are based on thorough understanding of how a species reproduces, survives, and grows within a given landscape. Current research programs on mahogany, summarized in Box 1, offer opportunities to extend observations of growth and reproduction over many years, opportunities which for mahogany are not likely to arise again in the near future on these increasingly fragmented landscapes. New research initiatives should be included as an integral part of management projects in southwest Pará, Rondônia, and Acre where mahogany grows on landscapes very different from southeast Pará.

Box 1. **Research programs on mahogany in the Brazilian Amazon.**

Major research programs on the ecology, genetic structure, and management of mahogany in natural forests have been initiated in Brazil in recent years. These include:

Kayapó / Conservation International. Since 1993 at the Pinkaití Research Station near the village of Aukre within the Kayapó Indigenous Area, southeast Pará. This program addresses mahogany's distribution patterns, growth, and natural regeneration in unlogged primary forest. Collaborating institutions include the University of São Paulo, the University of Toronto (Canada), and the Fundação Nacional do Índio (FUNAI). The Pinkaití Research Station is located within a 5000-ha biological reserve set aside by the Kayapó for research and conservation purposes. Contact: Dr. Barbara Zimmerman, b.zimmerman@utoronto.ca.

Instituto Nacional de Pesquisas da Amazônia (INPA). Since 1995 at sites in southeast Pará, Mato Grosso, Rondônia, and Acre. This research addresses genetic structure and patterns of gene flow within mahogany populations, and the impacts of logging and fragmentation on mahogany's mating system, using DNA microsatellite markers. Collaborating institution is EMBRAPA – Recursos Genéticos e Biotecnologia. Contact: Dr. Maristerra Lemes, mlemes@inpa.gov.br.

Instituto do Homem e Meio Ambiente da Amazônia (IMAZON) / Yale University School of Forestry & Environmental Studies. Since 1995 in selectively logged forests near Redenção and Agua Azul in southeast Pará. This research addresses mahogany's spatial distribution patterns across seasonal landscapes, population structures, adult growth and mortality rates, reproductive phenology, fruit production, seedling ecology, and implications of mahogany life history for management in natural forests and plantation systems. Collaborating institutions include the IAN Herbarium at EMBRAPA/CPATU, Belém, the University of São Paulo, Pennsylvania State University (USA), and the College of Wooster (USA). Research sites include timber industry-owned management areas (Serraria Marajoara Ltda, Madeireira Juary Ltda, Peracchi

Timber Ltda), and privately held forests (Sr. Honorato Babinski, owner). Contact: Dr. James Grogan, jgrogan@imazon.org.br.

Embrapa Amazônia Oriental (EMBRAPA/CPATU), Belém / DFID – Forestry Research Programme (UK). Since 1998 in primary and selectively logged forests near Rio Maria, Marabá, and Parauapebas in southeast Pará. This research addresses mahogany's spatial distribution patterns, population structures, fruit production, seed predation, natural regeneration after logging, seedling ecology, and silvicultural management prescriptions derived from ecological studies. Collaborating institutions include the Oxford Forestry Institute, Bep Noi Association of the Xikrin Indians, and the Instituto Socioambiental. Research sites include timber industry-owned management areas (MG Madeireira e Agropecuária Ltda, Nordisk Timber Ltda) and the Xikrin Indigenous Area. Contacts: José do Carmo Alves Lopes, carmo@cpatu.embrapa.br, Dr. José Natalino Macedo Silva, natalino@cpatu.embrapa.br, and Dr Olegário Carvalho, olegário@cpatu.embrapa.br.

IMAZON, World Wide Fund for Nature (WWF), and the Government of Acre. Since 2001 on privately held forested land south of Sena Madureira, Acre. Project objectives include: to test management practices derived from field studies of mahogany and associated high-value timber species; to evaluate the technical and financial feasibility of these management practices; and to document and disseminate information about forest management to the forest industry, small-holder agriculturists, extractivist communities, and government agencies. Collaborating institutions include Madeireira A.F.G. Oliveira, the State Department of Forestry and Extractivism (SEFE), the Technology Foundation of Acre (FUNTAC), USAID, and the U.S. Forest Service – International Institute of Tropical Forestry. Contact: Dr. James Grogan, jgrogan@imazon.org.br.

INICIATIVES TO CONTROL MAHOGANY'S EXPLOITATION

Recent initiatives to control mahogany's exploitation include those by the Brazilian federal government, bilateral international treaties, and environmental groups at national and international levels. We discuss these increasingly effective initiatives below along with possible new mechanisms for control.

Management Plans

Any commercial logging operation in the Brazilian Amazon, including those involving mahogany, must be implemented according to federal environmental regulations. Timber extraction from primary forests may be authorized under two categories: forest management plans, and forest conversion to other uses through clear-cutting. By far the majority of mahogany logged in Brazil is legalized through forest management plans. Unfortunately, state and federal supervision of these management plans has been extremely weak. A study by Embrapa (1996) revealed that most required management practices are not implemented in the field. Management plans within a given region are frequently used to legalize timber extracted without authorization from other areas. Mahogany's illegal extraction from untitled federal land (*terra devoluta*) and Indigenous Areas is made possible through transfer of these fraudulent credits. The transport of illegal timber is easily "legalized" because the control mechanism – documents specifying volumes to be transported – is easily circumvented (Barreto & Souza Jr. 2001).

Beginning in 1995, when Ibama began to systematically review all management plans registered within Brazilian Amazonia, weaknesses in control mechanisms began to be more evident (Ibama 1998, 1999, 2001c). An Ibama report published in 1999 revealed problems with field evaluations of management plans including mahogany during the years 1995-1998 (Ibama 1999). Re-evaluation of these management plans by technical advisors from outside the region led to suspension of 85% of management plans still operational. In 1996, indications that control mechanisms were being systematically circumvented led the President of Brazil to declare a two-year moratorium on authorization of new management plans involving mahogany (Presidential Decree 1963, July 1996). In 1998 and 2000 this moratorium was renewed (Decrees 2687/1998 and 3559/2000, respectively).

By October 2001 it had become clear that the remaining valid management plans for mahogany were being used to legitimize continued illegal extraction of mahogany. Ibama and the Federal Police launched "Operation Mahogany" to shut down illegal activities, principally in south Pará between the Xingu and Iriri Rivers within the so-called Middle Land. Eleven remaining valid management plans for mahogany were suspended (Normative Instruction 17/2001, Ibama) in lieu of field evaluations by independent consultants. After evaluation, 10 of these management plans were cancelled in December 2001 due to technical improprieties or fraudulent practices (Normative Instruction 22/2001, Ibama). With this decision Ibama prohibited export of mahogany that had been logged based on permits from these cancelled management plans, on the understanding that this timber originated illegally from forests outside these management areas and that management plans were not being fully implemented.

A group of logging companies whose timber had been confiscated by Ibama subsequently won a sustaining order in state court allowing export of mahogany in port at the time of suspension. The Brazilian government (Ibama 2002a) and environmental groups (Greenpeace 2002a) requested international assistance in blocking commercialization of this timber. As a result, mahogany shipments were detained by European and United States customs authorities. Foreign governments indicated that legal commerce could be re-instated only after verification that impounded mahogany had originated from legal sources (Greenpeace 2002b). In April 2002, the President of Brazil announced on his weekly radio program that he would maintain the ban on mahogany's extraction and commended Ibama and NGOs contributing to its control (Ibama 2002b).

Export Quotas

The Brazilian government has attempted to limit mahogany's extraction through export quotas since 1990, a policy that implicitly acknowledges the threat of commercial exhaustion to national mahogany stocks. Export quotas fell dramatically during the 1990s, from 150,000 m^3 to 65.000 m^3 in 1998 and further to only 30.000 m^3 in 2001. Even so, this policy's actual impact on illegal logging is difficult to assess. For example, true export volumes are said to exceed export quotas due to mahogany's commercialization under false names. More likely, however, is that the steep decline in reported exports is due more to shrinking natural stocks than to falling export quotas.

Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)

CITES is a United Nations-sponsored treaty regulating international trade in species under threat of extinction. Mahogany's inclusion on Appendix II of CITES as a species potentially threatened if current practices are not modified was proposed at treaty conventions in 1992, 1994, and 1997. Appendix II provides for increased control over supply at the point of origin towards avoiding further drastic reductions in natural populations. This proposal's principal proponents, including countries like the Netherlands and the United States as well as NGOs, emphasized mahogany's vulnerability to local and regional extinction and the possibility of genetic erosion across mahogany's range (Rodan *et al.* 1992, NRDC 1994, Bass *et al.* 1999). Opponents of mahogany's inclusion on Appendix II, including Brazil and other major producing countries, argued that this would represent a non-tariff barrier to international trade in tropical timber. They asserted that criteria listed by CITES do not justify mahogany's listing on Appendix II, given insufficient proof of population declines across its natural range (Figueroa Colón 1994). No proposal for listing was supported by the two-thirds majority vote necessary for inclusion, and no proposal for listing was submitted during the most recent CITES convention in Kenya in April 2000.

Nevertheless, in April 1999 the federal government registered Brazilian mahogany populations on Appendix III of CITES, requiring that producer nations provide documentation certifying that exported mahogany was legally extracted. The CITES Secretariat advised its member countries to halt imports from Brazil in March 2001 on grounds that the Brazilian government had suspended management plans and prohibited mahogany's export. Based on this recommendation, the General Director of the European Commission's Environment Ministry also advised its member countries to suspend all purchases of Brazilian mahogany.

Greenpeace Campaign for the Protection of Old-Growth Forests

Mahogany's illegal extraction has been the focus of intense pressure by international environmental groups. Greenpeace has been one of the most active NGOs applying pressure within context of its global campaign for the protection of old-growth forests. This campaign opposes uncontrolled logging in primary forests around the world, including tropical, temperate, and boreal forests. Greenpeace's contributions to the mahogany debate have ranged from documentation of illegal extraction to media campaigns against illegal commerce. In Brazil, Greenpeace has pressured the federal government to improve control over extraction while at the same time supporting government initiatives to do so by providing information about illegal logging activities (Greenpeace 2001). At the international level, pressure exerted by Greenpeace has influenced the decision by many countries to suspend Brazilian mahogany imports. Among other measures, Greenpeace has proposed that management plans for mahogany should be certified according to socio-economic and environmental standards set by the Forest Stewardship Council (Greenpeace 2002a).

Suggestions for the Control of Mahogany's Exploitation

Largely uncontrolled extraction of mahogany has already occurred across most of its Brazilian range. But recent pressure exerted by the government, by environmental groups, and by market forces indicate that future commercial prospects for illegally harvested mahogany are limited. The only option for credible trade lies in adoption of rational forest management and improved control mechanisms. The most important additional control mechanisms include the following:

Improve government control of management plans. The current system for control of logging could be improved through adoption of new technologies and auditing procedures. Management plans should be periodically audited by non-governmental technical consultants. Studies supported by Ibama and the Ministry of the Environment indicate that new technologies could be employed towards control of logging. The boundaries of management projects and rural properties could be demarcated on satellite images noting vegetation cover by type (forest, deforested areas, etc.). Recently developed methodologies permit identification of logged areas by satellite images and could be used to monitor management areas and private properties (Souza Jr. & Barreto 2000, Barreto & Souza Jr. 2001, Monteiro *et al.* no prelo). The state of Mato Grosso is using this system to grant licenses for forest clearing. Control over log transport could be improved by installing georeferencing devices on transport vehicles that would allow trucks loaded with mahogany to be tracked between points of embarkation and delivery, alerting authorities when vehicles stray from authorized routes. As well, this system would rationalize the current credit system for log transport, providing confirmation by volume of actual deliveries. More details about remote systems for tracking transport can be found in Barreto & Souza Jr. (2001).

Encourage the independent certification process. Independent socio-economic certification is one of the few options remaining for maintaining market credibility for Brazilian mahogany, being accepted by most environmentalists and international consumers. The Brazilian government recently recognized the importance of encouraging certification, enacting forest legislation providing benefits such as reduced project evaluation costs to certified management projects or to those in process of certification (Normative Instruction 04/2002, Ministry of the Environment).

CONCLUSION

Mahogany is a late secondary forest species that moves easily about on the landscape, its seeds dispersing by wind. It has highly germinable seeds, grows rapidly in partial or full sunlight, and may achieve giant stature during a lifetime that may span centuries. Mahogany's "weaknesses" include susceptibility to the shootborer, *Hypsipyla grandella*, during sapling and pole stages, which may damage and indirectly kill developing stems; and poor growth response to nutrient-impoverished soils. Its highly specific regeneration requirements combined with the shootborer's regulating effect help to explain why mahogany occurs at extremely low densities in natural forests, and why conversion of these forests to high-density production systems, whether in managed forests or plantations, has proven so difficult in the past.

Robust population structures observed in southeast Pará indicate that sub-merchantable mahogany trees survive in logged forests even after repeated exploitation, except where forest habitat is converted to other uses or degraded by repeated fires. Intact populations are also still present in primary forests of Acre and southeast Amazonas. However, without management interventions directed at retention of reproductive capacity (seed trees), tending sub-merchantable trees (vine cutting, crown release), and establishing the next generation of merchantable trees through seedling regeneration (enrichment plantings), mahogany faces commercial extinction across most of its Brazilian range within the coming decade, and possible biological extinction at local scales where logged populations are not allowed to recover regenerative capacity.

Establishing a credible Brazilian mahogany supply will require implementation of new regulatory mechanisms involving new technologies (globally positioned management plans, effective tracking of log transport) and extra-regulatory processes such as independent socio-environmental certification. Continued predatory extraction of mahogany – Brazil's most valuable timber species – would represent a severe blow to the goal of achieving sustained-yield production of this national patrimony. Consumers and producers alike have limited time to demonstrate that this valuable resource can be used responsibly.

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