

Managing big-leaf mahogany in natural forests

Lessons learned from an ITTO-CITES Programme project

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Timber: Reduced impact logging of mahogany at Acre field site. Photo: J. Grogan

The *ITTO–CITES Programme for Implementing CITES Listings of Tropical Tree Species* seeks to ensure that international trade in CITES-listed tropical timber species is consistent with their sustainable management and conservation. Initiated in 2007 with funding from the European Union, the Programme’s specific objective is to assist national authorities to meet the scientific, administrative, and legal requirements for managing and regulating trade in important tropical tree species listed in the CITES Appendices such as *Pericopsis elata* (afroormosia) found in Central Africa, *Swietenia macrophylla* (big-leaf mahogany) found in Latin America, and *Gonystylus* spp. (ramin) found in Southeast Asia.

This article summarizes recent findings from a project supported by the ITTO-CITES Programme, “Big-leaf mahogany in the Brazilian Amazon: long-term studies of population dynamics and regeneration ecology towards sustainable forest management”. Starting in 2007, this project extended field research initiated in 1995 with support from the US Forest Service’s International Institute of Tropical Forestry. The goal is to establish a biological foundation for sustainable forest management systems for big-leaf mahogany across southern Amazonia based on long-term studies of growth, reproduction, and regeneration by natural populations in primary and logged forests. Detailed understanding of age- and size-related mortality, growth, and reproductive rates is essential for evaluating current management guidelines and adapting management practices to changing environmental and socio-economic contexts across this vast region. This study’s mahogany populations are the longest and most intensively studied populations in Amazonia.

Four research sites in southeastern Pará and the western state of Acre are visited annually or bi-annually during the dry season to re-census nearly 700 mahogany trees larger than 10 cm diameter mapped in approximately 4000 hectares of forest. Seedling performance in natural and artificial gaps in experiments initiated during 1996–1997 are also monitored, as are enrichment plantings in logging gaps opened during a 2002 reduced-impact harvest at the Acre site. These data help to explain the conditions fostering survival and growth of mahogany during all phases of its life cycle, the dynamics of natural populations, and potential recovery rates by logged populations. Principal findings from research undertaken to date are summarized in the following sections.

Historic range and current commercial stocks in South America

The controversy over mahogany’s proposed listing on CITES Appendix II during the 1990s was fueled by disagreement and confusion over its commercial and conservation status. In a technical report (Martinez et al. 2008) and published article in the journal *Conservation Letters* (Grogan et al. 2010), we revised Lamb’s (1966) historic range map for mahogany in South America and estimated the extent to which commercial stocks had been depleted as of 2001. Using a combination of satellite data, expert surveys, and sawmill processing data from Brazil, we estimate an historic range of 278 million hectares spanning Venezuela to Bolivia, 57% of this in Brazil alone. We found that Lamb overestimated mahogany’s range in South America by almost 20%. Of the revised historic range, 21% had been lost to forest conversion by 2001, while mahogany had been logged from at least 45% of

the remaining forested area, leaving approximately 34% of the historic range with commercial stocks. However, after several decades of intensive logging leading up to the Appendix II listing in 2002, most surviving stocks in Brazil, Peru, and Bolivia were extremely low-density populations in remote regions representing a smaller fraction of historic stocks than expected based on estimated current commercial range. The fact that these are low-density populations has important implications for sustainable management.

Impacts of logging on populations and prospects for second harvests

The sustainability of current management practices can be assessed by quantifying pre-logging population densities and projecting growth and survival by post-logging populations during intervals between harvests. In an article published in *Forest Ecology and Management* (Grogan et al. 2008), we report higher historical landscape-scale mahogany densities in southeastern Amazonia compared to southwestern Amazonia, where most remaining commercial stocks survive. From 100%-area inventories covering 200 to over 11 000 hectares, densities of trees larger than 20 cm diameter varied by two orders of magnitude and peaked at 1.17 per hectare. Using growth and mortality data from this project's principal field site, we project population recovery over the current legally mandated cutting cycle of 30 years. At seven out of eight sites, populations exceeded 20% retention densities by a range of 0 – 31%. Only at one site where sub-commercial trees dominated the population was the recovery of harvestable stems projected to exceed initial commercial densities. These results indicate that the currently allowable 80% harvest intensity will not be sustainable over multiple cutting cycles for most populations without silvicultural interventions ensuring establishment and long-term growth of artificial regeneration, including repeated tending of out-planted seedlings.

Impacts of logging on genetic structure

Whether logging negatively impacts genetic structures of natural mahogany populations has long been a controversial topic. In a collaboration with researchers from the Instituto Nacional de Pesquisas da Amazônia (INPA) published in *Forest Ecology and Management* (André et al. 2008), we assisted an investigation into the effects of selective logging on genetic diversity of the mahogany population at our principal research site in southeastern Amazonia. Comparing microsatellite loci in individuals from the pre-logging cohort (trees that survived logging) vs. the post-logging cohort (seedlings establishing after logging), a significant reduction in the number of alleles, observed heterozygosity, and distinct multilocus genotype number was found in the seedling (post-logging) cohort. This loss of genetic diversity likely

occurred due to a reduction in effective population size as a consequence of logging, which leads to the loss of alleles and limits mating possibilities. These results raise concerns about the conservation genetics of logged mahogany populations where a high proportion of adults are removed from the system.

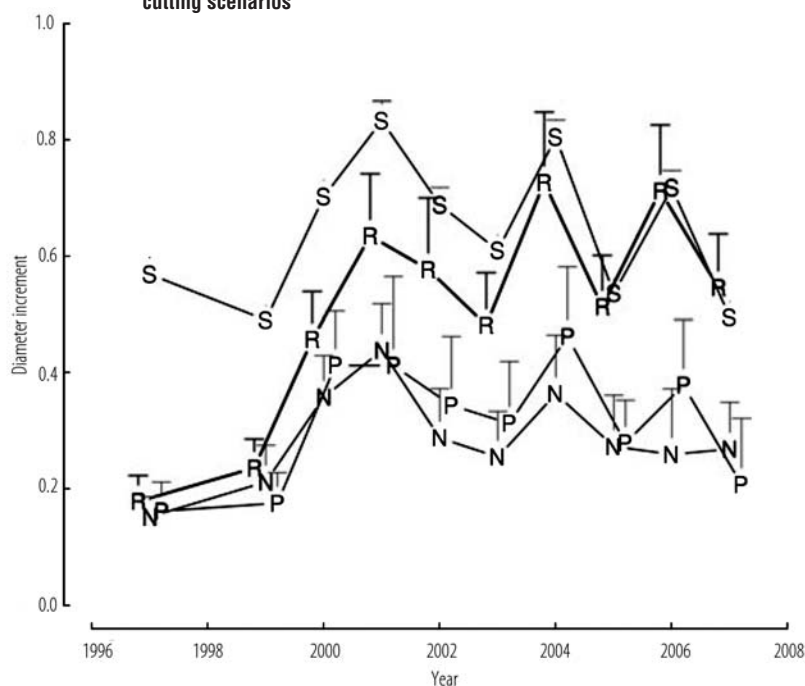
Impacts of crown vine coverage and vine cutting on survival and growth

While vines covering tree crowns have been implicated in reduced growth and fruit production rates by tropical tree species, we published the first experimental test of this dynamic in the *Journal of Applied Ecology* (Grogan and Landis 2009), comparing growth and fruit production rates by trees before and after vine cutting (previous studies have simply compared growth by trees with vines vs. trees without). Long-term monitoring and annual censuses at the Marajoara field site in southeast Pará made this possible, allowing comparison of performance by heavily infested trees during the period 1995–1998 vs. performance after vine cutting during the period 1998–2007. While vine cutting did accelerate growth and fruit production by previously moribund trees, five or more years passed before performance by 'released' trees matched that of trees without history of vine coverage (Figure 1). The message for forest managers is that targeted silvicultural practices such as vine cutting can reduce mortality during intervals between harvests and increase long-term growth and timber yield. Financial returns from vine cutting are likely to be higher than silvicultural treatments such as liberation thinning to reduce crown competition from neighboring trees because the effect – elimination of vines – is more persistent.

Mahogany population dynamics

Planned forest management requires basic understanding of the factors influencing tree survival, stem diameter growth rates (and by extension, commercial volume production), and seed production. Thirteen years (1995–2008) of annual censuses of large numbers of mahogany trees at multiple field sites enabled us to estimate the relative contributions of several readily observable tree-level factors to long-term survival and growth in an article published in the *Journal of Applied Ecology* (Grogan and Landis 2009). The best predictor of future survival and diameter growth rates turns out to be current growth rate – that is, trees that grew fast during the previous year or years are the ones most likely to survive the longest, and to grow the fastest during intervals between harvests. While this result may seem intuitively obvious, it confirms reports from other regions for other timber species and suggests an extremely useful management tool for forest managers faced with decisions about seed tree retention (in Brazil, 20% of commercial-sized trees must be retained for seed production between harvests). A single year of diameter growth measurements of both

Figure 1. Annual diameter growth (cm) of mahogany trees under different vine cutting scenarios



Note: Trees released from heavy vine loads (R) accelerated growth rates until they grew as fast as trees without vines (S, sample population) but partially released (P) and unreleased (N) trees did not.

commercial and sub-commercial trees before the first harvest could indicate which trees are growing fastest and therefore have the highest potential for survival and fruit production between harvests. All things being equal, these are the trees that should be retained under the 20% rule, because these are the trees that will maximize commercial volume and seed production during the interval before the second harvest in 25–30 years. This study also showed that after recent growth rate, crown vine load is the strongest predictor of growth and survival. This outcome further reinforces the importance of vine removal as a management tool with potentially strong benefits.

Enrichment planting after logging

With colleagues from this project's facilitating agency, the Instituto Floresta Tropical (IFT) based in Belém, Pará, a study of seedling enrichment planting in artificial gaps opened in liana-dominated forests after logging was published in the journal *Forest Ecology and Management* (Keefe et al. 2009). While mahogany growth performance lagged behind that of other fast-growing native timber species (e.g. *Ceiba*, *Schizolobium*, *Parkia* spp.), survival and growth by mahogany seedlings over the eight-year study period was nevertheless excellent, with a mean diameter of ~10 cm attained (pole size).

Seedling regeneration in the forest understory

Across southern Amazonia, larval caterpillars of the nocturnal moth *Steniscadia poliophaea* defoliate and kill

newly germinated mahogany seedlings in natural forests, representing a serious potential management issue. Studies carried out under the project found conclusive evidence that widely cited but rarely substantiated distance- and density-dependent seedling mortality occurs in mahogany regeneration. This finding, published in the journal *Oecologia* (Norghauer et al. 2010) and summarized in a recent book chapter (Norghauer and Grogan 2012), means that adult *Steniscadia* moths target adult mahogany trees in their search for germinating seedlings to serve as hosts for eggs and larval caterpillars. Seedlings establishing close to adult trees – and most seeds germinate within 35 m of adult trees due to limited wind-aided dispersal distance – suffer higher mortality due to *Steniscadia* predation than seedlings germinating far away, an 'escape clause' in mahogany's complex life cycle. This simple answer to one of tropical ecology's most influential theories (the Janzen-Connell hypothesis) has extremely important management implications. It tells us why some seedling regeneration has a greater likelihood of survival and growth than other seedling regeneration, and where forest managers should actively promote establishment and growth of natural regeneration: further from adult trees is better than closer, all things being equal.

Growth and fruit production by isolated trees in open growing conditions

In the Brazilian Amazon, big-leaf mahogany trees are often retained in agricultural fields and pastures for seed and timber production after selective logging and forest clearing. In a study published in the journal *New Forests* (Grogan et al. 2010), we monitored annual survival, stem diameter growth, fruit production, and date of dry season flowering initiation during 1997–2003 by trees growing scattered across a large open clearing after forest removal compared to trees growing in heavily disturbed forest after selective logging and canopy thinning. Trees in the open clearing died at faster rates, grew more slowly, produced fewer fruit, and initiated flowering earlier, on average, than trees in logged and thinned forest during this period. The principal cause of mortality and stem damage in both environments was dry season ground fires. Mahogany trees in logged and thinned forest at the study site grew faster than mahogany trees at a selectively logged but otherwise undisturbed closed-canopy forest site in this region during the same period. This was likely due to vine elimination by ground fires, increased crown exposure after canopy thinning, and soil nutrient inputs due to ground fires. Without effective regulation and control of anthropogenic fires, attempts to manage remnant mahogany trees for future timber yields or to restore commercially viable populations in seasonally dry southern Amazonia may prove futile.

Management challenges associated with single species production from mixed-species forests

Management of highly diverse mixed-species forests is particularly difficult when only one tree species produces the majority of high-value timber. In a paper published in the *Journal of Sustainable Forestry* (Kelty et al. 2011), current and past forest management practices in two regions with these characteristics are examined: Massachusetts, USA, where red oak (*Quercus rubra*) is the key timber species, and Quintana Roo, México, where big-leaf mahogany is by far the most valuable species. These regions have different ecological characteristics, forest ownership types, landowner income, and importance of timber in total income, yet the silvicultural approach (low-intensity selective logging) is similar, and generally fails to provide the conditions needed for regeneration and growth of the focal timber species. In both situations, the reluctance to harvest low-value species and interest in minimizing forest disturbance complicates management. Successfully balancing timber harvests and forest conservation may prevent conversion of these lands to agriculture or residential development, but socio-economic conditions (property tax policies and landowner affluence) play an important role in the outcome.

Management challenges associated with ecologically 'rare' timber species

Like mahogany, most high-value timber species in the Amazon occur at extremely low landscape-scale densities, that is, fewer than one tree larger than 20 cm diameter per hectare even where commonly occurring. Articles in the journals *Forest Ecology and Management* and *Biological Conservation* (Schulze et al. 2008a, 2008b) examined management issues raised by intensive harvesting of these species. Based on long-term survival and growth data for seven timber species, including species under study at our principal research site since 1997, we asked: Under current Brazilian forest legislation, what are the prospects for second harvests on 30-year cutting cycles given observed population structures, growth, and mortality rates?

Our data indicates that the most important determinant of recovery and future harvest levels is pre-harvest stocking levels of sub-commercial stems. Simulation models demonstrate that reducing species-level harvest intensity by increasing minimum felling diameters or increasing seed tree retention levels improves prospects for second harvests of those populations with a relatively high proportion of sub-commercial stems, but does not dramatically improve projections for populations with relatively flat diameter distributions (that is, poor representation by sub-commercial stems). It turns out that restrictions on logging timber tree populations occurring

at very low densities, such as the current Brazilian 10% retention rate for non-mahogany species, provide inadequate minimum protection for vulnerable species. Population declines, even if reduced-impact logging (RIL) is eventually adopted uniformly, can be anticipated for a large pool of high-value timber species unless harvest intensities are adapted to timber species population ecology, and silvicultural treatments are adopted to remedy poor natural stocking in logged stands.

Summary and recommendations

Our annual return to research sites in southeast Pará ensures the continued survival of threatened mahogany populations. These populations survive in isolated patches of logged forest on a regional landscape where most natural forests have been converted to pasture and agricultural uses. In fact, within this larger region, where Brazil's richest mahogany stands occurred before logging began in the early 1970s, commercial stands have been almost completely extirpated. Natural populations comparable to those under study in this research program simply do not exist elsewhere in this region.

From our on-going research on mahogany in southern Amazonia, it is clear that minimum steps towards managing and restoring mahogany populations across the species' historic range in southern Amazonia will require:

- **Managing population structures:** In populations with few sub-commercial trees, the 20% retention rate will lead to sharply reduced volume production during second and third harvests on 25- to 30-year cutting cycles.
- **Choosing remnant (seed) trees:** All things being equal, the fastest-growing trees during the year or years before the first harvest should be retained to maximize volume recovery and seed production during the interval before the second harvest.
- **Thorough vine cutting** with follow-up after one or two years is the most cost-effective silvicultural treatment available for improving long-term timber and seed production by remnant trees.
- **Enrichment planting** in logging gaps can be cost-effective and is essential for maintaining timber yields during third harvests and beyond.
- **Genetic structure:** Further studies are needed to evaluate whether the 20% retention rate in Brazil is sufficient to avoid negative impacts on genetic structure observed under higher harvest intensities (10% retention or less.)

Copies of all papers/journal articles referred to are available from the first author.

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to the finished product, with a focus on the links in the chain that are most at risk from log or lot swapping.

The scientific validity of the methodology has been demonstrated. Further improvements can be made to the DNA extraction protocols to improve the reliability and quality of DNA extraction to obtain an even higher success rate. This would reduce the need to repeat tests and would further reduce the cost of the testing process.

At the far end of the supply chain, the methodology is currently limited to solid wood products such as flooring, decking and furniture, where the extent of processing (heat and chemical treatment) and therefore the impact on the wood's DNA is relatively low. Improvements to DNA extraction protocols may enable the application of the technology to further-processed products such as plywood.

DNA testing is not designed to replace existing paper-based systems; rather, it is designed to support, simplify and strengthen them. Genetic mismatches highlighted by DNA testing can act as a 'red flag' to auditors, who can then conduct more thorough investigations. We believe that this DNA tracking methodology is now suitable for industry uptake to track certified wood and check for illegal substitutions along solid-wood-product supply chains.

The methodology will not only complement paper-based CoC methods, it will contribute to future methods that use databases on genetic structure (e.g. Deguilloux et al. 2003; Lowe et al. 2004; Lowe 2008; Lemes et al. 2010).

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