How sustainable is mahogany management?

Modelling indicates that the management of big-leaf mahogany in Guatemala's Maya Biosphere Reserve is on track, but changes are needed in Brazil

by James Grogan[1], Mark Schulze[2], Iran Paz Pires[3], Christopher M. Free[4], R. Matthew Landis[5], Gustavo Pinelo Morales[6] and Andrea Johnson[6]

1 Mount Holyoke College, Department of Biological Sciences, South Hadley, MA, USA (jegrogan@mtholyoke.edu)

2 HJ Andrews Experimental Forest and Oregon State University, Blue River, OR, USA

3 Instituto Floresta Tropical, Belém, Pará, Brazil

4 Rutgers University, Department of Marine and Coastal Sciences, New Brunswick, NJ, USA

5 Middlebury College, Middlebury, VT and ISciences, Burlington, VT, USA

6 Centro Agronómico Tropical de Investigación y Enseñanza, Turrialba, Costa Rica

Mark Schulze (foreground) from Oregon State University and the Instituto Floresta Tropical's Miguel Alves de Jesus inspect *Swietenia macrophylla* (mahogany) trees at a field site in Marajoara, Pará, Brazil, as part of a project conducted under the ITTO–CITES Programme. *Photo: S. Hirakuri*

The ITTO–CITES[1] Programme for Implementing CITES Listings of Tropical Timber Species seeks to ensure that international trade in CITES-listed tropical timber species is consistent with their sustainable management and conservation. For Appendix II species such as big-leaf mahogany (*Swietenia macrophylla*, referred to in this article simply as mahogany), this means that exported volumes must be acquired legally and without detriment to natural populations. "Non-detriment" is generally equated to sustainable forest management (Smith et al. 2011). From a biological point of view, "sustainable" requires that current management practices do not imperil future harvests by reducing population densities during repeated harvests below levels that can be biologically sustained.

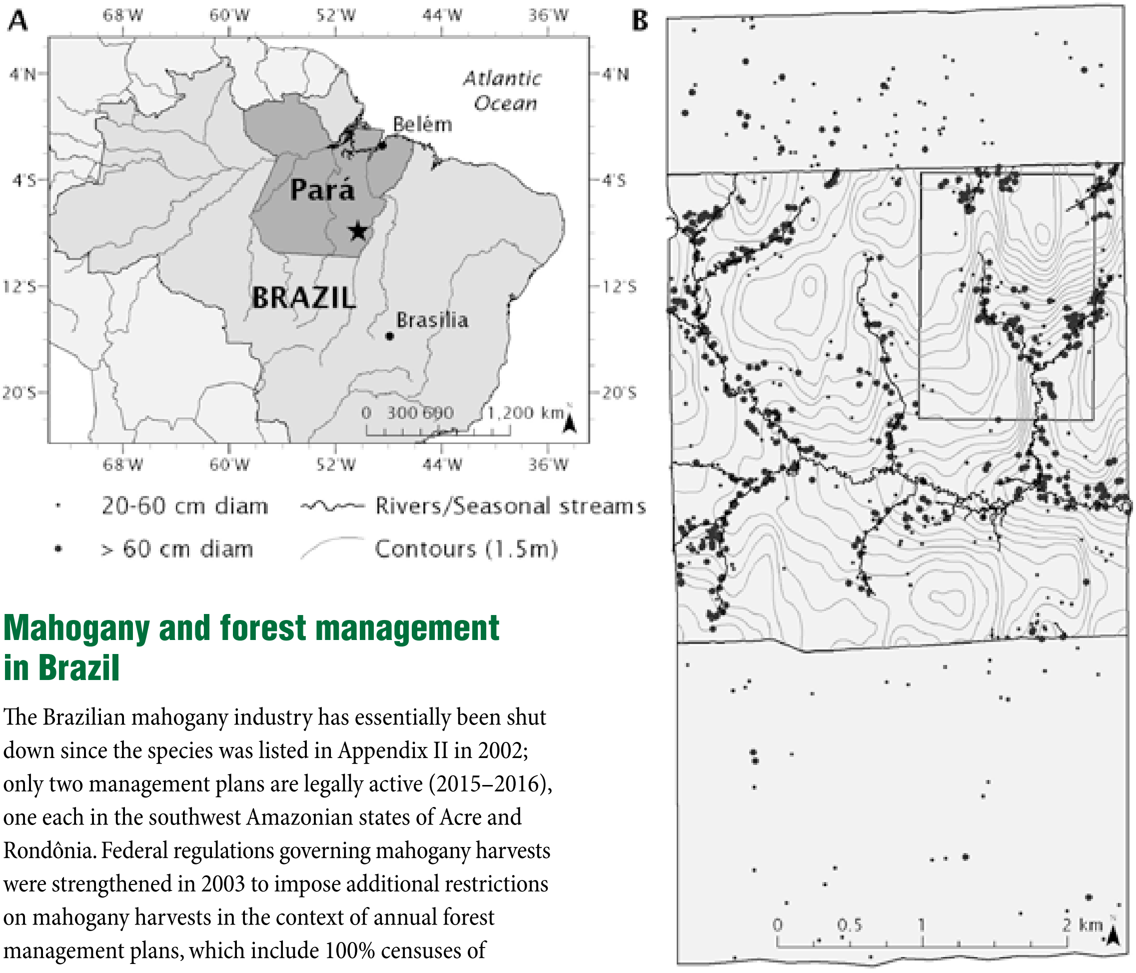
This article summarizes findings on the sustainability of management practices in Brazil and Guatemala generated by a project supported by the ITTO–CITES Programme called "Big-leaf mahogany in the Brazilian Amazon: long-term studies of population dynamics and regeneration ecology towards sustainable forest management". Starting in 2007 and continuing through 2015, this project is extending field research initiated in 1995 with support from the United States Forest Service's International Institute of Tropical Forestry. The goal is to establish a biological foundation for sustainable forest management systems for mahogany based on long-term studies of key demographic rates—growth, reproduction and regeneration—by natural populations in primary and logged forests. A detailed understanding of age- and size-related mortality, growth and reproductive rates is essential for evaluating management guidelines and adapting practices to changing environmental and socioeconomic contexts. This study's mahogany populations have been studied more intensively and for longer than any other mahogany populations in the Amazon.[2]

The impacts of harvesting practices on future timber yields can be evaluated if empirical data are available on demographic rates spanning a given species's life cycle. Demographic analysis may also need to account for other aspects of life history and landscape ecology, such as density-dependent mortality factors and gap formation rates, especially for light-demanding tree species like mahogany (Norghauer et al. 2016). We built an individual-based demographic model for mahogany parameterized from field data collected in 1995–2015 in the Brazilian Amazon. Research sites in southeastern Pará are visited annually during the dry season to re-census nearly 500 mahogany trees larger than 10 cm diameter mapped in 2700 hectares of forest. We also monitor several thousand mahogany seedlings, saplings and pole-sized juveniles in natural and artificial gaps in experiments initiated in 1996–1997. The demographic model is based on regression equations of stem diameter growth, mortality and fruit production estimated as functions of stem diameter and prior growth; it includes functions for germinating seeds, growing trees from seedlings to adult senescence, producing seeds, and creating disturbances at specified spatial scales and return intervals, including logging. The model also incorporates growth autocorrelation, which has been shown to strongly influence model predictions (Grogan and Landis 2009; Grogan et al. 2014; Free et al. 2015; see also www.swietking.org/model.html for model details).

1 CITES = Convention on International Trade in Endangered Species of Wild Fauna and Flora.

2 See *TFU* 22(1) for descriptions of recent scientific and technical publications resulting from this project (Grogan et al. 2013).

Figure 1: (A) Map of Pará, Brazil, with star symbol showing location of the field site at Marajoara; (B) the 2050-hectare principle research area at Marajoara



Note: Seasonal streams, topography and live + logged mahogany trees are mapped within 1035 hectares. The smaller rectangle outlines a 204-hectare permanent plot. Only live mahogany trees were located outside the core research area (top and bottom). Adapted from Grogan et al. 2014 (Figure 1).

Mahogany and forest management in Brazil

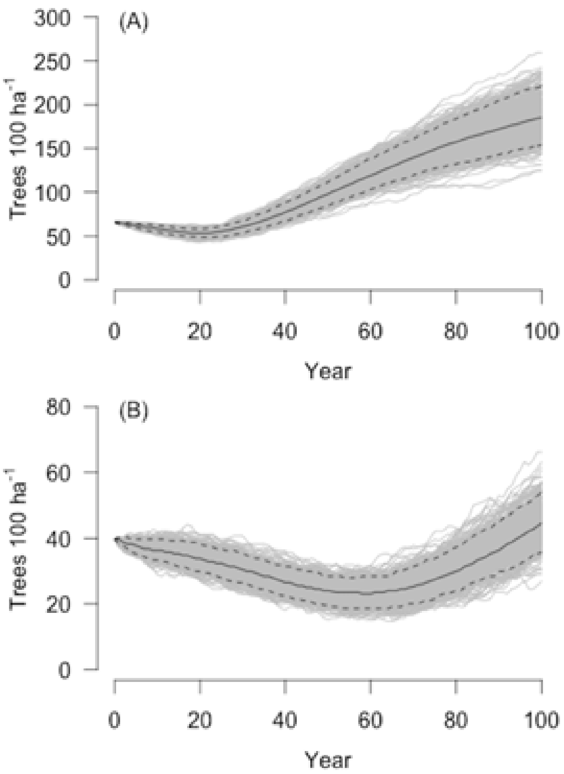
The Brazilian mahogany industry has essentially been shut down since the species was listed in Appendix II in 2002; only two management plans are legally active (2015–2016), one each in the southwest Amazonian states of Acre and Rondônia. Federal regulations governing mahogany harvests were strengthened in 2003 to impose additional restrictions on mahogany harvests in the context of annual forest management plans, which include 100% censuses of commercial-sized trees of all commercial species and cutting cycles of 25–30 years. Mahogany harvests are restricted to mahogany trees larger than 60 cm diameter; at least 20% of commercial-sized trees must be retained for seed and future timber production; and logging is prohibited where population densities are lower than five commercial-sized trees per 100 hectares. Rules based on stem quality are in place for determining which trees should be retained as seed trees and for future harvests. Moreover, a technical committee must approve any industrial or community management plan that includes mahogany after the field verification of plan details.

To evaluate whether these tightened rules for managing mahogany would yield sustained harvests, we used the project's demographic model to simulate harvests at 30-year intervals over three cutting cycles (harvests in years 0, 30, 60 and 90) based on mahogany's population structure and demographic behaviour at our principle research site of Marajoara in southeast Pará (Figure 1). Simulations were repeated 500 times to estimate median outcomes at each harvest.

When we simulated the Marajoara population without logging, the median density of trees larger than 20 cm diameter and of trees larger than commercial size (60 cm diameter) increased over time (Figure 2). This suggests, first, that one or more parameters in the model may overestimate long-term demographic rates on this landscape and, second, that outcomes for simulated harvests are more likely to overestimate recovery rates than the reverse. Under current harvesting regulations for mahogany in Brazil, simulations indicate that commercial densities at Marajoara would decline from 40 commercial-sized trees per 100 hectares at the time of the first harvest to only eleven trees per 100 hectares at the time of the fourth harvest in year 90, yielding an estimated 16% of the initial harvest volume in the fourth harvest (Figure 3). That is, current harvesting regulations designed specifically for mahogany in Brazil will lead to population decline and commercial depletion within 3–4 cutting cycles (60–90 years) at sites where populations lack subcommercial trees at densities sufficient for short-term replacement. Without strict adherence to the minimum density requirement of five commercial-sized trees per 100 hectares, few commercial-sized trees would survive after four harvests (Grogan et al. 2014).

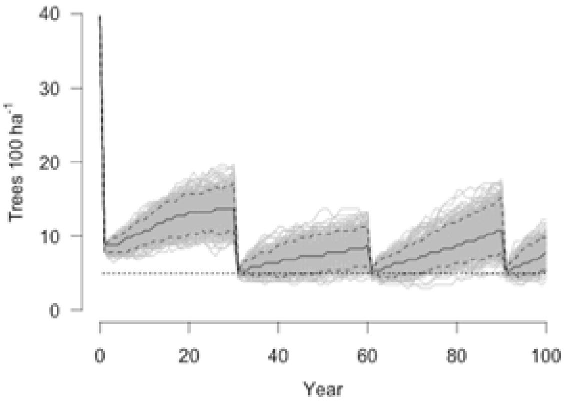
These results indicate that current harvesting regulations in Brazil for mahogany and other high-value timber

Figure 2: Simulated mahogany population dynamics in southeast Pará, Brazil, in the absence of logging: (A) density of trees ≥ 20 cm diameter during 100-year simulations; (B) density of commercial-sized trees ≥ 60 cm diameter over the same period



Note: Grey lines indicate 500 replicate simulations, the solid black line indicates the median value, black dashed lines indicate 5th and 95th percentiles. Adapted from Grogan et al. 2014 (Figure 3).

Figure 3: Simulations of mahogany population dynamics in southeast Pará, Brazil, under current legal harvest regulations with harvests in years 0, 30, 60 and 90



Note: There were 40 commercial-sized trees per 100 hectares in year 0. Median recovered population density in year 90 was 11 trees per 100 hectares. See Figure 2 for key. The horizontal dashed line indicates the minimum post-harvest commercial density of 5 trees per 100 hectares. Adapted from Grogan et al. 2014 (Figure 4).

species with similar life histories will lead to commercial depletion over repeated cutting cycles. Sustainable harvesting will require, in combination, an increase in the retention rate, investment in artificial regeneration to boost population recovery, and the implementation of silvicultural practices designed to increase the growth rates of future crop trees. Moreover, these estimated outcomes are likely to overstate post-harvest recovery rates by surviving mahogany populations in Brazil, which are concentrated in the southwestern Amazon. Those populations are characterized by lower densities of subcommercial stems relative to commercial-sized trees compared with populations in southeastern Amazon, like Marajoara's (Grogan et al. 2008, 2010).

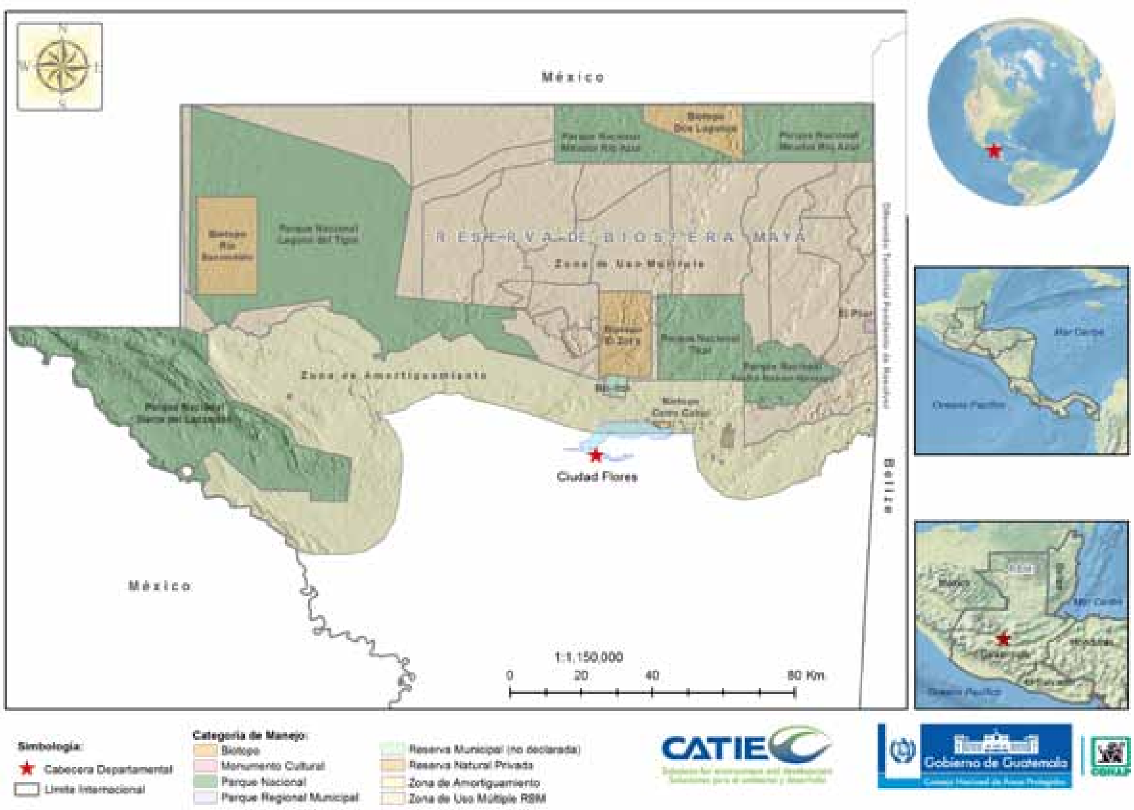
Mahogany and forest management practices in Guatemala

Forest concessions in the Maya Biosphere Reserve (MBR) in the department of Petén, Guatemala, have been harvesting mahogany and associated high-value timber species under multiple-use forest management systems since the late 1990s with the twin goals of conservation and socioeconomic development. In the MBR's Multiple Use Zone (MUZ), nine community organizations and two industrial firms manage timber and non-timber forest products in concessions representing nearly 25% of the MBR's total area of 2.1 million hectares (Figure 4). The regulatory entity for forest management in the MUZ is the National Council of Protected Areas (*Consejo Nacional de Áreas Protegidas*—CONAP), which has the power to adjust regulations in response to emerging concerns and needs.

Similar to Brazil, concessions must submit detailed plans for each annual harvest parcel, including 100% inventory data for commercial-sized and subcommercial-sized trees with spatial locations, excluding areas with steep slopes and other high-conservation-value areas. Concessions have flexibility in setting minimum diameter cutting limits (MDCLs) and cutting cycle lengths; the MDCL for mahogany is almost always 60 cm diameter (occasionally 55 cm), and cutting cycles range from 25 to 40 years (30 years being most common). The allowable harvesting or cutting intensity for a given timber species is determined by a formula that uses an assumed median diameter growth rate to estimate the amount of subcommercial basal area that will recruit to commercial size during the cutting cycle following harvest, based on the best understanding of species-level diameter growth rates. That is, the number of commercial-sized trees that can be harvested is determined by the number and size distribution of subcommercial trees in position in the forest to replace logged trees in the coming 25–40 years. In addition, all concessions must obtain and uphold Forest Stewardship Council certification; this requirement was established by CONAP in 1999 in response to social and political pressure to use best practices in protected areas such as the MBR.

To evaluate whether these management practices for mahogany and associated high-value species would yield sustainable harvests, we adapted the project's demographic model to the Guatemalan context. We used concession inventory data from annual operating plans from the

Figure 4: The Maya Biosphere Reserve in the Petén region, northern Guatemala



Adapted from Grogan et al. 2015 (Figure 1).

mid-2000s, supplemented by field data collected in 2014 estimating landscape-scale densities of seedlings, saplings and pole-sized juveniles in each harvest area. We simulated harvests over three cutting cycles that varied in length between concessions. Simulations were repeated 100 times to estimate median outcomes at each harvest. Although simulation outcomes for mahogany population dynamics in the MUZ were based on growth, mortality and reproductive rates obtained from Brazilian populations, the mahogany growth function from Brazil matched almost perfectly the available growth data from MUZ concessions. Indeed, the model used in this study provides the best-available interpretation of the current understanding of mahogany life history (Grogan et al. 2015).

Model simulations indicate that, on average, concession mahogany populations logged during the mid-2000s under forest management parameters described above will recover or exceed initial commercial densities and volumes during cutting cycles between successive harvests. The overall recovery trajectory of simulations spanning three cutting cycles (75–120 years) was positive or nearly so for 17 of the 22 annual harvest parcels evaluated in this study. Median commercial densities of simulated populations recovered to 109–156% of initial densities from the first to fourth harvests and to 83–142% of initial commercial volumes. Whether or not commercial density and timber volume recovered between harvests was a direct consequence of the distribution and densities of subcommercial trees, poles and saplings. Where these individuals occur at relatively high densities compared with commercial trees, future harvests can be comparable with initial harvests because subcommercial trees recruit to commercial size during the coming decades. By linking cutting intensity to assumed growth rates by subcommercial trees, forest managers in the MUZ restrict harvests to sustainable levels (Grogan et al. 2015).

Implications for CITES-listed timber species

For Appendix-II species such as mahogany, legal and non-detrimental or sustainable acquisition are prerequisites for international trade. With sufficient understanding of species' life histories, and especially of the demographic rates that underlie the distribution of juvenile and mature individuals on a landscape, we can model the future impacts of current management practices in much the same way that actuarial professionals analyze survival probabilities in human populations for health and life insurance purposes. "One-size-fits-all" management regulations like those for mahogany in Brazil are common across the tropics, but they fail to recognize that each tree species in a natural forest survives and functions differently from every other. Harvesting 80% of commercial-sized mahogany trees in Brazil will lead to commercial extirpation over repeated harvests because populations there tend to have few subcommercial trees relative to commercial trees, leading to the depletion of commercial size classes over time. Other commercial species with similar life histories to mahogany's, such as red cedar (*Cedrela odorata*) and ipê (*Tabebuia* spp.), may be harvested at even higher intensities (90%) and to smaller diameters (50 cm) than mahogany in Brazil, meaning that commercial depletion of those species could occur in 1–2 cutting cycles (Schulze et al. 2008a,b).

Mahogany harvests in Guatemala's MBR appear to be sustainable because biological realities—growth, mortality, and the size-class frequency distribution of juvenile and mature trees—determine cutting intensity, not an arbitrary number. There, mahogany populations—and populations of four associated high-value commercial species—are (on average) expected to recover initial commercial densities and volumes during cutting cycles between successive harvests. Such a finding sets the MBR apart from most other commercial forestry operations in the tropics.

This conclusion is particularly notable given that most of the concession area in the MBR is under the management of local communities whose capacity to implement sustainable forestry has been and continues to be questioned, both in Guatemala and across the tropics. The finding that community-based enterprises, working with government and technical assistance agencies, are practising better forest management than highly capitalized industrial firms operating in other parts of the tropics is important. The model of sustainable species-level forest management in Guatemala's MBR deserves recognition and replication in other tropical countries. Considering the long history of mahogany's unsustainable exploitation across its neotropical range, forest management in the MBR represents a significant achievement and a CITES success story.

References

Free, C.M., Landis, R.M., Grogan, J., Schulze, M.D., Lentini, M. & Dünisch, O. 2015. Management implications of long-term tree growth and mortality rates: a modeling study of big-leaf mahogany (*Swietenia macrophylla*) in the Brazilian Amazon. *Forest Ecology and Management* 330: 46–54.

Grogan, J., Jennings, S.B., Landis, R.M., Schulze, M., Baima, A.M.V., Lopes, J.C.A., Norghauer, J.M., Oliveira, L.R., Pantoja, F., Pinto, D., Silva, J.N.M., Vidal, E. & Zimmerman, B.L. 2008. What loggers leave behind: impacts on big-leaf mahogany (*Swietenia macrophylla*) commercial populations and potential for post-logging recovery in the Brazilian Amazon. *Forest Ecology and Management* 255: 269–281.

Grogan, J. & Landis, R.M. 2009. Growth history and crown vine coverage are principal factors influencing growth and mortality rates of big-leaf mahogany *Swietenia macrophylla* in Brazil. *Journal of Applied Ecology* 46: 1283–1291.

Grogan, J., Blundell, A.G., Landis, R.M., Youatt, A., Gullison, R.E., Martinez, M., Kometter, R.F., Lentini, M. & Rice, R.E. 2010. Over-harvesting for commercial purposes leads to population decline: the case of big-leaf mahogany (*Swietenia macrophylla*) in South America. *Conservation Letters* 3: 12–20.

Grogan, J., Schulze, M., Lentini, M., Zweede, J., Landis, R.M. & Free, C.M. 2013. Managing big-leaf mahogany in natural forests. *Tropical Forest Update* 22(1): 12–15,19.

Grogan, J., Landis, R.M., Free, C.M., Schulze, M.D., Lentini, M. & Ashton, M.S. 2014. Big-leaf mahogany *Swietenia macrophylla* population dynamics and implications for sustainable management. *Journal of Applied Ecology* 51: 664–674.

Grogan, J., Free, C.M., Morales, G.P., Johnson, A. & Alegria, R. 2015. Sustaining the harvest: assessment of the conservation status of big-leaf mahogany, Spanish cedar, and three lesser-known timber species populations in the forestry concessions of the Maya Biosphere Reserve, Petén, Guatemala. Report. Projecto Finnfor: Bosques y Manejo Forestal en Américal Central/Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Turrialba, Costa Rica.

Norghauer, J.M., Free, C.M., Landis, R.M., Grogan, J., Malcolm, J.R. & Thomas, S.C. 2016. Herbivores limit the population size of big-leaf mahogany trees in an Amazonian forest. *Oikos* 125: 137–148.

Schulze, M., Grogan, J., Landis, R.M. & Vidal, E. 2008a. How rare is too rare to harvest? Management challenges posed by timber species occurring at low densities in the Brazilian Amazon. *Forest Ecology and Management* 256: 1443–1457.

Schulze, M.D., Grogan, J., Uhl, C., Lentini, M. & Vidal, E. 2008b. Evaluating ipê (*Tabebuia*, Bignoniaceae) logging in Amazonia: sustainable management or catalyst for forest degradation? *Biological Conservation* 141: 2071–2085.

Smith, M.J., Benítez-Díaz, J., Clemente-Muñoz, M.A., Donaldson, J., Hutton, J.M., McGough, H.N., Medellin, R.A., Morgan, D.H.W., O'Criodain, C., Oldfield, T.E.E., Shippmann, U. & Williams, R.J. 2011. Assessing the impacts of international trade on CITES-listed species: current practices and opportunities for scientific research. *Biological Conservation* 144: 82–91.