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Sustained mahogany (*Swietenia macrophylla*) plantation heartwood increment

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Abstract

In a search for an increment-based rotation for plantation mahogany (*Swietenia macrophylla* King), heartwood volume per tree was regressed on DBH (trunk diameter outside bark at 1.4 m above the ground) and merchantable height measurements. We updated a previous study [Wadsworth, F.H., González González, E., Figuera Colón, J.C., Lugo Pérez, J., 2003. Fifty-nine year performance of planted big-leaf mahogany (*S. macrophylla* King) in Puerto Rico. In: Lugo, A. Figueroa Colón, J.C., Alayón, M. (Eds.), Big-leaf Mahogany, Genetics, Ecology, and Management. Springer-Verlag, New York, pp. 343–357] and determined heartwood volume increment in a plantation between the 40th and 69th years. Although DBH growth rate declined with age, that for heartwood increased throughout the entire 69 years. This, with expected growing value per unit of heartwood volume with tree size, presents incentives for long rotations.

Keywords: Puerto Rico; *Swietenia*; Mahogany; Forest plantations; Tree growth; Heartwood increment

1. Introduction

Projections of increasing temperate zone supplies of cellulose and construction timber (Bryan and Ruiz Nieves, 1996) foretell a future focus on cabinet grade timbers from tropical forests. A species of this quality is big-leaf mahogany (*Swietenia macrophylla* King). Its wood is almost non-refractory during drying (shrinkage almost equal radially and tangentially) and easily workable (Chudnoff, 1984); the heartwood is moderately resistant to dry-wood termites (Wolcott, 1946) and of unsurpassed natural beauty. The tree is fast growing (Bauer and Francis, 2000). Insect problems, widely publicized (Bauer and Francis, 2000), may be overstated, since plantations in both tropical hemispheres cover more than 100,000 hectares (Whitmore, 1993) in spite of the shoot borer *Hypsipyla*. Many of these plantations lie outside of the native range of mahogany.

To be certified as sustainable, tropical forest management must provide a rationale for the rate of harvest (Forest Stewardship Council, 2004). Knowledge of the plantation growth period for optimum yield is becoming important as the supply shifts from natural forests to plantations. Mahogany heartwood, the most marketable component, has not been isolated in traditional growth studies. Its volume increment can be expected to rise more rapidly than DBH increment, offering an exponential yield of heartwood of larger dimensions. Yield prospects can be predicted approximately from repeated tree growth measurements. The present study exposes a trend of heartwood increment over time as one guide for plantation rotations.

2. Methods

The mahogany plantation studied is in latitude 18°N, about 200 m above sea level on the Caribbean island of Puerto Rico. A 20-year annual average of rainfall is 185 cm (range 131–258 cm), with means of less than 10 cm in January and February (NOAA, 1976–1995). The Holdridge (1978) life zone is subtropical moist (Ewel and Whitmore, 1973). The soil is a clay inceptisol averaging 60 cm in depth over fragmented tertiary limestone (Roberts, 1942). In 1937, along a river terrace a forest plantation was established by the Puerto Rico Reconstruction Administration in an abandoned sugarcane field that later became part of the Boy Scout camp Guajataka. The plantation was a mixture of big-leaf mahogany from Venezuelan seed, *Senna siamea* (Lam.) Irwin & Barnaby, *Calophyllum calaba* L., and *Petitia domingensis* Jacq. Due to

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the mixture, trees of each species were widely separated. No soil nutrients were applied. At plantation age 47 (1984), Scouts girdled the few *Senna* and *Calophyllum* trees that had reached the canopy among the mahoganies, temporarily increasing illumination on the forest floor. Over the time course of the plantation, only two mahogany trees were felled, and those by a Category Three hurricane that passed directly over the plantation in 1998 (F. Wadsworth, personal observation). Abundant natural regeneration up to trees 40 cm in DBH has appeared beneath these planted mahoganies (Wadsworth et al., 2003).

DBH and height were measured annually by Scouts between 1977 (age 40) and 2006 (age 69) on 73 mahogany trees in a 1.6 ha study area within the plantation. Crown positions of each mahogany in the canopy (dominant, codominant, intermediate, and suppressed; Smith, 1986) were recorded. In 1984, in order to develop equations for heartwood and inner bark volumes per tree, 104 mahoganies of the same age without major low branches were selected from within the study area and nearby. These were measured for bark thickness with a bark gauge, and sapwood thickness with an increment borer. Merchantable heights were estimated by clinometer, and upper merchantable diameters by pentaprism.

Heartwood diameters were approximated by subtracting from the outside bark DBH measurements double the mean thicknesses of bark and sapwood (Wadsworth et al., 2003). Heartwood volumes per tree were determined using Huber's formula (mean area of ends multiplied by length) (Wenger, 1984). The regression equation for heartwood volumes in cubic meters to an upper 20 cm stem diameter limit (including branches) was: Volume(m^3) = 0.448 [DBH(m)^2 × ht(m)] − 0.0608 (R^2 = 0.93). This was compared with an inside bark volume (sapwood plus heartwood) equation derived from the same source: Volume(m^3) = 0.549 [DBH(m)^2 × ht(m)] + 0.023 (R^2 = 0.95). The measurements collected by the Scouts were used to project heartwood and diameter volumes and increments by age and crown position class.

3. Results and discussion

The site, despite relatively shallow soil and former intensive agricultural use (sugarcane) proved capable of producing large trees and of maintaining a closed canopy to 30 m. By its 40th year (1977), the mahoganies had outgrown most of the trees of associated species, and many developed broad crowns with widths averaging 17.4 times their DBH (Wadsworth et al., 2003). Stocking became full. Nevertheless, growth of 80% of the trees continued to age 69. Crown illumination was critical to rapid growth.

Final density of mahogany trees at 40 years was 46 per hectare. Heartwood volume for trees of 40 cm DBH, for example, ranged between 70 and 80% of total stem volume inside bark. Heartwood volume is seen as almost directly related to merchantable height (Table 1). Trees with merchantable heights of 12 m contained 50% more heartwood than those with merchantable height of 8 m. Heartwood volume per tree increased at an accelerating rate throughout the range of DBH (Table 1). DBH growth and heartwood volumes by ages and crown position classes are averaged in Table 2. Trees in dominant canopy positions produced nearly one third more heartwood than codominant trees, and more than three times that of trees in intermediate canopy positions (Table 2).

Table 1
Mahogany heartwood volumes per tree[a] in m^3 by DBH and merchantable height

DBH (cm)	Merchantable height (m)			
	4	8	12	16
30	0.10	0.26	0.42	0.58
40	0.23	0.51	0.80	1.09
50	0.38	0.84	1.28	1.73
60	0.58	1.23	1.87	2.52
70	0.82	1.70	2.57	3.45
80	1.09	2.23	3.38	4.53
90	1.39	2.84	4.29	5.75
100	1.73	3.52	5.32	7.11

[a] Heartwood volumes according to V (m^3) 0.448[DBH(m)^2 × ht(m)] − 0.0608 (see Section 2).

In 40 years, dominant and codominant trees attained an average DBH of 59 cm and a heartwood volume of 1.8 m^3. After 53 years, the corresponding figures were 74 cm and 2.7 m^3; after 64 years, 88 cm and 3.5 m^3; and after 69 years, 94 cm and 3.9 m^3. Not only the volume of heartwood but also its rate of increment was still increasing to the 69th year. For the plantation as a whole, heartwood volume at 40 years had reached 64 m^3 ha^{-1} (periodic heartwood increment of 1.60 m^3 ha^{-1} $year^{-1}$). By the 53rd year, it was 94 m^3 ha^{-1} (periodic heartwood increment of 2.00 m^3 ha^{-1} $year^{-1}$). By 64 years, it was 133 m^3 ha^{-1} (periodic heartwood increment of 3.55 m^3 ha^{-1} year). After 69 years, it was 151 m^3 ha^{-1} (periodic heartwood increment of 3.60 m^3 ha^{-1} $year^{-1}$). The 69-year-old plantation had attained an average basal area of 27 m^2 ha^{-1}, good stocking for growing tropical moist forests (Silva, 1989).

Fifty one percent of all trees had retained a major branch in the first 10 m of their trunks, a feature ostensibly of negative influence on merchantable volume (Wadsworth et al., 2003). And, as mentioned, there is much natural regeneration of mahogany on this site. Of the progeny, unlike most of their open-grown parents, only 5% had branching within the first 10 m of tree trunk, apparently a response to shade. This suggests good prospects for well-formed heartwood in the next generation. Although the productivity of heartwood rose to only a little more than 3 m^3 ha^{-1} $year^{-1}$, the value of wide boards from large trees resulting from the wide spacing should compensate. Interestingly, hurricane effects (1998) on increment were not evident (Table 2).

4. Implications for management

Because of the high value of mahogany heartwood, foresters should take into account heartwood volume increment as well as diameter increment in order to select an optimal rotation. In the present study, on one site, but probably indicative of others, heartwood increment was still increasing 69 years after

Table 2
Mahogany DBH growth and heartwood volume[a] increment as a function of tree dominance

	Crown position			
	Dominants	Codominants	Intermediates	Suppressed
	Number of surviving trees			
	17	23	7	4
DBH, cm				
After 40 years, 1977	67.8	52.3	38.9	32
After 53 years, 1990	89.4	62.7	42.6	38.1
After 64 years, 2001	100.5	78.4	56.2	44.1
After 69 years, 2006	107.9	83	58.4	46.9
DBH growth, cm/year				
0–40 years (1937–1977)	1.79	1.41	0.97	0.74
40–53 years (1977–1990)	1.41	0.88	0.66	0.66
53–64 years (1990–2001)	1.12	0.75	0.61	0.47
64–69 years (2001–2006)	1.09	0.86	0.55	0.51
Heartwood volume, m^3				
After 40 years, 1977	2.17	1.53	0.84	0.36
After 53 years, 1990	3.41	2.22	1.26	0.6
After 64 years, 2001	4.07	3.01	1.6	0.72
After 69 years, 2006	4.59	3.32	1.68	0.83
Heartwood increment/year, m^3				
0–40 years (1937–1977)	0.051	0.041	0.021	0.009
40–53 years (1977–1990)	0.084	0.051	0.032	0.018
53–64 years (1990–2001)	0.087	0.064	0.03	0.014
64–69 years (2001–2006)	0.091	0.066	0.03	0.021

[a] Heartwood volumes according to $V\ (m^3) = 0.448\ [DBH(m)^2 \times ht(m)] - 0.0608$ (see Section 2). All values are means per tree.

planting, although diameter increment was slowing. Thus, decisions as to rotation length should not be based simply on a slowing of diameter increment. Because of continued heartwood increment in this plantation, there is as yet no basis for mathematical determination of rotation length. An arbitrarily decided tree diameter or rotation length might be used to determine time of harvest. But early harvest just to avoid the constant costs of management could mean loss of potential gain.

As for optimal size of heartwood pieces, larger veneer logs or boards are certainly more valuable than the same volume of heartwood of smaller dimension. Without information on the local pricing difference for small and large mahogany heartwood logs, a decision on timing of harvest could be far from optimum. Therefore, the prospect of increasing tree value as a driver for rotation length indicates a need to assess the local value of mahogany heartwood by tree size prior to harvesting.

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