Available online at www.sciencedirect.com
ScienceDirect
Forest Ecology and Management 255 (2008) 300–307
Forest Ecology and Management
www.elsevier.com/locate/foreco

Planting mahogany in canopy gaps created by commercial harvesting

J. do C.A. Lopes [a], S.B. Jennings [b,*], N.M. Matni [c]

[a] Embrapa Amazônia-Oriental, CP 48, Belém, Pará 66.095-100, Brazil
[b] Oxfam GB, Oxfam House, John Smith Drive, Oxford OX4 2JY, UK
[c] Nordisk Timber Ltda., CP 1541, Belém, Pará 66.820-000, Brazil

This paper is dedicated to the memory of Tim Whitmore.

Abstract

Attempts at natural forest management of mahogany (*Swietenia macrophylla* King) have so far met with limited success, whilst many plantations are beset by the shoot borer *Hypsipyla* spp. In this paper we present preliminary results of an approach to enrichment planting that aims to balance economic returns (rapid growth and good silvicultural form) with intervention costs and changes to forest structure. Mahogany seedlings were planted in gaps created by selective timber harvesting and that ranged in vertical projected area from 91 to 542 m^2 (mean = 257 m^2). Seedlings grew within the matrix of gap regrowth, with limited control of competing vegetation. Sixty-one percent of seedlings had survived by 4.4 years (equivalent to an annual mortality rate of 10.5% $year^{-1}$), and had reached a mean height of 4.5 m. Stocking levels of mahogany were similar to that of naturally regenerated commercial species in unplanted gaps of the same age, but mahogany seedlings were significantly taller. The incidence of shoot borer attack on mahogany stems was relatively low (54.7%), but, more importantly, most damaged stems (58%) responded by producing a single replacement leader. The cost of the proposed methodology (US$ 94 per gap over 4.4 years) was low compared to the high value of mahogany timber relative to other species in the forest. The implications of planting mahogany in gaps for forest management and the potential benefits to conservation of the species are considered.

Keywords: Brazilian Amazon; Canopy gaps; Height growth; *Hypsipyla*; Silviculture; *Swietenia macrophylla*

1. Introduction

Mahogany (*Swietenia macrophylla* King) is one of the world's most valuable timbers. Yet most mahogany logging in Brazil and elsewhere has been at best poorly regulated and at worst illegal (Rodan et al., 1992; Greenpeace, 2002). Such logging removes most of the commercial-sized trees (Gullison et al., 1996; Snook, 1996), may deplete the genetic variability of the species (Newton et al., 1996), and has acted as a catalyst for deforestation (Veríssimo et al., 1995). The unsustainable nature of this trade resulted in the neotropical populations of mahogany being included in Appendix II of the Convention on International Trade in Endangered Species (CITES) in November 2002. More recently, legislation has been adopted in Brazil that seeks to ensure long-term management of the species. The effects of these measures remain to be seen.

Sustainable management of mahogany in natural forest is seen as an important means of ameliorating these impacts (Jennings et al., 2000). However, several studies have argued that there is little or no regeneration after logging in Bolivia (Quevedo, 1986; Gullison et al., 1996), Mexico (Snook, 1993; Dickinson and Whigham, 1999), and Brazil (Veríssimo et al., 1995; Grogan et al., 2003, 2005). It has been suggested that this is because mahogany regenerates as single-aged stands following catastrophic disturbance, and that selective logging causes insufficient disturbance to provide the conditions necessary for regeneration (Snook, 1996). This view was challenged in a recent review of the available evidence, which concluded that not only there was no evidence that mahogany requires catastrophic disturbance in order to regenerate, but that regeneration is often dense after logging in areas transitional between savannah and high forest (Brown et al., 2003). Unfortunately, attempts to increase the density of natural regeneration of mahogany through silvicultural interventions have been attempted only rarely, and have met with mixed success (reviewed in Mayhew and Newton, 1998).

* Corresponding author. Tel.: +44 1865 472153.
E-mail address: stjennings@oxfam.org.uk (S.B. Jennings).

0378-1127/$ – see front matter
doi:10.1016/j.foreco.2007.09.051

In contrast to the limited application of natural forest management of mahogany, the species has been grown in plantations throughout the tropics. Although it has grown rapidly in different types of plantation (monospecific and mixed planting in the open, enrichment planting in lines, etc.) and on different soils, most plantations have been bedevilled by the all but ubiquitous shoot borers, *Hypsipyla grandella* and *H. robusta* (Lepidoptera: Pyralidae) (Griffiths, 2001). Shoot borers rarely kill mahogany trees, but they do kill the terminal shoot, as a result of which the tree usually produces several replacement stems. This usually results in trees with low branches and reduced commercial value. The most successful approaches to controlling the species are likely to involve a variety of silvicultural techniques that together: reduce the chance of *Hypsipyla* locating mahogany trees; reduce susceptibility to attack; promote vigorous vertical growth after attack; and encourage natural enemies of the shoot borer (Newton et al., 1993; Mayhew and Newton, 1998; Hauxwell et al., 2001).

In this paper, we describe a technique of enrichment planting in which small numbers of mahogany seedlings are planted within canopy gaps created by timber harvesting. The seedlings grow within the matrix of gap regeneration vegetation, with periodic cleaning confined to maintaining overhead light. The methodology was developed with the full participation of the site's forest manager (N. Matni) in order to identify a practical balance between competing influences on forest management. These influences include the high economic costs and severe change to forest structure caused by traditional planting methods, against the need for high economic return, which can be achieved by rapid growth and good tree form. The desired outcome of this method is commensurately limited to having at least one marketable mahogany stem available during the next rotation for each tree harvested (of whatever species). The expectations were that (1) the forest gap environment would provide sufficient illumination for silviculturally acceptable growth and survival of mahogany with limited maintenance, (2) the incidence and/or impact of *Hypsipyla* would be lower than in conventional plantations and (3) there would be economic advantages over leaving the forest to regenerate after logging without seedling enrichment planting in gaps.

2. Materials and methods

2.1. Study area

Research was conducted at Fazenda Pataua (5°42′S, 48°56′W), approximately 570 km south of Belém, in Pará state, Brazil. The forest is approximately 3000 ha in size, and is surrounded by pasture and eucalypt plantations. Precipitation was 1600 mm in 1999 and 2100 mm in 2000, with a dry season of 5 months during which monthly precipitation was <100 mm. The topography is gently undulating, with ridges usually no more than 5–10 m above the courses of the numerous small, seasonal streams that dissect the area. The forest is evergreen with a 25 m canopy surpassed by emergents, most commonly Brazilnut (*Bertholletia excelsa* Humb. & Bonpl.). The area was logged for mahogany in 1983 and for 21 other species between 1992 and 1998. Mahogany is present at very low density: 0.05 trees ≥20 cm ha^{-1} and 0.033 logged stumps ha^{-1} (Jennings and Baima, 2005), and natural regeneration is scarce (0.14 individuals ha^{-1} between 1 and 20 cm diameter).

2.2. Design and measurements

Fifty gaps created by logging operations during the 1998 dry season (July–October) were selected for the experiment. The most common tree felled to create these gaps was *Cedrelinga catenaeformis* (Ducke) Ducke (Mimosaceae). As the gaps were all recent, natural regeneration was still poorly developed (generally <0.5 m tall). The vertical projection of the canopy gaps was estimated by measuring the diameter of the longest axis and the diameter perpendicular to that, and gap area estimated according to the formula for an ellipse (Barton et al., 1989). Gap size ranged from 91 to 542 m^2 (mean 257 m^2, S.E. = 134).

Twenty gaps were randomly allocated as controls and were not manipulated in any way. These effectively control for the null hypothesis that growth, density and species value are higher in the absence of intervention. The other possible type of control – planting mahogany and then not carrying out maintenance – was not done because of its negligible practical value: mahogany stems would have been rapidly overtopped and suffered low growth and high mortality.

Mahogany seedlings were produced from locally collected seeds planted in 2 l polythene sacs filled with a mixture of forest soil, sand and well-rotted manure at a ratio of 3:1:1. They were raised in a field nursery under light neutral shade for 4 months until they were 0.22 m in height (S.E. = 0.05).

Mahogany seedlings were planted in the remaining 30 gaps early in the first wet season after logging (December 1998). Some of the coarse woody debris remaining in the gaps was cut to improve accessibility and facilitate planting. Seedlings were planted at a spacing of 5 m × 5 m and were uniquely labelled. The only criteria for planting were that (1) the planting site should be clear from coarse woody debris or stumps; and (2) the seedling should be within the vertical projection of the gap (i.e., have direct overhead illumination). The number of seedlings planted per gap therefore varied according to gap size, from 6 to 16 (total planted = 290; mean per gap = 9.7; S.E. = 3.2). Natural regeneration within 1 m diameter of the seedling was manually cut back. Soil samples, homogenised from four sub-samples collected from 0 to 20 cm and 20–40 cm depth, were taken from each gap and analysed for chemical composition by the Soil Laboratory at Embrapa Amazônia Oriental, Belém, Pará.

The rationale for this planting methodology was that mahogany seedlings should grow within the matrix of natural gap regeneration (Oliveira, 2000; Snook and Negreros-Castillo, 2004). Maintenance of the planted gaps was therefore kept to a minimum, manually cutting back only vegetation growing directly above each seedling (such as the fast-growing pioneer species *Cecropia* spp. and *Trema micrantha* (L.) Blume), and vegetation within 1 m diameter of the base of the stem. Cut material was left *in situ*. Maintenance was carried out 3 months