



# Enrichment planting in logging gaps with *Schizolobium parahyba* var. *amazonicum* (Huber ex Ducke) Barneby: A financially profitable alternative for degraded tropical forests in the Amazon



Gustavo Schwartz<sup>a,\*</sup>, Paulo C.G. Pereira<sup>b</sup>, Marco A. Siviero<sup>b</sup>, José F. Pereira<sup>c</sup>, Ademir R. Ruschel<sup>a</sup>, Jorge A.G. Yared<sup>c</sup>

<sup>a</sup>Embrapa Eastern Amazon, P.O. Box 48, 66095-100 Belém, PA, Brazil

<sup>b</sup>The Arboris Group, 68633-970 Dom Eliseu, PA, Brazil

<sup>c</sup>Embrapa Amapá, P.O. Box 10, 68903-419 Macapá, AP, Brazil

## ARTICLE INFO

### Article history:

Received 29 November 2016

Received in revised form 24 January 2017

Accepted 26 January 2017

Available online 10 February 2017

### Keywords:

Silvicultural systems

*Cecropia* spp.

Cost-benefit analysis

Lamination

Roundwood

Sawnwood

## ABSTRACT

Conservation of degraded forests is a challenging issue in the tropics, since the maintenance of environmental services and economic demands must be conciliated. Environmental services must be conserved while degraded tropical forests are demanded to be competitive against more financially profitable land uses as crop fields and pastures. The objective of this study was to evaluate productivity and financial profitability of enrichment planting in degraded forests. Seeds of *Schizolobium parahyba* var. *amazonicum* were planted in logging gaps of a 108-ha degraded forest in southeast Pará (Brazil) in February 1995 (average = 91.7 seeds ha<sup>-1</sup> and 15.3 seeds gap<sup>-1</sup>). After 13 years (2008), *S. parahyba* presented a volume increase of 3.1 m<sup>3</sup> ha<sup>-1</sup> yr<sup>-1</sup> for individuals ≥25 cm in DBH. More than 30% of the planted seeds were able to germinate, establish, and grow up to sizes ≥25 cm in DBH. A cost-benefit analysis through Net Present Value (NPV) and a sensitivity analysis with different interest rates were performed to compare financial profitability of the treated and control area under roundwood and laminated plus sawnwood production. Enrichment planting using *S. parahyba* seeds presented higher NPVs in the treated than in control area for all simulations, except roundwood under interest rate of 9% per year.

© 2017 Elsevier B.V. All rights reserved.

## 1. Introduction

Despite of great improvements in management of tropical forests for wood production, many forests in the Brazilian Amazon were degraded due to selective and constant illegal logging (Lawson and MacFaul, 2010). According to Putz and Redford (2010), degraded forests are old growth forests that lost their compositional and structural attributes due to factors such as substantial human interventions, including selective logging. In the tropics, degraded forests became an increasing problem, since their environmental services must be maintained in opposition to economic pressures to shift their areas into financially more profitable land uses (Aguiar et al., 2007; Keefe et al., 2012; Diniz, 2013).

Special attention has been spent from the scientific community on losses in environmental services of the tropical forests as biodiversity, watershed and soil protection, and CO<sub>2</sub> sink. However, much less attention has been given to ways of conserving degraded

forests under a more financially profitable management, including timber and non-timber production (Paquette et al., 2009). In the tropics, degraded forests face substantial risks to be wiped out for the establishment of agriculture or livestock projects, since they have lower economic value when compared to primary forests. Hence, it is crucial to find solutions for these forests that include: (a) conservation of their environmental services and (b) sustainable production of timber and non-timber products.

Degraded forests are normally located in regions of old agricultural frontiers, which bring some advantages in relation to the primary forests: (a) easier products accessibility to markets; (b) consolidated infrastructure of roads and labor; and (c) wood industry with plants adapted to process smaller log diameters. However, differently from primary and little altered tropical forests under management, the degraded forests still lack better established legal frames to regulate their economic management. This is the case in Brazil for the management of its Amazonian primary forests (MMA, 2006).

Tropical forest management for wood production has incorporated significant technical improvements over the last 50 years

\* Corresponding author.

E-mail address: [gustavo.schwartz@embrapa.br](mailto:gustavo.schwartz@embrapa.br) (G. Schwartz).

(De Graaf and Van Eldik, 2011). It is currently carried out in poly-cyclic silvicultural systems (PSS) with harvestings done through reduced-impact logging (RIL). Most of the forest regulators in the tropics have adopted PSS with RIL techniques as a legal requirement for harvesting interventions over primary forests (Silva, 1997; Pereira et al., 2002; MMA, 2006; Dykstra, 2012). The main purpose of RIL is to cause the least possible disturbance on the remaining trees as well as to conserve all environmental goods and services offered by harvested forests (Putz et al., 2008; Schwartz and Lopes, 2015).

Without post-logging care, as observed in managed primary forests, most of the degraded forests are cut down to establish crop fields and pastures. An aftermath of this land use change in Brazil is the current loss of 20% in its original Amazonian forests, nearly 800,000 km<sup>2</sup> (INPE, 2017). When considered only private lands, out of conservation units, concessions, or indigenous lands, the proportion of degraded forests in the region is significantly higher (Martorano et al., 2016). Moreover, it is from these lands that most of the wood produced in the Brazilian Amazon has been harvested and commercialized (SEMAS, 2015). These forests are characterized by low densities of trees larger than 50 cm in DBH, where most of the volume is composed by light-wood species (Carim et al., 2007; Reis et al., 2010). Because of their low numbers of individuals and volumes of valuable hard-wood species in comparison to primary forests, degraded forests have called less attention of forest managers and conservationists (Veríssimo et al., 2011). Thus, it is essential to develop and apply adapted silvicultural systems on degraded forests in tropical environments to increase their wood production and conservation value.

Long-term sustainable production in degraded tropical forests can be attained through silviculture intensification (De Graaf et al., 2003; Fredericksen and Putz, 2003; Putz and Ruslandi, 2015; Schwartz et al., 2015). Among the feasible alternatives of silviculture intensification, there is the application of post-harvesting silvicultural treatments aimed to increase growth and diminish mortality of commercial species individuals. These post-harvesting silvicultural treatments include the enrichment planting with commercial species in logging gaps (Gomes et al., 2010). So, logging gaps offer the ideal conditions to grow commercial species and increase financial profitability of degraded forests (Schwartz et al., 2016).

As far as we know, this is the first scientific study testing enrichment planting of a fast-growing species planted in logging gaps of degraded forests under a commercial scale up to its harvesting in a complete cutting cycle. The aims of this study were to assess the productivity and financial profitability of harvesting a degraded tropical forest enriched with the fast-growing and long-lived pioneer species *Schizolobium parahyba* var. *amazonicum*. To reach these aims, two questions were tackled in this research: (a) How productive can be a degraded tropical forest using enrichment planting in logging gaps with a fast-growing commercial species? (b) Is this silvicultural treatment financially profitable?

## 2. Materials and methods

### 2.1. Study species and study area

As a promising species for enrichment planting in logging gaps, the fast-growing and long-lived pioneer species *Schizolobium parahyba* var. *amazonicum* (Huber ex Ducke) Barneby (family Fabaceae), locally known as paricá, was used in an experiment to increase timber production in degraded forests. *S. parahyba* is a native species of the Eastern Amazon, with a geographical distribution from north Mexico to south Brazil (De Souza et al., 2003). Due to its fast growing, good timber features for industry, and high

commercial value, *S. parahyba* figures among the greatest potential wood species for enrichment planting in degraded forests (Cordeiro et al., 2016). The species has had increasing commercial importance in the Brazilian timber sector to wood lamination for plywood (Terezo and Szücs, 2010). Owing to technological advances in processing machinery, *S. parahyba* logs are no longer laminated to 12 cm, but up to 4 cm in diameter (Marques et al., 2006).

The experiment was carried out in a degraded forest of Fazenda Shet (4°30'48"S and 47°39'36"W), municipality of Dom Eliseu, southeast of Pará state, Brazil. Fazenda Shet belongs to the Arboris Group, a business group that works with agriculture and forestry in the Amazon, including wood production from planted and native forests. *S. parahyba* has been planted by the Arboris Group in logging gaps, monoculture plantings, or associated with soybean. The study was developed in a partnership between the Arboris Group and Embrapa Eastern Amazon, under the project "Rede Biomassa Florestal". This project aimed to find scientific and technological solutions for the sustainable management of degraded native forests in the Amazon to increase their economic competitiveness in relation to agriculture and livestock.

In Fazenda Shet, the original vegetation was dominated by submontane dense rain forest (IBGE, 2004). The average temperature is 25.4 °C with annual precipitation of 2000 mm and rainy season from February to April. The average altitude in the study area is 320 masl and the most common soil type is yellow Oxisol (Veloso et al., 1991; SUDAM, 1993; Embrapa, 2006).

### 2.2. Experimental design

A total area of 535.6 ha covered by a native degraded forest in Fazenda Shet was used in the experiment. Such forest became degraded due to selective illegal logging occurred from the 70s to the 90s with no information on the timber volume lost. The last logging in the area occurred along 1993 to 1996. This was also the first legal logging in the area, which was allowed by the Brazilian forestry authorities, with an average harvesting volume of 64.2 m<sup>3</sup> ha<sup>-1</sup>. The current norm prescribing a maximal harvesting of 30.0 m<sup>3</sup> ha<sup>-1</sup> for the Brazilian Amazon began only in 2006 (MMA, 2006). From the total managed area, 158.0 ha harvested in 1994–1995 were selected specifically for this study. Within the selected area, 108.0 ha served as treatment to make enrichment planting and the remaining 50 ha were used as control with no plantings. Logging residuals inside gaps were burnt to give space for enrichment planting. It started after logging operations in January and February 1995 (beginning of the rainy season). A buffer zone was made (1 m wide) in each gap border to avoid fire propagation into the forest.

Seeds of *S. parahyba* were buried individually using a hoe (Trivino-Diaz et al., 1990). A total of 9 kg of *S. parahyba* seeds (nearly 1100 seeds kg<sup>-1</sup>) was planted in logging gaps of the treated area at the beginning of the rainy season in February 1995 (average = 91.7 seeds ha<sup>-1</sup> and 15.3 seeds gap<sup>-1</sup>). The total estimated numbers of logging gaps used in the experiment (considering an average of 6 gaps ha<sup>-1</sup>) were 648 in treated area (108 ha) and 300 in the control area (50 ha). Planting did not follow a set spacing, but seeds were not buried closer than 2.5 m from each other. Gaps created by tree felling were not larger than 200 m<sup>2</sup>. After seed planting, two maintenance treatments were applied (May 1995 and April 1996) over the seedlings inside logging gaps. They consisted in cutting lianas and possible light and nutrient competitors from non-commercial tree species against planted individuals of *S. parahyba*.

A forest inventory was carried out in 2008 where all individuals ≥25 cm in DBH (1.3 m aboveground) were assessed. According to the Brazilian regulations for harvesting in primary forests, only individuals ≥50 cm in DBH are allowed to be cut (MMA, 2006).

For experimental purposes, a special research allowance was issued to harvest trees  $\geq 25$  cm in DBH. All calculations and simulations presented here were based on the maximum potential productivity of the treated and control area. No harvesting procedures were done by the time of data collection for this study. Individuals from the sampled species were distributed in six 5-cm diameter classes (25–30, 30–35, 35–40, 40–45, 45–50, and  $\geq 50$  cm in DBH) for the treated and control area.

Wood produced from individuals of *S. parahyba* and *Cecropia* spp. has been normally used for lamination to produce plywood. *Cecropia* spp. was considered, up to a few years ago, as competing vegetation. More recently, a rapid technological development permitted its industrial applications, including lamination (Iwakiri et al., 2010; Zeller et al., 2013). Natural hollows are not a significant issue to laminate individuals  $\geq 25$  cm in DBH of *Cecropia* species.

Each individual  $\geq 25$  cm in DBH inventoried was identified at the lowest taxonomic level and tagged with a small numbered metal plate. Diameter was measured and commercial height was estimated. Density (individuals  $\text{ha}^{-1}$ ) and volume ( $\text{m}^3 \text{ha}^{-1}$ ) were calculated for each individual and species in the two areas (Table 1). Volumes were calculated using a form factor equal to 0.7 (Silva et al., 1985).

### 2.3. Cost-benefit analysis

Net present value (NPV) was used to estimate profitability of enrichment planting in degraded forests using *S. parahyba*. NPV is a tool to calculate profitability of projects through discounted cash flow analysis. Costs and benefits are calculated through the formula:

$$\text{NPV} = \sum_{t=0}^n \left( \frac{B_t}{(1+r)^t} - \frac{C_t}{(1+r)^t} \right)$$

where  $B_t$  is the harvesting revenue in year  $t$ ,  $C_t$  is the total cost in year  $t$ ,  $r$  is the discount rate per year,  $t$  is the year when revenue or cost occurs, and  $n$  is the time demanded for revenues. Only NPVs larger than zero indicate profitability of the investment (Klemperer, 2003). Costs were based on field worksheets provided by the Arboris Group and cost estimations on harvesting, transport, and processing were estimated according to Pereira et al. (2010) and Schwartz et al. (2016) (Table 2). Benefits were calculated from the volumes of each inventoried individual from all species. The calculated volumes were multiplied by the average commercialization price of each species for roundwood and sawnwood. The same procedure was done considering commercialization prices for roundwood and laminated wood of *S. parahyba* and *Cecropia* spp. (Table 3a). *Cecropia* presents great natural regeneration in disturbed

**Table 2**

Average costs of establishment and maintenance of enriched logging gaps with *Schizolobium parahyba* var. *amazonicum* and average costs of harvesting, transport, and processing to produce roundwood and laminated plus sawnwood ( $\text{USD ha}^{-1}$ ) in a treated and in a control area at Fazenda Shet, Dom Eliseu, Pará, Brazil.

Activity	Treated ( $\text{USD ha}^{-1}$ )	Control ( $\text{USD ha}^{-1}$ )
Seed production	20.00	0.00
Gap preparation	200.00	0.00
Seed planting	55.00	0.00
Maintenance – year 1	40.00	0.00
Maintenance – year 2	40.00	0.00
Roundwood production	1377.65	1156.87
Laminated plus sawnwood production	5641.49	4737.41

**Table 3**

Average prices ( $\text{US\$ m}^{-3}$ ) in Pará state, Brazil according to SEMAS (2015) for roundwood and laminated wood of *Schizolobium parahyba* var. *amazonicum* and *Cecropia* spp. (a) and average benefits ( $\text{US\$ ha}^{-1}$ ) of enrichment planting in logging gaps with *S. parahyba* in a treated and in a control area to produce roundwood and laminated plus sawnwood at Fazenda Shet, Dom Eliseu, Pará, Brazil (b).

(a) Average prices ( $\text{US\$ m}^{-3}$ )		
Species	Roundwood ( $\text{USD m}^{-3}$ )	Laminated wood ( $\text{USD m}^{-3}$ )
<i>Schizolobium parahyba</i> var. <i>amazonicum</i>	55.00	240.40
<i>Cecropia</i> spp.	49.29	240.40
(b) Average benefits ( $\text{US\$ ha}^{-1}$ )		
Activity	Treated ( $\text{USD ha}^{-1}$ )	Control ( $\text{USD ha}^{-1}$ )
Roundwood production	7409.61	6430.55
Laminated plus sawnwood production	17838.99	13147.42

or degraded forests in southeast Pará. The average prices used in this study were obtained from the State Secretary for the Environment and Sustainability of Pará (SEMAS, 2015). The institution publishes average prices of timber products per species traded in the state yearly.

Laminated wood was estimated only for *S. parahyba* and *Cecropia* spp. using an efficiency index of 84% obtained through sawmill measurements carried out by the Arboris Group. The estimated sawnwood was calculated for all species, except *S. parahyba* and *Cecropia* spp., with an efficiency value of 55%, which is the average processing efficiency in the region.

Future benefits of harvesting a degraded forest enriched with *S. parahyba* seeds in logging gaps were based on the diameter of the

**Table 1**  
Volume ( $\text{m}^3 \text{ha}^{-1}$ ) and density (individuals  $\text{ha}^{-1}$ ) with percentages in relation to all individuals  $\geq 25$  cm in DBH belonging to the ten highest volume species in the treated and control area of Fazenda Shet, Dom Eliseu, PA, Brazil.

Species	Volume		Density	
	Treated	Control	Treated	Control
<i>Schizolobium parahyba</i> var. <i>amazonicum</i>	40.1 (35.5)	0.1 (0.1)	28.5 (30.0)	0.1 (0.1)
<i>Cecropia</i> spp.	7.7 (6.8)	12.6 (13.3)	11.8 (12.4)	17.9 (21.4)
<i>Trattinnickia burseraefolia</i>	7.3 (6.5)	5.9 (6.2)	7.3 (7.7)	6.0 (7.2)
<i>Jacaratia spinosa</i>	4.0 (3.5)	3.2 (3.4)	6.8 (7.2)	4.7 (5.6)
<i>Geissospermum sericeum</i>	3.4 (3.0)	0.6 (0.6)	1.2 (1.3)	0.3 (0.4)
<i>Pouteria guianensis</i>	3.3 (2.9)	2.4 (2.5)	2.7 (2.8)	1.9 (2.3)
<i>Sterculia pruriens</i>	3.1 (2.7)	2.9 (3.1)	2.4 (2.5)	1.6 (1.9)
<i>Inga</i> sp.	2.9 (2.6)	4.2 (4.4)	4.7 (5.0)	7.0 (8.4)
<i>Hymenaea courbaril</i>	2.7 (2.4)	2.5 (2.6)	1.2 (1.3)	1.0 (1.2)
<i>Pouteria pachycarpa</i>	2.4 (2.1)	2.8 (3.0)	1.0 (1.1)	1.5 (1.8)
Total	76.9 (68.2)	37.2 (39.3)	67.6 (71.2)	42.0 (50.1)
All species	112.8 (100.0)	94.7 (100.0)	94.9 (100.0)	83.8 (100.0)

inventoried individuals in 2008. This represents 13 years of growing after logging and the treatment of enrichment planting in Fazenda Sht. Thus, the net benefits per hectare (NPV ha<sup>-1</sup>) were calculated for both areas (treatment and control) regarding: (a) roundwood of every individual from all species and (b) laminated wood from individuals of *S. parahyba* and *Cecropia* spp. plus sawnwood from all remaining tree species.

Establishment and maintenance costs of the enrichment planting treatment were calculated per hectare, where the following costs were taken into account: (a) seed production, (b) gap preparation, (c) labor, and (d) workers transport (Table 2). Labor, as part of the maintenance costs, was calculated in relation to the time demanded to liberate individuals of *S. parahyba* inside gaps against the competing vegetation (Table 2). Individuals of *Cecropia* spp. that reached the minimum allowed DBH for laminating (25 cm) had no liberating treatments during the experiment.

A basic discount rate of 6% per year was used to estimate profitability of enrichment planting with *S. parahyba* seeds in degraded forests. This is a long-term interest rate adopted by the National Development Bank (BNDES) of Brazil. The bank is responsible to promote long-term financing for projects in industry, infrastructure, agriculture, trade, and services.

#### 2.4. Sensitivity analysis

Scenarios with different interest rates were built through a sensitivity analysis to project the profitability of producing roundwood and laminated wood from *S. parahyba* and *Cecropia* spp. plus sawnwood from the remaining native species. Besides the 6% basic rate, other scenarios were built with interest rates of 3% and 9% per year.

### 3. Results

#### 3.1. Enrichment planting in logging gaps with *Schizolobium parahyba* var. *amazonicum*

Thirteen years after harvest followed by the application of enrichment planting in logging gaps using *S. parahyba* seeds, the 100% inventory showed a total of 14433 stems assessed in both treated and control area. From these, 5242 stems were from *S. parahyba* and *Cecropia* spp. In the treated area there were 83 species in 108 ha against 71 species in 50 ha of the control area. Total volumes were 112.8 m<sup>3</sup> ha<sup>-1</sup> in the treated area and 94.7 m<sup>3</sup> ha<sup>-1</sup> in the control area (Table 1). The highest volumes were presented by *S. parahyba* in the treated area and *Cecropia* spp. in the control area. Due to the treatment of enrichment planting, *S. parahyba* had a remarkable volume of 40.1 m<sup>3</sup> ha<sup>-1</sup> in the treated area against 0.1 m<sup>3</sup> ha<sup>-1</sup> in the control area (Table 1).

From the nearly 10000 seeds of *S. parahyba* used to enrich 108 ha in the treated area, 3074 individuals attained the harvestable diameter of 25 cm in contrast to five individuals reaching the same size in the control area. This represents a success higher than 30% in germination, establishment, and growth of the seeds planted 13 years before. This success in enriching logging gaps with *S. parahyba* ended up with a density of 28.5 harvestable individuals per hectare in the treated area and 0.1 harvestable individuals per hectare in the control area, which grew up naturally with no silvicultural care. Assuming a complete absence of individuals belonging to *S. parahyba* before enrichment planting, the volume accumulation was expressive. The planted individuals accumulated an average of 3.1 m<sup>3</sup> ha<sup>-1</sup> yr<sup>-1</sup> during the years following the silvicultural treatment.

*S. parahyba* showed a concentration of individuals in the three first diameter classes, from 25 cm to 40 cm in DBH, while *Cecropia*

spp. had more stems in the first class (Fig. 1). Differently from *S. parahyba*, *Cecropia* spp., which trees came from natural regeneration, presented high densities in both areas (Table 1). However, it presented higher density in the control than in the treated area in every diameter class (Fig. 1).

The treated area, besides enrichment planting establishment and maintenance costs, also presented higher costs to timber laminating and sawing. These higher costs reflected the greater wood volumes of *S. parahyba* to be processed (Table 2). The treated area also presented higher benefits in relation to the control area for roundwood and laminated plus sawnwood (Table 3b). Both treatments were profitable for roundwood and laminated plus sawnwood production under the basic interest rate of 6% per year, since their NPVs were higher than zero in all simulations (Table 4). The differences, however, weighted positively in favor of laminated plus sawnwood in both treatments. Simulations also showed that the treatment of enrichment planting was more profitable for both wood uses (roundwood and laminated plus sawnwood) in the treated area than in the control area under the basic interest rate of 6% (Table 4).

#### 3.2. Sensitivity analysis

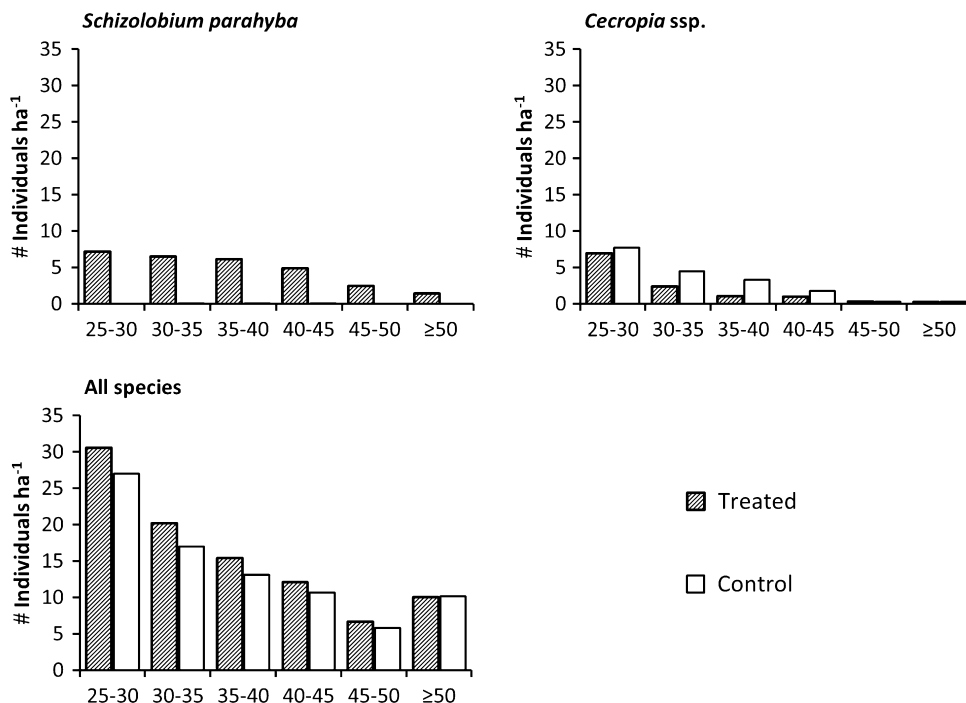
Scenarios with interest rates lower and higher than the basic rate of 6% per year showed positive NPVs in every simulation. In both treatments, roundwood and laminated plus sawnwood were financially profitable. In all simulations the treated area (with enrichment planting) was more profitable than the control area, except for roundwood produced under an interest rate of 9% per year (Table 4).

### 4. Discussion

#### 4.1. Enrichment planting in logging gaps with *Schizolobium parahyba* var. *amazonicum*

Low numbers of individuals from *Schizolobium parahyba* var. *amazonicum* found in the control area's inventory confirm the species small natural densities. Based on its rareness (Velooso et al., 1991; De Souza et al., 2003), the industrial use for lamination of naturally grown *S. parahyba* trees in the region is unviable as an economic activity.

With results from this study, it is reasonable to infer that the use of *S. parahyba* in logging gaps of degraded forests, due to intensive logging, is a viable alternative under an economic perspective. Due to its rapid growth, *S. parahyba* can outcompete lianas and non-commercial pioneer species. This can reflect in a lower demand of silvicultural treatments of seedling liberation and, consequently, in lower cost. Another possible advantage of growing *S. parahyba* is its ecological competitiveness that can force individuals from other commercial species spontaneously established in the forest to grow more rapidly. Such competition can result not only in a higher wood production but in a more rapid recovery of degraded forests. A possible indication of this is the higher total volume and density of the treated area in relation to the control area (Table 1), since the two areas started from the same degradation conditions. Rapid growth and economic viability of wood production from *S. parahyba* plantings in degraded forests highlight the necessity to emphasize management of each commercial species, according to their ecological and production cycles. This way of management can bring better ecological and economic results. In southeast Amazon there are other commercial fast-growing species abundant in natural regeneration as *Jacaranda copaia*, *Zanthoxylum ekmanii*, and *Z. rhoifolia* that have a great potential to enrich degraded forests. So, these species could be



**Fig. 1.** Distribution of individuals from *Schizolobium parahyba* var. *amazonicum*, *Cecropia* spp., and all species together in six 5-cm wide diameter classes through the treated and control area where enrichment planting in logging gaps with seeds of *S. parahyba* was applied at Fazenda Shet, Dom Eliseu, Pará, Brazil.

**Table 4**  
Net present value (USD ha<sup>-1</sup>) for the treated and control area in relation to roundwood and laminated plus sawnwood produced through enrichment planting in logging gaps using seeds of *Schizolobium parahyba* var. *amazonicum* at Fazenda Shet, Dom Eliseu, Pará, Brazil under discount rates varying from 3% to 9%.

Interest rate (%)	Treated		Control	
	Roundwood	Laminated + Sawnwood	Roundwood	Laminated + Sawnwood
3	3775.93	7954.36	3591.12	5726.81
6	2479.68	5370.33	2472.50	3942.95
9	1622.13	3633.20	1720.16	2743.17

managed for wood production in association with *S. parahyba* and *Cecropia* spp.

Successful enrichment planting in logging gaps using *S. parahyba* in this study confirms the results from other experiments as Doucet et al. (2009), Gomes et al. (2010), Schwartz et al. (2013), and Quédráogo et al. (2014). The authors suggest ecological and economic efficiency of enrichment planting in logging gaps, which comes as a viable silvicultural alternative for managing tropical forests.

In terms of costs, the establishment of enrichment planting in logging gaps using *S. parahyba* summed a total of US\$ 355.00 ha<sup>-1</sup> (Table 2). This value is similar to the values found in other enrichment planting studies in Brazil, as US\$ 400.37 ha<sup>-1</sup> and US\$ 248.67 ha<sup>-1</sup> described by Schwartz et al. (2016) in north Amazon and US\$ 378.00 ha<sup>-1</sup> found by Lopes et al. (2008) in south Amazon. However, it is much higher than US\$ 22.80 ha<sup>-1</sup> found in Cameroon by Doucet et al. (2009) and US\$ 40.00 ha<sup>-1</sup> in east Amazon, Brazil, described by Schulze (2008). Seedling production, transport, and planting, whose cost is usually the highest in enrichment plantings, were zero in this study. Moreover, costs of this enrichment planting experiment could be reduced in 11% if maintenance in year two was suppressed. Field observations from another experiment in southeast Amazon showed that *S. parahyba* seedlings can thrive after a single liberation treatment in the first year (G. Schwartz – personal observation).

Higher profitability values observed for the treatment of enrichment planting with *S. parahyba* and for laminated plus sawnwood

under every interest rate simulated in this work were due to: (a) elevated laminated wood prices in the region (Table 3a) and (b) rapid technological advance for wood lamination observed in the region. On the other hand, low roundwood prices of *S. parahyba* and *Cecropia* spp. worsened profitability of roundwood. Thus, roundwood produced in the treated area became less profitable than roundwood from the control area for an interest rate of 9% per year (Table 4).

#### 4.2. Implications for the management of degraded tropical forests

Most of the current studies dealing with enrichment planting in logging gaps present data from the first months or years after the experiment beginning (Schulze, 2008; Gomes et al., 2010; Schwartz et al., 2013). The present study brings data from 13 years, a complete harvesting cycle of *S. parahyba* planted in logging gaps as a post-harvesting silvicultural treatment. So that, it shows how enrichment planting can bring higher financial returns and contribute to recover degraded tropical forests.

Harvestings 13 years after enrichment planting could also be seen as a silvicultural treatment of thinning where the felled trees (all above 25 cm in DBH) would be commercialized. In Fazenda Shet, for example, there were many planted individuals below 25 cm in DBH that will be harvestable within the next 13-year cutting cycle. In this way, thinning could be applied each 10–13 years in forests enriched with *S. parahyba* in a PSS with 30-year cutting cycles for the slower growth species. The 10–13 year thinning

operations would bring extra revenues and improve the forest manager's cash-flow. Forest managers would no longer have to wait 30 years for a new harvest. Cutting cycles including 10–13 year cycles of thinning comes as an applicable option to the reality of small forest management areas, run by lower income land owners.

*S. parahyba* could be benefitted from the low canopy height (20 m) of the degraded forest in Fazenda Shet. Lower canopy heights contribute for a larger illumination reaching the forest floor (Miller et al., 2007). This can be one of the reasons why *S. parahyba* grew successfully (average = 3.1 m<sup>3</sup> ha<sup>-1</sup> yr<sup>-1</sup> in 13 years) in the experiment. Hence, the species becomes a recommendable alternative to promote wood production in degraded forests through enrichment planting in logging gaps.

As a viable silvicultural alternative, enrichment planting in logging gaps can be applied in tropical forests under risks of land use changes (Paquette et al., 2009; Keefe et al., 2012). Such treatment can provide a high timber production while the treated forest maintains its environmental services. This is particularly important in the arc of deforestation region (Fearnside, 2005; Costa et al., 2012; Schwartz et al., 2015), in the Brazilian Amazon, where the experiment was developed. The arc of deforestation, a 500,000-km<sup>2</sup> area in south and southeast Amazon, presents high levels of forest losses and degradation due to decades of uncontrolled logging. Its landscapes are formed by a mosaic of lands covered by crop fields, pastures, and degraded forests.

Financial returns, however, are not the only benefit of enrichment planting in degraded tropical forests. Fazenda Shet typically represents private areas with degraded forests in the arc of deforestation. It is not part of a public protected area (conservation unit), but a private area under significant deforestation risks, once taken into account high pressures of land use changes to more financially competitive activities such as agriculture and livestock. Under this scenario, enrichment planting with fast-growing commercial species can turn degraded tropical forests in a more competitive land use in relation to agriculture and livestock.

In opposition to the long harvesting cycles allowed in the Brazilian Amazon (30–35 years), a minimum cutting diameter of 25 cm permits shorter cycles (13 years in this experiment). In a shorter cutting cycle, enrichment planting with *S. parahyba* turns harvestings more profitable. However, specific legal regulations addressed to the management of degraded natural forests are necessary to guarantee their conservation and economic viability.

## 5. Conclusions

Enrichment planting in logging gaps using seeds of *S. parahyba* showed to be a successful post-harvesting silvicultural treatment. In 13 years (1995–2008), the species presented a volume increase of 3.1 m<sup>3</sup> ha<sup>-1</sup> yr<sup>-1</sup> for individuals ≥ 25 cm in DBH. More than 30% of the planted seeds were able to reach sizes ≥ 25 cm in DBH. The treatment was profitable for roundwood and laminated plus sawn-wood production. In all simulations the treated area presented the best cost-benefit relation when compared to the control area, except in roundwood under an interest rate of 9% per year.

## Acknowledgements

This research was funded by FAPESPA (Pará state, Brazil) through the project “FAPESPA/ICAAF 014/2008 – Silvicultura de Floresta Nativa” and counted on the support of Embrapa Eastern Amazon and the Arboris Group. The authors are grateful to an anonymous reviewer for comments and suggestions that substantially improved this paper's quality.

## References

- Aguiar, A.P.D., Câmara, G., Escada, M.I.S., 2007. Spatial statistical analysis of land-use determinants in the Brazilian Amazonia: exploring intra-regional heterogeneity. *Ecol. Model.* 209, 169–188.
- Carim, S., Schwartz, G., da Silva, M.F.F., 2007. Riqueza de espécies, estrutura e composição florística de uma floresta secundária de 40 anos no leste da Amazônia. *Acta Botânica Brasílica* 21, 293–308.
- Cordeiro, I.M.C.C., De Oliveira Jr., M.C.M., Gazel Filho, A.B., De Barros, P.L.C., Lameira, O.A., Oliveira, F.A., 2016. Growth of *Schizolobium parahyba* var. amazonicum cropping in presence of *Ananas comosus* var. *erectifolius* in Para state, Brazil. *Agrociencia* 50, 79–88.
- Costa, L.G.S., Miranda, I.S., Grimaldi, M., Silva Jr., M.L., Mitja, D., Lima, T.T.S., 2012. Biomass in different types of land use in the Brazil's 'arc of deforestation'. *For. Ecol. Manage.* 278, 101–109.
- De Graaf, N.R., Filius, A.M., Huesca Santos, A.R., 2003. Financial analysis of sustained forest management for timber perspectives for application of the CELOS management system in Brazilian Amazonia. *For. Ecol. Manage.* 177, 287–299.
- De Graaf, N.R., Van Eldik, T., 2011. Precious woods, Brazil. In: Werger, M.J.A. (Ed.), *Sustainable Management of Tropical Rainforests: The CELOS Management System*, Tropenbos Series, 25. Paramaribo, pp. 186–199.
- De Souza, C.R., Rossi, L.M.B., De Azevedo, C., Vieira, A.H., 2003. Paricá (*Schizolobium parahyba* var. *amazonicum* (Huber & Ducke) Barneby. *Circular Técnica* 18, Embrapa, Manaus, Brazil, 12p.
- Diniz, F.H., 2013. From landless to forestless? Settlers, livelihoods and forest dynamics in the Brazilian Amazon PhD thesis. Wageningen University, Wageningen, The Netherlands, p. 184.
- Doucet, J.L., Kouadio, Y.L., Monticelli, D., Lejeune, P., 2009. Enrichment of logging gaps with moabi (*Baillonella toxisperma* Pierre) in a Central African rain forest. *For. Ecol. Manage.* 258, 2407–2415.
- Dykstra, D.P., 2012. Has reduced-impact logging outlived its usefulness? *J. Trop. For. Sci.* 24, 1–4.
- EMBRAPA, Centro Nacional de Pesquisa de Solos, 2006. Sistema Brasileiro de Classificação de Solos. Embrapa Solos, Rio de Janeiro.
- Fearnside, P.M., 2005. Deforestation in Brazilian Amazonia: history, rates, and consequences. *Conserv. Biol.* 19, 680–688.
- Fredericksen, T.S., Putz, F.S., 2003. Silvicultural intensification for tropical forest conservation. *Biodivers. Conserv.* 12, 1445–1453.
- Gomes, J.M., Carvalho, J.O.P., da Silva, M.G., Nobre, D.N.V., Taffarel, M., Ferreira, J.E.R., Santos, R.N.J., 2010. Sobrevivência de espécies arbóreas plantadas em clareiras causadas pela colheita de madeira em uma floresta de terra firme no município de Paragominas na Amazônia brasileira. *Acta Amazon.* 40, 171–178.
- IBGE (Instituto Brasileiro de Geografia e Estatística), 2004. Mapa de Vegetação do Brasil. [online] URL: <<http://www.ibge.gov.br/home/presidencia/noticias/21052004biomas.shtml>> (accessed on 23 October 2014).
- INPE (Instituto Nacional de Pesquisas Espaciais), 2017. Projeto PRODES: Monitoramento da floresta amazônica brasileira por satélite. [online] URL: <<http://www.obt.inpe.br/prodes/index.php>> (accessed on 17 January 2017).
- Iwakiri, S., Zeller, F., Pinto, J.A., Ramirez, M.G.L., Souza, M.M., Seixas, R., 2010. Avaliação do potencial de utilização da madeira de *Schizolobium amazonicum* “Paricá” e *Cecropia hololeuca* “Embaúba” para produção de painéis aglomerados. *Acta Amazon.* 40, 303–308.
- Keefe, K., Alavalapati, J.A.A., Pinheiro, C., 2012. Is enrichment planting worth its costs? A financial cost-benefit analysis. *For. Policy Econ.* 23, 10–16.
- Klemperer, W.D., 2003. *Forest Resource Economics and Finance*. USA, 551p.
- Lawson, S., MacFaul, L., 2010. *Illegal Logging and Related Trade*. Chatham House, London, United Kingdom, p. 132p.
- Lopes, J.C.A., Jennings, S.B., Matni, N.M., 2008. Planting mahogany in canopy gaps created by commercial harvesting. *For. Ecol. For. Manage.* 255, 300–307.
- Marques, L.C.T., Yared, J.A.G., Siviero, M.A., 2006. A Evolução do Conhecimento sobre o Paricá para reflorestamento no Estado do Pará. *Comunicado Técnico* 158, Embrapa Amazônia Oriental, Belém, Brazil, 5p.
- Martorano, L.G., Siviero, M.A., Tourne, D.C.M., Vieira, S.B., Fitzjarrald, D.R., Vettorazzi, C.A., Brienza Jr., S., Yared, J.A.G., Meyering, E., Lisboa, L.S.S., 2016. Agriculture and forest: a sustainable strategy in the Brazilian Amazon. *Aust. J. Crop Sci.* 10, 1136–1143.
- Miller, S.D., Goulden, M.L., Da Rocha, H.R., 2007. The effect of canopy gaps on subcanopy ventilation and scalar fluxes in a tropical forest. *Agric. For. Meteorol.* 142, 25–34.
- MMA, 2006. Instrução Normativa N° 5 de 11 de dezembro de 2006. Ministry of Environment (MMA) – Brazil. [online] URL: <[www.mma.org.br](http://www.mma.org.br)> (accessed on 28 April 2014).
- Paquette, A., Hawryshyn, J., Senikas, A.V., Potvin, C., 2009. Enrichment planting in secondary forests: a promising clean development mechanism to increase terrestrial carbon sinks. *Ecol. Soc.* 14, Article 31.
- Pereira, D., Santos, D., Vedoveto, M., Guimarães, J., Veríssimo, A., 2010. *Fatos Florestais da Amazônia*. Imazon, Belém, p. 122.
- Pereira, R., Zweede, J., Asner, G.P., Keller, M., 2002. Forest canopy damage and recovery in reduced-impact and conventional selective logging in eastern Pará, Brazil. *For. Ecol. Manage.* 168, 77–89.
- Putz, F.E., Redford, K.H., 2010. The importance of defining ‘Forest’: tropical forest degradation, deforestation, long-term phase shifts, and further transitions. *Biotropica* 42, 10–20.
- Putz, F.E., Ruslandi, 2015. Intensification of tropical silviculture. *J. Trop. For. Sci.* 27, 285–288.

- Putz, F.E., Sist, P., Fredericksen, T., Dykstra, D., 2008. Reduced-impact logging: challenges and opportunities. *For. Ecol. Manage.* 256, 1427–1433.
- Quêdraogo, D.Y., Fayolle, A., Dainou, K., Demaret, C., Bourland, N., Lagoute, P., Doucet, J.L., 2014. Enrichment of logging gaps with a high conservation value species (*Pericopsis elata*) in a Central African Moist Forest. *Forests* 5, 3031–3047.
- Reis, L.P., Ruschel, A.D., Coelho, A.A., Luz, A.S., Martins-da-Silva, C.V., 2010. Avaliação do potencial madeireiro na Floresta Nacional do Tapajós, após 28 anos da exploração florestal. *Pesquisa Florestal Brasileira* 30, 265–281.
- Schulze, M., 2008. Technical and financial analysis of enrichment planting in logging gaps as a potential component of forest management in the eastern Amazon. *For. Ecol. Manage.* 255, 866–879.
- Schwartz, G., Bais, A.L.S., Peña-Claros, M., Hoogstra-Klein, M., Mohren, G.M.J., Arts, B. J.M., 2016. Profitability of silvicultural treatments in logging gaps in the Brazilian Amazon. *J. Trop. For. Sci.* 28, 68–78.
- Schwartz, G., Ferreira, M.do S., Lopes, J.do C., 2015. Silvicultural intensification and agroforestry systems in secondary tropical forests: a review. *Amazon. J. Agric. Environ. Sci.* <http://dx.doi.org/10.4322/rca.1830>.
- Schwartz, G., Lopes, J.C.A., Mohren, G.M.J., Peña-Claros, M., 2013. Post-harvesting silvicultural treatments in logging gaps: a comparison between enrichment planting and tending of natural regeneration. *For. Ecol. Manage.* 293, 57–64.
- Schwartz, G., Lopes, J.C., 2015. Logging in the Brazilian Amazon forest: the challenges of reaching sustainable future cutting cycles. In: Daniels, J.A. (Ed.), *Advances in Environmental Research*, vol. 36. Nova, New York, pp. 113–137.
- SEMAS (Secretaria de Estado de Meio Ambiente e sustentabilidade), 2015. Beneficiamento e comércio de produtos madeireiros por espécies florestal. Período de 1-1-2014 até 31-12-2014. Belém, PA, Brazil. 122p.
- Silva, J.N.M., 1997. Manejo de florestas de terra firme na Amazônia brasileira. In: EMBRAPA-CNPQ. *Tópicos em manejo florestal sustentável*, vol. 34. Documentos, pp. 59–96.
- Silva, J.N.M., de Carvalho, J.O.P., do Ca Lopes, J., 1985. Forest inventory of an experimental area in the Tapajós National Forest. *Boletim de Pesquisa Florestal* 1, 38–110.
- SUDAM-DRN/EMBRAPA-SNLCS, 1993. Estudos climáticos do estado do Pará, classificação (Köppen) e deficiência hídrica (Thorntwaite, Mather). Superintendência de Desenvolvimento da Amazônia, Belém, p. 53.
- Terezo, R.F., Szücs, C.A., 2010. Análise de desempenho de vigas em madeira laminada colada de paricá (*Schizolobium amazonicum* Huber ex. Ducke). *Scientia Forestalis* 38, 471–480.
- Trivino-Diaz, T., Acosta, R., Castillo, A., 1990. Técnicas de manejo de semillas para algunas especies forestales neotropicales en Colombia. Colombia, 91 p.
- Veloso, H.P., Rangel-Filho, A.L.R., Lima, J.C.A., 1991. Classificação da vegetação brasileira adaptada a um sistema universal. IBGE, Rio de Janeiro, p. 124p.
- Veríssimo, A., Rolla, A., Vedoveto, M., de M. Futada, S., 2011. Áreas protegidas na Amazônia brasileira: avanços e desafios. Imazon/ISA, São Paulo, p. 87p.
- Zeller, F., Barbu, M.C., Iwakiri, S., 2013. Paricá (*Schizolobium amazonicum*) and embaúba (*Cecropia* sp.) as new raw materials for particleboards. *Eur. J. Wood Wood Prod.* 71, 823–825.