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PRODUCTIVE FOREST RECOVERY IN LEGAL RESERVE AREA: A CASE STUDY IN EASTERN AMAZON

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Resumo

Recuperação florestal produtiva em área de reserva legal: estudo de caso no lesta da Amazônia. Este trabalho teve como objetivo avaliar um modelo de recuperação de Reserva Legal (RL) baseado em um sistema produtivo madeireiro misto (plantio + regeneração natural), no leste da Amazônia, estado do Pará. Para a coleta de dados foram instaladas sete parcelas de 50 m x 20 m, sendo inventariados todos os indivíduos com DAP (diâmetro a 1,30 m acima do solo) ≥ 5 cm. A diversidade de espécies, a estrutura horizontal e a produção de madeira comercial foram avaliadas aos 13 anos de idade. Foram encontradas 103 espécies, distribuídas em 69 gêneros e 33 famílias. A densidade populacional foi de 1.425 indivíduos ha^{-1} e a dominância correspondeu a 19,45 $m^2.ha^{-1}$. O volume total de madeira foi de 121,4 $m^3.ha^{-1}$, sendo 63,3 $m^3.ha^{-1}$ proveniente da espécie plantada (*S. parahyba* var. *amazonicum*) e 58,1 $m^3.ha^{-1}$ da regeneração natural. Entre as espécies regenerantes, *Cecropia distachya* foi a que apresentou os maiores valores para os parâmetros avaliados. O modelo adotado apresentou potencial para ser utilizado na recuperação ambiental da RL, conciliando esta ação com a geração de receita, através de intervenções silviculturais que podem ser aplicadas no povoamento, visando a produção de madeira. Para isto, são necessárias adequações nos instrumentos que normatizam o manejo florestal de áreas em recuperação.
Palavras-chave: regeneração natural, resiliência, reincorporação produtiva, paricá.

Abstract

This study aimed to evaluate a model for Legal Reserve (LR) recovery based on a mixed timber production system (planting + natural regeneration) in the eastern Amazon, state of Pará. For data collection, seven plots of 50 m x 20 m were established, and all individuals with DBH (diameter at breast height) ≥ 5 cm were inventoried. Species diversity, horizontal structure, and commercial wood production were assessed at 13 years of age. A total of 103 species were found, distributed among 69 genera and 33 families. The population density was 1,425 individuals per hectare, and dominance corresponded to 19.45 $m^2.ha^{-1}$. The total wood volume was 121.4 $m^3.ha^{-1}$, with 63.3 $m^3.ha^{-1}$ coming from the planted species (*S. parahyba* var. *amazonicum*) and 58.1 $m^3.ha^{-1}$ from natural regeneration. Among the regenerating species, Cecropia distachya showed the highest values for the evaluated parameters. The adopted model showed potential for use in LR environmental recovery, reconciling this action with revenue generation through silvicultural interventions that can be applied to the stand, aiming for wood production. To achieve this, adjustments to the regulations governing the forest management of recovering areas are necessary.
Keywords: natural regeneration, resilience, productive reincorporation, paricá.

INTRODUCTION

Deforestation and degradation of the Amazon rainforest have reached alarming levels, causing negative effects on climate, biodiversity, and the relationship of local populations with the forest (LAPOLA *et al.* 2023). The eastern region of the Amazon forest has exhibited the highest rates of carbon emissions, releasing more CO_2 than it absorbs (GATTI *et al.* 2021).

Strategies have been incorporated into policy instruments aimed at the recovery of degraded areas, such as the Forest Code and the National Policy for the Recovery of Native Vegetation, highlighting the concern to reverse the degradation scenario that has advanced over decades into Legal Reserve (LR) areas. These areas are of great importance for ecological balance, biodiversity maintenance, and the generation of socio-economic benefits (NUNES *et al.* 2016; METZGER *et al.* 2019).

To advance the forest recovery agenda, policy-administrative instruments such as the Rural Environmental Registry and the Environmental Regularization Program have been implemented. These instruments involve the identification of liabilities and monitoring of recovery, with deadlines and methods more closely aligned with the reality of rural property owners (NUNES; LEHFELD, 2018). This enables the sustainable use of areas in the process of recovery within the boundaries of the LR (BRANCALION *et al.* 2016).

However, the recovery techniques adopted for the environmental adjustment of the property typically result in the abandonment of productive areas, leading to the cessation of economic practices and the interruption of the producer's remuneration (CAMPOS; BACHA, 2016). Several factors contribute to the resistance to adopting more sophisticated recovery systems, including the high cost, owners' unawareness that economic activity is allowed in the Legal Reserve (RL) during the recovery process, and bureaucratic obstacles for the implementation and harvest clearance by environmental agencies.

In this context, there is an urgent need to develop recovery systems with low-cost and efficient strategies, making them appealing to producers. These systems should combine biodiversity conservation and the return of ecosystem services with agroforestry production, generating environmental, economic, and social benefits.

Thus, the present work consisted of a case study aimed at evaluating species richness, horizontal structure, and commercial wood volume resulting from recovery based on a productive timber system. The goal is to generate information that can support silvicultural decisions and contribute to productive forest recovery in Legal Reserve areas. The study hypothesized that the model of productive forest recovery, based on natural regeneration and planting of commercial tree species, facilitates the restoration of vegetation in the Legal Reserve area, as well as its productive capacity, within a time frame equivalent to other recovery methodologies.

MATERIALS AND METHODS

Study Area

The study was conducted on a rural property located in the municipality of Dom Eliseu, state of Pará, eastern Amazon, at coordinates 04º10'19" S and 47º43'34" W. The municipality is situated in the region known as the "arc of deforestation." The property is managed by the Arboris Group, a business group engaged in agriculture and forestry in the Amazon, including the production of wood from both planted and native forests. The original vegetation on the property was dominated by Amazon Rainforest (IBGE, 2012). The average temperature is 25.4 ºC, and the annual precipitation is 2,000 mm, with a rainy season from February to April. The average altitude in the study area is 320 m, and the predominant soil type is Yellow Latosol (VELOSO *et al*., 1991; EMBRAPA, 2006).

The property was acquired in 1997 and exhibited the characteristics of a degraded natural forest, which is typical of properties located in the arc of deforestation region in the Amazon. The degradation was the result of intense, unplanned timber extraction that occurred from the 1970s to the 1990s and forest fires. There is no information on the volume of extracted wood. Although the area has never undergone a change in land use, its structure was compromised, with predominantly pioneer tree species. Due to attempted invasions and forest fires around 2005, the area's recovery process was initiated. The surrounding areas still have remnants of natural vegetation. No soil degradation or presence of invasive species was observed.

Spatial Arrangement

The model used in the restoration was a mixed timber production system that combined homogeneous forest planting and non-induced natural regeneration. The area was cleared (removal of remaining vegetation), and soil preparation was carried out. Subsequently, two alternating strips were established, one being a natural regeneration (NR) strip without interventions, with a width of 5 m, and the other strip, 4 m wide, where direct planting of *Schizolobium parahyba* var. *amazonicum* (paricá) seeds was conducted, forming a pattern of two rows spaced 2.75 m apart within the strip. The distance between the planting holes was 3 m, resulting in approximately 740 holes per hectare. In each hole, two seeds were planted to increase planting survival rates. After three months, a thinning operation was performed, keeping the individual with the greatest height growth. Silvicultural practices (fertilization and pruning) were applied only in the first year of planting.

Data Collection and Analysis

After 13 years of implementation, seven plots measuring 50 m x 20 m (1,000 m²) were installed and inventoried. These plots were arranged perpendicular to the strips, encompassing individuals from both the natural regeneration strips and the strips of the commercially planted species. In the plots, all tree individuals with a Diameter at Breast Height (DBH) ≥ 5 cm were measured. Commercial height was visually estimated, following the practice applied in forest management projects. Commercial height was defined as the height from the stem to the first branching. The trees were identified at the species level and associated with their common names adopted in the region. In cases where identification in the field was not possible, botanical material samples were collected and sent to the Botany Laboratory of Embrapa Eastern Amazon for identification. To assess the recovery system used, the data analysis focused on species richness and the horizontal structure of the tree community. Phytosociological parameters such as Absolute Density (AD), Relative Density (RD), Absolute Dominance (ADo), Relative Dominance (RDo), and Cover Value Index (CVI) were calculated.

To assess the volumetric production of natural regeneration in the area, the commercial volume of standing trees was determined, considering only individuals with a Diameter at Breast Height (DAP) ≥ 10 cm. Due to the lack of adjusted models for volume calculation, it was decided to use the geometric volume corrected by the form factor 0.7, proposed by Heinsdijk and Bastos (1963). This method is widely employed for volume calculation in the initial harvest in forest management plans in the Amazon.

$$V = g * H * ff$$

Where: V is the commercial volume (m³), g is the cross-sectional area at 1.30 m above the ground (m²); H is the commercial height (m), and ff is the form factor (0.7).

To determine the volume of the planted trees, the equation proposed by Hoffmann *et al.* (2011) was used.

$$V = 0{,}000201 * D^{2{,}021123} * H^{0465923}$$

Where: V is the commercial volume (m³), D is the diameter measured at 1.30 m above the ground (m), and H is the commercial height (m).

RESULTS

A total of 998 individuals were sampled, belonging to 111 species, distributed across 69 genera and 33 families (Table 1). Among the sampled individuals, 08 were not identified.

Table 1. List according to the hierarchy of botanical classification: family, genus, and species, and the population density that occurred in the forest restoration area.

Table 1. Lista conforme hierarquia da classificação botânica, família, gênero e espécie, e densidade populacional que ocorreram na área de recuperação florestal.

Family	Species	Common name	individuals ha^{-1}
Anacardiaceae	*Astronium graveolens Jacq.*	Aroeira	1,43
	Tapirira guianensis Aubl.	Tatapiririca	2,86
	Thyrsodium spruceanum Benth.	Breu-de-leite / Amaparana	7,14
Annonaceae	*Annona densicoma Mart.*	Envira	1,43
	Annona exsucca DC.	Envira-fofa	52,86
	Annona montana Macfad.	Envira-folha-grande	1,43
	Guatteria punctata (Aubl.) R.A.Howard	Envira-preta	38,57
	Guatteria schomburgkiana Mart.	Envira-preta-surucucu	4,29
	Xylopia aromatica (Lam.) Mart.	Envira-cana-cheirosa	1,43
	Xylopia calophylla R.E.Fr.	Envira-cana	1,43
Apocynaceae	*Aspidosperma desmanthum Benth. ex Müll.Arg.*	Araracanga	1,43
	Geissospermum sericeum Miers	Quinarana	4,29
	Himatanthus articulatus (Vahl) Woodson	Sucuúba	2,86
Araliaceae	*Didymopanax morototoni (Aubl.) Decne. & Planch.*	Morototó/Mandiocão	15,71
Bignoniaceae	*Handroanthus serratifolius (Vahl) S.Grose*	Ipê-amarelo	1,43
	Jacaranda copaia (Aubl.) D. Don.	Parapará	45,71
Boraginaceae	*Cordia exaltata Lam.*	Freijó-branco	2,86
	Cordia goeldiana Huber	Freijó-cinza	5,71
	Cordia lomatoloba I.M.Johnst.	Freijó-preto	11,43
	Cordia ssp.	Freijó-branco	58,57
Burseraceae	*Protium pallidum Cuatrec.*	Breu-branco-folha-grande	2,86
	Protium pilosissimum Engl.	Breu-pretinho	1,43

Family	Species	Common name	individuals ha^{-1}
	Protium robustum (Swart) D.M.Porter	Breu-folha-grande.	1,43
	Trattinnickia burserifolia Mart.	Breu-sucuruba	5,71
	Trattinnickia rhoifolia Willd.	Amesclão	12,86
Chrysobalanaceae	*Hirtella sp*	Azeitona-do-mato	1,43
	Hymenopus heteromorphus (Benth.) Sothers & Prance var. heteromorphus	Macucu	4,29
	Licania canescens Benoist	Casca-seca/Caripé	1,43
	Licania kunthiana Hook.f.	Casca-seca/Pintadinho	2,86
Erythropalaceae	*Heisteria densifrons Engl.*	Canela-de-vó	1,43
Euphorbiaceae	*Glycydendron amazonicum Ducke*	Glícia/Mirindiba-doce	1,43
	Sagotia racemosa Baill.	Arataciú	11,43
	Sapium glandulosum (L.) Morong	Burra- leitera	2,86
Fabaceae	*Amphiodon effusus Huber*	Gema-de-ovo	11,43
	Bauhinia acreana Harms	Pata-de-vaca	28,57
	Cynometra bauhiniifolia Benth.	Condurú-de-sangue	1,43
	Hymenaea courbaril L.	Jatobá	14,29
	Inga alba (Sw.) Willd.	Ingá-vermelho	27,14
	Inga macrophylla Humb. & Bonpl. ex Willd.	Ingá-folha-grande.	24,29
	Inga marginata Willd.	Ingá-feijão	1,43
	Inga rubiginosa (Rich.) DC.	Inga peludo	1,43
	Inga thibaudiana DC.	Ingá-dez-folhas	8,57
	Parkia multijuga Benth.	Fava-arara-tucupi	1,43
	Parkia ulei (Harms) Kuhlm.	Fava-esponjeira	4,29
	Pterocarpus rohrii Vahl	Mututi-da-terra-firme	4,29
	Schizolobium parahyba var. amazonicum (Huber ex Ducke) Barneby	Paricá	124,29
	Stryphnodendron pulcherrimum (Willd.) Hochr.	Paricazinho/Fava-de-paca	1,43
	Stryphynodendron sp.	Paricazinhho	4,29
	Swartzia laurifolia Benth.	Gombeira-vermelha	1,43
	Swartzia polyphylla DC.	Pitaíca-da-terra-firme.	1,43
	Tachigali sp.	Tachi	1,43
Humiriaceae	*Sacoglottis guianensis Benth.*	Uchirana	1,43
Hypericaceae	*Vismia guianensis (Aubl.) Pers.*	Lacre-vermelho	27,14
	Vismia latifolia (Aubl.) Choisy	Lacre-folha-grande	104,29
Lamiaceae	*Vitex triflora Vahl*	Tarumã	1,43
Lauraceae	*Nectandra canescens Nees*	Louro	2,86
	Ocotea longifolia Kunth	Louro-raiz-aérea	25,71
Lecythidaceae	*Couratari guianensis Aubl.*	Tauari-folha-peluda	2,86
	Eschweilera amazonica R.Knuth	Matamatá-cinza	1,43
	Eschweilera apiculata (Miers) A.C.Sm.	Matamatá-vermelho	1,43
	Eschweilera coriacea (DC.) S.A.Mori	Matamatá-branco	17,14
	Eschweilera ovata (Cambess.) Mart. ex	Matamatá-jibóia	2,86

Family	Species	Common name	individuals ha^{-1}
	Miers		
	Lecythis idatimon Aubl.	Jatereua	1,43
	Lecythis lurida (Miers) S.A.Mori	Jarana	2,86
	Lecythis pisonis Cambess.	Castanha-sapucaia	1,43
Malpighiaceae	*Byrsonima aerugo Sagot*	Murucí-da-mata	1,43
	Byrsonima ssp.	Murucí-da-mata	5,71
	Byrsonima stipulacea A.Juss.	Murucí-estípula	2,86
Malvaceae	*Apeiba albiflora Ducke*	Pente-macaco-folha-coriáceae	1,43
	Apeiba glabra Aubl.	Pente-macaco-disco-folha-lisa	37,14
	Apeiba tibourbou Aubl.	Pente-macaco-pluma	51,43
	Theobroma speciosum Willd. ex Spreng.	Cacauí	4,29
Melastomataceae	*Bellucia grossularioides (L.) Triana*	Muúba/goiaba-anta	12,86
Moraceae	*Bagassa guianensis Aubl.*	Tatajuba	32,86
	Batocarpus amazonicus (Ducke) Fosberg	Inharé-de-leite	4,29
	Brosimum guianense (Aubl.) Huber	Janitá-folha-pequena.	1,43
	Helicostylis pedunculata Benoist	Muiratinga-folha-peluda	4,29
Myrtaceae	*Campomanesia grandiflora (Aubl.) Sagot*	Guabiroba	1,43
	Myrcia cuprea (O.Berg) Kiaersk.	Cumatê	4,29
	Myrcia deflexa (Poir.) DC.	Goiabinha	2,86
	Myrcia fenestrata DC.	Goiabinha-nervura	2,86
Não Identificada	Não Identificada	Não Identificada	11,43
Nyctaginaceae	*Neea floribunda Poepp. & Endl.*	João-mole-folha-grande	5,71
	Neea ssp.	João mole	1,43
Phyllanthaceae	*Margaritaria nobilis L.f.*	Aquiqui	2,86
Quiinaceae	*Quiina sp.*	Papo-mutum-folha-pequena.	1,43
	Touroulia sp.	Papo-mutum	1,43
Rhamnaceae	*Colubrina glandulosa Perkins*	Maranhoto	1,43
Rubiaceae	*Duroia macrophylla Huber*	Cabeça-de-urubu	5,71
Rutaceae	*Zanthoxylum ekmanii (URB.) Alain.*	Mamica de cadela/limãozinho	104,29
	Zanthoxylum rhoifolium Lam.	Limãozinho	1,43
Salicaceae	*Banara guianensis Aubl.*	Pelo-cutia	1,43
	Casearia arborea (Rich.) Urb.	Espeteiro	8,57
	Casearia decandra Jacq.	Guaçatunga	2,86
	Casearia grandiflora Cambess.	Passarinheira	11,43
	Casearia javitensis Kunth	Canela-de-velho	5,71
	Homalium guianense (Aubl.) Oken	Casearia do frutão	5,71
	Laetia procera (Poepp.) Eichler	Pau-jacaré	7,14
Sapindaceae	*Cupania scrobiculata Rich.*	Espectorana	2,86
	Talisia ssp.	Pitomba	1,43
Sapotaceae	*Manilkara elata (Allemão ex Miq.) Monach.*	Maçaranduba	2,86
	Pouteria bilocularis (H.K.A.Winkl.) Baehni	Goiabão	1,43

Family	Species	Common name	individuals ha^{-1}
	Pouteria caimito (Ruiz & Pav.) Radlk.	Abiu-caimito	1,43
	Pouteria cladantha Sandwith	Abiu-cladantha	1,43
	Pouteria guianensis Aubl.	Abiu-vermelho	11,43
	Pouteria macrophylla (Lam.) Eyma	Abiu-cutite	12,86
	Pouteria sagotiana (Baill.) Eyma	Abiu	1,43
Siparunaceae	*Siparuna guianensis Aubl.*	Capitiú	2,86
Urticaceae	*Cecropia distachya Huber*	Embaúba-branca	218,57
	Cecropia palmata Willd.	Embaúba-vermelha	28,57
	Cecropia sciadophylla Mart.	Embauba-Torém	5,71
	Cecropia spp	Embaúba	8,57
	Pourouma guianensis Aubl.	Embaubarana	1,43

The absolute density (AD) of the entire tree community in the recovering area was 1,425.71 individuals per hectare, and the basal area of the stand corresponded to 19.46 m².ha^{-1} (Table 2). The results presented for the top 15 values of the Cover Value Index (CVI) indicate that these species account for 71.2% of the total coverage index of the area. In terms of Relative Density (DR) and Relative Dominance (DoR), they represent 63.1% and 79.4%, respectively.

The planted species, S. parahyba, contributed the highest CVI results (23.07%), explained by high values of DR (8.71%) and DoR (37.42%).

Table 2. Phytosociological parameters of the 15 species with the highest CVI values.
Table 2. Parâmetros fitossóciológicos, das 15 espécies com maiores valores de IVC.

Species	Common name	n	AD	RD	ADo	RDo	CVI
S. parahyba	paricá	87	124,29	8,71	7,28	37,42	23,07
C. distachya	embaúba-branca	153	218,57	15,32	2,53	13,02	14,17
Z. ekmanii	mamica-de-cadela	73	104,29	7,31	1,10	5,66	6,49
V. latifolia	lacre-da-folha-grande	73	104,29	7,31	0,52	2,69	5,00
J. copaia	para-pará	32	45,71	3,20	0,60	3,06	3,13
Cordia ssp.	freijó-branco	41	58,57	4,10	0,27	1,37	2,74
A. tibourbou	pente-macaco-pluma	36	51,43	3,60	0,33	1,71	2,66
H. heteromorphus	macucu	3	4,29	0,30	0,92	4,75	2,52
G. punctata	envira-preta	27	38,57	2,70	0,45	2,30	2,50
A. exsucca	envira-fofa	37	52,86	3,70	0,22	1,11	2,41
P. guianensis	abiu-vermelho	8	11,43	0,80	0,52	2,68	1,74
A. glabra	pente-macaco-disco-folha-lisa	26	37,14	2,60	0,16	0,85	1,72
B. guianensis	tatajuba	23	32,86	2,30	0,16	0,80	1,55
D. morototoni	morototó/mandiocão	11	15,71	1,10	0,38	1,95	1,52
B. acreana	pata-de-vaca	4	28,57	0,17	2,01	0,89	1,45
Subtotal		630	900,00	63,06	15,45	79,39	71,23
Total		998	1.425,71	100,00	19,46	100,00	100,00

Legend: n, number of individuals; DA, Absolute Density (individuals per hectare); DR, Relative Density (%); DoA, Absolute Dominance (m² ha^{-1}); DoR, Relative Dominance (%); CVI, Cover Value Index (%).

C. distachya represents the most abundant species in the area (218.6 individuals per hectare), considering all species (planted + natural regeneration). Among the species resulting from natural regeneration, *C. distachya* also stood out with the highest CVI (14.17%), RDo (13.02%), and RD (15.32%), representing more than double the results obtained for *Z. ekmanii* (CVI: 6.49%; RDo: 5.66%; RD: 7.31%), which was the second species with the highest values for the analyzed parameters.

The species *S. parahyba* (planted) and *C. distachya* (natural regeneration) were the most representative in the area, together contributing to 24% of RD and 40.4% of RDo, raising the CVI (37.2%) for these two species.

The total volume of trees accumulated to 121.37 m³.ha^{-1} of wood produced in the area, with 63.3 m³.ha^{-1} corresponding to planting and 58.1 m³.ha^{-1} in natural regeneration, for individuals with DBH ≥ 10 cm. Considering individuals ≥ 25 cm DBH, the volume is 75.7 m³.ha^{-1} (62.4%) (Figure 1).

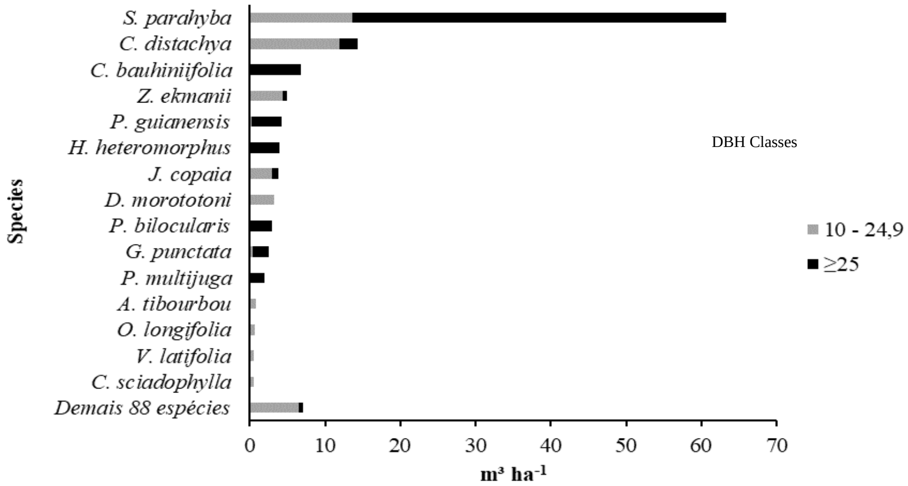

Figure 1. Commercial wood volume of the 15 most representative species occurring in the study area.
Figura 1. Volume comercial de madeira das 15 espécies mais representativas ocorrentes na área de estudo.

Considering only the 15 species with the highest volume values, a total of 114.3 m³.ha^{-1} was obtained, representing 94% of the total volume. The species *S. parahyba*, due to planting, had a notable volume and contributed 63.3 m³.ha^{-1}, with 49.7 m³.ha^{-1} in the compartment above 25 cm DBH. For tree components resulting from natural regeneration, the volume for the top 15 species was 51.07 m³.ha^{-1}, evenly distributed in the two diameter classes. This volume was primarily represented by *C. distachya* (14.3 m³.ha^{-1}), equivalent to 12%. *S. parahyba* and *C. distachya* accounted for 64% of the commercial wood volume produced. Among the species resulting from natural regeneration, the second species with the highest volume was *C. bauhiniifolia* with 6.8 m³. ha^{-1}, followed by *Z. ekmanii* with 4.93 m³.ha^{-1}.

DISCUSSION

The floristic richness was diversified; studies adopting natural regeneration as a recovery strategy indicate that this technique favors this parameter (VILLAA *et al.* 2018). Species widely known in the timber market, considered of noble use and high commercial value, were observed in the natural regeneration area, including *C. goeldiana* (freijó-cinza), *H. courbaril* (jatobá), *H. serratifolius* (ipê-amarelo), and *M. elata* (massaranduba), as well as potential species to meet the local market, commonly used in the timber industry, such as *B. guianensis* (tatajuba), *Z. ekmanii* (mamica-de-cadela/limãozinho), *D. morototoni* (morototó/mandiocão), *J. copaia* (para-pará), species of the genus *Cecropia* (embaúbas), among others.

Evaluating the composition of the 15 most representative species for phytosociological parameters and commercial volume, it was observed that ten species remained among the main ones, namely, *S. parahyba*, *C. distachya*, *Z. ekmanii*, *V. latifolia*, *J. copaia*, *A. tibourbou*, *H. heteromorphus*, *G. punctata*, *P. guianensis*, and *D. morototoni*. This information can assist in management and harvesting decisions for the area.

The performance of the recovery model, at 13 years, can be considered satisfactory concerning environmental and productive factors. From an environmental perspective, using basal area as an indicator, the area could be classified as being in an advanced regeneration stage (>8 m².ha^{-1}) (SEMAS, 2015), influenced especially by the species *S. parahyba* (planted), *C. distachya*, and *Z. ekmanii*. In terms of production, the accumulated wood volume in both planted and naturally regenerated individuals can ensure economic activity in the Legal Reserve through forest management. It is necessary to highlight that the use of any natural regeneration-based forest recovery strategy depends on the level of degradation of the area and the existence of remnants of natural vegetation in the surroundings, which directly influences the ecosystem's resilience and, consequently, the success of the recovery project (GUARIGUATA; OSTERTAG, 2001).

S. parahyba has characteristics that benefited the recovery process, such as its rapid growth, facilitating the overcoming of competition with pioneer species resulting from natural regeneration. These characteristics reduce maintenance costs, form a commercial wood stock, enabling the producer to achieve financial returns in a shorter time and restoring the area's productive capacity (GOMES *et al.* 2019; SCHWARTZ *et al.* 2017). It is worth noting here the need to adapt harvesting techniques to reduce the impacts of this activity on the remaining vegetation, as well as monitoring the area to provide information for decision-making on silvicultural treatments and future harvests.

The highlighted species have potential for commercialization and can be considered key species to drive the adopted recovery model, managed based on technical parameters resulting from monitoring and economic-financial analyses, supporting silvicultural decisions, determining harvest intensities and intervals. Management should assist secondary ecological succession, gradually replacing species with different ecological characteristics, accelerating the area's recovery process, and generating extra revenue to offset recovery costs for the producer.

Harvests in both planting and tree components resulting from natural regeneration in shorter cycles can be adopted as silvicultural treatment, based on the analysis of horizontal stand structure indicators and available commercial wood volume, continuing with timber management in the area over time, without the need for complete abandonment. Timber management at the beginning of the recovery process is possible due to the availability of technologies for processing low-diameter wood (MARQUES *et al.* 2006).

Among the highlighted pioneer species, species of the *Cecropia* genus, especially *C. distachya* (embaúba-branca), showed potential for harvest. *Cecropia* species commonly have wood used in the production of laminates and veneer panels in the region (MACHADO *et al.* 2018). These species, among other pioneers, exhibit rapid growth and a short life cycle, making them preferable for harvesting, maintaining as remnants species considered rare in terms of abundance and requiring more time to grow (2020a), applying post-harvest silvicultural treatments.

Other commercial species in the area, with high population density and rapid growth, such as *Z. ekmanii* (mamica-de-cadela/limãozinho), *D. morototoni* (morototó/mandiocão), *J. copaia* (para-pará), can also be managed considering their ecological characteristics, aiming to obtain wood to meet the regional veneer and sawmill market (DEARMOND *et al.* 2022; SALES *et al.* 2021; SIVIERO *et al.* 2020b; SCHWARTZ *et al.* 2017). Criteria based on abundance, basal area, and commercial wood volume indicators, together, can contribute to defining harvest criteria; however, genetic criteria must be considered to avoid genetic erosion, aiming for the balance of the recovering ecosystem, as well as measures to reduce harvesting impact, aiming for the sustainability of the activity.

Although economic use of LR areas is permitted, serving as a timber reserve, subject to intervention through management, there is a need for adaptation and updating of normative instruments that guide and regulate the management of natural forests and their successor formations in the Amazon, making them clearer and meeting specificities (CANETTI *et al.* 2021), encouraging the adoption of recovery models that anticipate harvests in natural regeneration, making them more attractive.

Among the technical parameters to be reviewed, the minimum cutting diameter (MCD) is highly relevant, considering that the current norm establishes that only individuals with DBH $\geq$ 50 cm are eligible for harvesting. This criterion limits the management of the recovering area because the predominance is of pioneer species, which rarely reach this diameter (SIVIERO *et al.* 2020a). Shorter periods between harvesting interventions can also be defined (10 to 15 years), unlike the long cycles established in the legislation (25 to 35 years), as the predominant species in recovering areas usually have a short life cycle in the forest (less than 25 years) (SCHWARTZ *et al.* 2017).

CONCLUSIONS

Planting paricá in association with natural regeneration areas proved to be a satisfactory methodology for the recovery of the studied forest ecological parameters. Additionally, it has the potential for generating revenue through timber forest management, thereby reducing recovery costs in Legal Reserve areas.

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