Pesquisa Florestal Brasileira
Brazilian Journal of Forestry Research
http://pfb.cnpf.embrapa.br/pfb/
e-ISSN: 1983-2605
Articles

Structural changes of common tree species populations in a managed natural forest in Brazilian Amazon

Fernanda da Silva Mendes[1]*, Renildo Medeiros da Silva[1], Ademir Roberto Ruschel[2], João Olegário Pereira de Carvalho[3], Aurélio Lourenço Rodrigues[4], Sebastião do Amaral Machado[5], Afonso Figueiredo Filho[6]

[1]Universidade do Estado do Pará, Travessa Enéas Pinheiro, 2626, CEP 66095-100, Belém, PA, Brasil
[2]Embrapa Amazônia Oriental, Travessa Doutor Enéas Pinheiro, CEP 66095-903, Belém, PA, Brasil
[3]Universidade Federal Rural da Amazônia, Av. Tancredo Neves, 2501, Terra Firme, CEP 66077-830, Belém, PA, Brasil
[4]Companhia de Saneamento do Paraná, Rua Engenheiros Rebouças, 1273, Rebouças, CEP 80215-900, Curitiba, PR, Brasil
[5]Universidade Federal do Paraná, Departamento de Ciências Florestais, Rua Lothário Meissner, 632, Jardim Botânico, CEP 80210-170, Curitiba, PR, Brasil
[6]Universidade Estadual do Centro-Oeste, Campus de Irati, PR 153, km 7, S/N, Riozinho, CEP 84500-000, Irati, PR, Brasil

*Corresponding author: :
mendes.fsm@gmail.com

Index terms:
Silvicultural treatments
Eastern Amazon
Forest management

Termos para indexação:
Tratamentos silviculturais
Amazônia oriental
Manejo florestal

Received in 09/07/2020
Accepted in 19/04/2023
Published in 02/10/2023

Abstract - The knowledge of forest populations dynamics after logging and under the events of silvicultural treatments is important to establish management and conservation strategies. We aimed to show results of structural changes of tree species populations (from seedlings to adult trees), during 27 years in an area where reduced impact logging and silvicultural treatments were performed. In 1985 timber of trees with DBH ≥ 60 cm was logged from 400 ha, considering three volume reduction intensities (15, 25, 35%). In 1994, thinning was applied considering individuals with DBH ≥ 15 cm, and four intensities of basal area reduction (0, 30, 50, 70%). Twelve statistical treatments were performed considering the thinning combined with harvest intensities. Trees, saplings, sticks and seedlings were monitored and measured in 40 permanent sample plots. The plots were assessed in 1984, 1986, 1994, 1996, 2004 and 2011. Statistical analyses were performed using generalized linear models. Our results show that forest structure was not altered significantly even in areas where the trees basal area reduction was higher. There was no significant influence on the establishment of the main species in the area and in dynamics of the remnant forest after logging.

Alterações da estrutura populacional de espécies arbóreas comuns em floresta natural manejada na Amazônia brasileira

Resumo - O conhecimento da dinâmica das populações arbóreas pós-exploração e sob tratamentos silviculturais são importantes para o estabelecimento de estratégias de manejo e conservação. O objetivo desse trabalho foi mostrar resultados da mudança estrutural das populações de espécies arbóreas (de mudas a árvores adultas), durante 27 anos, em uma área com colheita de madeira e aplicação de tratamentos silviculturais. Em 1985, colheu-se madeira com DAP ≥ 60 cm, em 400 ha, com três intensidades de redução volumétrica (15, 25, 35%). Em 1994, realizou-se desbaste dos indivíduos com DAP ≥ 15 cm, com quatro intensidades de redução da área basal (0, 30, 50, 70%). Doze tratamentos estatísticos foram aplicados, considerando-se desbaste combinado com intensidades de colheita. O monitoramento ocorreu em 40 parcelas permanentes, medindo-se árvores, arvoretas, varas e mudas em 1984, 1986, 1994, 1996, 2004 e 2011. Realizou-se análises estatísticas com modelos lineares generalizados. A estrutura da floresta não foi alterada significativamente, mesmo nas áreas onde foram aplicados tratamentos silviculturais com maior redução de área basal, não sendo registrada influência significativa no estabelecimento das principais espécies na área, nem na dinâmica da floresta remanescente.

https://doi.org/10.4336/2023.pfb.43e202002139

Introduction

The Brazilian Amazon timber production is traded worldwide, and logging follows forest management plans that are elaborate under Brazilian forest laws (Brasil, 2006, 2009, 2012), although sometimes the trees are still harvested without technical criteria. In this context, the sustainable forest management seems to be the best alternative to produce tropical timber, contributing to the biodiversity conservation and better use of the forest resources (Carreño-Rocabado et al., 2012; Vieira et al., 2014).

The application of silvicultural treatments is necessary to ensure natural regeneration and to increase growth rates of desirable species, taking into account the high abundance of natural regeneration of undesirable species that could interfere on the sustainability of timber production (Souza et al., 2015).

Reduced impact logging is an essential activity of the sustainable forest management practices, causing less damage than conventional logging (Schulze & Zweede, 2006). The thinning techniques have been used on experimental scales (Sandel & Carvalho, 2000; Oliveira et al., 2006; Azevedo et al., 2012), but little or not used on commercial scales because they are not compulsory and attractive in the current context of the forest policy to use forest resources in Brazil. However, silviculture in canopy gaps has shown to be promising for increasing forest productivity (Schwartz et al., 2017).

The abundance of a particular species in the understory of a tropical rainforest may be due to different strategies and factors that may favor its occurrence (Svenning, 2000). However, due to specific features, only a small number of species can reach and compose the forest canopy (Botrel et al., 2013). In this context, it is essential to know aspects of populations in response to forest management practices, mainly in the Amazon, which is characterized by a high species richness, but low floristic similarity between sites or regions, resulting in a few common species among sites (Matos et al., 2013; Steege et al., 2013). In areas with high species richness such as the Amazon, the sampling should be representative to obtain enough data for analyzing the vegetation structure and its common species populations (Moro & Martins, 2013).

Considering the hypothesis that treatments with greater reduction in basal area change the vegetation structure, influencing the establishment of some species in the area, the aim of this study was to evaluate the dynamics of the most abundant species, showing the behavior of their population structures in response to silvicultural treatments in a Ombrophylous Dense Forest, during 27 years, in order to understand aspects of successional dynamics of tree species populations in that managed forest in the Eastern Amazon.

Material and methods

Study area

The study was carried out in a 500 ha forest area monitored by Embrapa Amazônia Oriental, owned by Jari enterprises group, in the municipality of Vitória do Jari, Amapá State, Brazil. The research area is located in the northern region of Brazil, between the longitudes 52º10’ and 52º11’ W and latitudes 0º53’ and 0º55’ S, approximately 150 m above the sea level. The climate type is “Am” according to Köppen’s classification (Alvares et al., 2013), presenting annual average temperature of 25.8 °C. The average annual rainfall is 2,234 mm, with a rainy season from December to May and a dry season from June to November. The soil is a Dystrophic Yellow Latosol, with heavy clay (Azevedo et al., 2008a) and the vegetation is classified as Ombrophylous Dense Forest (IBGE, 2012).

In 1984, 40 permanent sample plots (100 m x 100 m) were established in the 500 ha study area to carry out continuous monitoring of tree species (Carvalho et al., 1987). In 400 ha, three blocks (I, II and III) of 48 ha (600 m x 800 m) totaling 144 ha were established as sample area, considering each block as an experiment replication. After logging 400 ha, the remnant 100 ha (block IV) were maintained unlogged and were used for comparison (Figure 1).

The logging in the 400 ha was performed in 1985, when 26 species were harvested. Trees from all harvested species were maintained in the forest considering the proportion of abundance of each species. Some commercial species were not harvested because there were few trees in the area (Carvalho et al., 1987). The 144 ha that constitute the experimental sample area (three 48 ha blocks) were divided into nine 200 m x 800 m tracks randomly distributed, each track with three volume reduction intensities (light – 15% of the volume, medium – 25% and heavy – 35%) (Figure 1),

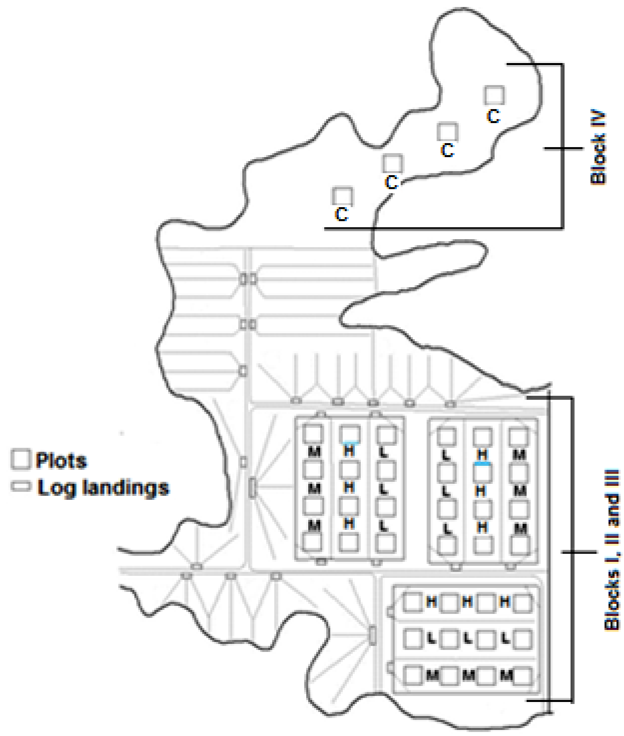

Figure 1. Permanent sample plots in the experimental area, in the municipality of Vitória do Jari, Amapá State, Brazil. Where: L – light intensity of volume reduction; M – medium intensity of volume reduction; H – heavy intensity of volume reduction; C – control area (Adapted from Azevedo et al., 2008a).

considering trees with DBH (diameter at 1.30 m above ground level) ≥ 60 cm (Azevedo et al., 2008a).

In 1994 two techniques of silvicultural treatments were applied in the area: systematic thinning (girdling plus poisoning); and selective thinning (girdling plus poisoning) (Azevedo et al., 2012). The systematic thinning consisted of poisoning trees with DBH ≥ 15 cm from non-commercial species to get the planned basal area reduction, including the basal area reduced by logging. The selective thinning consisted of poisoning trees with DBH ≥ 15 cm from non-commercial species presenting crowns that were competing for space with potential commercial trees species. This poisoning procedure was carried out in 581 trees from 87 species, avoiding the less abundant tree species. Four reduction intensities of the original basal area (0, 30, 50 and 70%) were considered (Costa et al., 2001; Azevedo et al., 2012).

The combining of those thinning intensities (0, 30, 50 and 70% of basal area) with the harvesting intensities (reduction of 15, 25 and 35% of the volume), resulted in 12 statistical treatments in the 400 ha logged area plus the 100 ha unlogged area (Table 1) (Azevedo et al., 2012).

Sampling Data

Experimental design was in blocks, collecting data by continuous inventories of permanent plots (100 m x 100 m). Each block consisted of 12 plots and 12 treatments, which were randomly allocated (Table 1; Figure 2). The permanent plots were subdivided into 100 subplots (10 m x 10 m), in which trees were measured according to the size classes (SC): trees, saplings, sticks and seedlings. Trees presenting DBH ≥ 20 cm were measured in all subplots. Saplings (individuals 5 ≤ DBH < 20 cm) were measured in 10 subplots randomly selected in each plot. Sticks (individuals 2.5 ≤ DBH < 5 cm) were measured in 5 m x 5 m subplots installed in the center of each 10 m x 10 m subplots, where the saplings were measured. The seedlings (individuals from 30 cm < total height to DBH < 2.5 cm) were counted by species in a 3.54 m x 3.54 m x 5 m triangular sample plot established in the 5 m x 5 m sample plots (Figure 2).

Table 1. Number of trees and accumulated volume for trees from 20 cm in diameter observed before and after logging and 12 silvicultural treatments applied to a 40 ha sample, during 27 years of monitoring, in Vitória do Jari, Amapá State, Brazil.

Treat	Intensity (%)			Number of trees ha^{-1}							Accumulative volume (m³ ha^{-1})						
	Harvest 1985	Thinning 1995	Type	Before harvest 1984	Harvest 1985	After harvest 1986	Thinning 1995	After thinning 1996	2011	Balance 1984 to 2011	Before harvest 1984	Harvest 1985	After harvest 1986	Thinning 1995	After thinning 1996	2011	Balance 1984 to 2011
T0	0	0	-	195	-	200	0.00	198	201	6	290.07	-	293.48	-	292.48	274.15	-15.92
T01	15%	0%		187	3.67	180	-	177	189	2	292.22	22.41	265.29	-	269.04	293.20	0.98
T02	15%	30%	SYS	185	2.33	178	23.67	171	182	-3	256.06	19.63	256.50	36.06	236.79	236.80	-19.26
T03	15%	50%	SYS	170	3.00	168	23.33	151	150	-20	278.07	21.15	291.81	37.88	283.40	239.59	-38.48
T04	15%	70%	SEL	185	3.00	185	8.33	173	191	6	304.30	22.43	224.50	13.16	223.31	280.73	-23.57
T05	25%	0%		173	5.33	164	-	168	186	13	281.88	41.59	232.31	-	248.27	271.99	-9.89
T06	25%	30%	SYS	166	5.67	157	19.67	158	169	3	250.81	45.38	206.62	22.74	207.41	239.19	-11.62
T07	25%	50%	SYS	175	4.33	161	12.67	144	160	-15	278.01	27.67	243.37	22.52	239.99	232.46	-45.55
T08	25%	70%	SEL	175	5.67	161	24.00	164	196	21	291.13	42.94	229.35	32.19	228.48	256.00	-35.13
T09	35%	0%		179	4.67	169	-	181	198	19	280.90	42.48	226.68	-	247.01	281.49	0.59
T10	35%	30%	SYS	165	6.00	148	30.33	162	195	30	283.63	59.71	209.03	32.34	207.92	256.46	-27.17
T11	35%	50%	SYS	172	7.67	158	11.00	133	172	0	259.93	43.57	216.41	14.35	201.56	210.53	-49.40
T12	35%	70%	SEL	175	6.67	164	12.00	172	188	13	270.59	50.32	209.32	14.86	225.59	234.85	-35.74
	Average			**177**	**4**	**169**	**13**	**166**	**183**	**6**	**278**	**34**	**239**	**17**	**239**	**254**	**-24**

Where: Treat – experimental treatment; SYS – systematic thinning; SEL – selective thinning.

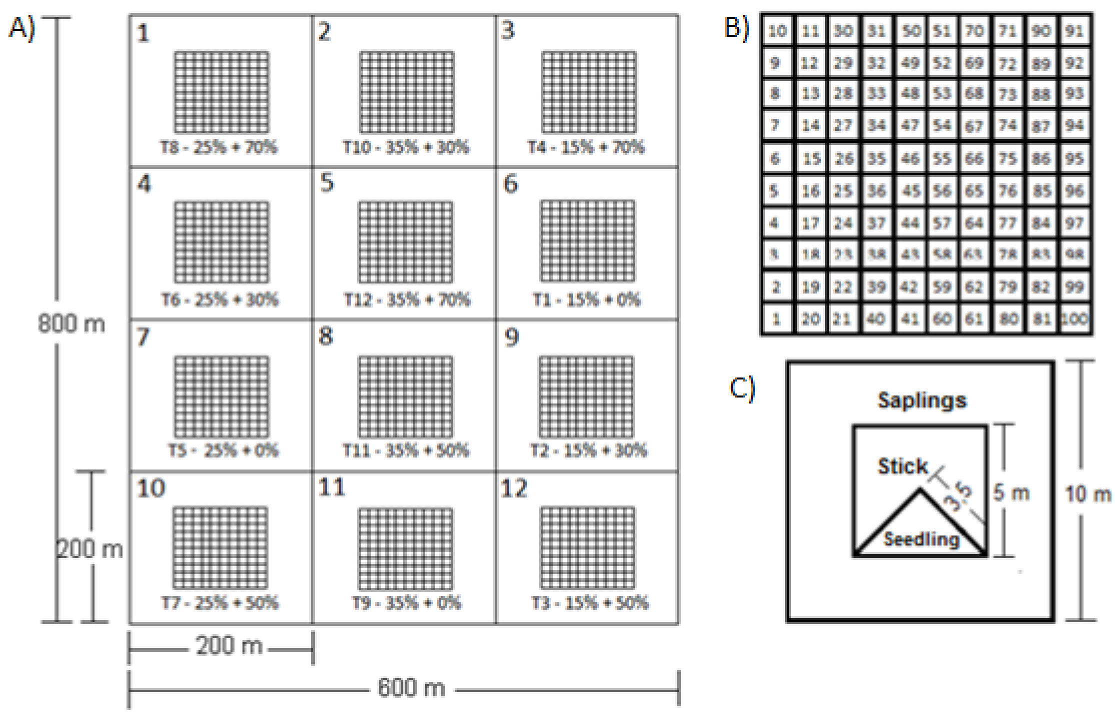

Figure 2. (A) Experimental block with twelve plots; (B) permanent plot of 1 ha (100 m x 100 m); and (C) natural regeneration sampling in a subplot (100 m²), with the subplots for sticks (25 m²) and seedlings (6.25 m²).

Trees and saplings were identified, numbered and had their DBH measured; sticks were identified and had their DBH measured; while seedlings were identified and the numbers of individuals per species in each subplot were counted. The first measurement was performed in 1984, before logging, while other measurements were performed after logging, in 1986, 1994, 1996, 2004 and 2011. Data from the 1994 measurement (before silvicultural treatments) and the 1996 measurement (after silvicultural treatments) were used only to evaluate the basal area reduction for the models that consider this independent variable.

Species identification were first performed in the forest by experienced local tree identifiers. Botanical material was collected for identification in the herbarium, following the APG III (2009) classification system and the species name was checked in Lista de Espécies da Flora do Brasil (2015) and Tropicos (2015).

Data analysis

The forest structure was evaluated according to Curtis & McIntosh (1951), including species density, frequency and basal area (dominance). This parameter was calculated only for trees, saplings and sticks, considering that seedlings DBH were not measured. The importance value index (IVI) that combines the relative density, frequency and dominance (basal area) was calculated to indicate the contribution of each species to the forest community.

The IVI was used to select the common species, in all vegetation strata. According to Moro & Martins (2013), the IVI is an attempt to equalize the more clumped or less clumped species participation, those more abundant or those with bigger trees, considering that some species present many trees while others present big trees in the community; furthermore, some species get clumped and local trees' distribution while others get wide distribution in the community.

The IVI average per species in the area in all different years was obtained and divided by the median (50% of the IVI average), in which the upper half species were considered locally common and the lower half locally rare. This methodology was adapted from the rarity measure defined by Hubbell (2013), where instead of IVI, the density values for this median are adopted.

The IVI was used for selecting the species, but in the analyses the basal area and density of individuals were emphasized. We evaluated the structure of the common species, highlighting the harvested species and the girdled/poisoned ones. All trees which were girdled were considered as girdled trees, being dead or alive, in the following measurements after girdling.

Statistical analysis - generalized linear models (GLM)

The data were evaluated for normality and homoscedasticity assumptions required for parametric tests, but no change met the parametric tests assumptions. Then the generalized linear models (GLM) were used to evaluate the data.

GLM allow regressions more flexible than linear, making possible other distributions beyond the normal for the response variable, as Binomial, Poisson, Negative binomial, or Gamma. They enable to include in the data processing the linear analysis of variance (ANOVA) as well as the semiquantitative or qualitative variables (Guisan & Zimmermann, 2000; Guisan et al., 2002).

The GLM were adjusted by the maximum likelihood method, according to Guisan & Zimmermann (2000) and Guisan et al. (2002), to identify the influence of interventions (timber logging and silvicultural treatments by thinning) on the dependent variables (density and dominance) of the common species; harvested species or girdled species. The independent variables were the years of measurement (YEAR), size classes (SC) and treatments. All the years of measurement, as well as all treatments, including the control area and all size classes were considered in all models used. The harvest intensity was considered as an independent variable when the treatment was not significant; but the basal area reduction by plot was considered as independent variable when the harvest intensity was not significant.

Results

Common species, considering the adapted classification of importance value index (IVI) for common species according to Hubbell (2013), are shown in Table 2.

Only 15 species (*Dendrobangia. boliviana*, *Geissospermum sericeum*, *Goupia glabra*, *Iryanthera juruensis*, *Manilkara elata*, *Miconia poeppigii*, *Myrcia splendens*, *Myrciaria floribunda*, *Ocotea petalanthera*, *Paypayrola grandiflora*, *Protium decandrum*, *Tabernaemontana rupicola*, *Tachigali glauca*, *Toulicia bullata* and *Virola michelii*) were observed in all treatments. For 52.5% of the common species, there was at least one girdled tree. *M. elata* and *G. glabra* accumulated 57.3% of the total logged basal area.

Three common species with higher density (*M. splendens*, *M. poeppigii* and *G. sericeum*) were not logged due to their no commercial value (Figure 3). Nevertheless, those with higher basal area and commercial value (*M. elata*, *G. glabra* and *P. oppositifolia*) were logged (Figure 4).

The number of trees and basal area from the main species varied during the study period (Figures 3 and 4). *M. splendens* that was girdled had its number of trees reduced in all the treatments, with girdling or not. The density of *M. elata* increased in the area for most of the treatments mainly due to the natural regeneration, but its basal area was reduced. The opposite occurred for *M. splendens*, an unlogged species under silvicultural treatment, in which the density of trees reduced and the basal area increased over time. However, those changes were not statistically significant between treatments or years.

The estimated parameters for the adjusted models are shown in Table 3, considering the structure of the populations of common species, harvested species and girdled species. The ANOVA of the models that consider as dependent variables the estimated absolute values of density and dominance, as well as the independent variables, species, year and treatment were significant, showing a statistically significant relationship between the dependent variable and the predictor variables ($p < 0.05$).

The ANOVA considering the absolute dominance of the common species, harvested species and girdled species showed significant results for species and size classes, but results were not significant for treatment and year. The density of the common species as dependent variable was significant for all variables except treatment. The timber harvesting combined with the tree girdling had no significant effect on the density of the common species. Then the variables were tested considering only the timber harvesting, but there were no significance as well.

The results obtained by this model were not significant for harvesting, considering the density of the harvested species as well as for the common species. Then, the variables were tested considering the reduction of basal area per plot, but the results of the ANOVA for this model were also not significant for this independent variable.

Table 2. Common species corresponding to 50% of the medium importance value of the community species in all years (trees; saplings; sticks; seedlings), classified in decreasing order of importance in a 40 ha sample, during 27 years of monitoring, with importance values of the species in the first and the last year of monitoring for demonstration.

Family	Scientific name	ST	IVI_{1984}	IVI_{2011}
Myrtaceae	*Myrcia splendens* (Sw.) DC.	T	0.69	0.84
Apocynaceae	*Geissospermum sericeum* Miers	T	0.55	0.58
Sapotaceae	*Manilkara elata* (Allemão ex Miq.) Monach	H	0.55	0.63
Goupiaceae	*Goupia glabra* Aubl.	H	2.62	2.73
Melastomataceae	*Miconia poeppigii* Triana	T	0.86	0.92
Apocynaceae	*Tabernaemontana rupicola* Benth	NI	0.77	0.92
Cardiopteridaceae	*Dendrobangia boliviana* Rusby	T	0.97	0.73
Burseraceae	*Protium decandrum* (Aubl.) Marchand	NI	1.03	1.00
Lauraceae	*Ocotea petalanthera* (Meisn.) Mez.	NI	1.21	1.38
Burseraceae	*Protium opacum* Swart	NI	0.71	0.63
Violaceae	*Rinorea flavescens* (Aubl.) Kuntze	T	1.03	0.61
Sapindaceae	*Toulicia bullata* Radlk.	T	0.57	0.67
Violaceae	*Paypayrola grandiflora* Tul.	NI	0.91	1.04
Rubiaceae	*Psychotria mapourioides* DC.	NI	1.18	1.05
Lecythidaceae	*Eschweilera coriacea* (DC.) S. A. Mori	NI	3.11	2.09
Fabaceae	*Tachigali tinctoria* (Benth.) Zarucchi & Herend.	T	0.53	0.35
Myristicaceae	*Virola michelii* Heckel	NI	1.25	1.16
Fabaceae	*Tachigali glauca* Tul.	NI	1.10	0.88
Lecythidaceae	*Eschweilera* sp.	T	0.79	0.82
Melastomataceae	*Mouriri collocarpa* Ducke	T	0.92	1.02
Burseraceae	*Protium sagotianum* Marchand	NI	1.46	1.47
Sapotaceae	*Micropholis guyanensis* (A. DC.) Pierre	T	1.04	1.08
Annonaceae	*Anaxagorea dolichocarpa* Sprague & Sandwith	T	0.75	0.93
Myrtaceae	*Myrciaria floribunda* (H. Westex Willd.) O. Berg	T	0.92	0.74
Sapotaceae	*Pouteria oppositifolia* (Ducke) Baehni	H/T	1.00	0.97
Myristicaceae	*Iryanthera juruensis* Warb.	T	1.18	1.19
Olacaceae	*Minquartia guianensis* Aubl.	T	0.44	0.54
Lecythidaceae	*Eschweilera amazonica* R. Knuth	NI	1.76	1.21
Sapotaceae	*Manilkara* sp.	H	0.46	0.74
Lecythidaceae	*Corythophora rimosa* W. A. Rodrigues	NI	0.73	0.66
Lecythidaceae	*Lecythis poiteaui* O. Berg	NI	1.07	1.16
Myrtaceae	*Eugenia patrisii* Vahl	NI	0.03	0.73
Lauraceae	*Aniba megaphylla* Mez	NI	0.53	0.47
Annonaceae	*Guatteria poeppigiana* Mart.	T	0.88	0.68
Ebenaceae	*Diospyros vestita* Benoist	T	3.09	1.99
Annonaceae	*Duguetia cauliflora* R. E. Fr.	T	1.22	1.09
Fabaceae	*Inga paraensis* Ducke	T	1.35	1.20
Fabaceae	*Dipteryx odorata* (Aubl.) Willd.	H	1.25	1.19
Salicaceae	*Casearia javitensis* Kunth	T	0.81	0.34
Nyctaginaceae	*Neea floribunda* Poepp. & Endl	T	0.79	0.86

Where: ST = silvicultural treatment; T = thinned species; H = harvested species; NI = specie not subject to intervention; IVI_{1984} and IVI_{2011} = importance values in 1984 and 2011, respectively.

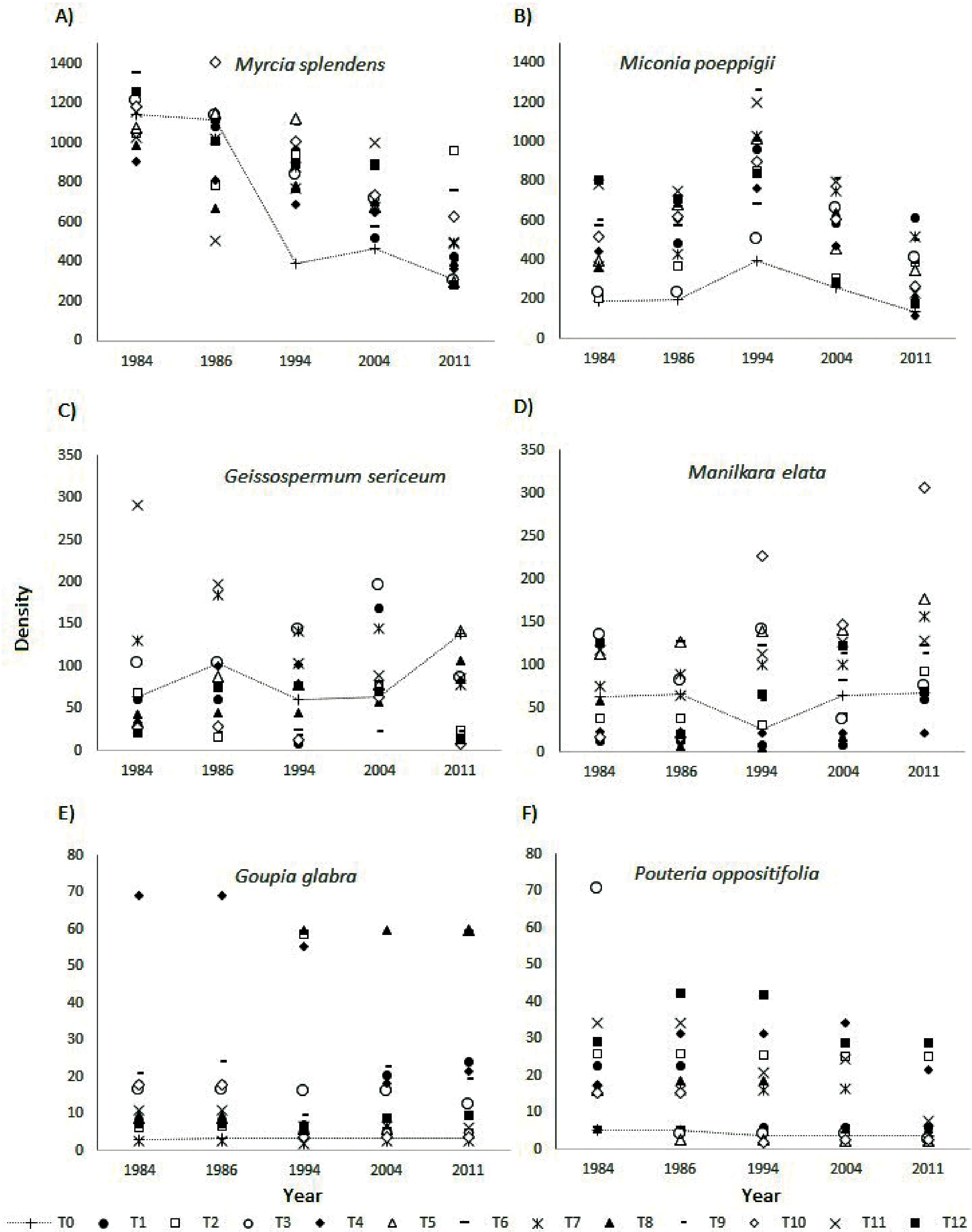

Figure 3. Number of individuals (trees; saplings; sticks; seedlings) per hectare of the three girdled species (A, B, C) and of the three logged species (D, E, F), in a 40 ha sample in five measurements during 27 years of monitoring, in Vitória do Jari, State of Amapá, Brazil.

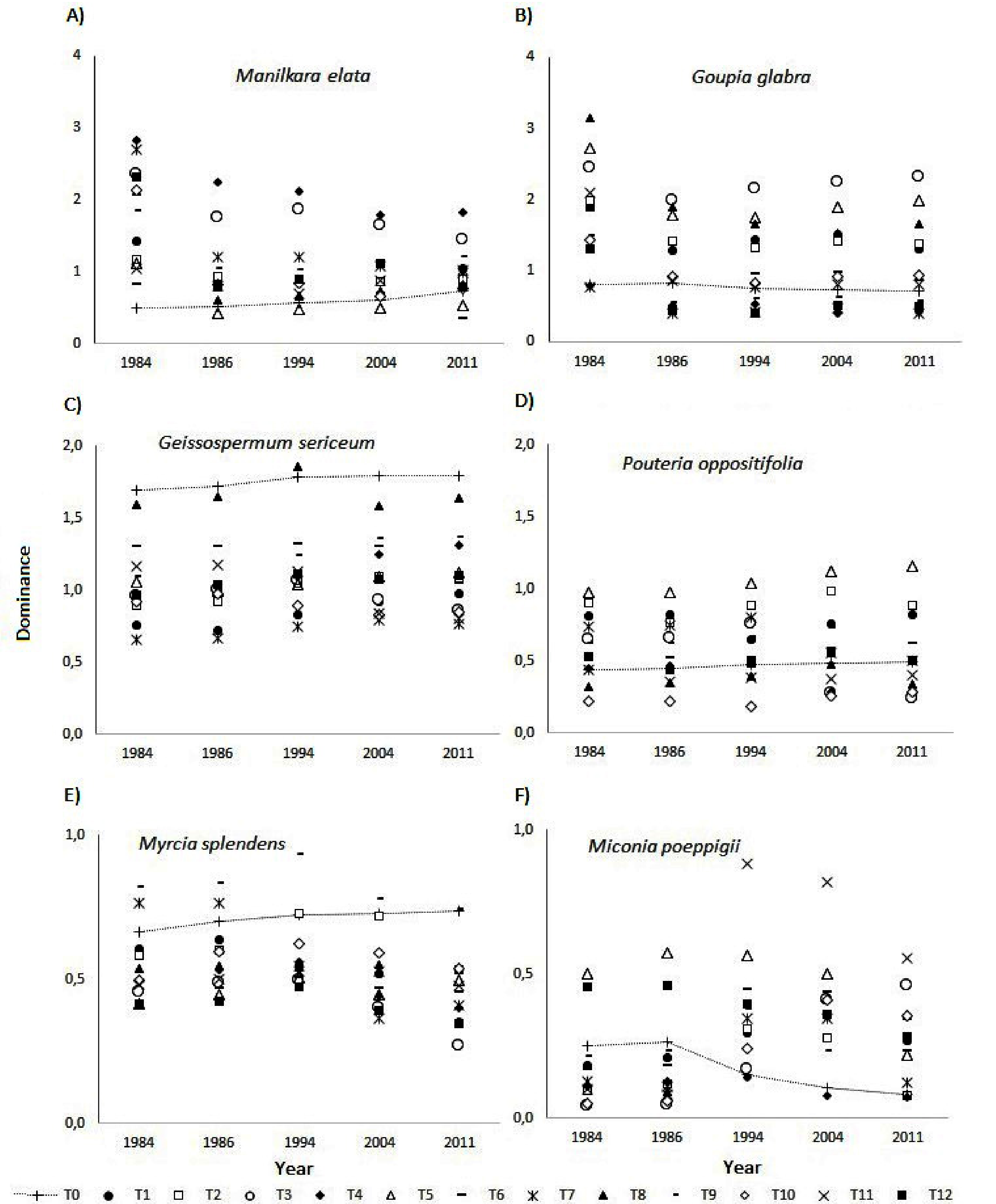

Figure 4. Dominance (basal area in m^2 ha^{-1}) of the populations (saplings and trees) more representative logged species (A, B, D) and girdled species (C, E, F) per treatment in a 40 ha sample in five measurements during 27 years of monitoring, in Vitória do Jari, State of Amapá, Brazil.

Table 3. Estimated parameters in the analysis of variance (ANOVA) for structure of the common species (trees; saplings; sticks; seedlings), harvested species and girdled species, according to the intensity of treatment and harvest in a 40 ha sample, during 27 years of monitoring in Vitória do Jari, State of Amapá, Brazil.

	ANOVA	Year	Treat.	Harvest	G-%.	Sp.	SC
Density (common species)	0.0000	0.0000	0.8505^NS	0.6283^NS	0.3819^NS	0.0000	0.0000
Dominance (common species)	0.0000	0.3154^NS	0.5499^NS	*	*	0.0000	0.0000
Density (harvested species)	0.0000	0.0000	*	0.5123^NS	0.5489^NS	0.0000	0.0000
Dominance (harvested species)	0.0000	0.0785^NS	*	0.3838^NS	*	0.0000	0.0000
Density (girdled species)	0.0000	0.0000	0.8208^NS	*	*	0.0000	0.0000
Dominance (girdled species.)	0.0000	0.6031^NS	0.5636^NS	*	*	0.0000	0.0000

Where: P-value at 95% probability; year = 1984, 1986, 1994, 2004 and 2011; treatment = harvest intensity + thinning intensity; harvest = 0, 15, 25 and 35%; size classes (tree, sapling, stick and seedling); * = variable not included in the model treat. = treatment; G-% = percentage of basal area reduction; SC = size classes; NS = not significant.

Discussion

Only 15 species (4.36%), considering all species in the forest community occurred in all treatments, demonstrating the large natural heterogeneity in the area (Table 2). According to Salomão et al. (2007) and Procopio et al. (2010), "terra firme" rain forests in Amazon have high natural diversity, even in small areas, as it was found in the present study. According to Alves & Miranda (2008), some species show low density in some areas but are abundant in others. This variability should be considered in forest management plans. Furthermore, we also recommend to include peculiar characteristics of each forest community and each tree species population in the forest management plans.

Although intensely harvested, *Manilkara elata* remained among the most important species in the community due to its high density, tending to have a basal area greater than that from the first cut after the establishment of its natural regeneration. Pinheiro et al. (2021), in a study carried out in the same area, claim that this species can be selected for a second harvest, due to the great abundance of individuals and its growth rate.

The reduced impact logging and post-harvesting silvicultural treatments, even causing canopy opening, did not influence the establishment and dynamics of the common species as well as the harvested species and the girdled species. In general, the timber harvest produces more damage to the remnant forest than the girdling (Sandel & Carvalho, 2000). In the present study, timber harvest plus silvicultural treatments together, as well as separately, caused no significant changes in the populations of the studied species (Table 3).

The different species establishment patterns, even for those belonging to the same ecological group, make difficult to recommend silvicultural treatments in tropical forests (Jardim et al., 2007). In the present study, the establishment of common species populations did not occur according to the treatments, contrasting to the results obtained by Andrade et al. (2015) who reported that common species, those with higher importance values index (IVI) in the community, had tendency to success for establishment in disturbed areas.

On the other hand, in a study carried out in the same reduced impact logging area, Pinheiro et al. (2021) studied the potential of commercial species using IVI, concluded that some species, previously considered non-commercial, showed commercial potential. These results confirm the study carried out by Castro et al. (2021) in Tapajós National Forest. The authors mentioned that the considered volume at the current Brazilian forest management regulations (30 m^3 ha^{-1} in a 35-years cutting cycle), could be harvested when new species, not logged in the first cut, were included in the new species logging list. The harvest of trees by itself sometimes is not enough to guarantee high growth rates for commercial species and to guarantee the stock of volume for future cycles. Thus, the application of silvicultural treatments can help to get a sustainable yield, resulting in a high timber volume percentage after the first cutting cycle (Peña-Claros et al., 2008). However, thinning was not significant for any variable analyzed (Table 3), indicating that harvest and thinning did not influence those variables.

About half of the common species had their trees girdled, however the effectiveness of girdling was 65%, mainly due to trees with peculiar stem characteristics, as *Geissospermum sericeum* and *Mouriri collocarpa*, which according to Azevedo et al. (2012) present low mortality. In general, girdled trees died slowly causing a progressive canopy open, minimizing damage to the forest community. This fact plus the low effectiveness (65%) of the silvicultural treatments reflected the low basal area of the more representative girdled species, resulting in no significance in the statistical analyses (Table 3).

The harvest as well as the silvicultural treatments caused no significant influence on the population structure of the main tree species, suggesting that the establishment of the common species, logged or girdled, was due to natural changes. The solar radiation into gaps allows the establishment of natural regeneration of tree species (Mendes et al., 2013). The gaps created by logging close gradually when the competition process begins (Chazdon, 2008). In the present study, the canopy closing process occurred until nine years after logging, when the thinning was applied.

In a closed forest, Mendes et al. (2012) observed that twelve years after logging the canopy gaps were reduced causing changes in the forest understory, suggesting the application of silvicultural treatments. But in the present study, nine years after logging, the application of silvicultural treatments caused no significant effects on the forest dynamics, possibly due to the low effectiveness of related treatments described by Azevedo et al. (2012).

Azevedo et al. (2008b) found significant difference in basal area immediately after logging and also after the application of silvicultural treatments. However, they did not find significant difference between statistical treatments for the commercial species group in all the monitored period (first 20 years after logging). In the present study, 27 years after logging the estimated basal area of common species also had no significant changes (Table 3).

The results of the estimated basal area and density found in the present study disagree with those found by Sist & Ferreira (2007), who stated that reduced impact logging, when applied alone, is not enough to maintain the sustainability in the Amazonian forests. Azevedo et al. (2008b) in the same area of the present study found that logging did not change the ecological functions of the species in the forest, neither improved the trees growth of commercial species, tending to led to cutting cycles longer than 30 years. However, the authors considered only the species harvested in the first logging, although they should consider the entrance of new species, from the common species group.

The selection of the new commercial species which were not cut in the first logging brings the possibility to compose the new cut cycle, since this group showed a significant increase in biomass in logged areas (Wadsworth & Zweede, 2006; De Avila et al., 2017; Carneiro, et al. 2019; Castro et al., 2021).

The abundance and volume of some species in an experimental area at the Tapajós National Forest were benefited by logging, according to analysis by Reis et al. (2010) 28 years after logging, although the main harvested species did not recover their density and volume in that period. In general, the harvested species had the number of trees reduced, even with the forest biomass recover. These authors concluded that a second harvest could be performed 30 years after the first, but cutting trees from those dominant species, which were not cut in the first logging.

We have to emphasize that in the present study we included individuals from seedlings class, so the density of natural regeneration is more significant than the density from the other classes. According to Londe et al. (2015), as greater is the canopy open as greater will be the recruitment of individuals from natural regeneration, which is responsible by the majority of the forest population in any development stage of the forest. However, the effects of canopy open on natural regeneration in the present study were not significant for the common species, harvested species and girdled species (Table 3).

The study results indicate that the research hypothesis was not accepted because the main forest structure parameters related to common species, harvested species and girdled species were not statistically significant (Table 3). Therefore, the treatments with high basal area reduction did not change the population structure of the main species evaluated in the forest.

Conclusions

The forest structure under management did not show significant changes even in the treatment areas where the trees basal area reduction was higher; so, there was no significant influence on the establishment of the main species in the area and in dynamics of the remnant logged forest.

Conflict of interest

The authors have no conflict of interest to declare.

Authors' Contributions

Fernanda da Silva Mendes: conceptualization; formal analysis; investigation; methodology; writing – original draft, review & editing.

Renildo Medeiros da Silva: formal analysis; writing – original draft, review & editing.

Ademir Roberto Ruschel: conceptualization; formal analysis; investigation; methodology; supervision; writing – review & editing.

João Olegário Pereira de Carvalho: conceptualization; formal analysis; investigation; methodology; supervision; writing – review & editing.

Aurélio Lourenço Rodrigues: formal analysis; methodology.

Sebastião do Amaral Machado: supervision.

Afonso Figueiredo Filho: supervision.

Origem do artigo: O artigo é originado de parte da Tese da Drª. Fernanda da Silva Mendes, cujo título é "Dinâmica de espécies arbóreas e arbustivas sob manejo florestal madeireiro, durante 27 anos, em uma floresta ombrófila densa no estado do Amapá, Brasil" – Universidade Federal do Paraná (UFPR) – 2016.

References

Alvares, C. A. et al. Köppen's climate classification map for Brazil. **Meteorologische Zeitschrift**, v. 22, n. 6, p. 711-728, 2013. https://doi.org/10.1127/0941-2948/2013/0507.

Alves, J. C. Z. O. & Miranda, I. de S. Análise da estrutura de comunidades arbóreas de uma floresta amazônica de Terra Firme aplicada ao manejo florestal. **Acta Amazonica**, v. 38, n. 4, p. 657-666, 2008. http://dx.doi.org/10.1590/S0044-59672008000400008.

Andrade, D. F. et al. Inventário florestal de grandes áreas na Floresta Nacional do Tapajós, Pará, Amazônia, Brasil. **Biota Amazônia**, v. 5, n. 1, p. 109-115, 2015. http://dx.doi.org/10.18561/2179-5746/biotaamazonia.v5n1p109-115.

APG III. The Angiosperm Phylogeny Group. An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG III. **Botanical Journal of the Linnean Society**, v. 161, n. 2, p. 105-121, 2009. https://doi.org/10.1111/j.1095-8339.2009.00996.x.

Azevedo, C. P. et al. Efeito da exploração de madeira e dos tratamentos silviculturais no agrupamento ecológico de espécies. **Floresta**, v. 38, n. 1, p. 53-69, 2008a. http://dx.doi.org/10.5380/rf.v38i1.11027.

Azevedo, C. P. et al. Efeito de diferentes níveis de exploração e de tratamentos silviculturais sobre a dinâmica da floresta remanescente. **Floresta**, v. 38, n. 2, p. 277-293, 2008b. http://dx.doi.org/10.5380/rf.v38i2.11622.

Azevedo, C. P. et al. Eficiência de tratamentos silviculturais por anelamento na floresta do Jari, Amapá. **Floresta**, v. 42, n. 2, p. 315-324, 2012. http://dx.doi.org/10.5380/rf.v42i2.17610.

Botrel, R. T. et al. Avaliação de um método de análise silvigênica em uma Floresta Estacional Semidecidual. **Ciência Florestal**, v. 23, n. 2, p. 391-402, 2013. https://doi.org/10.5902/198050989284.

Brasil. Instrução Normativa do Ministério do Meio Ambiente nº 5 de 11 de dezembro de 2006. Dispõe sobre procedimentos técnicos para elaboração, apresentação, execução e avaliação técnica de Planos de Manejo Florestal Sustentável PMFS nas florestas primitivas e suas formas de sucessão na Amazônia Legal. **Diário Oficial [da] República Federativa do Brasil**, Brasília, DF, n. 238, seção I, p. 155-159, 13 dez. 2006.

Brasil. Lei nº. 12.651, de 25 de maio de 2012. Dispõe sobre a proteção da vegetação nativa; altera as Leis nº. 6.938, de 31 de agosto de 1981, 9.393, de 19 de dezembro de 1996, e 11.428, de 22 de dezembro de 2006; revoga as Leis nº. 4.771, de 15 de setembro de 1965, e 7.754, de 14 de abril de 1989, e a Medida Provisória n°. 2.166-67, de 24 de agosto de 2001; e dá outras providências. **Diário Oficial [da] República Federativa do Brasil**, Brasília, DF, 25 maio 2012.

Brasil. Resolução CONAMA (Conselho Nacional do Meio Ambiente) n° 406, de 2 de fevereiro de 2009. Estabelece parâmetros técnicos a serem adotados na elaboração, apresentação, avaliação técnica e execução de Plano de Manejo Florestal Sustentável-PMFS com fins madeireiros, para florestas nativas e suas formas de sucessão no bioma Amazônia. **Diário Oficial [da] República Federativa do Brasil**, Brasília, DF, n. 26, seção I, p. 100, 6 fev. 2009.

Carneiro, F. S. et al. Resiliência do volume de madeira de espécies comerciais em diferentes áreas experimentais na Amazônia Oriental. **Revista Ibero-Americana de Ciências Ambientais**, v. 10, n. 6, p. 15-31, 2019. http://doi.org/10.6008/CBPC2179-6858.2019.006.0003.

Carreño-Rocabado, G. et al. Effects of disturbance intensity on species and functional diversity in a tropical forest. **Journal of Ecology**, v. 100, n. 6, p. 1453-1463, 2012. https://doi.org/10.1111/j.1365-2745.2012.02015.x.

Carvalho, J. O. P. et al. **Pesquisas com vistas ao manejo de matas nativas na região do Rio Jari**.Belém: Embrapa-CPATU, 1987. 21 p. (EMBRAPA-CPATU, Documentos, 45).

Castro, T. C. et al. The continuous timber production over cutting cycles in the Brazilian Amazon depends on volumes of species not harvested in previous cuts. **Forest Ecology and Management**, v. 490, p. 119124, 2021. https://doi.org/10.1016/j.foreco.2021.119124.

Chazdon, R. L. Chance and determinism in tropical forest succession. In: Carson, W. P.; Schnitzer, S. A. (ed.). **Tropical forest community ecology**. Oxford: Wiley-Blackwell, 2008. p. 384-408.

Costa, D. H. M. et al. Efetividade e custo do desbaste com aplicação de arboricida em floresta natural na região do Tapajós, Pará e Jarí, Amapá. In: Silva, J. N. M. et al. (ed). **A silvicultura na Amazônia Oriental**: contribuições do projeto Embrapa/DFID. Belém: Embrapa Amazônia Oriental, 2001. p. 339-352.

Curtis, J. T. & McIntosh, R. P. An upland forest continuum in the prairie-forest border region of Wisconsin. **Ecology**, v. 32, n. 3, p. 476-496, 1951. https://doi.org/10.2307/1931725.

De Avila, A. L. et al. Recruitment, growth and recovery of commercial tree species over 30 years following logging and thinning in a tropical rain forest. **Forest Ecology and Management**, v. 385, p. 225-235, 2017. http://dx.doi.org/10.1016/j.foreco.2016.11.039.

Guisan, A. et al. Generalized linear and generalized additive models in studies of species distributions: setting the scene. **Ecological Modelling**, v. 157, n. 2, p. 89-100, 2002. https://doi.org/10.1016/S0304-3800(02)00204-1.

Guisan, A. & Zimmermann, N. E. Predictive habitat distribution models in ecology. **Ecological Modelling**, v. 135, n. 2-3, p. 147-186, 2000. https://doi.org/10.1016/S0304-3800(00)00354-9.

Hubbell, S. P. Tropical rain forest conservation and the twin challenges of diversity and rarity. **Ecology and Evolution**, v. 3, n. 10, p. 3263-3274, 2013. https://doi.org/10.1002/ece3.705.

IBGE. **Manual técnico da vegetação brasileira**. Rio de Janeiro, 2012. 271 p.

Jardim, F. C. S. et al. Efeito de diferentes tamanhos de clareiras, sobre o crescimento e mortalidade de espécies arbóreas, em Moju-PA. **Acta Amazonica**, v. 37, n. 1, p. 37-48, 2007. http://dx.doi.org/10.1590/S0044-59672007000100004.

Lista de Espécies da Flora do Brasil. Rio de Janeiro: Jardim Botânico, 2015. Avaliable from: http://floradobrasil.jbrj.gov.br/. Access on: 20 april. 2015.

Londe, V. et al. Assessment of a 5-year-old rehabilitated riparian forest: is it already sustainable? **Revista Árvore**, v. 39, n. 4, p. 603-610, 2015. http://dx.doi.org/10.1590/0100-67622015000400002.

Matos, D. C. L. et al. Influence of geographical distance in richness and composition of tree species in a tropical rain forest in eastern Amazônia. **Rodriguésia**, v. 64, n. 2, p. 357-367, 2013. http://dx.doi.org/10.1590/S2175-78602013000200012.

Mendes, F. S. et al. Dinâmica da composição florística do sub-bosque em floresta tropical manejada, no município de Moju, estado do Pará, Brasil. **Revista de Ciências Agrárias**, v. 55, n. 2, p. 117-123, 2012. http://dx.doi.org/10.4322/rca.2012.050.

Mendes, F. S. et al. Dinâmica da estrutura da vegetação do sub-bosque sob influência da exploração em uma floresta de terra firme no município de Moju–PA. **Ciência Florestal**, v. 23, n. 2, p. 377-389, 2013. https://doi.org/10.5902/198050989283.

Moro, M. F. & Martins, F. R. Métodos de levantamento do componente arbóreo-arbustivo. In: Felfili, J. M. et al. (org.). **Fitossociologia no Brasil**: métodos e estudo de caso. v. 1. Viçosa, MG: Ed. UFV, 2013. v. 1, p.174-212.

Oliveira, L. C. et al. Efeito da exploração de madeira e tratamentos silviculturais sobre a estrutura horizontal de uma área de 136 ha na Floresta Nacional do Tapajós, Belterra – Pará. **Revista de Ciências Agrárias**, v. 46, p. 195-214, 2006.

Peña-Claros, M. et al. Beyond reduced-impact logging: Silvicultural treatments to increase growth rates of tropical trees. **Forest Ecology and Management**, v. 256, n. 7, p. 1458-1467, 2008. https://doi.org/10.1016/j.foreco.2007.11.013.

Pinheiro, K. A. O. et al. Potential of commercial species analyzed by the importance value index in a reduced impact exploration area. **Research, Society and Development**, v. 10, n. 2, p. e16610212292, 2021. https://doi.org/10.33448/rsd-v10i2.12292.

Procópio, L. C. et al. As espécies de tauari (Lecythidaceae) em florestas de terra firme da Amazônia: padrões de distribuição geográfica, abundâncias e implicações para a conservação. **Acta Botanica Brasilica**, v. 24, n. 4, p. 883-897, 2010. https://doi.org/10.1590/S0102-33062010000400002.

Reis, L. P. et al. Avaliação do potencial madeireiro na Floresta Nacional do Tapajós após 28 anos da exploração florestal. **Pesquisa Florestal Brasileira**, v. 30, n. 64, p. 265-281, 2010. https://doi.org/10.4336/2010.pfb.30.64.265.

Salomão, R. de P. et al. As florestas de Belo Monte na grande curva do rio Xingu, Amazônia Oriental. **Boletim do Museu Paraense Emílio Goeldi, Ciências Naturais**, v. 2, n. 3, p. 55-153, 2007. https://doi.org/10.46357/bcnaturais.v2i3.696.

Sandel, M. P. & Carvalho, J. O. P. de. Anelagem de árvores como tratamento silvicultural em florestas naturais da Amazônia Brasileira. **Revista de CiênciasAgrárias**, n. 33, p. 9-32, 2000.

Schulze, M. & Zweede, J. Canopy dynamics in unlogged and logged forest stands in the eastern Amazon. **Forest Ecology and Management**, v. 236, n. 1, p. 56-64, 2006. https://doi.org/10.1016/j.foreco.2006.08.333.

Schwartz, G. et al. Enrichment planting in logging gaps with *Schizolobium parahyba* var. *amazonicum* (Huber ex Ducke) Barneby: afinancially profitable alternative for degraded tropical forests in the Amazon. **Forest Ecology and Management**, v. 390, n. 1, p. 166-172, 2017. https://doi.org/10.1016/j.foreco.2017.01.031.

Sist, P. & Ferreira, F. N. Sustainability of reduced-impact logging in the Eastern Amazon. **Forest Ecology and Management**, v. 243, n. 2, p. 199-209, 2007. https://doi.org/10.1016/j.foreco.2007.02.014.

Souza; D. V. et al. Crescimento de espécies arbóreas em uma floresta natural de terra firme após a colheita de madeira e tratamentos silviculturais, no município de Paragominas, Pará, Brasil. **Ciência Florestal**, v. 25, n. 4, p. 873-883, 2015. http://dx.doi.org/10.5902/1980509820585.

Steege, H. ter. et al. Hyperdominance in the Amazonian Tree Flora. **Science**, v. 342, n. 6156: 1243092, 2013. http://dx.doi.org/10.1126/science.1243092

Svenning, J. C. Small canopy gaps influence plant distributions plant distributions in the rain forest understory. **Biotropica**, v. 32, n. 2, p. 252-261, 2000. https://doi.org/10.1111/j.1744-7429.2000.tb00468.x.

TROPICOS.org. **Missouri Botanical Garden**. Avaliable from:http://www.tropicos.org. Access on: May, 16, 2015.

Vieira, D. dos S. et al. Estrutura populacional e padrão de distribuição espacial de *Pouteria cladantha* Sandwith em uma floresta sob regime de manejo sustentável, Pará. **Biota Amazônia,** v. 4, n. 3, p. 42-47, 2014. http://dx.doi.org/10.18561/2179-5746/biotaamazonia.v4n3p42-47.

Wadsworth, F. H. & Zweede, J. C. Liberation: acceptable production of tropical forest timber. **Forest Ecology and Management**, v. 233, n. 1, p. 45-51, 2006. https://doi.org/10.1016/j.foreco.2006.05.072.