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Diversity and similarity of species of natural regeneration after logging in commercially managed forest in Central Amazon

Diversidade e similaridade de espécies da regeneração natural pós-exploração em floresta sob manejo comercial na Amazônia Central

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Abstract

This study aimed to evaluate the medium-term impacts of forest management on natural regeneration in central Amazon forest. The study was conducted in the logged forest belonging to Mil MadeirasPreciosas (Amazonas, Brazil). It was used data from continuous inventories that were carried out in 41 permanent parcels distributed in three Annual Production Units (APU), named APU B, C and D, logged in 1996, 1997 and 1998, respectively. In all units, forest inventories were carried out before logging and in the years 2001 and 2014; for APU B there was an additional inventory in 1998. The sample included trees with diameter at breast height between 5 cm and 14.9 cm. The species diversity analysis was performed by Shannon (H') and Pielou (J) indexes and the similarity analysis by Jaccard index and cluster analysis. The analyzes were made for all grouped species and commercial species group. A total of 8,090 trees families were sampled, distributed in 244 species and 48 families. Shannon index ranged from 3.77 to 4.08; Pielou index ranged from 0.74 to 0.84. There was a significant difference between H' for all species in two APUs 16 and 18 years after logging. There was significant difference between H' for commercial species before and 16 and 18 years after logging. Jaccard indexes ranged from 66.7% to 100%. The largest differences for the species composition were observed between pre-exploration inventories and the last measurement. Diversity and composition of species in the natural regeneration in the logged forest changed in a period by 16, 17 and 18 years after logging.

Keywords: Forest management; Species composition; Regenerative dynamics

Resumo

O objetivo deste estudo foi avaliar os impactos de médio prazo do manejo florestal na regeneração natural em floresta na Amazônia Central. O estudo foi conduzido na área de manejo da empresa Mil Madeiras Preciosas (Amazonas, Brasil). Foram utilizados inventários contínuos realizados em 41 parcelas permanentes distribuídas em três Unidades de Produção Anual (UPA), denominadas UPAs B, C e D, exploradas em 1996, 1997 e 1998, respectivamente. Em todas as unidades foram realizados inventários antes da exploração e nos anos de 2001 e 2014; para a UPA B houve um inventário adicional no ano de 1998. O nível de inclusão neste estudo foram árvores com diâmetro à altura do peito entre 5 cm e 14,9 cm. A análise de diversidade de espécies foi realizada considerando os índices de Shannon (H') e Pielou (J).A análise de similaridade considerou o índice de Jaccard e análises de agrupamentos. As análises foram feitas para todas as espécies agrupadas e para grupo comercial de espécies. Foram amostrados um total de 8.090 indivíduos distribuídos em 244 espécies e 48 famílias. O H' variou de 3,77 a 4,08; o J variou de 0,74 a 0,84. Houve diferença significativa entre H' para o conjunto de todas as espécies nas UPAs B e D, 18 e 16 anos após exploração, respectivamente. Houve diferença significativa entre H' de espécies comerciais em duas unidades (C e D), 17 e 18 anos após a exploração. Os índices de Jaccard variaram de 66,7% a 100,0%. As maiores diferenças para composição de espécies foram observadas entre os inventários pré-exploração e a última medição. A regeneração natural da floresta sob manejo florestal sofreu alterações na diversidade e composição de espécies no período de 16, 17 e 18 anos após a exploração.

Palavras-chave: Manejo florestal; Composição de espécies; Dinâmica de regenerantes

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Introduction

The Amazon is the largest forest on the planet. According to estimates, it houses more than 12,000 species of trees (TER STEEGE *et al*., 2013).Its total wood volume is around 85 billion cubic meters, which represents 87% of the total forests in Brazil. Moreover, it has a huge diversity of environments, with about 600 different types of terrestrial and freshwater habitats (SERVIÇO FLORESTAL BRASILEIRO, 2013). All this heterogeneity of species and sites is a great challenge for those who want to manage the Amazon rainforest. A greater application of silvicultural treatments could improve management results in tropical native forests (GÜNTER *et al*., 2012). Sustainable development in these regions will occur mainly in areas with some level of anthropogenic influence whether from business activities or from traditional populations. In this sense, forest scientists consider silvicultural interventions as tools capable of effectively conserving biodiversity and ecosystem services, stimulating forest production (PETROKOFSKY *et al*., 2015).

To combine the use of forest resources with the conservation of the original biodiversity, management practices cannot cause substantial or long-term changes in the composition and diversity of species at other trophic levels. So far, there is little information about the limits of the intensity of intervention and the changes resulting from these activities on the forest. Studies point to the use of different species as a way of diversifying production, reducing pressure on certain species, and promoting sustainable management. These studies found that the species harvested in the first cutting cycle do not recover to offer wood with the same quality in the second cycle (AVILA *et al*. 2015; 2017; RICHARDSON; PERES, 2016).

Ecosystem disturbances, whether natural or man-made, are important for understanding the coexistence of plant species and the spatial patterns of composition and diversity. As the frequency, size, or intensity of the disturbance decreases, the floristic diversity increases. Subsequently, this diversity decreases as the composition of the community changes from a large number of individuals of species with greater aptitude for colonization to a higher abundance of competing species (CONNELL, 1978). Both natural and anthropic factors affecting the ecosystem can influence the regeneration and floristic composition of a forest.

In this sense, the focus of the discussion is again the knowledge about the natural regeneration of the different forest ecosystems. Correct decision making in management involves understanding the processes that govern forest succession (CHAZDON, 2013). Natural regeneration does not guarantee that, after harvesting a tree of commercial interest, the open clearing will be colonized by the same species or by another species of equal commercial interest. This leads to a low recovery of wood stocks within a cutting cycle. This dynamic provides an environment different from the first which managers must consider in decision making (AVILA *et al*., 2015). There is a large information gap regarding the remaining forest stand. During management, after choosing the species of interest, the professionals define the minimum inventory level, which the law determines to be only 10 cm below the cutting diameter (currently 50 cm). Thus, little is known about the impact of forestry on the remaining forest in individuals with diameters below 40 cm.

Given the above, this study evaluates the medium-term impacts of commercial forest management on the diversity and composition of species of natural regeneration (treelets with diameter at breast height between 5 cm and 14.9 cm) remaining in a dense ombrophilous forest in Central Amazon. For this analysis, we propose two hypotheses: i) forest intervention does not affect the diversity of species of natural regeneration over time; ii) forest logging does not affect the composition of species of natural regeneration.

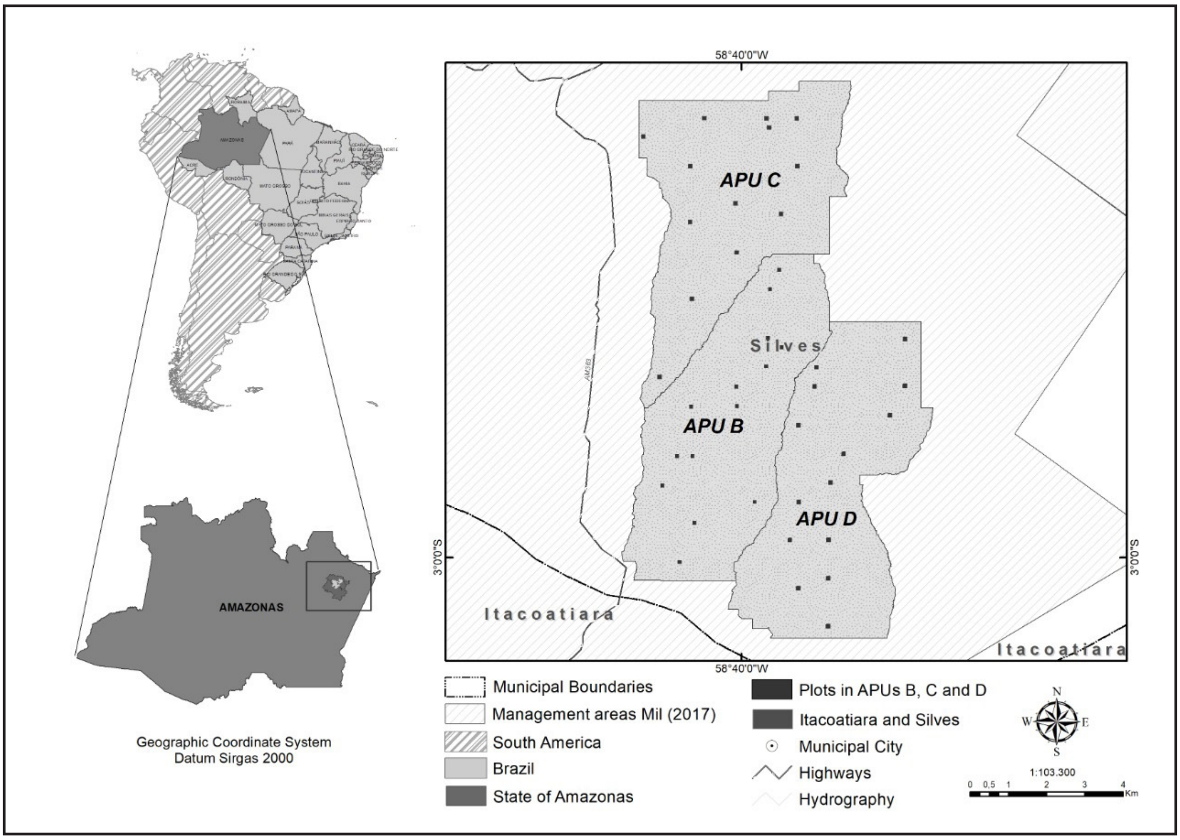
Materials and methods

Study area

We conducted the study at the Dois Mil farm, a forest managed area belonging to the company Mil Madeiras Preciosas Ltda., located between parallels 2°43' and 3°04' S and 58°31'and 58°57' W (Figure 1).

Figure 1 – Study area: Mil Madeiras Preciosas. Highway AM – 363, Km 01, Itacoatiara – AM state, Brazil

Figura 1 – Área de estudo: Mil Madeiras Preciosas. Rodovia AM – 363, Km 01, Itacoatiara – AM, Brasil



Source: Authors (2019)

The area consists of Dense Ombrophilous Forest of Terra Firme, with large arboreal individuals, woody lianas, and epiphytes (IBGE, 2012). According to the Köppen classification, the climate of the region is Am (rainy tropical monsoon). The average annual rainfall ranges between 1,355 and 2,839 mm. The wettest months are December to May, and the driest months are August to November. Monthly rainfall is never less than 50 mm. The average temperature ranges from 25.6°C to 27.6°C, with average relative air humidity between 84% and 90%. The predominant soils in the area are Yellow Latosol, with a very clayey texture, and hydromorphic soils, covered predominantly by dense lowland forest vegetation, with emergent canopy (IBGE, 1999).

Sampling units

The sampling units (SU) are permanent plots installed in the respective annual production units (APUs) where continuous forest inventories are implemented to monitor post-logging forest dynamics. APUs B, C, and D have, respectively, 14, 13, and 14 permanent plots, totaling 41 SU. These units have the standard dimensions of 100 m x 100 m, subdivided into 100 subplots of 10 m x 10 m, and were randomly allocated in each APU.

The sampling units are not free from forest intervention, capturing activities common to forest management such as: cutting trees; opening roads; trails; and landings, which influence natural regeneration (HIRAI *et al*., 2012). Logging intensity within the sampling units was: 39.45 m^3 ha^{-1} (APU B); 13.85 m^3 ha^{-1} (APU C); 29.17 m^3 ha^{-1} (APU D). Considering the subplots within the SU, logging affected mostly APU C, which had 10 subplots affected by skid roads and two by landings. Thus, opening of infrastructure affected mostly this APU, although it had fewer trees cut. The other APUs had only one subplot affected in each unit, one by branch opening (APU B) and the other by skid road (APU D).

Database

This study used data from continuous forest inventories conducted in the following years: i) APU B in 1996 (pre-logging), 1998, 2001, and 2014; ii) APU C in 1997 (pre-logging), 2001, and 2014; iii) APU D in 1998 (pre-logging), 2001, and 2014. In these inventories, data collection followed the methodology described by Silva and Lopes (1984). Thus, initially, 20 subplots were randomly drawn within each 1 ha plot, making a total of 820 subplots (280 subplots in APU B, 260 in APU C, and 280 in APU D), with a total sampled area of 8.2 hectares for natural regeneration.

Regarding diameter at breast height (DBH), all individuals within the drawn subplots have 5 cm ≤ DBH <15 cm, being classified as treelets. These treelets received identification plates with continuous numbering, which restarts with each new measuring of subplots. Botanical identification took place at the species level, with verification of the names on the Missouri Botanical Garden public database. We revised and updated the botanical classification of each species according to the Brazilian Biodiversity Information System (SiBBr).We grouped the species into two groups: total species and commercial species.

Data analysis

Floristic diversity

We analyzed the floristic diversity of the community from the calculations of the Shannon diversity index (H') and Pielou evenness (J). Considering that the Shannon index calculation usessampledata and that each set of plots has its respective diversity value according to the year of inventory, we conducted the Student t-test, as proposed by Magurran (1988), to test the following hypotheses:

H0: species diversity has not changed over the years;
H1: the compared communities have different diversities.

Species similarity

To analyze species similarity, we calculated the Jaccard index (S_j). We conducted pair wise analyses for the inventories, comparing a previous and a later inventory for the analyzed years in each APU. To exemplify, for APU B, we analyzed the similarity between species identified in the inventory of the year 1996 (pre-logging) and those identified in all other inventories after logging (1998, 2001, 2014).

A proper assessment of the similarity between the different years of measurement requires multivariate data analysis. Therefore, we used Nonmetric Multidimensional Scaling (NMDS) techniques for simpler ordering and visualization of data dimensions. In the graph resulting from this method, each color, figure, and label represents the data collections in each different year, and each point represents a plot. In this way, there is a graphic representation of the 41 plots for all inventories conducted in the three units.

Results and discussion

Floristic composition

We sampled a total of 8,090 individuals, distributed in 244 species and 48 botanical families (results referring to all inventories) (Table 1). The number of total families per APU did not differ significantly. APU D maintained the number of families from the initial measurement, and only APU B had an increase of 2 families 18 years after the first measurement. Regarding the number of species and number of individuals, only APU B accounted for an increase between the first and the last measurement.

Table 1 – Number of families, species, and individuals per APU at the first, second, and last measurement in a logged forest in Central Amazon

Tabela 1 – Número de famílias, espécies e indivíduos por UPA nas ocasiões da primeira, segunda e última medição em floresta manejada na Amazônia Central

APU	First measurement			Second measurement			Last measurement		
	Families	Species	NI	Families	Species	NI	Families	Species	NI
B	41	117	1661	42	116	1348	43	125	1895
C	36	145	1985	35	125	1594	35	125	1793
D	38	143	1785	37	126	1349	38	139	1757

Source: Authors (2019)

Where: APU = Annual Production Unit. NI = Number of individuals. First measurement: B - 1996, C - 1997, D - 1998; Second measurement: B - 1998, C and D - 2001; Last measurement: B, C, and D - 2014.

The families that presented the largest number of species in the three measurements were: Lauraceae (40 species), Fabaceae (39), Lecythidaceae (28), Myrtaceae (26), Sapotaceae (18), and Annonaceae (10). The family Cecropiaceae had six species, and another six families had five species: Apocynaceae, Burseraceae, Chrysobalanaceae, Malvaceae, Moraceae, and Myristicaceae. The other families had less than five species.

The area under study is a tropical forest, thus the values presented in Table 1 show a wide variety of tree species and families, in addition to a high abundance in their populations. Studies that address species composition in managed forests corroborate these values. Vieira *et al.* (2014) identified 172 species and 40 families in their survey, with some families in common with the present study, as those with the largest number of species: Fabaceae, Sapotaceae, Moraceae, Lecythidaceae, and Apocynaceae. Jardim and Quadros (2016) evaluated the composition of species of natural regeneration over an interval of nine and a half years of forest intervention; these authors found that the number of species increased from 230 to 266. Mendes *et al.* (2013) observed two families in common as the most representative for natural regeneration: Burseraceae and Lecythidaceae. These factors reinforce the biodiversity richness of the Amazon rainforest, which has an immeasurable potential and environmental value.

Table 2 shows the variation of species with the highest number of individuals in the first and last inventory. Of the total species, five stand out for their occurrence in all APUs: *Licania heteromorpha*, *Protium paniculatum*, *Guatteria procera*, *Perebea guianensis*, and *Licaria rigida*. Furthermore, five species among those listed are considered of commercial interest for timber management (*Protium paniculatum*, *Licaria rigida*, *Ocotea fragrantissima*, *Protium puncticulatum*, and *Eschweilera coriacea*) (SILVEIRA, 2019). This indicates the importance of monitoring this vegetation extract for forest management since these species may compose future cutting cycles.

Among the listed species (Table 2), five new ones appear between the first and the last inventory. Of these, three occurred at APU B, one at APU C, and two at APU D. After an interval of 16 to 18 years, most species consist of ecological groups of slow or moderate growth, of medium or higher canopy, with a single pioneer species – *Pithecellobium cauliflorum* (LIRA, 2011). The main differentiation between species composition in a short interval, right after logging, is due to the initial increase in the density of pioneer species due to the opening of clearings, roads, and landings (AVILA *et al*., 2015). Thus, for this vegetation component (trees with 5 cm ≤ DBH < 15 cm), the time interval under study was sufficient for these slower-growing species to predominate again in the forest community.

TerSteege *et al*. (2013) present the 20 most abundant species in the entire Amazon region, among which *Licania heteromorpha* and *Eschweilera coriacea* are also listed in the present study (Table 2). There are several reports of the latter in the Brazilian Amazon, either in logged (ALMEIDA *et al*., 2012; MENDES *et al*., 2013; JARDIM; QUADROS, 2016; VIEIRA *et al*., 2014) or unlogged forests (SILVA *et al*., 2011; 2015; SOUSA *et al*., 2018). However, this species only entered among the most abundant on a single occasion in the present study (before the logging of APU D). In addition to the differences between communities, the comparison of species occurrence should consider the level of inclusion of other studies. Studies usually consider measuring trees with DBH from 10 cm. Thus, it is clear that, from the limit established in the present study (5 - 14.9 cm), the results for species composition tend to differ from those of other studies. This reinforces the importance of evaluations within this data range to know the succession dynamics of this vegetation component.

Table 2 – Species with the highest number of individuals per APU at the first (pre-logging) and last measurement in a logged forest in Central Amazon

Tabela 2 – Espécies com maior número de indivíduos por UPA nas ocasiões da primeira (pré-exploração) e última medição em floresta manejada na Amazônia

APU	Pre-logging	2014
	Licania heteromorfa Benth. (130)	*Protium paniculatum*(Engl.)(123)
	Perebea guianensis Aubl. (108)	*Licania heteromorpha* Benth. (105)
	Guatteriaprocera R. E. Fr. (106)	*Guatteria procera* R. E. Fr. (101)
	Pouteria platyphylla (A. C. Sm.) Baehni (104)	*Perebea guianensis* Aubl. (88)
	Protium paniculatum (Engl.) (97)	*Pithecellobium cauliflorum* (Willd.) C. Mart. (77)
B	*Ocotea fragrantissima* Ducke. (77)	*Pouteria platyphylla* (A. C. Sm.) Baehni (75)
	Pithecellobium cauliflorum (Willd.) C. Mart. (66)	*Ocotea fragrantissima* Ducke. (71)
	Licaria rigida (Kosterm.) Kosterm. (62)	*Vismia guianensis* (Aubl.) Pers.[2](63)
	Eschweileracollina Eyma[1](50)	*Licaria rigida* (Kosterm.) Kosterm. (62)
	Eugenia patrisii Vahl.[1](50)	*Protium puncticulatum* J. F. Macbr.[2](61)
	Theobroma sylvestre Mart.[1](50)	*Rinorea macrocarpa* (C. Mart. ex Eichler)[2](60)

Continua ...
Continuation ...

Tabela 2 – Conclusão ...
Table 2 – Conclusion ...

APU	Pre-logging	2014
C	*Licania heteromorpha* Benth. (200)	*Licania heteromorpha* Benth. (189)
	Protium paniculatum (Engl.) (142)	*Protium paniculatum* (Engl.) (165)
	Guatteria procera R. E. Fr. (103)	*Guatteriaprocera* R. E. Fr. (87)
	Protium puncticulatum J. F. Macbr. (96)	*Rinorea macrocarpa* (C. Mart. ex Eichler) (84)
	Rinorea macrocarpa (C. Mart. ex Eichler) (95)	*Protium puncticulatum* J. F. Macbr. (71)
	Pouteria platyphylla (A. C. Sm.) Baehni (87)	*Pouteria platyphylla* (A. C. Sm.) Baehni (68)
	Theobroma sylvestre Mart. (85)	*Perebea guianensis* Aubl. (68)
	Perebea guianensis Aubl. (80)	*Theobroma sylvestre* Mart. (62)
	Eugenia patrisii Vahl. (78)	*Licaria rigida* (Kosterm.) Kosterm. (50)
	Licaria rígida (Kosterm.) Kosterm. (71)	*Ocotea fragrantissima* Ducke.[2](62)
	Not Identified[1] (71)	*Eugenia patrisii* Vahl. (46)
D	*Licania heteromorpha* Benth. (179)	*Licania heteromorpha* Benth. (165)
	Pouteria guianensis Aubl. (145)	*Pouteria guianensis* Aubl. (90)
	Guatteria procera R.E.Fr.(96)	*Guatteriaprocera* R.E.Fr. (96)
	Not Identified[1] (96)	*Protium paniculatum* (Engl.)(85)
	Protium puncticulatum J. F. Macbr. (88)	*Perebea guianensis* Aubl. (74)
	Perebea guianensis Aubl. (85)	*Protium puncticulatum* J. F. Macbr.(67)
	Ocotea fragrantissima Ducke. (80)	*Rinorea macrocarpa* (C. Mart. ex Eichler) (54)
	Protium paniculatum (Engl.) (76)	*Ocotea fragrantissima* Ducke. (53)
	Eugenia patrisii Vahl. (75)	*Pithecellobium cauliflorum* (Willd.) C. Mart.[2](52)
	Licaria rigida (Kosterm.) Kosterm. (65)	*Eugenia patrisii* Vahl. (50)
	Eschweilera coriacea (DC.) S. A. Mori[1](56)	*Licaria rigida* (Kosterm.) Kosterm. (49)

Source: Authors (2019)

Where: APU = Annual Production Unit. [1]Species among those with the largest number of individuals in the first measurement, but not in the last; [2]Species among those with the largest number of individuals in the last measurement, but not in the first.

Diversity

The Shannon index ranged from 3.77 to 4.08 for the total of species. The highest values occurred in the last measurement, which took place in 2014, that is, 16, 17, and 18 years after logging in the respective APUs (Table 3). All units showed an increase in H' over time, in which APU D stood out for the values before logging and in 2014. The group of commercial species showed lower H' values, ranging from 2.60 to 3.01. For this group, only APU D had increasing values, especially between the first and the last measurement.

According to Knight (1975), the Shannon index for Amazonian forests ranges between 3.83 and 5.85, which is a high value. Studies in both logged and unlogged forests in the Amazon have shown a variation in this index, which may be within the aforementioned range (BEZERRA *et al*., 2018; SILVA *et al*., 2011; VIEIRA *et al*., 2014) or slightly below it (CONDÉ; TONINI, 2013;

LIMA *et al.*, 2012). Table 3 shows that the forest targeted in the present study had Shannon indices within the variation commonly observed for the Amazon region when considering the total of species. The H' values for commercial species were below that range since this group is composed of only 67 species classified by the forestry company with potential for current or future logging. However, the evenness index shows that there is no predominance of one species within this group, in the same way as for the total of species.

Table 3 – Shannon diversity (H') and Pielou evenness (J) for the groups of total and commercial species in APUs B, C, and D in their respective years of forest inventory

Tabela 3 – Índices de diversidade de Shannon (H') e Equabilidade de Pielou (J) para os grupos de espécies totais e comerciais nas UPAs B, C e D, nos seus respectivos anos de inventário florestal

Index	Species	APU B				APU C			APU D		
		1996	1998	2001	2014	1997	2001	2014	1998	2001	2014
H'	Total	3.85	3.86	3.86	4.04	3.77	3.76	3.83	3.77	3.77	4.08
	Com.	3.01	2.99	2.96	2.88	2.73	2.76	2.60	2.83	2.84	2.97
J	Total	0.81	0.81	0.82	0.84	0.76	0.78	0.79	0.76	0.78	0.83
	Com.	0.80	0.79	0.80	0.77	0.75	0.75	0.74	0.77	0.79	0.81

Source: Authors (2019)

Where: APU = Annual Production Unit.

The evenness index remained in a range between 0.74 and 0.84, similar to that of other studies on Amazonian vegetation (ALMEIDA *et al.*, 2012; ROSA-JUNIOR *et al.*, 2015; VIEIRA *et al.*, 2014). This index indicates maximum or minimum dominance of a species, with values ranging from 0 to 1, where 0 indicates that all individuals belong to the same species (minimum diversity), and 1 indicates that each individual belongs to different species (maximum diversity). The values of the present study indicate that at no time and in any specific APU there was dominance of a species in the community. Thus, the area under study is closer to reaching maximum diversity than a possible reduction in that diversity. Only on two occasions was the J value higher for commercial than for total species, namely the pre-logging and first post-logging measurements in APU D. For the total of species, the J index increased over the years in all APUs. For commercial species, this happens only for APU D, whereas in APU B there is an oscillation of growth and decrease, and APU C shows a slight decrease in the measurement of 2014.

Table 4 shows the p values of the Student t-test in the pairwise comparison of Shannon indices calculated for the different years in each APU. For the total population of species, only at APU C there is no significant difference between the calculated H' values. For APUs B and D, the difference relates to comparisons with the index for 2014, showing that in the medium term the diversity of species tends to differ from that observed before logging or even in the first years after these activities. APUs C and D show a significant difference for the group of commercial species. Again, differences relate to comparisons with the indices for the year 2014, whereas APU C shows a significant difference only in the comparison between the years 2001 and 2014.

Forest management altered species diversity in the medium term since most of the comparisons of the indexes for the group of all species showed a highly significant statistical difference ($p<0.001$) in relation to the inventory of the year 2014, except for APU C, in which there was no difference. Areas with less logging impact tend to have greater species diversity (HIRAI *et al.*, 2012; IMAI *et al.*, 2012; SCHWARTZ; FALKOWSKI; PEÑA-CLAROS, 2017). APU

C was the one with the lowest logging intensity within its permanent plots. Notwithstanding, it suffered the greatest impact from the opening of infrastructure for logging within subplots. This factor may explain the statistical nondifferentiation of species diversity for this production unit, resulting in a lower H' value in comparison to the other APUs for 2014.

Table 4 – p values of the Student t-test (α = 0.05) for pairwise comparison of the Shannon index for total and commercial stands in APUs B, C, and D

Tabela 4 – Valores de p, segundo o teste t de Student (α = 0,05), para comparação em pares do índice de Shannon para os povoamentos total e comercial nas UPAs B, C e D

APU	Period	p value	
		Total	Commercial
B	1996-1998	0.824	0.7870
	1996-2001	0.9471	0.4892
	1996-2014	0.03×10^{-4}*	0.0596
	1998-2001	0.8842	0.6846
	1998-2014	0.03×10^{-3}*	0.1254
	2001-2014	0.02×10^{-3}*	0.2706
C	1997-2001	0.7508	0.6312
	1997-2014	0.1727	0.0582
	2001-2014	0.1041	0.0239*
D	1998-2001	0.9989	0.7921
	1998-2014	0.05×10^{-11}*	0.0141*
	2001-2014	0.01×10^{-9}*	0.0380*

Source: Authors (2019)

Where: APU = Annual Production Unit.(*) Significant difference in the Student t-test at 95% significance.

When analyzing the group of commercial species, it is important to consider the dynamics of the p values in each situation (Table 4). APU D was the only one that showed a significant difference in the two comparisons with 2014, following the trend of the group of all species. At APU C, the first post-logging period (1997-2001) does not show a statistical difference between species. For the period 1997-2014 in that same unit, although there is no significance in the p value, it is already closer to the alpha value (α = 0.05). This also occurs in the comparisons for APU B, in which, even though there is no significant difference, the lowest p values take place for comparisons with the year 2014.In addition, the comparisons between the pre-logging inventory (1996) and the three post-logging inventories (1998, 2001, 2014) show a trend of decrease in the p value, which approaches the considered significance, indicating a tendency of differentiation in species diversity over the years.

The company adopted in its management plan a cutting cycle of 35 years. Thus, the periods considered in the present study represent half of that cycle. According to Avila *et al.* (2015), forest management does not affect species diversity in the first 30 years post-logging. Following the trend of the results of the present study, we believe that the diversity indexes will remain at the same level at the second cutting cycle. Moreover, these indexes may, over time, be similar or remain different from those pre-logging. Although permanent plots capture forest management activities, Chaudhary *et al.* (2016) highlight that making decisions about the sustainability of management based solely on the classification of the impacts of alpha diversity may be somewhat erroneous. The authors mention that one must verify the impacts on a regional scale and within the context of heterogeneous landscapes and not just at the plot level.

Similarity

The highest levels of similarity between species occurred for the comparison between the pre-logging inventory and the first post-logging inventory. For the group of commercial species, the similarity is 100% in APUs B and C, and 95% in APU D, which corresponds to the highest value for this unit (Table 5).

Table 5 – Jaccard similarity indices calculated for total and commercial stands in APUs B, C, and D according to the period of analysis

Tabela 5 – Índices de similaridade de Jaccard calculados para a os povoamentos totais e comerciais nas UPAs B, C e D de acordo com o período de análise

UPA	Period	Jaccard (%)	
		Total	Commercial
B	1996-1998	96.64	100.00
	1996-2001	91.60	93.02
	1996-2014	85.50	93.18
	1998-2001	94.83	93.02
	1998-2014	85.38	93.18
	2001-2014	85.04	95.24
C	1997-2001	86.21	100.00
	1997-2014	66.67	82.50
	2001-2014	70.07	82.50
D	1998-2001	88.73	94.87
	1998-2014	71.34	88.10
	2001-2014	76.67	87.80

Source: Authors (2019)

Where: APU = Annual Production Unit.

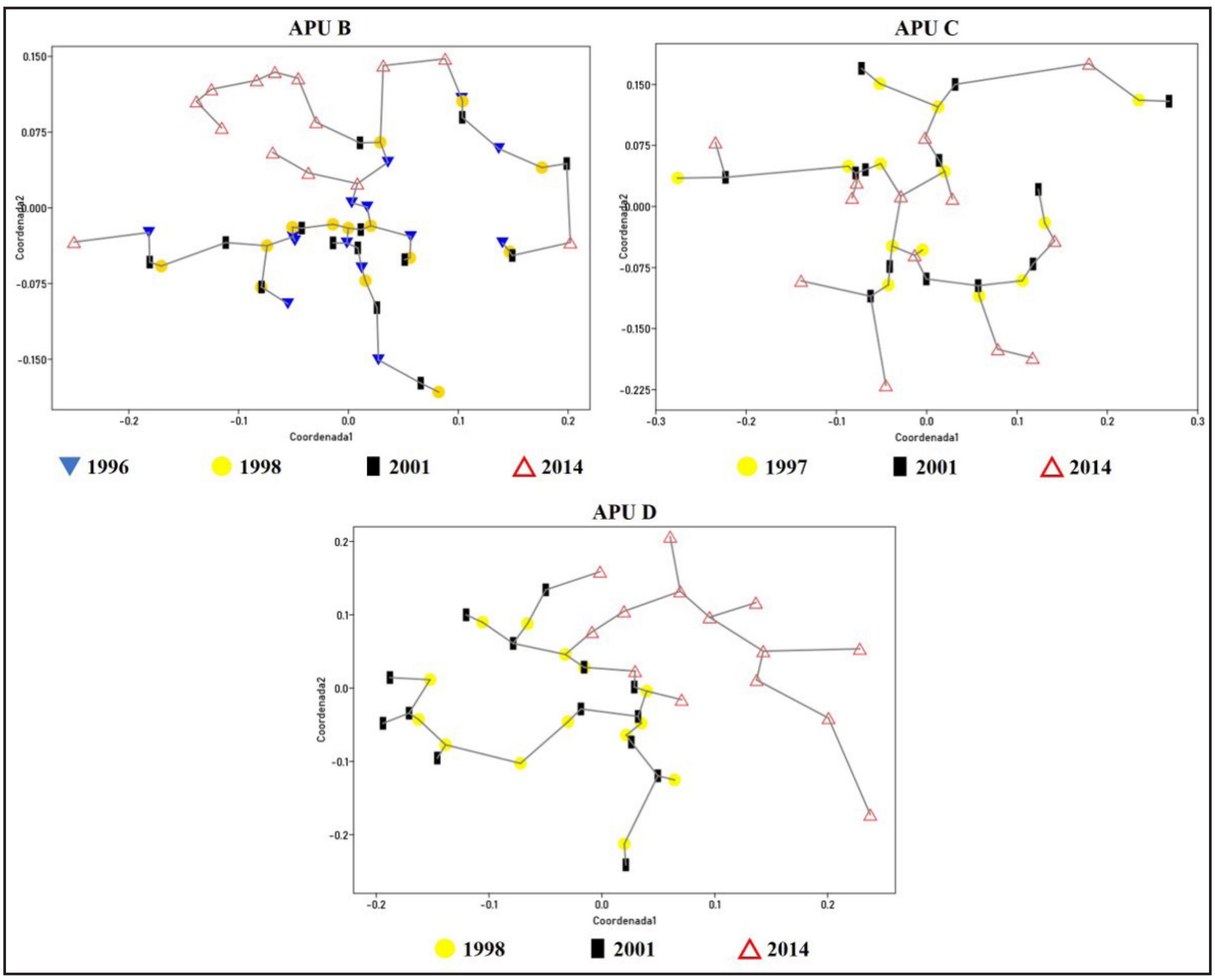
The similarity in species composition between the periods under study is high. However, the comparison between the first and the last inventory in all APUs shows that this similarity tends to decrease in the medium term. This indicates that species composition changes after forest logging. This is mostly clear in APU C, which showed the least similarity for the period 1997-2014, where about 67% of the species are the same in the two measurements considering the total population. For the commercial stand in this APU, similarity decreased from 100% in the first post-logging period to 82.5% in 2014. When comparing the values of post-logging inventories, it appears that these indexes are closer to each other and, in some cases, with an increase in similarity.

There is a tendency for the plots to be grouped according to the year of inventory (Figure

2), with a more pronounced difference for the year 2014 in relation to the initial collections. This shows that, over the years (approximately 17 years after forest logging), the composition of species of natural regeneration tends to differ from that recorded before logging. Avila *et al.* (2015) found a similar result when evaluating a period of 30 years post-logging. According to Avila *et al.* (2017), the decrease in similarity between a pre-logging and a post-logging stand confirms the management effect on species composition. Forest logging can lead domination by generalist species that take advantage of the new conditions to colonize the space provided by the removal of a given tree. However, these changes should not be interpreted as a failure in the adopted silvicultural system since the techniques take place precisely to alter the structure and composition of the forest to favor the remaining commercial species that will be the target of the next cutting cycle.

Figure 2 – Nonmetric Multidimensional Scaling (NMDS) for spatial visualization of the total population in the plots in all years of data collection at APUs B, C, and D according to the Jaccard index

Figura 2 – Escalonamento Multidimensional Não Métrico – NMDS para visualização espacial do povoamento total nas parcelas em todos os anos de coleta de dados nas UPAs B, C e D de acordo com o índice de Jaccard



Source: Authors (2019)

Even with a high similarity index, there is a change in the composition of species of natural regeneration. As with the diversity indexes, APU C presents the lowest values of similarity between species. This confirms the higher level of impact caused by the opening of infrastructure inherent to forestry activities in this area. Prado Junior *et al*. (2014) confirmed the hypothesis that forests under different disturbance intensities differ in floristic composition and diversity. For the authors, the abundance and frequency of some families and species can help in the classification of the stages of conservation of the different forest stands. This is because these disturbances give space for the appearance and/or development of species previously suppressed, changing species composition and diversity.

Logging leads to beneficial effects on natural regeneration for at least the first three years. Logged forests differ from unlogged ones with regard to seedling recruitment, density, and increment, recruitment, and mortality rates. The contrasts occur mainly in the places directly affected with the opening of roads and clearings (DUAH-GYAMFI *et al*., 2014). In the present study, when considering the population of commercial species, there is a negative effect on the remaining natural regeneration. This may be due to the dynamic balance between recruitment and mortality. In this context, Silveira (2019) found mortality rates higher than recruitment rates, which is not appropriate to the principles of sustainable forest management.

Conclusions

Natural regeneration of the forest managed for commercial purposes included changes inspecies diversity and composition in the period of 16, 17, and 18 years after logging.

The commercially managed forest shows a greater diversity of species of natural regeneration after the period of 16, 17, and 18 years of logging for the total population. For shorter intervals, there is no difference in species diversity. For the commercial population, however, there is a decrease in diversity, although without statistical difference.

Over the years, changes resulting from management reduce vegetation similarity in comparison to the pre-logging state.

As the vegetation in natural regeneration underwent changes due to forest logging over time, it is necessary to expand the knowledge about the remaining forest. In this sense, future studies must assess whether the logging will drastically change the forest and if there is an imminent need for silvicultural interventions.

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