ORIGINAL ARTICLE

Effect of two management systems on an open ombrophilous forest, Maranhão state, Brazil***Efeito de dois sistemas de manejo em uma floresta ombrófila aberta, estado do Maranhão, Brasil***

Diego dos Santos Vieira¹ , Karla Mayara Almada Gomes² , Lizandra Elizeário dos Santos² ,
Axa Emanuelle Simões Figueiredo³ , Bruno Oliveira Lafetá⁴ , Marcio Leles Romarco de Oliveira¹ ,
João Ricardo Vasconcellos Gama²

¹Universidade Federal dos Vales do Jequitinhonha e Mucuri – UFVJM, Diamantina, MG, Brasil

²Universidade Federal do Oeste do Pará – UFOPA, Santarém, PA, Brasil

³Instituto Nacional de Pesquisa da Amazônia – INPA, Manaus, AM, Brasil

⁴Instituto Federal de Educação, Ciência e Tecnologia de Minas Gerais – IFMG, São João Evangelista, MG, Brasil

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Abstract

The objective of this study was to evaluate the floristic composition, diversity and structure of an Open Ombrophilous Forest, before and after harvesting, using the forest management systems in alternate strips (SAS) and the selective system (SS). The study was conducted at the Forest Management Unit of the MAGELA project, located in the municipality of Codó, state of Maranhão. The data were collected in six permanent plots of 50 m x 200 m located in the Annual Production Units (APU) 1 and 2, in which all trees with a diameter at 1.30 m from the ground (DBH) greater than or equal to 15 cm were measured, while trees with 5 cm < DBH < 15 cm were measured in rectangular subplots of 5 m x 50 m. Data were collected on two occasions, namely: before (2001) and after (2004) the harvest. Species' richness and diversity recovered, and even increased, after the application of the SAS and SS systems, but there were changes in species composition, as many new species were registered, while others were extinct. The community structure was extremely affected by the systems, as there were major changes in the ranking of the most ecologically important species. In the short term, the volume of SAS, after exploration, was greater than that registered for the SS, indicating that, probably, the APU submitted to the SS will take longer to recover the harvested volume.

Keywords: Forest management systems in alternate strips; Selective system; Harvest impacts; Silvicultural systems.

Resumo

O objetivo deste estudo foi avaliar a composição florística, diversidade e estrutura de uma Floresta Ombrófila Aberta, antes e após a colheita, utilizando os sistemas de manejo florestal em faixas alternadas (SAS) e o sistema seletivo (SS). O estudo foi realizado na Unidade de Manejo Florestal do projeto MAGELA, localizada no município de Codó, estado do Maranhão. Os dados foram coletados em seis parcelas permanentes de 50 m x 200 m localizadas nas Unidades de Produção Anual (APU) 1 e 2, nas quais todas as árvores com diâmetro de 1,30 m do solo (DAP) maior ou igual a 15 cm foram medidos, enquanto árvores com 5 cm ≤ DAP < 15 cm foram medidas em subparcelas retangulares de 5 m x 50 m. Os dados foram coletados em duas ocasiões, a saber: antes (2001) e depois (2004) da colheita. A riqueza e a diversidade de espécies se recuperaram, e até aumentaram, após a aplicação dos sistemas SAS e SS, mas ocorreram mudanças na composição das espécies, pois muitas espécies novas foram registradas, enquanto outras foram extintas. A estrutura da comunidade foi extremamente afetada pelos sistemas,

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Corresponding author: diegovieira4@gmail.com

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pois ocorreram grandes mudanças no ranking das espécies ecologicamente mais importantes. A curto prazo, o volume de SAS, após a exploração, foi maior que o registrado para o SS, indicando que, provavelmente, as UPAs submetidas ao SS levarão mais tempo para recuperar o volume colhido.

Palavras-chave: Sistema de manejo em faixas alternadas; Sistema seletivo; Impactos da colheita; Sistemas silviculturais.

INTRODUCTION

The continuous and accelerated use of Brazilian forest resources has aroused the interest in carrying out studies that minimize the effects of the timber harvest, as well as the interest in adopting ecologically correct, socially responsible, and economically viable management systems. This could ensure the sustainability and continuous production of forest products and services. The selective management system (SS) seems to be efficient, as it performs a rational harvest of the wood with the least possible impact. However, this application and evaluation is more concentrated in the regions of the Amazon Rainforest, with fewer studies on the impact of the system in areas such as on the Open Ombrophilous Forest in the Brazilian northeast - where there are harvests for energy purposes.

Alternative systems are diversified. Among these we can mention the forest management system in alternate strips (SAS), which also guarantees sustainable wood production, mainly for energy purposes (Souza & Soares, 2013). The SAS system allows the maintenance of the genetic diversity and structure of the population, through the replacement of genetic material, originated from selected remaining seed-trees in the areas and asexual propagation (Gama, 2004). It is a system that adopts the area - not the volume - for the calculation of permissible annual cuts and suggests the gradual cutting of forests in strips. Thus, the forest is made up of settlements with multiple structures; as a consequence there will always be strips in early stages of succession and later ones (Alonso, 1996; Hawley & Smith, 1972).

The successful application of the SAS and SS systems depends on monitoring the succession process in the harvested strips, which is commonly carried out through continuous forest inventories (Gama, 2004). Continuous inventories assess the damage caused by the harvest to the floristic composition and forest's structure. The study of the remaining vegetation aims to reduce losses for the future production and allows the planning of management systems with sustainable production (Francez et al., 2009; Jardim & Quadros, 2016; Pinto et al., 2002). Okuda et al. (2003) reinforce the need to assess the damage caused to species of non-commercial interest, which contribute directly and indirectly to forest regeneration. The system used affects the dynamics of the future population because some species find a favorable environment for their growth. Other species may become partially or totally disadvantaged, particularly when there are strong harvesting pressures, as is the case with many highly valuable species in the Amazon region (Macpherson et al., 2010; Schulze et al., 2008). The knowledge of these problems is the basis for the application of silvicultural treatments that improve recruitment and increase the survival and growth rates of regeneration of commercial and non-commercial species (Pariona et al., 2003). The SS and SAS systems are formed by a set of techniques designed to keep the structure and functions of the forest as similar as possible to pre-harvest conditions, reducing damage. Studies have shown that the SAS and SS systems are financially and operationally viable for firewood production, with SS being the best economic alternative and SAS being the best operational alternative (Gama, 2004; Gama et al., 2018).

However, in environmental and ecological terms, there is still no solid knowledge about the viability of these systems and the damage caused to the remaining vegetation, mainly in relation to SAS, which has high harvest intensities, when compared to the SS. According to Roy et al. (2000) the SAS system is highly dependent on the natural regeneration after harvesting. Thus, our goal in this study was to evaluate the floristic composition, diversity and structure of an Open Rainforest before and after harvesting using the SAS and SS systems.

MATERIAL AND METHODS

Study area

The data used in this study were collected in the Annual Production Units 1 and 2 (APU 1 and 2), within the Forest Management Unit (UMF) of the "Magela" project (04°35'20 " S and 43°49'55.2 " W), located in the municipality of Codó, state of Maranhão. The region's climate, according to the Köppen classification, is of the Aw type, with average annual temperature and precipitation of 28 °C and 1,600 mm, respectively (Alvares et al., 2013). The relief formation varies from flat to gently wavy, with a predominance of Grayish Yellow Latosol, with sandy/clay texture and good permeability. The UMF typology is classified as Open Ombrophilous Forest with two well-defined floristic factions: with lianas and with Palm Trees (Gama et al., 2018).

Data collection

We collected the data in six permanent plots of 50 m x 200 m, three in each APU collected by the SAS and SS systems, which were inventoried before (2001) and after (2004) the harvest activities. In these plots, all trees 1.30 m from the ground (DBH) with a diameter greater than or equal to 15 cm (Inclusion Level I) were measured. Trees with 5 cm < DBH < 15 cm (Inclusion Level II) were measured in rectangular subplots of 5 m x 50 m (0.025 ha), located at the northwest vertices of each plot (Gama et al., 2018). The information collected during the continuous forest inventory (CFI) was the common name, DHB and commercial heights (Hc) and total (Ht) of the trees. We also collected the botanical material of the species for taxonomic identification in the herbaria of the Emílio Goeldi Museum and the Brazilian Agricultural Research Corporation of the Eastern Amazon. The classification system adopted was APG III (Angiosperm Phylogeny Group, 2009). The monitoring systems and occasions will be expressed as SAS₂₀₀₁, SAS₂₀₀₄, SS₂₀₀₁, and SS₂₀₀₄. The denominations SAS₂₀₀₁ and SAS₂₀₀₄ mean that the harvest was carried out through the SAS system, and that the CFI (continuous forest inventory) was carried out in 2001, before the harvest, and 2004, after the harvest, respectively. The same interpretation applies to SS₂₀₀₁ and SS₂₀₀₄, but with harvesting was done through the selective management system (SS).

Data analysis

Floristic composition and diversity

The SAS and SS systems were evaluated on two occasions: before and after the harvest (SAS₂₀₀₁-SAS₂₀₀₄ and SS₂₀₀₁-SS₂₀₀₄) and after the harvest between systems (SAS₂₀₀₄-SS₂₀₀₄). The study of the floristic composition was based on the number of species and families. The degree of similarity during monitoring was estimated using the Sorensen index (Sorensen, 1984). Diversity was calculated using the Shannon-Weaver index (1) and Pielou's Equability (Pielou, 1969). Shannon-Weaver values were compared using the Hutchinson t test (2), at 95% probability (Brower et al., 1998). We elaborated Whittaker diagrams, the axes of the ordinates (y) being presented in a log10 format. In the diagram, species that covered many magnitudes of abundance were accommodated on the same graph (Whittaker, 1965),

$$H' = - \sum_{i=1}^S \frac{n_i}{N} \cdot \ln \left(\frac{n_i}{N} \right) \quad (1)$$

$$t = \frac{H'_1 - H'_2}{\sqrt{\hat{\sigma}_{H'_1}^2 + \hat{\sigma}_{H'_2}^2}} \quad (2)$$

where: n_i = total number of trees sampled from the i -th species; N = total number of trees sampled; S = number of species sampled; and $\ln$ = Neperian-based logarithm.

The estimator for the variance and degree of freedom of the Hutchinson t test was obtained by Equations 3 and 4, respectively

$$\sigma_{H'}^2 = \frac{\sum p_i \cdot [\ln(p_i)]^2 - \frac{(\sum p_i \cdot \ln(p_i))^2}{N}}{N} \quad (3)$$

$$GL = \frac{\left(\frac{\hat{\sigma}_{H_1}^2 + \hat{\sigma}_{H_2}^2}{N_1 + N_2} \right)^2}{\frac{\hat{\sigma}_{H_1}^2}{N_1} + \frac{\hat{\sigma}_{H_2}^2}{N_2}} \quad (4)$$

where: N_1 and N_2 = number of trees sampled during monitoring (2001 and 2004).

Horizontal and parametric structure

The estimated phytosociological parameters were: absolute density, relative density, absolute dominance, relative dominance, and coverage value (Freitas & Magalhães, 2012). We used the canopy value as an indicator of the ecological importance of the species in the community rather than the importance value due to the low number of plots available. This could influence the relative frequency and, consequently, the importance value. The behavior of the parametric structure considered the number of trees, basal area and volume per hectare and per diametric class with an amplitude of 5 cm, from the minimum inclusion diameter (DBH $\geq$ 5 cm). However, due to the presence of multiple intertwined trunks in *Cenostigma macrophyllum* Tul. (caneleiro) and the need for more reliable estimates of the volume and individual basal area of the species, we divided the data into two groups: "caneleiro" and "other species". We calculated the "caneleiro" basal area (Equation 5) with the estimation of the percentage of solid sectional area of all trees. Subsequently, through simple conversion, its basal area was obtained, while the volume was obtained using Equation 6 (Gama et al., 2017). The individual volume of "other species" was estimated by Equations 7 and 8 for trees with and without hollows, respectively (Gama et al., 2017). The basal area was obtained by Equation 9. The distributions of the number of trees, basal area and volume per hectare and by diameter class, before and after harvest, were compared using the Graybill F test, at 95% probability,

$$SA = 11.17647 (DBH + 29.173125)^{-0.7196937} \quad (5)$$

$$\ln(V) = -10.4338 + 2.2923 \ln(DBH) + 0.7222 \ln(Ht) - 0.0119 DBH \cdot D \quad (6)$$

$$\ln(V) = -10.8656 + 1.6775 \ln(DBH) + 1.6489 \ln(Ht) - 0.0140 DBH \cdot D \quad (7)$$

$$\ln(V) = -9.8388 + 2.1688 \ln(DBH) + 0.8060 \ln(Ht) - 0.0188 DBH \cdot D \quad (8)$$

$$G = \sum_{i=1}^n g_i, \text{ where } g_i = \frac{\pi \cdot DBH^2}{40,000} \quad (9)$$

where: SA = percentage of the solid sectional area of the i -th tree; V = total volume of the i -th individual tree, with bark (m^3); DBH = diameter at 1.30 m in height of the i -th tree (cm); Ht =

total height of the i -th individual tree (m); $D = 0$ for total volume; $D = 1$ for bole volume; and $\ln =$ Neperian logarithm; G = basal area of the i -th species; g = cross-sectional area of the i -th tree; $\pi = 3.1416$.

The variables: richness index, equability, number of trees, basal areas and volume were analyzed statistically, variance and HSD test at 95% probability - per hectare and occasion of monitoring. We designed a completely randomized experiment with an equal number of replications, where the SAS and SS systems are the groups, the monitoring occasions are treatments, and the number of plots are the replications. Prior to the application of the HSD test, Shapiro-Wilk normality tests and Levene's homogeneity tests of variance were applied. When necessary, the Box and Cox transformation was applied. All calculations were performed using software R version 3.3.2 (R Core Team, 2018).

RESULTS AND DISCUSSION

Floristic composition and diversity

The inventory carried out in the SAS₂₀₀₁ system, registered 834 trees distributed in 25 families and 55 species, while SAS₂₀₀₄ identified 560 trees, belonging to 31 families and 62 species. The SS₂₀₀₁ system registered 808 trees, belonging to 27 families and 61 species, while the SS₂₀₀₄ identified 754 trees, distributed in 30 families and 75 species. The richness before and after the harvest were not significantly different ($p \geq 0.05$). However, this does not indicate, necessarily, that a species did not occur after the application of SAS and SS. On the contrary, new species replaced those that were "extinguished". The SAS system, for example, did not register 19 species after harvest, such as *Brosimum acutifolium*, *Licania micrantha*, *Manilkara amazonica*, *Pouteria macrophylla* and *Pouteria surinamensis*. Before harvest, these species had 26.6, 13.6, 27.1, 14.2 and 13.3 tree.ha⁻¹, respectively. The entire *Copaifera* genus was also not registered after applying the SAS system.

The complete absence of abundant and harvested species is worrying, since sustainable management systems must ensure that the vegetation returns to its pre-harvest condition after the cutting cycle, as well as the occurrence of parent trees for species conservation in the area. The absence of abundant species affects the fauna due to the scarcity of fruits and the surrounding community, which use the species mentioned above for timber, herbal and energy purposes (Gama et al., 2007). The loss of species was offset by the 26 new species registered in SAS₂₀₀₄, most of which are rare, that is, with at least 1 tree.ha⁻¹. The most abundant species at that time were *Guilielma microcarpa* and *Helicteres pentandra*, which presented 15.3 and 16.1 trees.ha⁻¹. It is a species of palm and shrub, respectively, which are heliophilous and which were registered by Gama et al. (2007) in surrounding areas, which explains their high abundance.

We suggest SAS sustains favored the germination and development of *G. microcarpa* in the APU and the emergence of new species, because in the harvested strips the incidence of light is greater (Oliveira et al., 2005). The SS system did not register, after harvest, 16 species such as: *Apeiba macropetala*, *B. acutifolium*, *Eugenia protracta*, *P. macrophylla* and *Roupala* sp., which had 13.3, 67.1, 13.3, 13.3 and 1, 3 trees ha⁻¹, respectively. However, 29 new species were registered in SS₂₀₀₄ with an average abundance of 1.0 trees ha⁻¹, of which *H. pentandra* and *Zanthoxylum monogynum* stood out with 15.3 and 3.7 trees ha⁻¹, respectively. The species *G. microcarpa* occurred on the two occasions of monitoring the SS, but all palm trees registered after harvest were considered as inputs. This suggests that the SS harvest prescription also favored its germination and development, in addition to the appearance of new species, due to the opening of the canopy that increased the availability of light.

The floristic composition in the APUs responded very dynamically to the entry and exit of species. However, it is not possible to claim that the current species will be the base of the vegetation after the end of the cutting cycles and that the extinct ones will no longer occur in the APUs. In other studies that evaluated the consequences of reduced impact exploration - a consolidated system in the Amazon region - for a short time, there were similar trends for the

dynamics of species entering and leaving; however, with significant differences for species richness (Colpini et al., 2009; Francez et al., 2007; Oliveira et al., 2005). The richness index in both systems, before and after harvest, were in the Fabaceae, Myrtaceae, Sapotaceae and Annonaceae families, which together added up 56.4, 40.3, 52.5 and 40.0% of all species occurring in SAS₂₀₀₁, SAS₂₀₀₄, SS₂₀₀₁ and SS₂₀₀₄, respectively.

The greatest richness of species belonging to the Fabaceae family was recorded in areas harvested in the Amazon (Francez et al., 2007; Vieira et al., 2015). Although the harvest has changed the composition of these areas, at the family level it is still equal. The Shannon-Weaver indices and Pielou's equability demonstrated that a diversity of APUs before harvesting using SAS and SS systems was less than 3.0, while one equation did not exceed 0.75 (Table 1). After harvesting, the HSD and t-tests of Hutchinson indicated significant increases, exceeding the values of 3.4 and 0.80, respectively. This demonstrates that an increase of about 20% would be necessary to achieve maximum diversity. Some studies affirm that, right after the harvest a floristic diversity of successional vegetation is greater than that of a mature forest (Jardim & Quadros, 2016; Mendes et al., 2012). Thus, forest management based on natural regeneration is, above all, a guarantee of maintenance and even an increase in biological diversity.

Table 1. Floristic variables, similarity, HSD test and Hutchinson t test for the SAS and SS systems, before and after the APU harvest.

Variable	Silvicultural systems			
	SAS ₂₀₀₁	SAS ₂₀₀₄	SS ₂₀₀₁	SS ₂₀₀₄
Richness (S)	55.0 a	62.0 a	61.0 a	75.0 a
Maximum diversity ($H_{\max}$)	4.01	4.13	4.09	4.32
Shannon-Weaver (H')	2.97 a	3.45 b	2.96 a	3.51 b
Pielou Equability(J)	0.74 a	0.83 b	0.72 a	0.81 b
Silvicultural systems	Sorensen Index			
	SAS ₂₀₀₁	SAS ₂₀₀₄	SS ₂₀₀₁	SS ₂₀₀₄
SAS ₂₀₀₁	-			
SAS ₂₀₀₄	0.61	-		
SS ₂₀₀₁	0.73	0.67	-	
SS ₂₀₀₄	0.75	0.71	0.67	-

Note: treatments with the same lower case letters horizontally do not differ statistically, at 95% probability.

The higher degrees of equability recorded after harvest suggests a greater uniformity in the proportions of the number of trees per species within the APUs. This was expected because equability is directly proportional to diversity and antagonistic to dominance (Uhl & Murphy, 1981). The values of diversity and equability for the combinations SAS₂₀₀₁-SS₂₀₀₁ and SAS₂₀₀₄-SS₂₀₀₄ were statistically equal. This increase in diversity and equability occurred due to the difference in the representativeness of species in the APUs (Vieira et al., 2017). After harvesting, dominant species became less dominant, which increased the uniformity in the proportion of the number of trees per species - which associated with the entry of new species resulted in higher Shannon-Weaver indexes (Oliveira et al., 2005).

The dominance relationship is easily perceptible in the Whittaker diagrams of the SAS and SS systems, which demonstrate the dominance of a group of species, mainly *Cenostigma macrophyllum* with 25.9 and 30% of all the trees inventoried in SAS₂₀₀₁ and SS₂₀₀₁, respectively (Figure 1A and 1B). In an assessment of the diversity of an island in the Amazon, Vieira et al. (2017) stated that the low diversity was a result of the high dominance of a small group of species that comprised approximately 48.8% of all trees in the area. After harvesting the APUs, there was a reduction in species dominance, especially for *C. macrophyllum*, with

greater diversity and uniformity in the tree proportions by species within the APUs. The greatest richness, diversities and equability recorded after the application of the SAS and SS systems are further confirmed by the Whittaker diagrams, as the length and slope of the curve is always greater in SAS₂₀₀₄ and SS₂₀₀₄ (Figure 1).

Figure 1. Whittaker diagrams in the SAS and SS systems, before and after the activities to harvest the APUs.

In the short term, the impacts of applying the SAS and SS systems on richness and diversity have been eliminated. The harvest yielded higher values, but significant changes were registered in the species composition. Wealth, diversity and equability were significantly equal between the SAS₂₀₀₄-SS₂₀₀₄ systems. We found high similarity (0.71) in the SAS₂₀₀₄ and SS₂₀₀₄ systems (Table 1). Similarity values equal to or greater than 0.5 are considered high (Kent, 2011). We observed that there was a high similarity for the SAS and SS systems in the APUs of each system (before and after harvest), with values of 0.61 and 0.67, respectively. This suggests that the SS preserved almost the same number of species as the SAS.

Horizontal and parametric structure

The SAS system showed reductions of 86.6, 73.4 and 76.3% for number of trees (DA), basal area (G) and volume (V) per hectare, respectively, producing 91.6 m³ha⁻¹ of firewood (Table 2). The SS system recorded reductions of 80.8, 82.1 and 88.7% for DA, G and V, respectively, generating 187.7 m³ha⁻¹ of firewood. The reduction levels are within the standards of sustainable production (Jesus & Garcia, 1991). The HSD test showed significant differences ($p < 0.05$) for G and DA within each system, before and after harvest, but no significant differences were detected between the systems ($p \geq 0.05$). We found the same pattern for the means of V, except for the SAS₂₀₀₄-SS₂₀₀₄ combination, where significant differences were detected ($p < 0.05$).

Table 2. Structural variables and HSD test for SAS and SS systems, before and after APU harvest.

Variable	Silvicultural Systems			
	SAS ₂₀₀₁	SAS ₂₀₀₄	SS ₂₀₀₁	SS ₂₀₀₄
Density (trees ha ⁻¹)	1396.2 a	186.7 b	1309.3 a	251.3 b
Basal area (m ² ha ⁻¹)	17.5 a	4.66 b	14.94 a	2.67 b
Volume (m ³ ha ⁻¹)	272.4 a	64.6 b	232.5 a	26.3 c

Note: treatments with the same lower case letters horizontally do not differ statistically, at 95% probability.

The most abundant species (DA ≥ 85 trees ha⁻¹) in SAS₂₀₀₁ were, in decreasing order, *Duguetia cadaverica*, *Galipea jasminiflora*, *Lindackeria paraenses*, *Eugenia tapacumensis*, *Oxandra reticulata*, *Xylopia nitida* and *C. macrophyllum*, which together account for 66.6% of the entire DA. The most dominant (DoA ≥ 0.9 m² ha⁻¹), in descending order, were *D. cadaverica*, *Hymenaea*

parviflora, *L. paraensis*, *Actinostemon klotzschii*, *O. reticulata*, *Drypetes variabilis*, *E. tapacumensis*, which together account for 51.9% of the entire SAS₂₀₀₁ DoA. The most ecologically important species (VC ≥ 5%), in decreasing order, were *D. cadaverica*, *G. jasminiflora*, *L. paraensis*, *H. parviflora*, *O. reticulata*, *E. tapacumensis* and *A. klotzschii*, which together accounted for 56.7% of VC of SAS₂₀₀₁ (Table 3).

Table 3. Estimation of phytosociological parameters of species of greatest ecological importance, before and after harvest, in the SAS system.

Species	SAS ₂₀₀₁			SAS ₂₀₀₄		
	DA	DoA	VC	DA	DoA	VC
<i>Duguetia cadaverica</i> Huber	255.7	1.9331	14.7 ⁽¹⁾	17.3	0.1522	6.3 ⁽³⁾
<i>Galipea jasminiflora</i> (A.St.-Hill) Engl.	190.0	0.8733	9.3 ⁽²⁾	9.0	0.0597	3.1 ⁽¹²⁾
<i>Lindackeria paraensis</i> Kuhlm.	119.0	1.3388	8.1 ⁽³⁾	5.3	0.0971	2.5 ⁽¹⁶⁾
<i>Hymenaea parviflora</i> Huber	49.0	1.7858	6.9 ⁽⁴⁾	2.0	0.0965	1.6 ⁽²⁰⁾
<i>Oxandra reticulata</i> Maas	94.7	1.0006	6.3 ⁽⁵⁾	3.7	0.0703	1.7 ⁽¹⁹⁾
<i>Eugenia tapacumensis</i> O.Berg	98.3	0.9147	6.1 ⁽⁶⁾	5.0	0.0707	2.1 ⁽¹⁸⁾
<i>Actinostemon klotzschii</i> (Didr.) Pax	61.3	1.1348	5.4 ⁽⁷⁾	5.7	0.1932	3.6 ⁽⁸⁾
<i>Xylopia nitida</i> Dunal	87.0	0.6458	5.0 ⁽⁸⁾	-	-	-
<i>Drypetes variabilis</i> Uittien	22.7	0.9738	3.6 ⁽⁹⁾	3.3	0.2094	3.1 ⁽¹¹⁾
<i>Manilkara huberi</i> (Ducke) A.Chev.	45.0	0.6498	3.5 ⁽¹⁰⁾	7.0	0.1091	3.0 ⁽¹³⁾
<i>Cenostigma macrophyllum</i> Tul.	85.0	0.0463	3.2 ⁽¹¹⁾	16.3	0.0081	4.5 ⁽⁶⁾
<i>Pouteria</i> sp.	34.7	0.5415	2.8 ⁽¹²⁾	6.3	0.1402	3.2 ⁽¹⁰⁾
<i>Hylenaea comosa</i> Miers	11.7	0.6987	2.4 ⁽¹³⁾	9.7	0.4445	7.4 ⁽²⁾
<i>Buchenavia grandis</i> Ducke	4.3	0.7898	2.4 ⁽¹⁴⁾	-	-	-
<i>Manilkara amazonica</i> (Huber) Standl.	27.0	0.3413	1.9 ⁽¹⁵⁾	-	-	-
<i>Eugenia polystachya</i> Rich.	26.7	0.3354	1.9 ⁽¹⁶⁾	-	-	-
<i>Lecythis lurida</i> (Miers) S.A.Mori	9.0	0.5442	1.9 ⁽¹⁷⁾	4.3	0.1711	3.0 ⁽¹⁴⁾
<i>Brosimum acutifolium</i> Huber	26.7	0.1737	1.5 ⁽¹⁸⁾	-	-	-
<i>Dipteryx polyphylla</i> Huber	19.7	0.2441	1.4 ⁽¹⁹⁾	7.0	0.1810	3.8 ⁽⁷⁾
<i>Myrcia bracteata</i> (Rich.) DC.	27.0	0.1110	1.3 ⁽²⁰⁾	-	-	-
<i>Helicteres pentandra</i> L.	-	-	-	16.0	0.7316	12.1 ⁽¹⁾
<i>Guilielma microcarpa</i> Huber.	-	-	-	15.3	0.0881	5.1 ⁽⁴⁾
<i>Swartzia flaemingii</i> Raddi	-	-	-	1.3	0.4027	4.7 ⁽⁵⁾
<i>Unonopsis lindmanii</i> R.E.Fr.	-	-	-	7.0	0.1516	3.5 ⁽⁹⁾
<i>Terminalia ivorensis</i> A. Chev.	-	-	-	1.3	0.2361	2.9 ⁽¹⁵⁾
<i>Caryocar villosum</i> (Aubl.) Pers.	-	-	-	3.0	0.1355	2.3 ⁽¹⁷⁾
Subtotal	1294.5	15.0765	89.4	146.0	3.7484	79.3
Others	101.7	2.4186	10.6	40.7	0.9164	20.7
Total	1396.2	17.4951	100.0	186.7	4.6648	100.0

Legend: DA = absolute density of the i-th species; DoA = absolute dominance of the i-th species; VC = coverage value of the i-th species.

After harvesting, the APUs in the SAS₂₀₀₄ system, *D. cadaverica* continued as the most abundant species, followed by *C. macrophyllum*, *H. pentandra*, *G. microcarpa*, *Hylanaea comosa*, *G. jasminiflora* and *Dipteryx polyphylla* which together accounted for 48.7% of the DA registered in SAS₂₀₀₄. Regarding DoA, only *A. klotzchii* (6th) remained among the seven most dominant, the others were *H. pentandra* (1st), *H. comosa* (2nd), *Swartzia flaemingii* (3rd), *Terminalia ivorensis* (4th), *D. variabilis* (5th) and *D. polyphylla* (7th), which together accounted for 51.4% of all SAS₂₀₀₄ DoA. The most important, ecologically were *H. pentandra* (1st), *H. comosa* (2nd), *D. cadaverica* (3rd), *G. microcarpa* (4th), *S. flaemingii* (5th), *C. macrophyllum* (6th) and *D. polyphylla* (7th) that, together, they accounted for 43.7% of SAS₂₀₀₄'s VC.

The SAS system caused major changes in the community structure, as of the 20 most important species in SAS₂₀₀₁, two (*M. amazonica* and *B. acutifolium*) did not occur after harvest and four (*X. nitida*, *Buchenavia grandis*, *Eugenia polystachya* and *Myrcia bracteata*) were not observed among the 20 most important of SAS₂₀₀₄. Another 14 species, not described in Table 3, were also not inventoried after harvest, such as *Copaifera guianensis*, *Copaifera reticulata* and *Copaifera duckei*. In addition, 26 new species emerged in SAS₂₀₀₄, three (*H. pentandra*, *G. microcarpa* and *T. ivorensis*) of which were among the 20 most ecologically important, taking 1st, 4th and 15th positions in the VC ranking. It was also observed that *S. flaemingii*, *Unonopsis lindmanii* and *Caryocar villosum*, changed their positions in the ranking of importance from 28th, 29th and 37th in SAS₂₀₀₁ to 5th, 17th and 9th in SAS₂₀₀₄, respectively.

The most abundant species (DA ≥ 73 trees ha⁻¹) in the SS₂₀₀₁ system were, in decreasing order, *C. macrophyllum*, *H. parviflora*, *L. paraensis*, *G. microcarpa*, *A. klotzchii*, *D. poliphylla* and *O. reticulata*, which together totaled 54.5% of all recorded abundance. The most dominant (DoA ≥ 0.72 m² ha⁻¹), in descending order, were *B. grandis*, *H. parviflora*, *D. poliphylla*, *L. paraensis*, *H. comosa*, *A. klotzschii* and *Pouteria* sp. which together accounted for 51.9% of the dominance observed in SS₂₀₀₁. The most important species in SS₂₀₀₁ (VC $\geq 5.0\%$) were, in descending order, *H. parviflora*, *L. paraensis*, *D. poliphylla*, *A. klotzschii*, *C. macrophyllum*, *G. microcarpa* and *B. grandis*, which together accounted for 47.3% of the coverage value in SS₂₀₀₁ (Table 4).

Table 4. Estimation of phytosociological parameters of species of greatest ecological importance, before and after harvest, in the SS system.

Species	SS ₂₀₀₁			SS ₂₀₀₄		
	DA	DoA	VC	DA	DoA	VC
<i>Hymenaea parviflora</i> Huber	119.0	1.4407	12.1 ⁽¹⁾	-	-	-
<i>Lindackeria paraensis</i> Kuhlman	115.7	1.1265	7.4 ⁽²⁾	7.7	0.0807	3.0 ⁽¹⁰⁾
<i>Dipteryx poliphylla</i> Huber	82.7	1.1983	6.3 ⁽³⁾	8.3	0.1453	4.4 ⁽⁵⁾
<i>Actinostemon klotzchii</i> (Dir.) Pax	83.0	0.9472	5.1 ⁽⁴⁾	10.3	0.1170	4.2 ⁽⁶⁾
<i>Cenostigma macrophyllum</i> Tul.	145.7	0.0444	4.7 ⁽⁵⁾	8.7	0.0032	1.8 ⁽¹⁶⁾
<i>Guilielma microcarpa</i> Huber.	93.3	0.5172	4.5 ⁽⁶⁾	25.0	0.1614	8.0 ⁽³⁾
<i>Buchenavia grandis</i> Ducke	8.7	1.4762	3.8 ⁽⁷⁾	-	-	-
<i>Hylanaea comosa</i> Miers.	42.3	1.0166	3.6 ⁽⁸⁾	-	-	-
<i>Galipea jasminiflora</i> (A.St.-Hill) Engl.	69.3	0.6879	3.5 ⁽⁹⁾	23.0	0.2115	8.5 ⁽²⁾
<i>Oxandra reticulata</i> Maas	73.7	0.5789	3.2 ⁽¹⁰⁾	8.0	0.1013	3.5 ⁽⁸⁾
<i>Duguetia cadaverica</i> Huber	67.0	0.4034	3.1 ⁽¹¹⁾	36.7	0.2362	11.7 ⁽¹⁾
<i>Pouteria</i> sp.	37.0	0.7244	3.1 ⁽¹²⁾	10.7	0.0693	3.4 ⁽⁹⁾
<i>Brosimum acutifolium</i> Huber	67.0	0.3671	3.0 ⁽¹³⁾	-	-	-
<i>Myrcia bracteata</i> (Rich.) DC.	54.0	0.2124	3.0 ⁽¹⁴⁾	5.0	0.0271	1.5 ⁽²⁰⁾

Table 4. Continued...

Species	SS ₂₀₀₁			SS ₂₀₀₄		
	DA	DoA	VC	DA	DoA	VC
<i>Manilkara huberi</i> (Ducke) A.Chev.	40.3	0.2943	2.9 ⁽¹⁵⁾	3.7	0.0434	1.5 ⁽¹⁹⁾
<i>Psidium guianensis</i> Sw.	20.7	0.3841	2.5 ⁽¹⁶⁾	4.3	0.0549	1.9 ⁽¹⁴⁾
<i>Roupala</i> sp.	18.3	0.3650	2.3 ⁽¹⁷⁾	-	-	-
<i>Eugenia tapacumensis</i> O.Berg	28.3	0.1989	2.1 ⁽¹⁸⁾	5.7	0.0868	2.8 ⁽¹²⁾
<i>Lecythis lurida</i> (Miers) S.A.Mori	15.7	0.2614	1.7 ⁽¹⁹⁾	5.3	0.1050	3.0 ⁽¹¹⁾
<i>Parkia pendula</i> (Willd) Benth. ex Walp.	1.7	0.3876	1.6 ⁽²⁰⁾	-	-	-
<i>Helicteres pentandra</i> L.	-	-	-	15.3	0.2364	7.5 ⁽⁴⁾
<i>Unonopsis lindmanii</i> R.E.Fr.	-	-	-	9.3	0.0938	3.6 ⁽⁷⁾
<i>Drypetes variabilis</i> Uittien	-	-	-	2.0	0.0888	2.1 ⁽¹³⁾
<i>Derris sericea</i> (Poir.) Ducke	-	-	-	3.3	0.0602	1.8 ⁽¹⁵⁾
<i>Duguetia</i> sp.	-	-	-	4.3	0.0462	1.7 ⁽¹⁷⁾
<i>Peltogyne confertiflora</i> (Mart. Ex Hayne) Benth.	-	-	-	1.3	0.0731	1.6 ⁽¹⁸⁾
Subtotal	1.183.4	12.6326	87.5	198.0	2.0417	77.7
Others	126.0	2.3054	12.5	53.3	0.6254	22.3
Total	1309.3	14.9379	100.0	251.3	2.6671	100.0

Legend: DA = absolute density of the i-th species; DoA = absolute dominance of the i-th species; VC = coverage value of the i-th species.

After harvesting the APUs in the SS₂₀₀₄ system, only *A. klotzschii* (6th) and *G. microcarpa* (2nd) remained among the seven with the most number of trees per hectare, *D. cadaverica* (1st), *G. jasminiflora* (3rd), *H. pentandra* (4th), *Pouteria* sp. (5th) and *U. lindmanii* (7th) completed the list. Together, these species account for 51.8% of the DA. Regarding dominance, only *D. polyphylla* (5th) and *A. klotzschii* (6th) were among the seven most dominant, the others were *H. pentandra* (1st), *D. cadaverica* (2nd), *G. jasminiflora* (3rd), *G. microcarpa* (4th) and *Lecythis lurida* (7th) who together accounted for 45.5% of DoA. The most important, ecologically, in SS₂₀₀₄ were *D. cadaverica* (1st), *G. jasminiflora* (2nd), *G. microcarpa* (3rd), *H. pentandra* (4th), *D. polyphylla* (5th), *A. klotzschii* (6th) and *U. lindmanii* (7) which together accounted for 48.0% of the SS₂₀₀₄ coverage value.

In the SS system, of the 20 most important species in SS₂₀₀₁, two (*Roupala* sp. and *B. acutifolium*) did not occur after harvest and four (*H. parviflora*, *B. grandis*, *H. comosa* and *Parkia pendula*) were not observed among the 20 most important in the SAS₂₀₀₄. Another 14 species, not described in Table 4, were also not recorded after harvest, such as *Manilkara huberi*, *C. reticulata* and *P. macrophylla*. 29 new species emerged in SS₂₀₀₄, one (*H. pentandra*) of which is among the 20 most important, taking 4th place in the VC ranking. We observed that *U. lindmanii*, *D. variabilis*, *Derris sericea*, *Duguetia* sp. and *Peltogyne confertiflora*, changed their positions in the ranking of importance from 31st, 21st, 33rd, 38th and 30th in SS₂₀₀₁ to 7th, 13th, 15th, 17th and 18th in SS₂₀₀₄, respectively.

The structural changes registered in the APUs after the application of the SAS and SS systems are probably the result of the intervention levels, which caused changes in the canopy, as there was an increase in light, temperature and water deficit and an increase in the availability of nutrients while dead plants were decomposed. These changes in the physical environment alter biocenosis, since established seedlings die due to sensitivity to light, plants of secondary species appear and others have their growth maximized (Jardim & Quadros, 2016). The interaction between the altered APU environment caused by the harvest and the different ecological groups that make up the vegetation explains the rise, the VC hierarchy of species known to be more intolerant of shade. Thus, species like *G. microcarpa* and

H. pentandra, whose recruitment was favored over the three years of monitoring, display a tendency to stabilize after the canopy closes.

The communities have an exponential diametric structure in the form of inverted J, before and after the application of the SAS and SS systems (Figure 2). The largest number of trees is in the diametric classes below 15 cm. The J-inverted behavior recorded after the application of the systems is explained by the selection of matrix trees in all diametric classes (Gama et al., 2018). The differences noted between SAS₂₀₀₁-SAS₂₀₀₄ and SS₂₀₀₁-SS₂₀₀₄ were significant ($p < 0.05$), according to Graybill's F test, as well as those detected between SAS₂₀₀₁-SS₂₀₀₁ and SAS₂₀₀₄-SS₂₀₀₄. We observed that in the APU explored by SAS, 90.1% of trees with DBH < 15 cm were harvested, 62.1% of trees with 15 cm < DBH < 40 cm and 83.7% of trees with DBH $\geq$ 40 cm. 186.7 trees ha⁻¹ remained in the area, of which 104.0 trees ha⁻¹ had DBH < 15 cm. In the SS system, these percentages were 80.3, 81.9 and 93.2%, respectively, with 251.3 trees ha⁻¹ remaining, of which 211.7 trees ha⁻¹ had a DBH < 15 cm.

Figure 2. Parametric structure of SAS and SS systems, before and after APU harvesting.

The volumetric structures of the APUs before the application of the SAS and SS systems, demonstrate that the highest volumes occurred in the intermediate diametric classes (Figure 2). The same trend was observed after harvest, but with reductions in all classes, except the first in SAS₂₀₀₄, which recovered 3.36 m³ ha⁻¹ after the harvest. The differences between SAS₂₀₀₁-SAS₂₀₀₄ and SS₂₀₀₁-SS₂₀₀₄ were significant ($p < 0.05$) at 95% probability, as well as those observed between SAS₂₀₀₁-SS₂₀₀₁ and SAS₂₀₀₄-SS₂₀₀₄. The volume collected in the diametric classes with DBH < 15 cm was 68.8%, while in the classes with 15 cm < DBH < 40 cm and DBH $\geq$ 40 cm, 64.7 and 88.5% were observed, respectively, with 64.6 m³ ha⁻¹ remaining in the area, of which 89.9% were in the classes with DBH < 50 cm. In the SS system, these percentages were 88.7, 85.8 and

91.9%, respectively, with $26.3 \text{ m}^3 \text{ ha}^{-1}$ remaining, of which 74.3% were in the classes with $\text{DBH} < 50 \text{ cm}$.

The same trend described in the volumetric structure was observed in the basal area, before and after the harvest, but with discrepant values in classes 10-15 and 50-55 cm (Figure 2). We observed that only SAS_{2001} and SS_{2001} were significantly equal ($p \geq 0.05$), while the combinations $\text{SAS}_{2001}\text{-SAS}_{2004}$, $\text{SS}_{2001}\text{-SS}_{2004}$ and $\text{SAS}_{2004}\text{-SS}_{2004}$ were statistically different ($p < 0.05$), at 95% probability. The baseline percentages collected in classes with $\text{DBH} < 15 \text{ cm}$, $15 \text{ cm} < \text{DBH} < 40 \text{ cm}$ and $\text{DBH} \geq 40 \text{ cm}$ were 80.5, 57.5 and 86.8%, respectively, while in the SS system the percentages were 84, 8, 77.0 and 85.6%, respectively. The basal areas remaining after harvest were 4.6648 and $2.6671 \text{ m}^2 \text{ ha}^{-1}$ for SAS_{2004} and SS_{2004} , respectively. The differences recorded for all possible occasions in the diametric, basal area and volumetric structures are directly related to the intensity of the interventions performed by the SAS and SS systems.

In the short term, the impacts of applying SAS and SS on the community structure are extremely significant. There were major changes in the ranking estimated by the coverage value, caused by the high variations of DA and DoA of the species, resulting from the harvesting prescriptions of the systems and changes in the physical environment of the APUs. The high impacts are confirmed by the highly significant differences recorded in the parametric structures of each system, before and after exploration. The volume at community level and diametric class were higher in the SAS_{2004} system, when compared to SS_{2004} , indicating that the APU submitted to the SS will take longer to recover the harvested volume.

The vegetation is in recovery and will probably recover the entire volume of firewood removed by the end of the 26 and 30 year cycles for the SAS and SS systems, respectively. Gama et al. (2018), evaluated the technical viability of SAS and SS and the quality of the remaining vegetation in the same APUs and concluded that the SAS had a higher operational yield, there was less damage to the boles and canopy of the trees. SAS produced a remaining vegetation with better genetic and structural qualities - which avoids the genetic degeneration of the harvested species. In addition, the results shown show that the volume of SAS, after exploration, was greater than that registered for the SS. Therefore, in the short term, SAS is the best option for energy usage.

CONCLUSION

There was a recovery of species richness and diversity, and even an increase, after the application of the management system in alternative ranges and selected system. Species composition has changed, as many new species have been registered, while others were extinguished. Management systems have greatly affected the structure of the community, as there were significant changes in the ranking of the most important ecological species.

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