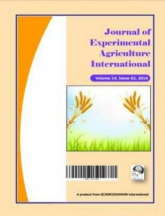

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Natural Regeneration in Tropical Rainforest, Northeastern Brazil

Fabiana Estigarribia[1], Joselane Príscila Gomes da Silva[1*], Paulo Fernando Rodrigues Cândido[1], Nelio Domingos da Silva[1], João Antonio Tanajura Silva[1] and Lúcia de Fatima de Carvalho Chaves[1]

[1]Department of Forestry Sciences, Rural Federal University of Pernambuco, 52171-900, Brazil.

Authors' contributions

This work was carried out in collaboration between all authors. Authors FE, JPGS, PFRC, NDS, JATS and LFCC conceived and designed the research. The authors FE, JPGS, PFRC, NDS and JATS participated in the collection of data within the forest remnant. Authors FE, JPGS, PFRC, NDS, JATS and LFCC analyzed the data, wrote and edited the manuscript. All authors read and approved the final manuscript

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ABSTRACT

Aims: To evaluate the shrub-tree species of natural regeneration in a remnant of Tropical Rain Forest, located in the northeastern region of Brazil.
Study Design: Systematic sampling.
Place and Duration of Study: The study was carried out in a remnant of Tropical Rainforest, categorized as a Forest of Miritiba Wildlife Refuge, located in the municipality of Abreu and Lima, distant approximately 42 km from the city of Recife, state of Pernambuco, Brazil. The area has approximately 273.40 ha. The data were collected in November 2016.
Methodology: The data were collected in 12 plots (25 m² each) allocated in 3 transects of 100 m in length, equidistant 50 m from each other, perpendicular to the edge of the weir located inside the fragment. The inclusion level established was a minimum height of 1.0 m and a base circumference

**Corresponding author: E-mail: joselane.gomess@gmail.com;*

at 30.0 cm from the ground (CAB $_{0.30\ m}$) ≤ 15.0 cm. Three height classes (H) were considered, where Class I included individuals with 1.0 ≤ H ≤ 2.0 m; Class II with 2.0 <H <3.0 m and Class III with H> 3.0 m and CAP <15.0 cm.
Results: A total of 41 species belonging to 24 botanical families and 31 genus were recorded, representing a density of 8,867 ind.ha^{-1}. The five richest families were Fabaceae, Myrtaceae, Melastomataceae Anacardiaceae and Sapindaceae. The species with the highest estimated densities were *Protium heptaphyllum*, *Erythroxylum mucronatum* and *Hirtella racemosa*.
Conclusion: Among the species sampled in the regenerating component, which presented higher density and can be used for enrichment of areas in recovery process are *Protium heptaphyllum, Erythroxylum mucronatum, Hirtella racemosa, Myrcia tomentosa* and *Eschweilera ovata*.

Keywords: Natural regeneration; atlantic forest; seed dispersal; anthropic action; forest restoration.

1. INTRODUCTION

Natural regeneration is part of the forest establishment cycle, resulting from the interaction of a series of ecological processes, and even though it is difficult to reach a consensus on its scope and definition, its knowledge and quantification make up aspects of great importance on the characterization of plant formations [1,2].

The understanding of natural regeneration is fundamental both for the conservation, preservation and recovery bases of fragmented forest stands [3,4], as well as to understand the changes in structural levels of natural regeneration, and can be considered as indicative of degradation of the area [5] because, depending on the surrounding landscape, natural regeneration has the ability to establish a new highly diversified vegetation, which will not occur in situations of degraded environments [6].

The analysis of the natural regeneration of a given area will allow, by surveying the number of individuals that can be recruited to another stage of the plant's life cycle, an evaluation of the current conservation status of that area, as well as its reaction to the outbreaks of disturbance that affect [3]. Nevertheless, there is a lack of relation to the natural regeneration knowledge in fragments of Atlantic Forest, which makes even more important the conduction of studies in these places [7].

The development of natural regeneration studies allow inferring on the state of conservation, such as the regenerative potential of the forest in the face of natural or anthropogenic disturbances [3], since regeneration is part of the development cycle and establishment of forests and results from the interaction of natural processes of ecosystem restoration, being essential to understand the forest functioning [2].

Understanding of regenerative potential is essential, since natural regeneration is a genetic stock of vegetation, ready for substitution as the environment provides for its recruitment to the immediately larger size class [8].

In view of the above, the present work had as objective to carry out a survey of the natural regeneration stratum in a fragment of Tropical Rainforest located in the northeastern region of Brazil.

2. MATERIALS AND METHODS

2.1 Area of Study

The study was carried out in a remnant of Tropical Rainforest, categorized as the Forest of Miritiba Wildlife Refuge [9], located within the Marechal Newton Cavalcanti Instruction Field (MNCIF) under coordinates 7°50'00 "S and 35°06'00" W, at approximately 100 m altitude, located in the municipality of Abreu and Lima, at 42 km from the city of Recife, capital of Pernambuco.
.
The fragment has an approximate area of 273.40 ha. The forest of Miritiba Wildlife Refuge is also part of the Aldeia-Beberibe Environmental Protection Area, being considered important for the protection of the relief, soil and hydrographic system [10].

The predominant climate of the region is the tropical wet type As' or pseudotropical, according to the climatic classification of Köppen, with precipitation of approximately 2.300 mm [11], being the period with greater precipitation from April to August and the smaller period from November to December. The vegetation is

classified as Dense Ombrophilous Lowland Forest [12].

The soils of this geoenvironmental unit are represented by the Latosols and Podzolic in the tops of chapadas and residual moles; by Podzolic with Fregipan, Podzolic Plzticos and Podzols in the small depressions in the trays; by Concrete Podzolic in dissected areas and slopes; and Gleysols and Alluvial Soils in the floodplain areas [13,14].

2.2 Collection of Data

The data were collected in plots allocated in 3 transects 100 m long, equidistant 50 m apart, perpendicular to the edge of the weir located inside the fragment. In each transect four plots of 5 m x 5 m (25 m²), equidistant 25 m, totaling 12 plots, were established.

The inclusion level established was a minimum height of 1.0 m and a base circumference at 30 cm from the ground ($CAB_{0.30\ m}$) ≤ 15.0 cm. Three height classes (H) were considered, where Class I included individuals with 1.0 ≤ H ≤ 2.0 m; Class II with 2.0 <H ≤ 3.0 m and Class III with H > 3.0 m and CAP < 15.0 cm, according to the methodology proposed by Marangon et al. [2].

When possible, the species were identified in the field and the botanical material collected for comparison with exsiccates of the Sérgio Tavares Herbarium, located in the Forest Science Department of the Federal Rural University of Pernambuco. The nomenclature of species and correction of spelling and authorship of scientific names were made through the website The International Plant Names Index (http://www.ipni.org).

2.3 Data Analysis

The successional classification of the species was carried out according to the methodology proposed by Gandolfi et al. [15] and observations in the field, where the species were classified as pioneers, which are those that depend on high luminosity for their development, which is common in open areas, clearings and edges of fragments; which are developed under intermediate conditions of shading and luminosity; secondary events occurring in forest sub-forest environments or with intense shading, which grow and complete their cycle in the shadows but occupy the upper forest strata in adulthood; and without characterization, the latter are species that due to lack of studies or were not identified at specific levels could not be included in any of the groups mentioned above.

The individuals identified were classified as dispersion syndrome according to the methodology proposed by Pijl [16] and consulted literature. The following phytosociological parameters were calculated: Density, Absolute (DA) and Relative (DR); Frequency, Absolute (FA) and Relative (FR); Dominance, Absolute (DoA) and Relative (DoR) [17]; and Relative Natural Regeneration (RNR) [18] with the aid of software Microsoft Excel for Windows™ 2013.

3. RESULTS AND DISCUSSION

In the survey carried out on the natural regeneration of shrub-tree species, 41 species belonging to 31 genera and 24 botanical families, and one morphospecies were registered. Two hundred sixty six individuals were counted, obtaining a density of 8,867 ind ha^{-1} (Table 1) The estimated density value was higher than that found in similar remnants in the state of Pernambuco, such as those studied by Silva et al. [19] and Aparício et al. [20], respectively, 5,680, 2,854 and 4,123 ind. ha^{-1}, and lower than that found by Oliveira et al. [7] which estimated 10,853 ind. ha^{-1}. These values may indicate that the study area is in a good state of conservation, considering the variations in density among fragments of the same phytophysiognomy, although the area of study has as a history of disturbance regarding to its constant use as a military training area.

The species with the highest estimated densities were *Protium heptaphyllum, Erythroxylum mucronatum and Hirtella racemosa*, respectively 1,333, 1,133 and 933 ind.ha^{-1}. In relation to the species distribution, it is observed that *Erythroxylum mucronatum, Protium heptaphyllum and Cupania revoluta* were the most frequent in the sample units. These species have the zoocoria as dispersion syndrome, which contributes to their dispersion in long distances and more favorable places for their germination and consequent establishment, since the dispersion can influence in the distribution patterns of the species, mainly of the arboreal ones [32].

The five richest families were Fabaceae and Myrtaceae with 12.5%, Melastomataceae with 10%, Anacardiaceae and Sapindaceae with 7.5% of the species, being responsible for 50% of the total species identified and 39.47% of the individuals sampled. The other families were represented by a single species each.

Table 1. Floristics of the shrub-tree species found in the regenerating stratum of a Atlantic Forest remnant, Forest of Miritiba Wildlife Refuge, northeast region, Brazil

Family/Species	N.	EG	DS	Reference[1]
Anacardiaceae				
Schinus terebinthifolius Raddi	1	P	Zoo	[21]
Tapirira guianensis Aubl.	3	P	Zoo	[22]
Thyrsodium spruceanum Benth.	1	Ls	Zoo	[23]
Annonaceae				
Xylopia frutescens Aubl.	1	Is	Zoo	[23]
Apocynaceae				
Himatanthus phagedaenicus (Mart.) Woodson	7	Is	Ane	[24]
Araliaceae				
Schefflera morototoni (Aubl.) Maguire, Steyerm. & Frodin	1	Is	Zoo	[22]
Boraginaceae				
Cordea nodosa Lam	3	iS	Zoo*	[21]
Burseraceae				
Protium heptaphyllum (Aubl.) Marchand	40	Ls	Zoo	[25]
Celastraceae				
Maytenus obtusifolia Mart.	2	Ls	Zoo*	[21]
Chrysobalanaceae				
Hirtella racemosa Lam.	28	Is	Zoo	[22]
Clusiaceae				
Clusia nemorosa G.Mey.	1	Ls	Zoo*	[22]
Erythroxylaceae				
Erythroxylum mucronatum Benth.	34	Ls	Zoo*	[22]
Euphorbiacae				
Pera glabrata (Schott) Poepp. ex Müll.Arg.	2	Is	Aut	[26]
Fabaceae				
Andira nitida Mart	1	Is	Zoo	[26]
Bowdichia virgilioides Kunth.	2	Ls	Ane	[27]
Inga thibaudiana DC.	5	Is	Zoo	[22]
Plathymenia foliolosa Benth.	6	Is	Ane	[28]
Swartzia pickelii Killip ex Ducke	3	Is	Zoo*	[21]
Hypericaceae				
Vismia guianensis (Aubl.) Choisy	1	P	Zoo	[29]
Lauraceae				
Ocotea gardneri (Meisn.) Mez	1	Is	Aut	[30]
Lecythidaceae				
Eschweilera ovata (Cambess.) Mart. ex Miers	19	Is	Aut	[24]
Malphigiaceae				
Byrsonima sericea DC.	1	Is	Zoo	[23]
Melastomataceae				
Miconia cuspidata Naudin	2	Is	Zoo	[31]
Miconia hypoleuca (Benth.) Triana	1	Is	Zoo	[31]
Miconia multiflora Cogn. ex Britton	1	P	Zoo	[31]
Miconia prasina (Sw.) DC.	6	P	Zoo	[31]
Moraceae				
Brosimum guianense (Aubl.) Huber	7	Is	Zoo*	[21]
Brosimum lactescens (S.Moore) C.C.Berg	2	Is	Zoo	[22]
Myrtaceae				
Eugenia punicifolia (Kunth) DC.	1	Ls	Zoo*	[21]
Myrcia guianensis (Aubl.) DC.	14	Is	Zoo	[24]
Myrcia silvatica Barb. Rodr.	1	Is	Zoo	[21]
Myrcia splendens (Sw.) DC.	3	Is	Zoo	[21]
Myrcia tomentosa (Aubl.) DC.	20	Is	Zoo*	[21]

Family/Species	N.	EG	DS	Reference[1]
Nyctaginaceae				
Guapira laxa (Netto) Furlan	5	Is	Zoo*	[21]
Ochnaceae				
Ouratea castaneifolia (DC.) Engl.	3	Is	Zoo*	[21]
Primulaceae				
Myrsine guianensis (Aubl.) Kuntze	3	Ls	Zoo	[26]
Salicaceae				
Casearia javitensis Kunth	4	Ls	Zoo	[26]
Sapindaceae				
Cupania oblongifolia Mart.	6	Is	Zoo	[26]
Cupania racemosa (Vell.) Radlk.	3	Is	Zoo	[26]
Cupania revoluta Radlk.	16	Is	Zoo	[24]
Morfoespécie				
Morfoespécie 1	5	Wc		
Total geral	**266**			

*In what: EG= Ecological group P= pioneer; Is= initial secondary; Ls= Late secondary, Wc= without characterization; DS = Dispersion syndrome; Zoo = Zoochorical; Ane = Anemochorical; Aut = Autochorical. [1]References consulted for the classification of the dispersal syndrome of the diaspores of the species. *Species that were only classified by the same genus*

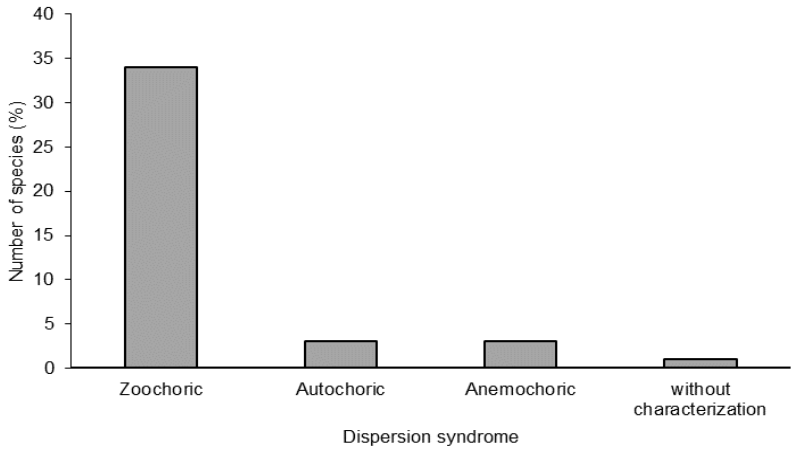

Fig. 1. Diaspora dispersal syndrome of shrub-tree species identified in natural regeneration in Atlantic Forest remains, Forest of Miritiba Wildlife Refuge, Pernambuco, Brazil

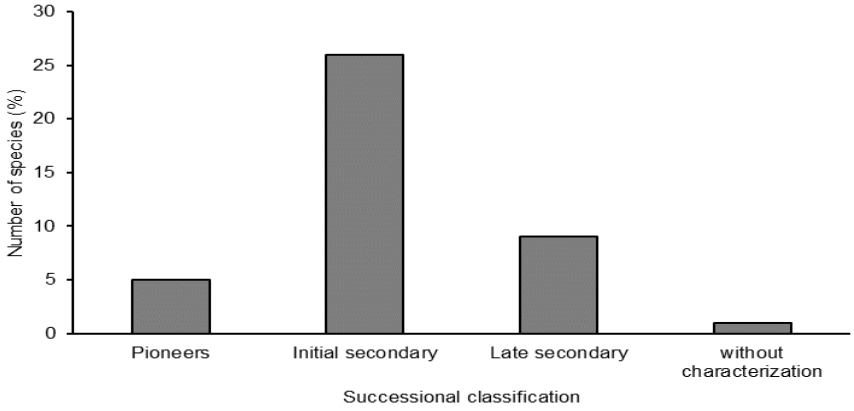

Fig. 2. Successional classification of arboreal species identified in natural regeneration, Atlantic Forest remnant, forest of Miritiba Wildlife Refuge, Pernambuco, northeast region Brazil

Table 2. Estimation of the total natural regeneration and by height class of the shrub-tree species found in the regenerating stratum of a atlantic forest remnant, forest of Miritiba Wildlife Refuge, northeast region of Brazil

Scientific name	DA(Ind./ha)	FA(%)	Height class									
			DR*	FR*	RN*	DR**	FR**	RN**	DR***	FR***	RN***	RNT***
Protium heptaphyllum	1.333	66.67	14.13	9.43	11.78	10.53	11.32	10.92	17.95	13.21	15.58	12.76
Erythroxylum mucronatum	1.133	75.00	26.09	13.21	19.65	15.79	11.32	13.56	0.85	1.89	1.37	11.52
Hirtella racemosa	933	50.00	2.17	3.77	2.97	12.28	7.55	9.91	16.24	11.32	13.78	8.89
Myrcia tomentosa	667	41.67	5.43	5.66	5.55	7.02	5.66	6.34	9.40	7.55	8.47	6.79
Eschweilera ovata	633	58.33	7.61	7.55	7.58	7.02	7.55	7.28	6.84	7.55	7.19	7.35
Cupania revoluta	533	66.67	1.09	1.89	1.49	1.75	1.89	1.82	11.97	15.09	13.53	5.61
Myrcia guianensis	467	58.33	5.43	7.55	6.49	10.53	7.55	9.04	2.56	1.89	2.23	5.92
Brosimum guianense	233	50.00	5.43	7.55	6.49	0.00	0.00	0.00	1.71	3.77	2.74	3.08
Himatanthus phagedaenicus	233	41.67	3.26	5.66	4.46	0.00	0.00	0.00	3.42	7.55	5.48	3.31
Cupania oblongifolia	200	41.67	1.09	1.89	1.49	1.75	1.89	1.82	3.42	3.77	3.60	2.30
Miconia prasina	200	16.67	3.26	1.89	2.57	1.75	1.89	1.82	1.71	1.89	1.80	2.06
Plathymenia foliolosa	200	8.33	2.17	1.89	2.03	0.00	0.00	0.00	3.42	7.55	5.48	2.50
Guapira laxa	167	25.00	2.17	1.89	2.03	5.26	5.66	5.46	0.00	0.00	0.00	2.50
Morfoespécie	167	25.00	3.26	3.77	3.52	3.51	3.77	3.64	0.00	0.00	0.00	2.39
Inga thibaudiana	167	16.67	1.09	1.89	1.49	1.75	1.89	1.82	2.56	5.66	4.11	2.47
Casearia javitensis	133	25.00	0.00	0.00	0.00	3.51	3.77	3.64	1.71	3.77	2.74	2.13
Cordea nodosa	100	25.00	3.26	5.66	4.46	0.00	0.00	0.00	0.00	0.00	0.00	1.49
Cupania racemosa	100	25.00	1.09	1.89	1.49	0.00	0.00	0,00	1.71	1.89	1.80	1.09
Myrcia splendens	100	16.67	0.00	0.00	0.00	1.75	1.89	1.82	1.71	1.89	1.80	1.21
Myrsine guianensis	100	8.33	0.00	0.00	0.00	0.00	0.00	0.00	2.56	3.77	3.17	1.06
Ouratea castaneifolia	100	8.33	3.26	1.89	2.57	0.00	0.00	0.00	0.00	0.00	0.00	0.86
Swartzia pickelii	100	8.33	1.09	1.89	1.49	1.75	1.89	1.82	0.85	1 89	1.37	1.56
Tapirira guianensis	100	8.33	0.00	0.00	0,00	1.75	1.89	1.82	1.71	3.77	2.74	1.52
Bowdichia virgilioides	67	16.67	0.00	0.00	0.00	1.75	1.89	1.82	0.85	1.89	1.37	1.06
Brosimum lactescens	67	16.67	1.09	1.89	1.49	1.75	1.89	1.82	0.00	0.00	0.00	1.10
Maytenus obtusifolia	67	16.67	1.09	1.89	1.49	1.75	1.89	1.82	0.00	0.00	0.00	1,10
Miconia cuspidata	67	8.33	1.09	1.89	1.49	0.00	0.00	0.00	0.85	1.89	1.37	0.95
Pera glabrata	67	8.33	1.09	1.89	1.49	1.75	1.89	1.82	0.00	0.00	0.00	1,.10
Andira nitida	33	8.33	1.09	1.89	1.49	0.00	0.00	0.00	0.00	0.00	0.00	0.50
Byrsonima sericea	33	8.33	0.00	0.00	0.00	0.00	0.00	0.00	0.85	1.89	1.37	0.46
Clusia nemorosa	33	8.33	1.09	1.89	1.49	0.00	0.00	0.00	0.00	0.00	0.00	0,50
Eugenia punicifolia	33	8.33	1.09	1.89	1.49	0.00	0.00	0.00	0.00	0.00	0.00	0.50

Scientific name	DA(Ind./ha)	FA(%)	Height class									
			DR*	FR*	RN*	DR**	FR**	RN**	DR***	FR***	RN***	RNT***
Miconia hypoleuca	33	8.33	0.00	0.00	0.00	0.00	0.00	0.00	0.85	1.89	1.37	0.46
Miconia multiflora	33	8.33	0.00	0.00	0.00	1.75	1.89	1.82	0.00	0.00	0.00	0.61
Myrcia silvatica	33	8.33	0.00	0.00	0.00	0.00	0.00	0.00	0.85	1.89	1.37	0.46
Ocotea gardneri	33	8.33	0.00	0.00	0.00	0.00	0.00	0.00	0.85	1.89	1.37	0.46
Schefflera morototoni	33	8.33	0.00	0.00	0.00	0.00	0.00	0.00	0.85	1.89	1.37	0.46
Schinus terebinthifolius	33	8.33	0.00	0.00	0.00	1.75	1.89	1.82	0.00	0.00	0.00	0.61
Thyrsodium spruceanum	33	8.33	0.00	0.00	0.00	0.00	0.00	0.00	0.85	1.89	1.37	0.46
Vismia guianensis	33	8.33	0.00	0.00	0.00	0.00	0.00	0.00	0.85	1.89	1.37	0.46
Xylopia frutescens	33	8.33	0.00	0.00	0.00	1.75	1.89	1.82	0.00	0.00	0.00	0.61
Total Geral	**8.867**											

*Where: *Species included in class I height: 1 m ≤ Height ≤ 2 m; ** Species included in class II height: 2 m > Height ≤ 3 m; *** Species included in class III height: Height > 3 m and CAP < 15 cm*

In relation to the dispersion syndrome (Fig. 1) zoochoric predominated with 83%. This greater representativeness of zoochory is common in surveys carried out in forests of the Brazilian coast as verified by Borgo et al. [21], in a floristic survey of the arboreal component in an area of Ombrophylous Dense Forest, Paraná, which found 81.7%.

In tropical forests, about 98% of the species have zoochoric dispersion [33,22,26], which demonstrates the importance of forest remnants as a source of propagules and food for local and surrounding fauna, facilitating their dispersion to nearby areas and increasing local diversity.

In relation to successional classification, there was a predominance of 63% of the species categorized as initial secondary (Fig. 2.) indicating that the remainder studied is in the middle stage in the succession, this probably can be related to anthropic actions, since it is an area of military training and is located near housing.

Studies carried out in forest remnants in the region, with the same forest typology, have presented similar results with predominance of initial secondary species as verified by Oliveira et al. [26], in a fragment of Dense Ombrophylous Forest, found 66% of the species as initial secondary; Silva et al. [19] with 46% and Brandão et al. [34] with 55% of the species at the beginning of succession, initial secondary.

Through natural regeneration of the forest, the floristic composition and structure are changing and the community tends to become more and more diversified over time, since succession is a continuous process, with several successional stages that vary between regions, climatic zones and land uses [35]. Thus, it is evident that the regenerating species are still in the process of establishment in the fragment.

Of the 41 species, only 11 were in all three size classes, which may probably indicate a variation in the entry of new individuals. The species best represented in the three classes were *Protium heptaphyllum*, *Eschweilera ovata, Myrcia guianensis, Myrcia tomentosa* and *Hirtella racemosa* (Table 2). The species that stand out with the highest estimates of natural regeneration can be considered well adapted in the community, presenting good efficiency in the establishment and development [2,7].

The species that occurred in the three regeneration classes can be considered species indicative of the future composition of the forest [2], since they constitute stock of vegetation and tend to occupy the upper classes gradually, as favorable conditions for their growth arise.

However, those that were well represented in the higher class were: *Cupania revoluta, Hirtella racemosa, Protium heptaphyllum* and *Myrcia tomentosa*, probably due to a good seed production in previous years of the adult individuals of these species. In relation to the species *Erythroxylum mucronatum*, the highest concentration of individuals is in the smaller height class, because it is a shrub fairly found in the natural regeneration.

The estimated Shannon diversity index was 3.04 nats.ind^{-1} and the Pielou equability index was 0.82 for the regenerating component, indicating high diversity and some uniformity in the number distribution of individuals per species. Similar results were found by Silva et al. [3], which observed a diversity of 3.5 nats.ind^{-1} and 0.85 equability in a remnant of Tropical Rainforest located in the Zona da Mata Sul of Pernambuco, and for Oliveira et al. [7], which found the Shannon diversity index of 3.45 nats.ind^{-1} and the Pielou equability index was 0.88 for the regenerating component of forest of the Onça, Pernambuco, Brazil.

According to Marangon [36], this variation in the values of the diversity index, even within the same phytogeographic region, can probably be related to differences in succession stages, sampling methodologies, inclusion levels, floristic dissimilarity among different communities.

4. CONCLUSION

The studied fragment was conserved, although anthropic activities are developed in the area. Among the species with higher density that can be indicated for enrichment of areas in recovery process are *Protium heptaphyllum, Erythroxylum mucronatum, Hirtella racemosa, Myrcia tomentosa* and *Eschweilera ovata.*

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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