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Diversity and Structure of the Arbor Component in Ravine and Flat Land Environmental Conditions: A Case Study in Tropical Rainforest, Brazil

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Authors' contributions

This work was carried out in collaboration with all authors. All authors developed the study proposal. Authors JNBS, GS, NDS, JATS and PFRC implemented and collected the data and participated in the writing of the article together with authors LCM and ALPF. The species identification was performed by author NDS, the phytosociological data were calculated by authors JNBS and GS. Author JNBS performed all the statistical calculations. All authors read and approved the final manuscript.

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ABSTRACT

The objective of this research was to study the diversity and forest structure in fragments with different topographic conditions, relating these components to the tree biomass compartment. Two small fragments of post-disturbance Atlantic Forest, on ravine and flat land areas, were sampled. The numbers effective Hill diversity (qD) and the intensity curves was obtained in both environmental conditions and compared by rarefaction ($P = .05$). The forest structure was dimensioned using the basal area (BA); diameter of breast height (DBH), total height (H) and tree biomass above ground (AGB), estimated using an adjusted local equation for endangered forests. According to the diversity profiles, it was proved that the ravine has a higher qD for all orders, for both dominant and uncommon species ($P < .05$). Regarding the forest structure, the ravine showed higher H (greater competitive tendency), a lower investment in DBH ($\bar{x} = 13.05 \pm 7.94$ cm) in

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relation to the flat land (x̅ = 38.01 cm ± 17.28 cm), and consequently, low investment in AGB (x̅ = 306.20 ± 354.08 kg e x̅ = 2336.37 ± 2078.34 kg ravine and flat land, respectively). The present study confirmed the hypotheses of structural change and diversity of the tree component in the different conditions studied, being these factors considered important for the processes of community structuring. These evidences trace back the importance of small forest fragments in ravine conditions and their role in maintaining the Atlantic Forest biodiversity.

Keywords: Diversity profiles; ravine forest; dense ombrophilous forest; rough relief.

1. INTRODUCTION

Biodiversity is a complex, multifaceted concept that includes not only the species richness but also the abundance and factors that leads this particular effect on the community structure, considered crucial to their understanding [1,2]. There is a consensus that processes that structure plant communities can be driven by biogeographic factors (large scale) that operates in regional species groups, and community processes (small scale) that influence the composition and diversity of the regional species pool [3,4]. From these emerging concepts on biodiversity and the magnitude of geographic scales, several questions about ecological patterns can be widely discussed, e.g., the role of environmental complexity on species structure and diversity, and how these properties are maintained throughout biological communities [5].

In light of these questions, small environmental gradients such as forest ravines provides opportunities to understand ecological patterns and preferences of plants and can foster a greater degree of understanding about underlying community mechanisms and patterns. Changes in environmental conditions, in small landscape segments, provide extremely diverse habitats, since spatially heterogeneous abiotic conditions should provide greater diversity of niches than the homogeneous landscapes [6,7]. Proof of this, are works that drew attention about the diversity of soil fauna [8] and of plants, in similar latitude environments [9,10], evidencing very particular results in ravines. Nevertheless, studies in this field of threatened fragments on the Atlantic Forest are shown as practically nonexistent, and when they do exist, they are centered in the "Zona da Mata" area of the state of Minas Gerais, especially for phytophysiognomies of semideciduous seasonal forests [11,12,13,14,15].

Considering the topographic complexity, ravines with forest vegetation are considered microclimatic gradients due to slope differences of the terrain, considered conductors of flora, fauna, physical and chemical soil properties (humidity, pH and nutrients) [8]. For example, the declivity may interfere with the organization of forest structure (canopy verticalization) and promote variations in the light penetration angles within the forest. This promotion in the forest extract lowers the canopy in areas of lower slope and accentuates the canopy in areas of higher elevations [16]. Parallel to that, humidity can also provide a suitable living environment for species that prefer hot and humid environments [9]. Given these aspects, it is expected that adjustments in composition or abundance in the community provides differences in the ecological processes and changes on the aesthetic, functional and ecophysiological characteristics of plants [17].

For decades, plant communities diversity was sized based only on floristic composition or the absolute number (or percentage) of species. In these studies, the different facets that composes the diversity end up being inferiorized and consequently underutilized; first, because they are quantified by inconsistent methodologies; second, the traditional methodologies are more sensitive to the quantification of rare species and difficult to consider the common species [18,19]. This problem is because the species richness has complex mathematical properties, increasing in a non-linear way, be it in function of the number of individuals, the number of samples collected or the area sampled. Therefore, the way the wealth is calculated by simple indexes are inevitably biased estimates of the true diversity [20]. In this sense, an emerging view is that the studies direct information for conservationists' actions and that seek to understand the underlying processes and mechanisms responsible for modeling the structure of the communities through more accurate and appropriate methodologies.

The Atlantic Forest suffers constantly with the effects of fragmentation and the disorderly population growth. Large urban areas provide evidences for the most diverse ecological problems, such as habitat loss, considered a worldwide widespread problem, and the declining of native species diversity [21]. In this scenario, a variety of conditions comes into existence, given the great heterogeneity of anthropogenic factors and ways of exploiting resources. Many problems emerge when the majority of forest fragments are located in urban areas that are becoming mosaics of besieged vegetable formations. Despite the intense fragmentation (post-disturbances), there is clear evidence that small fragments play an important role for the biodiversity conservation, since regulated reserves are still shown as insufficient to compensate for the losses generated by anthropogenic factors [22]. Understanding how the topographic heterogeneity effects acts about tree community processes can be important to support flood and erosion studies and on the perspective of climate change, species adaptability, gain management and diversity loss [23]. In addition to that, to back the conservation through restoration techniques in environments with a certain degree of ecological peculiarity in the Endangered Tropical Forests scenario. The importance of conducting studies on threatened fragments of Atlantic Forest are very strong, because they can subsidize contributions to the preservation of the fragments that still exist, as well as support actions for the restoration of environments that are degraded [24].

It is essential to reconcile different emerging approaches in the ecology of communities; one that seeks to understand diversity patterns and plants distribution and another that emphasizes the fine-tuning of species in communities governed by different abiotic conditions. The objective of the present work was to study the diversity and forest structure of the vegetation under different environmental conditions, i.e., between the topographic condition of the ravine and flat land. For this purpose, it was evaluated the floristic composition; the different diversity profiles in the tree component; the forest structure (here described by canopy heterogeneity and tree diameter) and the relation of species richness and the forest biomass compartment. All vegetation components were investigated in post-disturbed small fragments of Atlantic Forest (3.6 - 6.8 ha), under two distinct conditions, ravine and flat land, considering the heterogeneity of abiotic factors in the light availability in tropical forests [25] and its effects on diversity and biomass [26,27]. The hypothesis of the present study is that small-scale environmental changes, in small post-disturbance fragments, promotes systematic effects on the effective numbers of species diversity, species composition, and on the forest structure throughout the two studied conditions. It is also expected that the ravine condition has a greater variation in the canopy verticalization, smaller investment in diameter and consequently, smaller compartment of the forest biomass above the ground.

2. MATERIALS AND METHODS

The present work was developed in two small fragments of rainforest - Atlantic Forest [28], located in the municipality of Paudalho, Pernambuco, Brazil. The two geographically close fragments were classified in two distinct environmental conditions; (i) ravine condition: considered the portions of the middle and upper thirds of the slopes (the ravine base was not sampled due to the existence of a body of water); and (ii) flat land condition: considered part of the plain, located at the top area and without significant changes in the slope of the terrain. The flat land fragment is located at the coordinates: 7º 55' 57.31" S and 35º 02' 10.59" W, having approximately 6.8 ha and elevation ranging from 141 to 143 m. The ravine fragment is located at 434.56 m from the center of the flat land fragment, having approximately 3.6 ha and located at the coordinates: 7° 55' 59.93" S and 35° 02' 23.51" W (Fig. 1). The formation process of the ravine is of a natural order, being that its headbed, to this day, faces problems associated to erosion and top water runoff towards the base, Northwest portion (see map), the depth of the ravine varies from 120 to 135 m of elevation.

The region climate is defined as “As” and conforms to the determinations of the climatic types of Köppen-Geiger; characterized by the existence of seasonal seasons with little air temperature variation throughout the year (monthly precipitation ranging from 39.6 to 239.5 mm), considered, predominantly humid with regulated water deficiency in the summer (accumulated annual rainfall of 2,000 mm) [29]. The study site soils are classified as yellow Latosol of texture varying from sandy-loam to very clayey, with a predominantly weak development degree; being soils of good physical condition, of easy handling and mechanization, facilitating the roots penetration, with good capacity of water storage. In addition, they are also described as weathered and

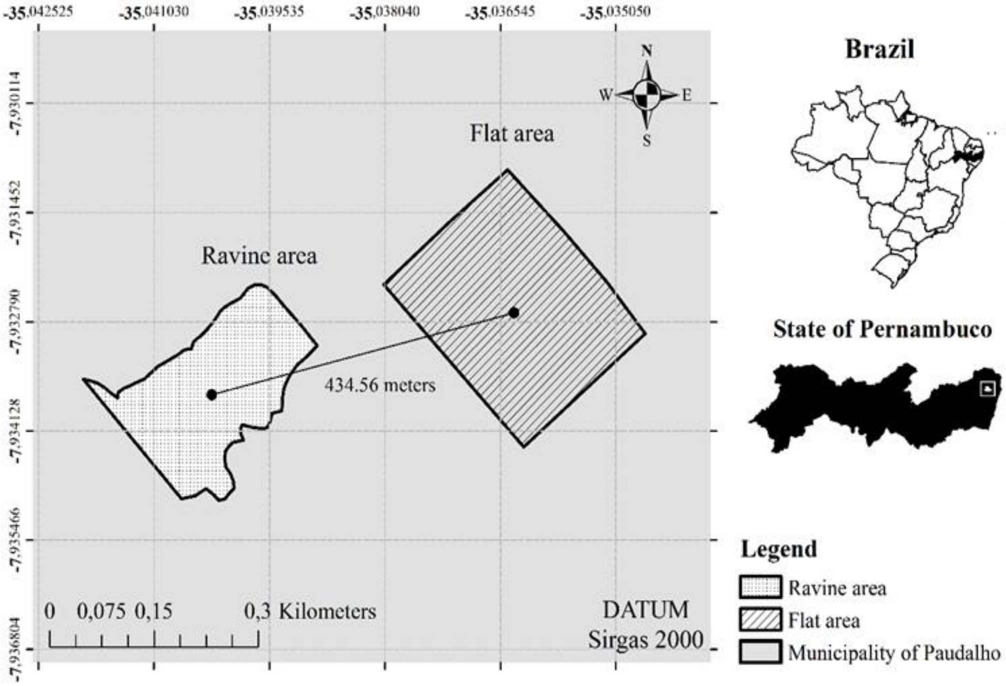

Fig. 1. Geographic location of the two fragments destined to the conservation of the Atlantic Forest, municipality of Paudalho - PE, Brazil

evolved, almost devoid of primary materials with low cationic exchange capacity, acids and low base saturation [30]. The landscape in the past had the original vegetation modified by the historical process of fragmentation, based on the timber trees exploitation and land clearing for the planting of sugarcane [31]. After the deforestation process, both fragments were destined for conservation as private property of a residential condominium. These vegetation areas are inserted in a landscape surrounded by dozens of remnants and forest fragments, where the matrix is, predominantly, sugarcane and urban.

The community descriptors were measured from a phytosociological survey (random plots) [32]. The plots were randomly allocated in order to cover the entire study area. In both fragments, a distance of 25 m from the fragment boundary border was obeyed. A total of 8 plots with a size of 10 x 25 m were allocated, being four plots in the environmental flat condition fragment and four plots in the ravine fragment, totaling a sample area of 2000 m². All individuals with circumference at breast height equal to or greater than 15 cm (CBH ≥ 15 cm) were measured and their respective heights estimated with high pruning scissors modules with 1 m modules.

The species were identified according to the Angiosperm Phylogeny Group - APG III [33], by comparison with exsiccates deposited in the Herbarium Professor Vasconcelos Sobrinho and Herbarium Sérgio Tavares, both of the Federal Rural University of Pernambuco (UFRPE). The current species nomenclature was checked by consultations to the Missouri Botanical Garden database (http://www.tropicos.org). The main phytosociological parameters of the community in the different areas were estimated [34], being them: absolute density (AD), absolute frequency (AF), absolute dominance (ADo) expressed by the basal area, abundance and/or relative density (RD), relative frequency (RF), relative dominance (RDo) and importance value (IV).

In order to quantify the sampling intensity ($\hat{C}_n$) of the surveys in each condition (ravine and flat land), the sample coverage estimator [35] was used, whose parameter can be calculated by the following equation:

$$\hat{C}_n = 1 - \frac{f_1}{n}\left[\frac{(n-1)f_1}{(n-1)f_1+2f_2}\right] \quad (1)$$

where: $\hat{C}_n$ = sample coverage intensity; f_1 = species represented by exactly one individual in the sample and f_2 = number of duplicate species in the sample. Beyond that, the entropy based on

Hill's effective numbers of diversity was calculated for each condition [36]. This estimator includes the three diversity measures of species most used as: species richness (q = 0), exponential of the Shannon diversity (q = 1) and Simpson diversity (q = 2), the latter can also be called number of common species [18]. This estimator can be calculated by the following equation:

$$qD = \left(\sum_{i=1}^{S} p_i^q\right)^{1/(1-q)} \tag{2}$$

where: S = number of species; pi = relative abundance and q = is the parameter that determines the sensitivity to the relative densities and/or abundances. The "iNEXT" package functions of the R software (iNterpolation /EXTrapolation), which provides functions for calculating and plotting the sample curves by interpolation and extrapolation, based on the sample coverage intensity, were used along with the 95% of probability confidence intervals [19]. The bootstrap randomization method was applied to obtain approximate variances for each diversity component (q = 0, 1 and 2), and, later, the associated confidence limits (α = 0.05) were constructed.

The vertical structure of the different conditions was measured using the basal area (BA), which, together with the diameter of the breast height (DBH) can provide a better explanation about the trunks heterogeneity; the total height (H), which means to describe the extracts heterogeneity within the forest and at the same time is associated to the competitive capacity of the plants, since smaller trees are often associated with more stressful environments [37; 38]. Finally, aboveground tree biomass (AGB) can provide insight into the productivity and storage of carbon in each environmental condition. The AGB was estimated from a regression equation (non-destructive method), which allows estimating the biomass of this compartment by measurements of the trees aerial parts, such as the basal area (BA), total height (H) and diameter at breast height (DBH). This equation (Equation 01) was adjusted for threatened Atlantic Forest fragments, in an area near the study site, and presented satisfactory efficiency according to the statistical criteria used; low bias, accuracy and homogeneity in the error variance (εi) [39].

$$AGB = 1.5292 * DBH^{2.0601} * H^{-0.2187} \tag{3}$$

The hypothesis of differences between the structural components (i.e., DBH, BA, H and AGB) in each environmental condition was verified by the Student's t-test (P = .05). For this, all the assumptions necessary for the statistical inference was evaluated, followed by protocol recommendations for the ecological data exploration [40]. Most of the data presented homogeneity of variance by logarithmic transformation. However, even so, when the assumption of homogeneity was not met, the "var.equal = FALSE" function of the "stats" package was used in the R environment, considered more appropriate for heterogeneous variances between data samples.

Parallel to the effective numbers diversity, the traditional Shannon (H') and Simpson dominance (-ln(D')) indexes were calculated from the environment R's “vegan” (ecological diversity) package in order to provide a slight discussion of the use and limitations of these indices.

All statistical manipulation of the data, as well as the graphs construction were performed with the aid of the R environment version 3.4.0 [41].

3. RESULTS

3.1Species Composition

In the ravine interior, 115 tree individuals (1150 ind.ha^{-1}) were recorded, distributed in 26 families, 36 genera and 45 species (3 identified at the family level). The families with the greatest wealth were: Fabaceae (5 species), Moraceae and Myrtaceae (4 species each) and Sapotaceae (3 species). The genera with the greatest abundance and/or relative density (RD) were: Eschweilera (1 species - 24 individuals), Anaxagorea (1 species - 8 individuals) and Pera (1 species - 7 individuals). In the flat land, 145 arboreal individuals (1450 ind.ha^{-1}) were sampled, distributed in 21 families, 31 genera and 39 species (4 identified only at the family level and 1 at the genus level). The families with the greatest richness were: Fabaceae (8 species), Melastomataceae and Sapindaceae (3 species each). The genus of higher RD was also Eschweilera (1 species - 50 individuals), followed by Chamaecrista (1 species - 13 individuals) and Tapirira (1 species - 11 individuals).

The floristic profile sampled for the two areas is characteristic of Atlantic Forest remnants in the state of Pernambuco [42; 43; 44]. Both areas share 16 species, that is, that occurred in both conditions, with at least 1 sampled individual.

The species composition clearly differed between the conditions; 29 species (64%) were sampled, preferably in the ravine, while in the flat land 23 species (74%) were sampled (Anex. 1 - supplementary material). The relative abundance patterns of the species in the areas also showed a change. The flat land concentrated most of the relative values of individuals density in 9 species (RD = 70.0%). In contrast, in the ravine area, the relative abundance of individuals shows as more distributed, about twice as many species (RD = 70.43%).

Anex. 1. Floristic composition of tree species for the ravine and flat land conditions and alphabetical order of family, genus and species (R = ravine; F = flat land and Ni = number of individuals) in the Atlantic Forest, Paudalho municipality - PE. Details with dash (-), denotes the absence of the species in the studied condition

Family/Species	Common name	Ni	
		R	F
Anacardiaceae			
Tapirira guianensis Aubl.	"Cupiúba"	1	11
Annonaceae			
Anaxagorea dolichocarpa Sprague & Sandwith	"Aticum-da-mata"	8	−
Araliaceae			
Schefflera morototoni (Aubl.) Maguire, Steyerm. & Frodin	"Sambacuim"	1	6
Arecaceae			
Bactris ferruginea Burret	"Coquinho-da-mata"	4	1
Boraginaceae			
Cordia superba Cham.	"Babosa-branca"	1	4
Burseraceae			
Protium aracouchini (Aubl.) Marchand	"Amesclinha"	2	−
Protium giganteum Engl.	"Amesclão"	3	−
Protium heptaphyllum (Aubl.) Marchand	"Amescla-de-cheiro"	−	1
Celastraceae			
Maytenus distichophylla Mart. ex Reissek	"Bom-nome"	−	2
Chrysobalanaceae			
Licania kunthiana Hook. f.	"Marinheiro"	1	−
Clusiaceae			
Garcinia gardneriana (Planch. & Triana) Zappi	"Bacupari"	2	−
Tovomita brevistaminea Engl.	"Mangue-da-mata"	1	−
Combretaceae			
Buchenavia tetraphylla (Aubl.) R.A. Howard	"Tanimbuca"	−	2
Elaeocarpaceae			
Sloanea garckeana K. Schum.	"Urucurana-brava"	−	4
Sloanea guianensis (Aubl.) Benth.	"Mamajuba-preta"	4	−
Euphorbiaceae			
Senefeldera verticillata (Vell.) Croizat	"Maria-mole"	1	−
Fabaceae			
Abarema cochliacarpos (Gomes) Barneby & J.W. Grimes	"Barbatimão"	−	1
Albizia pedicellaris (DC.) L. Rico	"Jaguarana"	1	1
Bowdichia virgilioides Kunth	"Sucupira"	3	1
Chamaecrista ensiformis (Vell.) H.S. Irwin & Barneby	"Pau-ferro"	−	13
Dialium guianense (Aubl.) Sandwith	"Azedinha"	2	1
Inga capitata Desv.	"Ingá"	−	1
Parkia pendula (Willd.) Benth. ex Walp.	"Visgueiro"	3	−
Plathymenia foliolosa Benth .	"Amarelinho"	−	1
Pterocarpus rohrii Vahl	"Pau-sangue"	1	−
Sclerolobium densiflorum Benth.	"Ingá-porco"	−	1

Family/Species	**Common name**	**Ni**	
		R	**F**
Fabaceae			
Swartzia pickelii Killip ex Ducke	“Jacarandá”	−	1
Fabaceae 1		−	2
Continuação... Anexo 1			
Lauraceae			
Ocotea glomerata (Nees) Mez	“Louro-abacate”	−	2
Lecythidaceae			
Eschweilera ovata (Cambess.) Miers	“Embiririba”	24	46
Lecythis pisonis Cambess.	“Sapucaia”	−	4
Malvaceae			
Luehea paniculata Mart.	“Açoita-cavalo”	−	5
Melastomataceae			
Miconia affinis DC.	“Jacatira-branca”	1	8
Miconia hypoleuca (Benth.) Triana	“Carrasco-branco”	−	2
Miconia pyrifolia Naudin	“Jacatirão”	−	1
Moraceae			
Artocarpus heterophyllus Lam.	“Jaqueira”	3	−
Brosimum discolor Schott	“Muirapinima”		1
Brosimum guianense (Aubl.) Huber	“Quiri”	1	2
Clarisia racemosa Ruiz & Pav.	“Oiticica”	1	−
Helicostylis tomentosa (Poepp. & Endl.) Rusby	“Amora-da-mata”	5	−
Myrtaceae			
Campomanesia dichotoma (O.Berg) Mattos	“Guabiraba”	1	1
Eugenia umbrosa O.Berg	“Eugênia”	1	−
Myrcia racemosa (O.Berg) Kiaersk.	“Murta”	1	−
Myrtaceae 1		1	−
Nyctaginaceae			
Guapira opposita (Vell.) Reitz	“Maria-mole”	1	2
Peraceae			
Pera glabrata (Schott) Poepp. ex Baill.	“Sete-cascos”	7	1
Pogonophora schomburgkiana Miers ex Benth.	“Cocão-amarelo”	2	3
Primulaceae			
Myrsine guianensis (Aubl.) Kuntze	“Capororoca”	1	−
Rubiaceae			
Alseis pickelii Pilg. & Schmale	“Pau-candeia”	4	−
Rubiaceae 1		−	2
Rutaceae			
Rutaceae 1		1	−
Sapotaceae			
Manilkara salzmannii (A. DC.) H.J.Lam	“Maçaranduba”	1	−
Sapotaceae			
Pradosia lactescens (Vell.) Radlk.	“Abiu-de-macaco”	−	1
Pouteria torta (Mart.) Radlk.	“Guapeva”	3	−
Pouteria sp.		1	−
Salicaceae			
Casearia javitensis Kunth	“Cafézinho”	2	2
Casearia sylvestris Sw.	“Cafézinho-do-mato”	−	1
Sapindaceae			
Allophylus edulis (A. St.-Hil., A. Juss. & Cambess.) Hieron. ex Niederl.	“Chal-chal”	2	2
Continuação... Anexo 1			
Cupania racemosa (Vell.) Radlk.	“Camboatã”	−	3
Cupania impressinervia Acev.-Rodr.	“Camboatã-de-rêgo”	−	1

Family/Species	**Common name**	**Ni**	
		R	**F**
Simaroubaceae			
Simarouba amara Aubl.	"Praíba"	2	–
Violaceae			
Rinorea guianensis Aubl.	"Aquariquara"	4	–
Indeterminadas			
Indeterminada 1		2	–
Indeterminada 2		1	–
Indeterminada 3		1	–
Indeterminada 4		1	–
Indeterminada 5		1	–
Indeterminada 6		–	1
Total		115	145

The species with the highest value of importance (VI) in the ravine were *Eschweilera ovata* (12.62%), *Sloanea guianensis* (10,37%), *Helicostylis tomentosa* (4,83%), *Clarisia racemosa*, *Parkia pendula* (4.11%), *Pera glabrata* (3.59%), *Anaxagorea dolichocarpa* (3.09%), that together accounts for 45.22% of the relative contribution of RD, except: *Clarisia racemosa* (which exerts a pioneering behavior) and *Sloanea guianensis*, both presented low RD in the area. The high values of LV, in this case, are justified by the relative contribution of BA. For the flat environmental condition, the species with the highest VI in the area were: *Eschweilera ovata* (19.62%), *Tapirira guianensis* (9.15%), *Schefflera morototoni* (8.29%), *Chamaecrista ensiformis* and *Miconia affinis* (5.15%), which together accounts for 57.93% of relative contribution to RD in the area. It is worth mentioning that the species: *Helicostylis tomentosa* registered in the ravine area and the species *Chamaecrista ensiformis*, *Abarema cochliacarpos*, *Plathymenia reticulata* and *Sclerolobium densiflorum*, present in the flat land, are included in the list of officially endangered flora by the IUCN (The World Conservation Union) [45], which reinforces the importance of preserving the biodiversity of the areas. Beyond that, the presence of an exotic species in the ravine area (*Artocarpus heterophyllus*) was recorded.

The calculated Shannon diversity index (H') for the study areas were: 3.31 nats.ind.$^{-1}$ and 2.77 nats.ind.$^{-1}$, ravine and flat land conditions, respectively. While the Simpson dominance index (-ln(D')), the values found were: 2.71 and 2.07, ravine and flat land conditions, respectively. According to the values of these indexes, the diversity (H') and species dominance (D'), were show as, significantly, higher for the environmental condition of the ravine.

3.2 Structural Attributes and Biomass Compartment

Tree density was slightly lower in the ravine area, being: 1150 ind.ha^{-1} and 1450 ind.ha^{-1}, ravine and flat land, respectively. Only H presented data normality, confirmed by the Kolmogorov-Smirnov test (n > 30; P = 0.063). The other variables (i.e., DBH, BA and AGB) were log-transformed to meet the variance normality and homogeneity criteria, required for Student t-test inference [40].

The ravine area showed a lower DBH investment ($\bar{x}$ = 13.05 ± 7.94 cm) in relation to the flat land ($\bar{x}$ = 38.01 cm ± 17.28 cm) (Fig. 2a). This component had a direct contribution to AGB, since the DBH is positively correlated with the biomass (for this study: AGB ~ DBH; R^2 = 0.8344; $P < .001^{**}$ - linear model). Significant differences were also found for the AGB, where it was proved that this component in the ravine is 86.89% smaller in relation to the flat land, mean and standard deviation of 306.20 ± 354.08 kg and 2336.37 ± 2078.34 kg for total AGB, ravine and flat land, respectively (Fig. 2d). In general, tree communities with this diametric profile (shown in Fig. 2d), tend to a J-inverted shape distribution.

The canopy verticalization changed systematically throughout the environmental conditions. In the ravine area, larger trees ($\bar{x}$ =11.37 ± 3.68 m) were sampled in relation to the flat land ($\bar{x}$ = 9.36 ± 3.35 m) (Fig. 2c). A more detailed exploration of the hypsometric data revealed that in the ravine 60.87% of the individuals were in higher classes of H ($7.5 < h \leq$

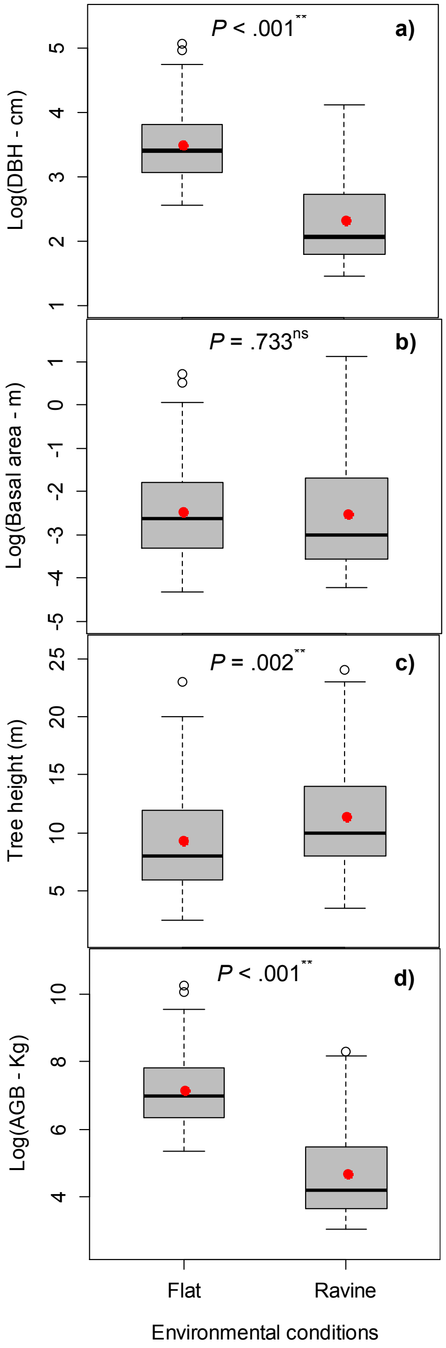

Fig. 2. Box plots for structural variables DBH (a), H (b), BA (c) and the biomass compartment (d). The boxes show interquartile ranges and median (center line); The upper and lower limits on these indicate the minimum and maximum values. Significant differences are indicated by asterisks (**) between the environments: ravine and flat land surface (t-Student test; *P* = .01)

12.5 m); contrasting with the flat land condition data, where 66.21% of the individuals remained in lower classes (2.5 m < h ≤ 10 m). Despite this, the hypothesis heterogeneity of the canopy stratification was not confirmed, since the variances found are similar (Fig. 2c).

The BA estimate in the ravine totaled 2.71 m² (27.15 $m^2.ha^{-1}$), while in the flat land it was 2.35

m^2 (23.47 $m^2.ha^{-1}$). However, these values in statistical terms (m²) did not differ according to the inference of Student's t test (*P* = .01) (Fig. 2b).

3.3 Diversity Profiles

For any sample size, considering both interpolation and extrapolation, in both conditions studied the confidence limits at 95% probability do not overlap. This clarifies significant differences between observed and expected diversities for ravine and flat land conditions for all orders of q. In all diversity components (Hill numbers in the order of q = 0, 1 and 2), data were extrapolated to twice the size of the reference sample (i.e. up to 230 individuals for the ravine area and up to 290 for the flat land) (Fig. 3). The curves for Shannon and Simpson diversity, respectively, level before the reference sample (Figs. 3b and c). The curve shown for species richness (q = 0, Fig. 3a), requires the theoretical sample to the asymptote reach. Of course, it is known that the theoretical limit for asymptote in this component is considered more difficult to achieve [20]. Hill's numbers of higher order (i.e., q = 1, 2), are dominated by more common species and less sensitive to rare species, therefore, dependent on less exhaustive samples.

The effective species numbers (*q*D) are estimated at 45, 27.55 and 15.05 species for the ravine condition and 39, 17.29 and 7.92 species for the flat land condition (orders q = 0, 1 and 2, respectively). The integrated sampling curve allows reliable comparisons, starting from any size of an observed sample (interpolation) to twice as many individuals (extrapolated). From the multifaceted profile of diversity, it was proved that the ravine environment has greater diversity (*q*D), for all components studied. As abundances were considered, as being important in the diversity measures (order q > 0), it is also possible to verify that the ravine condition still maintains with greater diversity (Fig. 3). This fact is due to that RD is more distributed in a larger number of species. In contrast, the flat land condition concentrated high values for RD in a smaller effective number of species.

The inclination in the rarefaction curve is an expected increase, if an individual is added to the sample; in other words, it is the probability of the next sampled individual being a new species not previously sampled [35]. Considering the standardized sample at 79% and 88%, for the intensity curve of the sample ($\hat{C}_n$), ravine and flat land conditions, respectively (Fig. 4), it is noted that the effective number of species (*q*D), in the ravine condition, is more pronounced than in the flat land condition, the two ranges of the confidence interval (95% limits - generated by the bootstrap method do not completely overlap). Furthermore, it is noted that there is a substantial increase in *q*D with the increasing sample in both conditions (Fig. 4a). In relation to the other diversity facets (q = 1 and 2), the estimates of the sample coverage for both conditions slightly increase the *q*D values with the sample increase (Figs. 2b and c). This property becomes more visible in the diversity components, whose Hill's numbers have the following property: q > 0 (Fig. 4c) [18]. This occurs due to the effect on the sample intensity curve ($\hat{C}_n$) being more dominated by common species, therefore, with smaller tendency curves for the effective species numbers (*q*D). In theoretical terms, when the theoretical sample size for the ravine condition is doubled from 115 to 230 individuals, the intensity is increased from 79% to 89%. While in the flat land condition, when the sample size is doubled from 145 to 290 individuals, the $\hat{C}_n$ is increased from 88% to 96%. This procedure is important because it allows different communities to be compared from observable samples, theoretical trends and different sizes samples [35].

4. DISCUSSION

The studied fragments are in advanced process of post-disturbance ecological succession (fragmentation), being the most representative species classified as late secondary [46; 47]. This shows that the disturbances that have occurred in the area have been circumvented, which led to the establishment of these species. The fact that *E. ovata* presented higher relative density (RD), relative frequency (RF), relative dominance (RDo) and importance value (IV) in both studied conditions may be associated with the high regeneration capacity in fragmented areas. The performance in these parameters was also observed by other authors [24,48], both studies suggests that the species has great expectations in this scenario and can demonstrate excellent performances for resources exploitation, especially in the initial and intermediate stages of ecological succession and be recommended for the composition of mixed reforestations destined to the recovery of the degraded areas vegetation.

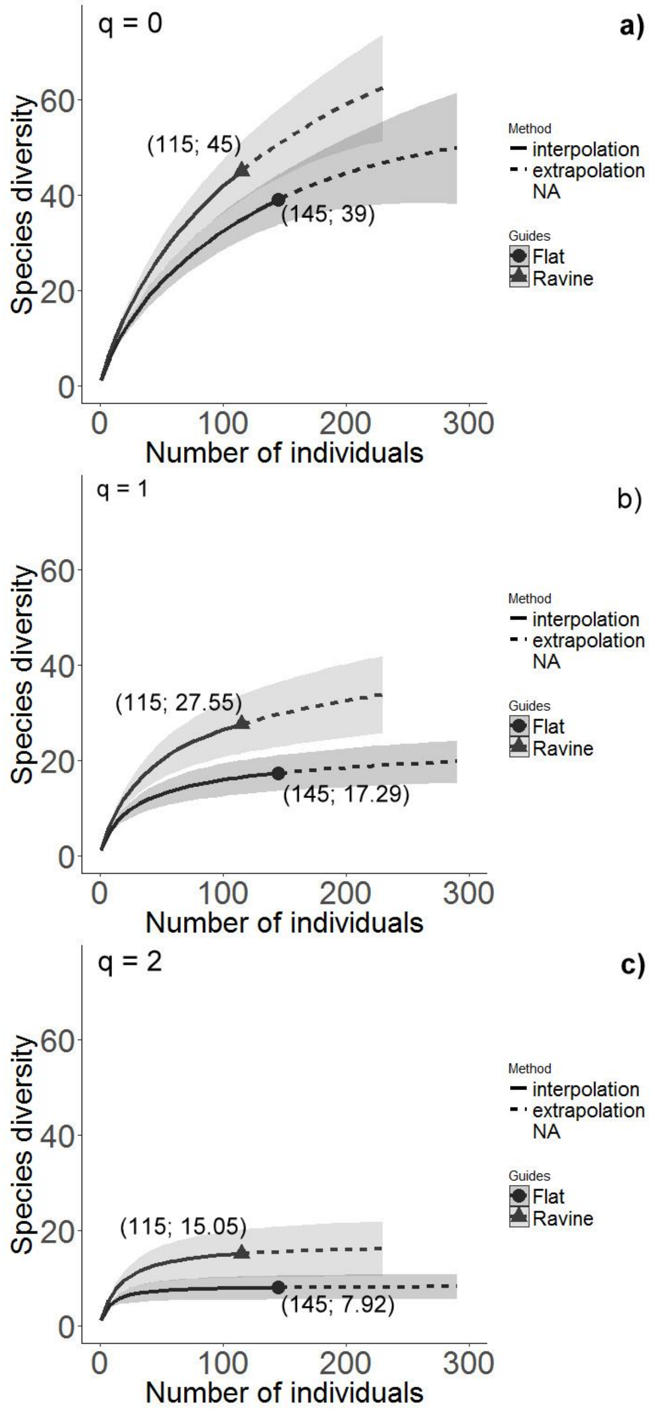

Fig. 3. Sampling curves by interpolation (-) and extrapolation (-) with 95% confidence intervals (shaded areas), obtained by the bootstrap method based on 50 replicates. Data from the tree community: ravine and plan environmental condition, are shown separately by diversity profiles, q = 0 (species richness, a), q = 1 (Shannon diversity, b) and q = 2 (Simpson diversity; c). The solid points and triangles represent the limits of the reference samples, the numbers in parentheses are the number of individuals and the effective number of species (*q*D = Hill numbers in q order)

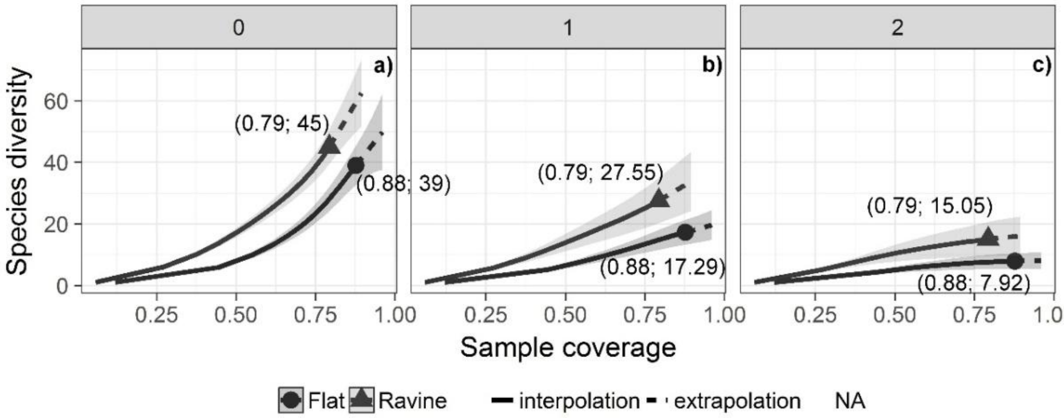

Fig. 4. Sample intensity curve by interpolation (-) and extrapolation (-) with 95% confidence intervals (shaded areas), obtained by the bootstrap method based on 50 replicates. The data of the arboreal community: ravine and flat land environmental condition, are shown separately by diversity profiles (order: q = 0, 1 and 2). The solid points and triangles represent the sample limits of the reference sample, the numbers in parentheses are the sample adequacy (%) and the effective number of species (*q*D = Hill numbers in q order)

In areas of Dense Ombrophylous Forest (Atlantic Forest) in the state of Pernambuco were found 3.09 nats. ind.$^{-1}$ [49]; 3.20 nats. ind.$^{-1}$ [48]; 3.83 nats. ind.$^{-1}$ and 3.43 nats. ind.$^{-1}$ [50] for H'. These diversity estimates are in agreement with those found for the ravine condition (3.31 nats. ind.$^{-1}$) and significantly above the value presented by the flat land condition location, which has lower diversity (2.77 nats. ind.$^{-1}$). However, a general tendency is that the estimated values in the present work are shown as inferior to other studies developed in fragments of Atlantic Forest in the state results, considering the same inclusion criterion adopted [42,48]. The use of traditional indexes may hinder the understanding of basic properties in biological communities, because the half of the estimated value does not necessarily reflect half the value in terms of the species number, causing clear limitations in terms of use and applications in the conservation of fragments [2,18].

Regardless of the intense fragmentation, these areas continue to be responsible for environmental services such as CO$_2$ sequestration from the atmosphere, protection of the soil and the hydrological cycle and biodiversity maintenance. Furthermore, they generate potentials for both functionality and stochasticity, increasing the recovery chances of environments degraded by recolonization and restoration of gene flow of populations [51]. Small fragments should be considered in conservation policies, not only because of diversity related aspects, but also because of the role they play to the reduction of isolation in fragmented landscapes [22]. Another justifiable factor is given by the fact that the Atlantic Forest in Brazil consists mainly of 80% of remnants smaller than 50 ha [52].

Despite being incipient, the studies of ravines in the Atlantic Forest are usually described by their heterogeneous and complex character in the face of diversity on the Tropical Forests scenario [8,9,10]. Consistent ecological effects have been described in ravines of the Danxia Mountain (a region located in southeastern China - hot tropical climate and humid to subtropical seasonal), causing an evident increase in the proportion of flora species when associated with vegetation in similar latitude regions [9]. For the same authors, the ecological modifications occurred mainly due to geomorphological changes in ravines that could be called geo-climax communities. On the other hand, even associating the species diversity to the soil characteristics on different ravine pedoambients in the (semi deciduous seasonal forest), divergent results of the present studies were found [15]. For these authors, the greatest richness was found on the slope, followed by the ravine condition. At first sight, these results proved to be distinct, possibly due to the methodological discrepancies adopted. For this work, the slopes of the middle and upper thirds were considered as geomorphological parts of the ravine condition; while in the previous work, only the most inclined geomorphological portion (position of the middle third) was considered. Added to these factors, the differences in phytogeographic terms and successional stages of the areas should also be taken into account.

The heterogeneity in the resources availability in the environment was shown as a key factor in the tree community structuring. In special character, conditions of extreme availability of resources seem to maintain lower levels of diversity [53]. Nevertheless, the environmental conditions with intermediate restrictions, traces back a positive trend between species richness and environmental heterogeneity. Reinforced that, in plant communities, average levels of resources can affect species richness at smaller spatial scales [54]. This fact explains part of the results consistency found in the present work, since the ravine environment presents more heterogeneous and limiting conditions in the availability of resources due to the effects of reflected light intensity.

Even with advances in plant community surveys, the relative importance of topographic factors at different geographic scales, still show gaps. For example, the stochastic processes relevance in space and the biological processes of coexistence at local and regional scales [55]. Specifically, regarding aspects of the forest edge, it is feasible that the areas with ravine and flat land conditions studied, because they are small fragments, have their ecological diversity processes and structure influenced by recurrent effects to the forest border, once that small fragments tend to present larger proportions of altered environments. In this work, the border effect is understood as a set of post-disturbance factors of fragmentation that trigger the emergence of an inevitable successional process [56]. On this concept's basis, although a substantial distance from the margin of the fragments was respected, part of this effect is considered to be dissolved simultaneously on both conditions, due to the fragments proximity in terms of geographic scale, and the very extension of two study areas.

In this study, it was shown that the forest tree component biomass is lower in the ravine environmental condition, suggesting that this component can act independently of the species diversity, although this relationship (diversity-productivity) is overshadowed by some questions that involve the scale and trophic levels in ecosystems. Species richness hardly influences forest productivity, which remains relatively constant; on the other hand, the increase of the basal area (BA), results in a positive association with the forest support productivity (for cases of low to moderate height heterogeneity) [26]. In contrast to the structure effect, productivity variability is negatively affected by species richness [27]. In a related way, a wide variety of strategies of light between species, as important prerequisites for positive relations with productivity and biodiversity, can also favor this association.

In communities where no species permits ositive productivity, the number of trees is reduced. Allied to this, in Tropical Forest there is a consensus about the main limiting factors for plant productivity, among which the light is shown as one of the most important factors [25,26]. In this condition, the plants would have less productive efficiency due to the forest canopy stratification, which increase the competition levels among the plants by this resource. In fact, these mechanisms sets seem to explain very well the higher productive efficiency for environments with lower diversity conditions [57].

Although the heterogeneity variances of the forest extracts in both evaluated conditions are similar, the height (H) in absolute terms is higher for the ravine condition. This structural component is consistently linked to the plants competitive capacity [37,38]. In biological terms, ravine environments would tend to demonstrate greater competitiveness among individuals, reducing AGB. Under a consensus of ecological strategies, it is understood that similar or divergent sets of genetic characteristics may predominate between different species and lead to the appearance of more similar characteristics in communities [58].

The range of plant characteristics and strategies found in the studied conditions (ravine and flat land condition), can be applied in other studies, considering the differences in forest structural terms for DBH, H and AGB. From these details, new researches can incorporate functional characteristics, since abiotic and biotic factors under the environmental gradients effects are excellent predictors of the functionality in communities [59]. Beyond that, this approach has been very promising for the understanding of services and functions and functional diversity of communities, especially when associated with taxonomic, functional and phylogenetic diversity studies [55].

5. CONCLUSION

The present study confirmed the hypotheses of structural and diversity changes in the different fragments, on an approach that the heterogeneity of the topographic conditions in small post-disturbance forest fragments, are determinant for the change of the species richness and structural processes of the forest community. Only the hypothesis about the canopy heterogeneity in the ravine condition was not confirmed, since the variances found were similar in both conditions.

The complexity of the ravine abiotic factors was shown as important for the species promotion of the arboreal component, concerning a higher degree of distinction in the distribution pattern of the species and the diversity effective numbers, independently of the importance of uncommon or common species. These findings, beyond providing a framework for diversity studies, traces back the importance of small forest fragments in ravine conditions and their role in maintaining the Atlantic Forest biodiversity. In order to compose a better understanding of these evidences, the contribution of each ravine micro-form to the characteristics of the vegetation, the analysis of the landscape and other facets of the diversity, such as functional and phylogenetic, and the effect of different soil components, should also be taken into account for future work.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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