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Forest structural analysis of a seasonal semideciduous area in the northeast Brazil

Raquel Elvira Cola[1]* , Carlos Frederico Lins e Silva Brandão[2] , Regis Villanova Longhi[3] , Mayara Dalla Lana[4] , Lucas Galdino da Silva[5]

Abstract
As a prominent aspect of forest fragmentation, arboreal individuals' diameter and height structure are impaired. The forest structure allows identifying each population's behavior and habit and collects information on growth and survival that assists in establishing and managing conservation strategies. This work aimed to perform the diametric and height distribution of an adult tree community and the five highlighted species of the area located in the Northeast Brazil. We implanted 20 permanent plots with 250 m^2 and measured all arboreal individuals sampled with a circumference at breast height (CBH) $\geq$ 15 cm in addition to heights. The tree community presented a graph of the negative exponential type in the diametric distribution and a higher concentration in the 6-8 m in height median class, a typical pattern found in remnants of Atlantic Forest. *Guapira nitida*, *Manilkara* sp., *Byrsonima crassifolia*, and *Sloanea obtusifolia* presented the same pattern as the community due to their ecological attributes as succession group and dispersion syndrome. These data are compatible with the ecological succession process of Brazilian's northeast Seasonal Semideciduous Forest. Moreover, the species *Buchenavia tetraphylla* diverged because of its ecological characteristics that do not allow new individuals to develop in the study area. The fragment was classified according to CONAMA Resolution n^o. 31 as secondary vegetation in the medium regeneration stage. The analyzed remnant is still in the regeneration process, resulting from the disturbances caused. The most important species of the fragment still present young individuals, representing young communities with potential for establishment.

Keywords
Atlantic Forest — diametric and hypsometric structure — forest fragmentation — tree community

[1] *Mestra em Ciências Florestais pela Universidade Federal Rural de Pernambuco, Recife (PE), Brazil. E-mail: colaraquel0@gmail.com*
[2] *Professor adjunto da Universidade Federal do Agreste Pernambucano, Boa Vista - Garanhuns (PE), Brazil. E-mail: cflsbrandao@hotmail.com*
[3] *Técnico do Instituto de Ciências Biológicas, Universidade Federal de Alagoas, Maceió (AL), Brazil. E-mail: regis.longhi@icbs.ufal.br*
[4] *Professora Adjunta do Instituto Federal de Pernambuco, Garanhuns Campus, Garanhuns (PE), Brazil. E-mail: mayaradallalana@hotmail.com*
[5] *Graduando em Engenharia Florestal, Campus de Engenharias e Ciências Agrárias, Universidade Federal de Alagoas, Maceió (AL), Brazil. E-mail: galdinolsc@gmail.com*
*__Corresponding author__: colaraquel0@gmail.com

1. Introduction

Outstanding biodiversity is one of the main aspects that characterize the Atlantic Forest. It has a high degree of endemism of the species, with about 20 thousand flora species and 1,680 species of fauna (ICMBio, 2015). However, this biodiversity is not being preserved, since data from the Fundação SOS Mata Atlântica and Instituto Nacional de Pesquisas Espaciais (2020) report that, between 2018 and 2019, there was a 30% increase in the deforestation rate. Several anthropic factors cause the fragmentation of natural forests, making them unbalanced (Laurance et al., 2018), such as urbanization, logging, and farming.

Inside the northeast region of Brazil, the state of Pernambuco is intensely affected by deforestation and least protected due to sugarcane exploration, urban expansion, and real estate speculation (Silva et al., 2019). Garanhuns is a municipality located in the southern Agreste region of Pernambuco, in a transition area between the forest and the backland in the Borborema Plateau. The analysis of the forest fragment's phytosociology, struc-

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ture, and ecological behavior are fundamental studies to understand the full dynamics of a forest. These studies are pioneers in the Garanhuns region and should, therefore, add scientific knowledge about the behavior of the Seasonal Semideciduous Atlantic Forest (Jansen et al., 2021).

As a prominent aspect of forest fragmentation, arboreal individuals' diameter and height structure are impaired. This structure is modified through changes in habitats, in the mechanisms of competition and mutualism between species, in the availability of resources, and, consequently, affecting the individual's growth within the fragment. The diametric distribution is applied to know the tree composition's organization, succession, and dynamics in several Brazilian phytophysiognomies (Pulz et al., 1999). The hypsometric distribution complements phytosociological studies in tropical forests and can be configured in different ways according to their ecology, the evolution of the ecosystem, and existing edaphoclimatic conditions (Marangon et al., 2008). This analysis allows identifying the behavior and habit of each population and collects information on growth and survival that assist in the establishment and management of conservation strategies (Silva et al., 2001).

Therefore, to evaluate the site's structural conditions, this analysis aimed to perform the diametric and height distribution in an adult tree community and the five highlighted species of this area, in the Northeast Brazil.

2. Materials and Method

2.1 Study area

The present area is located in Garanhuns, Brazilian State of Pernambuco, which has a humid tropical coastal climate (As), according to the Köppen climate classification, with an average annual temperature of 21.4^{o}C, and precipitation of 909 mm (Alvares et al., 2013; IBGE, 2017). It belongs to a mountainous region with around 700 to 950 m. The soils are derived from weathering or transport, and deposition is often found in yellow Latosols and Argisols (Azambuja and Corrêa, 2015).

Costa et al. (2014), carrying out a mapping of the vegetation and phytogeography of Garanhuns, state that the municipality has very intense anthropic and natural factors, as it is the largest urban center in the region and still explores the countryside. Two vegetation types were recorded in the city: Seasonal Semideciduous Forest and Areas of Ecological Tension (Figure 1).

Inside the Fazenda Fojos, the property's forest fragment has 23 ha with the coordinates 5^{o}26'08.34" E and 8^{o}54'20.53" S (Figure 2). Compared with the previous map, it is possible to define that the fragment is included

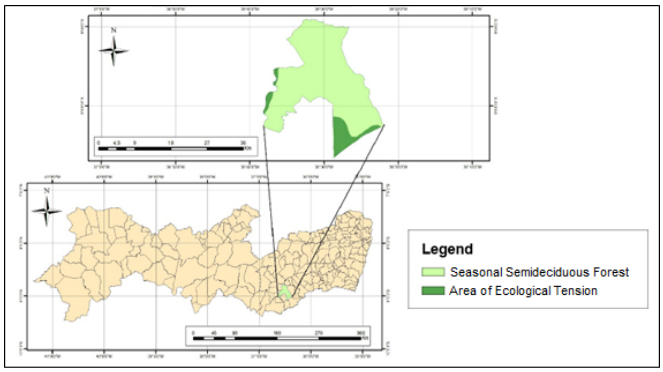

Figure 1. Garanhuns's vegetation– PE, Brazil. Source: Costa et al. (2014).

in the classification of Seasonal Semideciduous Forest. Nearby the fragment, there are pasture areas, causing frequent disturbances and intensifying the degree of isolation. Until 2002, this fragment was the only one remaining for over a decade. Then, looking 16 years later, the surrounding areas had their land use abandoned and have passed through natural regeneration.

2.2 Data collection and analysis

For data collection, with the help of 62S Garmin GPs, three trails were created to deploy 20 permanent plots (10 m x 25 m), with a distance of 25 m between them, totaling a sample area of 0.5 ha. On track 1 were allocated seven plots, track 2 eight, and track 3 five. The measurement was made only once in 2019.

The sampling sufficiency of the variables of interest (density of individuals and basal area) considered a sampling error of 20% to 95% confidence probability. All statistical parameters and graph generation were performed in Excel for Windows^{TM} 2019 software.

All arboreal individuals with a circumference at breast height (CBH) $\geq$ 15 cm present within each plot had their CBH measured with a metric tape and total height with giant pruning scissors with four modules of 2 meters. All CBH and height data were used to analyze the diametric and hypsometric distribution of the sample community. With this information, the regeneration stage of the studied fragment was determined based on CONAMA Resolution n^o. 31, of December 7, 1994, which determines the regeneration stages of primary and secondary vegetation in the state of Pernambuco.

The diametric and hypsometric distributions of the five species' populations with the highest value of importance index (VI) were analyzed, which are *Guapira nitida* (Mart. ex J.A.Schmidt) Lundell, *Buchenavia tetraphylla* (Aubl.) R.A.Howard, *Manilkara* sp., *Byrsonima crassifolia* (L.) Kunth, and *Sloanea obtusifolia* (Moric.) Schum,

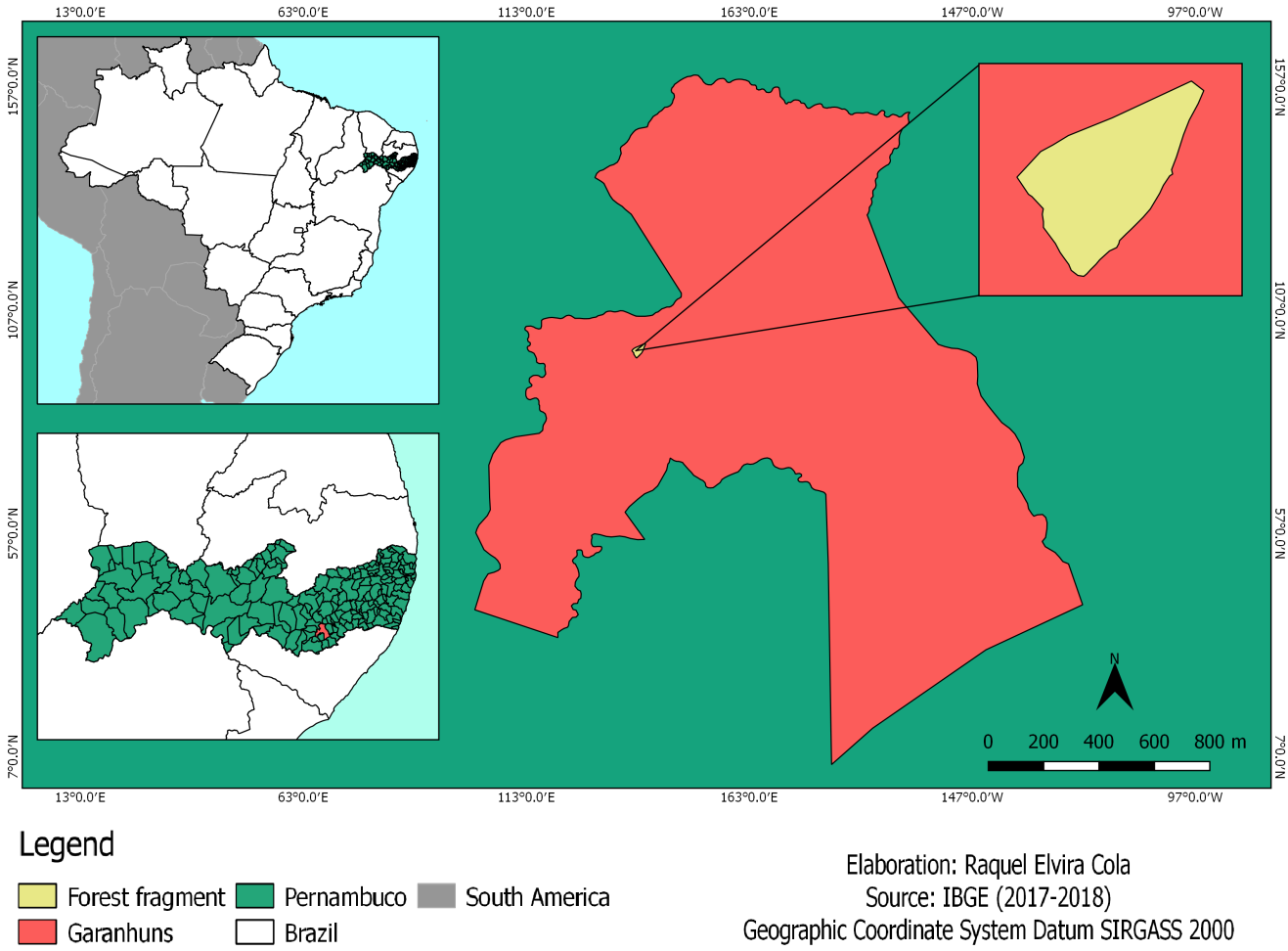

Figure 2. Forest fragment analyzed in the municipality of Garanhuns – PE, Brazil.

according to Cola et al. (2020). These species were selected because they represent 31% of the total VI. The structure indicators were distributed as follows, following the methodology of Bellotto et al. (2009) and adapted by Fonseca (2011):

- *Average diameter by classes*: the diameters were distributed in classes, with an amplitude of 5 cm, starting from the minimum diameter found (4.77 cm), and then the average diameter was calculated.

- *Average height by classes*: the individuals were distributed in height classes, with an amplitude of 2 m from the value 0, and then obtained the average height between them.

3. Results and Discussion

3.1 Sampling sufficiency

By analyzing sample sufficiency (Table 1), only six and 11 plots based on basal area and density, respectively, would be needed to achieve sampling sufficiency (Figure 3). Thus, the number of plots implanted in the study was satisfactory. The mean standard error values, coefficient of variation, and sampling error were satisfactory, and the research was feasible (Table 1).

According to the data obtained by Cola et al. (2020), it was identified 74 tree species. The remnant has 944 adult individuals measured, totaling a basal area of 10.8 $m^2.ha^{-1}$ and a density of 1,888 $ind.ha^{-1}$. Also, in Garanhuns, Jansen et al. (2021) found a total basal area of 18.0 $m^2.ha^{-1}$, considering that their study included trees with a basal diameter $\geq$ 5 cm. Other work based in the Seasonal Forest region in Brazil, such as Silva et al. (2021),

Table 1. Statistical data from the study in the Fazenda Fojos, Garanhuns, Brazil.

Parameters	Basal Area (m^2)	Density (ind)
n (optimal number of plots)	6 un.	11 un.
Total	10.818 m^2	944 ind.
Mean	0.5409 m^2/0.025 ha	47.2 ind/0.025 ha
Standard Deviation	0.1111 m^2/0.025 ha	14.2961 ind/0.025 ha
Variance	0.0123 (m^2/0.025 ha)^2	204.3789 (ind/0.025 ha)^2
Mean Variance	0.0006 (m^2/0.025 ha)^2	9.9968 (ind/0.025 ha)^2
Mean Standard Error	0.0246 m^2/0.025 ha	3.1618 ind/0.025 ha
Coefficient of Variation	20.5453%	30.2884%
Tabulated t value	2.093	2.093
Absolute Sampling Error	0.0514 m^2/0.025 ha	6.6177 ind/0.025 ha
Relative Sampling Error	9.5104%	14.0204%

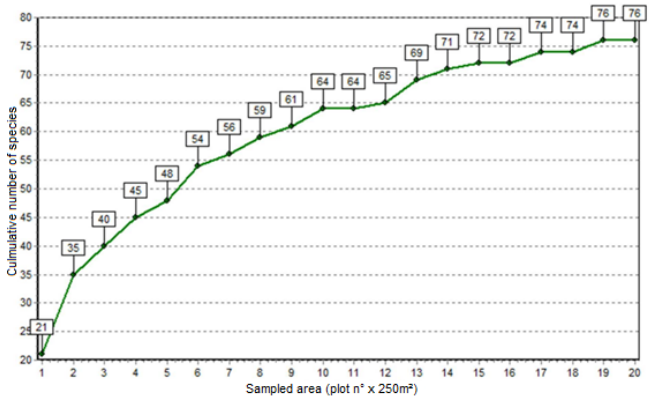

Figure 3. Species x area curve of the adult tree component of a stretch of a fragment of Seasonal Semideciduous Forest, in Garanhuns – PE, Brazil. Source: Cola et al. (2020).

in two different forest fragments, have a total basal area of 23.4 and 20.7 $m^2.ha^{-1}$.

3.2 Tree community's diversity and phytosociological data

Cola et al. (2020) identified the tree species following the APG IV classification (Chase et al., 2016) and performed the phytosociological analysis of the community's fragment (Table 2). The five species with the highest VI represented 31.1% in this index, 47.3% of the individual's density, and 53.8% of the dominance.

Cola et al. (2020) also revealed that the Shannon-Wiener Diversity Index (H') was 3.21 nats.ind^{-1} for this forest population. According to Felfili and Rezende (2003), the values for this index in forest environments usually vary between 1.5 and 3.5, sometimes exceeding 4 nats . ind^{-1}. The value found for this parameter agrees with the values found in other works from different areas in the State of Pernambuco.

The Pielou Uniformity Index (J) for this study was 0.73. Therefore, it can be assumed that an increase of 27% is needed for the fragment diversity to reach its maximum level (Arruda and Daniel, 2007).

The values found corroborate with works carried out in areas of Seasonal Semideciduous Forest, such as Lopes et al. (2012), who found the 2.92 and 3.97 for H', and 0.73 and 0.87 for J in two areas of Seasonal Semideciduous Forest. In the same type of phytophysiognomy, Santana et al. (2017) and Araújo et al. (2019) found 2.95 and 3.72 for H', and 0.77 and 0.78 for J, respectively. This type of vegetation occurs from the south of the state of Rio Grande do Norte to the north of Rio de Janeiro (IBGE, 2012), being present in transition areas between the Atlantic Forest and the Caatinga dryland vegetation or semiarid zones with higher altitudes (Cunha and Silva Júnior, 2014). It has two types of climatic regimes: $\leq$ 1600 mm/year, which is considered a tropical regime with periods of intense precipitation followed by severe drought; and a regime with dry period and cooler temperatures, being considered a subtropical regime (IBGE, 2012; Pennington et al., 2000). Also, the deciduousness percentage in these regions is 20 to 50% of the loss of leaves during the dry period (IBGE, 2012).

3.3 Tree community's diametric and hypsometric distribution

The diametric distribution of the tree community (Figure 4a) presented a graph of the negative exponential type, typical in unequal natural forests, where there are more individuals concentrated in the first diameter class (57.2%), which ran between 4.5 and 9.5 cm, with 1,080 ind . ha^{-1}. The intermediate classes, which ranged from 19.5 to 29.5 cm in diameter, were represented by 24.3% (18) of the total number of species found. The smallest diameter value found in the analyzed stretch was 4.77

Table 2. Species with the highest value of importance (VI) in the Fazenda Fojos, Garanhuns, Brazil.

Species	Family	Ecological Group	Density (ind.ha^{-1})	Dominance (m^2.ha-1)	VI (%)
Guapira nitida	Nyctaginaceae	ES	302	3.06	28.42
Buchenavia tetraphylla	Combretaceae	ES	142	3.65	21.29
Manilkara sp.	Sapotaceae	NC	174	2.11	17.63
Byrsonima crassifolia	Malpighiaceae	PI	140	1.26	13.45
Sloanea obtusifolia	Elaeocarpaceae	ES	136	1.56	12.59

ES: Early Secondary; PI: Pioneer; NC: No Classification. Source: Cola et al., (2020).

cm, and the largest was 47.4 cm, which belongs to the species *Clusia nemorosa* G. Mey. The average diameter of the community was 10.46 cm.

The graph's pattern in the diametric distribution represents forests that have suffered severe disturbances or the opening of large clearings (Nunes et al., 2003; Lisboa et al., 2019). It was observed that the graph produced by the diametric distribution corroborates the pattern highlighted by Jorge et al. (2015), Lima et al. (2019), and Lisboa et al. (2019) for secondary forests which may be related to their resilience (Martins, 2012). The high number of thin individuals refers to a high natural regeneration, it can indicate a place that has been explored and is now regenerating.

Araújo et al. (2018) and Fazlollahi Mohammadi et al. (2022) suggests that the higher quantity of individuals in the first diameter classes found demonstrates an anthropized area and reflects a small fragment in a degraded matrix, related to the indication of disturbances within the fragment. Forest maturity also directly or indirectly affects the diameter distribution of individuals (Lü et al., 2012). However, regenerating individuals can replace mature ones in ecological succession, causing the species to self-regenerate and compensate for mortality over time (Dalla Lana et al., 2013).

The hypsometric distribution presented 43.6% of individuals' density (824 ind.ha^{-1}) concentrated in the fourth class, which was the most represented, with a height between 6 and 8 m (Figure 4b). The most diminutive height was 2.5 m, and the highest was 20 m (*Guatteria* sp. 1). The average height of the analyzed stretch was 7.6 m. By CONAMA (Brazilian National Environment Council) Resolution n^o. 31 of December 7, 1994, the analyzed stretch is classified as secondary vegetation in a medium stage of regeneration, according to Art. 2.

It is noticed that the largest diameter species is not related to the highest height in this fragment. The species *C. nemorosa* is a selective hygrophyte and heliophytic plant (Lorenzi, 2009); that is, it needs sunlight and moisture to develop. These environmental conditions are present in Garanhuns so the tree presented the individual with a greater diameter (47.4 cm), and the species in general presented high dominance (1.47 m^2/ha) (Cola et al., 2020). This height of 20 m happened due to the individual's position from *Guatteria* sp. 1 in the fragment, located in the second plot closer to the edge, receiving more sunlight intensity and favoring its horizontal growth.

Regarding the distribution of heights, Pinheiro and Monteiro (2009) indicate that the higher quantity of individuals in the first height classes suggests that the forest is in a renovation process, a consequence of a youth community arising from forest fragmentation. For Pinto and Oliveira-Filho (1999), the sigmoid pattern is typical for heterogeneous tropical forests. Lima et al. (2017) also found the same height distribution pattern for the tree community of an Atlantic Forest fragment in Pombos – PE. According to Lima et al. (2017), trees with a size $\leq$ 15 m are considered intermediate and are therefore in the intermediate process of succession. Couto et al. (2011) also showed most species with individuals ranging from 6 to 9 m in height in Chapada Diamantina - BA. This variation in height is characteristic of western edge forest canopies (Nascimento, 2009). And at the same municipality of this study, Jansen et al. (2021) found 56% of tree individuals in the first hypsometric extract, which ranged from 0.0-5.0 m, 34% in the second extract from 5.1-7.0 m, and 10% in the upper extract, above 7.1 m.

Thus, if human intervention is controlled within the fragment, the younger species will have the possibility of remaining in the forest structure (Araújo et al., 2018).

3.4 Diametric and hypsometric distribution of species with higher VI

The inverted J-graph (negative exponential) pattern was configured for all species, with higher density in the first diameter classes and decreasing as the diameter increases, except for *B. tetraphylla* (Figure 5). The same pattern was observed by Araújo et al. (2018) in its highlighted species in a fragment of Atlantic Forest in the municipality of Macaíba - RN.

B. tetraphylla also showed higher density in the first three classes, but irregularly. The first and third classes have the same proportion (23.9%). It was also the species with the highest number of robust individuals, highlighting

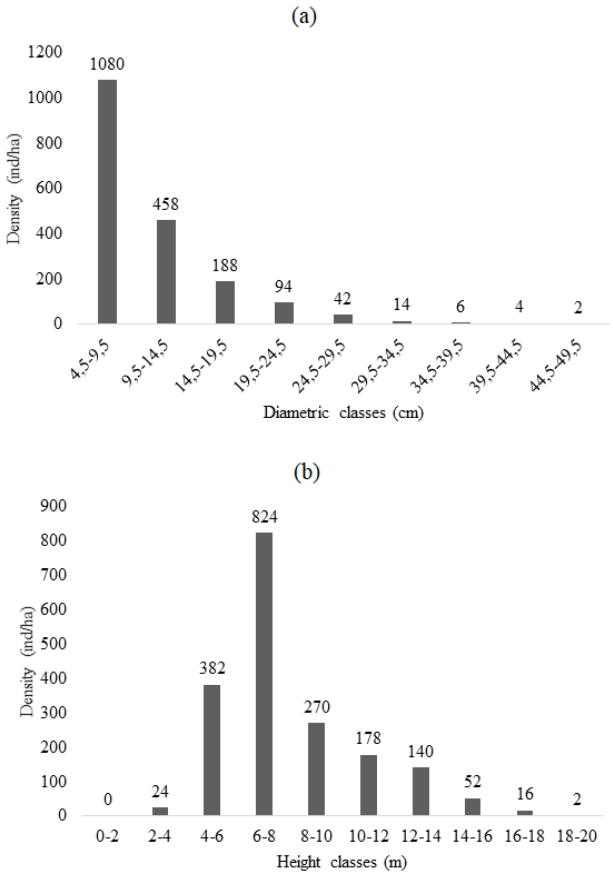

Figure 4. Diametric (a) and hypsometric (b) distribution of the study's adult tree community sampled in Garanhuns, Brazil.

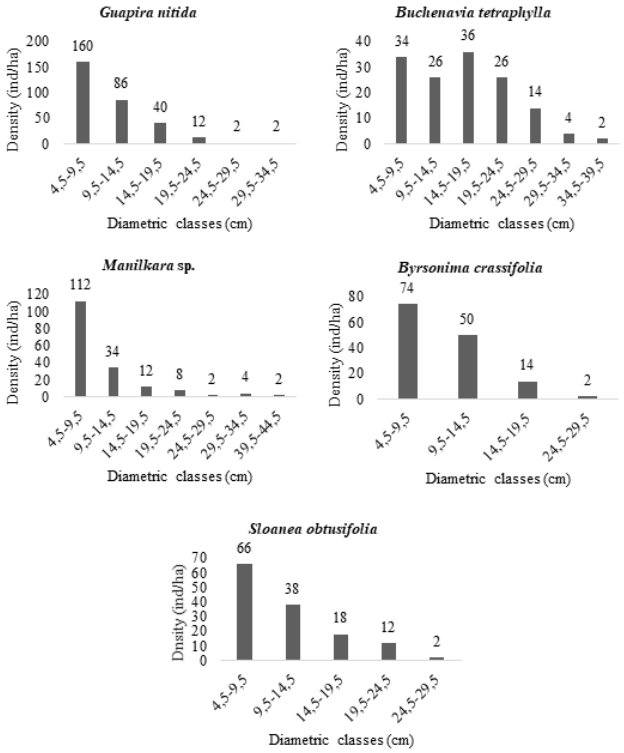

Figure 5. Diametric distribution of the five species' populations with the highest value of importance sampled in Garanhuns, Brazil.

the fourth and fifth classes. This behavior is due to the slow growth of the species, causing the individual's density to take time to increase and, together, its monopodial growth with the thick branch's presence (Carvalho, 2014).

The hypsometric distributions (Figure 6) of the species *G. nitida*, *Manilkara* sp., *B. crassifolia*, and *S. obtusifolia* presented the same graph pattern, with higher density in the class of 6-8 m, 41%, 49.4%, 51.4%, and 47%, respectively. The distribution of the species *B. tetraphylla* was irregular, obtaining more density of individuals in the fifth (10-12 m) and sixth classes (12-14 m), with 28.1% and 25.3% of individuals each. Cola et al. (2020) classified the species *G. nitida, B. tetraphylla*, and *S. obtusifolia* are early secondary species; *B. crassifolia* was classified as a pioneer, and *Manilkara* sp. unclassified because it is identified at the gender level.

Many possible causes determine the *B. tetraphylla* species' distinct behavior with the tree community and other species' populations with higher VI in the fragment. Weaver (2000) states that few trees of the species produce fruit in a given year, with broad time intervals between yields on individual trees. This aspect already decreases the number of regenerating individuals of the species, compared to other species of the fragment, by the lower frequency of seed dissemination.

According to the same author, the *B. tetraphylla* fruits fall within a radius close to the mother plant (approximately 4 m), decomposed by insects and microorganisms. Thus, the species has an aggregated distribution pattern where the presence of an individual favors the establishment of others.

The species has zoochoric dispersion, being made by birds, mammals, and insects (Campos Filho and Sartorelli, 2015). If no fauna disperses these fruits before they decompose, the propagation of the ecosystem's species is reduced. This means that the area is under intense edge effect. Additionally, sunlight is necessary for the germination of the seeds of *B. tetraphylla*. In places with dry seasons, which characterize deciduous and semideciduous forests, the top of the maternal tree usually loses its leaves and allows the seeds to germinate with sunlight's penetration (Weaver, 2000). Therefore, the absence of small young individuals is perceived in the

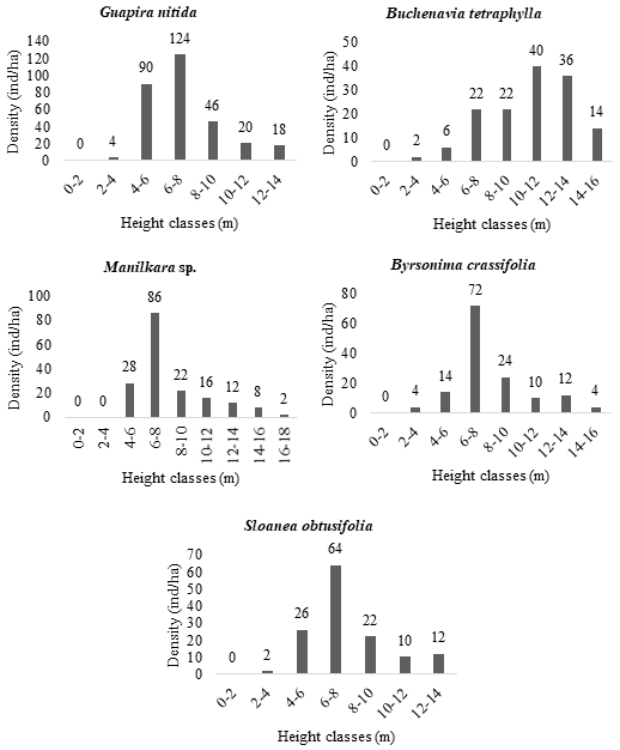

Figure 6. Hypsometric distribution of the five species' populations with the highest value of importance sampled in Garanhuns, Brazil.

hypsometric distribution of the species. This condition can be a consequence of the extraction of individuals for the construction of fences and firewood or the presence of cattle since the area is not adequately monitored.

The other species analyzed followed the same behavior as the remnant tree community, both in diameter and height. The fragment situation is due to the recovery of disturbances that the edge effect and fragmentation caused in its history. The edge effect commonly alters structural changes in vegetation, distribution, richness, abundance, and diversity (Oliveira et al., 2013). Since 2002 the surrounding area has been undergoing a natural regeneration process.

The interactions of ecological processes in the fragments are directly linked to the distance of disturbances from the edge to the forest's interior (Blumenfeld et al., 2016). These disturbances can reach hundreds of meters into the forest (Laurance et al., 2011), with the first 30 m suffering the most impacts (Rigueira et al., 2012). As the effect advances towards the interior of the fragment, it is possible to predict how much of the conserved area, the area that does not suffer from the impact, exists in the interior or core area (Lagos, 2017). Therefore, it is assumed that the more irregular and smaller the fragment, the greater the contact area with the matrix and the greater the edge effect.

That is, the pioneer and early secondary species have young individuals that favor the development of slow-growing species (Amador, 2003) that, in the future, will characterize the vegetation in the advanced stage of regeneration.

Besides, the five species' dispersion analyzed in this study are zoochoric (Cola et al., 2020). The proportion of species with this dispersion type is independent of the area's size (Brasil, 2005). For Venzke et al (2014), understanding the predominant dispersion in a given area is an efficient strategy for the forest succession process and its regenerative capacity.

4. Conclusions

It can be concluded that the analyzed remnant is still in the regeneration process, resulting from the disturbances caused by the abandoned agricultural activities of the surrounding area.

The most important species of the fragment still present young individuals, representing young communities with potential for establishment. The species *B. tetraphylla* was the only one of the five analyzed that showed to be ahead with the size of the individuals, having trees slightly thicker and taller than the other species.

Therefore, intensifying the area's conservation measures, aiming at this development potential, is fundamental for the forest's maintenance.

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