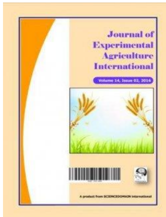

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Spatial Distribution and Diametric Structure of Tree Species in a Dense Ombrophilous Forest in Rio Grande do Norte, Brazil

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Authors' contributions

This work was carried out in collaboration between all authors. Author LHBA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors CCN and CHAB managed the analyses of the study. Authors FAV and JASS managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The Atlantic Forest is considered to be one of the world's most biodiverse wetlands. However, the misuse of natural resources exposes it to physical and biogeographical changes caused by both natural and anthropic disturbances. Consequently, changes in the composition and structure of the remnants forests are expected. Although many studies are performed in this biome, few address the population structure and spatial distribution. The objective of this study was to analyse the spatial distribution pattern and the diametric structure of most representative tree species in a patch of Dense Ombrophilous Forest in the State of Rio Grande do Norte, Brazil. Floristic and parametric

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vegetation surveys were performed based on quadrants sampling, with 175 sampling points distributed systematically over five transects. At each point, four quadrants were defined, and the living arboreal individual closer to the center of the point, presenting diameter at breast height (DBH) ≥ 3.18 cm, was measured and identified. The Payandeh index was employed to detect the spatial pattern of the species. The diametric structure was analysed by the frequency distribution variation for each species and was estimated by Sturges method. Excluding *Coccoloba alnifolia*, the other species with high importance value index (IVI) in the forest patch showed an aggregate spatial distribution pattern or a tendency to group. It was observed that the diametric distribution pattern exhibted an inverted-J pattern, with some peculiarities. The study showed an unbalanced distribution for the studied species, but with a tendency to remain in the structural arrangement of the forest, once the human intervention is curbed. Except for *C. alnifolia*, the other species of higher IVI presented a pattern of aggregate distribution or tendency to aggregate. It was thus possible to understand the behaviour of these plant species of the environment, subsidising actions that aim at the conservation of the studied forest patch.

Keywords: Diameter classes; competition between species; population dynamics; aggregation pattern.

1. INTRODUCTION

The Atlantic Forest is one of the richest biodiversity rainforests in the world, with a high degree of endemism [1], but the unsustained exploitation of the natural resources has intensified the deforestation process [2]. Nowadays, the remnants of native forest (around 11-16%) [3], are exposed to physical and biogeographic changes caused by natural and anthropogenic disturbances that result in the disappearance of tree species [4].

In northeastern Brazil, the situation is critical when compared to the southeastern parts [3]. There are few forest remnant, and most are limited to small patches. This scenario occurs because of the intensification of activities that cause degradation of native vegetation such as the expansion of urban centres, sugar cane cultivation and cattle breeding [5]. Human intervention in a forest, such as deforestation or extensive stockbreeding, can cause a significant reduction in the number of species and change the dynamics of populations, harming natural regeneration process and sustainability of the system [6,7].

Although many works are carried out in this biome, few studies have addressed the population structure and spatial distribution of plant species in the Atlantic forest [4,8–12]. The population structure and spatial distribution of species in the community are related to the competition between individuals and considering the auto-ecological features; some have a significant risk of not surviving. In a forest in normal conditions, many young individuals fail to complete their life cycle due to intense competition, which reflects the natural succession process [6].

The diametric structure evaluation assumes importance in understanding the process of recruitment and mortality of the native plant species in their development record and allows evaluating the intensity and extent of disturbance that occurred in the local forest community, besides helps to determine the growth of plant species and plant communities [13].

The spatial distribution of plant individuals an area depends on the production and dispersal of seeds and the ability of the seeds to germinate and seedlings to survive [6]. It is important for conservation studies to recognise the distribution pattern of individuals in an area, to understand the dynamics of populations [14], and consequently generate subsidies for the maintenance of biological diversity.

Marangon et al. [15] cite maintenance factors of a conservation area, which are brought to know the pattern of aggregation of individuals, such as morphological factors that involve mechanisms of dispersion, environmental factors, which are related for example with the type of soil, as well as the phytosociological factors that relate to the inter- and intraspecific competition. For this, the floristic indexes and spatial aggregation estimation [6] provide an important understanding of the diversity of the environment and can be utilised as a parameter in the evaluation of the data [16].

According to Ribeiro et al. [3], more than 80% of the remnants of the Atlantic Forest are limited to small patches with areas less than 50 ha. Often, it is possible to find small remnants of Atlantic Forest isolated in anthropic landscapes and unprotected - as the studied forest patch of the present study located in the Brazilian Northeast. The anthropogenic impacts can lead to ecological changes in the forest structure and, consequently, threaten the biological diversity of the environment.

In this sense, this work was aimed to analyse the spatial distribution pattern and diameter structure of the most representative tree species in a fragment of Atlantic forest in the state of Rio Grande do Norte (RN), Brazil. This could provide information for future management actions and conservation of the area.

2. MATERIALS AND METHODS

2.1 Study Area

The study was carried out in an Atlantic forest patch of 6.5 ha, located in the municipality of Macaíba/RN. Denoted “Mata do Bebo”, the forest patch has the center coordinates 5° 53 '30 "S and 35° 21' 30 ’’W and an average altitude of 40 m above sea level. Currently, there is a constant human activity in this area due to the practice of monocultures, and other signs of environmental degradation, such as openings trails and thinning of trees.

According to Koppen classification, the climate is As’ type (rainy tropical), with high temperatures throughout the year and the rainy season from March to July. The average annual precipitation is 1070.7 mm, and the average annual temperature is around 27.1°C with 21°C minimum and 32°C maximum [17].

2.2 Sampling

The floristic and parametric vegetation survey was carried during the months from March to June 2013, out based on the quadrant sampling method proposed by Cottan and Curtis [18], being among the most used sampling methods in native forests to record floristic, phytosociological and quantitative parameters [19]. Around 175 sampling points were systematically distributed every eight meters, over five transects, laid parallel to each other at a distance of 15 m. In each transect, the allocation of the first point started at least, 10 m from the forest patch edge (Fig. 1).

At each sampling point, four quadrants were defined. Then in each quadrant, the individual live tree closest to the center point with diameter at breast height (DBH) ≥ 3.18 cm and total height (Ht) ≥ 1.30 m, was measured and identified. For individuals with branches below 1.30 m, the DBH’s were measured and the DBH equivalent was determined according to Equation 1 [20]:

$$DBH_{eq.} = \sqrt{(DBH_1^2 + DBH_2^2 + \ldots + DBH_i^2\ )}$$

In which:

$DBH_{eq.}$ = Diameter at Breast Height equivalente;
DBH_i = the respective DBHs measured in the field, in cm.

When it was not possible to identify plants in the field, photographic records and collection of botanical material were carried out. Herbarium specimens were prepared for later identification with the help of experts and specialised bibliography.

2.3 Statistical Analysis

From the phytosociological analysis performed in the forest patch by Araújo et al. [21], a diameter distribution graph was constructed for the four species with the highest importance value index (IVI) in the forest patch, when added they represent 41.49% of this ratio (Table 1).

These plant species were selected for analysis because they presented relatively high values of density, frequency and dominance in the phytosociological analysis of the studied forest patch. Therefore they can be used as indicators to express changes in the structure and dynamics of the forest.

The distribution analysis of the individuals in different diameter classes was performed using histograms. The width of the bands in the construction of the diameter distribution graphs varied according to each species and was estimated according to Sturges [22]:

$$k = 1 + 3.3\ (\log_{10} n);\ w = R/k$$

In which:

k = number of classes;
n = number of observations;
w = total amplitude;
R = difference between the highest and the lowest observed value.

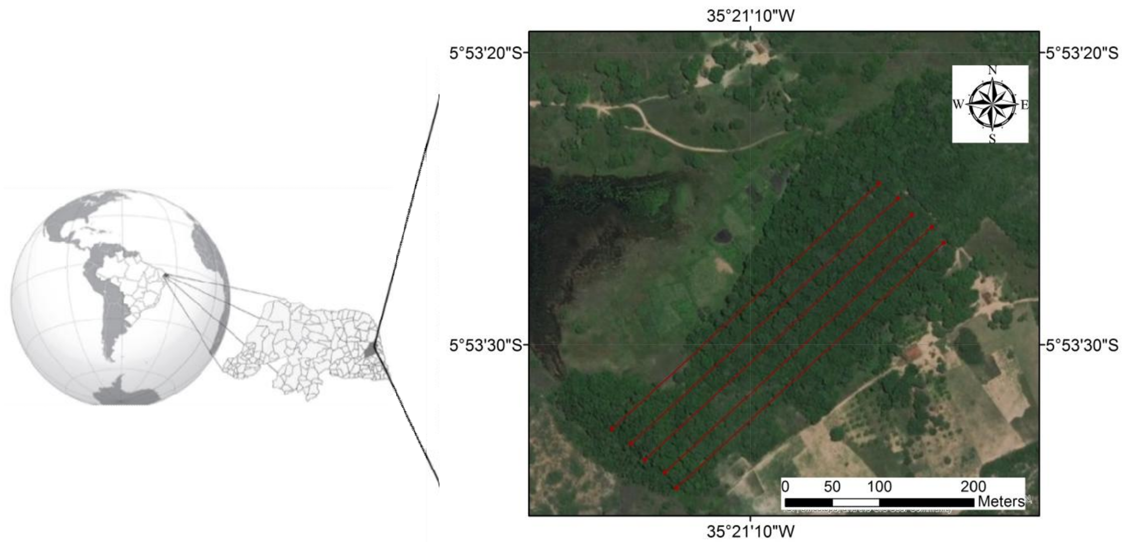

Fig. 1. Transect layout for the floristic survey in the patch at Ombrophilous Dense Forest, Macaíba, RN

Table 1. List of species with the highest important value index (IVI) in the Atlantic forest patch, Macaíba, RN

Species	Family	IVI (%)
Coccoloba alnifolia Casar.	Polygonaceae	9.57
Copaifera cearenses Huber ex Ducke	Fabaceae	12.37
Eugenia rostrifolia D.Legrand	Myrtaceae	9.83
Protium heptaphyllum (Aubl.) March.	Burseraceae	9.72

According to Bongers et al. [23], to compare size structures between different species, it is not advisable to use uniform classes in the construction of the diagrams. Different species have specific genetic characteristics, regarding size and, in this case, using regular classes would result in a pseudo differentiation between species with different sizes, instead of differentiating species that have different size structures.

The spatial distribution pattern analysis of the species with higher IVI in the forest patch was determined according to Payandeh [24]. This method determines the degree of aggregation of the species through the relationship between the variance of the number of trees per sample and the average of the number of trees, where: Pi (Payandeh Index) ≤ 1.0 indicates random pattern; 1.0 < Pi ≤ 1.5 indicates a tendency to group, and Pi > 1.5 indicates the group of species individuals.

For the graphical representation of the histograms of individuals and data processing the software Microsoft Excel 2007 and BioEstat 5.3 [25] were employed.

3. RESULTS AND DISCUSSION

In this study 700 trees belonging to 57 species, in 30 botanical families was catalouged. Of these, 93 individuals belonged to *Eugenia rostrifolia*, 61 to *Coccoloba alnifolia* and 74 to *Copaifera cearenses* and *Protium heptaphyllum* species that had similar number of individuals. Among the 175 quadrants installed, the mean plant-point distance was 2.31 m, which corresponds to a total density of 1,873 individuals ha^{-1} and a basal area of 22.13 m^2ha^{-1}.

The stem diametric structure showed differences in the amplitude of the size classes, where *Copaifera cearenses* presented individuals with a larger diameter in the forest patch, followed by *Protium heptaphyllum, Coccoloba alnifolia* and *Eugenia rostrifolia*. The same pattern was also observed for the amplitude of the size classes (Table 2).

Table 2. Amplitude of diameter classesfor the four species of tree with the higher importance value in the Ombrophilous Dense Forest, Macaíba, RN

Diametric classes	Species with higher IVI			
	Coccoloba alnifolia	***Copaifera cearenses***	***Eugenia rostrifolia***	***Protium heptaphyllum***
	interval (cm)			
Class 1	3.18 |— 7.48	3.18 |— 9.61	3.18 |— 4.68	3.18 |— 6.9
Class 2	7.48 |— 11.78	9.61 |— 16.04	4.68 |— 6.18	6.98 |— 10.78
Class 3	11.78 |— 16.08	16.04 |— 22.47	6.18 |— 7.68	10.78 |— 14.58
Class 4	16.08 |— 20.38	22.47 |— 28.90	7.68 |— 9.18	14.58 |— 18.38
Class 5	20.38 |— 24.68	28.90 |— 35.33	9.18 |— 10.68	18.38 |— 22.18
Class 6	24.68 |— 28.98	35.33 |— 41.76	10.68 |— 12.18	22.18 |— 25.98
Class 7	28.98 |— 33.28	41.76 |— 48.19	12.18 |— 13.68	25.98 |— 29.78
Class 8	-	48.19 |— 54.62	13.68 |— 15.18	29.78 |— 33.58
Mean (cm)	11.43	11.74	6.19	10.22
Standard Deviation (cm)	7.90	10.83	2.72	7.40

IVI: important value index

The four species with highest IVI in the forest patch showed a pattern of diametric distribution tending to the inverted-J, behaving as expected for the uneven-aged forests, where the high number of regenerating individuals compensates the mortality over time [26]. However, the distribution pattern of individuals over the diameter classes was irregular for *Coccoloba alnifolia*, *Copaifera cearenses* and *Protium heptaphyllum*. Variations were observed in the J-inverted structure, with subsequent classes having a higher proportion of individuals compared to diametric class earlier, suggesting an imbalance between mortality and recruitment (Fig. 2).

Such an imbalance may have been caused by anthropogenic interventions such as selective culling of individuals in the intermediate diameter classes, causing an interruption in the flow of individuals (Fig. 3). On the other hand, the high proportion of individuals in the first classes indicates a high of self-regeneration of the species, once smaller individuals substitute the most advanced in the ecological succession process.

The *Eugenia rostrifolia* although presented an irregular distribution pattern, with a high concentration of individuals in the smaller diameter classes, had an uniform decrease in the number of individuals among the different size classes when compared to other to other species of higher IVI in the forest patch (Fig. 2).

A large amount of individuals in lower diametric classes has an important function to ensure the resilience of secondary forests [27], but can also indicate the occurrence of disturbances in vegetation. This scenario is due to possible burnings, constant attacks of pests or insects and wood extraction purposes in the recent past [28]. These disturbances, caused by possible anthropogenic interventions can provoke changes in the structure of forest [10].

Bernasol and Lima-Ribeiro [29] analysing the diametric structure of tree species in a forest patch of Cerrado observed unbalanced diametric distributions for *Piptocarpha rotundifolia* and *Butia purpurascens*, indicating the susceptibility of these species to environmental variations and disturbances when compared to others analysed in the forest patch.

Carvalho et al. [10] analysing the diametric structure of the community, and the main tree populations in the remnant of Submontane Atlantic forest report that species that presents the low amount of individuals, in smaller diameter classes, can have problems regarding the permanence in the remnant.

Additionally, the concentration of individuals in smaller diameter classes is important to ensure the survival and perpetuation of the plant in the forest succession process [30]. In this case, it is a sign that the recruitment of individuals is higher than mortality, which characterises the community as self-regenerating [31].

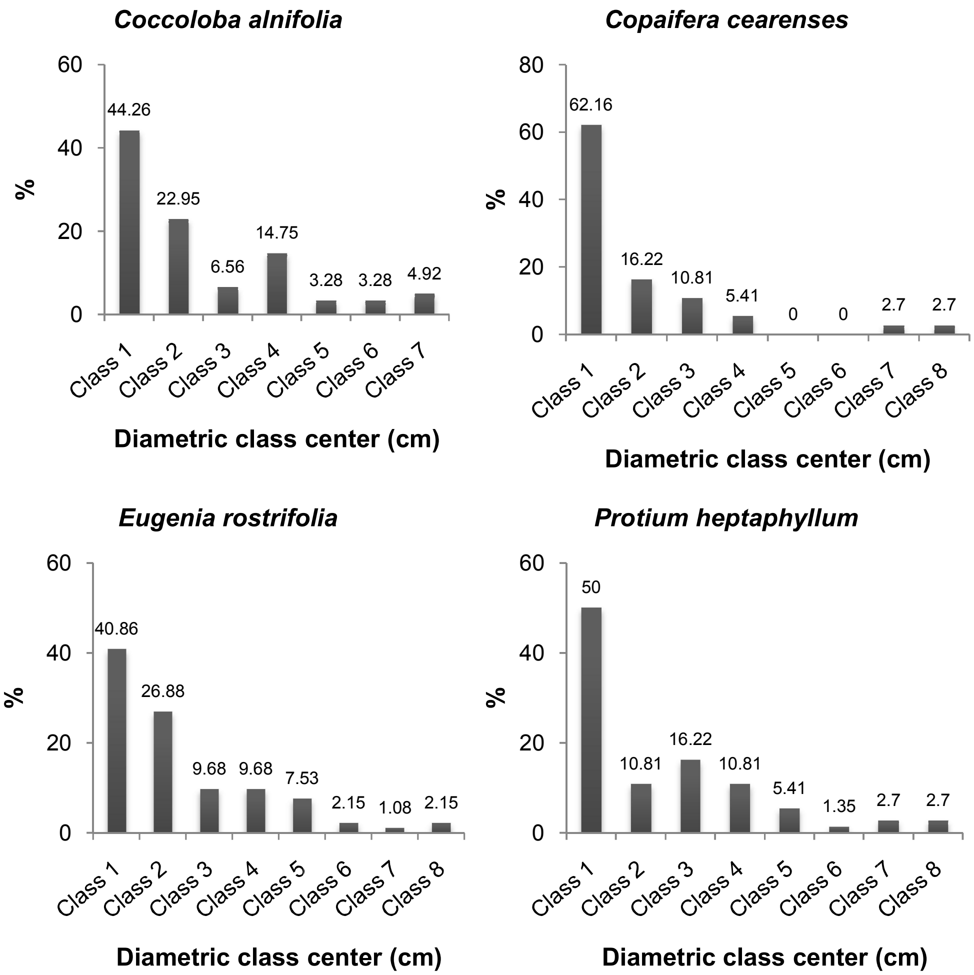

Fig. 2. Frequency distribution of individual in diametric classes for the most important tree species in the Ombrophilous Dense Forest patch, Macaíba, RN

Fig. 3. Evidence of tree removal for firewood in Ombrophilous Dense Forest patch, Macaíba, RN

Table 4. Spatial distribution pattern of tree species with the highest importance value index in the patch of Atlantic forest, Macaíba/RN

Scientific name	Pi index	Classification
Coccoloba alnifolia	0.98	Random Distribution
Copaifera cearenses	1.45	Tendency to group
Eugenia rostrifolia	1.03	Tendency to group
Protium heptaphyllum	1.69	Aggregated distribution

Pi: Payandeh Index

The results of this study indicate that despite the plant species with higher IVI in the forest patch presented an unbalanced diametric distribution, their respective diametric distribution patterns tended to J-inverted. The plant species which have a higher concentration of juvenile individuals, indicate that in the long run, these species tend to remain in the structural arrangement of the forest once the human intervention is curbed.

Regarding the spatial distribution pattern of the species with the highest IVI in the forest, it was observed through Payandeh index that the individuals of *Protium heptaphyllum* occur aggregated, while *Copaifera cearenses* and *Eugenia rostrifolia* presented a tendency to group, and *Coccoloba alnifolia* is randomly distributed in the forest patch (Table 4).

Kanieski et al. [16] analysing the floristic composition and diversity in a forest patch of Mixed Ombrophilous Forest in Rio Grande do Sul, observed that most of the species that occur in vegetation are classified as aggregated or with a tendency to group. Almeida et al. [32] studying the spatial distribution of *Pseudopiptadenia contorta* in a seasonal deciduous forest in Vitória da Conquista, BA, reported that the specimen is distributed in the environment, mainly influenced by the chemical soil quality.

The plants are typically distributed in aggregate form because they are structured mainly by abiotic factors such as texture, fertility, soil water availability, luminosity, temperature, among others; that are directly influenced by the variations in the production and provision of energy [33].

Alves Júnior et al. [34] analysing the edge effect in the structure of tree species in a forest patch of Ombrophilous Dense Forest in Recife, found that the most representative species in the vegetation usually occur in the aggregate form or with a tendency to cluster. According to Martins et al. [35], this pattern is commonly observed in abundant species in Tropical Forests.

In fact, the spatial distribution exposes how individuals are arranged horizontally in the environment and this organisation is the result of a combination of biotic and abiotic factors, such as environmental requirement, seed dispersal, predation and herbivory, and inter and intraspecific competition, among others.

Excluding *Coccoloba alnifolia*, the other species with highest IVI in the forest patch have shown an aggregate spatial distribution pattern or with a tendency to group. It is possible that this result is related to a low rate of intraspecific competition on the population or restricted dispersal of seeds near the mother-plant, as reported in other studies [36,37]. However, studies that address the spatial genetic structure in a microscale become necessary to confirm these hypotheses.

The standard knowledge of the spatial distribution of trees individuals in a population is crucial because it allows inferences about the ecology of the species and identifies possible dysfunctions in the propagation of individuals of a given species, thus subsidising, forest management practices.

4. CONCLUSION

The tree species with highest IVI in the forest patch showed an unbalanced diametric distribution pattern but tended to be J-inverted, indicating the tendency to remain in the structural arrangement of the forest, once the human intervention is curbed.

Except for *Coccoloba alnifolia*, the other highest IVI in the forest patch showed an aggregate spatial distribution pattern or with a tendency to group, a fact that allows understanding the behaviour of these species in the environment, subsidising actions aiming the conservation of the forest patch studied.

It is suggested that projects aiming to recover degraded areas in the studied forest patch should consider the pattern of distribution of the plant species in the forest patch to maintain them in the structural arrangement of the forest.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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