SPATIAL PATTERN AND ALLOMETRY OF A KEY TREE FOR THE AGROINDUSTRY SECTOR: *Hancornia speciosa* Gomes

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Resumo

Padrão espacial e alometria de uma árvore-chave para o setor agroindustrial: Hancornia speciosa Gomes. Os frutos da mangabeira (*Hancornia speciosa*) são utilizados, principalmente, na região Nordeste do Brasil, para abastecer o setor agroindustrial, com produção de sucos, doces, sorvetes e outros derivados. Para contribuir com a conservação e o manejo populacional, buscamos analisar o padrão espacial e as relações alométricas de *H. speciosa* em populações naturais. Para o padrão de distribuição espacial, foi utilizada a função densidade de vizinhança de segunda ordem (FDN). As equações de regressão polinomial foram ajustadas a partir dos dados alométricos e baseadas no coeficiente de determinação (R^2), também usamos estatísticas descritivas. As árvores de *H. speciosa* não ocorrem de forma aleatória nas áreas estudadas, e o padrão de agregação (até 15 e 20 m) pode estar associado à dispersão limitada de sementes (por exemplo, barocoria). A relação positiva entre o DAP (diâmetro à altura do peito) e a altura total resultou em um bom ajuste da equação (R^2 = 0,72). Além disso, foram encontradas altas correlações entre a área da copa, a altura geral e o DAP (R^2 = 0,83; R^2 = 0,81, respectivamente). Os resultados obtidos refletem estratégias adaptativas de *H. speciosa* em seu habitat natural, subsidiando informações para manejo e conservação de populações naturais submetidas a uma colheita intensiva de frutos.
Palavras-chave: mangaba, estrutura da árvore, estabilidade mecânica.

Abstract

The fruits of the mangabeira tree (*Hancornia speciosa*) are used mainly in the Brazilian Northeast region to supply the agroindustry sector to produce juices, sweets, ice cream and other derivatives. To support conservation and population management, we analyzed the spatial pattern and the allometric relations of *H. speciosa* in natural populations. For the spatial distribution pattern, we used a second-order neighborhood density function (NDF). Polynomial regression equations were fitted from the allometric data based on the coefficient of determination (R^2). We also used descriptive statistics. The *H. speciosa* trees studied did not occur in a random pattern in the studied areas, and the aggregation pattern (up to 15 and 20 m) was associated with the limited dispersion of seeds (e.g., barochory). The positive relation between the DBH (diameter at breast height) and total height showed good fit of the equation (R^2 = 0.72). Also, there were high correlations between the crown area and the overall height and DBH (R^2 = 0.83; R^2 = 0.81, respectively). The results obtained reflect adaptive strategies of *H. speciosa* in its natural habitat and provide information to support management and conservation of natural populations submitted to intensive fruit harvesting.
Keywords: mangaba, tree structure, mechanical stability.

INTRODUCTION

The frequency and density of trees establish their spatial distribution within the sampling units of a studied area (CONDIT *et al*., 2000). The spatial pattern is influenced by biotic factors like herbivory, competition, and seed dispersal (LIU *et al*., 2020), together with abiotic factors (e.g., nutrients, water, and light availability), all of which are essential to determine the seed germination and establishment (MARTINI *et al*., 2019; JACQUEMYN *et al*., 2012). Also, trees' degree of aggregation affects their genetic structure in populations (VIEIRA *et al*., 2010), indicating the survival strategy in the natural landscape and the implications for conservation and management (FAJARDO *et al*., 2014).

Studies related to the population structure of a natural community assist in management programs of tree species. These studies are crucial to understand forest ecology and how the establishment and development of trees occur (CONDIT *et al*., 2000). Allometric study is also essential to recognize the relationship between the size and shape of trees (FISCHER *et al*., 2019). Plant allometry inferences indicate species adaptation mechanisms, interspecific interactions, and the dynamics of the forest. The size of trees and physical variations can be related to the natural life-history traits and anthropogenic impacts, including selective logging (RODRIGUES *et al*., 2019).

Among the existing architectural characteristics of trees, the relation between height and diameter is the most comprehensive in the scientific field, since this is the factor that determines mechanical stability (FELDPAUSCH *et al*., 2011). The mechanical stability is a property that has been guided by the process of natural selection, Height growth depends on the height-diameter relationship. However, for trees to grow normally without compromising the balance, they need to invest part of their total mass to support their growth (ANTEN; SCHIEVING, 2010).

Although the tree *Hancornia speciosa* is considered to have high economic value mainly in the Brazilian Northeast region, there are still insufficient studies of the population structure. The mangaba fruits are used to produce juices, sweets, ice cream and other derivatives. The harvest brings in around $1 million per year in Brazil (IBGE, 2018). Most fruits are collected from natural habitats. Thus, it is crucial to obtain information to support management and conservation programs (FAJARDO *et al*., 2018).

Given the economic value of *H. speciosa* fruits for the agroindustry sector and the intense exploitation of its native populations, this study analyzed the spatial pattern and the allometric relations among trees. We hypothesized the existence of an aggregated spatial pattern, probably associated with the limited dispersion of seeds. Also, we expected to detect significant correlations between the architectural characteristics of *H. speciosa* according to the mechanical stability predictions for trees (PRETZSCH, 2019).

MATERIAL AND METHODS

Spatial pattern

All trees were inventoried in natural remnants of seasonal semideciduous Atlantic Forest in Rio Grande do Norte State, Brazil. The *H. speciosa* populations are historically threatened by the marked reduction of the natural habitats due to the deforestation and development of monoculture agricultural activities, causing a decrease in the effective population size (FAJARDO *et al*., 2018). The geographical coordinates of each plant were recorded by the Global Positioning System (GPS) in two populations in an area called Macaíba. In the first one (Mac1), trees were inventoried in an area of 1.32 ha (5°53'21,30" S, 35°21'23,16" W); in the second one (Mac2), the trees were inventoried in an area of 1.38 ha (5°53'35,23" S, 35°21'02,18" W). In both areas, anthropic interventions were noticeable due to the presence of communities.

The spatial pattern was determined using univariate analysis (CONDIT *et al*., 2000) in the SpPack version 1.38 software (PERRY, 2004). A second-order neighborhood density function (NDF) was employed. The spatial pattern was determined for classes between 5 m distance (t) in a correlogram up to 60 m. The definition of class number and intervals between them was determined through simulations so that the final correlogram did not have a "jagged pattern" in the analysis (WIEGAND; MOLONEY, 2004). Heat mapping of *H. speciosa* trees was performed using the ArcGis Pro software (ESRI Inc., 2019).

The correlograms were plotted with the NDF values (t) according to the t distance class and compared to intervals of complete randomness (confidence interval) obtained from 499 replications by Monte Carlo testing (alpha = 0.01) (PERRY, 2004). The null hypothesis of complete spatial randomness of the samples was accepted when the NDF values were within the range of confidence interval values (upper CI and lower CI). In general, NDF values higher than the upper CI indicate that the alternative hypothesis of an aggregate pattern is true, while values under the lower CI suggest that the alternative hypothesis of the segregated spatial pattern is true.

Allometry

Total height (m), bole height (m), circumference at breast height (CBH, cm) and crown area (m^2) were recorded for each tree (n = 80) from the Mac1 and Mac2 populations. The plants were sampled without height restrictions but considered an inclusion criterion of CBH equal or greater than 6 cm. This criterion was utilized to include small trees living in a transition area with the Caatinga biome subject to human intervention.

The total height was estimated by projecting a reference of a known length. For that, we considered the distance between the soil surface until the last branch of the plant. The bole height was considered from the ground height to the base of the first branch of the tree crown component. The bole height and the CBH were determined with a tape measure. For forked trees, CBHs were determined according to Scolforo and Mello (1997): $Ct = \sqrt{((c1^2 + c2^2 + \cdots ci^n))}$, where "*Ct*" is the total circumference, and "*ci*" is the CBHs measured (up to 1.30 m from the ground). Subsequently, the "*Ct*" value was converted to DBH (diameter at breast height) using the formula: DBH = Ct/π. The crown area was determined using the ellipse area (A = Rr) where "R" is half of the major axis of the crown and "r" is half of the minor axis.

The data were analyzed using the BioEstat software version 5.3 (AYRES *et al*., 2007). All allometry parameters were analyzed using univariate statistics and dispersion measures. The asymmetry (S) and kurtosis (K) were interpreted as follows: S > 0, right asymmetric distribution, and S < 0, left asymmetry distribution; K > 3, a more "tapered" distribution than the normal curve (leptokurtic), and K < 3, a flatter distribution than the normal curve (platykurtic).

Regressions were tested to predict the best model performance (linear, exponential, power, polynomial or logarithmic). The best relationship between the variables was described by equations obtained from polynomial regression (ZAR, 2010). The fit of the second-order polynomial regressions were determined based on the coefficient of determination (R^2) and how a variable was explained by the others, considering the data variation. There was no need for adjustments of the equations to reduce the data amplitude since the data collected were compared among themselves, to obtain the best model by the fit of Y on X. However, allometric variables were submitted to the Lilliefors normality test. Then the nonparametric correlation coefficient of Spearman (r_S) and its significance level (p) were applied (ZAR, 2010).

RESULTS

Allometry

The Mac1 population contained trees with medium height (average of 2.45 m) and average DBH of 5.40 cm. The Mac2 population also contained trees with medium height (mean of 3.08 m) and average of DBH 8.43 cm. The standard errors for all allometric features evaluated were considered low, indicating good precision of the collected samples (Table 1). The tallest tree sampled was 8.30 m. The heights of *H. speciosa* trees presented a wide variation, as they were measured without size restriction, with an average height of 3.18 m.

The crown area was highly variable according to the coefficient of variation. The maximum value of CBH was high because some trees are bifurcated above 1.30 m, but they were considered just one tree. The asymmetry (S) was positive, indicating asymmetric distribution and predominance of trees with lower CBH, DBH, total height, bole height, and crown area in the sample. The values of CBH, DBH and crown area showed a more tapered distribution than the normal curve, and the kurtosis coefficient (K > 3) indicated leptokurtic distribution. Thus, most of the data were concentrated around the mean. Both total and bole height showed distribution flatter than the normal curve (K < 3, platykurtic), i.e., the values were scattered closely around the mean.

Table 1. Allometric features of *Hancornia speciosa*. n: sample size, Max: Maximum, Min: Minimum, CV: coefficient of variation, S: asymmetry, K: kurtosis.
Tabela 1. Características alométricas de *Hancornia speciosa*. n: tamanho da amostra, Max: Máximo, Min: Mínimo, CV: coeficiente de variação, S: assimetria, K: curtose.

Allometric variables	***n***	**Max**	**Min**	**Mean ± standard error**	**Standard deviation**	***CV (%)***	***S***	***K***
CBH (cm)	80	118	6	28.21 ± 2.62	23.52	83.38	2.2	4.9
DBH (cm)	80	37.7	1.9	8.95 ± 0.84	7.5	83.86	2.2	4.9
Total height (m)	80	8.3	1.1	3.18 ± 0.16	1.46	45.86	1.6	2.3
Bole height (m)	80	1.87	0	0.70 ± 0.05	0.42	59.74	1	0.4
Crown area (m^2)	80	105	0.7	10.78 ± 1.95	17.47	62.04	3.9	7.2

Traditionally, the ratio between DBH and total height indicates the mechanical stability of a tree. In this study, this allometric relation was represented by the model: $y = -0.0007x^2 + 0.1867x + 1.6033$ (Table 2). The goodness off fit of this equation can be verified by the significance level of r_S.

Table 2. Parameters obtained from the polynomial regression analysis for all allometric relationships of *Hancornia speciosa*.
Tabela 2. Parâmetros obtidos da análise de regressão polinomial para todas as relações alométricas de *Hancornia speciosa*.

Allometric relations	Equations	R^2	r_S
DBH x Total height	$y = -0.0007x^2 + 0.1867x + 1.6033$	0.71	0.74 *
DBH x Bole height	$y = 0.0002x^2 + 0.0056x + 0.6199$	0.06	0.11^{ns}
DBH x Crown area	$y = 0.049x^2 + 0.3726x + 0.7941$	0.81	0.82 *
Total height x Bole height	$y = 0.0101x^2 + 0.007x + 0.5555$	0.11	0.23 *
Total height x Crown area	$y = 2.7013x^2 – 13.607x + 21.044$	0.83	0.77 *
Bole height x Crown area	$y = 11.648x^2 – 10.005x + 10.053$	0.09	0.17 *

Legend: R^2: determination coefficient, r_S: Spearman correlation. * = P < 0.05; ns = not significant.

The correlation between DBH and bole height was not significant. The polynomial regression between DBH x crown area fit well, with a determination coefficient (R^2) of 81%. On the other hand, the correlation between bole height and total height was low, with R^2 equal to 11%. Although significant, the correlation between the bole height and crown area was low (r_S = 0.17; R^2 = 9%).

Spatial distribution patterns

Eighty-two trees of *Hancornia speciosa* were sampled: 34 trees in the Mac1 population (Figure 1A), and 48 trees in the Mac2 population (Figure 1B).

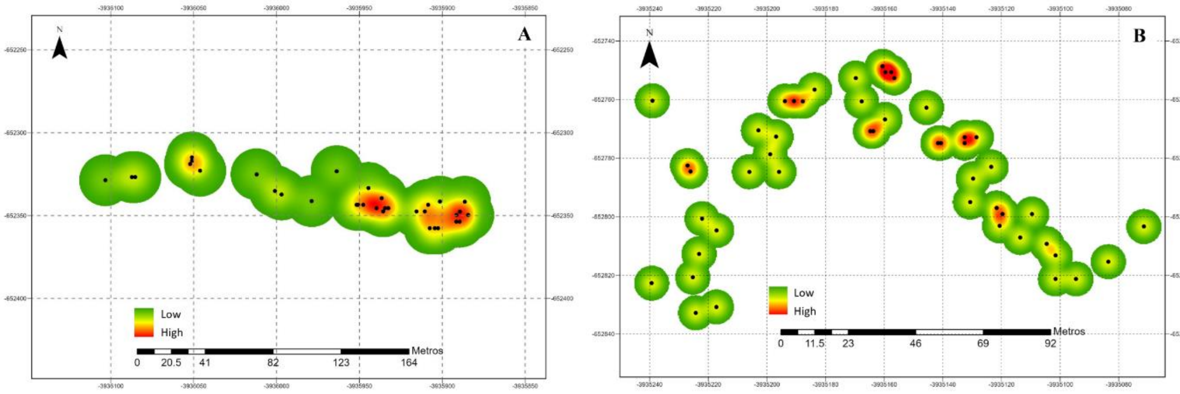

Figure 1. Heat map of *Hancornia speciosa* trees sampled in Mac1 (A) and Mac2 (B). Green color indicates low density and red color high density.

Figura 1. Mapa de densidade das árvores de *Hancornia speciosa* amostradas em Mac1 (A) e Mac2 (B). A cor verde indica baixa densidade e vermelha indica alta densidade.

The spatial pattern (NDF) in the Mac1 population was higher than the interval of complete randomness (Figure 2A). Therefore, a species aggregation level up to 20 m was observed, and from that distance onward, the trees were randomly distributed in the population. The highest density of trees was around 5 to 15 m distance.

As for the Mac2 population, the aggregation level was up to 15 m from the focal tree and random pattern in subsequent intervals (Figure 2B). Segregation level of trees in this population was observed at 60 m of distance from the focal tree. Significant levels of NDF by the Cramer-von Mises test (p = 0.002) were observed for both Mac1 and Mac2, confirming the spatial pattern statistically.

In both populations, a decreasing relation between NDF and the distance (t) was noted, showing that the sampled trees occurred in a dense aggregation, especially in smaller distance classes. In contrast, the lower density of the neighboring trees indicated a random spatial distribution in larger distance classes.

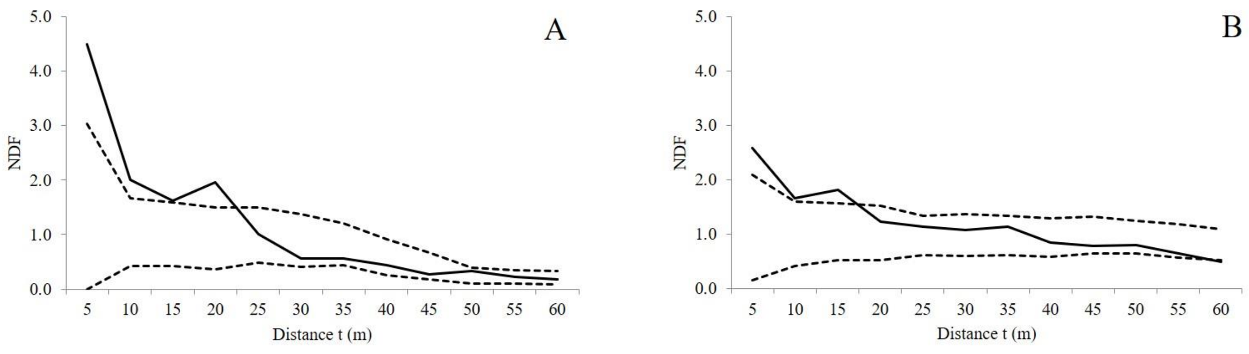

Figure 2. The spatial pattern obtained by the univariate neighborhood density function (NDF) for *Hancornia speciosa* trees sampled in Mac1 (A) and Mac2 (B) (continuous line). Confidence interval (CI) of 99% for the null hypothesis of completely random spatial pattern (dotted line).

Figura 2. O padrão espacial obtido pela análise univariada de densidade de vizinho (NDF) para árvores de *Hancornia speciosa* amostradas em Mac1 (A) e Mac2 (B) (linha contínua). Intervalo de confiança (IC) de 99% para a hipótese nula de padrão espacial completamente aleatório (linha pontilhada).

DISCUSSION

The trees of *H. speciosa* do not occur in isolation in the studied areas, showing an aggregated spatial pattern. In tropical forests, the most abundant species typically occur in groups or with a tendency to grouping (VIEIRA *et al*., 2012). The NDF levels of aggregation in the populations of *H. speciosa* probably reflect dynamics among cohorts or life stages, showing that the sampled trees in both populations had dense aggregation, especially in smaller distance classes. In contrast, the low density of the neighboring trees reflected a random spatial distribution in larger distance classes.

The aggregation pattern can also be associated with the restricted seed dispersal, since *H. speciosa* presents fruits have zoochoric dispersion, in which animals usually defecate and accumulate the seeds at a given point in the population (DALPONTE; LIMA, 1999). The absence of the primary disperser, the fox *Lycalopex vetulus* (DALPONTE; LIMA, 1999), probably made the zoochoric dispersion inefficient in the areas studied. Additionally, *H. speciosa* has relatively large and dense fruit (LÚCIO *et al*., 2019), and the dispersion can be performed by barochory, so that seeds are allocated around the crown of the parent plant.

Nasi (1993) stated that species present in disturbed habitats, e.g., large clearings, and vegetation edges usually tend to present an aggregated pattern. Indeed, the populations of this study occurred in open spaces, submitted to a certain level of anthropization. This fact may have contributed to the spatial pattern of the species in disturbed environments in open forests, as also noted by Fajardo *et al*. (2014).

Also, it is important to note that in tropical forests, abiotic and biotic factors which act on populations may be indicative of the community size and the regeneration vegetation status (CONDIT *et al*., 2000). Thus, it is essential to deepen studies of the consequences of the expansion of human activities in tropical forests, to elucidate the significant biotic and abiotic variables that influence the patterns of succession and regeneration in tropical forests.

The investment in crown by the sampled *H. speciosa* trees in this study can be explained by the fact that the trees occurred in an open environment, with abundant light, without light or space competition as would happen in areas with closed crowns, so that shortage of light was not a limiting factor. In addition, the crown can easily spread the additional increment in height and DBH.

Finally, the pattern found was sufficient to ensure stability and protection against mechanical damage caused by wind. Thus, *H. speciosa* trees with the largest crown area had more significant increment in height and DBH. Santos (2000) studied the allometric relationship between diameter and bole height of two species of *Cecropia* in the same habitat. They concluded there were allometric differences due to phylogenetic evaluations, which are not influenced by the environment.

Ganga *et al*. (2010) found for *H. speciosa* trees an average of 4.58 m for height, ranging from 1.5 m to 10 m. The observed variation may be related to the existing phenotypic variation among trees, also observed for the CBH and DBH, and genetic diversity (FAJARDO *et al*., 2018). The relation between DBH and total height is a key factor to help trees to maintain their balance and is related to the ability of the trunk to remain standing. Also, this gives the tree resistance its mass and against the forces of wind.

The high incidence of light due to the open vegetation possibly increased the crown area, allowing lower branches due to higher light penetration. Because of the strong relationship between total height and crown area, the mechanical stability of the trees did not appear to be compromised because the *H. speciosa* trees stopped investing in the bole height, since a low ratio between bole height and crown area was observed. Moreover, according to the results, trees with greater total height did not necessarily have the highest bole height.

CONCLUSIONS

- The aggregation level found in both populations was possibly related the fruit (seed) dispersion type (restricted zoochory or barochory).
- The results obtained reflect adaptive strategies of *H. speciosa* trees in their natural habitat, providing information to support management and conservation of natural populations submitted to intensive fruit harvesting.
- The relationship among the allometric variables studied showed evidence of mechanical stability of the species in the study area.

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