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POPULATION STRUCTURE OF *Euterpe edulis* Mart. AND RELATIONSHIPS WITH SOIL CHARACTERISTICS IN THE ATLANTIC FOREST

Pedro Henrique Candiota Bevilaqua[1], Eduardo Vinicius da Silva[2*], Emanuel José Gomes de Araújo[3], Jerônimo Boelsums Barreto Sansevero[4], Danilo Henrique dos Santos Ataíde[5]

[1]Universidade Federal Rural do Rio de Janeiro - Departamento de Silvicultura - Seropédica, Rio de Janeiro, Brasil – pedrohbevilaqua@gmail.com
[2*]Universidade Federal Rural do Rio de Janeiro - Departamento de Silvicultura - Seropédica, Rio de Janeiro, Brasil – evsilva@ufrrj.br
[3]Universidade Federal Rural do Rio de Janeiro - Departamento de Silvicultura - Seropédica, Rio de Janeiro, Brasil – emanuelaraujo@ufrrj.br
[4]Universidade Federal Rural do Rio de Janeiro - Departamento de Ciências Ambientais - Seropédica, Rio de Janeiro, Brasil – guapuruvu@gmail.com
[5]Universidade Federal Rural do Rio de Janeiro - Departamento de Silvicultura - Seropédica, Rio de Janeiro, Brasil – daniloataide.florestal@gmail.com

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Resumo

Estrutura da população de Euterpe edulis Mart. e sua relação com características do solo na Mata Atlântica. O objetivo deste estudo foi avaliar a relação das características granulométricas e químicas do solo com a estrutura da população de *Euterpe edulis* e a distribuição de indivíduos em um trecho da Mata Atlântica sob regeneração. Para isso, dividiu-se a topossequência da área em uma posição superior, média e inferior. Em cada posição, foram instaladas três parcelas de 100 m². Mediu-se o diâmetro à altura do peito (DAP) e a altura total daqueles indivíduos com altura superior à 1,3 m. Os indivíduos com altura inferior foram contabilizados e classificados de acordo com seu estágio ontogenético através da instalação de subparcelas de 1 m² no interior das parcelas. As amostras de solo foram coletadas na camada de 0-30 cm em cada parcela. Como resultado, contabilizou-se 187 indivíduos com mais de 1,3 m de altura distribuídos nas três posições da topossequência, concentrando-se estes na posição superior (118 indivíduos). Para os estágios ontogenéticos, a fase Plântula foi a mais representativa (231 indivíduos). A posição superior também apresentou maior número de indivíduos neste estágio (85% de ocorrência). Observou-se que as características do solo influenciaram a distribuição populacional da espécie bem como sua estrutura. A análise de componentes principais (PCA), mostrou que 64,32% da variação total relacionou-se com as características do solo. Cada variável do solo apresentou maior ou menor grau de correlação, dependendo da posição na topossequência. No entanto, o maior teor de potássio e de argila correlacionaram positivamente com a distribuição da espécie e estrutura populacional na área de estudo.
Palavras-chave: Jussara, Restauração, Manejo, Estágios ontogenéticos

Abstract

The objective of this study was to evaluate the relationship between the granulometric and chemical characteristics of the soil and the population structure of *Euterpe edulis* and analyze the distribution of individuals in a regenerating area of Atlantic Forest. A toposequence divided into top, middle, and lower positions was analyzed. Three 100 m² plots were established in each position and individuals taller than 1.3 m within these plots had their diameter at breast height (DBH) and total height measured. Individuals shorter than 1.3 m within 1 m² subplots installed within the plots were counted and classified according to their ontogenetic stage. Soil samples were collected from the 0-30 cm layer in each plot. A total of 187 individuals taller than 1.3 m were counted across the toposequence, with greater concentration in the top position (118 individuals). Among the ontogenetic stages, the seedling phase was the most representative (231 individuals), with the top position also showing the highest number of individuals at this stage (85%). It was observed that soil characteristics influenced the population distribution and structure of *E. edulis*. The principal component analysis (PCA) revealed that 64.32% of the total variation was related to soil characteristics. Each soil variable showed varying degrees of correlation depending on the position in the toposequence. However, higher potassium and clay content positively correlated with the species' distribution and population structure in the study area.
Keywords: Jussara, Restoration, Management, Ontogenetic stages

INTRODUCTION

The species *Euterpe edulis*, belonging to the family Arecaceae, occurs naturally throughout the Atlantic Forest biome, from the southern region of Bahia (15ºS) to the northern part of Rio Grande do Sul (30ºS) along the Brazilian coast (FÁVARO *et al*., 2021). For many years, it was primarily valued for its heart-of-palm, found at the upper part of the stem (MULER *et al*., 2014). Due to overexploitation without proper management practices, *E. edulis* was considered vulnerable and was included in the list of endangered species (CNCFLORA, 2012; RODRIGUES *et al.*, 2017). The species has a tall, straight, and cylindrical stem with diameter ranging from 5 to 32 cm in adulthood, and it can reach up to 20 meters in height (BRANCALION *et al.*, 2012). According to Ribeiro *et al.* (2011), *E. edulis* produces a large number of fruits, allowing various bird and mammal species to disperse its seeds. This interaction and its prominent role in ecological succession makes *E. edulis* a key species in ecosystems (MENDES *et al.*, 2022). Furthermore, *E. edulis* is commercially exploited in native forests through sustainable management, an aspect that contributes to its conservation (CERQUEIRA *et al.*, 2024).

The continuous degradation of forests and overexploitation of *E. edulis* reduce the populations of adult seed-producing individuals, also impacting the dispersing fauna (RIBEIRO *et al*., 2011; SANTOS *et al*., 2023). This intricate relationship, involving the decline of adult populations, the dispersal capacity of fauna, and the resulting pattern of seed and seedling dispersion, highlights the urgent need to halt the ongoing degradation of tropical forests to ensure the survival and regeneration of the species (MULER *et al*., 2014).

A large number of studies have been conducted with *E. edulis*, most of them focusing on the biochemical properties and ecology of the species (CERQUEIRA *et al*., 2024). Although research on habitat loss and fragmentation processes has advanced, most studies do not consider the crucial influence of the environment on populations (BENCHIMOL *et al*., 2017). There is therefore a need to better understand the factors that contribute to the establishment and mortality of *E. edulis* individuals throughout the stages of their development (BAGGIO *et al*., 2023).

According to Portela *et al*. (2011), *E. edulis* individuals undergo distinct developmental periods marked by unique morphological, anatomical, physiological, and biochemical changes (qualitative characteristics) that serve as biological indicators of their developmental stage. They also observed that key phenological aspects such as flowering, fruiting, and seed size exhibit significant variations according to different edaphoclimatic characteristics of the environment. These variations can affect the species' reproduction and, consequently, population structure. These findings emphasize the importance of investigating the intricate relationship between *E. edulis* and its surrounding environment in order to understand the broader dynamics of its establishment.

According to Broschat (2009), potassium is essential for the growth and development of palm trees, specifically for the regulation of water balance, activation of enzymes, and nutrient transportation. The author emphasized that, since palm trees are frequently found in sandy and leached soils, they depend on adequate levels of potassium (K) to maintain the production of healthy leaves and trunks, as well as to ensure tolerance to abiotic stresses such as high salinity and drought. Therefore, potassium deficiency can significantly compromise stem diameter, reducing heart-of-palm productivity and the overall resistance of the plants. Regarding soil nutrients, Brancalion *et al*. (2012) stands out as one of the few studies conducted with *E. edulis* establishing a connection between these variables and palm growth and fruit production in two distinct types of vegetation: Restinga and Atlantic Forest. The authors revealed the influential role of K in the growth of this palm tree. However, they did not consider the ontogenetic stages of the palm trees in their analysis, but focused only on the mean diameter at breast height (DBH) as the variable of interest for comparison.

Therefore, the objective of the present study was to characterize the population structure of *E. edulis* based on ontogenetic stages along a toposequence, taking into account variations in the granulometric and chemical attributes of the soil.

MATERIAL AND METHODS

Environmental characterization of the area

This study was conducted in the municipality of Queluz, state of São Paulo, within the boundaries of the Vargem Grande da Bela Aurora property (Latitude: 22°28'17.73"S; Longitude: 44°48'16.17"O). The study area covers approximately 1.12 hectares and is located within a fragment of Atlantic Forest, within the territory of the Serra da Mantiqueira Environmental Protection Area (APA) and the Mananciais do Rio Paraíba do Sul APA, Federal Conservation Units managed by ICMBio, and part of the Mantiqueira Mosaic.

There are reports that part of the forest where the study area is located may have undergone tree cutting and burning for charcoal production (charcoal production) in the last century. Therefore, there is historical evidence suggesting that the forest is in a secondary stage of regeneration.

The altitude of the experimental area ranges from 900 to 1,000 meters. The climate in the region is of the Köppen Cb type (humid subtropical and mesothermal), with an average annual temperature of 16.7 ºC and precipitation of 2,108 mm, respectively.

Sampling

The study divided the area into three positions based on topography (toposequence): top (higher elevation and steeper terrain), middle (intermediate elevation and flatter terrain), and lower (lower elevation and relatively flat terrain). Data were collected by allocating three rectangular plots of 4 x 25 m (100 m²) in each position of the toposequence, resulting in a total sampling area of 900 m². This sampling area was defined based on a decree from the state of São Paulo’s Secretariat for Environment, Infrastructure, and Logistics (Portaria CBRN No. 01, dated January 23, 2015).

For the proper installation of the plots in the field and georeferencing of all measured *E. edulis* individuals, the following devices were used: a GPS (Global Positioning System) model Garmin II Plus, a compass, and an altimeter (model SCHOENINGER, 2002).

After this step, the processing of the geographic coordinates data obtained in the field was carried out using the GPS TrackMaker software and the QGis software, allowing a more precise visualization of the location of plots and individuals in the field.

All *E. edulis* individuals with a height greater than 1.3 m had their DBH measured. Height was measured using a 2.5 m graduated pole, visually extending it to the top of the palms. Measurements were always taken by the same person in order to minimize sampling errors.

The soil in the experimental area at all positions of the toposequence (top, middle and lower) was classified as clayey Humic Cambisol. This classification was performed by excavating a profile at each of these positions to a depth of approximately 1 meter.

Granulometric and chemical analyses were conducted at a depth of 0-30 cm (Table 1). Simple soil samples were collected for these analyses, forming a composite sample from each plot at the three positions of the toposequence.

Data analysis

A histogram was constructed using Sturges' rule to examine the distribution of height and diameter data obtained in the field. The size of each class was determined by dividing the range of the data by the number of classes, ensuring a more appropriate representation of the data distribution.

Ontogenetic stages were classified according to the criteria of BAGGIO *et al.* (2023), using both quantitative and qualitative measures. Four pre-reproductive stages and one reproductive stage (adult phase) were observed. Leaf type, stem appearance, and reproductive events served as key characteristics for identifying the stages. For younger individuals, the presence of the third leaf indicated a reduction in dependence on seed reserves, accompanied by vertical growth and leaf area expansion, although without the formation of pinnate leaves. Thus, the five stages used were:

- Seedling: Individuals with up to the first two open leaves. Stage related to dependence on seed nutrient reserves;
- Young 1: Individuals that have already produced the third leaf up to individuals with a height of 30 cm, measured from the base of the stem to the point of intersection of the youngest leaf with the immediately previous leaf. Stage related to depletion of seed reserves;
- Young 2: Individuals over 30 cm but still without a woody stem. Stage related to leaf area expansion and appearance of pinnate leaves;
- Immature 1: Individuals with an exposed stem, but less than 1.3 m tall. Stage related to the beginning of vertical growth;
- Adult: Individuals with an exposed stem and taller than 1.3 m, recognized by the presence of reproductive structures such as inflorescences, infructescences, scars on the leaf sheath, or even recently fallen clusters near the plant, provided the origin of the cluster is evident.

For this assessment, 1-m² subplots were placed near parental plants within the plots using a wooden template. The template was positioned close to the parental plants in the plot in a way that represented the aggregated pattern of seedling distribution around the parental plant. According to Nascimento *et al.* (2016), *E. edulis* is a species with a seedling bank regeneration strategy, with aggregated spatial distribution near the mother plants.

Statistical analyses were performed through Principal Component Analysis (PCA) and the Pearson correlation matrix in R version 3.6.1.

A total of 20 quantitative variables were considered for each ontogenetic stage: number of individuals per hectare (N/ha), total height (Ht), diameter at breast height (DBH), organic matter (OM), pH (Hydrogen potential), hydrogen and aluminum (H+Al), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), manganese (Mn), zinc (Zn), base sum (SB), cation exchange capacity (CEC), base saturation (V%), clay, silt, and sand content.

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The number of individuals per hectare was extrapolated from the absolute number within the respective sampling unit to estimate the density per hectare. Total height represented the average total height, and DBH represented the average diameter at breast height for plants taller than 1.3 m. Boron (B) and copper (Cu) showed no significant correlations and were excluded from the analysis.

Table 1. Granulometric and chemical characteristics of the soil Clayey humic cambisol at a depth of 0-30 cm in each position of the toposequence.
Tabela 1. Características granulométricas e químicas do Cambissolo húmico argiloso na profundidade de 0-30 cm em cada posição da topossequência.

Soil characteristics		**Toposequence**		
		Top	**Middle**	**Lower**
Granulometry (%)	Sandy	39.3	44.2	49.2
	Silty	31.5	33.0	29.1
	Clay	39.3	44.2	49.2
pH ($CaCl_2$)		4.9	4.8	4.2
OM (g dm^{-3})		40.7	71.0	38.7
S (mg dm^{-3})		14.7	23.0	27.3
P (mg dm^{-3})		29.7	30.3	29.7
K (mmolc dm^{-3})		3.7	1.8	1.9
Ca (mmolc dm^{-3})		47.3	79.3	22.3
Mg (mmolc dm^{-3})		8.0	12.7	5.7
H+Al (mmolc dm^{-3})		62.3	84.0	97.7
B (mg dm^{-3})		0.5	0.5	0.5
Cu (mg dm^{-3})		0.9	0.9	1.2
Fe (mg dm^{-3})		100.7	245.7	146.3
Mn (mg dm^{-3})		46.2	51.9	61.0
Zn (mg dm^{-3})		3.3	5.1	3.5
SB (mmolc dm^{-3})		59.0	90.8	29.9
V (%)		48.7	52.0	22.7
CEC (mmolc dm^{-3})		121.3	174.8	127.6

Legend: pH (Calcium chloride 0.01); H+Al (Calcium-magnesium phosphate buffer solution); P, K, Ca, Na, and Mg (Ion Exchange resin); S (Calcium phosphate); B, Cu, Fe, Mn, and Zn (DTPA).
Legenda: pH (Cloreto de cálcio 0.01); H+Al (Solução tampão de fosfato de cálcio-magnésio); P, K, Ca, Na e Mg (Resina de troca iônica); S (Fosfato de cálcio); B, Cu, Fe, Mn e Zn (DTPA).

RESULTS

In this study, 187 individuals were sampled in the nine plots, with a predominant presence of individuals in early stages of development (Figure 1). The distribution of individuals in diameter classes showed an overrepresentation of the class 5.2 to 7.3 cm and a decreasing trend in higher classes, then an increase in the class 11.5 to 13.6 cm, a decreasing trend again in higher classes, and another increase in the class 17.8 to 20.1 (Figure 1 A). As for the representation of height classes, there was a sharp decline in the class 4.9 and 6.7 m, then an increase in the next class, 6.7 to 8.5 m, followed by a decline in higher classes (Figure 1 B).

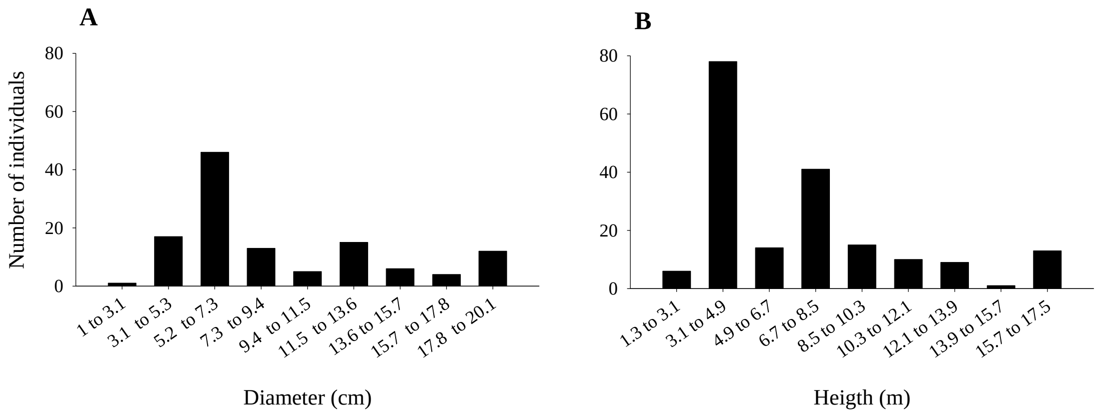

Figure 1. Overall distribution of individuals in the toposequence as a function of diameter (A) and height (B).
Figura 1. Distribuição geral de indivíduos na topossequência em função do diâmetro (A) e da altura (B).

A total of 118 individuals were sampled in the top position of the toposequence (Figure 2). This position had the highest number of individuals, representing a significant population stock in the early stages of development, with diameters up to 5.3 cm and heights up to 4.9 m (Figure 2 A). However, there was a reduction in the number of individuals in the diameter class 7.3 to 9.4 cm, followed by an increase in the class 9.4 to 11.5 cm, and then maintaining a relatively homogeneous distribution in the other classes. Similarly, in the height variable, in this position, there was a underrepresentation of individuals between 4.9 to 6.7 m high, aligning with the general distribution pattern observed in all other positions (Figure 2 B).

In the middle position of the toposequence, there was a total of 44 individuals sampled (Figure 2). Individuals were concentrated in the class 5.2 to 7.3 cm, followed by a sharp reduction in higher classes with a slight increase again from the class 15.7 cm to 17.8 cm (Figure 2 A). Regarding the height variable, a non-homogeneous distribution pattern was observed. The most representative classes were 3.1 to 4.9 m and 6.7 to 8.5 m (Figure 2 B).

The lower position showed the lowest number of individuals sampled, totaling 24 palms (Figure 2). A more uniform distribution of diameter and height was observed in this position, especially in the early stages, with individuals having an average diameter of 6.5 cm and an average height of 3.9 m. This position presented a more homogeneous population at all stages, indicating that the recruitment of individuals in the early stages is insufficient to sustain a substantial number of individuals in the adult stage. This pattern suggests a disturbance in the natural regeneration of the species and in the adult population stocks, with lower recruitment rates. These results highlight the importance of enrichment efforts to increase the number of recruits in the intermediate and early stages of development, thus promoting the species' regeneration strategy.

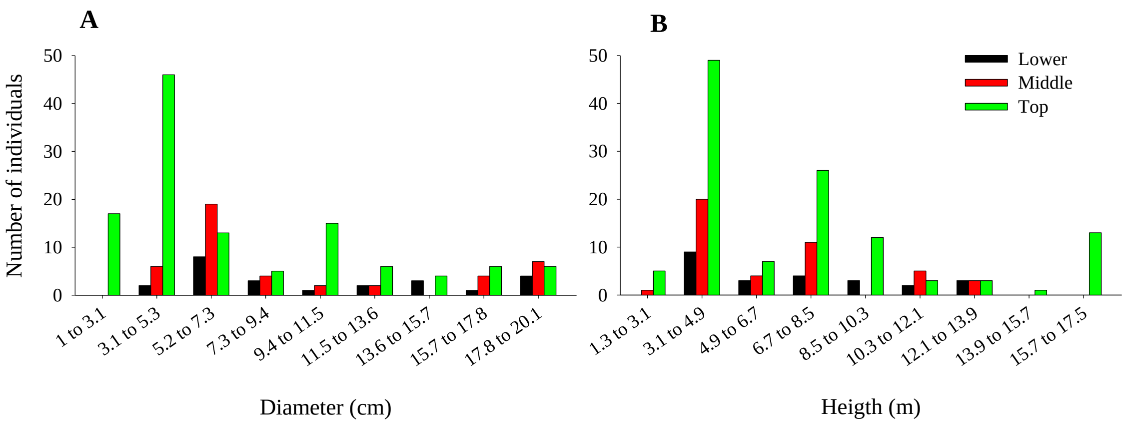

Figure 2. Distribution of individuals in the topographic position as a function of diameter (A) and height (B).
Figura 2. Distribuição de indivíduos na posição topográfica em função do diâmetro (A) e altura (B).

Regarding the ontogenetic stages, a total of 231 individuals were sampled in the Seedling stage; 72 in the Young 1 stage; 7 in the Young 2 stage; 3 in the Immature 1 stage, and 15 in the Adult stage (Figure 3A).

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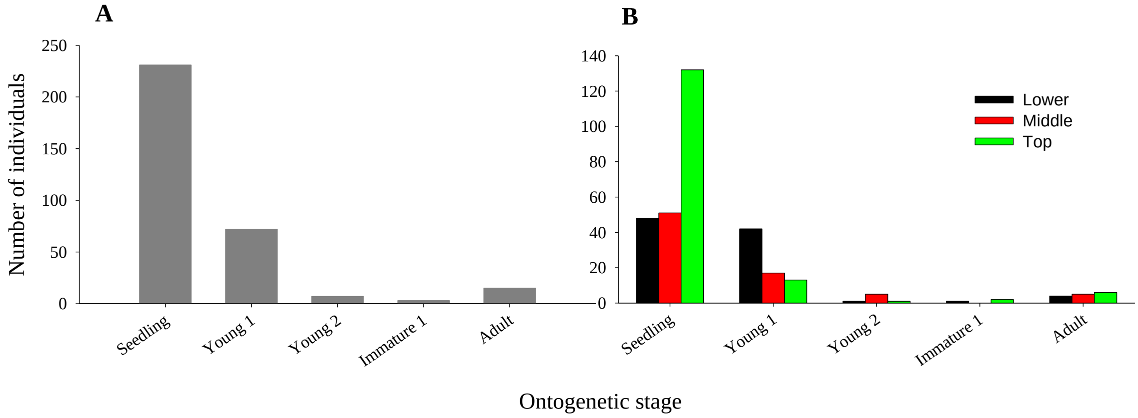

Figure 3. General distribution of all individuals analyzed in the study as a function of ontogenetic stage (A) and distribution of individuals in each position of the toposequence as a function of ontogenetic stage (B).
Figura 3. Distribuição geral de indivíduos na topossequência em função do estágio ontogenético (A) e Distribuição de indivíduos em cada posição da topossequência, dependendo do estágio ontogenético (B).

In the top position of the toposequence, the number of individuals in the seedling stage (132) was proportionally higher than that of individuals in other stages, with 85% of the total number of individuals in this position (Figure 3B). The stage Young 1 accounted for 8% of the sampled individuals (13) and the other stages totaled 7% of the individuals. In the middle position, a smaller number of individuals were collected (78). However, seedlings also represented the largest number of individuals collected (65%; 51 individuals), while Young 1 accounted for 21% (17 individuals). In the lower position, 96 individuals were collected. In this position, a shift in the population structure was observed, with the Seedling and Young 1 stages showing very similar values (Figure 3B). In this position, the number of individuals in the Seedling stage was higher (42).

According to the matrix of significant linear correlations (Figure 4), the number of individuals per hectare in the Adult stage (Nha_A) showed a positive correlation with pH and clay and a negative correlation with sulfur (S), H+Al, and sand. The number of individuals per hectare in the Seedling stage (Nha_Pl) and in the Immature 1 stage (Nha_I1) showed a positive correlation with K. The number of individuals per hectare in the Young 2 stage (Nha_J2) showed a positive correlation with organic matter (OM), iron (Fe), and magnesium (Mg). The sand variable showed a negative correlation with the number of individuals per hectare in the Adult and Seedling stages. Finally, the number of individuals per hectare in the Young 1 stage (Nha_J1) showed a positive correlation with H+Al. Regarding the soil variables, the number of individuals in the Young 1 stage (Nha_J1) correlated with the H+Al variable, which is present in the lower position of the toposequence.

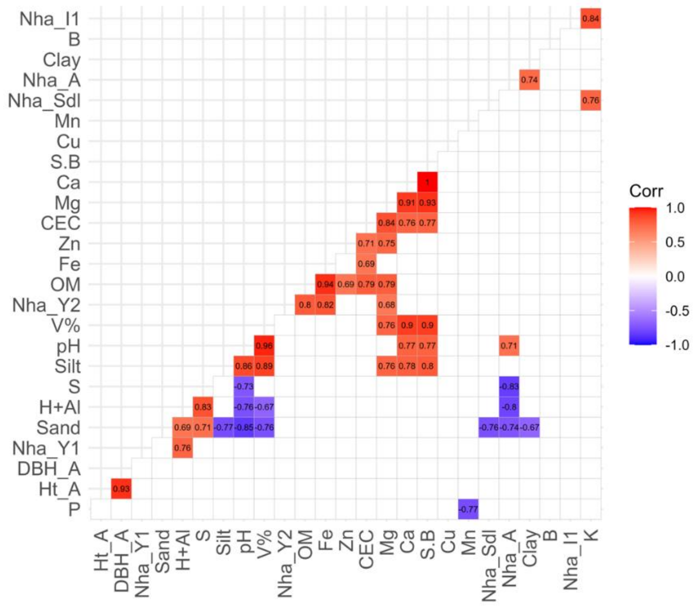

Figure 4. Significant linear correlations chart.
Figura 4. Gráfico de correlações lineares significativas.

In the PCA, the Principal Component 1 (PCA 1) and Principal Component 2 (PCA 2) accounted for 64.32% of the total variation in the data (Figure 5). The chemical attributes of the soil that most influenced the population structure and early ontogenetic stages were, respectively, K and clay.

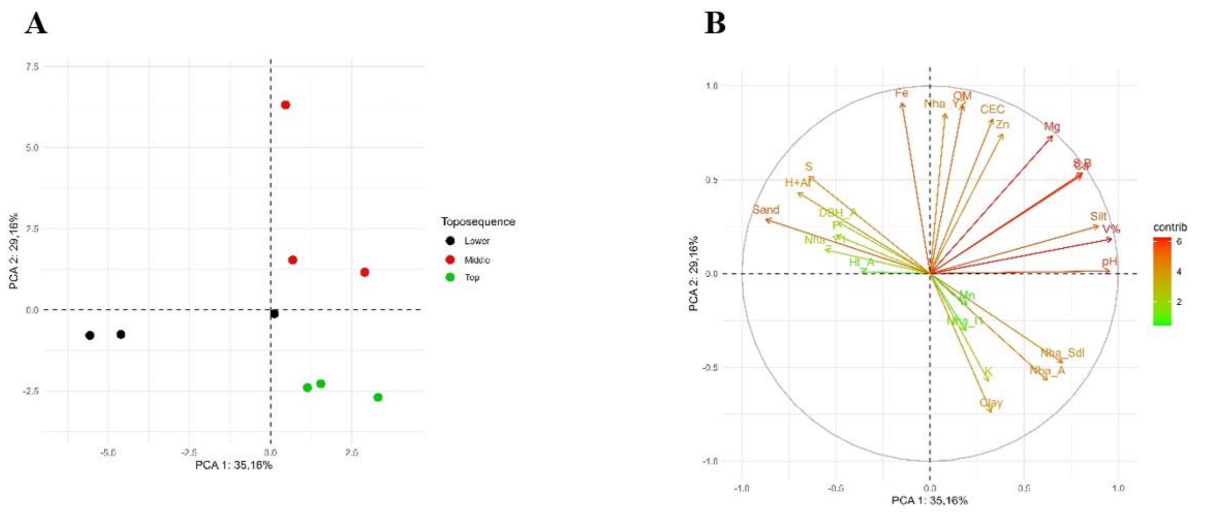

Figure 5. Principal Component Analysis. A: Relations with the position in the toposequence, and B: Relations with soil attributes.

Figura 5. Análise de componentes principais. A: Relacionando a posição na topossequência e B: Relacionando aos fatores do solo.

DISCUSSION

The concentration of individuals in the smaller height and diameter classes suggests a population stock with significant recruitment in the early stages. Similarly to other tropical species, the distribution of *E. edulis* individuals showed a pattern close to a negative exponential function (inverted J) which usually results from high mortality in the early stages of development due to intraspecific competition (FÁVARO *et al.*, 2021).

The top position of the toposequence exhibited a high population stock in the early developmental stages, with a higher absolute number of individuals observed across all classes. However, the distribution pattern in the middle position indicates a disturbance in the natural regeneration process, likely caused by a lower population stock in intermediate height classes. This situation will likely have significant implications for the replacement of individuals in advanced stages in the future. Baggio *et al*. (2023) observed an association between the distribution of juveniles and adults, suggesting limitations in dispersal and recruitment patterns centered around established adult individuals.

In the lower position, there was a similar distribution of individuals between the Seedling and Young 1 stages, indicating that recruitment in the early stages is insufficient to sustain a substantial number of individuals in the adult stage. This pattern suggests a disturbance in the natural regeneration of the species and in the adult population stocks, with lower recruitment rates. These results highlight the importance of enrichment efforts to increase the number of recruits in the intermediate and early developmental stages, thereby promoting the species' regeneration strategy.

In the top position, the smaller number of plants in the Young 2 and Adult stages can be explained by high intraspecific competition for nutrients, water, and light immediately after the plant exhausts the seed nutrient reserves. This competition is often responsible for high mortality rates in early developmental stages, as demonstrated in the study by Ribeiro *et al.* (2011).

Baggio *et al.* (2023) identified a slow transition from the Young 1 stage to the Young 2 stage. According to this study, such slow transition may represent a disturbance in the proper development of the species and a bottleneck in population growth.

Regarding the density of individuals in the present study, extrapolated values ranging from 500 to 5,200 *E. edulis* individuals per hectare were found. Silva-Matos *et al.* (1999) identified densities of 300 $ind.ha^{-1}$, while the recruits (early stages) had a density of 35,600 $ind.ha^{-1}$. Favaro *et al*. (2021) examined *E. edulis* individuals taller than 1.30 m with exposed stems and found densities greater than 500 $ind.ha^{-1}$, whereas NODARI *et al.* (2000) observed a density of 750 $ind.ha^{-1}$.

In this study, a positive correlation was observed between K levels and the plots that exhibited the highest density of *E. edulis* individuals. Moreover, both K and clay content showed a positive correlation with the top position of the toposequence. Specifically regarding ontogenetic stages, the Young 1 stage correlated with H+Al, while the Adult stage correlated with pH, indicating that acidic soils are not ideal for the development of the species. These results suggest significant associations between nutrient availability and *E. edulis* distribution in the studied ecosystem. The fact that different ontogenetic stages of *E. edulis* related to different soil characteristics may be related to the possible chemical and nutritional requirements of each stage (ALVARADO, 2015). Individuals in early stages have a higher demand for nutrients to maintain their growth rate, while adult individuals rely more on the nutrients accumulated and subsequently recycled.

The results of the present study are in agreement with those of Brancalion *et al*. (2012) with respect to the connection between potassium-rich soils and the plant development, particularly in terms of DBH. Although DBH did not show a direct correlation with K content in the soil in the adult stage in this study, our observation of this lack of correlation is an important finding because it confirms the influence of K on the population structure. The relationship between K and sodium (Na) may also have a significant impact on palm growth (Brancalion *et al.* 2012).

A correlation was observed with silt and calcium, and between cation exchange capacity (CEC), organic matter (OM), and zinc (Zn). The plots in the lower position of the toposequence had evidently a distinct nature in relation to the others. In the PCA, one of these plots was positioned near the center of the graph, indicating a minimal or nonexistent relationship with the principal components. The other two plots exhibited a negative correlation with the components and with all other plots in the study, showing a closer proximity to the variables H+Al, sulfur (S), phosphorus (P), and sand content. Furthermore, sand content and H+Al and S concentrations were negatively correlated with the most significant plots and density of individuals. Soils with higher sand content have greater macroporosity, making them more permeable and less able to retain water compared to clayey soils (PAIVA *et al*., 2000). Consequently, sandy soils exhibit lower nutrient levels, mainly due to leaching processes. Nutrient availability and organic matter (OM) content are known to influence plant development.

A correlation was observed with silt and calcium, and between cation exchange capacity (CEC), organic matter (OM), and zinc (Zn). The distinct nature of plots 7, 8, and 9 (lower position of the toposequence) compared to other sampled units in the study was evident. This difference between positions became clear in the PCA analysis, where plot 7 was positioned near the center of the graph, indicating a minimal or nonexistent relationship with the principal components. Plots 8 and 9 exhibited a negative correlation with the components and all the other plots, showing a closer proximity to the variables H+Al, sulfur (S), phosphorus (P), and sand. Furthermore, an increase in sand content, as well as H+Al and S concentrations, was negatively correlated with the most significant plots and individual density. Soils with higher sand content have greater macroporosity, making them more permeable and less capable of retaining water compared to clayey soils (PAIVA *et al*., 2000). Consequently, these sandy soils exhibit lower nutrient levels, mainly due to leaching processes (HUANG; HARTEMINK, 2020). The availability of nutrients and organic matter (OM) demonstrates a correlation with species development (GUERRINI *et al.*, 2024).

The variables H+Al, S, and P are sometimes associated with depleted soils that are less conducive to the ideal development of palm trees. In the study by Brancalion *et al.* (2012), negative effects of P, Ca, Mg, and Al on palm tree growth were observed. In this study, several chemical attributes of the soils and the DBH and number of fruits per bunch of *E. edulis* individuals were compared between Atlantic Forest and Restinga Forest areas. Higher concentrations of K, Ca, Mg, and Al were found in the soils of the Atlantic Forest area, while P and Na were found in higher concentrations in Restinga. Consequently, the authors observed palms with higher DBH and fruit bunch production in Atlantic Forest soils than in Restinga Forest.

K is a vital nutrient for the growth of palm species. K deficiency is commonly observed in palms growing in highly leached sandy soils. Broschat (2009) observed that K deficiency seems to affect palm trees worldwide; K availability in the soil is associated with the presence of palm individuals in specific environments. In line with these findings, the present study also revealed a positive correlation between K and the number of individuals during the early developmental stage, specifically seedlings.

There was a negative correlation between K and sand content in the present study. This may have occurred because soils with higher sand content often have lower cation exchange capacity and reduced nutrient levels, including K, since they are leached (MARTINEZ *et al.*, 2023). Sandy soils exhibit greater macroporosity, resulting in higher permeability and a reduced ability to retain water compared to clayey soils. Consequently, sandy soils tend to have lower nutrient levels due to leaching processes.

Finally, as demonstrated by Mendes *et al*. (2022), *E. edulis* can be considered a key species in the composition of tropical forests. Their field data showed that this species plays a significant role in the regeneration of the forest fragment analyzed in their study. However, further studies are needed to understand the interactions and associations of *E. edulis* with other species.

CONCLUSIONS

- In the top position of the toposequence, there was a higher number of individuals in the early stages of development, while in the middle position, there was a reverse J-shaped distribution pattern for diameter and a non-homogeneous distribution pattern for height.
- In the lower position of the toposequence, there was a smaller number of individuals and a more uniform distribution of individuals in diameter and height classes, indicating a disturbance in natural regeneration and lower recruitment rates.
- There was a significant positive correlation between K and clay content in the soil and abundance of individuals in the early developmental stage, pointing to the vital role of this nutrient and soil texture in facilitating the establishment of the species in natural forests.

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