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Articles

Environmental influences in the annual current increment of the basal area, in the Caatinga environment

Influências ambientais no incremento anual da área basal, em ambiente de Caatinga

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ABSTRACT

The growth of plant species is directly influenced by biotic and abiotic factors. With this, the objective was to identify variables that influence the current annual increment – CAI of the basal area, in two areas, considered as "least conserved" and "most conserved" in the Semiarid of Pernambuco, Brazil. The dendrometric data is from 40 permanent plots of (20 m x 20 m), in the years (2008 and 2011 to 2019), measurements were conducted on individuals and branches with a circumference at 1.30 m from the ground ≥ 6 cm. The environmental data came from the National Institute of Meteorology and the Water and Climate Agency of Pernambuco. Spearman's correlation was applied between the CAI and the environmental variables, given the problem of repeated measurements, the mixed linear regression model was used: $CAI_i = (\beta_0 + \alpha_{period} + \lambda_{specie}) + \beta_n Vdendrometric_n + \beta_m Venvironmental_m + \epsilon_i$, considering the random effects the period and species, and the fixed effects the dendrometric and environmental variables. Regarding the significance of the variables in the CAI, an influence was noted for the least conserved area only in relation to the fixed effects, whereas in the most conserved area it was significant in terms of the fixed effects for the dendrometric variables. In general, the model showed satisfactory performance, residual distributions, without outliers. Despite having shown influence of environmental variables only in the least conserved, long-term monitoring is necessary, to overcome seasonal drought events.

Keywords: Seasonally dry tropical forest; Growth; Climate conditions

RESUMO

O crescimento das espécies vegetais é diretamente influenciado por fatores bióticos e abióticos. Com isso, objetivou-se identificar variáveis que influenciam no incremento corrente anual – ICA da área basal, em duas áreas, considerada como “menos conservada” e “conservada” no Semiárido Pernambucano, Brasil. Os dados dendrométricos foram oriundos de 40 parcelas permanentes de (20 m x 20 m), nos anos de 2008 e 2011 a 2019, as mensurações foram realizadas nos indivíduos e fustes com circunferência a 1,30 m do solo ≥ 6 cm. Os dados ambientais foram provenientes do Instituto Nacional de Meteorologia e da Agência Pernambucana de Águas e Climas. Aplicou-se correlação de Spearman entre o ICA e as variáveis ambientais, diante o problema de medidas repetidas, foi utilizado o modelo de regressão linear misto: $CAI_i = (\beta_0 + \alpha_{período} + \lambda_{espécie}) + \beta_n Vdendrométricas_n + \beta_m Vambientais_m + \epsilon_i$, consideraram-se os efeitos aleatórios o período e as espécies, e os de efeitos fixos as variáveis dendrométricas e ambientais. Quanto à significância das variáveis no ICA, notou-se influência para a área menos conservada apenas em relação aos efeitos fixos, já na área conservada foi significativo quanto aos efeitos fixos para as variáveis dendrométricas. Em geral o modelo mostrou boa performance, distribuições dos resíduos, sem *outliers*. Apesar de ter apresentado influência das variáveis ambientais apenas na menos conservada, se faz necessário o monitoramento por longo período, de modo que ultrapasse os eventos de secas sazonais.

Palavras-chave: Floresta tropical sazonalmente seca; Crescimento; Condições climáticas

1 INTRODUCTION

The regions of the Caatinga remnants, known worldwide as Seasonally Dry Tropical Forests (SDTF) or simply Steppe Savanna, occupy approximately 844,000 km², corresponding to 10% of the national territory (IBGE, 2012; Dryflor *et al*., 2016; Koch; Almeida-Cortez; Kleinschmit, 2017).

Located in a polygon with a hot and semi-arid climate, whose annual supply varies among 240 and 900 $mm.year^{-1}$, in different geographic locations, with torrential rains and irregular distribution, lasting 3 to 5 months a year (Dombroski *et al.*, 2011; Mutti *et al.*, 2019). In addition, periodic cyclical drought events occur (Araújo *et al*., 2012).

As for the estimation of tree growth in SDTF in the northeast region of Brazil (NEB) linked to environmental events, it is extremely relevant, given the importance of its vegetation for the energy supply of its region, through Sustainable Forest Management Plans (SFMP) (Carvalho *et al*., 2020).

Most Caatinga species have the following characteristics: xerophytes, woody, thorny, deciduous, and semi-deciduous (Araújo; Sampaio; Rodal, 1995; Fernandes;

Cardoso; Queiroz, 2019), which favors the drought scenario. It can even be considered as a physiological growth mechanism, due to the fact that for its meristem activation to occur, it directly depends on local water availability (Diniz Neto *et al*., 2013; Bachtold; Melo Júnior, 2015; Martinkoski; Vogel; Jadoski, 2015).

According to Vanclay (1994), growth and production models can be used to test growth assumptions, make productivity predictions, and examine species variability. Due to computational advances, with greater data processing capacity, it was possible to apply more demanding techniques for these resources, such as the application of mixed models.

The use of mixed models includes fixed and random effects parameters, which express the observed values in a real manner, in addition to being recommended for the problem of repeated measures and longitudinal data (Pinheiro; Bates, 1996).

Its application encompasses the largest possible number of variables, expressing extremely valuable information for the understanding of the vegetation, which allows for analyzing the relationship between two or more variables, with the inclusion of fixed and random parameters, as it makes it possible to define population parameters with fixed and individual random effects coefficients.

However, the use of mixed models to predict growth of seasonally dry tropical forests in Brazil is scarce, even though they are models indicated due to the heterogeneity of these environments, as they consider the interaction of variables with random and fixed effects.

Determining factors that influence growth in terms of tree size allows the outline of ideal measures for the sustainable planning of forest resources (Costa; Finger; Hess, 2015). Factors such as climate variation, type of relief, soil, associated with land use history (Araújo, 2007), directly influence individual growth, as well as their floristic composition and morphological differentiation, influenced by environmental adaptations (Rodal; Sampaio, 2002; Araújo, 2007).

Therefore, this study was based on the hypothesis that environmental variables influence the current annual growth in the basal area of Caatinga species, in areas with different use histories. To this end, the objective was to understand and identify the main environmental variables such as precipitation, temperature (average, minimum and maximum), solar radiation and vapor pressure deficit that influenced the current annual growth in the basal area of vegetation, in two areas from Caatinga, Northeast Brazil.

2 MATERIALS AND METHODS

2.1 Location and general description

The study area is in the municipality of Floresta - PE, 433 km from the capital of Pernambuco, with an area of 5,695.65 ha, with the farm base located at the coordinates 08º 30’ 49.03” m South Latitude and 37º 57’ 44.02 ” m West Longitude, inserted in part of the Moxotó River Hydrographic Basin, a basin with a total area of 9,752.71 Km^2.

The project was implemented in two areas with different land disturbance histories, which are: Area 1 with vegetation in the regeneration stage since 1986, located at coordinates 08º 33’ 33.00” South Latitude and 37º 58’ 38.00” West Longitude, where its vegetation was suppressed through clear cutting, with the use of “big chain”, assigned as “least conserved”; Area 2: with vegetation in the regeneration stage since 1962, with no reported history of exploration through clear cutting since then, located at coordinates 08º 30’ 19.90” South Latitude and 37º 58’ 54.59” West Longitude, assigned as “most conserved”. The vegetation in this area is considered more preserved, with the existence of occasional selective logging, as verified in the field through the existence of stumps with different dimensions of their branches, it has approximately fifty hectares.

2.2 Climatic characterization

The region's climate, according to Köppen (1948), is semi-arid (BSh) with intermediate characteristics between desert climates (BW) and humid climates, with agricultural and ecological potential.

Data was consulted from the National Institute of Meteorology (INMET) and the Water and Climate Agency of Pernambuco (APAC), with an average of the historical series from 1990 to 2019, of 43.39 mm monthly and of 1301.64 mm annually, the highest records of rain occurs through the months of January to July, with averages of 51.59 mm, and a significant reduction in rainfall between August and December, in which averages are less than 17.90 mm. The average annual temperature is around 30.66°C, the summer season is very hot, with maximum temperatures between 30.52°C and 37.80°C, and minimum temperatures between 23.85°C and 28.47°C. The winter is mild, with maximums between 26°C and 33°C, and minimums between 11°C and 16°C, a very warm spring, with maximums reaching 40°C.

Regarding annual rainfall variability, values below the annual accumulated average were observed in the following years: 1990, 1991, 1993, 1995, 1998, 2003, 2006, 2012-2018 (Figure 1a). The smallest annual accumulated rainfall differences were recorded below the average in the 25% quantile percentiles (344.00 mm) of the mean and median. While the largest differences above the average were observed in the 50% (540.00 mm), 75% (692.00 mm) and 100% (836.00 mm) percentiles of the median quantiles (Figure 1b).

2.3 Continuous Forest Inventory and obtaining the basal area

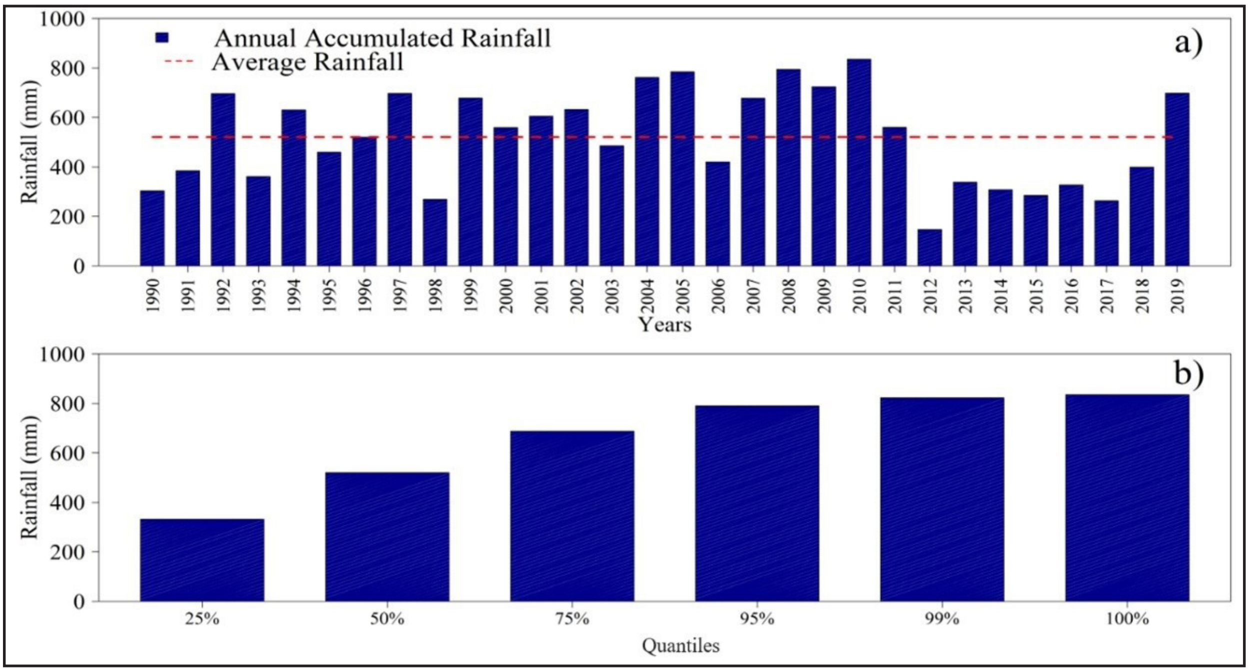
For the Continuous Forest Inventory (CFI), 40 plots of dimensions (20 m x 20 m) were allocated, 80 m apart, with a 50 m border, and sampling area of 1.6 ha for each monitored area, totaling 80 permanent installments measured annually.

The measurements analyzed were from 2011 to 2019, the inclusion criterion in the installation and monitoring was that all individuals and branches that had a circumference at breast height (CBH) at 1.30 m from the ground greater than or equal to 6 cm.

In the inventory, it was considered as single individuals those in which the bifurcation of branches (Branchn) occurred at height greater than 30 cm above ground level, consequently, individuals which had bifurcation at height lower than 30 cm were considered as multiple individuals. The bifurcations between 30 cm and 1.30 m in the same individual that had a diameter of at least 1.9 cm were measured and considered as branches, thus single-branched individuals and multi-branched individuals were found in the areas.

Thus, using a measuring tape, were obtained in the field the circumferences at 1.30 m from the ground (CBH), of all branches, transformed into diameter, and calculated the equivalent diameter (EqD) and mean quadratic diameter (MQD), considering all bifurcations. Then, the cross-sectional area of the individuals was calculated, consequently by annual difference, obtaining the current annual increment in basal area (CAI) of the trees for the period (2011 to 2019).

Figure 1 – a) average annual accumulated precipitation (mm); e b) Percentiles of precipitation quantiles, at Poço da Cruz Station, Ibimirim, Sertão mesoregion of Pernambuco, Brazil



Source: Costa Júnior *et al* (2022)

2.4 Relations between growth and dendometric and environmental variables

The annual periodic increments of the population's basal area - PAI were correlated to its quadratic mean diameter (QMD), using Spearman's correlation analysis. For the correlation between the current annual increment – CAI and environmental variables, such as rainfall, temperature (average, minimum and maximum), solar radiation and vapor pressure deficit, between the years 2011 and 2019 (Table 1), the Spearman correlation matrix was applied, at a 5% level of significance, respectively.

We chose to apply the Spearman correlation, as it is a non-parametric measure, as it is not sensitive to extreme values (outliers), in addition to possible monotonic relationships. Its magnitude varies from -1 to 1, -1 means perfect negative correlation, 0 no correlation and 1 indicates perfect positive correlation.

Table 1 – Environmental variables at Poço da Cruz Station, used to corelate the increment in basal area and mixed model adjustment, in two areas of seasonally dry tropical forest, with different land use histories

Variable - Code	Source	Unit	Annual Unit
Annual Precipitation - Prec	INMET e APAC	$mm.month^{-1}$	Sum
Precipitation 1º Semester - Prec1s	INMET e APAC	$mm.month^{-1}$	Sum
Precipitation 2º Semester – Prec2s	INMET e APAC	$mm.month^{-1}$	Sum
Nº of rainy days annually - Ndaysry	INMET e APAC	-	Sum
Annual minimum temperature - Minty	INMET	ºC	Annual mean
Annual mean temperature - Meanty	INMET e APAC	ºC	Annual mean
Annual maximum temperature - Maxty	INMET	ºC	Annual mean
Solar radiation - Rd	INMET	$MJ.m^{-2}$	Annual mean
Atmospheric pressure - Ps	INMET	kPa	Annual mean
Vapor pressure deficit - VPD	INMET	kPa	Annual mean
Relative humidity - RH	INMET	%	Annual mean
Standardized precipitation index – SPI-12	McKee *et al*. (1993)	-	Annual mean
Climatic effect – CE	Gómez-Aparício *et al*. (2011)	-	Annual mean
Storage capacity – ARM	Thornthwaite; Mather (1955)	$mm.month^{-1}$	Annual mean
Potential evapotranspiration – PET_o	Thornthwaite; Mather (1955)	$mm.month^{-1}$	Annual mean
Relative evapotranspiration – RET_o	Thornthwaite; Mather (1955)	$mm.month^{-1}$	Annual mean
Climatological water deficiency – DEF	Thornthwaite; Mather (1955)	$mm.month^{-1}$	Annual mean
Climatological water surplus – EXC	Thornthwaite; Mather (1955)	$mm.month^{-1}$	Annual mean
Water index – Hi	Thornthwaite (1948)	$mm.month^{-1}$	Annual mean
Aridity index – Ai	Thornthwaite (1948)	$mm.month^{-1}$	Annual mean
Humidity index – Im'	Thornthwaite (1948)	$mm.month^{-1}$	Annual mean
Humidity index – Im"	Thornthwaite; Mather (1955)	$mm.month^{-1}$	Annual mean

Source: Authors (2023)

The Climate Effect Index (CE) was quantified accordingly to the methodology proposed by Gómez–Aparicio, García-Valdés, Ruíz-Benito and Zavala (2011). Climatic effects were estimated using the log-normal function, using annual and monthly average temperature data, average annual and monthly precipitation.

The climate effect was estimated using a bivariate normal function, as shown in Equation (1):

$$CE = exp\ exp\left[-\frac{1}{2}\left(\frac{T-X1_a}{X1_b}\right)^2\right] * exp\ exp\left[-\frac{1}{2}\left(\frac{P-X2_0}{X2_b}\right)^2\right] \quad (1)$$

where: T = mean annual temperature; $X1_a$= mean annual temperature parameters; $X1_b$ = estimated function amplitude control parameters; P = mean annual precipitation; $X2_a$= mean annual precipitation parameters; $X2_b$ = estimated function amplitude control parameters.

To identify the best predictor variables, the correlation of the available variables with the response variable was observed using the Spearman correlation index, as well as the collinearity between the environmental variables, where it is possible to measure non-linear relationships between two variables, especially, monotonic relations (Spearman, 1904).

Based on the list of species with the highest importance value in both areas, in 2019 (Table 2), a mixed linear regression analysis was performed to identify possible significant variables in the current annual growth in basal area.

Table 2 – Species with the highest importance value (VI%), used as random effects, in identifying significant variables in the linear mixed model

Species	Common Name	VI (%)
Area 1 (least conserved)		
Cenostigma bracteosum (Tul.) E. Gagnon & G.P. Lewis	Catingueira	35,14
Jatropha mollissima (Pohl) Baill.	Pinhão bravo	9,91
Mimosa ophthalmocentra Mart. ex Benth.	Jurema de embira	5,41
Pityrocarpa moniliformis (Benth.) Luckow & Jobson	Quipembe	4,50
Myracrodum urundeuva (Engl.) Fr. All.	Aroeira	9,91
Other species	-	35,14

To be continued ...

Table 2 – Conclusion

Species	Common Name	VI (%)
Area 2 (most conserved)		
Cenostigma bracteosum (Tul.) E. Gagnon & G.P. Lewis	Catingueira	18,43
Myracrodum urundeuva (Engl.) Fr. All.	Aroeira	12,44
Jatropha mollissima (Pohl) Baill.	Pinhão bravo	4,61
Mimosa ophthalmocentra Mart. ex Benth.	Jurema de embira	9,68
Other species	-	54,84

Source: Authors (2022)

The basal area was examined over 9 years (2011 to 2019), which implied the use of a more specific regression model for this analysis, which is characterized in the literature as a repeated measures problem. In a problem of this type, it is necessary to consider that the response variable is correlated over time. The correlation matrix must also be estimated and in this case, the covariance matrix format used was that which estimates the intragroup covariance (Pinheiro; Bates, 1996).

To solve the problem of repeated measures, the mixed linear regression model was used. Since, for a repeated measures problem, it is assumed that time affects each plot randomly, hence, by definition, time (in years) is also an explanatory variable and is allocated to the random effects portion of the model, as well as the species that occur in the areas due to their genetic variability. Having the equivalent diameter (eqD) as the independent variable, other explanatory variables also belong to the portion of random effects.

For the analysis of variance, the random effects of period (time) and forest species were considered; for the fixed effects, the dendrometric and environmental variables that showed the highest correlation were considered.

The final model is constituted, accordingly to Equation (2):

$$CAI_i = (\beta_0 + \alpha_{period} + \lambda_{specie}) + \beta_n Vdendrometric_n + \beta_m Venvironmental_m + \epsilon_i \quad (2)$$

where: *CAI* is the mean annual increment; β_0 is fixed effects parameters; α is random effect parameter (period); λ is random effect parameter (forest species), random effects follow a normal distribution with mean 0 and estimated standard deviation (τ); β_n and β_m are fixed effects parameters; *Vdend* are dendometric variables; *Vamb* are environmental variables; ϵ_i is the residual that follows a normal distribution with mean 0 and standard deviation σ.

The evaluation of the assumptions of the mixed ANOVA was conducted based on the analysis of residuals. As data were collected from two different areas (least conserved and most conserved), two models were adjusted. Each model may have different functional forms.

All calculations and plots were made using the R programming language version 3.6.1. In particular, the *nlme* package version 3.1.140 for estimating models.

3 RESULTS AND DISCUSSIONS

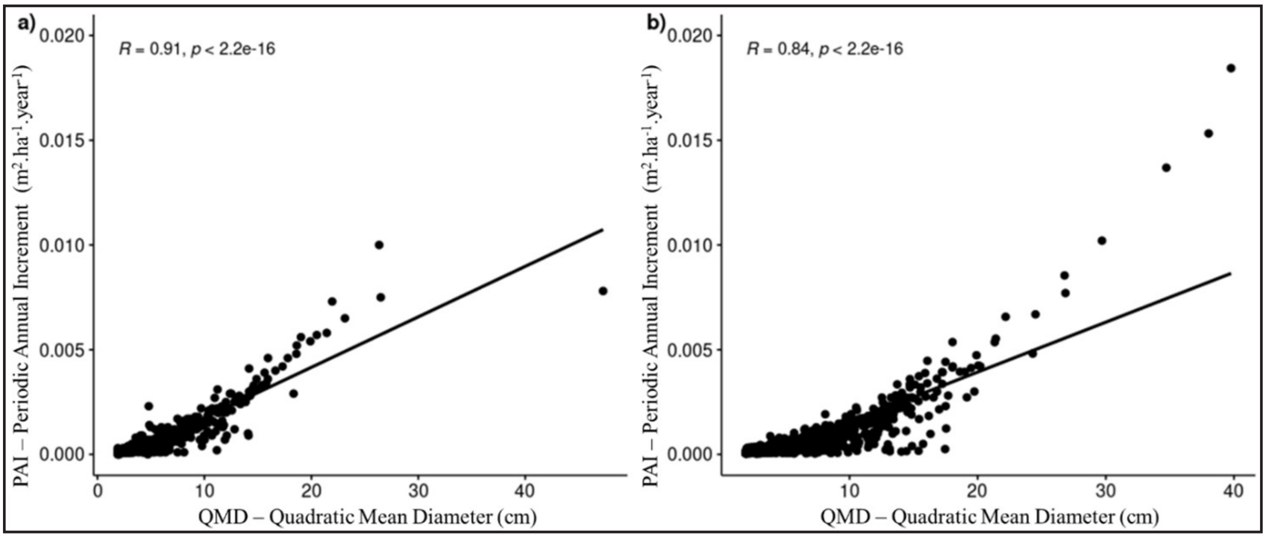
In both areas, there was a tendency towards an increment in basal area, according to the larger size classes, resulting in larger increments. The least conserved area presented higher increment values, possibly this scenario is due to greater spatial distribution, causing less competition for mineral resources, as also found by Lucena (2019), who, when analyzing the growth of trees as a function of competition, noted that without the presence of competing individuals, there are higher average increments.

Some researchers emphasize that trees with larger diameters tend to present less competition, as they are in the upper strata of a forest (Martins *et al*., 2011; Cunha, 2013; Castro *et al*., 2014; Vatraz; Alder; Silva, 2016), however, in semi-arid regions, especially Caatinga environments, the light factor does not interfere, as there is no formation of understory.

For the relationship between the mean quadratic diameter (MQD) and the average annual periodic increment in basal area (IPA), of the studied period, where trees that started with low MQD values obtained a lower average increment than those that started with higher MQD values, where the correlation found is considered strong (> 0.8), as can be seen in (Figure 2).

Studies have emphasized the strong positive correlation between the variables of tree size in diameter and their growth (Freitas *et al*., 2015; Silva *et al*., 2017), however, the strong correlation reflects competition effects between individuals, according to Lorimer (1983).

Figure 2 – a) Relation between the average (MQD) (cm) of trees and the average annual periodic increment in basal area ($m^2.ha^{-1}.year^{-1}$), least conserved; e b) most conserved

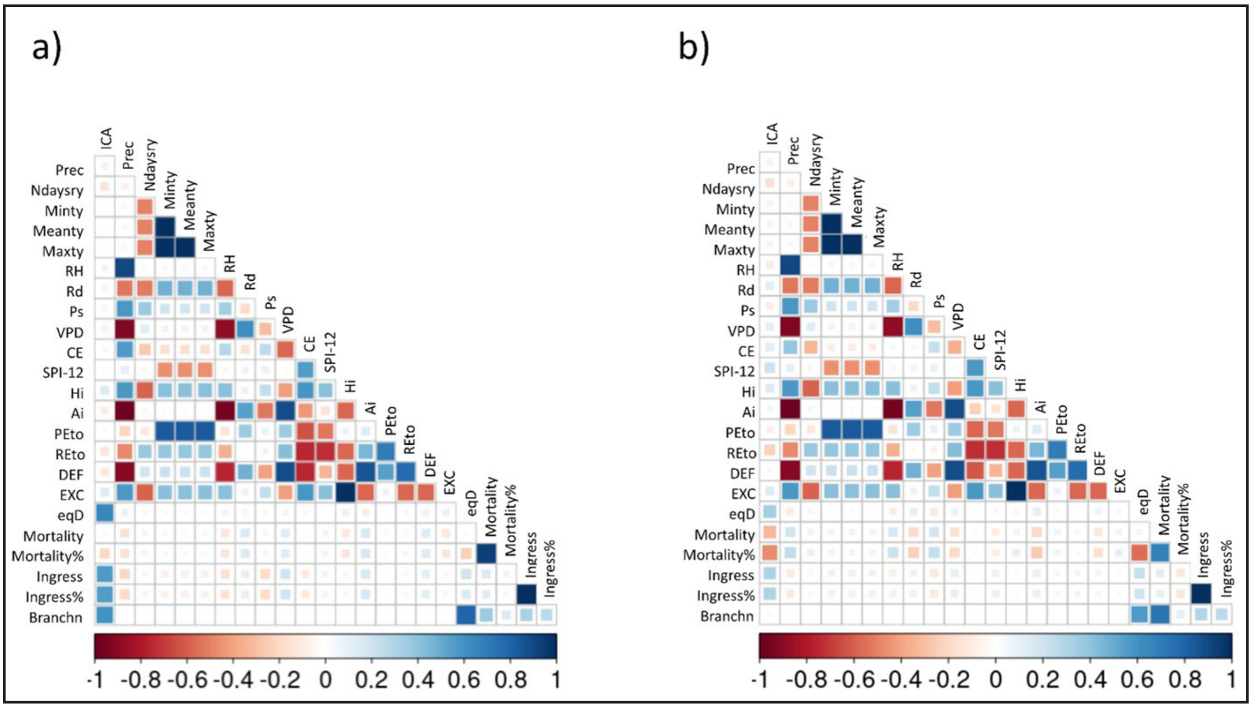


Source: Authors (2023)

The results expressed that, the larger the average diameter of the individuals, the greater the observed increment values, and in both areas greater growth was noted when their size was verified, similar growth curves were noted in both areas, however the values of increment in the least conserved area were greater, possibly the human intervention itself contributed, by eliminating possible competition, causing plants to develop in this environment in a more spaced out manner.

Below are the correlations between the explanatory variables and the current annual increment (CAI) of the basal area, which were the most notable, were the dendrometric variables with a positive correlation (Figure 3). When observing (Figure 3a), in the least conserved area it was noted that the explanatory variables linked to the trees are all correlated with each other, mainly the average (eqD). Furthermore, there was a low correlation between the climate variables and the response variable, with the climate variables showing a strong correlation structure, which refers to environmental characteristics, as Landsberg and Gower (1997). In the most conserved environment (Figure 3b), the results obtained were quite similar when compared to the least conserved area, thus considering one of the characteristics of the environmental variables.

Figure 3 – a) Spearman correlation between the variables investigated and current annual increment in basal area, from 2011 to 2019 in the least conserved area; and b) more preserved area



Source: Authors (2023)

No significant correlation was found between the annual current growth (CAI) of the basal area and any of the environmental variables. Correlation analyzes showed a positive association between the variables. However, it is interesting to continue the monitoring, including environmental variables that extend over a longer period of monitoring, given the existence of high climate variability, with the occurrence of an agricultural and hydrological dry period during the years 2012 to 2015, as verified per (Marengo; Cunha; Alves, 2016).

Climate conditions are responsible for the maintenance and variation of forest growth and development, in addition to precipitation as a direct responsible factor, other elements can be mentioned such as average air temperature, humidity, solar radiation, which can directly interfere with growth (Cordeiro; Schwartz; Barros, 2020).

According to Felippe (1985), plant growth is identified by physical attributes, with a progressive, irreversible increment, feasible to verify in terms of size, mass, and volume. However, it is not always possible to identify its growth in this way, considering that some organisms use sources of reserve materials, only to produce new cells, without increasing in size, to such an extent that, when the plant is subjected to exogenous factors, such as water deficit, growth in extension is the most affected (Peixoto; Cruz; Peixoto, 2011).

As an exogenous factor, water available in the soil can be highlighted (Soil Water Surplus – EXC), as one of the most key factors (Lira *et al*., 2015; Brito *et al*., 2017), as it is a fundamental element for plant growth in general. As seen, there is no water surplus in the region's soil, despite the occurrence of higher values of annual accumulated precipitation in the years 2016 to 2018, the increment in basal area was not verified, years that were outside the period of severe drought, as highlighted by Marengo, Cunha and Alves (2016). However, vegetation has appeared to have a greater growth response, although no correlation was found between precipitation and basal area during the study period.

Precipitation, in turn, is an important seasonal factor, associated with temperature, drought indices, where there is a clear correlation between climate variables, however, the accumulated annual rainfall did not show a strong relationship with the current annual increment in basal area, therefore, it is inferred that species may present different responses, according to precipitation levels (Camargo; Marenco, 2017).

With emphasis on the fact that, with annual precipitation values below 300 mm, exchange activities are ceased or limited. In tropical regions, exchange rate reduction is natural, due to the decrease or cessation of rainfall. Zanon and Finger (2010) highlight that climatic factors interfere with exchange rate activity and the formation of growth rings.

In this way, it can be said that the factors that influence plant growth are the most varied, whether exogenous, such as those already mentioned here, as well as the existence of endogenous factors, such as adaptive or genetic characteristics, as well as functional, in turn, it is known that the relevant characteristics of plants from semi-arid environments, specifically those from Caatinga, are species that have strategies and morphological characteristics, mostly adapted, benefiting their survival, in terms of stress due to lack of resources. water supply, even species with a well-developed root system, and/or with accumulation of reserve sources in their roots.

In fact, according to the data obtained, it was found that individuals in their most juvenile phase presented higher mortality rates, highlighting the existence of endogenous factors, which seem to be more linked to the growth of the species, suddenly in relation to the formation of roots with a well-developed root system, and well adapted to the water deficit region, in addition to the competition factor, with supposed effects of competition, as already listed.

Regarding the analysis of fixed effects and with the objective of verifying the influence of variables on growth in basal area, the fixed effects coefficients were obtained (Table 3) for the two study areas.

Table 3 – Fixed parameters of the mixed linear equation and quality indicators, in both areas

Fixed effects	(least conserved)			(most conserved)		
	Estimate	t value	p value	Estimate	t value	p value
Intercept	$-4,21e^{+03}$	-6,050	$2,10e^{-09}$ ***	$8,41e^{-01}$	0,558	0,611
Branchn	$2,38e^{-01}$	7,992	$4,37e^{-15}$ ***	$1,70e^{-02}$	6,563	$7,73e^{-11}$ ***
Ingress	$1,08e^{+01}$	11,169	< $2e^{-16}$ ***	$5,54e^{-01}$	6,802	$1,36e^{-11}$ ***
Mortality%	$-1,21e^{+01}$	-7,084	$3,34e^{-12}$ ***	$-1,11e^{+00}$	-12,072	< $2e^{-16}$ ***
Prec	$-3,16e^{-0}2$	-3,666	0,000261 ***	$7,96e^{-04}$	0,779	0,490
Ndaysry	$1,33e^{-01}$	3,368	0,000788 ***	$-4,47e^{-03}$	-0,481	0,663
SPI-12	$-7,77e^{+00}$	-4,775	$2,09e^{-06}$ ***	$2,60e^{-01}$	0,838	0,462
PETo	$-4,21e^{-02}$	-4,887	$1,20e^{-06}$ ***	$2,28e^{-04}$	0,146	0,893
eqD	$2,12e^{+00}$	6,072	$1,84e^{-09}$ ***	$4,98e^{-02}$	10,908	< $2e^{-16}$ ***

Source: Authors (2023)

Initially, the mixed effects model with random effects (Table 4) was adjusted for the three parameters using the likelihood ratio method. Several structures were tested, but they did not converge, which is why they were not presented.

Table 4 – Random parameters of the mixed linear equation and quality indicators, in both areas

(least conserved)			
Variable	**Random effects**	**Intercept**	**Standard deviation**
Period	2011-2012	-4,32159e^{-05}	0,000192944
Period	2012-2013	-0,000184372	0,000186042
Period	2013-2014	-0,000131895	0,000185175
Period	2014-2015	-0,000151529	0,000184026
Period	2015-2016	-0,000301666	0,000185403
Period	2016-2017	0,000211627	0,00018913
Period	2017-2018	0,000666073	0,000201139
Period	2018-2019	-6,50217e^{-05}	0,000219745
Species Group	Aroeira	-0,000579346	0,000202838
Species Group	Catingueira	0,000889511	0,000178372
Species Group	Other species	-0,000918157	0,000163484
Species Group	Jurema de Embira	0,000540235	0,000216415
Species Group	Pinhão Bravo	-0,00020929	0,000185639
Species Group	Quipembe	0,000277047	0,000286559
(most conserved)			
Variable	**Random effects**	**Intercept**	**Standard deviation**
Period	2011-2012	-1,51837e^{-05}	0,000109538
Period	2012-2013	3,99959e^{-05}	0,000114675
Period	2013-2014	-7,39068e^{-05}	0,000114651
Period	2014-2015	-4,5283e^{-05}	0,000111042
Period	2015-2016	-0,00033644	0,000110893
Period	2016-2017	0,000175673	0,000110991
Period	2017-2018	0,000146578	0,000113714
Period	2018-2019	0,000108566	0,000115503
Species Group	Aroeira	-0,000295431	0,000123784
Species Group	Catingueira	-0,000830042	0,000157533
Species Group	Other species	5,848e^{-06}	9,33063e^{-05}
Species Group	Jurema de embira	0,000724929	0,000138829
Species Group	Pinhão bravo	0,000394696	0,000125007

Source: Authors (2023)

Regarding the precision of the influences of the estimates, it was found that the insertion of coefficients was statistically significant for both areas, and, therefore, the estimates of the parameters of the analyzed model are presented, according to the pre-established criteria. The environmental variables are significant only for the least preserved area, in addition to the other dendrometric variables, whereas for the most conserved area, there was significance only for the dendrometric variables, possibly related to the higher mortality rates for this area.

It is known that drought has a major impact on plants (Worbes, 1999), precisely what has occurred in the last decade, such as the existence of severe drought events, namely the one that occurred between 2010 and 2015 (Marengo; Cunha; Alves, 2016). Such climatic events have contributed to population dynamics, which is reflected in high mortality rates of individuals and branches in the researched environments, influencing their growth.

The scarcity of precipitation consequently affects the availability of mineral resources to plants, so that even competition between individuals occurs. Competition is the most important process affecting plant development (Vanclay, 1994).

The low water availability and its seasonal variation affected growth in both areas, in addition to the ingress and mortality rates of individuals and branches, as a direct responsible factor. Low water availability in the soil affects, in a way, all the physiological mechanisms of plants, whether in their respiratory capacity, or even in assimilating carbon from the atmosphere, and in the roots because they no longer absorb nutrients. In fact, the first response of plants when subjected to water stress conditions is the reduction or cessation of their growth since metabolic reduction occurs (Bergamaschi; Bergonci 2017).

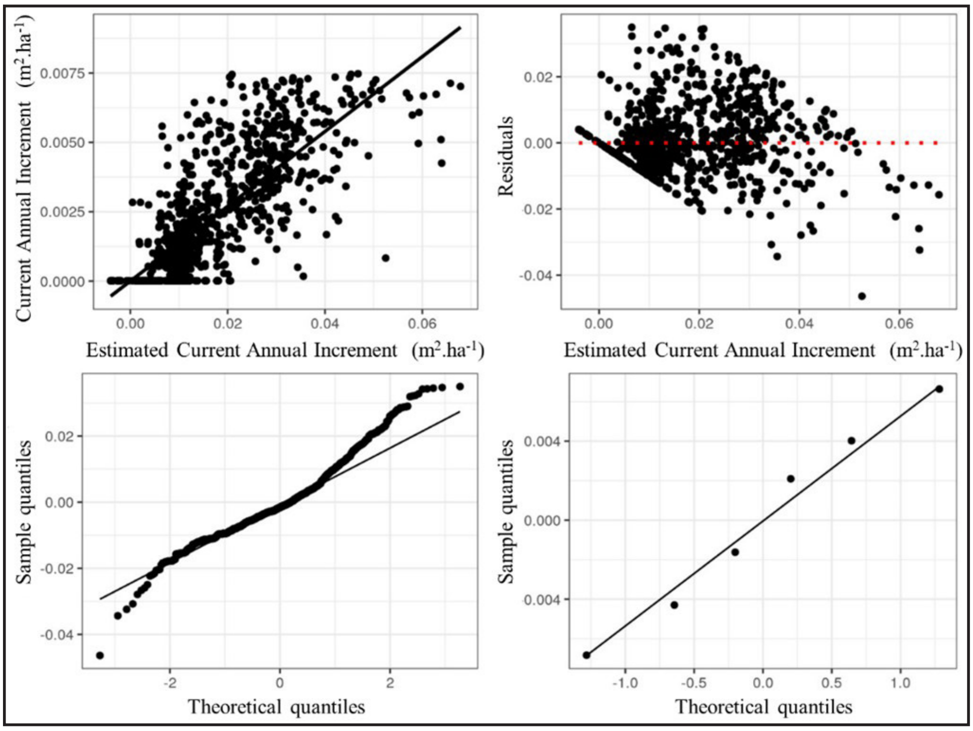
Since the unavailability of mineral solutes due to lack of water in the soil, prevents the translocation of nutrients through its vascular bundles, consequently the reduction and cessation of its root and aerial part growth according to Bang *et al*. (2020).

Another important factor is that tropical forests in general, when not managed, tend to have a stable growth rate, or even a decrease in growth rate over time, including low recruitment rates (inflows), with limited competition for available resources favorable to its growth (Beckert; Rosot; Rosot, 2014).

In this way, it was possible to identify the significance of environmental and dendrometric variables, as well as justify the higher growth values for the least conserved area, as well as lower mortality rates, including significance in environmental variables, whereas the opposite was noticed in the most conserved area, in which they showed significance only for the dendrometric variables, this fact can be explained by the same reason as vegetation maturity.

Regarding the adjustments of the mixed linear model in general for the least conserved area, it was well adjusted, without the presence of outlier values, consequently it did not affect the general performance of the model, the quality of the adjustment was evident through the scatter plots between the current annual increment (CAI), adjusted by the linear mixed model (Figure 4).

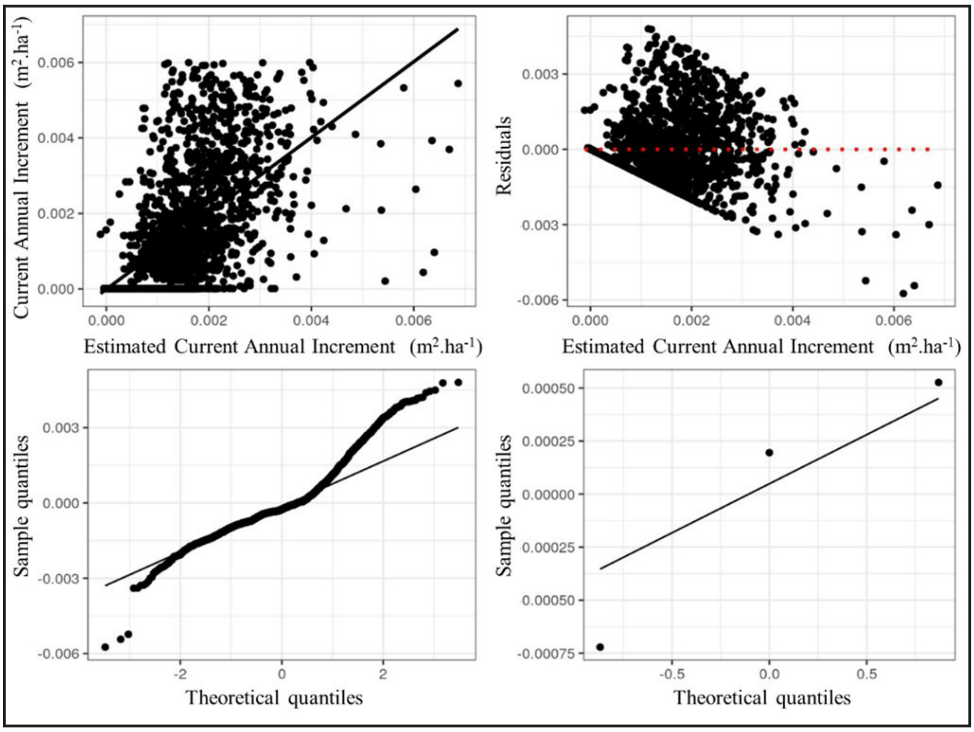
Figure 4 – Residual analysis of the linear mixed model, in the least conserved area



Source: Authors (2023)

The analysis of the residuals of the mixed linear model, for the most conserved area, showed that, in general, the model is well adjusted, with its distribution tending to be normal (Figure 5).

Figure 5 – Residue analysis of the linear mixed model, in the most conserved area



Source: Authors (2023)

It is worth highlighting that during the period analyzed, the values of SPI-12 and annual accumulated rainfall were, in most years, in the moderately to extremely dry categories, with greater insolation, evapotranspiration, and consequently a greater soil water deficit, which was reflected in the high mortality rates, consequently decreasing their current annual growth in basal area.

The greatest decrease in population density in the most conserved area was due to poor rainfall distribution, the occurrence of severe droughts, especially in the period from 2012 to 2015, which intensified the higher mortality, and competition for mineral resources.

The occurrence and intensification of droughts probably meant that only the dendrometric variables were significant in changing its growth for the most conserved area. Therefore, the significance of the environmental variables was verified only in the least conserved area, however, it cannot be inferred that the most conserved area had no interference from environmental conditions, the vegetation probably suffered more impact due to the lack of rain, and this caused the variables dendrometrics stood out in relation to the environmental ones.

4 CONCLUSIONS

The least conserved area added a greater increment in basal area, in relation to the most conserved area.

There was an influence of the variables: precipitation, number of rainy days, SPI, and EToR, in addition to the dendrometric variables, only for the least conserved area.

In the most conserved area, there were only significant influences on the fixed effects for the dendrometric variables.

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