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Diametric distribution modeling of forest species in arboreal Caatinga vegetation, Brazil[1]

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ABSTRACT

The distribution modeling in diameter classes is an important indicator of the potential use of a forest community, as well as the projection of future forest production. The objective of this study was to evaluate the diametric structure and to select probabilistic density functions for three woody species in forested arboreal Caatinga vegetation in Bahia, Brazil. The study was carried out in the Contendas do Sincorá National Forest in the state of Bahia, Brazil. A total of 16 plots of 20 x 20 m were installed and all individuals with diameter at breast height equal to or greater than 5.0 cm were measured. The three species with the highest population density (*Commiphora leptophloeos*, *Manihot catinga* and *Patagonula bahiensis*) were selected for analysis and modeling of the diametric structure. Four probabilistic density models were adjusted. The Akaike information criterion was used to select the best model. The results found indicated that the three species presented a decreasing type curve. The Log-Normal function best described the diametric distribution and it can be indicated to describe the diametric distribution and assist in making decisions about the management and conservation of these species. It is concluded that the Normal function was less adequate to represent the distribution of the studied species.

Keywords: probabilistic density functions; forest management; forested savanna-steppe.

INTRODUCTION

The Caatinga biome covers an area of approximately 844 square kilometers, representing 70% of the Northeast region and 11% of the Brazilian territory, encompassing the states Brazilian of Alagoas, Bahia, Ceará, Maranhão, Pernambuco, Paraíba, Rio Grande do Norte, Piauí, Sergipe and the north of Minas Gerais (Pereira, 2011). It consists of xerophilous vegetation of arboreal, shrub and herbaceous sizes, usually deciduous (Pereira *et al.*, 2018). It presents a great diversity of species and different phytophysiognomies due to variations in altitude, relief and rainfall (Giulietti *et al.*, 2004).

The Caatinga is generally characterized by a warm and semi-arid climate with strong seasonality, and less than 1,000 mm of precipitation distributed over a period of three to six months per year (Velloso *et al.*, 2002). In this context, there is the Contendas do Sincorá National Forest (*FLONA Contendas do Sincorá*), created by the presidential decree of September 21, 1999 (Ibama, 2006). The vegetation of FLONA Contendas do Sincorá is inserted in the Chapada Diamantina ecoregion complex and partly in the Southern Country Depression ecoregion (Velloso *et al.*, 2002).

Despite the importance of the Caatinga, the biome has suffered a progressive loss of native vegetation as a result of a lack of proper species management, wood removal for producing firewood and charcoal, and for the cultivation of monocrops and pastures. This leads to changes in vegetation dynamics and favors soil degradation, influencing the maintenance of fauna and flora (Medeiros *et al.*, 2018).

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The diametric structure of a forest enables better understanding of the species present in the area, of the dynamic processes and ecological groups (Reis *et al.*, 2014). In addition, from this distribution it is possible to know the structural behavior of the forest (Bila *et al.*, 2018) and to assess the need for forest replacement (Pulz *et al.*, 1999). Such information enables better planning of the use and management of available forest resources in order to ensure the sustainability of the ecosystem (Batista *et al.*, 2015).

Modeling the diametric distribution using mathematical probability density functions (PDF) or diametric distribution models (DDM) is considered the best way to represent the structure of a forest and/or a species (Machado *et al.*, 2009a; Téo *et al.*, 2015). According to Marangon *et al.* (2016), the use of these functions enables predicting optimized management plans and future production of the forest, it being fundamental for understanding the diametric structure. This highlights the importance of developing studies on the diametric structure of forest communities in order to support decision-making, since it is necessary to understand the behavior of the forest in order to conserve natural resources.

Studies have been carried out to characterize the diametric distribution in natural Caatinga forests (Alves *et al.*, 2013; Lima & Coelho, 2015; Santos *et al.*, 2017). However, the number of studies using PDF is still restricted (Marangon *et al.*, 2016; Medeiros *et al.*, 2018), especially on phytophysiognomy of arboreal Caatinga vegetation. In this context, the objective of this work was to evaluate the diametric structure and select probability density functions which best describe the distribution in diameter classes for three woody species of economic value in forested arboreal Caatinga vegetation in the state of Bahia, Brazil.

MATERIAL AND METHODS

This study was carried out at the *FLONA Contendas do Sincorá*, located in the municipality of Contendas do Sincorá, Bahia, Brazil (geographic coordinates: 13° 55' 21" South latitude and 41° 06' 57" West longitude), Figure 1.

Three experimental units were installed, each consisting of 16 plots of 20 x 20 m, totaling 48 plots of 400 m². The plot size was defined according to the methodology recommended by the Scientific Technical Committee of the Caatinga Forest Management Network (RMFC, 2005). During the inventory, diameters at breast height (DBH) and total height of all individuals who had a DBH e" 5 cm were measured in each plot. The measurements were obtained with the aid of a CM-HEC electronic clinometer. The measured individuals in the field had their species recognized by their common name, and a sample was taken for botanical identification. Species identification was conducted in the Ecology and Forest Protection laboratory of the State University of Southwest Bahia (UESB) by consulting specialized bibliography and access to the virtual herbarium.

Next, the three species with the highest population density in the area were selected for the diametric structure analysis and modeling: *Commiphora leptophloeos* (Mart.) J.B.Gillett, *Manihot catingae* Ule and *Patagonula bahiensis* Moric. The number of classes and their respective amplitudes in the diametric distribution was defined based on the procedure proposed by Sturges.

For each species, four models usually used in the forest area were adjusted and based on a probability density function: Normal, Log-Normal, Gamma and Weibull 2 parameters, as described in Table 1.

The PDFs which best represented the diameter distribution were selected based on the information criterion of Akaike - AIC (Medeiros *et al.*, 2018). The analyzes were performed using the RStudio® v.1.1.442 statistical software program (R Development Core Team, 2011).

The diameter, basal area and height data were submitted to descriptive statistics. Next, the coefficient of asymmetry moment was determined to assess the degree of deviation from the diametric distribution symmetry of the area, it being defined as the quotient between the third moment centered on the mean and the cube of the standard deviation. In addition, the kurtosis moment coefficient was determined, which it indicates the degree of the distribution flattening considered in relation to the normal distribution. This coefficient is defined by the quotient between the fourth moment centered on the mean and the square of the variance (Machado *et al.*, 2009b).

RESULTS AND DISCUSSION

A total of 794 individuals were sampled, 295 of *Patagonula bahiensis*, 252 of *Commiphora leptophloeos* and 247 of *Manihot catingae*. The three species together represented a total basal area of 8.73 m². The basal area found was considered low, since the value found was low when considering the three species. This fact is mainly due to the occurrence of young individuals close to the established inclusion limit, indicating that the area has gone through a process of disturbance and that the individuals are in regeneration. Greater results were observed for *Commiphora leptophloeos* when analyzing the species individually regarding the basal area and height of the individuals (Table 2).

The studied species had different mean diameters according to the descriptive statistics of the data referring to the diameter (Table 3), with the *Manihot catingae* species having the lowest average and the lowest maximum diameter. In contrast, *Commiphora leptophloeos* had the highest average and the highest maximum diameter.

When considering the asymmetry coefficients obtained for the DBH variable (Table 3), it was observed that all three studied species showed a distribution with positive asymmetry. The kurtosis values also showed similarity among species and presented a platykurtic distribution configuration (Table 3), meaning that the curves have a top and are more flattened in relation to a normal curve, and with positive excess.

According to Santos *et al.* (2016), these two dendrometric parameters are essential to assess the data dispersion since they provide information on the degree of distance and flatness of the diametric distribution. In this sense, based on the obtained information it is possible to have a general idea of the diametric structure of the studied species.

The results obtained herein are in line with those of other studies carried out in Caatinga areas which also it verified platykurtic diametric distribution, such as those by Lima *et al.* (2013) who studied the distribution of *Poincianella bracteosa*; and that of Marangon *et al.* (2016), who studied the distribution of different woody species. The distributions found in the present work were within the expected range for native forests, that is, the greater the concentration of individuals in the smaller classes, the greater the possibility of this individual being present in the adult forest community, thus ensuring future dispersion.

The parameter estimates of the models obtained by adjusting the diametric distribution of each species were shown in Table 4.

The discrepancy of the parameters of each function among species suggests that modeling the diametric distribution of these species together would not be satisfactory, making it necessary to apply the models for each species individually.

The Log-Normal function was the one among the tested models which best represented the series of diameters of the three studied species (Table 5). The next best adjustment was observed for the Gamma function. On the other hand, the Normal function showed the least adherence to the data set in relation to the other adjusted functions. This may be related to the fact that the Normal function considers the values of standard deviation and mean, which indicated high variability in this study.

According to Lima *et al.* (2013), the high variability of the data promotes non-adherence to the distribution by the Normal model, making it necessary to use models which express the vegetation structure by transforming variables

Table 1: Probability density functions tested for the diametric structure of three species in arboreal Caatinga vegetation, BA

Function	Formula
Normal	$f(x) = \frac{1}{\sigma\sqrt{2\pi}}\ exp - (\frac{1}{2})\ \frac{(x - \mu)^2}{\sigma^2}$
Log-Normal	$f(x) = \frac{1}{x\sqrt{2\pi\sigma^2}}\ exp - (\frac{1}{2\sigma^2})(lnx - \mu)^2$
Gamma	$f(x) = \frac{(x - xmin)^{\alpha - 1}\ exp^{-(\frac{1}{\beta})(x - xmin)}}{\Gamma(\alpha)\beta^{\alpha}}$
Weibull-2P	$f(x) = (\frac{\gamma}{\beta}) \cdot (\frac{x}{\beta})^{\gamma - 1}\ exp\left[-(\frac{x}{\beta})^{\gamma}\right]$

In which: x: variable diameter in cm; $f(x)$: probability density function of variable x; m: mean of the x values; s: standard deviation of x; s^2: variance of variable x; p: is the "pi" constant (3.14159); b,a, g: parameters to be estimated; G: Gamma function.

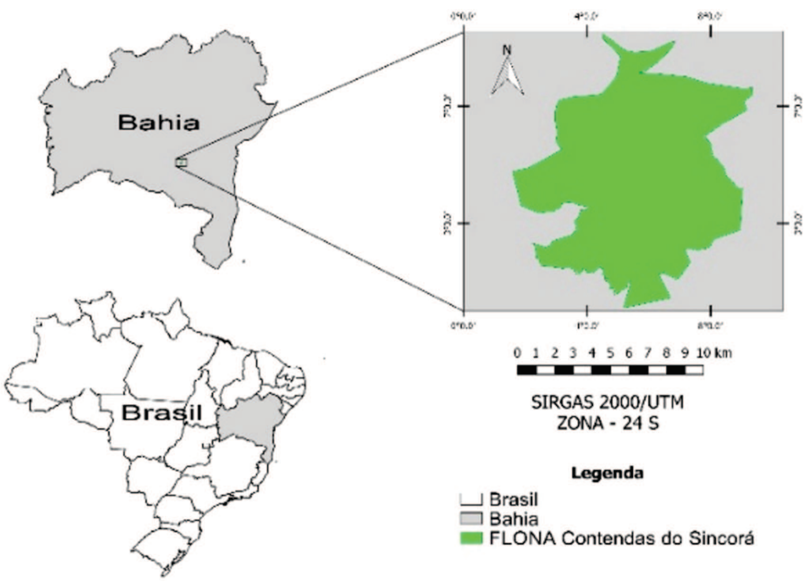

Figure 1: Map of Contendas do Sincorá National Forest, Bahia, Brazil.

or models that have parameters with more refined estimation methods.

In turn, the low adherence of the Weibull 2P function, which presented the second worst result in the AIC raking, can be attributed to the absence of the location parameter corresponding to the minimum diameter, which controls the curve position on the abscissa axis (Lima *et al.*, 2013).

In studying a Caatinga fragment, Medeiros *et al.* (2018) also found worse adjustments for the Normal and Weibull 2P functions. Other authors such as Lima *et al.* (2013), Lana *et al.* (2013), Lima (2014) and Marangon *et al.* (2016) also found a low adherence for the Normal function.

Figure 2 shows the frequency of individuals per hectare distributed in relation to the diameter class centers. A higher concentration of individuals was observed in the first three classes for *Patagonula bahiensis* and *Manihot catingae*, while a greater number of individuals were concentrated in the first two classes for *Commiphora leptophloeos*.

The diametric distribution curves estimated by the models in relation to the frequency histogram can be seen in Figure 2 and they in line with the AIC results, more

Table 2: Dendrometric parameters of three woody species from the arboreal Caatinga, Contendas do Sincorá National Forest, BA

Species	Parameters	Maximum	Minimum	Mean ± DP
Commiphora leptophloeos	Basal area	2,1253 m²	0,00196 m²	0,0243 ± 0,1355
	Height	14 m	3 m	6,2 ± 2,058
Manihot catingae	Basal area	0,0196 m²	0,00196 m²	0,0036 ± 0,0022
	Height	12 m	3 m	6,4 ± 1,497
Patagonula bahiensis	Basal area	0,0594 m²	0,00196 m²	0,0058 ± 0,0064
	Height	13 m	2 m	6,5 ± 2,018

Table 3: Descriptive statistics of the diameter variable for three woody species from arboreal Caatinga, Bahia

Measure	Species		
	Commiphora leptophloeos	***Manihot catingae***	***Patagonula bahiensis***
$\bar{d}$	12,49	6,57	7,95
M_d	9,05	6,1	7,0
M_o	6,0	5,0	5,5
$D_{min.}$	5,0	5,0	5,0
$D_{máx.}$	164,5	15,8	27,5
A	159,5	10,8	22,5
σ^2	153,84	2,73	10,81
σ	12,4	1,65	3,29
CV%	99,27	25,11	41,38
Assimetria	7,90	2,15	2,47
Curtose	90,33	6,13	8,0

$\bar{d}$: mean diameter (cm); Md: Median; Mo: Mode; *maxd*: maximum diameter (cm); *mind*: minimum diameter (cm); *A*: diametric amplitude (cm); σ^2: variance (cm²); σ: standard deviation (cm); CV: Coefficient of variation.

Table 4: Estimated parameters of the diametric distribution functions in arboreal Caatinga vegetation, BA, Brazil

Function	Parameters	Species		
		Commiphora leptophloeos	***Manihot catingae***	***Patagonula bahiensis***
Normal	σ^2	153,84	2,73	10,81
	σ	12,4	1,65	3,29
Log-Normal	σ	0,235	0,093	0,142
Gamma	Á	2,7894	20,0275	8,3031
	Â	0,2232	3,0457	1,0440
Weibull-2P	Γ	1,3748	3,6376	2,4365
	Â	13,8795	7,2181	8,9540

clearly demonstrating the lower adherence of the Normal function and the greater flexibility of the Log-Normal function data set for each species. In summary, the results obtained demonstrate that the Log-Normal function is more appropriate to represent the diametric distribution of the studied species, and therefore can be used in decision-making for the management and conservation of these species. This is because it showed good flexibility capacity, accurately estimating the density of individuals by diameter class, assuming different shapes for the data set.

The diametric distribution of all species showed the typical pattern of natural forests, meaning a negative exponential distribution curve in the form of an “inverted J” (Figure 2). Such a pattern is commonly observed in Caatinga areas (Lima, 2014; Alves *et al.*, 2013; Sanquetta *et al.*, 2014; Lima & Coelho, 2015; Santos *et al.*, 2017; Medeiros *et al.*, 2018) and indicates that the studied species are in a good level of regeneration, meaning that they present many young individuals, which guarantees the perpetuation of the species in the area.

Table 5: Akaike Information Criterion Parameter (AIC) used for classifying probability density functions (PDFs) for three woody species in the arboreal Caatinga, Bahia, Brazil

Species	Function	Ranking	AIC
Commiphora leptophloeos	Log Normal	1º	1586,264
	Gamma	2º	1667,704
	Weibull 2P	3º	1729,023
	Normal	4º	1987,208
Manihot catingae	Log Normal	1º	860,6554
	Gamma	2º	886,7801
	Normal	3º	951,8447
	Weibull 2P	4º	990,7603
Patagonula bahiensis	Log Normal	1º	1370,885
	Gamma	2º	1415,754
	Weibull 2P	3º	1514,326
	Normal	4º	1542,492

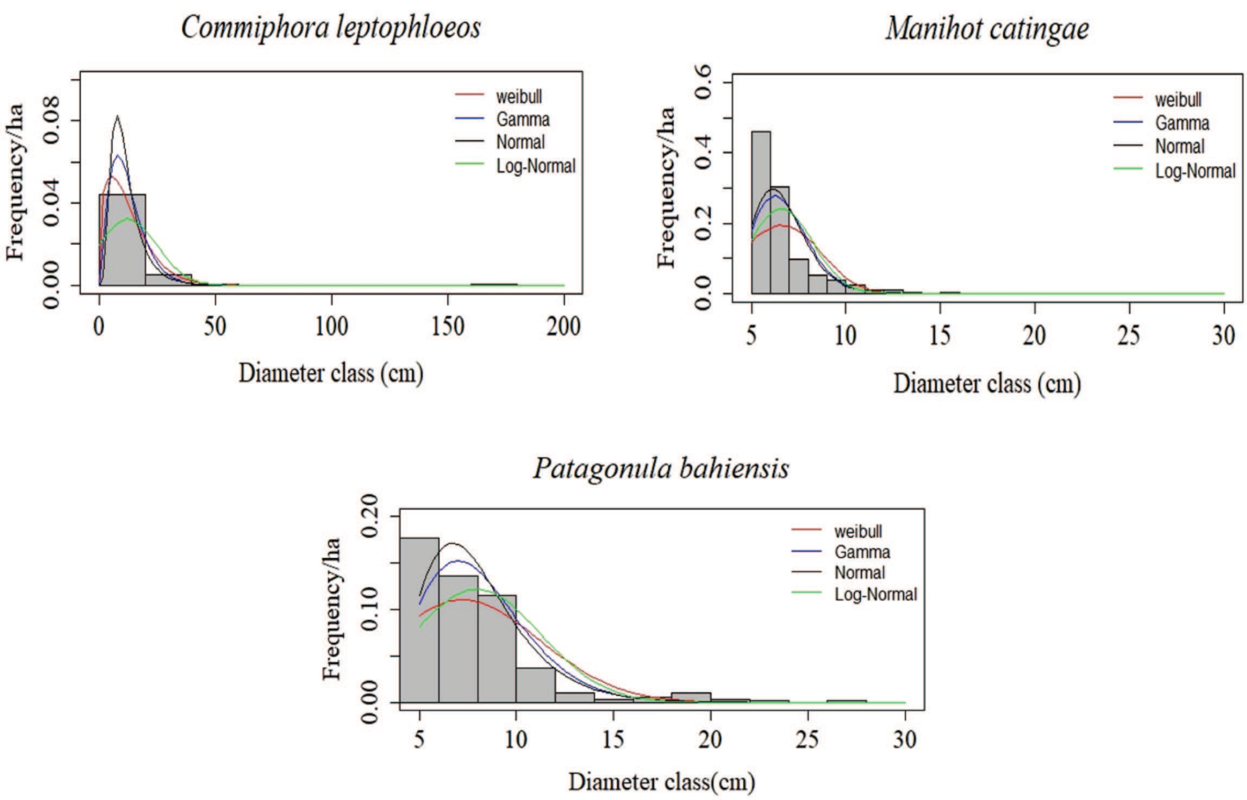

Figure 2: Diametric distribution and estimated distribution curves for arboreal Caatinga species, Contendas do Sincorá National Forest, BA, Brazil.

CONCLUSION

The diametric distributions of *Commiphora leptophloeos*, *Manihot catinga* and *Patagonula bahiensis* in the studied forest community show a decreasing curve with a higher concentration of individuals in the smallest diameter classes, which denotes a natural regeneration in continuous flow.

The Log-Normal function showed the best performance for the three studied species and can be indicated to describe the diametric distribution and assist in decision- making about the management and conservation of these species. The Normal function is less suitable to represent the distribution of the data set of these species.

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