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Diametric distribution of forestry species in riparian forest in the southern part of the Amazon

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Abstract - The expansion and changes in land use and land cover in the Southwest Amazon are mainly related to the activities of logging without management rules, agriculture and cattle production, which resulted in the conversion of natural forests, especially along water courses. This study aimed to verify the diametric distribution of forestry species with higher importance value index in the riparian forest of the Acre River (Acre, Brazil). The forestry inventory was performed at eight municipalities crossed by the Acre River, using two stage sample units (conglomerates) and applying stratified random sampling techniques at the river bank. Twenty-seven primary plots were installed, within which another four secondary plots were implanted. It was fitted Weibull's probability density functions with 2 and 3 parameters to species diametric distribution, provided by the maximum likelihood method. Graphic analysis verified that 86% of the species analyzed presented a distribution trend with positive asymmetry. The distribution of the Weibull function with two parameters presented better the best estimative of the frequency of species by diameter class of the natural forest evaluated. Considering the heterogeneity of the species, further studies to verify whether the distribution behavior follows the same trend is recommended.

Distribuição diamétrica de espécies florestais da mata ciliar na parte sul da Amazônia ocidental

Resumo - A expansão e as mudanças no uso e cobertura da terra na parte sul da Amazônia ocidental estão vinculadas principalmente às atividades do extrativismo madeireiro sem regras de manejo e à produção agropecuária, que resultaram na conversão de florestas nativas, especialmente ao longo de cursos d'água. Esse estudo teve como objetivo verificar a distribuição diamétrica de espécies florestais com maior índice de valor de importância da mata ciliar do Rio Acre, AC. O inventário florestal foi realizado em oito municípios cortados pelo Rio Acre, utilizando unidades amostrais com dois estágios (conglomerados) e técnicas de amostragem aleatória estratificada pela faixa marginal do Rio Acre. Foram instaladas 27 parcelas primárias, dentro das quais foram distribuídas quatro parcelas secundárias. Para estudo da classificação diamétrica, foram avaliadas as funções de densidade probabilística de Weibull 2 e 3 parâmetros pelo método da máxima verossimilhança. Pela análise gráfica, verificou-se que 86% das espécies analisadas apresentaram tendência de distribuição com assimetria positiva. A distribuição da função Weibull com dois parâmetros estimou melhor a frequência de espécies por classe de diâmetros. Diante da heterogeneidade das espécies, recomendam-se novas pesquisas para verificar se o comportamento da distribuição segue a mesma tendência.

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Introduction

The area by the Acre River is important for agricultural purposes, consequently the watershed has the higher rates of anthropic changes, including colonization projects in which forest coverage has been converted to homogeneous plantations. Many of those areas exceed the 20% allowed by legal limit, according to the Brazilian Forest Code (Law 12.727, of 2012) for forest areas located in the Legal Amazon (Brasil, 2012).

This intense occupation has damaged the watershed, with visible impacts (Aragão, 2012), such as the river overflowing during the Amazon winter (December to March) or intense drought during summer (April to November), leaving urban areas without water supply (Chambers & Artaxo, 2017).

Despite riparian forests being legally protected by Brazilian Federal Law (12.727/12), which classifies riparian forests as areas of permanent protection (Brasil, 2012), they are subjected and susceptible to various types of degradation (Rodrigues et al., 2013, 2017). To counteract this situation, some projects have been highlighting the importance of preserving and/or restoring the riparian forests, especially in areas containing native species, as stated in Resolution 429/11 of the Brazilian Council for Environment (CONAMA, 2011).

The analysis of vegetation is important to obtain a value that indicates the overall structure of the system being studied or that characterizes the importance of each species in the total conglomerate of the forest. Further, it is possible to integrate the 3 partial indexes (i.e., abundance, dominance and frequency), to obtain a unique expression capable of representing the forestry structure, named as importance value index (Chaves et al., 2013).

The diametric distribution of forests is important as basis to obtain information on growth dynamics and to infer the ecological relationship among tree species. As a result, the management strategy best fitted to the diametric structure at the forest area or tree level may be selected based on this information during the decision-making process (Campos & Leite, 2013; Santos et al., 2016).

There is a good correlation between tree diameter and certain variables, such as tree height, wood volume, timber value, conversion cost and product stratification (Binoti et al., 2013). The diametric distribution and its relationship with the site, forest area composition, tree age, and species density are important for biological and economical purposes (Binoti et al., 2013). Therefore, the diametric distribution is an indicator of the forest structure, helping to distinguish forest typologies and to identify natural regeneration at species level (Machado et al., 2010).

The diametric structure description of forests has been verified through probability density functions (pdf), as they allow the specimen probability to be obtained for determined diameter intervals, presenting the structural behavior of the forest clearly (Machado et al., 2010; Nascimento et al., 2012).

According to Nascimento et al. (2012), the first work performed in an Amazon area that implemented diametric classification using pdf was in 1979, which was largely diffused in the region. The same authors affirm that models based on the pdf have mathematical characteristics, making them flexible, allowing the use of several forms and asymmetries for the dendometric descriptions and forests typologies, precise and presenting good correlations between the coefficients and forests attributes.

The adjustment of the Weibull function by the maximum likelihood method provides reliable estimates, with lower tendentiousness than other methods, such as moments or percentages. This function is also considered superior to other probability density functions and is also easy to apply (Araújo Júnior et al., 2010; Binoti et al., 2012; Campos & Leite 2013).

Due to the characteristics of forest species, it is necessary to establish bases for sustainable management in natural forests. Diametric distribution and fitting models are good alternatives to understand the structure of the forest at diameter class level. Thus, this study aimed to analyze the diametric distribution of 30 forestry species identified with a higher importance value index in a riparian forest of the Acre River, using the 2 and 3 parameters Weilbull probability density functions.

Material and methods

The Acre River hydrographic basin is located in the South-Western Amazon, on the triple border between Brazil, Bolivia and Peru and has an approximate area of 35,967.5 km^2, of which 87.5% belong to the Brazilian territory (87.6% belong to the state of Acre and 12.4% to the state of Amazonas). This study was conducted in the remaining fragments of a riparian forest of the Acre River (Figure 1). The critical areas that were studied in this research are the result of the urbanization process, land occupation and use of the natural vegetation (riparian) on the banks of the Acre River.

The eight municipalities that are directly influenced by the Acre River in Acre territory were studied. They are, from the source to the delta: Assis Brasil (where the river is the border line with the city of Iñapari, Peru), Brasiléia (where the river is also the border line with the city of Cobija, Bolivia), Epitaciolândia, Xapuri, Capixaba, Senador Guiomard, Rio Branco and Porto Acre.

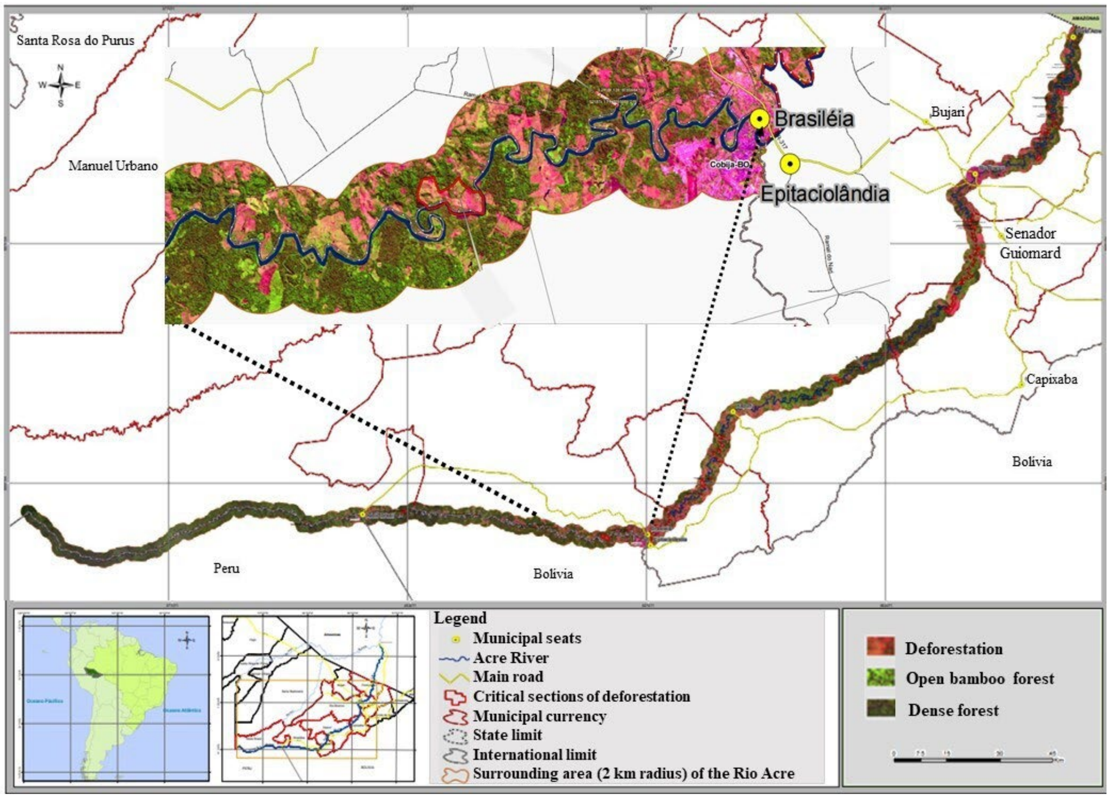


Figure 1. Critical sections of deforestation and primary units of the forest inventory in the area of influence of the Acre River in the eight evaluated municipalities, Acre.

The predominant climate is the Am, as proposed by W. Köppen (Alvares et al., 2014), corresponding to rainy tropical (hot and moist), with the annual rainfall varying from 1,800 to 2,000 mm, an average temperature of 24.7 °C and well-defined moist and dry seasons.

It is characterized by a very dissected relief, with convex tops and very high drainage density, with medium slopes in the central-north part, decreasing to the south, where it becomes wavy. The predominant soil class in the Acre River basin is the Ultisol, occurring in 72.6% of the study area, with extensions above 22,800 km^2, followed by Gleysols, Oxisols, Luvisols and Plinthosols (Acre, 2010). The presence of a plinthic character in Ultisols at the third categorical level indicates a fluctuation of the groundwater. This condition restricts oxygen in the soil and affects the development of some tree species, occurring mainly in regions with more rugged relief (Silva et al., 2019).

The database processed in study is partly from the Forest Inventory of the Ciliar Só - Rio Acre project (Rodrigues et al., 2013), totaling 3,498 individuals, from which 1,060 individuals presented the thirty largest importance value index (Equation 1).

$$IVI = \left(\frac{DRi + DoRi + FRi}{3}\right) \quad (1)$$

where: IVI = importance value index of the species; DRi = relative density of i species; DoRi = relative dominance of the i species, and FRi = relative frequency of the i species.

Mapping was performed to identify the remaining areas of the riparian forest and the visually deforested areas, using Arc GIS 9.3 software, with remote sensing and image reading through the Landsat 5 satellite. It was obtained from the database of the Brazilian Institute for Spatial Research (INPE).

After identifying the critical plots visually, the inventory was carried out using sample units with more than one stage (conglomerates), applying stratified random sampling techniques of the riverbank in eight municipalities that are crossed by the Acre River. The variables collected included species names, habit and diameter at 1.3 m above ground level (DBH) ≥ 20 cm.

Twenty-seven primary plots (PPs) were allocated in the riparian forests near the Acre River. PPs were 190 m x 1,000 m (or 19 ha). In each PP, four secondary plots (SP) measuring 10 m x 250 m (or 0.25 ha) were allocated systematically, totaling 1 ha where the trees were measured.

The scientific names of species in the Acre River basin were identified according to the Acre forest species list (Araújo & Silva, 2000). From the list generated, the species names were updated according to the current classification system of Flora do Brasil (Flora do Brasil, 2020).

To analyze the diametric distribution, adjustments were performed using the 2 and 3 parameters Weilbull probability density (Equations 2 and 3, respectively) ,by the maximum likelihood method for the 30 forestry species with greater frequency. For the adjustments, the data were grouped in classes with a 10 cm amplitude, following Umaña & Alencar (1998) for uneven-aged forests in the Amazon region.

$$f(x) = \frac{c}{b}\left(\frac{x}{b}\right)^{e-1} e^{-\left(\frac{x}{b}\right)^{e}} \quad (2)$$

where b = scale parameter; c = distribution form parameter, e = mathematical constant and x = DBH value.

$$f(x) = \frac{c}{b}\left(\frac{x-a}{b}\right)^{e-1} e^{-\left(\frac{x-a}{b}\right)^{e}} \quad (3)$$

where a = intersection point of the curve, b = scale parameter, c = distribution form parameter, e = mathematical constant and x = DBH value.

The quality of the adjustments was assessed by the Kolmogorov-Smirnov test (α = 0.01) in order to verify the adherence of the Weibull function to the data (Sokal & Rohlf, 1969).

Results

The Weibull 3 parameter function is not suitable for the used database since most of the adjustments did not converge with the species distribution; therefore, the presented data are based on the 2 parameters Weibull function, which was adequate for demonstrating that 100% of the adjustments were not significant. In other words, the distribution estimated was equal to that observed.

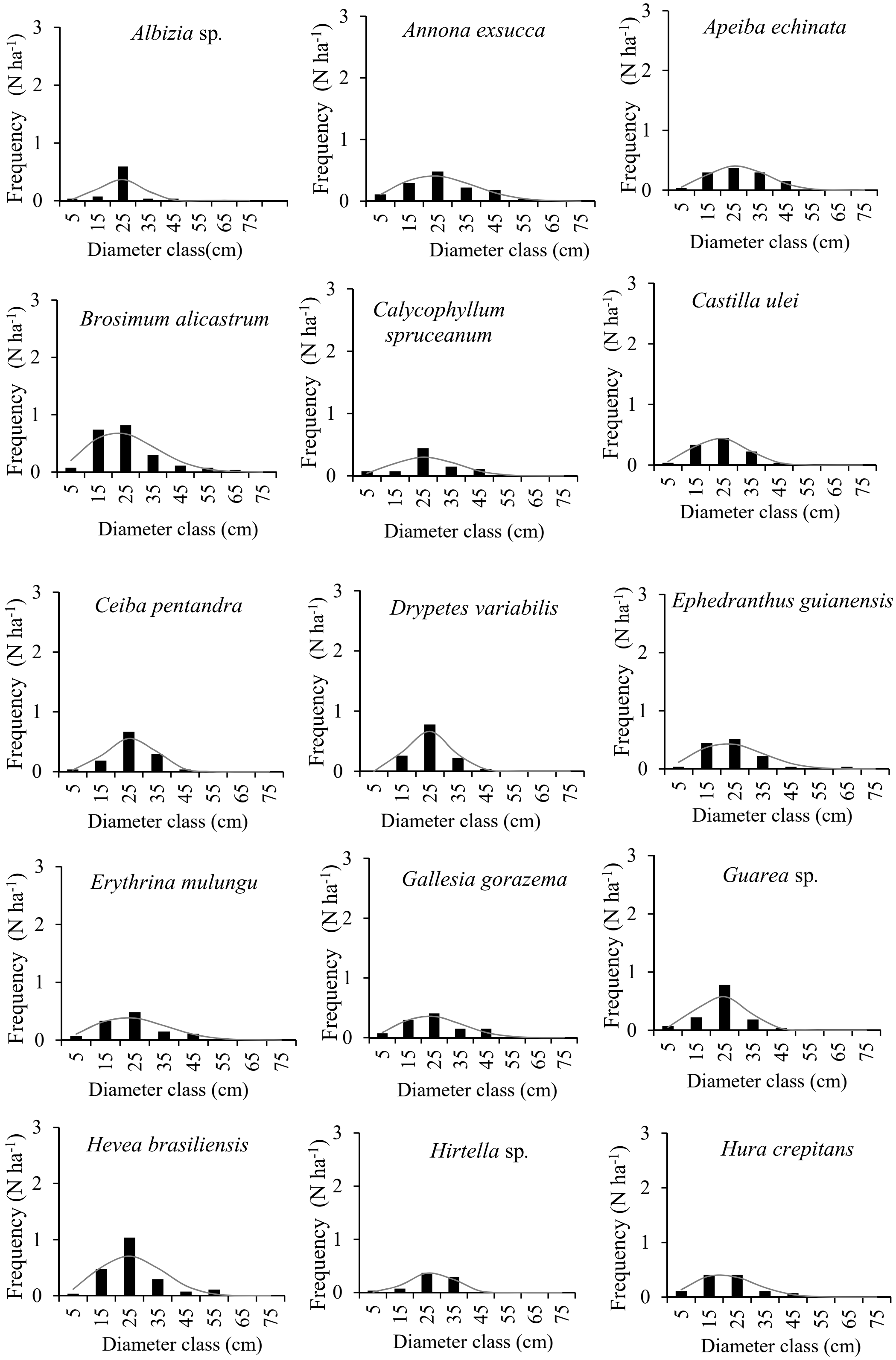
The 30 forestry species with higher importance value index (IVIi), distributed in 18 families, are presented on Table 1. *Sapium marmieri* presented the highest IVIi (12.2), followed by *Pseudolmedia murure* (9.0) and *Albizia* sp. (Fabaceae) presented the lowest (1.3). The most representative family was Mimosaceae, with six species, followed by Euphorbiaceae, with four species.

The parameters obtained by the function adjustment are presented in Table 1. These values were used directly on the distribution probability function, to obtain the frequency per diameter class of the 30 species.

The Weibull function may be controlled in several forms by the *c* parameter. For instance, when analyzing the *c* parameter, only *Ceiba pentandra* obtained c = 3.6 with a normal distribution. In comparison, *Acacia glomerosa*, *P. murure* and *Hirtella* sp. presented *c* higher than 3.6, with a negative asymmetric distribution trend. The results for all other species were $1 < c < 3.6$, with positive asymmetry (Figure 2). Eight diameter classes were found from the inclusion level (≥ 5 cm) (Figure 2), with the data tending to be normally distributed. Most specimens had diameters of 15 cm, 25 cm and 35 cm (Figure 2), with 25 cm diameter being prevalent. Few specimens occurred in the lower (5 cm) or higher (45 to 65 cm) classes. The equations presented were adherent for all species by the Kolmogorov-Smirnov test at 1% of significance.

Table 1. Parameters estimated by the Weibull function for 30 species with higher importance value index (IVIi) for the studied riparian forest.

Family	Scientific name	IVIi	Parameters	
			b	***c***
Annonaceae	*Annona exsucca* DC.	3.3	29.76	2.27
	Ephedranthus guianensis R. E. Fr	3.1	27.58	2.33
Bombacaceae	*Ceiba pentandra* (L.) Gaertn.	3.0	28.66	3.61
	Ochroma pyramidale Urb.	2.2	17.98	2.87
Burseraceae	*Tetragastris altissima* (Aubl.) Swart.	2.5	21.80	2.86
Cesalpiniaceae	*Schezolobium amazonicum* Hub.	2.6	32.14	2.33
Chrysobalanaceae	*Hirtella* sp.	1.7	29.58	4.05
Combretaceae	*Terminalia* sp.	2.9	28.48	2.359
Euphorbiaceae	*Drypetes variabilis* Vitt.	3.1	17.25	2.33
	Hevea Brasiliensis Muell Arg.	5.9	29.35	2.62
	Hura crepitans L.	2.4	24.46	2.27
	Sapium marmieri Hub.	12.2	21.06	2.44
Fabaceae	*Albizia* sp.	1.3	27.00	3.52
	Erythrina mulungu Mart ex Benth.	2.7	28.22	2.31
	Pterocarpus rhorii Vahl.	1.9	25.88	1.81
Lecythidaceae	Lecythidaceae A.Rich.	2.4	19.30	1.73
Meliaceae	*Guarea* sp.	3.0	26.80	3.26
Mimosaceae	*Inga laurina* (Sw.) Willd.	4.4	32.35	2.59
	Inga thibaudiana DC.	2.1	20.88	2.74
	Inga vera subsp. *affins* (DC.) T. D Penn.	3.7	25.38	2.43
	Senegalia glomerosa Benth.	2.1	30.35	4.18
	Senegalia polyphylla DC.	3.0	25.34	1.92
Moraceae	*Brosimum alicastrum* Sw.	6.1	28.29	2.22
	Castilla ulei Warburg	2.4	26.86	2.94
	Pseudolmedia murure Standl.	9.0	26.17	3.93
Phytolacaceae	*Gallesia gorazema* Moq.	2.5	28.20	2.39
Rubiaceae	*Calycophyllum spruceanum* Benth.	1.9	29.90	2.73
Sapotaceae	*Pouteria* sp.	1.6	17.48	1.93
Sterculiaceae	*Sterculia pruriens* (Aubl.) K. Schum.	2.4	27.58	2.96
Tiliaceae	*Apeiba echinata* Gaertn.	2.8	30.28	2.78


Albizia sp.
Annona exsucca
Apeiba echinata
Brosimum alicastrum
Calycophyllum spruceanum
Castilla ulei
Ceiba pentandra
Drypetes variabilis
Ephedranthus guianensis
Erythrina mulungu
Gallesia gorazema
Guarea sp.
Hevea brasiliensis
Hirtella sp.
Hura crepitans
Frequency (N ha-1)
0
1
2
3
5
15
25
35
45
55
65
75
Diameter class(cm)
Diameter class (cm)

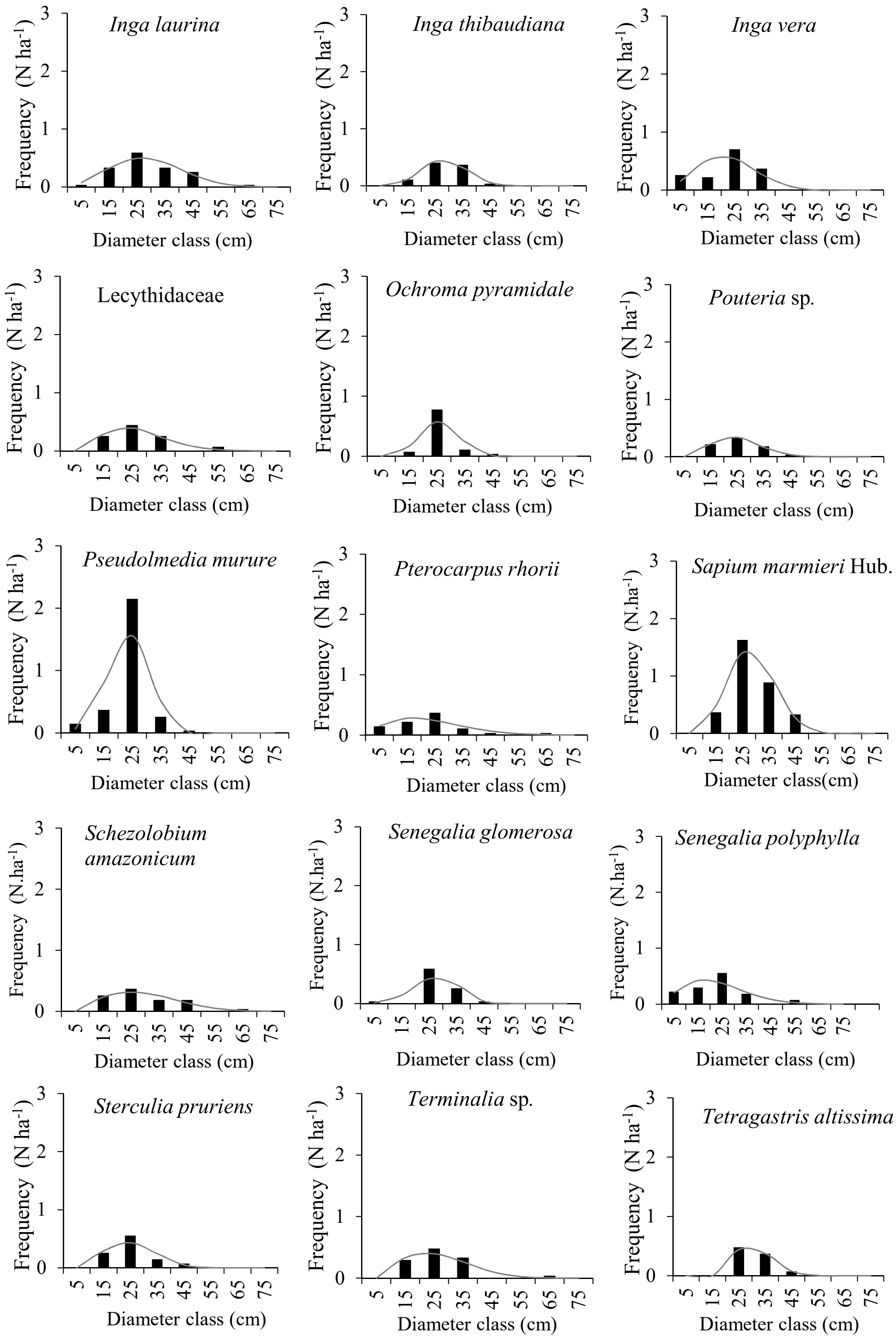


Figure 2. Frequency per diametric distribution class and diametric distribution curves adjusted by the Weibull 2 parameters function, for the 30-forestry species with higher IVIi in the studied riparian forest.

Discussion

In uneven-aged and heterogeneous forests, growth and production models are constructed with the aim of predicting and projecting global attributes and diametric distributions of the forest. In the Amazon the use of phytosociology started with the work of Cain et al. (1956), used since then to characterize the of phytosociological concepts and methods originated in studies of vegetation, such as density, frequency and importance value (Curtis & Mcintosh, 1951). These methods make it possible to quantitatively evaluate the variability of the estimated parameters and can also simultaneously provide information on the spatial pattern of distribution of individuals in each population (Salomão et al., 2012).

In this study most of the specimens had low and average diameters (Figure 2), with few specimens occurring in higher classes. The data did not present an exponential distribution trend in the shape of an inverted "J," which is characteristic of uneven-aged forests (Umaña & Alencar 1998; Schaaf et al., 2006; Machado et al., 2010; Lima & Leão 2013; Santos et al., 2013). This result might be due to the level of damage of the riparian forest fragments in the studied area (Figure 1), which might have caused irregular natural distribution in the native forests. This pattern in the frequency curve for each class indicates an elevated regeneration rate or evidence of exploitation in the inventoried area (Santos et al., 2013). In forests under sustainable management, this pattern may be maintained with the adoption of sustainable practices (Umaña & Alencar, 1998).

Although this pattern may be expected for native forests in general (there are more species whose maximum dimensions are smaller), in some forest typologies and, mainly, individual species may not follow the negative exponential model (Condit et al., 1998). For Pascal (2003), the deficit in some size classes or the accumulation in classes with larger diameters may be due to the stagnation of trees under the closed forest canopy, among other situations, causing the accumulation of certain diameter classes.

Brosimum alicastrum was the only species evaluated that had specimens in all diameter classes. The genus *Brosimum* is dominant in some tropical forests, and highly widespread in the Amazon region, characterized by its use in folk medicine and by the abundant production of a latex (Lima et al., 2013). According to Nascimento et al. (2012), the occupation level of the forest, dominance and number of individuals present, depend on the degree of succession of a given species, the conditions of the forest, the inherent species structure, beyond the economic and environmental value that they can represent.

In relation to families, it was observed that a greater number of species was found for Mimosaceae, and the diametric distribution was similar among them. The largest IVI species, *Sapium marmieri* (Table 1), belongs to the Euphorbiaceae family, which comprises about 300 genera and is one of the largest families of flowering plants, known for the diversity of growth forms, structural and functional distribution (Ramalho et al., 2018; Li et al., 2019). The second and third species of larger IVI, *Pseudolmedia murure* and *Brosimum alicastrum*, belong to the Moraceae family, which also has a great diversity of plants comprising about 40 genera and more than 1,000 species (Somashekhar et al., 2013).

Araújo (2015), when studying changes caused by forest fires in the region of Acre, found 19 species in common with our study, and 15 in stage of regeneration, considering individuals with DBH < 2 cm and height ≥ 1 m. The regenerating species common to both studies are *Hevea Brasiliensis*, *Inga thibaudiana*, *Pouteria* sp., *P. murure*, *S. marmieri*, *Senegalia polyphylla*, *Sterculia pruriens*, *Tetragastris altissima*, *Apeiba echinate*, *B. alicastrum*, *Ceiba pentandra*, *Hirtella* sp., *Ochroma pyramidale*, *Rollinia exsucca* and *Calycophyllum spruceanum.*

The species *S. marmieri* was highlighted as one with the lowest mortality rate (below 40%) among the 40 species of highest IVI found by Araújo (2015). The author also mentioned *P. murure* (IVI = 1.04 and 63% mortality) and *H. brasiliensis* (IVI = 0.94 and 56% mortality).

It is important to know the diametric distribution of natural forests because it reveals amplitudes in diameter and shows the trend of regeneration of species or its capacity to recover, allowing forest typologies to be differentiated and the verification of the levels of occupation and production potential, according to the values of their coefficients, various forms and asymmetries (Nascimento et al., 2012; Santos et al., 2013). Beyond indicating regeneration levels, the diametric distribution also indicates the growth stock, helping to find sustainable strategies, and even restore damaged environments.

The results of the current study in relation to the diametric distribution differ from those found by Machado et al. (2010) and Orellana et al. (2014). These authors obtained better adjustments presented by the Weibull function 3 parameters in a fragment of Mixed Rain Forest using Weibull 2 and 3 parameters.

The 3 parameters Weibull function (3P) is a density probability function that is frequently used in the field of forestry. The Weibull probability function may have a great number of shapes, all of which are defined by the c coefficient. For instance, if $c < 1$, the distribution is shaped as an "inverted-J." When $c = 1$, the distribution is exponential. For values in which $1 < c < 3.6$, the distribution has positive asymmetry. When $c = 3.6$, it defines approximately a normal distribution, and when $c > 3.6$, the distribution has negative asymmetry (Umaña & Alencar, 1998).

Despite variation in the number of classes, the 2 parameters Weibull function was well-adjusted to the database, presenting a correlation coefficient of 0.92. This result confirms its flexibility to describe diverse trends for parameters that have a shape greater than 3.6.

Due to its flexibility and adjustment alternatives, the 2 parameters Weibull function is considered the most adequate for fitting different ecological groups that compose the forest, and is successful for almost any kind of distribution. The implicit projection models developed from the probability functions provide an alternative for management, as well as for characterizing the dynamics of tropical forests. However, due the particularities of each site, its efficiency for management will always be a function of the forest manager needs, since it is an important technique for forest science development (Nascimento et al., 2012).

Conclusions

The species with the highest IVI were *Sapium marmieri* Hub (Euphorbiaceae), *Pseudolmedia murure* Standl. and *Brosimum alicastrum* Sw., (Moraceae). Of the 30 species studied in the riparian forest of Rio Acre, 16 showed a diametric distribution with a positive asymmetric trend. The Weibull 2 function was more suitable for estimating diametric classes and their frequency in the riparian forest, as it showed greater adherence to the data.

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