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Form of Distribution of Dendro/Morphometric Variables for Brazilian Pine in Southern Brazil

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Abstract

The form of distribution found for the dendro/morphometric variables determines the structure, stability, productivity of forest stands, being a tool to propose silvicultural interventions, management, conservation of species, and dynamics of this environment. Thus, this study evaluates, using probability density functions (pdf), the form of distribution of these variables for araucaria in five sites in southern Brazil, aiming to establish the dynamics and identify the existence of a standard—or the lack thereof—to propose the need for silvicultural interventions to conserve the species and the future forest structure. The Normal, Log-Normal, Weibull and Gamma probability density functions were tested. Results show no significant changes in the shape and dimension in the forest structure dynamics, but a period of stability in the pattern of dendro/morphometric values, resulting from the stagnation of the values of the variables, non-intervention in the forest, relationship with the site, density, competition, and position of the tree in the forest stratum, which compromises the future structure of this forest typology. The study proves that the distribution probability of the variables can be used in management for species conservation and future structure development, as this influences the growth dynamics and processes, resource availability, and the stability, diversity, vitality, and productivity of the species.

Keywords: *Araucaria* angustifolia, degree of slenderness, crown ratio, crown diameter

1. Introduction

As mixed species forests are advancing, forest science should provide forestry management with appropriate methods for establishing and regulating mixed species stands. Mixed species stands fundamentally differ from this, with trees exhibiting their full inter and intra-specific structural variability and plasticity. Their traits were probably developed by co-evolution in natural mixed species stands, but became less visible and important in artificial monocultures (Pretzsch, 2019). According to the same author, the structure and size of tree crowns are highly relevant for a tree's fitness. They determine the tree's access to resources, the availability and occupation of space, size growth, and seed production and dispersal. In fully stocked stands, crown size growth results in competition for space, leading to social differentiation, growth reduction of suppressed trees, mortality, and self-thinning (White et al., 2007).

The structure and size of the crown are also practically and economically relevant. Wide crowns mean high mechanical stability (Knoke et al., 2008), due to low slenderness ratio (hd), but low wood quality, due to the number and thickness of branches (Pretzsch et al., 2016). Many recent studies show that in mixed species stands, trees can have wider and longer crowns (Bayer et al., 2013; Barbeito et al., 2017; Olivier et al., 2016) and higher mechanical stability (Pretzsch, 2019), but also inferior wood quality (Pretzsch et al., 2016). In mono-specific stands, wider crowns are associated with more rigorous self-thinning and lower tree numbers per unit area; in mixed stands, in turn, the wider crown can be coupled with higher stand density.

From a forest management perspective, it is necessary to understand how the morphometric characteristics affect the forest's present and future productivity and structure. Studies on the morphometry of forest species aim to reconstruct the space occupied by the individual tree, assess the degree of competition in a stand, identifying the stability, vitality, and productivity of each tree (Costa et al., 2016; Hess et al., 2016; Hess et al., 2018b; Klein et al., 2017; Minatti et al., 2016; Roman et al., 2009).

Despite the several studies on araucaria morphometry, information regarding the form of distribution of dendro/morphometric variables is still insufficient, especially in forests subjected to a non-management regime, as in the Mixed Ombrophilous Forests in southern Brazil. Such information is of great importance, since the analysis of the form of distribution of dendro/morphometric variables works as a reference for the control of forest density, species composition, growth of individual trees, regeneration of understory, genetic diversity, structural conditions of future forests, intervention planning, and balance in the distribution of age and diameter classes.

Adjusting probability density functions (pdf) to assess the distribution of dendro/morphometric variables is an important tool to analyze the current situation of the forest structure at its site. Thus, aiming at the conservation of araucaria species, the multiple use and maintenance of mixed rainforest ecosystem, our hypotheses are: (1) the distribution of dendro/morphometric variables, their pattern or lack thereof, is related to the absence of forest management; (2) the pattern of morphometric indices is related to and influences the structure and dynamics of the forest; and (3) the probabilistic behavior of the distribution may indicate the need for silvicultural intervention.

This study aimed, thus, to adjust the probability density functions to establish the pattern of dendro/morphometric variables, or its absence, for *Araucaria angustifolia* (Bertol.) Kunzte, allowing us to obtain information and knowledge to assist in silvicultural interventions, management plans, and conservation of the future structure of araucaria forests.

2. Material and Methods

2.1 Study Areas and Data Measurement

The sites sampled are remnants of Mixed Ombrophilous Forest (MOF) with a natural occurrence of *Araucaria angustifolia*, located in the state of Santa Catarina (Figure 1). The sampled trees were grouped by site, totaling five site samples, each differing in the number of samples and individuals and sampling process (Table 1); this does not interfere in the result analysis, since our goal is to analyze dendro/morphometric variables per individual.

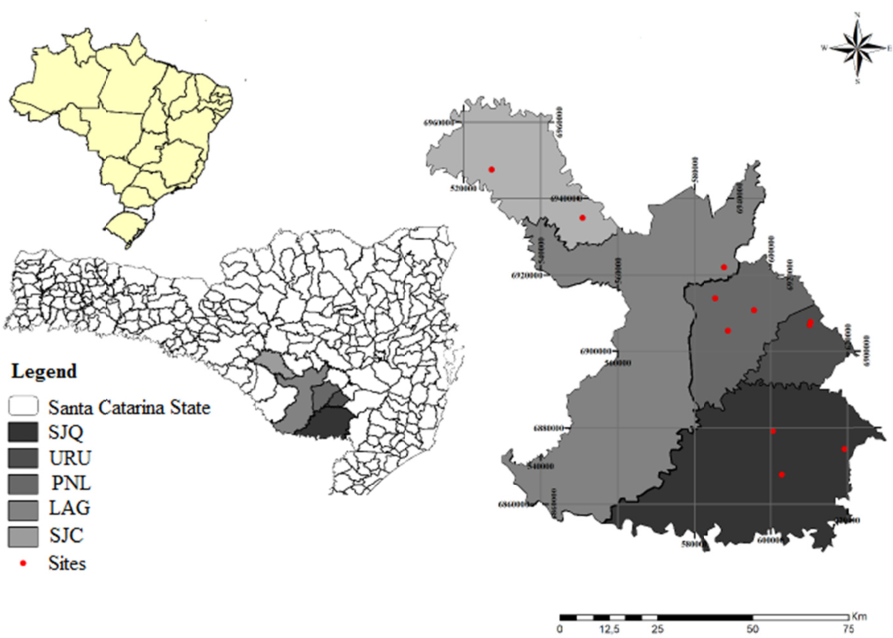

Figure 1. Map indicating the sites for measuring dendro/morphometric variables for araucaria in Santa Catarina, Southern Brazil

The region encompassing the five sites is characterized by Cfb climate according to the Köppen classification: temperate climate, constantly wet and without a dry season. In São Joaquim (SJQ), the altitude is 1,352 m, with 14 °C average annual temperature and 1,683 mm precipitation. In Urupema (URU), the altitude is 1,324 m, with 13.7 °C average temperature and 1,722 mm precipitation. In Painel (PNL), the altitude is 1,123 m, with 15.3 °C average annual temperature and 1,543 mm precipitation. In Lages (LAG), the altitude is 987 m, with 15.2 °C average temperature and 1,685 mm precipitation. In São José do Cerrito (SJC), the altitude is 876 m, with 16.7 °C average temperature and 1,570 mm precipitation (Alvares et al., 2013).

Table 1. Number of samples, sampling process per site and number of individual trees sampled from araucaria in the remnants of mixed ombrophilous forest in southern Brazil

Number of Samples	Site	N	Sampling process	Author
1		63	Individual tree	Hess et al. (2016) *
2	SJQ	53	Individual tree	Hess et al. (2016)
3		70	Individual tree	Minatti et al. (2016) *
4		62	Individual tree	Hess et al. (2016)
5	PNL	127	SAC	Ricken (2018) *
6		70	Individual tree	Minatti et al. (2016)
7	URU	61	Individual tree	Hess et al. (2016)
8		70	Individual tree	Minatti et al. (2016)
9	LAG	332	Fixed parcel	Silveira et al. (2018) *
10	SJC	77	SAC	Ricken (2018) *
11		127	Individual tree	Klein et al. (2017) *
Total		1.111		

Note. SJQ, PNL, URU, LAG, SJC: study sites São Joaquim, Painel, Urupema, Lages, São José do Cerrito; N: number of trees; * authors and studies cited in the references; SAC: sample by angular count Bitterlich method.

All trees with diameter at breast height greater than or equal to 10 cm had their diameter, total height and four crown rays in the north, south, east, and west cardinal directions measured with a compass and a TruPulse hypsometer. From these data, we calculated the following morphometric indices:

$$hd = h/d \quad (1)$$

$$cd = 2 \times \overline{cmr} \quad (2)$$

$$cr = \frac{cl}{h} \times 100 \quad (3)$$

where, hd: degree of slenderness; h: height in m; d: diameter at breast height in cm; cd: crown diameter in m; $\overline{cmr}$: crown mean radius; cr: crown ratio in %; cl: crown length.

2.2 Data Analysis

For each site, the data were classified by diametric class and respective morphometric value. Evaluation was based on the histogram of the frequency distribution of the diametric distribution and morphometric variables degree of slenderness (hd), crown ratio (cr) and crown diameter (cd). Sturges' rule was used to determine the number of classes, and the interval between classes was obtained by the ratio of the total amplitude to the number of classes.

2.3 Adjustment and Evaluation of Probability Density Functions (PDF) for Dendro/Morphometric Variables

The form of distribution of the variables was evaluated by adjusting probability density functions, then tested for normal, log-normal, Weibull, exponential and gamma distribution functions (Table 2). Distribution parameters were estimated using the maximum likelihood method. All adjustments were made using the PROC CAPABILITY procedure from the SAS statistical package (SAS Institute, 2011).

Table 2. Probability density functions tested to adjust diameter distribution and morphometric indices of *Araucaria angustifolia* at different sites in southern Brazil

Function	Formula	Conditions
N[a]	$f(X;\alpha,\beta) = \frac{1}{\beta\sqrt{2\pi}} \exp\left[\frac{(x-\alpha)^2}{2\beta^2}\right]$	α = population average β = population standard deviation
LN[b]	$f(X;\alpha,\beta,m) = \frac{e^{-\frac{\left[\ln\frac{(x-\alpha)}{m}\right]^2}{2\beta^2}}}{(x-\alpha)\beta\sqrt{2\pi}}$	α = location parameter β = shape parameter m = scale parameter
G[c]	$f(x) = \frac{1}{[\beta^{\alpha}\gamma(\alpha)] + (x-\varepsilon)^{\alpha-1}} .\exp\left[-\frac{(x-\varepsilon)}{\beta}\right]$	α = location parameter β = scale parameter ($\beta > 0$) ε = lowest observed value
W[d]	$f(x)=\left(\frac{c}{b}\right).\left(\frac{x-\alpha}{b}\right)^{c-1} .\exp\left\{-\left[\frac{(x-\alpha)^c}{b}\right]\right\}$	α = location parameter b = scale parameter c = shape parameter
E[e]	$f(x)=\begin{cases} 1 \\ \beta \; . \; e^{-\frac{x}{\beta}} \text{ for } x \geq 0, \beta > 0 \\ 0 \end{cases}$	β = function parameter e = Euler number

Note. a: Meyer, 1978; b: Limpert et al., 2001; c: Schneider et al., 2009; d: Silva, 2003; N: normal; LN: log-normal; G: gamma; W: Weibull; E: Exponential.

The Anderson-Darling test was used considering a 5% probability to assess the quality of the fit. Model performance was evaluated according to the probability value associated with the statistic. Non-significant values indicate fit and significant values indicate no fit. When there was no adjustment at 5%, we considered the model that fit at 1% probability.

The Anderson-Darling test, also known as the Anderson-Darling chi-square, is a way of estimating the minimum distance and one of the most powerful statistics for detecting most forms of normality, with two main applications: 1) test the null hypothesis that a batch of data is a random sample from a normally distributed population; 2) test the goodness of the fit of a distribution (SAS Institute, 2011). The Anderson-Darling statistic (A^2) is defined by the following equation:

$$A^2 = -n - \frac{1}{n}\sum_{i=1}^{n} [(2i-1)\log U_{(i)} + (2n+1-2i)\log(1-U_{(i)})] \quad (4)$$

where, A^2: Anderson-Darling statistic; U:F(X): transformation of the probability integral of variable X; X: morphometric variable considered; n: number of independent observations; i: observation number; log: natural logarithm.

2.4 Analysis of the Form of Distribution of Dendro/Morphometric Variables—Past and Future Characteristics

We used the frequency distribution graph and the frequency table for each variable and site to identify, analyze, and interpret the current distribution of the dendro/morphometric variables that make up the structure of individual trees in the forest. Thus, the form of distribution of the dendro/morphometric variables was identified based on their values and form of distribution generated by the probability density function. Analyzing and interpreting the form of distribution allowed us to determine the conditions of the individual trees and the forest structure, and to make inferences regarding the shape-dimension of the crown, diameter at breast height, growth conditions of the species and formation of a future structure.

3. Results

Results show that the dendro/morphometric variables at the studied sites are within a cycle of non-significant structure changes as a whole, seen in the concentration of values in a single form of distribution, showing similarities that may indicate slowly changes in the shape-dimension (Tables 3 and 4) (Figures 2, 3, 4 and 5). These similarities may appear as site characteristics, stage of forest succession, and degree of past disturbance, but occur mainly due to the lack of silvicultural intervention regimes in this forest typology over the past 25 years—causing the forest's stability and structural stagnation. Conditions that show the dominance and formation of a regular mono-species forest (araucaria), not ideal for mixed forests.

By analyzing and interpreting the RF percentage value (Table 4), can inform and identify this structural stability in terms of dimension, morphometry, canopy, and crown size. From an ecological perspective, such structural stability is extremely harmful in mixed forests, since it shows less complexity as an adaptive response to changes in the environment, diversity, and dynamics of the forest.

This interpretation finds confirmation in the d values and morphometric variables. Higher diametric concentration in the 30 to 60 cm classes shows that the forest has a lower rate of ingrowth (trees that migrate from one diameter class to another) and regeneration, while in mixed forests the correct would be an inverted J-distribution. This also indicates a compromise of a future structure with old growth trees, less diametric increase, closed canopy, less sunlight entry, lower temperature and, consequently, reduced seed dormancy break and less species diversity.

For sites presented hd ratio of 40, which indicates a higher growth in d than in h, older and slow-growing trees (Hess et al., 2020). Lower cr values influence the photosynthetic and productive capacity of the forest. For araucaria, trees with lower cr value indicate older age, trees that occupy the upper stratum, or are in extreme competition, and ontogenetic characteristics of the species (when in adequate growth conditions). Lower cd values, in turn, indicate a lack of lateral space, crown expansion, greater density, site characteristics (less soil depth, predregosity, etc.) and position of the tree in the stratum.

Table 3. Descriptive statistics for the dendro/morphometric variables of *Araucaria angustifolia* at five study sites in southern Brazil

Variable	Site	Average	Minimum	Maximum	CV%
d	SJQ	55.9	20.0	127.6	39.7
	PNL	51.2	17.8	94.2	29.0
	URU	46.3	18.8	89.4	31.0
	LAG	29.0	10.1	88.5	51.5
	SJC	37.3	11.5	97.1	38.6
hd	SJQ	37.0	14.3	77.1	35.1
	PNL	36.7	19.3	99.9	29.3
	URU	36.2	20.0	82.7	29.6
	LAG	65.8	20.8	134.7	35.9
	SJC	48.8	13.5	93.7	31.1
cr	SJQ	20.8	1.3	63.4	50.9
	PNL	27.5	2.7	72.7	52.4
	URU	37.3	2.3	66.9	33.5
	LAG	32.4	3.3	70.8	43.2
	SJC	46.1	5.3	84.8	32.0
cd	SJQ	10.4	4.2	18.3	26.3
	PNL	8.6	1.1	22.9	40.2
	URU	8.8	4.1	15.9	24.7
	LAG	5.5	0.1	14.3	53.3
	SJC	7.7	2.7	20.5	41.4

Note. d: diameter at breast height in cm; hd: degree of slenderness; cr: crown ratio in %; cd: crown diameter in m; SJQ, PNL, URU, LAG and SJC: study sites São Joaquim, Painel, Urupema, Lages and São José do Cerrito.

Table 4. Analysis results of the distribution of dendro/morphometric variables, lower and upper limit and model that identifies the form of distribution of the variables for araucaria at different sites in southern Brazil

Site	Morphometric indices	Morphometric pattern			Model (pdf)	Parameter			Prob. > A²
		Lower limit	Upper limit	RF (%)		Location	Scale	Form	
SJQ	d	32	68	65	Weibull	20.1	39.50	1.62	0.036
	hd	21	42	62	Weibull	14.3	25.44	1.77	0.250
	cr	8	29	74	Weibull	1.3	21.88	1.89	0.078
	cd	6	14	87	Normal	10.4	2.73	-	0.250
PNL	d	33	65	72	Normal	51.2	14.86	-	0.084
	hd	28	46	71	Weibull	19.3	19.40	1.66	0.010
	cr	10	34	63	Weibull	2.7	27.79	1.75	0.250
	cd	7	11	50	Normal	8.6	3.44	-	0.029
URU	d	26	58	74	Normal	46.3	14.34	-	0.250
	hd	27	43	70	Gama	19.9	6.88	2.38	0.021
	cr	18	58	92	Normal	37.3	12.50	-	0.250
	cd	7	10	57	Weibull	4.0	5.41	2.30	0.073
LAG	d	10	59	31	Weibull	10.1	19.80	1.15	0.011
	hd	32	68	58	Gama	20.7	14.16	3.18	0.025
	cr	10	52	87	Weibull	3.3	32.66	2.13	0.010
	cd	3	6	46	Weibull	0.4	5.85	1.87	0.189
SJC	d	20	50	80	Gama	11.5	8.42	3.07	0.061
	hd	31	67	75	Weibull	13.6	10.00	3.51	0.051
	cr	32	68	87	Weibull	5.1	45.60	2.77	0.011
	cd	4	10	75	Gama	2.7	2.02	2.49	0.027
Geral	d	10	60	85	Weibull	10.1	32.10	1.63	0.010
	hd	21	54	69	Weibull	13.5	38.49	1.74	0.010
	cr	8	48	80	Weibull	1.3	35.08	2.05	0.198
	cd	2	12	85	Weibull	0.4	8.42	2.30	0.250

Note. SJQ: São Joaquim; PNL: Panel; URU: Urupema; LAG: Lages; SJC: São José do Cerrito; d: diameter at breast height (cm); hd: degree of slenderness; cr: crown ratio (%); cd: crown diameter (m); RF (%): relative frequency of the interval; Prob. > A²: Probability of the Anderson-Darling statistic associated with the model.

Mathematically, the results indicate that 62.5% of the distribution of the tree's dendro/morphometric variables is described by a probability distribution function (pdf-Weibull), showing that changes in the forest dynamics occur slowly. Dynamics information (stability, productivity, structure, and diversity) are important indicators to manage forest resources (Pretzsch, 2019).

Such a pattern of slow changes in shape and dimension are validated by the probabilities of adjustment ($p > 0.01$) and the Anderson-Darling statistics. Changing the pdf function for the variables indicates that the conditions of the trees and the forest structure are different, since they reflect disturbances that took place in the past (anthropic or natural). They signal possible consequences for the current and future structure of the forest, contributing to forest management planning, if interventions are authorized by federal or state legislation.

Differences in size and shape for some variables are associated with lower/higher site density, growth space between trees, past interventions, competition, and position of the tree in the forest stratum, confirming hypothesis (1) of non-intervention in forest structure. Figures 2, 3, 4 and 5 present the similarities regarding the form of distribution of dendro/morphometric variables and structural stability, showing the non-differentiation in the development stage of natural auracaria forest stands.

Such results are detrimental to the forest ecosystem, since, according to Zeller and Pretzsch (2019), forests currently must produce a quantity of wood and fulfill several ecosystem functions in the same forest stand, simultaneously. The structure and distribution pattern of the variables that characterize it have, therefore, an influence on the diversity and productivity of the forest stand (Bourdier et al., 2016; Danescu et al., 2016; Jacob et al., 2010; Liang et al., 2016; Morin et al., 2011; Paquette & Messier, 2011; Pretzsch, 2013; Soares et al., 2016).

Variable d (Figure 2) showed concentration of trees at the 30 to 60 cm classes, resulting from the last intervention in the forest (in the 90's), favoring space and availability of resources for growth. Trees that currently occupy the strata of codominants and dominants in the forest structure. Diametric distribution indicates competition, reduction in ingrowth rate; also, lower natural regeneration, incidence of light, temperature below the canopy, floristic diversity, stability and complexity and impairment of a future structure.

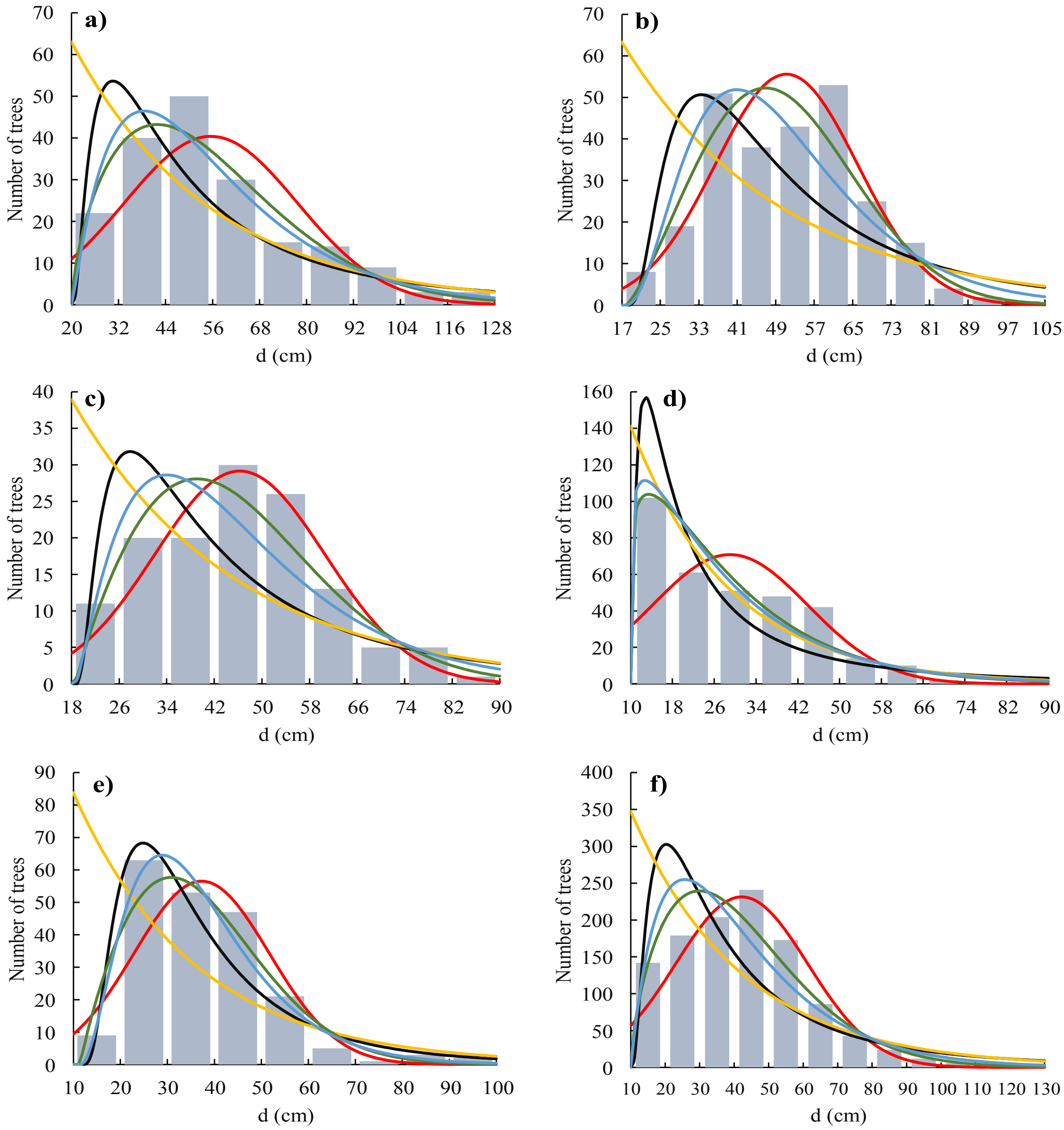

Figure 2. *Araucaria angustifolia* diametric distribution estimated by probability distribution function (pdf) for each site, plotted on their respective frequency histogram: a) São Joaquim (SJQ), b) Panel (PNL), c) Urupema (URU), d) Lages (LAG), e) São José do Cerrito (SJC), and f) All sites. PDF adjusted according to the color lines: red [Normal]; black [Log-normal]; yellow [Exponential]; green [Weibull]; and blue [Gamma]

The results show that there are similarities for the degree of slenderness with a concentration of values not exceeding 55 (Figure 3), meaning that the trees have already established themselves in the forest structure, with less growth in height than in diameter. This corroborates the hypothesis of stability in the vertical structure of the forest and araucaria dominance in the upper canopy.

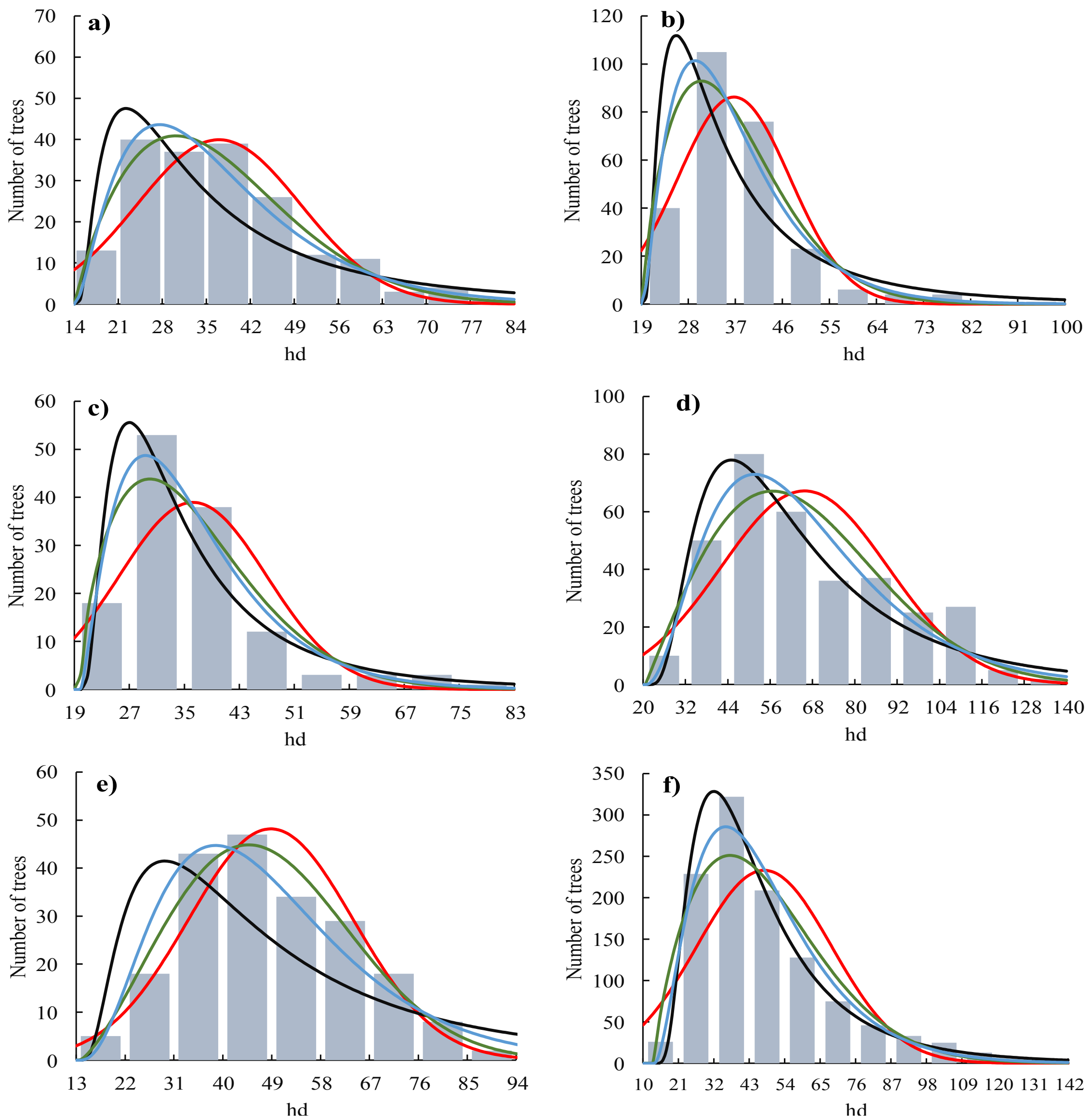

Figure 3. Distribution for the degree of slenderness of *Araucaria angustifolia* estimated by the probability density functions (pdf) tested for each site, plotted on their respective frequency histogram, a) São Joaquim (SJQ), b) Panel (PNL), c) Urupema (URU), d) Lages (LAG), e) São José do Cerrito (SJC), and f) All sites. PDF adjusted according to the color lines: red [Normal]; black [Lognormal]; green [Weibull]; and blue [Gamma]

The distribution of variable cr (Figure 4) also shows a constant pattern, that is, a lack of diversity in the dimension/shape values, which are constant at 35%. This is because cr is a characteristic value of adult stage species, or when the species are found in the dominated stratum, self-draining and stunting its growth. Such aspect, however, has not been proven, since our results show a concentration of trees in larger diameter classes (30-60).

These findings show the relationship with total forest productivity, that is, less cr, less photosynthetic capacity, less carbon absorption, less production. Number of trees with values greater than 45% cr indicate shorter crown length and large width, small formal crown, similar trees and dominant classes. In short, the sites present an increasing lower average rate of diameter (Hess et al., 2018b).

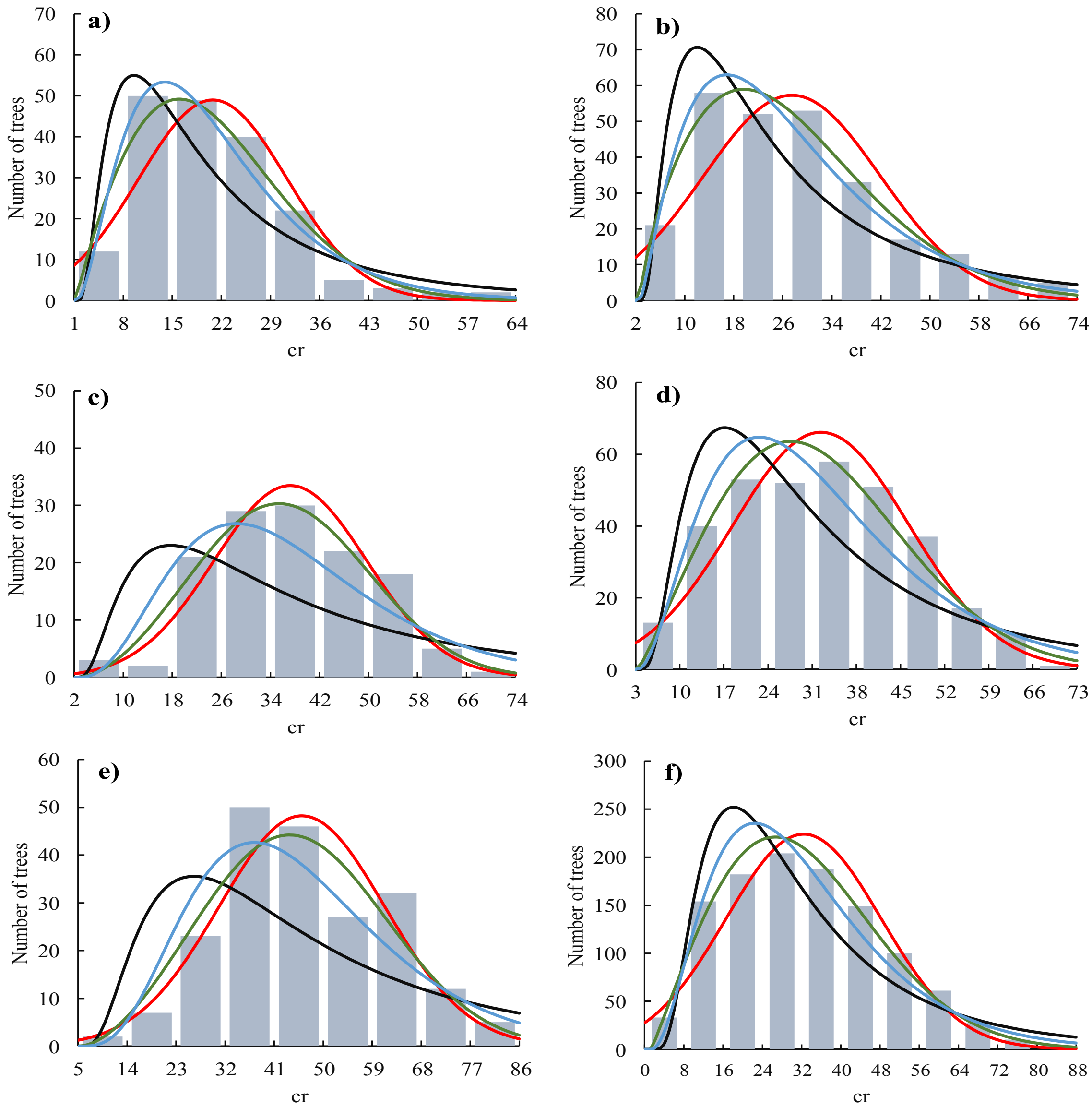

Figure 4. Distribution of the *Araucaria angustifolia* crown ratio estimated by probability density functions (pdf) tested for each site, plotted on their respective frequency histogram: a) São Joaquim (SJQ), b) Panel (PNL), c) Urupema (URU), d) Lages (LAG), e) São José do Cerrito (SJC), and f) All sites. PDF adjusted according to the color lines: red [Normal]; black [Log-normal]; green [Weibull]; and blue [Gamma]

Variable cd presents a distribution that behaves similarly. Since the higher the cd the better the horizontal canopy development and the lower density, the lower value of this variable indicate that trees have less lateral space, greater density and competition. The values for this variable also depend on the position the tree occupies in the canopy, their density and growth rate.

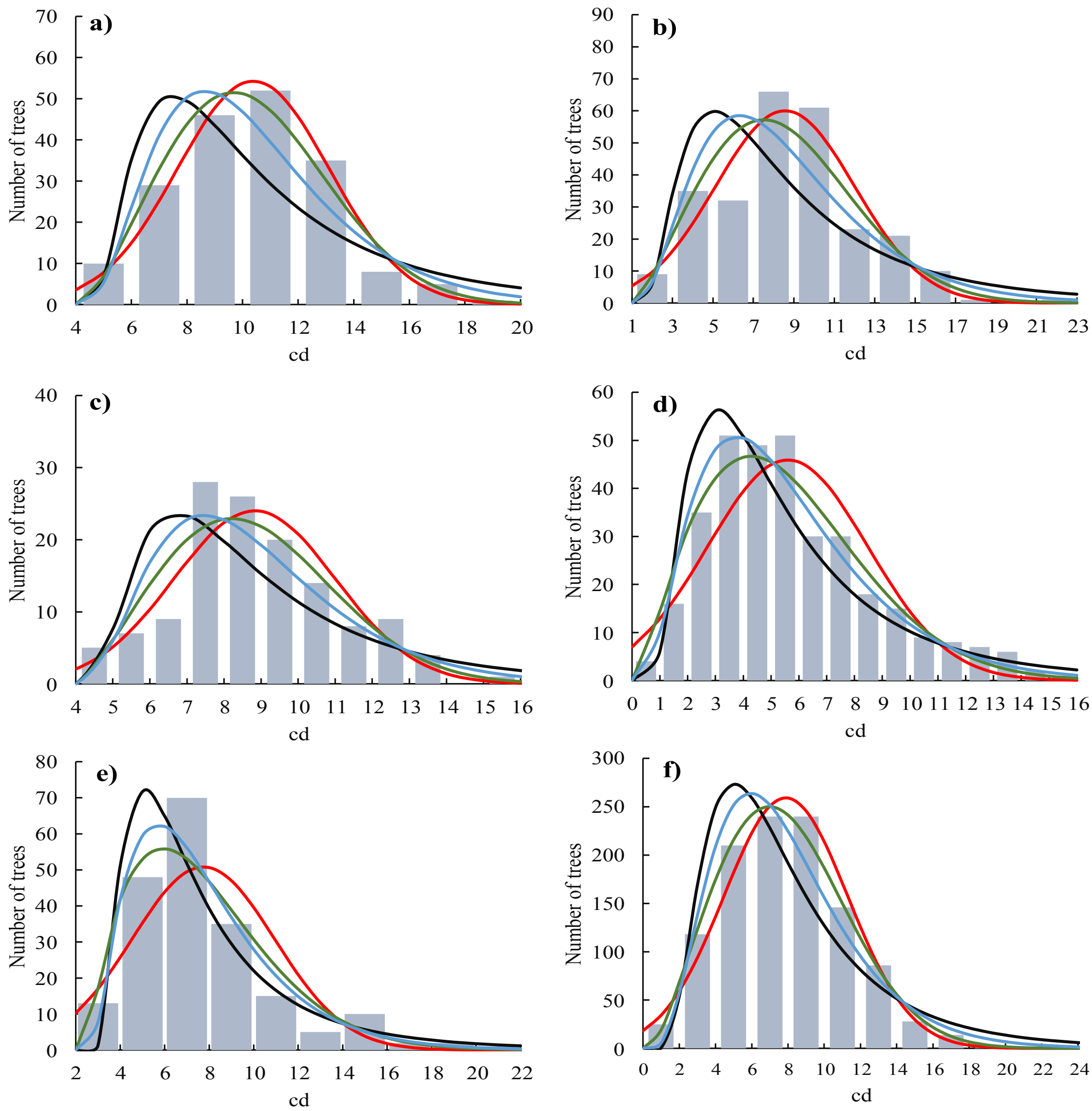

Figure 5. Distribution for *Araucaria angustifolia* crown diameter estimated by probability density functions (pdf) tested for each site, plotted on their respective frequency histogram: a) São Joaquim (SJQ), b) Panel (PNL), c) Urupema (URU), d) Lages (LAG), e) São José do Cerrito (SJC), and f) All sites. PDF adjusted according to the color lines: red [Normal]; black [Log-normal]; green [Weibull]; and blue [Gamma]

4. Discussion

Morphometric analysis allows us to evaluate the dynamics of changes in tree growth and development and ecological processes in forest communities (Mews et al., 2011). Studies on these dynamics are thus possible using the form of distribution of variables such as tree shape and size (dendro/morphometric). This knowledge should be used to aid the conservation and management of forest stands, especially mixed forests.

The similarities, or lack of significant changes, found by this study regarding the form of distribution of the dendro/morphometric variables results from the current and past conditions of tree development, indicating a compromise for a future structure.

Results show a stabilization pattern in the vertical and horizontal structure, with dynamic changes occurring slowly and gradually, or a negative instability. While this stabilization of the dynamics may indicate a lack of planned management, what is certain are its consequences for species conservation, and the stability, diversity, and productivity of forest resources. It is, thus, as harmful to the forest as the irrational use of resources.

The question remains whether to direct (manage) the dynamic processes or allow the forest to regulate itself. In the meantime, however, serious consequences due to competition and other processes may become irreversible. Results show that the largest number of trees is concentrated in the 30-60 cm d classes, structural consequences, and contribute in imbalances in mortality and recruitment rates contribute to the net reduction of total community biomass (Mews et al., 2011).

Another consequence is reflected in the rate of periodic diameter increase, as losses are more abrupt in smaller diameter trees than in those of larger size, due to competitive ability (Hess et al., 2018a). But the initial phase and growth acceleration when under continuous loss influence the tree's complete development. Its reflection on the structure will be greater in the future than the loss in already established trees in the canopy.

In part, our findings contradict the theory that in preserved forests, mortality is balanced by recruitment (Mews et al., 2011). Imbalance, periods of stability or instability in dynamics are rhythmic cycles in undisturbed forests (Sheil et al., 2000). Again, the paradigm reflects the dichotomy of using or not using forest resources. For forest science, forest management is the tool that reduces risks and uncertainties, does not disregard inputs, and favors full social and economic growth.

Considering the lack of intervention in the forest, the trees concentrated in d classes, reaching their maximum morphometric value and occupying the middle and upper strata, which inhibit sunlight entry and increase competition for resources such as space, light, nutrients and water. This competition affects young trees more intensively (Braga & Rezende, 2007), being detrimental to the formation of a future structure (old growth trees).

The lack of differentiation in size and shape constitute a serious issue, since phenotypic plasticity, phenology and canopy architecture are important in evolutionary ecology and in understanding plants, community, forest stand structure and production functioning (Barthélémy & Caraglio, 2007). According to Barthélémy and Caraglio (2007), a plant's architecture depends on the nature and relative arrangement of each of its parts; it is, at any given moment, the expression of a balance between endogenous growth processes and exogenous restrictions exerted by the environment. In forest science, this must be driven and managed by silviculture and forest management over time and space, providing goods and services to society and the ecosystem.

Using information from dendro/morphometric criteria and indices and considering the plant as a whole, these analyses and modeling are essential to understand forest dynamics, development, and management. Morphometric indices with reduced and stabilized values inform that forest dynamics are at a slow pace, which may compromise future structure and diversity, species conservation, and hinder the application of management regimes, especially traditional and known ones. These considerations are evident when analyzing the results of the distribution pattern for the dendro/morphometric variables.

Results show that the lack of structural heterogeneity can negatively affect the functioning of the forest ecosystem, thus confirming the hypothesis of a sustained silvicultural intervention. They indicate the need to open the canopy, remove trees in the classes with higher concentration, thus allowing for sunlight to enter and for regeneration within the species. This contribution is necessary and efficiently assists the processes of species conservation, forest structure, growth and ecosystem resources.

Failure to intervene in dynamic processes evokes detrimental effects regarding forest processes and structure. Removing the canopy through thinning can substantially increase light variability in the understory. Studies suggest that increasing spatial heterogeneity with thinning of different intensities could help restore biodiversity in temperate coniferous forests in northwestern US (Carey 2003; Curtis et al., 1998).

A study by Tsai et al. (2018) showed that thinning creates a link between resource heterogeneity and biodiversity in the understory or legacy effects associated with induced changes in understory regeneration. Studies have shown that, if practiced properly, thinning could facilitate the development of old-growth forest characteristics (O'Hara et al., 2010) and increase biodiversity (Longhi et al., 2018; Pollock & Beechie, 2014).

Interventions are important because size is related to life expectancy, size of living area and other aspects of life history and ecology, the relationship between size and density is an essential link between the individual - and population-level traits of species and the structure and dynamics of ecological communities. In addition, because body size is one of the primary determinants of metabolism and, therefore, resource use, the relationship between size and abundance also reveals how resources are partitioned in ecological systems (White et al., 2012).

In the same way, components of wood quality result from the tree's phenotype, which is determined by both the genotype and the environmental conditions, *i.e.*, the species-specific morphological plasticity and spatial arrangement within the stand (Assmann, 1970). Wide spacing and crown release by heavy thinning can increase light supply and foster crown width and length. Suppressed trees in the understorey, in contrast, may react to the light limitation by lateral rather than vertical crown extension.

The importance of forest management is in the recognition of identifying in which period of the dynamic which variable is an indicator of the need for intervention. And that needs to be modified in terms of reference value, need for change, in relation to lower or higher density. In short, interventions are also cyclical dynamics, with each variable, over a given period, having an importance in changes in the development of species in the forest.

Examples, studies where density reduction did not affect slenderness or even caused it to increase are exceptions. The crown ratio and crown projection ratio in all reviewed studies increased when stand density was reduced (Pretzsch & Rais, 2016). Indicating that the degree of slenderness has greater significance in the establishment of the tree, mainly in the early and juvenile stages, as crown variables in secondary growth, increase in size and production. What cannot happen is stabilization, concentration in values or dimension, or non-significant changes in time to the response and for the predictor variables in forest management models.

The concentration of values and trees in diameter classes is thus an indication that the MOF currently has a homogeneous structure. Confirming that not managing the stands for a long period of time we can have forests with regular structure having a dominant species. While uneven-aged mixed stands contain a broader spatial variety and more diverse and irregular structures. Uneven-aged pure stands may lie somewhere in between regarding structural heterogeneity.

In mixed forests the variations in the resource supply and of the variation in the morphological shapes, consequently, in the values of the dendro/morphometric variables may be broader. The density of regeneration in the sites is also shown to be lower as a lack of intervention in forest stands, as evidenced also by study of Cavallin and Vasseur (2008).

5. Conclusions

The analysis of the results allows us to conclude that interventions are necessary aiming at the questions of structure, regeneration, conservation, use of resources and changes in dynamics, not in a slow way, but accelerating processes. This is due to the fact that the araucaria has a lifetime that can last more than 200 years, actions of nature, such as opening gaps, with falls from old trees also take time.

Surveys with measurement of dendro/morphometric variables have been carried out by our forest management and growth laboratory for a decade. This helps to conclude that there are no significant changes in the dynamics of the forest with stabilization in its structure for more than 15 years. In a period of 4 years at the LAG site, there was a reduction in the number of trees in the class center by 12.5 cm in diameter (Silveira et al., 2018).

The analyzes of dendro/morphometric variables were carried out in terms of individual trees, indicating that even though the sampling processes at the sites were different, it did not influence the results in terms of reference values, concentration of values, dynamic analysis in terms of structure and yield. The results conclude that the lack of interventions (control thinning) in recent decades has caused harmful consequences in the life cycle of trees, competition, availability of resources, decrease in growth rate, increment and shape, in ecosystem diversity, stability, structure, productivity and conservation of the species.

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