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Amazon Forest morphometry on the tree management of the second harvest cycle

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Abstract
Knowledge of the morphometric relationships of Amazonian species can contribute to forest-sustainable tree management. The objective of this study is to describe and evaluate the morphometric relationships of 10 tree species from a tropical forest managed in a second cutting cycle. Morphometric data were collected in a forest located in the municipality of *Itaúba* ("Mato Grosso" state – MT, Brazil). In general, the DBH, Total Tree Height, and commercial morphometric parameters were similar for the species, except for copaiba, which presented a small value for minimum DBH, and low regeneration of the species in the area. The evaluated species showed a high value of Canopy Shape (average CS = 1.28) and the value of Canopy Proportion was 44.87%, slightly lower than those found in the literature. In the Salience Index, the data found ranged from 14 to 36, a result close to that expected for tropical forests. The average Slenderness Ratio (SR) observed in the area indicated that the trees are relatively robust and less prone to crown and trunk breaks. For the Salience Index, it was observed that the species showed a reduction of the index with the increase of DBH. There was a positive response for the relationships between variables evaluated, with 23.4% for the Canopy Diameter x DBH ratio (i.e., CD × DBH), 5.6% for the Canopy Ratio × DBH (CR × DBH), and 18.8% for the Total Height (HT × DBH). The morphometric correlations obtained low results (R^2: 0.234; 0.056 and 0.188 respectively). However, the average correlation between Total Tree Height and DBH was expected to be higher due to changes in tree growth due to the intervention carried out in the forest.

Keywords
Sustainable tree management — Amazon rainforest — Forest Biometrics — Morphometric relationships.

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1. Introduction

Used as a subsistence base for the local population since periods that date back to before the colonization by the Portuguese in Brazilian lands, the Amazon Forest has a gigantic ecological, economic and social importance. When dealing specifically with the timber sector, the forests that permeate the North and Midwest states of Brazil – notably Pará and Mato Grosso – are an important source of jobs and wealth generation through logging. Currently, Brazil has regulatory agencies whose main objective is to define minimum parameters for the sustainable use of forests, always aiming at rational exploitation that allows the forest to recover after certain cycles of time. However, we still face a reality that lacks details, suggestions, and information based on the scientific knowledge that allows the truly sustainable use of timber resources in the Amazon rainforest. Since the

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regulation of logging is defined by the Brazilian Forest Code, the standard followed in the Sustainable Forest Management Plans (SFMP) presents a cutting cycle that varies between 25 and 35 years between interventions in the forest, allowing removal of up to 30 m³/ there is.

This norm applies to a biome that has an approximate surface of 5,015,067,749 km², corresponding to about 58.9% of the Brazilian territory, and which, despite having small variations according to the legislation of each state, does not have options that suit it. the highly heterogeneous features that can be found in different sites within the Legal Amazon (Braz et al., 2014). The use of fixed parameters for forest management ends up making sustainable use impossible, which would be based on the structure and treatments for each managed area, using as information mainly the projected growth, stock, the response of the area after exploitation, data that can be obtained by monitoring the recovery of the area through the implementation and monitoring of permanent plots (Cola et al., 2022). However, in order to obtain more complete results regarding the response of the forest to management practices, we have as an option the study of morphometric parameters, which are obtained with the evaluation of the crowns that make up the forest strata.

The knowledge of the morphometric variables of the trees, obtained through the analysis of data such as the Diameter at Breast Height (DBH), height, and canopy data, presents an important aspect in the management and development of silvicultural interventions, a fact that is highlighted when analyzing them if the reforestation has a commercial objective. This type of planting is commonly developed with the use of exotic species such as Eucalyptus and Pinus, but it is also relevant for native forest management areas, both in the first and second cutting cycles, which, like homogeneous areas, may benefit from studies of prognosis and growth. Commonly, Brazilian forestry is focused on the direct production of wood, which is the main economic resource coming from forests, whose final destination is to supply the demand of large wood and fiber transformation industries. That said, most forest inventory works are conducted in order to quantify the growth and prognosis of usable woody biomass (Orellana & Koehler, 2008), as the higher the level of information obtained for the production of a certain area, the greater the can be the use of its productive potential. Aiming at maximizing the growth increment and, consequently, greater production of biomass, the study of the morphometry of the trees makes it possible to evaluate the ideal conditions for growth, living space, and competition, in addition to other variables that influence the dynamics of the forest (Costa et al. 2016).

According to Hasenauer (1997) the morphometry of a tree and its derived variables are used to infer interdimensional relationships, to reconstitute the space occupied by each tree, its stability, vitality, and productivity, as well as to judge the degree of competition to which each individual was or is subject. In general, forestry researchers have worked on the selection, creation, and adjustment of mathematical models that serve to predict the biomass in terms of easily obtainable variables (Sanquetta, 2002), such as the Total Tree Height (HT) and the Diameter at Breast Height (DBH) that can be correlated with variables such as commercial tree height, crown height, and crown diameter. Durlo and Denardi (1998) described the morphometric variables as a crown proportion or percentage, Slenderness Ratio, Salience Index, Canopy Shape, and Coverage Index.

In Brazil, we still have few works that study such aspects and that seek to relate morphometric variables that are easy to obtain, such as the Diameter at Breast Height (Durlo, 2009). Authors such as Durlo and Denardi (1998), Durlo (2001), Roman (2009), Nutto (2001), Condé et al. (2013) and Selle and Vuaden (2010) produced studies on the morphometry of native species, especially those that occur in southern and southeastern Brazil. On the other hand, Tonini and Arco-Verde (2005) worked on the verification of the relationships between the main morphometric indices of growth in diameter and height in relation to the canopy of four species native to the Amazon. If we focus on a point of great importance for future forestry interventions, which are studies on the recovery and dynamics of trees within a forest that is in the second harvest cycle, we will see that the existing publications dwindle in quantity and relevance – almost no studies are found that aim to assess the morphometry of trees in a forest after its exploitation and subsequent recovery. With this in mind, the species **Amescla** (*Trattinickia burserifolia* Willd), **Angelim-Saia** (*Parkia pendula* (Willd.) Benth. ex Walp.), **Cambará** (*Qualea paraensis*), **Canelão** (*Nectandra cissiflora* Nees), **Cedrinho** (*Erisma uncinatum* Warm), **Copaíba** (*Copaifera langsdorffii*), **Cupiúba** (*Goupia glabra*), **Farinha-seca** (*Albizia hassleri*), **Guarantã** (*Aspidosperma discolor*) and **Leiteiro** (*Brosimum lactescens* (S.Moore) CCBerg) species of great relevance and occurrence in the forests in the North/Northeast of Mato Grosso, which commonly represent a substantial portion of Sustainable Forest Management Plans (PMFS) carried out in this region and which are targeted for extraction and use in sawmills. The objective of the present study was to evaluate the relationships between biometric variables (DBH and Total Tree Height) and morphometric variables (CP, SI, CI, CS and SR) of 297 trees from a tropical humid "terra firme" forest that is in its second cycle. harvest.

2. Material and Methods

2.1 Description of the study area

The study area is located in the north of the state of Mato Grosso, a region characterized by the Amazon Forest, the study area is a humid tropical forest of "terra firme", described as Evergreen Seasonal Forest (IBGE, 2012). Limited by coordinates E: 55º11´57´´ - N: 11º15´10´´ at an altitude of 283 meters; the climate of the region according to the Köppen classification is Aw, tropical, hot and humid, with an average annual rainfall of 1974.5 mm/year, and an average annual temperature of 24.7℃ (Ivares, 2014).

Data collection took place in a forest with an area of 1,413 ha that had already been logged at an intensity of approximately 25 m^3. ha^{-1} (about 5 trees.ha^{-1}) in 1987, that is, this forest is in the second harvest cycle. In this area, 18 commercial tree species were inventoried, all authorized for exploitation in a forest management project approved by the state environmental agency (SEMA-MT). Morphometric data were randomly collected from individuals (diameter at breast height, measured at a distance of 1.30 meters from the ground) of 10 forest species – Amescla, Angelim-Saia, Cambará, Canelão, Cedrinho, Copaíba, Cupiúba, Farinha-Seca, Guarantã, and Leiteiro.

Using a digital clinometer, the Total Tree Height (HT) was collected, and the commercial height (HC), the Canopy Length (CL) was calculated using the expression: CL = HT - HC. The crown diameter (CD) was obtained through measurements of four crown radii in fixed directions north (R0o), south (R180o), east (R90o) and west (R270o) using a tape measure, taking as the center of the trunk and moving away to the edge of the crown, being calculated using the expression CD = [(R0o + R180o) + (R90o + R270o)]/2, method adapted from Condé et al. (2013).

The Base tree traits are: CL is the Canopy Length (m); CD: Canopy Diameter (m); HT is the Total Tree Height; DBH is the Diameter at Breast Height. Calculated tree traits: CP= (CL / HT) × 100 is the Canopy Proportion (%); SR = HT / DBH is the Slenderness Ratio; SI = CD / DBH is the Salience Index; CI=CD/HT is the Canopy Index; CS= CD/CL is the Canopy Shape.

The following morphometric variables were used: Canopy Insertion Height (HCI), Canopy Diameter (CD), Canopy Proportion (CP), Slenderness Ratio (SR), Salience Index (SI), Coverage Index (CI), and Canopy Shape (CS), according to Burger (1939).

For the evaluation of the morphometric relationships (CD as a function of DBH; CP as a function of DBH; HT as a function of DBH) two different models will be used: 1) Linear Model and 2) Logarithmic Model, as shown in the equations below, as used by Lima (2012) and Roman (2009).

$$Y = \beta_1 + \beta_2 \times X + \varepsilon$$

$$Y = \beta_1 + \beta_2 \times (LnX) + \varepsilon$$

Where: Y represents the dependent variable to be analyzed and × the independent variable.

The crown morphometric variables are considered difficult to obtain, so it is necessary to develop equations that estimate them, as a function of easily obtainable variables, such as the Diameter at Breast Height and Total Height. To evaluate the existing correlations between the morphometric variables and the diameter and height, regression analysis was used, in which the potential independent variable was selected for a level of 5% error and 95% probability.

3. Results and Discussion

3.1 Population Parameters

A total of 297 individuals of 10 species were evaluated, which presented similar values for the median heights analyzed in the stand parameters - they make up a forest that has an average canopy of approximately 25 meters with a commercial height of 14 meters. For the Diameter at Breast Height, we can observe greater variation in the mean, which fluctuates from 47 to 71 centimeters in diameter (Table 1). For maximum data, Cupiúba and Angelim-Saia had the highest DBH values (108.86 and 131.78 cm respectively), Cambará had the highest commercial height observed at 20 meters until the insertion of the first branch, followed by Guarantã with 19 meters, while Guarantã had the largest individual sampled, with a Total Tree Height of 39 meters, while the other species ranged between 27 and 35 meters.

The Copaíba species, in turn, did not present individuals with DBH less than 57.93 cm. This data may indicate that, after the first exploration in this area, the species did not regenerate satisfactorily, and may present the need for greater shading to develop optimally, or present slow growth and low capacity to compete with more aggressive species, such as Cambará and the Leiteiro. Another factor that can influence Copaíba regeneration is the high seedling mortality and negative recruitment rate (Resende et al., 2003) in their study on the dynamics of the species, Resende states that a positive correlation was also observed between the canopy and the growth rate of Copaíba seedlings, so it is a species that can suffer from disturbances such as opening gaps.

Cambará was present in almost all diameter classes found in the stand, making up the largest portion of the

Table 1. Population parameters of ten species in ”terra firme” forest in 2nd harvest cycle.

Species	IND. No.	DBH			HC			HT		
		Min	Average	Max	Min	Average	Max	Min	Average	Max
Amescla	42	40.74	61.79	91.35	5	13.38	18	18	25.57	35
Angelim-Saia	19	42.02	65.84	131.78	12	14.26	18	20	25.32	33
Cambará	94	23.55	59.56	98.68	8	13.67	20	15	25.7	34
Canelão	16	35.97	50.77	75.76	11	06.14	17	19	23.88	32
Cedrinho	11	45.52	61.4	76.39	11	13	15	17	22	27
Copaíba	8	57.93	71.46	95.17	11	13.5	18	18	24.63	31
Cupiúba	35	39.79	71.57	108.86	8	12.23	15	18	26.83	34
Farinha-seca	14	54.11	62.96	74.48	9	12.21	16	19	23.57	31
Guarantã	22	47.43	67.31	92.31	11	14.55	19	14	24.64	39
Leiteiro	36	33.42	47.81	77.99	10	08.13	18	14	03.22	29
Overall Average		42.05	62.05	92.28	9.6	13.39	17.4	17.2	24.42	32.5

DBH: Diameter at Breast Height (cm); HC: commercial height (m); HT: Total Tree Height (m).

trees sampled, and was just not found in the range of 100-110 cm in diameter. The Canelão was found in the first five diameter ranges, as well as the Leiteiro. The Amescla is well distributed in the diameter classes, similarly to Cupiúba.

Cupiúba was present in 7 of the 9 diameter classes, not occurring in classes 20-30 and 50-60 and together with Angelim-Saia, they were the only ones that presented individuals in the class of 100-110. The presence of individuals of Cupiúba only in the high ranges of diameter class is corroborated by the results found by Braz (2014) and Carvalho 1981) who state that in regions of the dense forest the species is observed only in the largest diameter classes, but can occur in the edges, natural or farm clearings. Copaíba was found in only 4 diameter classes, with no individuals sampled in the 20-30, 30-40, 40-50, and 70-80 ranges. Cedrinho occurred only in the 40-50, 60-70, and 70-80 ranges, indicating low regeneration, and these individuals are probably seed carriers kept in the field in the management.

With the realization of PMFS in a forest, a series of disturbances affect the balance of the area, mainly the opening of gaps that are considered one of the most important factors in the regeneration of forests (D'Oliveira, 2009). Effects such as an increase in the availability of light that reaches the forest floor, a reduction in the competition of the roots for the death of trees, a temporary increase in the availability of resources, a reduction in soil relative humidity and an increase in temperature in the understory after the opening of gaps can promote the growth of forest species (D'Oliveira, 2009; Brown, 1993). The intensity of solar radiation that a tree receives in its crown is a limiting factor for its growth, as there is a positive effect on the growth of a tree when there is an increase in the luminosity that falls on the crown (Souza, 2014; Baker et al., 2003). Studies already carried out on the effects of canopy opening demonstrate how variable growth can be within and between species in response to gap opening (Miranda, 2018), Costa (2008) studying the response of a forest to the intervention stated that heliophyte species (shade intolerant) showed growth three times greater than the sciophytic (shade tolerant) species during the forest monitoring period (1981-1997), but there are species whose growth does not directly depend on luminosity, but they can still benefit from the opening of the canopy, either naturally or by wood extraction.

Miranda (2018), Carmo (2018), Souza (2014) and Costa (2008) presented data that indicate that forest exploitation carried out in the Amazon rainforest ends up promoting the growth of trees, mainly affecting the gain in diameter of the trees. species that respond positively to higher incidence of luminosity. It can be said that for the area in question, the execution of PMFS ended up providing a more favorable area for the regeneration of Cambará, Leiteiro and Canelão, which in this sampling presented higher numbers than the other species. Cambará, in addition to presenting relatively fast growth, is an elastic species (Miranda, 2018), that is, it has optimal growth when exposed to favorable conditions such as those offered by the opening in the canopy. In this way, either by a greater number of propagules in the area.

3.2 Morphometric Variables

Canopy Proportion (CP). In relation to Canopy Proportion, it can be observed that the highest values were presented by the species Amescla, Cambará and Cupiúba (78.26%, 75.41% and 70.59%, respectively), therefore, these species present most of their morphometric con-

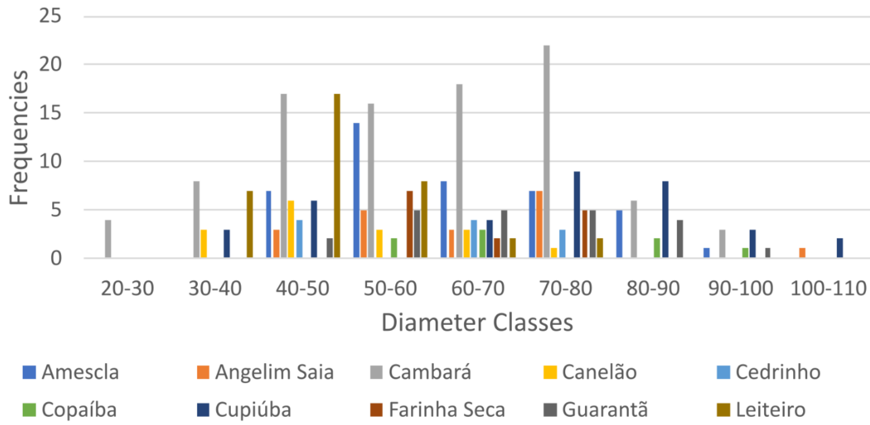

Figure 1. Frequency of individuals per diameter class per species in the Amazon Forest in the second harvest cycle. The colors are the evaluated species.

stitution in the canopy shape, The Copaíba, Canelão, Leiteiro and Guarantã in turn showed values close to 50% of Canopy Proportion. Durlo and Denardi (1998) studying the *Cabralea canjerana* found values similar to those of this study – variation from 10% to more than 80% of the Canopy Proportion, with the population average being 50%. The authors attribute this amplitude to the competition to which the trees are submitted, but the variation may be due to the dimensions of the individuals. The authors also emphasize the importance of knowing the influence of the variable on growth,

In the average parameters, the species are in similar levels with a variation of 39.51% of the Leiteiro to 53.8% of the Cupiúba, while in the minimums the Cambará has the lowest CP (6.67) probably due to the greater presence of the species in the lower diameter classes and the average Canopy Proportion of all individuals sampled was 44.87%. The values found can be seen in Figure 2.

According to Roman (2009), the CP variable is a good indicator of vitality and the higher the percentage, the more productive the tree can be. When studying Louro-Pardo (*Cordia trichotoma* (Vell.)), they found an oscillation from 26.2% to 76.7%, a fact that can be explained by the existence of different degrees of competition to which the trees are subjected and also by the dimensions of the samples sampled.

Durlo (2001) found an Average Canopy Proportion of around 49.2% for *Cabralea canjerana* (Vell.) Mart. in secondary forest in the state of Rio Grande do Sul. Orellana and Koehler (2008) verified an average Canopy Proportion of around 55.2% for 50 trees with DBH $>$ 10 cm of *Ocotea odorifera* (Vell.).

Salience Index (SI). The SI variable indicates how many times the crown diameter is greater than the stem diameter (DBH) and in this study the Angelim-Saia species presented the highest values with 61.93, followed by an approximate value of 40 for Amescla, Cambará, Cupiúba and Leiteiro, as can be seen in Figure 2. Evaluating the average parameters, the only species that stands out from the others is the Angelim-Saia, whose average SI was 36.7 – that is, its crown is 36.7 times larger than the DBH, which can be explained by the fact that the Angelim is an emerging species, which can reach up to 40 meters in height (Lorenzi, 2009) and occupy the upper stratum of the forest. In this situation, having a wide canopy like the one described does not cause damage to the tree, as competition for light is lower.

Tonini and Arco-Verde (2005) found values of 50.30 for Castanheiras trees, 14.7 for Andiroba trees, 32.3 for Ipê Roxo trees and 33.1 for jatobá, in a study carried out in homogeneous planting in the experimental field of Embrapa Roraima, at 7 years old. deity. Durlo and Denardi (1998) found a mean SI of 21.70 for *Cabralea canjerana*, in a study carried out in native secondary forest in the state of Rio Grande do Sul, while Orellana and Koehler (2008) detected a value of 39.20 for *Ocotea odorífera*, in a remnant of Ombrophilous Forest. Mixed, in Paraná. Dionisio (2018) when evaluating the effect of thinning on teak morphometry, did not find a significant relationship between the thinning intensities tested and this variable.

The Salience Index can be used to deduce the maximum number of individuals that would occupy a hectare, without competition as stated by Stampfer (1995), so it can be used as an indicator of thinning and according to Durlo and Denardi (1998) used to determine at any time the space that needs to be freed up around a tree for it to grow without competition. According to Durlo and Denardi (1998), the lower this index in a stand, the greater its basal area and probably its volume per hectare. According to Wadsworth (2000) the Salience Index in natural tropical forests varies between 14 and 28 – in this study, a greater range of value was observed, ranging

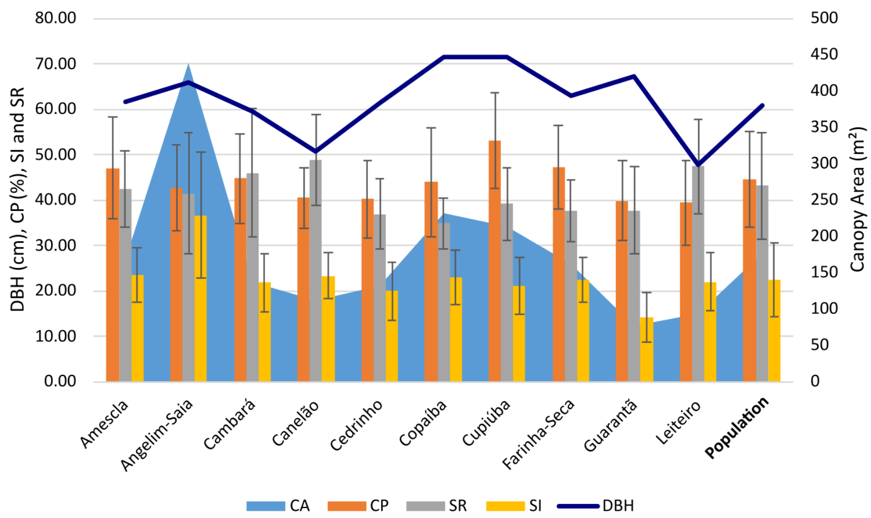

Figure 2. Canopy Proportion (CP), Slenderness Ratio (SR), Salience Index (SI), compared to Diameter at Breast Height (DBH) and Canopy Area (CA) for the analyzed species.

from 14 to 36.

Slenderness Ratio (SR). The species that presented the highest Slenderness Ratio was the Cambará (95.78), which indicates that it is the species in which the individuals are under a greater degree of competition during their growth. The other species mostly presented maximum Slenderness Ratio values between 40 and 60 (Figure 2). High values, close to 100, indicate very unstable trees, subject to trunk and crown breakage if exposed to strong winds (Tonini & Arco-Verde, 2005). Evaluating homogeneous stands, Tonini & Arco-Verde (2005) indicate that when the SR of the trees is greater than 100, a thinning operation should be carried out, aiming to favor certain individuals and promote diametric growth. The effect of management tends to reduce the Slenderness Ratio because, with the opening of the gaps, the diametric growth of the remaining trees is promoted, Evaluating homogeneous stands, Tonini and Arco-Verde (2005) indicate that when the SR of the trees is greater than 100, a thinning operation must be carried out, aiming to favor certain individuals and promote diametric growth. The effect of management tends to reduce the Slenderness Ratio because, with the opening of gaps, the diametric growth of the remaining trees is promoted, as shown by Miranda (2018) in her study of dendrochronology of Cambará and Carmo (2018) who studied the effects management of the properties of copaiba wood.

When studying Louro-Pardo (*Cordia trichotoma*) Roman (2009) observed that the individuals that presented the highest values of SR were those that were submitted to a high degree of competition and their crowns were located in the middle stratum of the forest. In this study, the most stable species in the area is the Copaíba, which has the lowest Slenderness Ratio - explained by the Copaíba individuals being present only in the larger diameter classes, representing mature trees, with reduced apical growth and increased diameter growth, in the opposite situation to the blond-pardo studied by Roman. In his work, Condé (2013) found the following slenderness degrees for Andiroba (79.34), Castanheira-do-Brasil (56.96), Copaíba (47.70), and Mahogany (66.79) in agroforestry systems in Roraima. The data found by Condé were higher than those obtained in this study, most likely due to the environmental and competition differences found between an already managed forest and plantations in Agro-Forestry Systems (AFS). For this study, it can be expected that the result of the Slenderness Ratio would be even more discrepant if the forest had not passed through the PMFS.

The Cambará Slenderness Ratio may indicate that the trees were at a higher level of competition with other trees, possibly vying for space in the gaps opened by previous selective logging. The presence of gaps (Oliveira, 1998) and high regeneration can result in a large number of trees in the lower diameter classes, with tall and thin trees, with small crowns, possibly located in the middle stratum and subjected to greater competition, so similar to the results of Roman (2009) for the Louro-Pardo. If we observe the average values of SR, we will see that all the evaluated species are in a close range – 34 to 48, which may indicate that the trees are in a similar state of competition in the area, lower than that found by Dionisio when studying 7-year-old teak (*Tectona grandis*) plantations (SR 0.86 to 1.12), Orellana (2008) found SR values for Canelão-sassafras (*Ocotea odorifera*) in a remaining mixed ombrophilous forest that ranged from 0.3 to 0.6, which are close to the data obtained in this study. At the population level, the forest followed the pattern proposed by studies carried out by several researchers such as Tonini and Arco-Verde (2005) and Roman (2009) who propose that the tendency of the Slenderness Ratio is to reduce as the diameter increases, as shown in the graph below (Figure 3-A).

Coverage index (CI). Cambará and Copaíba species did not present much variation (CV% = 27.96 and 21.87%) while Cupiúba presented a high value (46.14%), due to higher values of crown diameter presented by the species in some individuals. The tendency presented by the Coverage index is to increase with the growth in diameter, as demonstrated by Durlo (2001) in a study of *Cabralea canjerana*, where it was verified that as the trunk thickens, the rates of increase in canopy diameter increasingly exceed those of height. Dionisio (2018) found a different reason for *Tectona grandis* after the occurrence of thinning – a trend of increasing canopy diameter was observed proportionally with increasing height. Costa et al (2009), studying Brazil Nuts in Agro-Forestry Systems (AFS) in Central Amazonia, found that the IC tended to decrease with height and increase with increasing diameter, which consistent with the results found in this study (Figure 4).

The species that showed the highest CI was Cupiúba with a value of 1.74, as they are the trees that have the largest crown diameter, which usually grows inversely proportional to the height development of the trees (Durlo; Denardi, 1998; Roman et al., 2009). This indicates that for the species, crown development continues to occur as the tree ages. For the stand analysis, the results were correlated to those described by the authors mentioned above – as the DBH increased, the IC tended to increase proportionally (Figure 3-B). A similar situation occurs with the Angelim-Saia, which presented a CI of 1.42, which demonstrates a large crown and continues to grow – also confirmed by the high value of Canopy Proportion found for the species, in addition to presenting the highest mean value of CI.

Cambará presented the lowest value of CI indicating that it is possibly the species that has the highest height development of the species evaluated in the study and that its crown development has a behavior inversely proportional to height development – the taller the tree, the lower the Coverage index. Orellana and Koehler (2008) in a study on *Ocotea odorifera*, the highest values of Coverage index were found in the dominant trees in the stand, whereas Roman (2009), studying *Cordia trichotoma*, verified the occurrence of a tendency to increase the CI according to the thickening of the trees. trees. As previously mentioned, authors such as Miranda (2018) and Carmo (2018) evaluated that carrying out PMFS in areas of the Amazon Forest promotes a diameter increase in species.

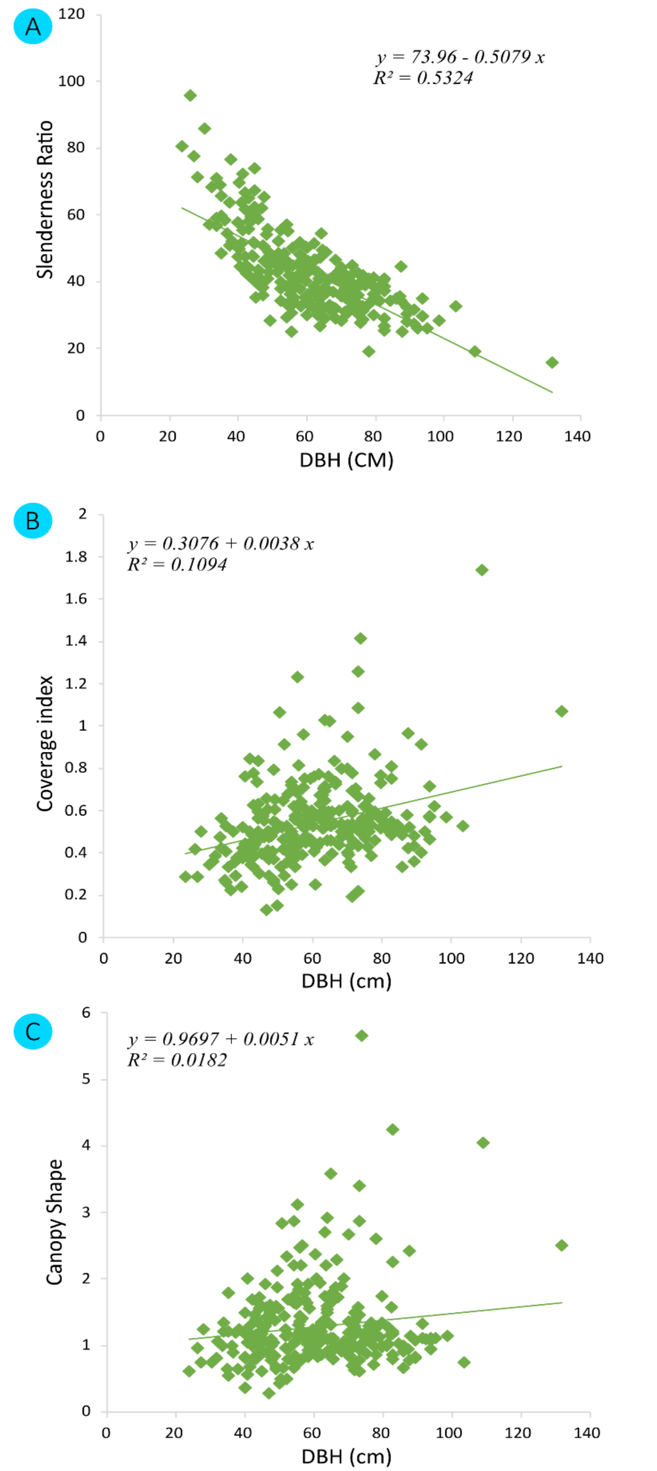

Figure 3. A - Graph of the relationship between Slenderness Ratio (SR) and DBH for the sampled species. **B -** Relationship between the Coverage index and the DBH for the evaluated species. **C -** Graph of the relationship between Canopy Shape and DBH.

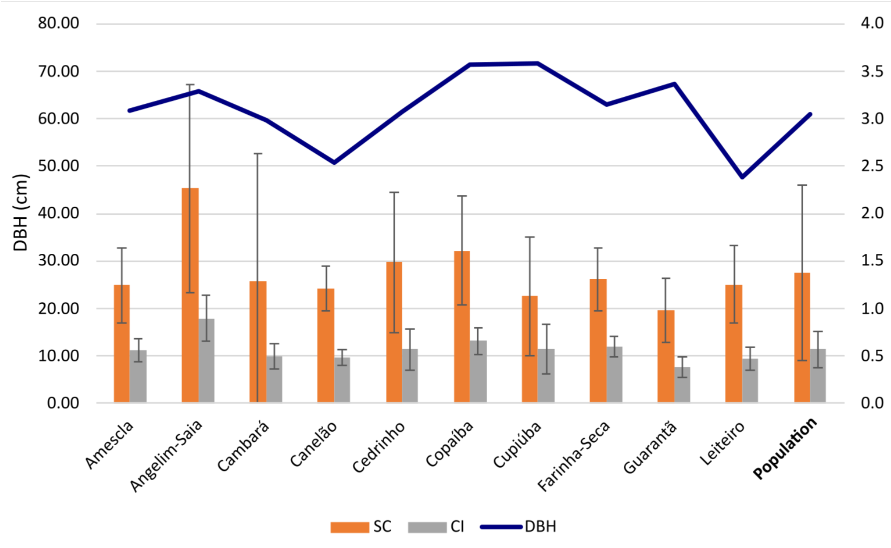

Figure 4. Canopy Shape (CS) and Coverage index (CI), compared to Diameter at Breast Height (DBH) for the analyzed species.

Canopy Shape (CS). Most of the species addressed in this study had lower average values of Canopy Shape, which indicates the presence of 'intermediate' crowns between rounded and elongated. In turn, Angelim-Saia presented the highest average values of Canopy Shape - which indicates that the crown continues to develop to a rounded and flattened shape as it ages, adopting a tabular aspect of easy identification, information corroborated by the SR and CP data.

Copaíba presented average data similar to those found by Condé (2013), who detected average values of 1.79 for Copaíba in agroforestry systems in Rondônia. A tree that has a slender crown (smaller Canopy Shape) tends to be more productive, either for fruit production as for Brazil nut (Tonini et al., 2008) or for growth, as demonstrated by Durlo and Denardi (1998) that mention that considering the same species and site, the smaller the Canopy Shape, the better the productivity, which is due to the relationship between the crown mantle and the crown projection area, so if two trees of the same species have the same diameter of canopy, the one with the slender canopy will produce more, as it will have a greater canopy mantle, for the same projection area.

Studying Brazil Nuts (*Bertoletia excelsa*) in homogeneous plantations and Roraima, Tonini and Arco-Verde (2005) identified a CS around 0.86, characterizing a tendency of the species to develop slender crowns. Dionisio (2018) observed that teak (*Tectona grandis*) in homogeneous planting, presented average values of CS of 0.45. Durlo and Denardi (1998) evaluating *Cabralea canjerana* found CS values of 0.74 in fragments of seasonal deciduous forest. Tonini and Arco-Verde (2005) in a study on the morphometry of Amazonian species in AFS observed values of 0.3 for Andiroba, 0.86 for Castanheira-do-Brasil, 0.73 for Ipê-Roxo and 0.79 for Jatobá. In these studies, more slender canopies were observed, both in homogeneous plantations, AFS and secondary forests in the south of the country. The results were different from those found in this work (Figure 4), where the average of the sampled species was 1.28 higher than that described by other authors. This indicates that the evaluated forest, which is in the second harvest cycle, has a tendency to present more rounded and flattened crown trees. Analyzing the effect of thinning on teak plantations, Dionísio (2018) stated that thinning with a 40% reduction in the basal area caused a significant increase in Canopy Shape values when compared to the control. Significant correlations between the increase in diameter and canopy lighting were found by Finegan (1999) and this is where the importance of the Canopy Shape is found, because the lower the index and the slenderer the canopy, the better the degree of lighting received by the tree, and so, growth is promoted. This indicates that the evaluated forest, which is in the second harvest cycle, has a tendency to present more rounded and flattened crown trees. Analyzing the effect of thinning on teak plantations, and canopy, the better the degree of lighting received by the tree, and so, growth is promoted.

Costa (2016) found that for araucaria (*Araucaria angustifolia*), the Canopy Shape is strongly altered with growth - increasing age and the degree of competition change the shape of the araucaria canopy. In young trees with growth in height proportionally greater than the lateral growth of the branches, the crown assumes characteristics of a conical shape (smaller Canopy Shape). When the increase in height decreases, the canopy takes on an ellipsoidal shape and at a more advanced age, when reaching maturity, it reaches an almost flat or umbel shape (large Canopy Shape). Evaluating the graph that shows the relationship between DBH and CS (Figure 3-C), we can observe that as DBH increases, there is a tendency to increase the Canopy Shape; the smaller the DBH, the smaller the Canopy Shape, demonstrating that there may be a behavior similar to that reported by Costa (2016) for Araucaria – a tendency to change the Canopy Shape as the tree ages and grows in diameter. This tendency to change the shape of the canopy can be affected by the effect of opening gaps, as evaluated by Hubbell and Foster (1986) when studying gap formation and development – in the final phase of growth, the regenerants reach the canopy and predominance occurs. of the diameter growth and the lateral expansion of the crown, or even by the action of the forest management carried out previously in the area.

3.3 Morphometric Relationships

3.3.1. CD ratio as a function of DBH

Analyzing the forest as a whole, the mathematical model that best explained the behavior of the canopy diameter ratio as a function of Diameter at Breast Height was number 2 (logarithmic), with which a coefficient of determination (R^2) of 23.45% was obtained.

The mathematical model nº 1 (linear) was the one that best expressed the behavior of the relationship between the crown diameter as a function of the Diameter at Breast Height for Cambará. In turn, model nº 2 (logarithmic) was able to better express the behavior of this relationship for Cupiúba (Table 2). The analysis of Copaíba, Angelim-Saia and Farinha-seca was unable to find a relationship between the data, resulting from the smaller number of individuals sampled.

The highest coefficient of determination found in the analysis of the relationship between CD and DBH was from Cupiúba ($R^2 = 0.476$), better expressing the behavior of the data, followed by Cambará ($R^2 = 0.388$). For most species, the logarithmic model was the most significant in the correlation analysis. Evaluating *Cordia trichotoma* in an induced forest fragment, Roman (2009) found positive correlations between DBH and canopy diameter (using a logarithmic model), as expected in the study, with an R^2 of 0.61, higher data than those found in this study.

3.3.2. CP ratio as a function of DBH

For the evaluated species, the Angelim-Saia, Leiteiro, Cupiúba, and Guarantã presented positive and significant correlations between the Canopy Proportion (CP) and the DBH, and the model that best expressed the behavior of the relationship between the variables of Angelim-Saia and Cupiúba number 2 (logarithmic) and for Leiteiro and Guarantã, the model that best explained the variations was number 1 – the same result found for the population analysis (Table 3).

Table 2. Correlation models (DC × DBH) were selected for the species and their coefficient of determination.

Species	Model	R^2
Population	CD = -23.2557 + 9.005741 (LnDBH)	0.234
Amescla	CD = -14.5401 + 7.018024 (LnDBH)	0.167
Angelim-Saia	CD = 22.39586 + 0.00438 (DBH)	-0.0586
Cambará	CD = 4.152463 + 0.142394 (DBH)	0.388
Canelão	CD = -14.5463 + 6.707969 (LnDBH)	0.212
Cedrinho	CD = -34.2794 + 11.36402 (LnDBH)	0.197
Copaíba	CD = 5.306553 + 0.16442 (DBH)	0.053
Cupiúba	CD = -46.7083 + 14.65721 (LnDBH)	0.476
Farinha-seca	CD = -6.29432 + 4.926682 (LnDBH)	-0.039
Guarantã	CD = 4.955039 + 0.0653863 (DBH)	0.0241
Leiteiro	CD = 2.73025 + 0.160921 (DBH)	0.217

Table 3. Correlation models (PC × DBH) were selected for the species and their coefficient of determination.

Species	Model	R^2
Population	CP = 35.40858 + 0.155221 (DBH)	0.056
Amescla	CP = 31.34832 + 3.852315 (LnDBH)	-0.0192
Angelim-Saia	CP = -14.3543 + 102.4854 (LnDBH)	0.105
Cambará	CP = 41.21372 + 0.06786 (DBH)	0.0012
Canelão	CP = -23.9363 + 16.52136 (LnDBH)	0.294
Cedrinho	CP = 2.363933 + 9.240638 (LnDBH)	-0.0614
Copaíba	CP = 22.5087 + 0.300753 (DBH)	-0.015
Cupiúba	CP = 1.5939 + 12,201 (LnDBH)	0.102
Farinha-seca	CP = -18.4954 + 15.9342 (LnDBH)	-0.033
Guarantã	CP = 29.1834 + 0.159872 (DBH)	0.0163
Leiteiro	CP = 24.41519 + 0.315667 (DBH)	0.104

Table 4. Correlation models (HT × DBH)

Species	Model	r^2
Population	HT = -6.40801 + 7.691193 (LnDBH)	0.188
Amescla	HT = -16.2567 + 10.20047 (LnDBH)	0.253
Angelim-Saia	HT = 49.75597 - 5.88477 (LnDBH)	0.158
Cambará	HT = 17.2972 + 0.13459 (DBH)	0.22
Canelão	HT = =0.16683 + 6.162158 (LnDBH)	0.083
Cedrinho	HT = 18.59595 + 0.055436 (DBH)	-0.0507
Copaíba	HT = -35.533337 + 14.1476558 (LnDBH)	0.302
Cupiúba	HT = -23.2577 + 11.84733 (LnDBH)	0.552
Farinha-seca	HT = 15.13771 + 0.13396 (DBH)	0.0043
Guarantã	HT = 19.33841 + 0.078712 (DBH)	0.0059
Leiteiro	HT = 15.55123 + 0.135469 (DBH)	0.109

In his study with *Trichotomy cord*, Roman (2009) found R^2 values equal to 0.41 for the correlation between Canopy Proportion and DBH. In this study, the correlation value was lower, with the standing average being 0.056, while the species that presented the highest correlation between these factors was the Canelão with 0.294.

3.3.3. HT ratio as a function of DBH

For Cambará, Farinha Seca and Leiteiro species, the model nº1 (linear) was the one that best expressed the behavior of the relationship between Total Tree Height and DBH. As for the population, Cupiúba, Canelão, Angelim-Saia, and Amescla, the most suitable model was number 2 (logarithmic), which also presented the highest coefficient of determination of the analysis (R^2 = 0.552) (Table 4). In turn, species such as Cedrinho, Farinha-seca, and Guarantã showed no significant correlation, a fact that may be caused by the small number of individuals sampled.

Roman (2009) states that the relationship between. Total Tree Height and DBH usually present a good correlation, but it is dependent on the sociological position of the tree, differing between trees according to the position they occupy in the stand and in the case of equine forests, the differentiation starts when the stand reaches the point of canopy intertwining and increased competition.

4. Conclusions

Due to the PMFS that occurred in the area, some species must have presented a better response to the opening of gaps and this may have influenced the correlations between biometric (DBH and Total Tree Height) and morphometric variables. Significant statistical relationships were found between morphometric and biometric variables. According to the morphometric variables observed, PMFS promoted diametric growth in the remaining trees. The Canopy Shape found shows that the trees in the forest have a rounded and flattened crown. The Slenderness Ratio showed that, on average, the trees sampled are stable and not prone to crown or trunk breakage.

The wide range of variation in the morphometric characteristics found among the species studied shows the need for further investigation about the variables and their correlations in tropical forests, not only with the dimensions of the trees, but also with other factors of great influence, such as site and cycle. of forest harvest. This information can guide practices for more efficient management.

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References

Alvares, C. A., Stape, J. L., Sentelhas, P. C., Gonçalves, J. D. M., & Sparovek, G. (2013). Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift*, 22(6), 711-728.

Baker, T. R.; Swaine, M. D.; and Burslem, D. F. R. P. 2003. Variation in tropical forest growth rates: combined effects of functional group composition and resource availability Perspect. Plant Ecol. Evol. Syst. 6 21–36

Braz, E. M., de Mattos, P. P., Oliveira, M. F., & Basso, R. O. (2014). Strategies for achieving sustainable logging rate in the Brazilian Amazon Forest. *Open Journal of Forestry*, v. 4, n. 2, p. 100-105.

Brown, N. (1993). The implications of climate and gap microclimate for seedling growth conditions in a Bornean lowland rain forest. *Journal of tropical ecology*, 9(2), 153-168.

Burger, H. (1939). Baumkronen und Zuwachs in zwei hiebsreifen Fichtenbeständen. Mitt. d. Schweiz. *Zentralbl. forstl. Versuchswes*. S, 141-173.

Carvalho, P. E. R. (2008). Espécies arbóreas brasileiras. Brasília, DF: Embrapa Informação Tecnológica; Colombo: Embrapa Florestas, v. 3.

Cola, R. E., Brandão, C. F. L. e S., Longhi, R. V., Lana, M. D., da Silva, L. G. (2022). Forest structural analysis of a seasonal semideciduous area in the northeast Brazil. *TreeDimensional*, v. 09, e022003.

Condé, T. M., Lima, M. L. M., de Lima Neto, E. M., & Tonini, H. (2013). Morfometria de quatro espécies florestais em sistemas agroflorestais no munícipio de Porto Velho, Rondônia. *Revista Agro@ mbiente* On-line, 7(1), 18-27.

Costa, D. H. M., Silva, J. N. M., & de Carvalho, J. O. P. (2008). Crescimento de árvores em uma área de terra firme na floresta nacional do tapajós após a colheita de madeira. *Revista de Ciências Agrárias* Amazonian Journal of Agricultural and Environmental Sciences, 50(1), 63-76.

Costa, E. A., Finger, C. A. G., & Fleig, F. D. (2016). Influence of social position on the morphometrics relations in Araucaria angustifolia. *Ciência Florestal*, 26(1), 225-234.

Costa, J. R., Castro, A. B. C., Wandelli, E. V., Coral, S. C. T., & Souza, S. A. G. D. (2009). Aspectos silviculturais da castanha-do-brasil (Bertholletia excelsa) em sistemas agroflorestais na Amazônia Central. *Acta Amazonica*, 39, 843-850.

Dionisio, L. F. S.; Araújo. H.X.; Correia. R. G.; Martins, W. B. R.; Costa, J. S.; Maciel, F. C. S. (2018). Influência do primeiro desbaste na morfometria de Tectona grandis L. f. em Roraima. Revista Floresta e Ambiente, 25(1): 8.

D'Oliveira, M. V. N. (2009). Regeneração florestal em clareiras artificiais após dois anos de abertura de dossel no Estado do Acre: Amazônia Ocidental. Embrapa Acre: Ciência e Tecnologia Para o Desenvolvimento Sustentável do Sudoeste da Amazônia; Gonçalvez, RC, de Oliveira, LC, Eds, 68-96.

Mattos, P. P., Braz, E. M., Hess, A. F., & de SALIS, S. M. (2011). *A dendrocronologia e o manejo florestal sustentável em florestas tropicais*. EMBRAPA, Doc218, p. 1-37.

Miranda, D. L. C., Higuchi, N., Trumbore, S. E., Latorraca, J. V. F., do Carmo, J. F., & Lima, A. J. (2018). Using radiocarbon-calibrated dendrochronology to improve tree-cutting cycle estimates for timber management in southern Amazon forests. *Trees*, 32(2), 587-602.

Carmo, J. F., Figueiredo Latorraca, J. V., Santos, G. C. V., Carmo, F. H. D. J., Miranda, D. L. C., & Lousada, J. L. P. C. (2018). Diametric growth and properties of *Copaifera langsdorffii* desf. by second cutting cycle. *Floresta*, 48(3), 435-442.

Durlo, M. A.; Denardi, L. (1998). Morfometria de Cabralea canjerana, em mata secundária nativa do Rio Grande do Sul. Ciência Florestal, Santa Maria, v. 8, n. 1, p. 55-66, nov.

Durlo, M. A. (2001). Relações morfométricas para Cabralea canjerana (Well.) Mart. Ciência Florestal, Santa Maria, v. 11, n. 1, p. 141-150, jun.

Finegan, B., Camacho, M., & Zamora, N. (1999). Diameter increment patterns among 106 tree species in a logged and silviculturally treated Costa Rican rain forest. *Forest Ecology and Management*, 121(3), 159-176.

Hasenauer H. (1997). Dimensional relationships of open-grown trees in Austria. For. Ecol. Manage. 96, 197–206

Hubbell, S. P. & Foster, R. B. (1986). Canopy gaps and the dynamics of a neotropical forest. In Plant Ecology (M.J. Crawley, ed.). *Blackwell Scientific*, Oxford, p.77-96.

Instituto Brasileiro de Geografia e Estatística. (2012). Manuais técnicos em geociências: manual técnico da vegetação brasileira. Rio de Janeiro, n. 1, 271 p.

Lima, E. L. (2012). Números e Funções reais. Coleção do Professor de Matemática, Sociedade Brasileira de Matemática, Rio de Janeiro. 107 p.

Lorenzi, H. (2009). *Árvores Brasileiras: manual de identificação e cultivo de plantas arbóreas nativas do Brasil*. vol. 2. Nova Odessa, Brazil: Instituto Plantarum de Estudos da Flora Ltda. 352p.-col. illus.. ISBN 8586714070

Nutto, L., Tonini, H., Borsoi, G. A., Moscovich, F. A., & Spathelf, P. (2001). *Utilização dos parâmetros da copa para avaliar o espaço vital em povoamentos de Pinus elliottii Engelm*. Boletim de Pesquisa Florestal, 42, 110-122.

Oliveira, M. D., & Braz, E. M. (1998). *Manejo florestal em regime de rendimento sustentado, aplicado à floresta do Campo Experimental da Embrapa-CPAF/AC*. EMBRAPA. 46 p.

Orellana, E., & Koehler, A. B. (2008). Relações morfométricas de Ocotea odorifera (Vell.) Rohwer. *Revista Acadêmica Ciência Animal*, 6(2), 229-237.

Resende, J. C. F., Klink, C. A., & Schiavini, I. (2003). Spatial heterogeneity and its influence on Copaifera langsdorffii Desf.(Caesalpiniaceae). *Brazilian Archives of Biology and Technology*, 46, 405-414.

Roman, M., Bressan, D. A., & Durlo, M. A. (2009). Variáveis morfométricas e relações interdimensionais para Cordia trichotoma (Vell.) Arráb. ex Steud. *Ciência Florestal*, 19, 473-480.

Sanquetta, C. R.; Watzlawick, L. F.; Balbinot, R.; Ziliotto, M. A. B.; GOMES, F. S. (2002). As florestas e o carbono. Curitiba: Ed. dos Autores, p. 119-140.

Selle, G. L., VUADEN, E. (2010). Crescimento de seis espécies nativas da região central do estado do Rio Grande do Sul. Ambiência, v. 6, n. 1, p. 169-192.

Souza, D. V., Carvalho, J. O. P.; Silva, M. F.; Oliveira M. L.; Silva, J. N. M.; & Silva J. F. C. (2014). Growth of *Manilkara huberi* and *Manilkara paraensis* after logging and silvicultural treatments in the municipality of Paragominas, Para, Brazil. *Floresta*, 44(3), 485-496.

Stampfer, E. (1995). Solitärdimensionen österreichischer Baumarten. Diplomarbeit. Universität für Bodenkultur, Wien. 102 p.

Tonini, H., & Arco-Verde, M. F. (2005). Morfologia da copa para avaliar o espaço vital de quatro espécies nativas da Amazônia. *Pesquisa Agropecuária Brasileira*, 40, 633-638.

Tonini, H., Kaminski, P. E., & Costa, P. D. (2008). Relação da produção de sementes de castanha-do-brasil com características morfométricas da copa e índices de competição. *Pesquisa Agropecuária Brasileira*, 43, 1509-1816.

Wadsworth, F. H. (2000). *Producción forestal para América tropical*. Departamento de Agricultura de los EE. UU., Serviço Forestal.