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ABANDONED PLANTATIONS OF *Hevea guianensis* Aubl. IN NATURAL FOREST IN THE BRAZILIAN AMAZON: METHODS FOR REVITALIZATION

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ABSTRACT: In the Tapajós National Forest, it is common practice to extract latex from rubber trees, and there are two large abandoned rubber plantations named Terra Rica and Seringal do Ponte, located in this conservation area. The objective of this research was to evaluate the dendrometric and silvicultural characteristics of the rubber trees as a way of providing subsidies for their reactivation. The data used were obtained from two 100% forest inventories, carried out in 2013 and 2018, and from a sampling to investigate the relationship of dendrometric, morphometric, and competition indices for tree diameters at 1.30 m above the soil, using the Pearson correlation index. 2,965 rubber trees were inventoried in 2013 and 2,927 in 2018, presenting a density of 97.9 trees.ha^{-1} and 96.6 trees.ha^{-1}, respectively. There was a difference between the total height and stem height of the rubber trees between the inventories; in diameter, the rubber trees remained the same and, in general, there were no problems of plant health in the plantations. To maintain productivity in the current settlement conditions, it is necessary to not surpass a maximum amount of 130 trees.ha^{-1}. Degree of insolation is one of the factors that affects latex production and rubber trees in abandoned plantations are predominantly shaded, suffer losses in panel quality and show high variability of the trees' diameters and heights. This suggests the need for thinning in the plantations in order to eliminate both trees that are thinner and that grow less, thus to favor the growth of the remaining rubber trees and elevate the production.

KEYWORDS: Amazon, Conservation unit, Forest management.

PLANTIOS ABANDONADOS DE *Hevea guianensis* Aubl. NA FLORESTA NATURAL DA AMAZÔNIA BRASILEIRA: MÉTODOS PARA REVITALIZAÇÃO

RESUMO: Na Floresta Nacional do Tapajós é comum a prática da extração de látex de seringueira e existem dois grandes plantios abandonados, denominados Terra Rica e Seringal do Ponte, localizados nessa unidade de conservação. O objetivo desta pesquisa foi avaliar as características dendrométricas e silviculturais das seringueiras como forma de fornecer subsídios para sua reativação. Os dados utilizados foram obtidos em dois inventários florestais 100%, realizados em 2013 e 2018, e em uma amostragem para investigar a relação dos índices dendrométricos, morfométricos e de competição para diâmetros de árvores a 1,30 m acima do solo, utilizando o índice de correlação de Pearson. Foram inventariadas 2.965 seringueiras em 2013 e 2.927 em 2018, apresentando uma densidade de 97,9 árvores.ha^{-1} e 96,6 árvores.ha^{-1}, respectivamente. Houve diferença entre a altura total e a altura do fuste das seringueiras entre os inventários; em diâmetro, os seringais permanecem iguais e, em geral, não houve problemas de fitossanidade nos plantios. Para manter a produtividade nas atuais condições do povoamento, é necessário não ultrapassar uma quantidade máxima de 130 árvores.ha^{-1}. O grau de insolação é um dos fatores que afeta a produção de látex e as seringueiras em plantios abandonados são predominantemente sombreadas, sofrem perdas na qualidade do painel e mostram alta variabilidade dos diâmetros e alturas das árvores. Isso sugere a necessidade de desbaste nas plantações, a fim de eliminar tanto as árvores mais finas quanto as que crescem menos, favorecendo o crescimento das seringueiras restantes e elevando a produção.

PALAVRAS-CHAVE: Amazônia, Unidade de conservação, Manejo florestal.

PLANTAS ABANDONADAS DE *Hevea guianensis* Aubl. EN EL BOSQUE NATURAL DE LA AMAZONIA BRASILEÑA: MÉTODOS DE REVITALIZACIÓN

RESUMEN: En el Bosque Nacional Tapajós, la práctica de extraer látex de caucho es común y existen dos grandes plantaciones abandonadas, llamadas Terra Rica y Seringal do Ponte, ubicadas en esta unidad de conservación. El objetivo de esta investigación fue evaluar las características dendrométricas y silvícolas de los árboles de caucho como una forma de otorgar subsidios para su reactivación. Los datos utilizados se obtuvieron de dos inventarios 100% forestales, realizados en 2013 y 2018, y en una muestra para investigar la relación de índices dendrométricos, morfométricos y de competencia para diámetros de árboles a 1,30 m sobre el suelo, utilizando el índice Correlación de Pearson. Se inventariaron 2.965 árboles de caucho en 2013 y 2.927 en 2018, con una densidad de 97,9 árboles.ha-1 y 96,6 árboles.ha-1, respectivamente. Hubo una diferencia entre la altura total y la altura del tallo de los árboles de caucho entre los inventarios; de diámetro, las plantaciones de caucho permanecen iguales y, en general, no hubo problemas fitosanitarios en las plantaciones. Para mantener la productividad en las condiciones poblacionales actuales, es necesario no superar una cantidad máxima de 130 árboles.ha-1. El grado de insolación es uno de los factores que incide en la producción de látex y los árboles de caucho en las plantaciones abandonadas son predominantemente sombreadas, sufren pérdidas en la calidad del panel y muestran alta variabilidad en los diámetros y alturas de los árboles. Esto sugiere la necesidad de raleo en las plantaciones, con el fin de eliminar tanto los árboles más delgados como los que crecen menos, favoreciendo el crecimiento de los árboles de caucho remanentes y aumentando la producción.

PALABRAS CLAVES: Amazonia, Unidad de conservación, Manejo forestal.

INTRODUCTION

The Brazilian forestry sector stands out in the national economy, being 1.1% of the National Gross Domestic Product (GDP) and 6.1% of Industrial GDP (IBÁ, 2019), as well as a significant participation in the international timber market. Exports in this industry have totaled around of US $ 206.4 billion (IPEA, 2019), especially in the segment of planted trees, for which Brazil has the highest levels of productivity in the world. Another relevant segment is that of products derived from plant extractivism, which guarantees the subsistence of numerous families in the interior of the country, moves local markets, and supplies large shopping centers, mainly in the Amazon (IBGE, 2016).

Among the products with economic, historical, and cultural importance is latex extracted in the Brazilian Amazon for at least two centuries. This has mainly pertained to the species *Hevea brasiliensis* Muell-Arg, belonging to the family Euphorbiaceae, of great natural occurrence in the region (SILVA, 2002). Rubber plantations represent a both renewable resource, however, the assurance that the production of natural rubber will be viable and result in profit is subject, in addition to the costs involved in production, to the quality and productivity of the trees, and these factors depend mainly on the management decisions of the rubber trees (PURNAMASARI et al., 2002).

The management of rubber plantations, in turn, should be planned based on the evaluation of these variables in order to obtain a characterization that subsidizes the prescription of suitable silvicultural treatments for two reasons: to reach the production in line with the potential of the area and guarantee a management with a basis for sustainable development (SILVEIRA et al., 2015; MENDONÇA et al., 2017; SOUZA et al., 2017; DOURADO et al., 2018; MEENAKUMARI et al., 2018). These evaluations are based on studies of dendrometric and morphometric characteristics and on the relationships between them, generating important metrics that can be used, for example, to define the optimum plant density (HESS, 2018).

In the Tapajós National Forest, a common practice among residents is the extraction of latex from native rubber trees, planted in the backyards or in areas destined for agriculture. In this conservation unit (UC), there are two large rubber plantations, surrounded for natural forest, called Terra Rica and Seringal of Ponte - remnants of the residents who lived in areas of the Tapajós National Forest. They are not occupied and were not compensated for their possessions in the 1970s - when the community began to plant rubber trees.

The management of the UC has granted authorizations for locals to serve as extractive dwellers to bleed in the rubber plantations of Terra Rica and Ponte, which consists of a superficial cut in the bark of the rubber tree, in order to extract the latex. The activity is carried out on a small scale and sporadically, without continuous use of the rubber plantations. As of 2011, the Flona Tapajós Mixed Cooperative (Coomflona), an economic entity formed by the residents who carry out the forest management in the UC decided to support the activity. This mediates the purchase and sale of the raw material and, thus, strengthens the extraction of latex, which is another working alternative for local residents.

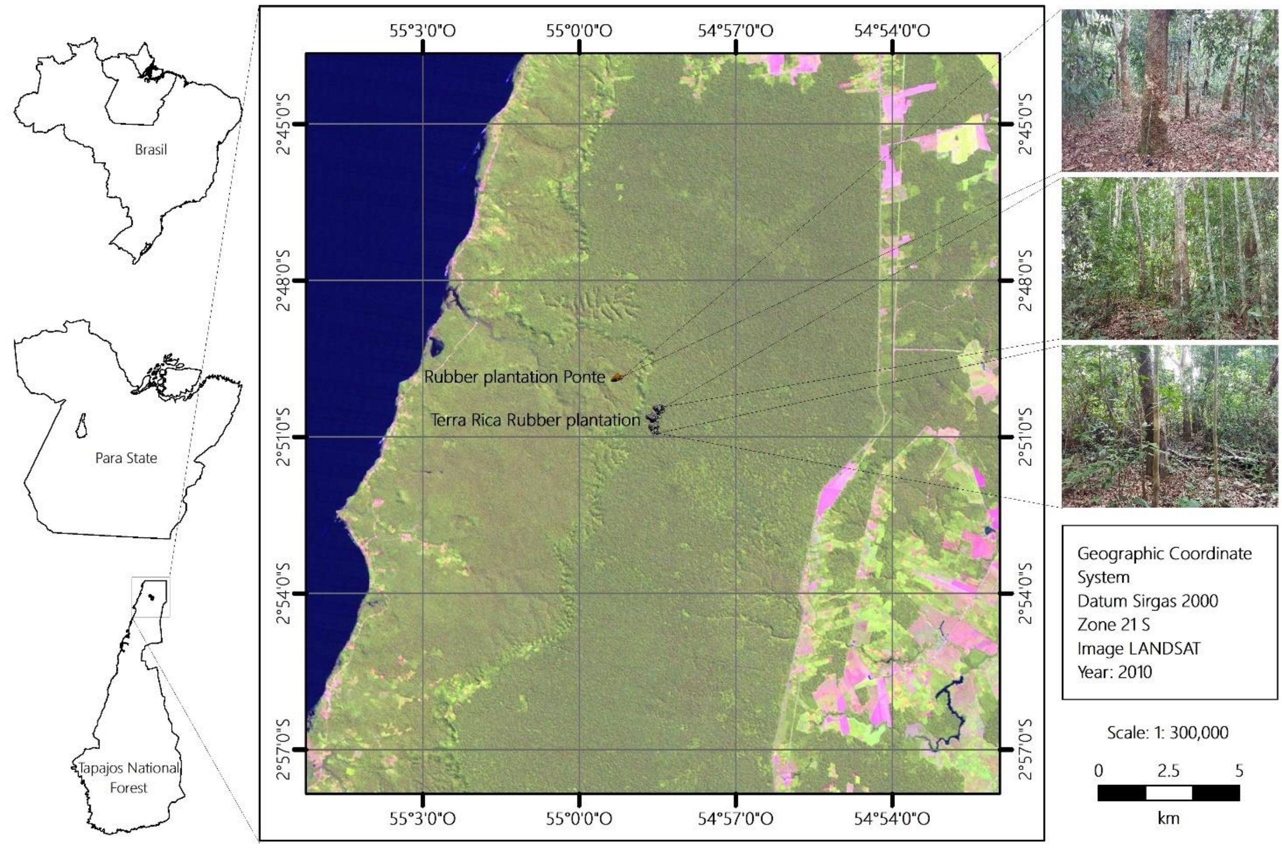
This research results from an integrated effort among cooperative residents and researchers that aims to provide subsidies for the management of *Hevea* in plantations, based on the experiences of the rubber plantations in Tapajós National Forest. Thus, the following scientific question arose: how to evaluate abandoned rubber tree plantations? The hypotheses tested were: H_0 = the evaluation through the relationship between the dendrometric, morphometric variables, the competition indices and the DBH is effective to characterize the structure of the rubber trees; H_1 = the evaluation through the relationship between dendrometric, morphometric variables, competition indices and DBH is not effective to characterize the structure of the rubber trees. The objective of this work was to evaluate the following: i) dendrometric and silvicultural characteristics of rubber trees; ii) growth of rubber trees under abandoned planting conditions; iii) morphometric indices and competition indices with the aim to establish the optimum density per hectare for the species.

MATERIAL AND METHODS

STUDY AREA

The study area comprises the rubber tree plantation in Terra Rica and Ponte, containing 27.41 and 2.90 hectares of extension, respectively: 02º50'08.96''S and 54º58'29.37''W. The distance between the plantations is approximately 1.5 km, both located in the Tapajós National Forest, municipality of Belterra in the western Pará state. Access to these sites is through a dirt road, near the kilometer (km) 67 of the BR 163 Highway, where there is a monitoring base of the UC approximately 10 km from the rubber plantations (Figure 1).

Figure 1. Map of the location of the rubber tree plantations in the Tapajós National Forest, Belterra, Pará.



Source: Elaborated by the author.

The climate of the region is of the Ami type, according to the classification of Köppen, which presents an average annual temperature of 25.5°C and average relative humidity of approximately 90% (ALVARES et al., 2013). The topography of the region varies from undulating to slightly undulating, the soil is characterized as Yellow Distrophic Latosol, and the vegetation is classified as Dense Ombrophylous Forest (IBAMA, 2004).

CHARACTERIZATION OF PLANTATIONS

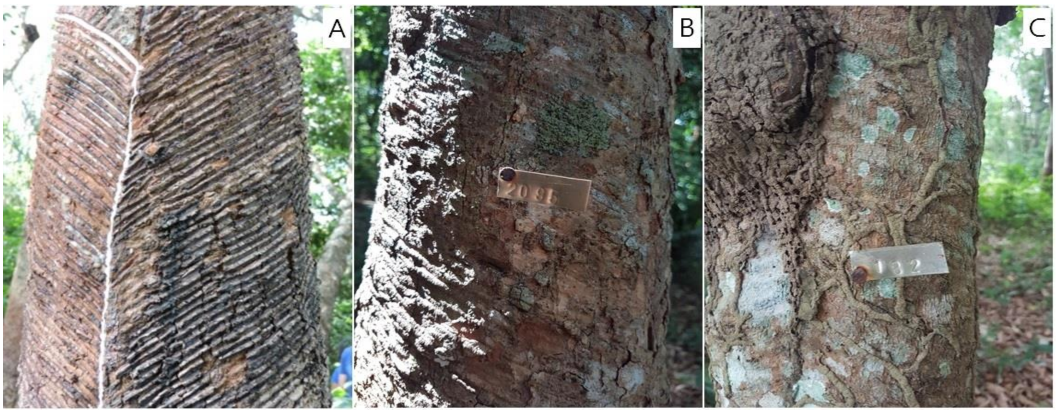
For the evaluation of dendrometric and silvicultural characteristics, two inventories were carried out, one in 2013 and the other in 2018, and during this time, there was no intervention in the rubber plantations. Quantitative and qualitative characteristics (Table 1) of all rubber trees with DBH (diameter measured at 1.30 m above the soil) ≥ 5 cm were measured in the inventories.

Table 1. Data collected in the first complete inventory of the rubber plantations.

Variable	Description
Total number of plants	Record the quantity and placement of aluminum plates in the trees.
CAP	Circumference measurement, in centimeters, at 1.30 m (DBH).
Total height	Height of the soil at the apex of the tree, in meters.
Stem height	Height of the ground at first bifurcation, in meters.
Crown lighting	Full illumination (1), Partial illumination (2), Shading (3) or Tree without crown (4).
Panel condition	Good condition (1), Average condition (2), or Poor condition (3).

The panel is the portion of the shaft used in the bleed and is classified as: in good condition when there is no knots or accumulation of rubber along the cutting area (Figure 2A); average condition when it presents some nodes and accumulation of rubber, but that does not impel the flow of latex during the bleeding (Figure 2B); and poor condition, when weed and rubber accumulation along the cutting area and the occurrence of pests and diseases is significant and limits the flow of latex, blocking or delaying bleeding (Figure 2C).

Figure 2. Representation of panel condition categories in Good condition (A), Average condition (B) or Poor condition (C).



Source: Elaborated by the author.

The rubber trees were also classified according to the shape of the crown, according to Silva and Lopes (1984), described in Table 2. The occurrence of diseases and pests was also observed to evaluate the sanity of the rubber trees.

Table 2. Classification of crown shape, adapted from Silva and Lopes (1984).

Crown shape	Description
Normal full crown	Tree showing the full and well distributed crown (1).
Irregular full crown	Tree with full crown, but poorly distributed, due to natural factors such as, growth towards areas with higher incidence of light (2)
Incomplete crown	Tree that lost part of the crown because of natural causes or exploitation (3).
Regrowth	Crown in process of regeneration, after severe damage as the pickling (4).
Without crown	Tree without crown, knocked down by other trees because of forest exploitation or natural causes. (5).

Botanical collection was carried out to identify the species present in the planting, according to traditional methods of exsicata mounting, pressing, and preservation for further botanical identification according to the methods of Ming (1996). Each material was herborized with the aid of a press and newspaper and taken to a greenhouse with a temperature of 60°C for 72 hours to dry the material. After identification, the samples were incorporated into the herbarium of the Federal Rural University of Amazonia (Ufra), located in Belém in the state of Pará under registry 3441.

To compare the quantitative variables between the measurements, the rubber trees registered in both the first and the second inventory were selected, and the paired t-test was applied at 95% probability.

The diametric structure was analyzed by means of frequency histograms with class intervals of 10 cm (GAMA et al., 2017). To compare the diametric distributions between the five years, the chi-square test was applied, at a significance level of 0.05. The sociological position was used to describe the structure of the plantations, considering the stratification by total height, based on the mean and the standard deviation of the total height of the trees, being: bottom stratum = $Ht < (\overline{H} - 1s)$; medium stratum = $(\overline{H} - 1s) \leq Ht < (\overline{H} + 1s)$; upper stratum = $Ht \geq (\overline{H} + 1s)$, where $\overline{H}$ = Average total height, Ht = Total height, and s = standard deviation of the total height (SOUZA; SOARES, 2013).

For the dendrometric characterization of the rubber trees, the arithmetic means of the diameters ($\bar{d}$), the mean square diameter (q), the basal area per hectare (G), and the mean total height ($\bar{H}$) were calculated.

COMPETITION AND MORPHOMETRIC INDICES

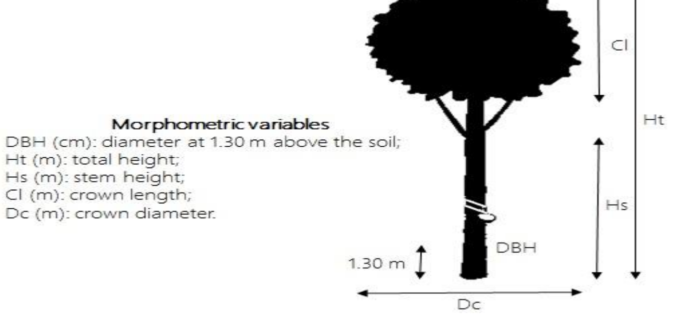
To characterize the morphometric indices and the competition indices, 103 trees were randomly sampled, covering the diametrical amplitude of the planting (5.0 cm ≤ DBH <97.0 cm) that were identified as the primary trees, according to the methodology by Silveira et al. (2015).

The sample size was determined based on the variability of latex production, considering the study population as a finite population, according to Soares and Paula-Neto (1997).

Each primary sampled tree had the following measured variables: total height and stem height measured in meters with a TruPulse 360 hypsometer; CAP - obtained with the help of graduated scale, in millimeters, and converted into DBH; crown diameter - obtained by the measurement of eight crown radiuses, using the TruPulse 360 hypsometer laser beam, in meters, taking the tree as a point of origin and distancing to the extreme projection point of the crown, according to the adapted methodology of Condé et al. (2013). The first radius was taken from the north cardinal point and the following measured in the sequence: northwest, west, southwest, south, southeast, east and northeast, determined with the aid of a compass.

The crown length was determined by the difference between total height and stem height. The following morphometric variables were presented in Figure 3 (SILVEIRA et al., 2015; SILVA et al., 2017):

Figure 3. Representation of total height and stem height, crown length and crown diameter.



Source: Elaborated by the author.

(a) Crown diameter: calculated at twice the arithmetic mean of the eight crown radiuses measured:

$$Dc = 2\overline{Rc} \qquad \overline{Rc} = \frac{\sum_{i=1}^{n} Rc_i}{n} \qquad \text{(Eq. 1)}$$

Where: Dc = crown diameter, in meters; Rc_i and $\overline{Rc}$ = crown radius and arithmetic mean of crown radius in meters, respectively.

The crown diameter refers to the distance between the projection lines of the outermost points of the tree crown (DURLO; DENARDI, 1998).

b) Crown projection area: calculated using the median crown radius:

$$Sc = \pi\overline{Rc} \qquad \text{(Eq. 2)}$$

Where: Sc = crown projection area, in m².

Crown projection area refers to the surface covered by the vertical projection of the tree crown, usually calculated from the measurement of four to eight projection radiuses of the crown (DURLO; DENARDI, 1998). This index allows to know the space occupied by the tree (SILVA et al., 2017).

c) Crown percentage:

$$Pc = \frac{Cc}{Ht} \times 100 \qquad \text{(Eq. 3)}$$

Where: Pc = Crown percentage; Cc = crown length, in meters; Ht = total height of the tree, in meters.

The ratio of crown length to total tree height determines the extension of the stem, referring to crown, that is, the percentage of stem with crown needed to maintain tree vital health (SILVA et al., 2017).

d) Formal crown:

$$Fc = \frac{Dc}{Cc} \quad \text{(Eq. 4)}$$

Where: Fc = formal crown, in meters.

The formal crown denotes the degree of flattening of the crowns, being characterized as slender crowns when presenting values below 1 and as flattened crowns when they present values above 1. A lower index results in higher productivity of the tree (SILVA et al., 2017). In general, the lower the value of this index suggests greater influence of the neighboring trees on the lateral expansion of the crown of the sampled tree (CUNHA; FINGER, 2013).

e) Slenderness Degree:

$$GE = \frac{Ht}{DAP} \times 100 \quad \text{(Eq. 5)}$$

Where: GE = Slenderness degree.

The slenderness degree indicates the instability against the wind, and a taller tree makes it more susceptible (SILVA et al., 2017; CARMONA et al., 2018). The decrease in the degree of slenderness, together with the increase in height of the trees indicates that for each meter that grows in height, they grow more than one centimeter in DBH, becoming more stable and robust (DURLO, 2001).

f) Coverage index:

$$IA = \frac{Dc}{Ht} \times 100 \quad \text{(Eq. 6)}$$

Where: IA = coverage index.

The coverage index is determined by the relation between crown diameter and total tree height (DURLO; DENARDI, 1998). This index indicates the need for space by the tree with the increase in total height, that is, for a same height, the tree that presents greater crown diameter will reach greater space (WEDGE; FINGER, 2013).

g) Salience index:

$$IS = \frac{Dc}{DAP} \times 100 \qquad \text{(Eq. 7)}$$

Where: IS = Salience index.

The salience index determines the vigor between trees of the same diameter and indicates the space required for growth as the tree grows in diameter. Moreover, the reduction of the index may suggest that the individual is under strong competition (CUNHA; FINGER, 2013).

Considering the average of the salience index and crown diameter as constant, the optimum density per hectare was determined, according to Silva et al. (2017):

$$NO = \frac{IS * DAP}{Dc} \qquad \text{(Eq. 8)}$$

Where: NO = optimal tree number per hectare.

Each sampled tree had distances measured with a laser beam to neighboring and competing trees, which had their total heights and DBH measured, to quantify the competition by calculating the competition indices, dependent and independent of the distance for each sampled tree (Table 3).

As a criterion for defining neighboring and competing trees, the methodology of Santos et al. (2015), who studied neighboring rubber trees closest to the primary trees and competing trees, consisted of neighboring trees that had a larger circumference at 1.30 m above the soil when compared to the primary tree.

The relationship between morphometric variables and competition indices with DBH was investigated. Pearson's correlation coefficient (r) was used to investigate the existence of a relationship between morphometric variables and competition indexes with the growth of rubber trees.

Table 3. Competition indices used in the determination of competition in abandoned rubber plantations in the Tapajós National Forest, Belterra, Pará. Adapted from Silveira et al. (2015).

Index	Equation	Relation to distance	Source
BAL (Bal_i)	$Bal_i = \sum_{j=i}^{n_j} G_j$	Independent	Davis (2001)
Glover e Holl (GH_i)	$GH_i = {d_i^2}/{\bar{d}^2}$	Independent	Husch et al. (2003)
Hegyi (H_i)	$H_i = \sum_{j=1}^{n_j} \frac{\left({d_j}/{d_i}\right)}{l_{ij}}$	Dependent	Gadow and Hui (1999)
Ratio height / distance (RHLi)	$RHL_i = \sum_{j=1}^{nj} {h_j}/{l_{ij}}$	Dependent	Husch et al. (2003)

n: number of competing trees; Gj: basal area of competing trees (m²); di: DBH of the primary sampled tree (cm); $\bar{d}$: Mean DBH of neighboring trees (cm); dj: DAP of competing trees (cm); lij: distance between primary sampled tree i and competing tree j (m); hj: total height of competing trees (m); i: order number of the primary tree; j: order number of the competing tree.

RESULTS AND DISCUSSION

In 2013, 2,965 rubber trees were inventoried and, in 2018, 2,927 were recorded, indicating a density of 97.9 trees.ha^{-1} and 96.6 trees.ha^{-1}, respectively. In the second inventory, the death of 56 rubber trees was recorded, and 44 recruitments were registered. In addition, 26 trees inventoried in 2013 and not located in 2018 were categorized as not found.

Plantation density is a determinant factor of production for the *Hevea* genus. There is a record that this variable correlates significantly with its morphometric characteristics and is strongly influenced by forest management (NAJI et al., 2012). The evaluated rubber plantations are unmanaged, and the density found is lower than that observed by Gama et al. (2017), which evaluated the density of randomly planted rubber plantations in Jamaraquá, Belterra municipality, a river community closest to the Terra Rica and Seringal of Ponte in the Tapajós National Forest. The authors recorded a density of 285.6, 307.6, and 210.3 trees.ha^{-1} in Terra Firme areas in the hills, in the backyard, and igapó, respectively.

However, in the Jamaraquá community, plantations are older because the "rubber economy" in the region occurred within economic cycles, and the Belterra region was extensively used, since the municipality was founded as a village with the primary objective of latex production to meet the demands of the external market (SILVA et al., 2016). In addition, the Jamaraquá rubber plantations are active and bring together the oldest rubber tappers, and the production of latex is an important source of income for the community.

In 2018, the average total height of rubber trees was lower than in 2013, and the minimum and maximum values of this estimate were lower than the first inventory. This result is attributed to the occurrence of mortality and recruitments in plantations. In addition to mortality and recruitments, it is noteworthy that different inventory teams estimated the height variable and, therefore, an estimation error must be considered. Regarding the stem height, there was an average increase of approximately one meter between the inventories (Table 4).

The heterogeneity among the trees, indicated by the variability of the diameters and heights in the rubber plantations, showed that although they are cultivating rubber trees, the rubber trees of Terra Rica and Ponte present high variability, which is characteristic of poorly formed or conducted settlements according to Scolforo (2005).

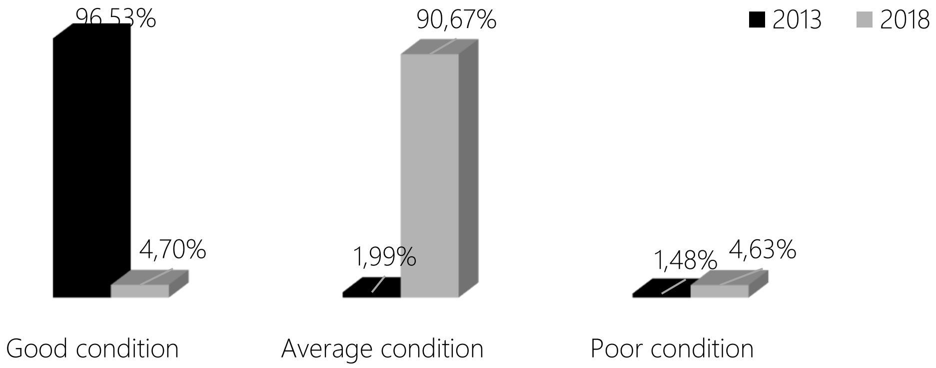
Table 4. Descriptive statistics of DBH, total height, and stem height variables for in the Tapajós National Forest, Belterra, Pará.

Descriptive Measures	DBH (cm)		Total height (m)		Stem height (m)	
	2013	2018	2013	2018	2013	2018
Arithmetic Mean	35.68	36.55	18.39	15.73*	5.96	6.86*
Minimum	6.68	10.50	5.00	3.00	1.00	1.00
Maximum	89.13	96.77	36.00	29.00	25.00	20.00
Standard deviation	11.44	11.82	5.41	3.76	3.27	3.31
Coefficient of variation	0.32	0.32	0.29	0.24	0.55	0.48

Where: DBH is the diameter at 1.30 m above the soil; * represents a significant difference by paired t-test at 95% probability.

As for the percentage of illumination of the crowns, the greatest variation between the inventories of 2013 and 2018 occurred between the shaded trees, which went from 23.3% to 19.5%, respectively. The percentage of partially illuminated rubber trees increased from 75.8% to 79.3%. Fully illuminated trees rose from 0.9% to 1.2%. It was observed that the rubber trees are predominantly shaded. This result is relevant, considering that the degree of insolation is one of the factors that affects latex production, noting that co-dominated trees are the most productive (GAMA et al., 2017). There is a negative correlation between latex production and radiation, and although light is essential as a primary source of energy in photosynthesis and, therefore, in latex production, light or sun promotes transpiration and makes water a limiting factor (CONFORTO et al., 2005). In addition to changes in lighting, rubber trees suffered losses in panel quality (Figure 4).

Figure 4. Percentage of panel condition of the rubber trees inventoried in 2013 and 2018 in the Tapajós National Forest, Belterra, Pará.



Source: Elaborated by the author.

The loss in the panel condition quality between 2013 and 2018 is a consequence of the abandonment of the plantations. The results indicate that although the panel is well done, if one spends a lot of time without cutting regularly, the quality is gradually reduced. The rubber tappers themselves say "once bled, it always has to be bled. In active plantations, silvicultural activity and interventions prevent the presence of pathogens, and adequate management of the plantations allows for good regeneration capacity of the panels, which favors the continuity of production (GONÇALVES; FONTES, 2009).

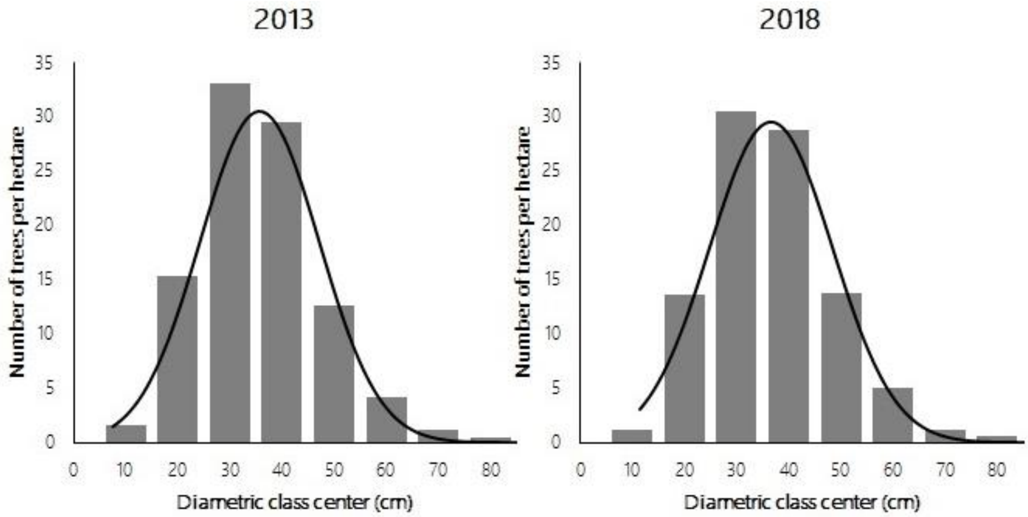
Regarding the shape of the crown, it was observed that the majority (67.29%) of the rubber trees have a normal or irregular full crown. Only 0.08% of the trees presented no crown. Considering that the plantations are abandoned, this result is positive, since trees whose crowns are well-formed usually show higher growth than those with incomplete or poorly distributed crowns (ZIMMERMANN et al. 2016; WEBER et al. 2018).

In general, there were no health problems in the plantations. Only 15 trees (0.51%) presented signs of disease, whose diagnosis indicated rotting and five trees that presented plague symptoms. As for the botanical identification, the occurrence of the species *Hevea guianensis* Aubl. was verified. The evaluation of the plantation health showed that although they are abandoned and are maintenance free, the plantations remain healthy, since less than 1% of the rubber trees presented disease or pests. This result is extremely satisfactory, since disease resistance is a limiting factor for latex production (GONÇALVES et al., 2002).

Most of the problems investigated by studies on genetic improvement in rubber plantations are disease and pest control and some point to the defense mechanisms of the plant itself as one of the main control methods (FURTADO et al., 2008). The Terra Rica and Ponte rubber plantations are located in the middle of the forest and without interventions, and these characteristics created a favorable condition for the self-defense of rubber trees. This resulted in good sanitation of the plantations, due to the relationship between the plantations and the forest, which could be observed through the few structural changes in the rubber plantations.

The plantations presented a low number of individuals in the lower diametric classes and a high frequency in the intermediate classes, noting a marked reduction in the larger classes in both 2013 and 2018 (Figure 5). No significant difference was detected between diametric measurement structures ($p = 0.0857$, in the chi-square test with a significance level of 5%).

Figure 5. Diametric distribution of rubber trees in 2013 and 2018 for abandoned plantations in the Tapajós National Forest.



Source: Elaborated by the author.

The diameter distribution of the rubber trees corroborated the results of Gama et al. (2017) for rubber trees grown in Jamaraquá and Araújo et al. (2018) for rubber plantations in the region of the Middle Amazon. Those characteristics do not fit as the traditional native rubber plantations of the Amazon, and neither are like the conventional plantations that are similar to the area under study. The distribution pattern found is characteristic of this forest type, unlike native populations, where this distribution would indicate an imbalance between mortality and recruitment, caused by probable disturbances (LIMA; LEÃO, 2013).

Considering the stratification by total height, the structure of the plantations remained similar between the inventoried years. Most trees were concentrated in the middle stratum in both the 2013 stratum (medium stratum = 12.97 <Ht <23.80) and that of 2018 (medium stratum = 11.97 <Ht <19.50). Although the rubber plantations were without silvicultural treatments, some trees moved from the lower to the middle stratum, indicating that there was growth in total height of the trees. During the second inventory, the fall of trees and crown opening were observed in certain points, which probably favored the growth in height of these trees, since the formation of small clearings favors the climax species and fills the crown with lateral growth (JARDIM et al., 2007).

Regarding the dendrometric variables evaluated, an increase was observed in relation to the mean square diameter, which increased from 37.5 cm in 2013 to 38.4 cm in 2018. A small variation was also observed in the basal area per hectare, which increased from 10.8 $m^2.ha^{-1}$ to 11.0 $m^2.ha^{-1}$ in the rubber trees. In comparison to the dendrometric characterization performed by Siqueira et al. (2017), the authors found similar or inferior means sampling 928 rubber trees composed of genetically improved clones, analyzing a 10 hectares plantation of *Hevea brasiliensis* with 25 years of implantation that was located at the Central Experimental Center of the Agronomic Institute in Campinas, São Paulo.

The mean values of the morphometric variables are presented in Table 5. The data shows the heterogeneity among the trees sampled, indicated by the variability of the diameters and heights. The analysis of morphometric indices is a good indicator of thinning and competition in plantations, providing results for silvicultural practices (SILVA et al., 2017).

The relation between crown diameter and DBH is called the projection index, which influences the free space around each tree in order to occupy space more efficiently and has a ideal area for crown projection (ORELLANA; KOEHLER, 2008; SILVEIRA et al., 2015). The reduction of the salience index with the increase in diameter was observed in the plantations, which according to Silva et al. (2017), indicates the need to perform thinning in the settlement.

The lack of significant diametric decrease demonstrated the need for silvicultural treatments so that the production activities in the plantations can be continued. According to Durlo and Denardi (1998), in areas with mixed and unequal population characteristics such as the rubber plantations under study, it is possible to use the salience index to determine the space to be maintained around a tree and optimize its growth without competition. This variable can therefore be used as a thinning indicator.

Table 5. Morphometric variables of the primary sampled trees in the abandoned rubber plantations in the Tapajós National Forest, Belterra, Pará.

Variable	DBH Category Counts								Average
	10	20	30	40	50	60	70	≥ 80	
Nº of trees	1	13	22	22	28	10	5	2	-
DBH (cm)	15.9	22.7	30.7	40.8	50.1	60.8	69.8	78.6	46.2
Total height (m)	10	14.2	14.3	18.2	18.3	21.2	22.0	21.0	17.4
Stem height (m)	8.9	10.8	5.4	6.0	4.7	6.1	5.5	6.3	6.7
Crown length (m)	1.0	3.2	4.6	7.4	7.1	8.7	11.0	8.0	6.4
Crown diameter (m)	13.5	9.4	11.0	11.1	12.2	13.2	12.9	13.9	12.2
Crown Projection Area (m^2)	143.1	81.0	102.7	106.9	127.9	144.9	133.4	156.6	124.6
Crown percentage (%)	10.0	20.8	29.9	40.1	39.1	41.2	50.3	38.0	33.7
Formal Crown	13.5	5.5	3.8	1.7	2.0	2.3	1.2	1.8	4.0
Slenderness Degree	62.8	63.3	46.9	44.8	36.7	35	31.6	26.7	43.5
Coverage Index	1.4	0.7	0.8	0.6	0.7	0.6	0.6	0.7	0.8
Salience Index	84.8	41.8	36.5	27.3	24.7	21.7	18.5	17.7	34.1

The salience index found for the plantations is considered high (mean = 34.13). In the studies carried out by Tonini and Arco-Verde (2005), andiroba (*Carapa guianensis*), castanheira-do-Brasil (*Bertholletia excelsa*), ipê-roxo (*Tabebuia avellanedae*), and jatobá (*Hymenaea courbaril*) were recorded, varying from 14.7 to 50.3, and indicated high competition at a value of 25 and higher for these four species native to the Amazon.

Considering the general average found for the salience index, the maximum optimum density of the plantations is 130 trees. ha^{-1}, so there is no crown competition. In order to avoid possible increased losses and, consequently, lesser productivity of the rubber trees when considering the general average found for the salience index, it is necessary to maintain a maximum amount of 130 trees. ha^{-1} to avoid competition by crown.

Regarding the crown percentage, the values ranged from 10.00% to 37.95%, presenting a general average of 33.66%, and this indicates that the rubber trees in the studied plantations with an average total height of 17.41 m have approximately 6.37 m in crown height. According to Silva et al. (2017), this percentage refers to how much of the total height of the rubber trees is intended for tree distribution, vitality, and productivity, since the interdimensional relationships of the trees infer the space necessary for their growth, influencing the competition in the plantation (DURLO, 2001).

The formal crown index expresses the photosynthetic capacity, that is, the productivity of the tree (WEDGE; FINGER, 2013). In the rubber plantations, the average crown was 3.98, ranging from 1.23 to 13.50, with flattened crowns. This index consists of the relationship between crown diameter and crown height and serves as a criterion for the definition of thinning, indicating that lower values result in higher productivity for the same species and site (DURLO; DENARDI, 1998).

Low values of slenderness indicate that trees are growing more in diameter than in height (TONINI; ARCO-VERDE, 2005). In the rubber trees evaluated, this index ranged from 26.71 to 62.83 among the diametric classes, demonstrating that in the highest classes of DBH, trees grow more in diameter than height and, in the lower classes, are the most unstable trees that break in the wind. Thus, it can be stated that *Hevea guianensis* is susceptible to the action of the wind, a diagnosis verified in the field when after a strong wind occurred in the first semester of 2018, some fallen trees were found, probably knocked down by the wind.

The coverage index, determined by the relation between crown diameter and total tree height (SILVA et al., 2017), ranged from 0.61 to 1.35 among diametric classes. These results are superior to those found by Carmona et al. (2018) when evaluating the morphometric variables of planted rubber trees for an agroforestry system in Monte Alegre, Pará state.

According to Finger (1992), tree growth is influenced by genetic factors of the species, which interact with environmental factors, with soil characteristics, and also with biological factors such as competition. In the rubber plantations, the absence of significant growth is also the result of competition, which was confirmed by the distance-dependent indices. Both the Hegyi index (H_i = 0.27) and the height-to-distance ratio (RHL_i = 3.41) of the competing trees have demonstrated the existence of competition, indicating that the primary sampled trees suffer great competition from neighboring trees. The higher these values and the greater the proximity of neighboring trees results in their greater influence on the growth of the sampled tree.

Regarding the competition indices for distance, the Glover and Hool index also signaled the existence of competition in the rubber plantations. A higher value suggests the primary tree has less competitors, that is, the less competition is suffered, as Silveira et al. (2015) found GH_i = 0.6 for *Trichilia claussenii*. This value is lower than that found for *Hevea guianensis* in the present study (GH_i = 1.40), thus inferring that the trees of this species are influenced by the growth of neighboring trees. When evaluating a plantation of *Ocotea porosa* implanted in 1967 in Paraná, Santos et al. (2015) confirmed that this value indicates a high degree of competition, as its growth was influenced by the neighboring trees with a value of 1.29 for the Glover & Hool index, which is inferior to the one found for *Hevea guianensis* in the plantations.

Only the BAL index (Bal_i = 0.24) indicated a low influence of the competition in the plantations, since a higher BAL index suggests more competition for the tree (SILVEIRA et al., 2015). However, this index was not very efficient in explaining the competition conditions in the rubber plantations under study.

The results of the Pearson correlation analysis of the DBH with the morphometric variables and the competition indices for the plantations are presented in Table 6. The results presented significant coefficients with a degree of slenderness (r = -0.7045) for the DBH. The negative sign indicates that a higher DBH will result in a lower degree of slenderness.

In general, none of the competition or morphometric indices showed a significantly strong correlation with the DBH of the rubber trees, and the degree of slenderness presented the highest index with a moderate negative correlation. The more unstable trees, that is to say, with a greater degree of slenderness, are concentrated in the smaller diametric classes. This suggests the need for thinning in the plantations in order to eliminate both trees that are thinner and that grow less, thus to favor the growth of the remaining rubber trees and elevate the production.

Table 6. Pearson correlation coefficients between morphometric variables and competition indices with DBH for *Hevea guianensis* Aubl. in abandoned rubber plantations in the Tapajós National Forest, Belterra, Pará.

Variable	r
Crown height (m)	0.5286*
Crown diameter (m)	0.2115*
Crown projection area (m²)	0.1903^{ns}
Crown percentage (%)	0.3944*
Formal Crown	-0.4215*
Slenderness Degree	-0.7045*
Coverage Index	-0.2676*
Salience Index	-0.6142*
Bal_i	0.3896*
GH_i	0.6853*
H_i	-0.5710*
RHL_i	0.1891^{ns}

Where: r: Pearson's linear correlation coefficient; Bal_i: BAL index; GH_i: Glover and Holl index; H_i: Hegyi index; RHL_i: relationship between height of competing trees and distance between primary sample tree i and competing tree j; i: order number of the primary tree; j: order number of the competing tree; ns: value of r with non-significant probability; *: significant r values at 5% probability.

CONCLUSION

Evaluation of the relationship between the dendrometric variables, morphometric variables, the competition indices, as well as the DBH, was effective to characterize the structure of the rubber trees.

Degree of insolation is one of the factors that affects latex production and rubber trees in abandoned plantations are predominantly shaded, suffer losses in panel quality and show high variability of the trees' diameters and heights. This suggests the need for thinning in the plantations in order to eliminate both trees that are thinner and that grow less, thus to favor the growth of the remaining rubber trees and elevate the production.

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