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Volumetric space distribution of wood as a tool in sustainable forest

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The objective of this work was to evaluate the distribution of forest volume identified through interpolation maps from data obtained from the forest. We sampled 36 plots with 1-ha area. Special maps were used by means of interpolation adjusted by the Spline method. The results indicate that after 20 years of traditional exploration, no significant oscillations were identified for volumes. However, the area explored showed a significant recovery in the total volume in this period. In addition, it showed the appearance of new species that contributed to the increase of biodiversity. This influenced the growth rates of the trees, the establishment of natural regeneration, the growth of seedlings and sticks. These will replace the losses occurring during the exploration and the increase in carbon sequestration. It should be emphasized that this method proved to be efficient in determining points of greater volumetric distribution and consequent forest recovery.

Key words: Geotechnologies, spatial distribution, forest volumetric.

INTRODUCTION

Brazil has the second largest forest area in the world and covers an area of approximately five million square kilometers (km²) situated in the Legal Amazon, which corresponds to approximately 65% of the national territory. Of this total, 3.3 million km² are wet tropical forests, destined to the sustainable exploitation, regulated

by a cycle of cut of 30 years (Higuchi et al., 2008).

Reduced impact exploration is carried out through forest management techniques, and the elaboration of the forest management plan is necessary.

It is necessary to analyze the logging maps and the volumetric distribution as a tool to know the efficiency of

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the management plan, if wood volume recovered after logging and future logging in the area.

Muñoz Braz et al. (2005) comments that the cutting cycle, the remaining stock and the periodic annual increment (IPA) of the species are the main factors to determine the annual extraction rate in a stand and the intensity of the forest cut, but are not taken into account before their exploitation, which implies a possible increase in the cutting cycle for the next harvest.

On the other hand, there is an intense process of deforestation and over-harvesting contributing to the growing decline in the demand for forest products in the world (Bradshaw et al., 2010). This event has increased the valorization of these species and consequently the exploratory pressure on individuals below the limit allowed for cutting, as well as the deforestation in the Amazon region. Thus, it becomes necessary to implement public policies as a mechanism to reduce this degradation left by forest overexploitation, deforestation and forest fires (Fonseca et al., 2015).

In terms of sustainable exploitation Brandelero et al. (2007) argued that interventions aimed at more accurate silvicultural treatments have been sought to achieve maximum yield according to the potential of species and other local environmental factors. Those measures contribute to reducing impacts to ecosystems, since the biodiversity of tropical forests undergo several changes in its structure due to the dynamics of growth, mortality and or exploitation of these species. Knowing the spatial distribution of the forest species of their volumetry will require the adoption of new tied tools, so that the forest inventory is carried out with precision.

For Ortiz et al. (2006), the techniques of geoprocessing assume great importance in the study of the identification and correlation of variables that affect the forest productivity through operations in Geographic Information Systems (GIS) associating these variables in the form of digital maps enabling a precision forestry. Remote sensing is an important tool that can support estimating and monitoring forest resources (Turner et al., 2003; Zolkos et al., 2013).

It is necessary to apply alternative techniques in obtaining data and even providing a complementary analysis of the dynamics of forest exploitation. In this context, geotechnologies can contribute to obtaining information quickly (before, during and after forest disturbance), with relative accuracy and low cost, contributing to the monitoring, planning and decision making of the forest manager (Facco et al., 2016).

Among the available options, we can highlight the vegetation indices obtained by red and infrared spectral bands close to the images obtained by orbital sensors, the most common being the normalized difference vegetation index (NDVI), which allows us to gather information about the amount of green biomass, vegetation growth and development (Martins and Silva, 2014).

Taylor et al. (2006) defined precision forestry as the planning and conduction of a particular site of the forest with the management of forestry activities and operations aimed at improving the quality and use of wood, reducing waste, increasing profits and maintaining the quality of the environment. The knowledge of the qualitative variables of a native forest, associated to geotechnologies with new tools of registries of maps with specialized information, has contributed to the sustainable planning of the use of the forest resources within the forest inventory (Souza et al., 2007).

Thus, this study aimed to evaluate the distribution of forest volume identified through interpolation maps, based on data obtained from the forest inventory. It is hypothesized that monitoring a forest scenario through interpolation maps applied to the forest inventory is capable of assessing forest production capacity in a given area, thus making forest exploitation more accurate.

MATERIALS AND METHODS

Characterization of the experimental area

The study area is located at Morro do Felipe, in the municipality of Vitória do Jari, Amapá State, at the coordinates (0°00'55 "S and 5°20'20" W) registered from January 8 to 16, 2012. The experimental area (Figure 1) presents a forest ecosystem of the Ombrophyllous Dense Forest type and type Am climate, by classification of Köppen.

The average annual precipitation reaches 2,234 mm with a rainy period from December to May. A dry season of three months occur that begins in June and that is characterized by a monthly precipitation inferior to 8% of the annual volume of rain. The average annual temperature is 25.80°C with the thermal amplitude varying more or less 20°C between the maximum and the minimum monthly value. The soils are of the Yellow Latosol type Dystrophic with heavy clayey texture (Azevedo et al., 2008).

Study area history

Over 27 years of monitoring (1984, 1985, 1986, 1988, 1990, 1994, 1996, 2004 and 2011) Jari's 36 ha experimental area underwent three interventions that led to a reduction in basal area, where statistical analysis was performed to compare volumes between periods.

In 1983, a forest inventory was carried out considering all trees with Chest Height Diameter (DBH) \geq 50 cm. In 1985, forest exploitation (1st intervention) occurred in the primary forest area removing 15, 25 and 35% of the total volume of trees with DBH \geq 50 cm, corresponding to approximately 25, 40 and 60 m³/ha, respectively. Trees with DBH \geq 60 cm from 26 species of commercial value in the region were explored. In 1990, there was a gale (natural phenomenon) that felled several trees (2nd intervention). Silvicultural treatment was carried out in 1994 by applying two types of thinning: systematic thinning, with two intensities of reduction of the original basal area (30 and 50%), and selective thinning (Carneiro et al., 2019).

Experimental design and data collection

Exactly 36 plots of one-hectare area (100 m \times 100 m) were sampled.

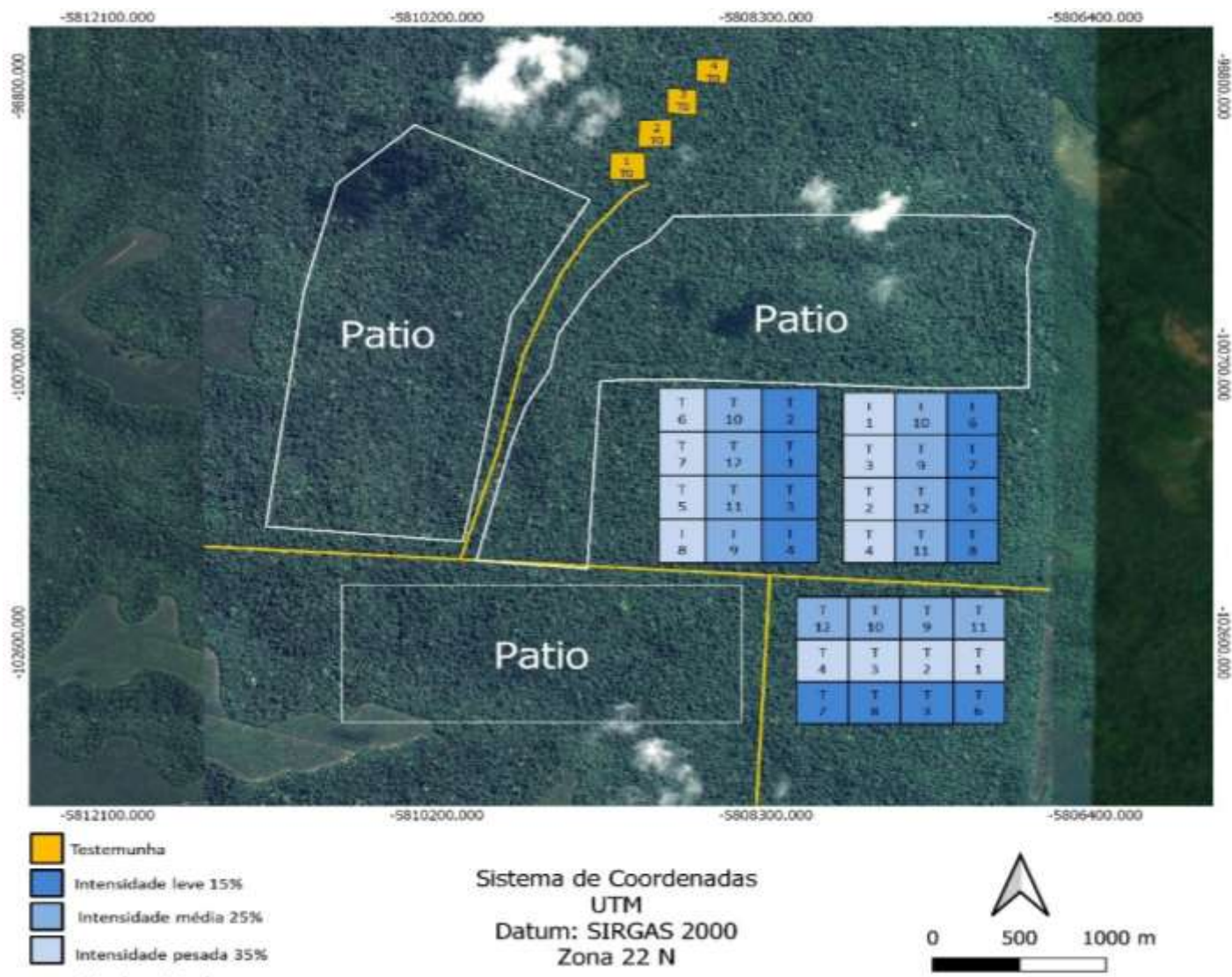


Figure 1. Location of the experiment and distribution of the plots and their respective repetitions of the 12 silvicultural treatments applied, presenting different combinations of intensity of exploration and thinning.

The legend classification was performed using the "natural breaks" method distributed in four color classes classified in low volumetry (blue color: 25-30 m³. ha⁻¹), medium volumetry (green color: 30-35 m³. ha⁻¹), moderate volumetry (yellow color: 35-40 m³. ha⁻¹) and high volumetry (red color: 40-45 m³. ha⁻¹).

Each plot of one hectare was divided into 10m x10m subplots to facilitate monitoring activities. The plots and subplots were demarcated with pickets (1.2m PVC pipes with a diameter of 25mm) which were painted on top with acrylic red paint for easy visualization (Silva, 2005).

For the analysis of floristic composition, the identification of the individuals was carried out in the forest by the usual name from an on-site visit by the Parataxibotan technicians of Embrapa Amazônia Oriental. The botanical material of the less common species and the groups of species that raised doubts was collected to be identified, by comparison, in the IAN Herbarium of Embrapa Amazônia Oriental.

Data collections were carried out by Embrapa Amazônia Oriental between 1984 and 2011. Spatial coordinates were collected in the

UTM system to correlate the spatial position with the total volume of each plot. Data collection was performed with Garmim 76CSX global positioning system (GPS) equipment, configured in DATUM and coordinate positioning by the SIRGAS 2000 system.

In the monitoring plots, tree species larger than 20 cm of CHC (circumference at the Height of the Chest) with subsequent transformation in DCH (Diameter at Chest Height) were selected. Only individuals with tree size required by current legislation were considered and sampled and identified in the field with specialist assistance (botanical identifier).

The diameter structure was characterized by the distributions of tree numbers, basal area, stem volume per hectare, species and diameter class.

Data analysis

For the data processing, the following programs were used: MFT (Tropical Rainforest Monitoring) developed by Embrapa Amazônia

Table 1. Comparison between the evaluated periods for the total volume values of the species from rank group-1 (number of individuals in row 1) and group-2 (number of individuals in column j), “U” statistic (values on upper diagonal) and Statistical probability values (P) of the Mann-Whitney U test for differences of commercial species groups in an area of 36 ha of native forest in Jari, Amapá, Brazil.

Correlation	1984	1986	1988	1990	1994	1996	2004	2011
1984		G1=1583 G2=1045 U =379	G1=1626 G2=1002 U= 336	G1=1673 G2=955 U =289	G1=1502 G2=1126 U= 460	G1=1600 G2=1028 U= 362	G1=1272 G2=1356 U= 606	G1=1188 G2=1368 U= 522
1986	Z=3.03 P=0.002**		G1=1353 G2=1275 U=609	G1=1406 G2=1222 U= 556	G1=1197 G2=1431 U= 531	G1=1333 G2=1295 U= 629	G1=1080 G2=1548 U4= 14	G1=1016 G2=1540 U=350
1988	Z=3.51 P=0.000**	Z= 0.44 P= 0.661		G1=1352 G2=1276 U= 610	G1=1136 G2=1492 U= 470	G1=1283 G2=1345 U= 617	G1=1042 G2=1586 U= 376	G1=992 G2=1564 U=326
1990	Z=4.04 P=0.000**	Z=1.04 P= 0.300	Z=0.43 P= 0.669		G1=1089 G2=1539 U=423	G1=1247 G2=1381 U= 581	G1=1010 G2=1618 U= 344	G1=963 G2=1593 U= 297
1994	Z=2.12 P=0.034**	Z=-1.32 P= 0.188	Z=-2.00 P =0.045*	Z=-.253 P= 0.0113		G1=1446 G2=1182 U= 516	G1=1124 G2=1504 U=458	G1=1041 G2=1515 U= 375
1996	Z=3.22 P=0.001**	Z=0.21 P= 0.831	Z=-0.35 P= 0.727	Z=-0.75 P= 0.451	Z=1.49 P= 0.137		G1=1043 G2=1585 U= 377	G1=979 G2=1577 U=313
2004	Z=-0.47 P=0.636	Z=-2.64 P= 0.008**	Z=-3.06 P= 0.002**	Z=-3.42 P= 0.001**	Z=-2.14 P= 0.032*	Z=-3.05 P= 0.002**		G1=1226 G2=1330 U= 560
2011	Z=-1.24 P=0.214	Z=-3.22 P=0.001**	Z=-3.50 P= 0.001**	Z=-3.83 P= 0.000**	Z=-2.93 P= 0.003**	Z=-3.65 P= 0.000**	Z=-0.81 P= 0.421	

Statistically significant values considering $\alpha=5\%$, ** $\alpha=1\%$.

Oriental, which will serve to analyze the parameters referring to floristic and forest structure and Excel to calculate the estimated volume in the 100%. In order to verify the sample sufficiency of the floristic composition, before the application of the treatments, the data of the number of species, according to the area, were adjusted and analyzed using the program R.

In 1984, the first forest inventory was carried out and one year later the exploitation occurred. Statistical analysis (Mann-Whitney U test) was performed to determine if there was a change in the growth dynamics of the species.

Anderson Darling's normality test was used to evaluate the normality of the total volume (m³) in the years that was considered not significant with the value of p = 0.448. The Bartlett variance homogeneity test was performed, which was significant with a value of 0.041. In view of the violation of the homoscedasticity assumption, the Krukal - Wallis test was used with seven degrees of freedom, which was significant p = 0.000 with H = 42.91. Then, the Mann-Whitney test (U) was used to test the equality of the medians in the years whose results are found in Table 1. Statistical analysis (Mann-Whitney U test) was performed to determine if there was a change in the growth dynamics of the species.

The volume of the first year of measurement (1984) was compared with all remedies (1986, 1988, 1990, 1994, 1996, 2004, 2011). There was logging in 1985, then the post-log remediation (1986) was carried out and compared with the following remediations and successively until the end of remediation 2011.

The maps elaborated to evaluate the wood volume were those of 1984 (before the logging), 1986, 1988, 1990, 1994, 1996, 2004 and 2011 (after the logging) of the plots calculated by the formulas (Equations 1 and 2), and from the value of this volume and linked to the UTM coordinates of each tree, the interpolation maps were

prepared by the inverse square distance method.

The first stage of the statistical analysis consisted of the exploratory study of the data, allowing to verify the trend of the characteristics evaluated as a function of longitude (WE) and latitude (NS). The inverse distance square method (IDS) was used which is a univariate deterministic interpolator of weighted averages. The farther an observed point is from the smaller estimate its influence on the value of inference. The IDS, described by is defined by the (Equation 1)

$$\hat{Z}_i = \frac{\sum_{i=1}^n \left[\frac{1}{d_i^2} Z_i \right]}{\sum_{i=1}^n \left(\frac{1}{d_i^2} \right)} \tag{1}$$

where: \hat{Z}_i is the interpolated value; Z_i is the value of the sampled attribute and d_i is the Euclidean distance between the sampled and the estimated point.

The Spline method was used to adjust the curve defined mathematically by two or more control points. Interpolation splines pass through all control points and are considered an approximation technique that consists of dividing the intervals of interest into several subintervals and interpolating, as smoothly as possible, these subintervals with small degree polynomial.

A Spline function $s(x, y)$ is a polynomial function in the variables x and y , more specifically a Spline of order p , with $p = 2k-1$ and k integer and positive. It is a polynomial of degree p in x for each fixed y , and in the same way it is a polynomial of degree p in y for each fixed x , that is (Equation 2):

$$s(x, y) = \sum_{j=0}^p \sum_{i=0}^p a_{ij} x^i y^j \tag{2}$$

It is a polynomial function that is adjusted to a small number of points and that are applied to sets of numbers ensuring that the joining of the various functions is continuous. They are suitable for very soft surfaces not fitting to surfaces with significant fluids.

The choice of this method was mainly due to the number of samples ($n = 36$), which was satisfactory for the proposed analysis. The ARCGIS 10.1 program was used for calculations of interpolation and mapping (ESRI, 2012).

RESULTS

Statistical analysis in the volumetric time line

Comparing 1984 with the other years, a statistical difference was observed with the 1986, 1988, 1990, 1994, and 1996 remedies, and there was no statistical difference with 2004 and 2011. In 1986, two years after exploration, compared with the other periods, statistical differences are detected over time. In the following measures, it was observed that the area began to come into equilibrium.

In 1986, there was biomass gain, but then it was gradually lost. After five years of exploitation, there was a slight increase (1986-1988-1990). But statistically, this growth showed no significant difference, a fact that may have been influenced by the loss of biomass caused by natural mortality.

Comparing the years of 1984, statistical difference was observed compared to the measurements of 1986, 1988, 1990, 1994 and 1996, and there was no statistical difference with 2004 and 2011. The 1986 remedy was compared with the other periods, and statistical differences over time were found, not unlike in the following remedies. It was observed that the area began to come into equilibrium with a small increase in biomass.

In 1986, there was biomass gain, but then it was gradually lost. After five years of exploration, there was a slight increase (1986-1988-1990). But statistically, this growth did not show a significant difference, a fact that may have been influenced by the biomass loss caused by natural mortality.

In the passage from 1990 to 1994, there was an increase in volumetry of almost $2 \text{ m}^3/\text{ha}$. In 1994, a new intervention was carried out in the area through the application of silvicultural treatment, where it had a new reduction of basal area, being close to the period of 1986; this event was the impicator for the decrease of volumetry. In the period 1994-1996, the statistical analysis was not significant, due to the short time after the silvicultural treatment (Table 1).

The Z value refers to statistics calculated to confirm hypothesis h_0 or h_1 of the values of the tests performed.

The post-harvest periods from 1986 to 1996 do not differ statistically, with the exception of the period from 1988 to 1994. Likewise, the period before the 1984 harvest does not differ from the post-harvest 20 years (2004 and 2011), indicating the recovery of the density of trees in the managed forest area. The variance between

1994-1996 was the determinant for the non-significance, which explains the difference between the periods, the dendrometric values practically remained, reflecting the equal effects of the applied silvicultural treatment, inhibiting the changes on the vegetation occurred.

Soon after in 2011, the total volume exceeded the initial volume by 1.7%, from 39.19 to 39.86 m^3 , confirming the volume recovery (m^3) in treated areas (Table 2).

The biomass growth in native forest depends on the type of disturbance that occurred in the period and the variation of the density of trees found in the plots can be explained by the intensity of exploitation and the silvicultural treatment that occurred in this area. After the exploration, the native forests enter the reconstruction phase (closing of large clearings) and can present high density of adult representatives of pioneer and secondary species, due to the high capacity of repopulation and growth in these areas.

The events (exploration plus treatment application) made a difference from 2004, becoming statistically significant. For the years 2004 and 2011, the analysis did not detect statistical differences due to the oscillation of the variance between the plots, recovering the total volume after 20 years, showing that the statistical analysis corroborated with information from the images of the volumetric maps.

Volumetric scenary before silvicultural treatment

For the year 1984, there was a predominance of commercial tree species with a volume of $35\text{-}40 \text{ m}^3 \text{ ha}$; there is also a high volumetric value of $40\text{-}45 \text{ m}^3 \text{ ha}$. After logging in 1986, there was an increase in the volume of individuals. $35 - 40 \text{ m}^3 \text{ ha}$ and $30\text{-} 35 \text{ m}^2$ and a reduction in the volume of individuals of $40\text{-}45 \text{ m}^3$. This increase may be related to the diameter growth of the remaining individuals. Featuring W –SW oriented spatial configuration. Before and after logging, there is a predominance of individuals of $35 - 40 \text{ m}^3$ (Figure 2).

In 1986, one year after the exploration, there was a slight reduction in the total volume of 6.4%, with no change in the scenery for moderate volumetry, but for the average volumetry explained by the process of succession of the individuals facilitated by the heavy exploration which removed the large individuals in the year 1984. For this period, we observe a spatial configuration oriented in the NE-E direction.

In 1988, there was still a decrease in total mean volume to $35.83 \text{ m}^3 \text{ ha}^{-1}$. The same characteristic was observed for the spatial dynamics of the previous period of 1986. However, there was an isolated increase in the mean volume ($30\text{-}35 \text{ m}^3 \text{ ha}^{-1}$) in the N-SE sense, predominance in the moderate volumetry ($35\text{-}40 \text{ m}^3 \text{ ha}^{-1}$). In this period, there was a decrease of individuals of the high volume class.

In 1990, there was a greater fall in total volumetry of 8.6% due to climatic phenomena in the region (Figure 3),

Table 2. Total volume ($\text{m}^3 \text{ha}^{-1}$) of silvicultural and control treatments and percentage volume variation over the years of study at Jari, Vitória do Jari, Amapá, Brazil.

Year	Volume (Treatment)	Volume change in %	Volume (Treatment)	Volume change in %
1984	39.19632		43.31995	
1986	36.68616	- 6.4	44.19451	+ 2.0
1988	36.21706	- 7.6	43.97722	+ 1.5
1990	35.82988	- 8.6	42.66765	- 1.5
1994	37.59115	- 4.1	43.88412	+ 1.3
1996	36.16934	- 7.7	44.01208	+ 1.6
2004	39.11322	-0.2	43.50308	+0.4
2011	39.86219	+ 1.7	44.87421	+3.6

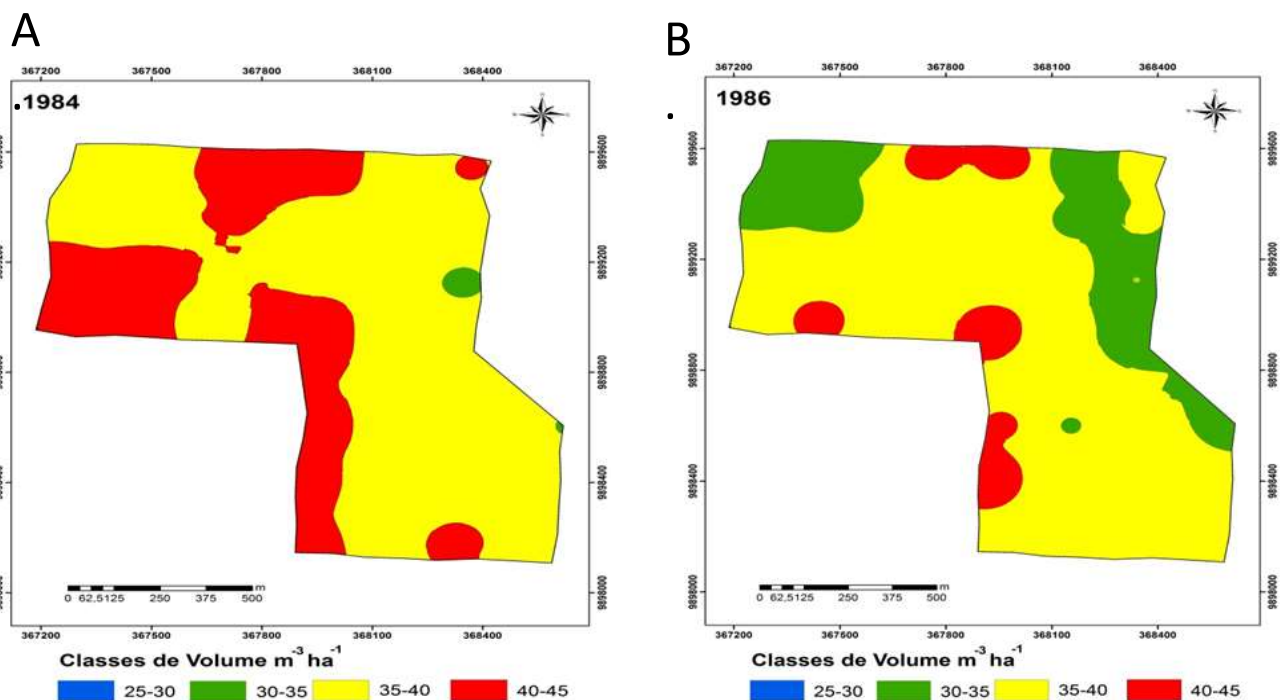


Figure 2. Volumetric configuration for the years (a) 1984 and (b) 1986 in a stretch of 36 ha of native forest no município de Jari in Amapá State.

which knocked down several large trees (surrounding area) and successional forest processes, significant in the occurrence of a change in the spatial configuration in the NE-E direction. It is observed that a decrease in the mean volume ($30 - 35 \text{ m}^3 \cdot \text{ha}^{-1}$) was explained by the successional process.

Volumetric scenario after silvicultural treatments

The forest scenery had a major change in 1994 (Figure 4) with the predominance of the moderate volume ($35-40 \text{ m}^3 \cdot \text{ha}^{-1}$). This scenery occurred through the application

of silvicultural treatments that reduced the basal area of non-commercial trees. The presence of isolated spots was observed in the spatial configuration oriented in the NW-SE direction, of the low volume ($25-30 \text{ m}^3 \cdot \text{ha}^{-1}$) and high volumes ($40-45 \text{ m}^3 \cdot \text{ha}^{-1}$).

It is important to note in these maps that there is the generation of points (islands) with volume value inside them for exploration and volume values below 30 m^3 . This is because the surface generated by the Spline method is adjusted by control points, assuring the continuous junction of the observed points, being appropriate for a phenomenon to be interpolated with gradual variations in its values. It was observed that there

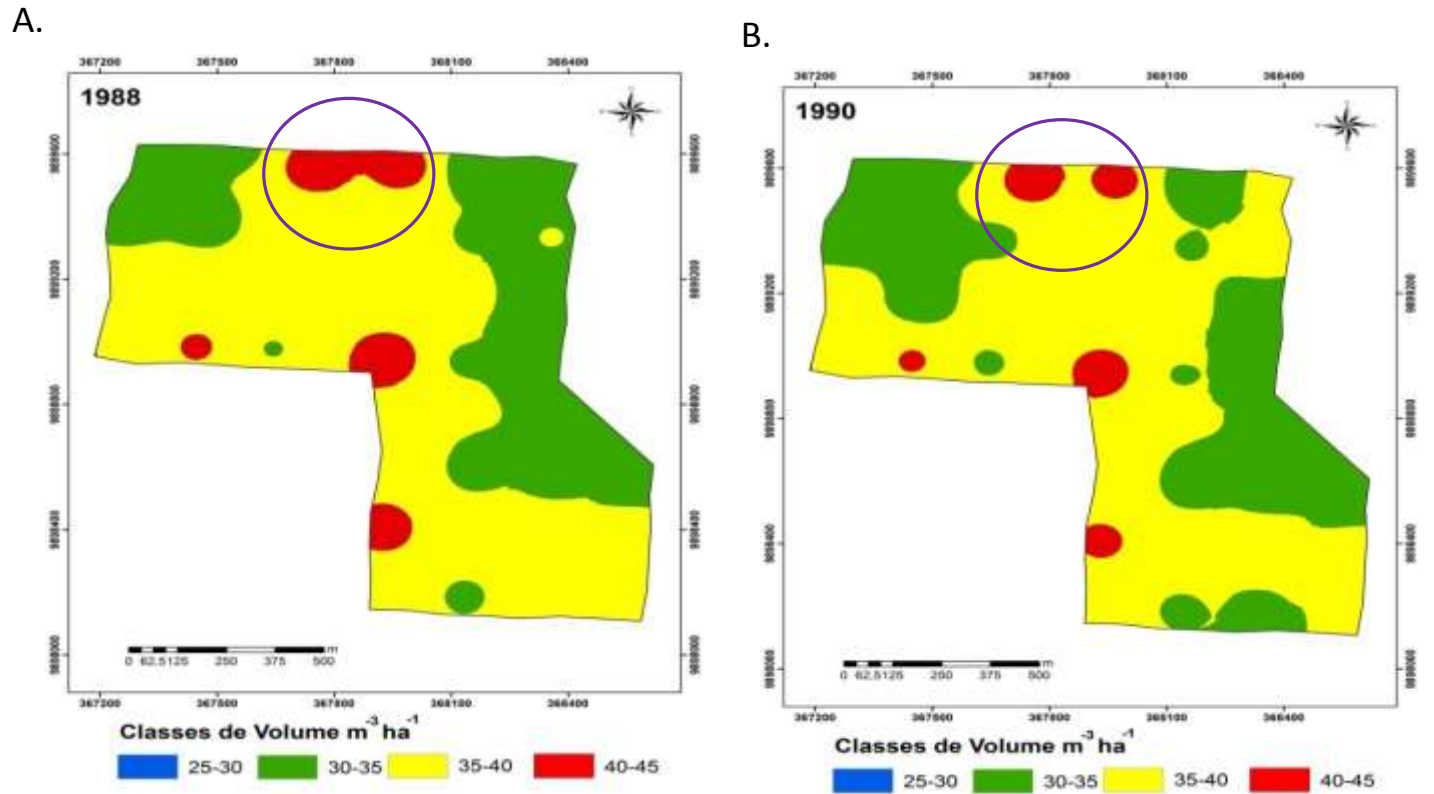


Figure 3. Volumetric configuration for the years (a) 1986 and (b) 1990 in a stretch of 36 ha of native forest in Amapá State.

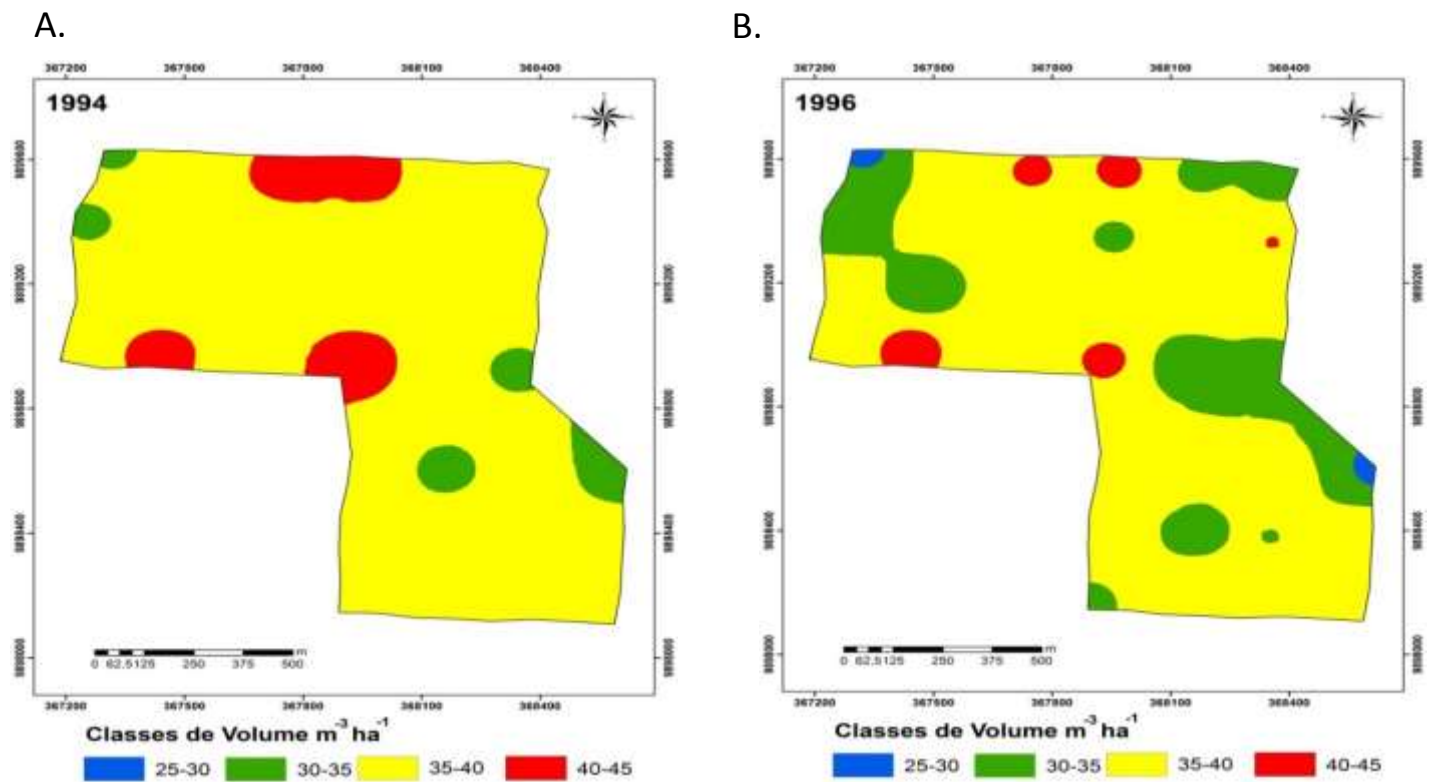


Figure 4. Volumetric configuration for the years (a) 1994 and (b) 1996 in a stretch of 36 ha of native forest in the Amapá State.

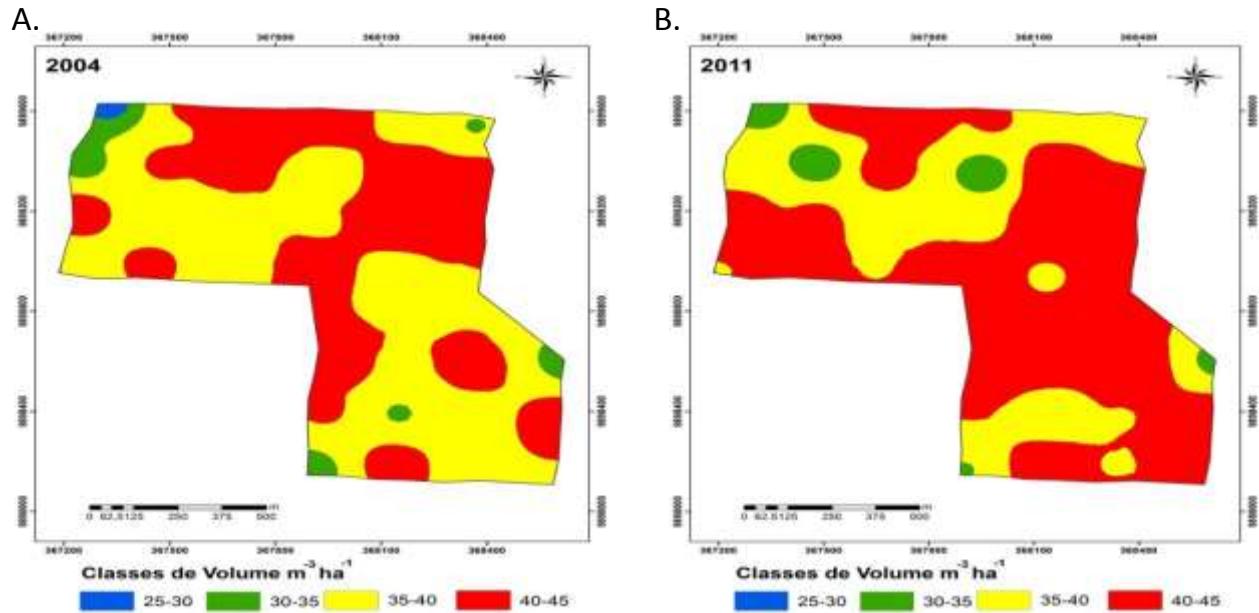


Figure 5. Volumetric configuration for (a) 2004 and (b) 2011 in a 36 ha stretch of native forest in the Amapá State.

was no statistical difference between the years of 1994 and 1996, for volumes above $40 \text{ m}^3 \text{ ha}^{-1}$. These sceneries are represented with the same scale and same caption classification. Note that there is the largest accumulation of mean volume in the NW-SE direction.

The forest scenery remained in 1996, with the predominance of the moderate volume ($35\text{-}40 \text{ m}^3 \text{ ha}^{-1}$) with emergence of several high volume points and a slight increase in the mean volume ($30\text{-}35 \text{ m}^3 \text{ ha}^{-1}$) concentrated in the extremities. This occurred through the application of silvicultural treatments in 1994 that reduced the basal area of the trees. Two points of the low volume ($25\text{-}30 \text{ m}^3 \text{ ha}^{-1}$) were observed in a spatial configuration oriented in the NW-SE direction and the reduction of points in the high volumes ($40\text{-}45 \text{ m}^3$).

From 2004 onwards, this scenario begins to change with reference to the dominance of the high volume ($40\text{-}45 \text{ m}^3 \text{ ha}^{-1}$) presenting a spatial configuration oriented in the direction N-E and N-S and five other isolated islands. The moderate volume configuration ($35\text{-}40 \text{ m}^3 \text{ ha}^{-1}$) predominates over the high volume ($40\text{-}45 \text{ m}^3 \text{ ha}^{-1}$) with the appearance of several medium volume points and only a low volume point located at the extremities. 2011 shows a small increase in the high volume scenario ($40\text{-}45 \text{ m}^3 \text{ ha}^{-1}$), surpassing the moderate scenario. In this year, the spatial configuration is oriented in the sense N-E and N-S added to four other isolated islands of the average volume (Figure 5).

The forest inventory applied to the interpolation method for the production of spatial maps was efficient, determining the point of greatest volume production (m^3) in the stands and the year of greatest variation in

percentage (1.7%) in total volume, indicating that this precision tool can be used in future analyzes of volume in the forest inventory to 100%.

There were no significant statistical differences for volume in the first 20 years after the exploration (1986, 1988, 1990, 1994 and 1996). This occurred only from 2004, twenty years after the forest harvest. With this, the capacity of recovery of the forest around two decades was verified. Therefore, only forest biomass was considered. This cannot be understood with the biomass of the commercial species of the structure observed before the exploration.

The results obtained by the spatial maps allow identifying which are the units of samples more productive to do the initial planning of the forest exploitation. In addition, the results allow identifying less productive areas to plan interventions (silvicultural treatments) and to provide volume increase (m^3).

Making the difference in commercial volume between 1984 and 2011, positive and negative values were obtained, and it was found that 76.92% of commercial species did not recover their initial volume. The species that were able to recover their volume over the 27 years were: *Carapa guianensis* ($4,4769 \text{ m}^3/\text{ha}$), *Caryocar villosum* ($1,2969 \text{ m}^3/\text{ha}$), *Dinizia excelsa* ($0,8161 \text{ m}^3/\text{ha}$), *Licaria crassifolia* ($4,4097 \text{ m}^3/\text{ha}$), *Qualea paraense* ($2,4453 \text{ m}^3$) and *Ruizterania albiflora* ($7,651 \text{ m}^3$). The species that came close to regaining their initial volume were: *Hymenelobium excelsum* ($1,0912 \text{ m}^3$), *Hymenelobium petraeum* ($0,2422 \text{ m}^3$), *Hymenelobium sericeum* ($2,4872 \text{ m}^3$), *Manilkara bidentata* ($17,5454 \text{ m}^3$), *Nectandra micranthera* ($11,9406 \text{ m}^3$), *Platymiscium* sp.

(2.0828 m³), *Pouteria oppositifolia* (19.7799 m³), *Pouteria* ssp. (69.0232 m³), *Vatairea* sp. (4.2838 m³) and *Vouacapoua americana* (0.4692 m³).

DISCUSSION

There is a growing demand for information on appropriate forestry techniques for native forests, especially information that takes into account trees that have fallen below the permitted cutting limit, with behaviors different from commercial species, with low increment, scarcity in number and volume of species new potentials (Azevedo et al., 2008).

Precision forestry aims to survey productivity spots within a field, identify potential areas for 2nd cut, make localized decisions, minimize costs, improve resources and productive activities, minimize environmental impacts, increase productivity and maximize profits (Ortiz et al., 2006).

In this study, the growth rate of forest species was 1.7% in 2011. This figure can be explained by the number of undesirable competing individuals that were removed, whose crowns were competing for light with the tree tops of species selected for the next harvest; and by reducing the basal area of undesirable species in order to reduce competition in the population, in general (Azevedo et al., 2012).

In this study, the three interventions that took place in the area (logging in 1985, the fall of trees caused by the windstorm in 1990 and the application of silvicultural treatments in 1994) enhanced the emergence of multiple timber species, multiple products and by-products of flora, favoring the natural regeneration of forest species, growth in height and basal area, contributing to the forest keeping its characteristics close to its original state.

The challenge of discussing a new timber harvesting proposal through spatial maps, verifying where the species with the largest basal area and the highest initial volume for the second cut can be found, may become an alternative to maintain the balance of the most commercial species exploited in the Amazon to avoid extinction.

Our biggest challenge is choosing new species to make up the second harvest cycle, since not all exploited species can recover the initial commercial volume of the first harvest. However, there are numerous publications focusing on the botany, phytosociology, ecology, technology of wood and little on subjects that select potential species for a second crop. Table 3 shows the commercially exploited forest species that succeeded and could not recover the initial volume, and those that were close to recovering the initial volume.

According to De Avila et al. (2015), the high intensity of exploitation coupled with the reduction of the basal area can cause damage to the forest harvest that can substantially influence the tree community (DBH \geq 10 cm). One way to combat this environmental damage is to

determine the minimum level of interventions and to avoid strong thinning. This can improve ecosystem recovery and maintain biodiversity at other trophic levels.

According to Silva et al. (2006), the diameter growth and the volumetric productivity of the dryland forests of the eastern Amazon are low. These factors should be taken into account when establishing cutting cycles in management plans. For a forest to be considered sustainable and have the same yield we must avoid heavy logging (80 m³/ha) which would take a long time to recover. Very long cutting cycles are economically unfeasible. In the present study, after 27 years of logging, the volume of wood from 40-45 m³. ha⁻¹ recovered.

Silva et al. (2006), studying growth models carried out in Flona do Tapajós with a cutting intensity of 75 m³.ha⁻¹, in 30-year cutting cycles, considered a 200-year period with cuts of less than 0 to be simulated 0,7 m³.ha⁻¹.year⁻¹. Sustainable production of 27 – 28 m³ ha⁻¹ in 30-year cycles has been shown to be possible; and after harvesting in a second cutting cycle it is recommended to include 60 - 70% of potential species.

According to Braz et al. (2012), studying forest growth in the State of Amazonas, found that the time required for non-commercial species (DAP \leq 35 cm) to enter commercial classes (DBH \geq 45 cm) was 19 years. Subjects less than 35 cm DAP did not cooperate for volume in the first post-cut cycle. Only species from 35 cm of DBH can reach the minimum diameter (50 cm) for a second exploration.

A forest management plan aimed at the conservation of native species has to take into account the dynamics of forest growth Schaaf et al. (2005) and the maximum exploitation limit per species. These factors must be evaluated individually prior to exploration. For this, account should be taken of 100% forest inventory information. In addition, the evaluation of natural regeneration according to its structure is considered for each species. The classification of the species becomes the possibility to compose the cut rate.

And finally, the effect of the interventions that occur in this work can recover the total and commercial volume and basal area of commercial species and favor the emergence of new species with potential in the timber market, which can significantly increase the growth rates of commercial and potential trees (Wadsworth and Zweede, 2006).

Conclusions

From the spatial distribution of the forest species, the productive potential of wood in its points of greatest volume was verified. Thus, the biomass growth and the interventions that took place during these periods were taken into account. Productivity data are generated to better plan the infrastructure for the future forest harvest, with greater productive efficiency and lower impacts to the forest.

Table 3. List of species exploited in 1985 and their respective commercial volumes and their variation in loss and gain in biomass (m³ ha) after 27 years of exploitation in Jari native forest, AP.

Species	1984	1986	1988	1990	1994	1996	2004	2011	1984-2011
<i>Bowdichia nitida</i>	4.79	3.89	3.89	3.90	3.92	3.71	3.74	2.19	-2.60
<i>Carapa guianensis</i>	3.85	3.13	3.17	3.38	3.21	3.60	4.00	4.48	0.62
<i>Caryocar villosum</i>	1.19	0.86	0.86	0.86	1.05	1.06	1.10	1.30	0.10
Combretaceae	2.64	1.50	1.51	1.52	1.54	1.55	1.35	1.36	-1.28
<i>Dinizia excelsa</i>	0.78	0.39	0.39	0.56	0.57	0.58	0.80	0.82	0.04
<i>Dipteryx odorata</i>	14.31	9.90	9.93	9.95	10.02	9.63	8.76	7.35	-6.96
<i>Goupia glabra</i>	54.86	37.16	36.59	36.37	35.14	34.80	35.47	34.43	-20.43
<i>Handroanthus serratifolius</i>	5.40	4.89	4.90	4.70	4.90	4.91	4.60	4.19	-1.21
<i>Hymenaea courbaril</i>	11.17	4.29	4.31	4.51	4.73	4.75	4.87	3.92	-7.25
<i>Hymenolobium excelsum</i>	1.88	1.38	1.38	1.39	1.41	1.42	1.09	1.09	-0.79
<i>Hymenolobium petraeum</i>	0.75	0.20	0.18	0.18	0.20	0.20	0.23	0.24	-0.51
<i>Hymenolobium sericeum</i>	2.96	2.30	2.34	2.54	2.52	2.55	2.59	2.49	-0.48
<i>Licaria crassifolia</i>	3.17	2.61	2.45	2.47	2.88	3.95	4.50	4.41	1.24
<i>Manilkara bidentata</i>	19.57	17.26	17.37	16.49	17.08	17.17	16.52	17.55	-2.02
<i>Manilkara huberi</i>	57.20	40.11	39.44	39.08	38.65	39.07	37.60	36.19	-21.01
Não identificada	14.99	13.07	12.01	9.78	8.11	6.35	2.44	4.21	-10.78
<i>Nectandra micranthera</i>	12.64	11.06	10.69	10.41	11.22	11.39	13.23	11.94	-0.70
<i>Platymiscium</i> sp.	2.09	1.60	1.62	1.81	2.02	2.03	2.25	2.08	-0.01
<i>Pouteria oppositifolia</i>	23.09	22.08	22.21	22.16	21.85	21.62	21.76	19.78	-3.31
<i>Pouteria</i> ssp.	77.81	75.04	72.37	69.70	69.77	69.00	69.49	69.02	-8.78
<i>Qualea paraensis</i>	2.26	1.67	1.70	1.42	1.64	1.66	2.33	2.45	0.19
<i>Ruizterania albiflora</i>	7.16	5.67	5.68	5.13	5.60	5.72	7.30	7.66	0.50
<i>Terminalia</i> ssp.	3.02	2.17	2.18	2.20	2.40	2.42	2.48	2.86	-0.16
<i>Trattinnickia rhoifolia</i>	7.73	6.79	6.86	6.88	7.21	0.44	7.37	6.59	-1.14
<i>Vatairea</i> sp.	4.93	4.18	4.23	4.12	4.19	4.23	4.58	4.28	-0.65
<i>Vouacapoua americana</i>	0.67	0.41	0.41	0.42	0.43	0.44	0.46	0.47	-0.20
Total	340.92	273.59	268.67	261.94	262.26	254.24	260.92	253.34	-87.58

The application of interpolation methods tends to result in spatial maps with precise information, especially when dealing with commercial volume of tree species, becoming a very important tool for forest management. Therefore, new tools for forest management that help in the recognition and monitoring of forest stands generate reliable and important information for forest management, contributing to the sustainability of the ecosystem, increasing the yield of available resources, besides reducing wood waste and operating costs in the exploration.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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