Australian Journal of Basic and Applied Sciences, 11(10) August 2017, Pages: 48-59

AUSTRALIAN JOURNAL OF BASIC AND APPLIED SCIENCES

ISSN:1991-8178 EISSN: 2309-8414
Journal home page: www.ajbasweb.com

Adjustment of volumetric equations from fallen trees for analysis of the logging effect in the Tapajós National Forest, Pará, Brazil

[1]Diego Ribeiro de Aguiar, [1]Adriano J. N. Lima, [2]João Ricardo Vasconcelos Gama, [3]Dárlison Fernandes Carvalho de Andrade, [1]Joaquim dos Santos, [1]Niro Higuchi

[1]Phd student, National Research Institute of Amazonia, Tropical Silvicultural Department, Faculty of Forest Management, Manaus, Amazonas, Brazil.
[1]Researcher, National Research Institute of Amazonia, Tropical Silvicultural Department, Faculty of Forest Management, Manaus, Amazonas, Brazil.
[2]Federal University of West of Pará, Department of Forest Management, Santarém, Pará, Brazil.
[3]Environmental Analyst, Chico Mendes Institute for Biodiversity Conservation (ICMBIO), Santarém, Pará, Brazil.
[1]Researcher,National Research Institute of Amazonia, Tropical Silvicultural Department, Faculty of Forest Management, Manaus, Amazonas, Brazil.
[1]Researcher, National Research Institute of Amazonia, Tropical Silvicultural Department, Faculty of Forest Management, Manaus, Amazonas, Brazil.

Address For Correspondence:
Diego Ribeiro de Aguiar, Phd student, National Research Institute of Amazonia, Tropical Silvicultural Department, Faculty of Forest Management, ZIP code: CEP 69060-000, Manaus, Amazonas, Brazil.
Tel: +55 93 99125 2462; E-mail: dribeiroaguiar@yahoo.com.br/conctribeiro@gmail.com

ARTICLE INFO

Article history:
Received 28 May 2017
Accepted 22 July 2017
Available online 26 July 2017

Keywords:
Continuous forest inventory, Smalian and Hohenald, Forest Management, Amazon.

ABSTRACT

Background: Forest management and planning purposes, it is vital to know the volume of wood resources and their growth rates. As forestry and forest, concessions have made progress in the discussions on forest policy and the new forest code, wood volume equations have become an indispensable tool for estimating wood stock. **Objective**: This work aimed to adjust volumetric equations and determine a volume variation (2010-2011) for the species of an area under forest management. **Results**: Model 6 was the one that obtained higher R^2ajust, lower Uncertainty (%) and good dispersion of residues and better AIC. However, because it was a double input (DBH and Hc), it was not used for the Annual Production Unit (APU) 5 inventory, so we chose to use the simple input model 1 (DBH) to calculate the volume, which also reached Satisfactory parameters for validation of its use. In general, the dependence of a biological variable on body mass is typically characterized by an allometric scale law in the non-linear model form. From the adjusted equations the total timber stock was 285.83 $m^3.ha^{-1}$ for 2010 and 252.41 $m^3.ha^{-1}$ for 2011 in the management area of COOMFLONA, as well as the effect of APU 5. The size classes respond according to the management impact level, with the highest volumetric losses of wood being in the classes of DBH ≥100 (21.86 $m^3.ha^{-1}$), 90–100 (3.53 $m^3.ha^{-1}$), 80–90 (2.64 $m^3.ha^{-1}$), 70–80 (1.60 $m^3.ha^{-1}$), 40–50 (1.73 $m^3.ha^{-1}$). These values represent the loss of wood during the exploratory activity in the FNT, where most of the classes had a volumetric deficit. This demonstrates how the activity affects the forest stock. **Conclusion**: Thus, it was possible to verify that the management used in the FNT made possible a positive response for some species and classes of forest size. This demonstrates how a vegetation reacts to the form of management used, which can make a new evaluation in the forest structure.

ToCite ThisArticle: Diego Ribeiro de Aguiar, Adriano J. N. Lima, João Ricardo Vasconcelos Gama, Darlison Fernandes de Carvalho Andrade, Joaquim dos Santos, Niro Higuchi., Adjustment of volumetric equations from fallen trees for analysis of the logging effect in the Tapajós National Forest, Pará, Brazil. ***Aust. J. Basic & Appl. Sci.,*** *11(10): 48-59, 2017*

INTRODUCTION

The drastic reduction on the stock of wood in tropical forests is a result of the expansion of agriculture and illegal logging, as well as a need to optimize the use of wood resources (Lanssanova *et al*., 2013). Thus, the challenge is to transform a wood supply crisis into a large window of opportunity for the Amazon (Clement and Higuchi, 2006). Amazon has a large continuous area of mature forest and wood volume is sufficient to ensure supply of the international market for another century (Malhi *et al*., 2008).

To maintain competitiveness, timber companies need to apply rational technologies for timber extraction and processing. Therefore, there is a need to improve the techniques used in estimating the volume of timber to be harvested in each annual production unit (APU) as part of a management plan (Santana *et al*., 2017).

Thus, the sustainability of the use of the available wood resources and their benefits requires adequate planning, which in turn requires knowledge of the extent of growing stock in the forest (Akindele *et al*., 2001).

In this context, the estimation of settlement volume is important for decision-making and efficient management of forest resources. Fracture volume estimates are useful in the forest inventory, because timber volume is the basic forest management unit (Chaidez 2009). For forest management and planning purposes, it is vital to know the volume of wood resources and their growth rates (Altriell *et al*., 2010). The volumetric equations are of general use and indispensable for the planning and execution of a forest management plan, being necessary to adjust them for different species, regions and physiognomic types (Tonini and Borges 2015).

Thus, the adjustment of volumetric equations for managed areas is an essential tool for estimating timber, with the purpose of improving future crop cycle planning, as well as the description of the exploration effect caused in the area. With the use of specific equations for managed areas it is possible to monitor the growth of species in the long term, thus knowing the levels of volumetric increase. Thus, the post-exploratory losses of the forest can also be known, which allows to evaluate the trees that were most affected during logging, as well as the quality of the forest activity employed in the area.

In this way, the response of the vegetation can be understood, since the effects can vary with the scale of time and intensity of exploitation. The composition of tree species is affected by the high intensity of exploitation (Avila *et al*., 2015), and as the forest reacts differently, depending on the volumetry removed from the area during the management, it is fundamental to monitor growth from equations With low error estimates.

However, there is a need for more comprehensive adjustment that can be used in forest monitoring. Presenting consistent and robust volumetric equations are important for use in forest management. This will reduce waste; will prevent discrepancies between the estimated volume in the forest and the processed. As a result, future forest use planning will be favored. In this context, the study had as objectives to adjust volumetric equations from fallen wood for analysis of the exploration effect for all species of the area managed in the TNF, Pará, Brazil.

MATERIAL AND METHOD

Study area:

The Tapajós National Forest (TNF) is located in the state of Pará, along the Cuiabá-Santarém Highway (BR-163), in the central part of the Amazon rainforest. Located between the parallels 2º 45 'and 4º 10' S and the meridians 54º 45 'and 55º 30' W. It covers part of the municipalities of Belterra, Aveiro, Rurópolis and Placas, extending over an approximate area of 545.000 ha Espírito-Santo *et al*., 2005). Managed by the Chico Mendes Institute for Biodiversity Conservation (ICMBio), it presents as a basic objective the multiple use of forest resources and scientific research, with emphasis on methods for sustainable exploitation (Brazil, 2002). The cubing area (CA) is located near the 117 km of the BR-163, which was held the Forest Management in 2015 by the “Cooperativa Mista da Flona Tapajós Verde” (COOMFLONA). In this place were measured fallen and felled wood.

The climate is of the type Ami (Köppen) with average temperature of 25.5 ° C. The rainy season occurs between January and May, resulting in an average rainfall during the year of 1,820 mm. The local relief is slightly uneven, with a topography of gently undulating to undulating. The predominant soil in the studied area is the Yellow Latosol Dystrophic type. The vegetation is classified as dense ombrophylous forest, characterized by the dominance of large trees (Gonçalves and Santos, 2008; IBGE, 2012).

Characterization of data:

The scaling trees followed the diameter distribution of the sample inventory (3.7 ha) held in forest management (Annual Production Units -APU- 5) located in the vicinity of 83 km of the BR-163. In this way, the number of trees was distributed in percentage, in each size class, to represent the structure of the vegetation.

Rigorous Cubing:

In scaling 167 trees (10 were felled in forestry and others derived from fallen wood 157 during activity). This sampling followed the proposal of Lima (2010), which combines the Smalian methods (measurement of the base and top diameters of each section) and Hohenadl (relative division of section length).

Thus, the diameter at breast height (DBH) and stump diameters (D_{stump}) were measured in individuals already felled and the wood dropped in the CA. The commercial height (Hc) was obtained from the base of the tree (considering the height of the stump (H_{stump}) for the felled trees and the base of the stem for the fallen woods) to the length of the shaft. To obtain the length of the sections, the length of the stem of each tree sampled was divided by 10 (Figure 1).

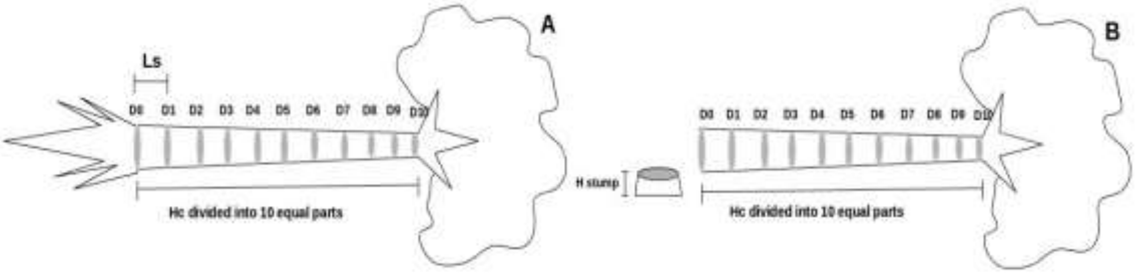

Fig. 1: Scheme scaling fallen tree (A) and tipping (B) dividing the commercial height into 10 equal parts.

The wood decay in the CA was obtained from 167 trees of 64 different species and three were not identified. All size classes were considered taking into account the diametrical distribution of the inventory carried out in APU 5 (Table 1).

Table 1: Distribution of the trees according to the inventory in the APU 5 and the one planned for the CA, Tapajós National Forest, Pará, Brazil

CDAP	Nº ind. APU 5	(%)	Nº ind. CA
5⊢10	1505	48.33	78
10⊢20	987	31.70	51
20⊢30	316	10.15	17
30⊢40	138	4.43	8
40⊢50	76	2.44	4
50⊢60	42	1.35	3
60⊢70	23	0.74	2
70⊢80	8	0.26	1
80⊢90	10	0.32	1
90⊢100	4	0.13	1
≥100	5	0.16	1
Total	3114	100	167

The inventory of fallen wood makes it easier to obtain the number of individuals for each diameter class, since with the representation of the entire diametric amplitude it is possible to obtain more precise equations. The fallen wood, besides facilitating this process, allowed the measurement of the desired trees in less time. The determination of the volume of trees and their parts by means of the basic characteristics, such as DBH and height, from the practical point of view, is overloaded with the errors resulting from changes in the shape of the shaft of the trees. This variation is a result of differences in the rate of increase in tree diameter and height (Socha and Kulej, 2007).

The diameter of each section was measured with a graduated inch in centimeters and then the relative division of the sections was performed by the method of Hohenadl. With the diameter measurements of each section the volume of the trees sampled was calculated from the Smalian formula (Soares *et al*., 2007).

Equation 1

$$V_{Smalian} = \left(\frac{\left(\frac{\pi * d_1^2}{40{,}000} \right) + \left(\frac{\pi * d_2^2}{40{,}000} \right)}{2} \right) . Ls + \ldots + \left(\frac{\left(\frac{\pi * d_n^2}{40{,}000} \right) + \left(\frac{\pi * d_n^2}{40{,}000} \right)}{2} \right) . Ls$$

Where: $V_{smalian}$ is the Smalian Volume, d1 is the diameter in cm squared from section 1; d_2 is the diameter in cm squared of section 2 and d_n is the diameter in cm squared of section n and Ls is the section length in meters.

Criteria for selecting models:

The volumetric models tested were 4 single input (DBH) as independent variable and 5 dual input models (4 with DBH and Hc and 1 with CBH and Hc). The adjusted coefficient of determination of the model (R^2 adjusted), standard error of the estimate (S_{yx}) and the uncertainty in percentage (Uncertainty%) were calculated. The graphical analysis of the waste distribution (R%) was also adopted. In order to analyze the significance of the coefficients of each model (p-value) Akaike's An Information Criterion (AIC) was used as the model selection criteria.

The $R^2{}_{ajust}$ is the measure that includes a new variable in the regression model, so it is not recommended to use it alone as a selection criterion. Due to this it is common to use the coefficient of determination adjusted for the number of coefficients of the equations (Field, 2009; Schneider *et al.,* 2009).

Equation 2

$$R^2{}_{ajust.} = R^2\left[\frac{K-1}{N-K}\right].(1-R^2)$$

Where: K is the number of independent variables of the equation, N is the number of observations, R^2 is the coefficient of determination.

The standard error of estimation (S_{yx}) and S_{yx} (%) were used as criteria for evaluating the quality of the tested models, with those with the lowest values of these statistics prevailing. The expressions for obtaining S_{yx} and Uncertainty according to the IPCC (2006) are:

Equation 3

$$S_{yx} = \sqrt{\frac{\sum_{i=1}^{n}\left(V_i(obs) - V_i(est)\right)^2}{n-k}}$$

Where: Vi (obs) is the observed volume of the i-th tree in m^3; V_i (est) is the estimated volume of the i-th tree in m^3; N is the total number of trees sampled and k is the number of coefficients.

Equation 4

$$Uncertainty(\%) = \left(\frac{z * \left(\frac{S_{yx}}{\sqrt{n}}\right)}{\overline{V}_{(obs)}}\right) * 100$$

Where: S_{yx} is the standard error of estimate; Z is the constant when considered a reliability level of 95%; N is the number of trees sampled and V_obs is the arithmetic mean of the observed volume of all trees sampled.

Equation 5

$$R(\%) = \frac{\left(V_{i(est)} - V_{i(obs)}\right)}{V_{i(obs)}} * 100$$

Where: V_i (est) is the estimated volume of the i-th tree in m^3 and V_i (obs) is the observed volume of the i-th tree in m^3.

The Akaike Information Criteria (AIC) is a simple, effective and objective way to select the best approximate (estimated) model and is a relatively new paradigm in the statistical and biological sciences as it differs to a large extent from the usual test-based methods Of null hypotheses (Burnham, Anderson, 2010). The AIC can be calculated for each possible combination of explanatory variables, in which the equation with the lowest AIC is chosen as the optimal model (Zuur *et al.,* 2007).

In the generic calculation function AIC is a biased estimator of "log likelihood" and the asymptotic bias is equal to K (Anderson and Burnham, 1994):

Equation 6

$$AIC = 2k - 2log\left(L(ð/y)\right)$$

Where K is the number of estimated parameters (degrees of freedom) and $\mathcal{L}$ (ð / y) is the log-likelihood at its maximum point of the estimated model. The "2" is the constant (Snipes and Taylorn, 2014).

It was used the calculation of the formation factor for the 167 trees planted in the forest management area (Batista *et al.,* 2014).

Equation 7

$$f = \frac{\sum V_{(i)smalian}}{\sum V_{(i)cilindro}}$$

Where: f is the form factor, Σ v (i) smalian sum of the observed volume of the ith tree obtained by the Smalian formula in m³; Σ v (i) summation cylinder of the volume of the ith tree obtained from the cylinder volume formula (π.DAP2 / 40,000) * Hc) in m³.

Models:

For wood production, an estimate of growth stock is often expressed in terms of volume of wood, which can be estimated from easily measurable tree dimensions. The most common procedure is the use of volume equations based on the relationship between volume and variables such as diameter and height (Akindele and LeMay, 2006).

It is important to point out that the use of mathematical models is valid only for the studied and considered conditions, since the results can vary between sites and the different forest typologies (Koehler *et al.*, 2005). In order to calculate the volume of wood, the traditional statistical models, compiled by Campos and Leite (2009) and Scolforo and Silva (1993) were used in table 2, below:

Table 2: Models tested to estimate the commercial volume through the DBH, CBH and Hc, Tapajós National Forest, Pará, Brazil.

N	Models	Author
1	$V_i = \beta 0 * DBHi^{\beta 1} + \varepsilon$	Husch
2	$Ln\ (V_i) = \beta 0 + \beta 1 * Ln\ DBHi + \varepsilon$	Berkhout/Husch
3	$V_i = \beta 0 + \beta 1 * DBHi^2 + \varepsilon$	Kopesky and Gehrhardt
4	$V_i = \beta 0 + \beta 1 * DBHi + \beta 2 * DBHi^2 + \varepsilon$	Hohenadl and Kreen
5	$V_i = \beta 0 * DBHi^{\beta 1} * Hci^{\beta 2} + \varepsilon$	Schumacher and Hall
6	$Ln\ (V_i) = \beta 0 + \beta 1 * Ln\ DBHi + \beta 2 * Ln\ Hci + \varepsilon$	Schumacher and Hall
7	$V_i = \beta 0 + \beta 1 * (DBHi^2 * Hci) + \varepsilon$	Spurr
8	$V_i = \beta 0 * (DBHi^2 * Hci)^{\beta 1} + \varepsilon$	Spurr
9	$V_i = \beta 0 + \beta 1 \times CBHi^2 \times Hci^{\beta 2}$	Scolforo and Silva

Where: V i is the volume of the ith tree in m³; DBHi is the diameter at breast height at 1.3 meters from the ground in cm; CBHi is the circumference at breast height at 1.3 meters from the ground in cm; Hc i is the commercial height of the i-th tree in meters; Ln is the neperian logarithm and ε is the random error.

2.6. Monitoring:

The area used to monitor the growth of vegetation management is situated after the APU 5, 10 and the UT 7 at this location 37 dimensions were 5x50 m clusters, and so a sample area of 3.7 ha, class Inclusion ≥ 5 cm of DBH. The purpose of this monitoring was to verify the damage caused by the exploitation in all strata of the forest, in order to know which levels were most affected and how the forest recovers.

Therefore, a forest inventory was carried out in June 2010, before the forest management carried out by COOMFLONA, in another later in the year 2011. With the data obtained it was possible to know the volumetric variation caused by the activity.

Data analysis:

The data processing for cubing and equation selection criteria were performed in R studio version 3.2.3 software. As well as, the residual dispersion graphs for the fitted models. The bar graphs were done in LibreOffice Calc 2010.

RESULTS AND DISCUSSION

Cubing:

The volume of the trees covered in the TNF was 104.46 ± 2.16 m³, the sampling varied in the range of 5.3 to 103.1 cm of DBH. The diametric distribution of cubed individuals obtained the J-Reverse pattern, characteristic of unequal forest, with a higher number of individuals in the lower classes (Figure 2). The percentage of individuals for the first three classes was 87% for the cubed trees.While in the work on the influence of plots in the diametric distribution, in the unmanaged area, at the Experimental Station of Tropical Forestry of INPA, Manaus, the value corresponded to 93% (Higuchi *et al.*, 2012).

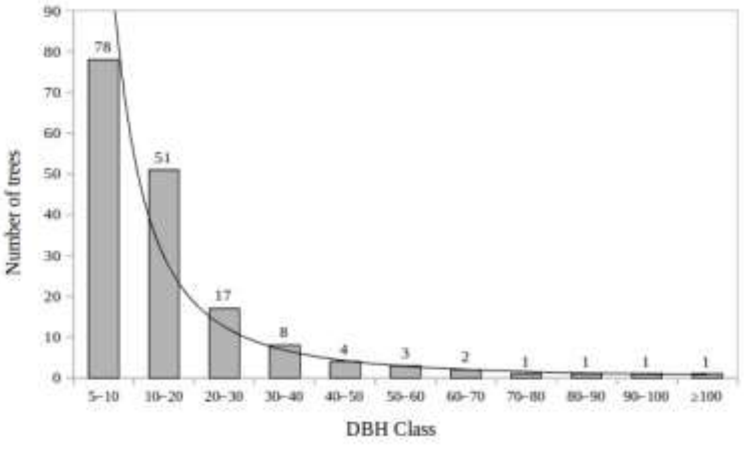

Fig. 2: Distribution of the number of trees cubed by DBH class, Tapajós National Forest, Pará, Brazil.

As this cube distribution was performed based on the APU 5 the inventory curve obtained the same pattern of this area. This type of distribution is common in tropical forests, where the flow of continuous regeneration occurs, in which the upper stratum is gradually replaced by the lower stratum (Silva and Alves Lopez, 1984).

Selection of equations:

The statistical criteria used to evaluate the best equations were R²just., Uncertainty (%), Akaike's An Information Criterion (AIC) and percentage distribution of residues (R%). Thus, the equations with the best results were 1 and 2 of single input (DBH), 6 and 9 of double input (DBH and Hc), which obtained satisfactory results for the parameters evaluated (Table 3).

The dispersion of the residues occurred differently among the models. Models 6 and 9 obtained the best results. While models 3 and 4 had high percentage values in dispersion pain residues, which made it unviable to overestimate and underestimate, respectively, the lower size classes (Figure 3).

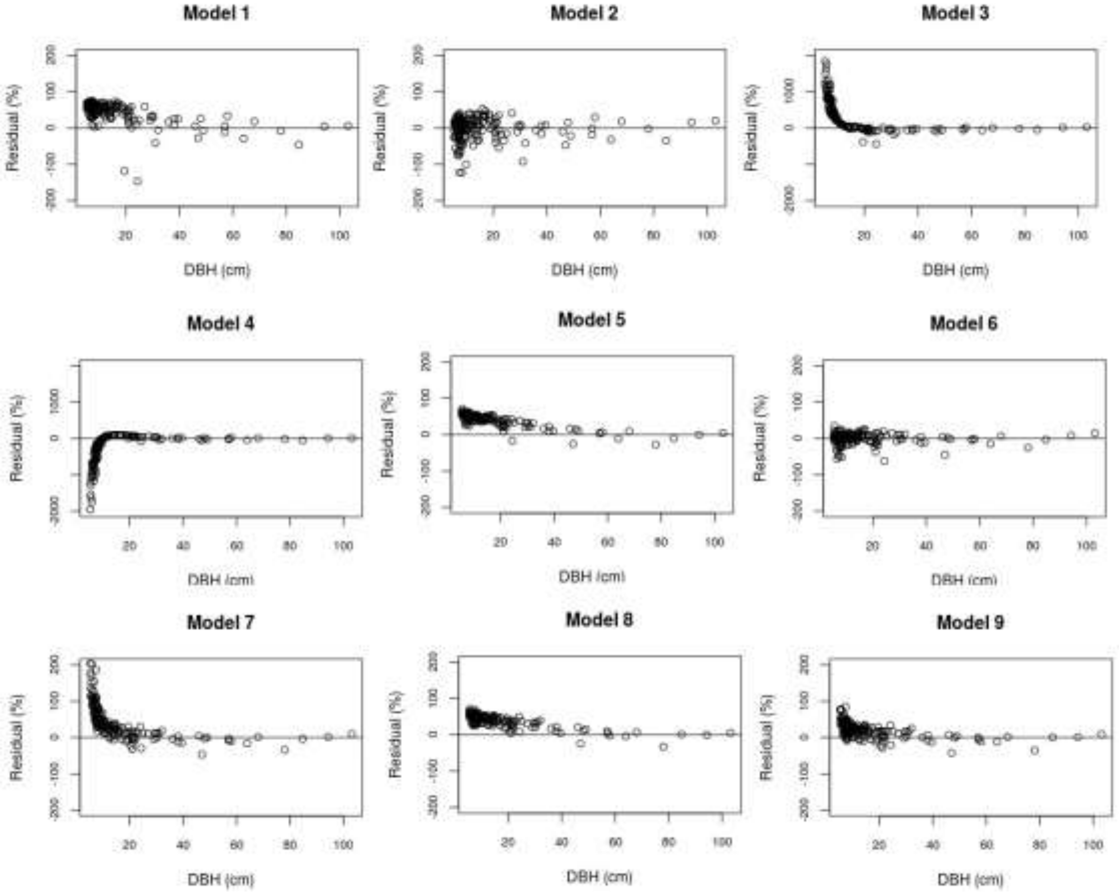

Fig. 3: Residual dispersion of the tested models with the variables DBH, CBH and Hc, Tapajós National Forest, Pará, Brazil.

Model 6 was the one that obtained higher R²ajust, lower Uncertainty (%) and good dispersion of residues and better AIC (Figure 3). However, because it was a double input (DBH and Hc), it was not used for the APU 5 inventory, so we chose to use the simple input model 1 (DBH) to calculate the volume, which also reached Satisfactory parameters for validation of its use. In general, the dependence of a biological variable on body mass is typically characterized by an allometric scale law in the non-linear model form (West *et al*., 1997). This type of model has a more common pattern in biology, species-area relationship and biogeography (Martin and Goldenfeld, 2006; Xiao *et al*., 2011).

In the tropics, forest inventories usually include only the DBH of the trees and Hc. In many cases, Hc is difficult to measure accurately. This problem results in biased estimates when tree height is included as an independent variable in volume and biomass models. Considering these sources of error, it is necessary to develop volume and biomass equations above the soil using DBH as an independent variable. This can be measured accurately and accurately in the field. The measurement of this variable requires less work, and is therefore efficient in reducing costs in forest inventories (Segura and Kanninen, 2005).

For the 167 cubed trees the shape factor of 0.82 was obtained. This is higher than the value found and commonly used in the Amazon for commercial species (0.70). This may be related to the fact that the inventory includes trees with smaller diameters, with 5 cm of DBH, which may have increased the value of the form factor. For other areas in the Amazon forest, values of 0.73 were found in the state of Roraima (Gimenez *et al.*, 2015) and 0.74 in Mato Grosso (Colpini *et al.*, 2009).

For the dense forest in central Amazonia, the shape factor increases with tree size (0.745 and 0.781 for trees with DBH≥10 and ≥50 cm, respectively). The form factor in this area was (0.709), a value similar to that used by the RadamBrasil Project (0.70) (Nogueira *et al.*, 2008).

The variability in the shape of the shaft causes a significant impact in the determination of the volume explored in the tropical forests of the Amazon biome. In general they are used in forest inventories for the calculation of volumetry. Standardized values of shape factors, without considering the difference between species, which simplifies the technical processes, however, leads to an inadequate estimation of the wood stock (Lanssanova *et al.*, 2013).

The main reason for the forest inventory in a natural forest ecosystem is to estimate wood volume with the full support of the installed plots (Oboite and Ade-Oni, 2014). For the adjustment of models for monitoring inventory, the precise representation of individual percentages per size class must be taken to minimize the error and thus obtain more accurate measurements of all strata of the forest. And for management it is important to know the level of loss in the strata to improve the management of the species. With stock values of all classes it is possible to predict which species will be more likely to be managed according to the increment acquired over the years.

Volume equations are used to estimate trees of various sizes and species. The reliability of volume estimates depends on the extent and extent of the available data sample and how volume equations can fit such sample data (Avery and Burkhart, 2002). Sustainable forest management requires, among other things, the total volume of forest stock growing. Normally, the volume is calculated as the total volume per unit area, while models are used predicting the total volume of the trees (Masota *et al.*, 2014). Thus, erroneous estimates of the volume of timber can lead to financial losses, as well as problems in the planning of future management.

Table 3: Models tested (Nº), the estimated coefficients and their stats: p-value, adjusted coefficient of determination (adjusted R^2) Estimated standard error (S_{yx}) m^3 and uncertainty percentage (In%), Akaike's An Information Criterion (AIC), confidence interval (CI), estimated volume (EV m^3).

Nº	Coeficient		Value-p	$R^2_{ajust.}$	S_{yx} (m^3)	In (%)	AIC	CI	EV (m^3)
	β 0	3.70E-05	3.00E-04	0.97	0.02	8.74	137.27	0.075	95.64±2.15
1	β 1	2.827	2.00E-16						
	β 2								
	β 0	-8.55172	2.00E-16	0.96	0.04	7.87	-374.02	0.074	100.17±1.92
2	β 1	2.43469	2.00E-16						
	β 2								
	β 0	-1.98E-01	2.20E-05	0.94	0.04	13.18	-201.58	0.073	104.46±2.09
3	β 1	1.47E-03	2.00E-16						
	β 2								
	β 0	4.49E-01	6.60E-09	0.96	0.03	10.38	-280.14	0.073	104.46±2.12
4	β 1	-6.11E+01	2.00E-16						
	β 2	2.14E-03	2.00E-16						
	β 0	2.13E-05	2.76E-08	0.99	0.03	5.29	-29.49	0.075	96.71±2.16
5	β 1	2.37E+00	2.00E-16						
	β 2	8.38E-01	2.00E-16						
	β 0	-9.40561	2.00E-16	0.99	0.03	3.51	-641.79	0.074	103.50±2.03
6	β 1	2.03117	2.00E-16						
	β 2	0.86905	2.00E-16						
	β 0	-1.69E-02	4.35E+02	0.99	0.02	6.46	-439.57	0.073	97.14±2.14
7	β 1	6.60E-05	2.00E-16						
	β 2								
	β 0	1.86E-05	1.60E-07	0.98	0.02	5.68	-6.58	0.075	104.46±2.16
8	β 1	1.11E+00	2.00E-16						

	β 2								
	β 0	-4.40E-03	8.48E+02	0.98	0.02	6.44	35.95	0.073	104.46±2.14
9	β 1	5.08E-06	1.46E-07						
	β 2	1.09E+00	2.00E-16						

Volume monitoring after forest management:

Forest management in the TNF is done with the prior planning of the trails. The logs are removed using Skidder from the steel cable, in order to reduce damage to the remaining vegetation. The volume estimate for the year 2010 was 285.83 $m^3.ha^{-1}$ and 252.41 $m^3.ha^{-1}$ for 2011. Thus, the volumetric loss in APU 5 (2010-2011) was 33, 42 ± 6.31 $m^3.ha^{-1}$, while the exploration, in the work of Blanc *et al.* (2009), one year after the management, was around 32.51 $m^3.ha^{-1}$ for the Skidder traffic, an amount equivalent to that of this study. The volume of felled trees ranged from 19.80 to 51.64 $m^3.ha^{-1}$ and destroyed from 3.16 to 7.02 $m^3.ha^{-1}$ in Suriname (Jonkers, 2003).

The mortality rate was 8.49% after management and this value must be related to high losses that occur with the fall of trees and traffic of machinery. In the study conducted at the TNF at km 67 of BR-163, mortality rates for all species and for commercial ones were 2.4 and 1.2%, respectively, for the period 1981-1987 (Silva *et al.*, 1995) And in Manaus in the BIONTE project of 3.0% per year (Chambers *et al.* 2004) and for an exploratory treatment with a 32% reduction of the basal area the mortality rate was 1.87% ± 0.62 for the From 1990 to 2007 (Lima, 2010).

The study conducted in a forest management company in the state of Amazonas for the period from 2001 to 2014, mortality rates were from 5.91% to 1.47% for the same time interval (Souza *et al.*). In a Brazilian forest subject to forest management (average cut intensity of 21 $m^3.ha^{-1}$), mortality rates of damaged trees were higher than those not damaged during the year after extraction, but were lower in the next 2-5 years (Mazzei *et al.*, 2010).

However, mortality of smaller trees is often higher in harvested forests compared to intact forests, since logging and logging may result in damage to non-target trees (Picard *et al.*, 2012). The impact of management has effects on the structure of the forest. The mortality of large trees in managed forests is high compared to intact forests, since large trees generally have higher value wood and are more likely to be extracted (Lindenmayer *et al.*, 2013).

In TNF, the exploration intensity corresponded to 17.60 $m^3.ha^{-1}$ for APU 5. When the volumetric variations in the period from 2010 to 2011 are evaluated, these are differentiated throughout the forest structure. This may correspond to the efficiency of forest activity planning, which minimizes the impact on the forest structure by targeting future cutting cycles.

Martins *et al.* (2015) suggest that the higher the intensity of exploitation applied in the larger area will be the residual damage and loss of wood. The central Amazonia, in a management area, with an exploitation intensity of 17 m³.ha-1, the exploration effect was vital for all species and for some beneficial, improving its performace in the management site (Darrigo *et al.* 2016).

The recovery of the forest is due to the techniques used by COOMFLONA, responsible for carrying out forest management in the FNT. Due to having an intensity of 17.60 m³.ha-1, lower than that established by Law (30 m³.ha-1), the forest, besides not having large losses between the classes, obtained a good timber recovery. This is important not only from the commercial point of view but also from the ecological point of view, considering that forest management besides generating income also contributes to forest conservation. These results corroborate with the theory that forest resources can be used over the years as long as they are properly exploited, thereby validating the sustainability of forest management.

When evaluating the volumetric variations in the period from 2010 to 2011, these are differentiated throughout the forest structure. This may correspond to the efficiency of forest activity planning, which minimizes the impact on the forest structure by targeting future cutting cycles. For a planned exploration, where 37 m³.ha-1 was removed, loss of individuals was 4.5 tree-ha-1 (Johns *et al.*, 1996), while the present study counted a withdrawal of 1.5 trees -1.

The size classes respond according to the management impact level, with the highest volumetric losses of wood being in the classes of DBH ≥100 (21.86 $m^3.ha^{-1}$), 90–100 (3.53 $m^3.ha^{-1}$), 80–90 (2.64 $m^3.ha^{-1}$), 70–80 (1.60 $m^3.ha^{-1}$), 40–50 (1.73 $m^3.ha^{-1}$) (Figure 4). These values represent the loss of wood during the exploratory activity in the FNT, where most of the classes had a volumetric deficit. This demonstrates how the activity affects the forest stock.

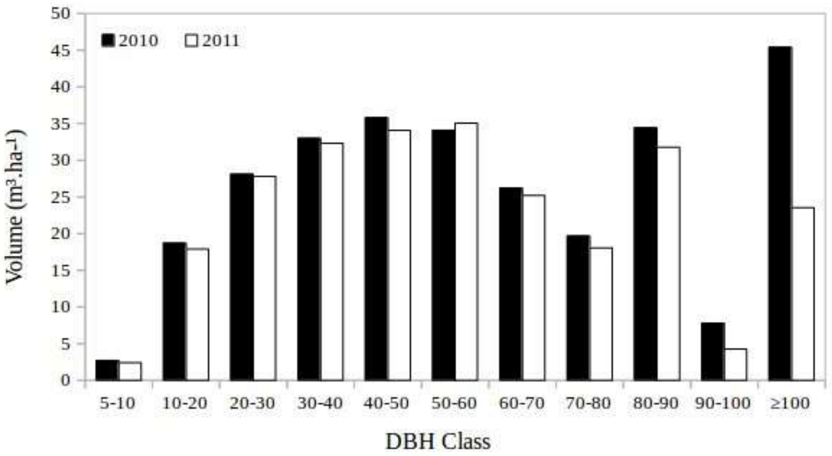

Fig. 4: Volume distribution in the APU for 2010-2011.

Despite the loss in total volume, size classes 50–60 had a volumetric increase over that time interval. This shows that some trees continued to grow even after activity in the area, this may be related to the low level of damage in the DBH class. The increment of the size classes benefited in the management corresponds to 0.98 ± 0.15 m³.ha^{-1} a lower value, when compared to Silva *et al*. (1995), obtained 1.8 m³.ha^{-1}.ano^{-1} in TNF for trees of DBH≥5 cm after 13 years of forest exploitation.

Thus, inventory from DBH ≥ 5 cm is important to assess the impact of forest management across the forest structure. With this, it is possible to have the representation of all strata of vegetation and how these are affected by the machinery and change in the ambient conditions caused by the opening of clearings.

In APU 5 the class of DBH 50–60 may have benefited from the canopy opening and the increase in brightness level. This contributed to an increase after the activity. Therefore, it corroborates the principle that forest management, when properly executed, can reduce damages and favor the development of other species.

This may be because the exploitation in tropical forests does not have a uniform effect on the forest structure (Burivalova *et al*., 2014). The growth and survival of trees varies with the type and severity of forest harvesting damage (Shenkin *et al*., 2015). The size of the clearing generated during the forest activity influences the microclimatic conditions, benefiting the species of the lower strata (Jardim *et al*., 2007).

The process of regeneration of tropical forests starts after the formation of clearings, which provoke edaphoclimatic changes, leading to forest succession (Whitmore, 1990). Thus, these alterations can also be considered in the management area, since canopy opening occurs during this process.

In the work of Oliveira (2005) at the TNF at km 114, in the 80's, the forest was submitted to four treatments with an average intensity of 61.1 m³.ha^{-1}. In that, it was verified that alterations in the structure of the vegetation are linked to the intensity of intervention of the methods used in the exploration. Thus, the larger the canopy opening, the greater the volume reduction of individuals.

To maintain biodiversity, resilience and productivity in managed forests, it is important to have a detailed understanding of these ecosystems, identifying at what level of use and handling thresholds there may be, since the system may lose the ability to recover from interventions (Thompson , 2011).

The species with higher volumetry in the year of 2010 had variation for the post exploratory year. While some recorded losses, others obtained a volumetric increase (Table 4). This variation in volume demonstrates the effect of management on each species after the activity, as well as, some classes of DBH had losses and gains in volume after the period.

Table 4: List of 10 species with higher volume in m³.ha^{-1} before and after handling

Specie	Family	2010	2011
Eschweilera blanchetiana Miers.	Lecythidaceae	19.25	18.96
Pouteria cladantha Sandwith	Sapotaceae	19.22	19.21
Tabebuia impetiginosa (Mart. ex DC.) Standl.	Bignoniaceae	16.71	10.89
Manilkara huberi (Ducke) Chevalier	Sapotaceae	10.50	10.53
Carapa guianensis Aubl.	Meliaceae	9.87	10.02
Aniba burchellii Kosterm.	Lauracea	9.48	1.33
Geissospermum sericeum Benth. & Hook.f. ex Miers	Apocynaceae	9.11	9.14
Buchenavia capitata (Vahl) Eichler	Combretaceae	8.73	8.77

Nectandra sp.	Lauraceae	8.15	6.19
Apuleia leiocarpa (Vogel) J. F. Macbr.	Fabaceae	7.95	0.00

Conclusion:

The use of fallen wood for the adjustment of the models was essential for the representation of each diametric class of the adjusted models. With the use of this methodology, in the area of management, a number of individuals were obtained in a short time, without having to shoot down several trees for the cubing process. In this way, the method proved to be quite efficient, and ecologically conservative, because it is directed to fallen trees in a natural way or in the exploratory activity.

COOMFLONA in its forest inventories may use models with an error of less than 10% for their estimates. However, the use of the simple input equation (Hush), besides providing satisfactory results, allows a less effort to obtain the variable in the field, due to the use of DAP only. This enabled both inventory work faster and cheaper. In this way, this equation can be considered the most efficient, considering the cost benefit in its application.

The determination of the volume variation (2010 to 2011) of the species after the forest management is very important for the projection of future stocks and evaluation of the vegetation structure. From these data it was possible to verify which trees had greater volumetric losses during the forest exploration, and also to know which were the least affected. This is important to define the species that can be exploited in the future, based on the remaining stock and growth levels of these individuals after the first cutting cycle. And since the models were adjusted for trees from 5 cm DBH, it was possible to know the effect caused by the forest activity in each size class, which is fundamental for the evaluation of the management quality in each forest stratum.

These equations may facilitate planning of future forest resources by considering smaller size classes, improving inventory projection for the next cutting cycle, reducing waste, and helping forest conservation. Thus, this work may contribute to research on wood estimation in the region, and especially to areas of forest management. These equations can be used over time to monitor the COOMFLONA area and thus obtain more information about the resilience of the vegetation.

In this job, a factor that may have contributed to the fact that a 50–60 cm diametric class had a post-exploratory volumetric increment was the intensity of exploration in the TNF. When compared with other works the value was low, and the fewer trees are felled the less damage will be caused to the remaining vegetation. This could contribute to the recovery of the forest in a shorter period, which would be beneficial in productive terms considering the next cutting cycle.

With this, the management used in the FNT enabled a positive response for some species and class of forest size. This shows that the vegetation reacts to the form of management used, which can make the difference in the recovery of the forest structure. With the use of these equations, it will be possible to monitor the timber inventory, which will help in planning for the next exploratory cycle. In this way, to know how each species behaves in function of the changes caused in the environment, such as the microclimatic changes caused by the opening of clearings in the area of forest management.

ACKNOWLEDGMENTS

To the Fundação de Amparo a Pesquisa do Amazonas (FAPEAM) for the PhD scholarship (POSGRAD / 2014), the Federal University of the West of Pará (UFOPA) and the Mixed Cooperative of Flona Tapajós Verde (COOMFLONA) for logistical support for the performance of the activity And the National Institute of Research of the Amazon – INPA Logistic support, training and scientific support.

REFERENCES

Akindele, S.O., J. Dyck, F.F. Akindunni, P.M. Papka, O.A. Olaleye, 2001. Estimates of Nigeria's Timber Resources. In Popoola L, Abu JE, Oni PI. (Eds.), Forestry and National Development, proceedings of the 27 th Annual Conference of the Forestry Association of Nigeria, Abuja, pp: 1-11.

Akindele, S.O. and V.M. Lemay, 2006. Development of tree volume equations for common timber species in the tropical rain forest area of Nigeria. Forest Ecology and Management, 226: 41-48.

Altriell, D., A. Branthomme, R. Tavani, 2010. Assessing growing stock and stock changes through multi-purpose national forest monitoring and assessment, FAO Forest Resources Assessment Programme Working paper, Rome. Available at: www.fao.org.

Anderson, D.R., K.P. Burnham, G.C. White, 1994. AIC model selection in overdispersed capture-recapture data. Ecology, 75: 1780-1793.

Avery, T.E. and H.E. Burkhart, 2002. Forest Measurements, 5th ed. McGraw-Hill Higher Education, New York, USA.

Batista, J.L.F., H.T.Z. Couto, D.F. Silva Filho, 2014. Quantificação de recursos florestais: Árvore, arvoredos e florestas. 1ª Edição, São Paulo, oficina de textos.

Blanc, L., M. Echard, B. Herault, D. Bonal, E. Marcon, J. Chave, C. Baraloto, 2009. Dynamics of aboveground carbon stocks in a selectively logged tropical forest. Ecological Applications, 19(6): 1397-1404.

Brasil, 2002. Lei n. 9.985, de 18 de Junho de 2000: Sistema Nacional de Unidades de Conservação da Natureza (SNUC). 2.ed. MMA, Brasília, Distrito Federal, pp: 52.

Burnham, K.P. and D.R. Anderson, 2010. Information and likelihood theory: A basis for model selection and inference. In: . Model selection and multimodel inference. New York: Springer. Chap. 2: 49-97.

Burivalova, Z., C.H. Sekercioğlu, L.P.P. Koh, Ç.H. Şekercioğlu, L.P.P. Koh, 2014. Thresholds of Logging Intensity to Maintain Tropical Forest Biodiversity. Current Biology, 24: 1893–1898. doi:10.1016/j.cub.2014.06.06

Campos, J.C.C. and H.G. Leite, 2009. Mensuração florestal:perguntas e respostas. Viçosa: Editora UFV.

Cháidez, J.N., 2009. Allometric equations and expansion factors for tropical dry forest trees of Eastern Sinaloa, Mexico. Tropical and Subtropical Agro-ecosystems, 10: 45-52.

Clement, C.R. and N. Higuchi, 2006. A floresta amazônica e o futuro do Brasil. Ciência e Cultura, 58(3): 44-49.

Chambers, J.Q., N. Higuchi, L.M. Teixeira, J. Santos, S.G. Laurance, S.E. Trumbore, 2004. Response of tree biomass and wood litter to disturbance in a Central Amazon forest. Oecologia, 141: 596-611.

Colpini, C., D.P. Travagin, T.S. Soares, V.S.M. Silva, 2009. Determinação do volume, do fator de forma e da porcentagem de casca de árvores individuais em uma Floresta Ombrófila Aberta na região noroeste de Mato Grosso. Acta Amazonica, 39(1): 97-104.

Darrigo, M.R., E.M. Venticinque, F.A.M. Santos, 2016. Effects of reduced impact logging on the forest regeneration in the central Amazonia. Forest Ecology and Management, 360: 52-59.

Espírito-Santo, F.D.B., Y.E. Shimabukuro, L.E.O.C. Aragão, E.L.M. Machado, 2005. Análise da composição florística e fitossociológica da floresta nacional do Tapajós com o apoio geográfico de imagens de satélites. Acta Amazônica, 35(2): 155-173.

Field, A., 2009. Descobrindo a estatística usando SPSS. 2º ed. - Porto Alegre: Artmed.

Gonçalves, F.G. and J.R. Santos, 2008. Composição florística e estrutura de uma unidade de manejo florestal sustentável na Floresta Nacional do Tapajós, Pará. Revista Acta Amazônica, 38: 229-244.

Instituto Brasileiro De Geografia E Estatística – IBGE. 2012. Manual Técnico da vegetação do Brasil. Rio de Janeiro, segunda edição.

IPCC (Intergovernmental Panel on Climate Change). 2006. IPCC Guidelines for National Greenhouse Gas Inventories. Em CD ou no site: www.ipcc.ch.

Jardim, F.C.S., D.R. Serrão, T.C. Nemer, 2007. Efeito de diferentes tamanhos de clareiras, sobre o crescimento e mortalidade de espécies arbóreas, em Moju-PA. Acta Amazonica, Manaus, 37(1): 37-48.

Jonkers, W.B.J., 2003. Long-term effects of logging in a Neotropical rain forest in Suriname. International Expert Metting on Forest and water, Chiba, Japan. November. Acessoem:http://www.rinya.maff.go.jp/codeh2003/PART_4/WYB_Jonkers_(Netherland).pdf

Lanssanova, L.R., J.A. Ubialli, J.E. Arce, A.L. Pelissari, C.M.C. Favalessa, R. Drescher, 2013. Avaliação de funções de afilamento para a estimativa de diâmetro de espécies florestais comerciais do bioma Amazônico Mato-Grossense. Floresta, Curitiba, PR., 43(2): 215-224.

Lima, A.J.N., 2010. Avaliação de um sistema de inventário florestal contínuo em áreas manejadas e não manejadas do estado do Amazonas (AM). 165 p. Tese (Doutorado em Biologia Tropical e Recursos Naturais) – Instituto Nacional de Pesquisas da Amazônia. Universidade Federal do Amazonas, Manaus.

Lindenmayer, D.B., W.F. Laurance, J.F. Franklin, G.E. Likens, S.C. Banks, W. Blanchard, P. Gibbons, K. Ikin, D. Blair, L. Mcburney, A.D. Manning, J.A.R. Stein, 2013. New policies for old trees: averting a global crisis in a keystone ecological structure. Conservation Letters, 7: 61-69 doi:10.1111/conl.

Gimenez, B.O., F.E. Danielli, C.K.A. Oliveira, J. Santos, N. Higuchi, 2015. Equações volumétricas para espécies comerciais madeireiras do sul do estado de Roraima. Scientia Forestalis., 43(106): 291-301.

Higuchi, F.G., J.D.P. Siqueira, A.J.N. Lima, A. Figueiredo Filho, N. Higuchi, 2012. Influência do tamanho da parcela na precisão da função de distribuição diamétrica de weibull na floresta primária da Amazônia Central. Floresta, Curitiba, PR., 42(3): 599-606.

Johns, J.S., P. Barreto, C. Uhl, 1996. Logging damage during planned and unplanned logging operations in the eastern Amazon. Forest Ecology and Management, 89: 59-77.

Koehler, H.S., L.F. Watzlawick, F.F. Kirchner, A.F. Valério, 2005. Fontes de erros na estimativa de biomassa e carbono fixado em floresta Ombrófila mista. Biomassa & Energia, 2(1): 69-77.

Malhi, Y., T. Roberts, R.A. Betts, T.J. Killeen, W. Li, C.A. Nobre, 2008. Climate change, deforestation, and the fate of the Amazon. Science, 319: 169-172.

Martin, H.G. and N. Goldenfeld, 2006. On the origin and robustness of power-law species-area relationships in ecology. Proceedings of the National Academy of Science USA 103: 10310-10315.

Martins, P.A., A. Newton, M. Pfeifer, M. Khoo, J. Bullock, 2015. The effects of reduced impact logging and logging intensity on stand damage, biomass loss and tree species richness in tropical forests: a meta-analysis. 2015. *PeerJ PrePrints,* 3:e846v1:https://doi.org/10.7287/peerj.preprints.846v1.

Masota, A.M., E. Zahabu, R.E. Malimbwi, O.M. Bollandsås, T.H. Eid, 2014. Volume models for single trees in tropical rainforests in Tanzania. Journal of Energy and Natural Resources, 3(5): 66-76.

Mazzei, L., P. Sist, A. Ruschel, F.E. Putz, P. Marco, W. Pena, J.E.R. Ferreira, 2010. Above-ground biomass dynamics after reduced-impact logging in the Eastern Amazon. For. Ecol. Manage, 259: 367-373.

Nogueira, E.M., P.M. Fearnside, B.W. Nelson, R.I. Barbosa, E.W.H. Keizer, 2008. Estimates of forest biomass in the Brazilian Amazon: new allometric equations and adjustments to biomass from wood-volume inventories. Forest Ecology and Management, 256: 1853-1867.

Oliveira, L.C., 2005. Efeito da exploração da madeira e de diferentes intensidades de desbastes sobre a dinâmica da vegetação de uma área de 136 ha na floresta nacional do Tapajós. São Paulo – Piracicaba.

Silva, J.N.M., J.D.C. Alves Lopez, 1984. Inventário florestal contínuo em florestas tropicais: a metodologia utilizada pela EMBRAPA/CPATU na Amazônia Brasileira. In. Simposio Sobre Inventário Florestal, (2.:1984:Piracicaba) Anais Piracicaba. USP, pp: 65-79.

Segura, M., M. Kanninen, 2005. Allometric models for tree volume and total aboveground biomass in a Tropical Humid Forest in Costa Rica. Biotropica, 37(1): 2-8.

Oboite, F.O., V.D. Ade-Oni, 2014. Comparative study of some non-linear models for predicting the yield of Gmelina arborea plantation. Journal of Applied and Natural Science, 6(2): 738-743.

Picard, N., S. Gourlet-Fleury, É. Forni, 2012. Estimating damage from selective logging and implications for tropical forest management. Canadian Journal of Forest Research, 42(3): 605-613, doi:10.1139/x2012-018.

Santana, A.C., Á.L. Santana, M.M. Amin, N.L. Costa, 2017. Evaluation of nonlinear econometric models to estimate the wood volume of amazon forests. African Journal of Agricultural Research, 12(6): 382-388, doi: 10.5897/AJAR2016.11897

Schneider, P.R., P.S.P. Schneider, C.A.M. Souza, 2009. Análise de regressão aplicada a engenharia florestal. Santa Maria, RS. 2º edição.

Shenkin, A., B. Bolker, M. Peña-Claros, J.C. Licona, F.E. Putz, 2015. Fates of trees damaged by logging in Amazonian Bolivia. Forest Ecology and Management, 357: 50-59.

Silva, J.N.M., J.O.P. Carvalho, J.C.A. Lopes, B.F. Almeida, D.H.M. Costa, L.C. Oliveira, J.K. Vanclay, J.P. Skovsgaard, 1995. Growth and yield of a tropical rainforest in the Brazilian Amazon 13 years after logging. Forest Ecology and Management., 71: 267-274.

Scolforo, J.R.S. and S.T. Silva, 1993. O conceito de "floresta balanceada de Meyer" como opção para intervenção em cerrado senso stricto. In: Congresso Florestal Brasileiro, 7, 1993, Curitiba. Anais. Curitiba: SBS, 1: 378-381.

Snipes, M. and D.C. Taylorn, 2014. Model selection and Akaike Information Criteria: An example from wine ratings and prices. Wine Economics and Policy, 3: 3-9.

Soares, C.P.B., F. Paula Neto, A.L. Souza, 2007. Dendrometria e inventário florestal. Viçosa: Editora UFV.

Socha, J. and M. Kulej, 2007. Variation of the tree form factor and taper in European larch of Polish provenances tested under conditions of the Beskid Sądecki mountain range (southern Poland). Journal of forest science, 53(12): 538-547.

Souza, M.A.S., C.P. Azevedo, C.R. Souza, M. França, E.L. Vasconcelos Neto, 2017. Dinâmica e produção de uma floresta sob regime de manejo sustentável na Amazônia central. Floresta, Curitiba, PR. 47(1): 55-63.

Tonini, H. and R.A. Borges, 2015. Equação de volume para espécies comerciais em Floresta Ombrófila Densa no sul de Roraima. Pesquisa florestal brasileira, Colombo, 35(82): 32-37.

Thompson, I., 2011. Biodiversity, ecosystem thresholds, resilience and forest degradation. Unasylva, 238: 25-30.

Vieira, S., P.B. Camargo, D. Selhorst, R. Silva, L. Hutyra, J.Q. Chambers, I.F. Brown, N. Higuchi, J. Santos, S.C. Wofsy, S.E. Trumbore, L.A. Martinelli, 2004. Forest structure and carbon dynamics in Amazonian tropical rain forests. Oecologia, 140: 468-479.

West, G.B., J.H. Brown, B.J. Enquist, 1997. A General Model for the Origin of Allometric Scaling Laws in Biology. Science, pp: 276.

Whitmore, T.C., 1990. An introduction to tropical rain forest. Oxford: Clarendon Press.

Xiao, X., E.P. White, M.B. Hooten, S.L. Durham, 2011. On the use of logtransformation vs. nonlinear regression for analyzing biological power-laws. Ecology, 92: 1887-1894.

Zuur, A.F., E.N. Ieno, G.M. Smith, 2007. Analyzing ecological data. New York: Springer.