Journal of Sustainable Forestry

ISSN: 1054-9811 (Print) 1540-756X (Online) Journal homepage: https://www.tandfonline.com/loi/wjsf20

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To cite this article: Robson B. de Lima, Rinaldo L. Caraciolo Ferreira, José A. Aleixo da Silva, Marcelino C. Guedes, Cinthia P. de Oliveira, Diego A. Silva da Silva, Renan M. Santos, Erik Patrik F. Carvalho & Robson Matheus de A. Silva (2019) Lumber volume modeling of Amazon Brazilian species, Journal of Sustainable Forestry, 38:3, 262-274, DOI: 10.1080/10549811.2018.1546596

To link to this article: https://doi.org/10.1080/10549811.2018.1546596

Published online: 22 Nov 2018.

JOURNAL OF SUSTAINABLE FORESTRY
2019, VOL. 38, NO. 3, 262–274
https://doi.org/10.1080/10549811.2018.1546596

Lumber volume modeling of Amazon Brazilian species

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ABSTRACT

Accurate estimates of lumber volume become an important indicator of production and monetary value for a sawmill. However, such estimates are only obtained directly after logging, and no accurate predictions are made for the Amazonian commercial species. In this sense, the objective was to generate equations of lumber volume for commercial species in Amapá (a state in northern Brazil) by adjusting and selecting regression models. The data of 50 logs processed from 10 commercial species were collected, as well as the quantity and volume of sawn products. Sixteen (16) statistical models were adjusted and statistical weights were performed to evaluate the quality of the estimates and to select the best equation by species. In summary, precise estimates of lumber volume can be obtained by the nº16 model for *Carapa guianensis*, while the models nº13 and nº15 are the most recommended for *Dinizia excelsa* and *Hymenolobium petraeum*, respectively. Model 7 presented the best adjustments for *Hymenaea courbaril* and *Vochysia guianensis*. Equations using only the log diameter variable suggest less precise estimates. Also, the log volume should be considered as an important predictor variable to obtain the serrated/lumber volume for the different Amazonian commercial species.

KEYWORDS

Amazon rainforest; forest production; regression analysis; sawmill

Introduction

In Brazil, among the states that comprise the Legal Amazon, the State of Amapá is the sixth largest producer of lumber/sawn timber, being ahead of only Roraima and Acre (Hummel, Alves, Pereira, Veríssimo, & Santos, 2010). With approximately 70% of its forest cover intact, it has a high timber volume and diversity of commercial importance, which has resulted in the creation of federal and state public forests to promote sustainable forest management (IBGE, 2012; IEF, 2017; Rabelo, 2008).

Although the timber industry in the Amazon has been studied since the 1960's (Lentini, Veríssimo, & Pereira, 2005; Pereira, Santos, Vedoveto, Guimarães, & Veríssimo, 2010; Santos, Pereira, & Veríssimo, 2013; Veríssimo et al., 1999; Veríssimo, Lentini, & Lima, 2002; Veríssimo & Pereira, 2014), the volumetric quantification of Amazonian species in Amapá is still performed based on the form factor of 0.7 proposed by Heinsdijk and Bastos (1963). This value was generalized for different species, sites, formations and forest

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types, causing systematic errors in the productive chain from forest management all the way to the lumber in transformation industries (Cysneiros, Pelissari, Machado, Figueiredo Filho, & Souza, 2017; Rolim, Couto, Jesus, & França, 2006).

Until now, indirect estimates of timber production in the native forests of Amapá are only obtained considering the “standing tree”, without the use of generic and/or specific predictive models. On the other hand, information is still scarce in relation to the volumetric lumber production, which in fact contributes to a lack of precise statistics for the region and especially for Amapá in the wood processing industries.

Accurate estimates of lumber volume are an important indicator of the production of a species in a sawmill, and consequently generate useful information about the quantity of sawn products/lumber and waste generation, and further and equally important they support an estimation of the monetary value (costs and revenues) of the product. The lumber volume is obtained by measuring the width (W), thickness (T) and length (L) of a given product. The sum of the volumes of all the generated products from sawing logs makes up the total lumber volume of a species or set of species.

In this context, the development and application of lumber volume equations can become essential for calculating the indirect quantification of products, as well as to generate reliable valuation information based on the measurements of wood logs. In order to fill this gap, regression analysis has been used with an emphasis on solving most of the forest problems, especially when the intention is to obtain estimates based on biometric relations (Schneider, Schneider, & Souza, 2009). Thus, volume equations are obtained after the adjustment of statistical models which relate a difficult to obtain variable (in this case the lumber volume) with variables that are more easily and consequently cheaper to measure, such as the mean diameter, length and volume of the log, although the latter is not commonly used (Couto & Bastos, 1987; Gomes & Garcia, 1993).

The policy of concession of public forests for the development of the forestry sector in the State of Amapá currently seeks to regulate and increase wood production, and for that reason obtaining the lumber volume is fundamental for guiding the action plans of the industries that will be supplied. Thus, this study was developed with the purpose of generating lumber volume equations for commercial species in Amapá through the adjustment and selection of regression models.

Material and methods

Description of the study site and species selection

The study was developed in a medium-sized sawmill that processes up to 20,000 m^3 of wood logs per year. The sawmill is located in the rural area of the Municipality of Porto Grande, Amapá (N 00° 41′ 53.91” W 051° 26′,4.27”), approximately 130 km distance from Macapá-AP. Access is via the perimetral highway north km 02.

The volumetric production of wood logs and lumber of ten commercial species that in addition to being established by the consumer market as the most used are also those that presented processing of more than 50 logs during the analyzed period. These species are also provided from authorized managements by annual operating plans which present good economic return for the company, including: *Dinizia excelsa* Ducke (popular name in Brazilian Portuguese – *Angelim vermelho); Dipteryx odorata* W. (*Cumarú); Manilkara* *huberi* W. (*Massaranduba); Carapa guianensis* Aubl. (*Andiroba); Hymenolobium petraeum* Ducke (*Angelim pedra); Goupia glabra* Aubl. (*Cupiúba); Tabebuia serratifolia* Vahl. Nichols. (*Ipê); Hymenaea courbaril* W. (*Jatobá); Ocotea rubra* Mez (*Louro vermelho*) and *Vochysia guianensis* Aubl. (*Quaruba tinga*).

Sampling and data collection

Fifty (50) logs with an average diameter greater than 50 cm were randomly selected for each species. The diameters of the base and top with the bark, in addition to the total length of each log were measured, and the volume was estimated by strict cubic measurement. Hollow measurements were also carried out by measuring the cross-section of the dimensions that they occupied in the log. Only one measurement was made for logs that did not have any length distortions.

The sample adequacy calculation was performed to estimate the optimal number of logs that would be representative for the study of lumber volume models. An acceptable 10% error limit with a 5% probability was adopted for all cases. Thus, data were considered for an infinite population according to Equation 1:

$$n = \frac{t_{\alpha}^{2} S^{2}}{T^{2} + \frac{t_{\alpha}^{2} S^{2}}{N}} \quad (1)$$

in which: n = optimal number of logs; t^2 = pre-determined Student's t-test value (α = 0.05); S^2 = sample variance; E^2 = admitted error limit (10%); N = total number of logs measured (50).

The log volume was estimated in accordance with the provisions in CONAMA Resolution number 411, from May 6th, 2009. The volume was calculated individually by the Smalian geometric method(Equation 2):

$$V_i = \frac{\pi}{4} \times \left(\frac{g_i + g_{i+1}}{2} \right) \times W \quad (2)$$

in which: V_i = volume of the section i; g_i = cross-sectional area of the base in m^2; g_{i+1} = cross-sectional area of the top in m^2; W = length of the section in m.

The wood logs from each species were transformed by tangential sawing in a vertical band saw, generating products of different shapes and sizes according to the sawmill's commercial demand. Although the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA, 2009) standardizes the parts and products according to defined dimensions, the log sawing of the species generated products mostly defined as slats(with dimensions ranging from 0.01 to 0.040 cm in thickness), rafters (0.2 to 0.40 cm wide), and boards-and-battens with widths and thicknesses greater than 4 cm. The total length of each product did not exceed 10 m according to the definition of sectioning in log routing/transport.

The thickness (T) measurements at each end were obtained using a caliper. The width (W) at each end of the product and the length (L) were measured with a measuring tape. The volume of each product was determined according to Equation 3:

$$V_p = T \times W \times L \quad (3)$$

After determining the volumes of the products, they were summed up to obtain the lumber volume for each processed log.

Statistical modeling

The first effort was made in the exploratory data analysis and the main descriptive measures for the dendrometric variables of each species were analyzed. The Shapiro-Wilk test (α = 0.01) was applied to the lumber volume data for all analyzed species with the purpose of verifying the normality of the data. Logarithmic transformation was performed when non-normality and/or heterogeneous variances were verified. The box-plot technique was used to verify the distribution and symmetry of the lumber volume for each species.

To estimate the lumber volume, the models were adapted based on common volumetric models typical of the Amazon region (Barros & Silva Junior, 2009; Higuchi et al., 2015; Rolim et al., 2006; Silva, Carvalho, Lopes, & Carvalho, 1984). In addition, inclusion of the log volume variable was performed in the regression analysis as a predictor for lumber volume. Thus, 16 statistical models defined as single and multiple (models) were tested (Table 1).

The parameters of the arithmetic models (1–15) were estimated using the least squares method, and their significance was verified by the t-test (α = 0.05). The non-linear model (16) was adjusted by modifying the Levenberg-Marquardt algorithm using the *minipack.lm* package. All analyzes were performed using the Software R program (R Development Core Team, 2017).

The adjusted equations were analyzed by comparisons of the following statistical criteria (Schneider et al., 2009; Vanclay, 1994):

– Akaike Information Criteria (AIC):

$$AIC = -2LL + 2k \tag{4}$$

Table 1. Adjusted models for estimating the lumber volume for commercial species in Amapá.

Model	Equations	Input Type
nº1	$Vls = \beta_0 + \beta_1 d + \varepsilon$	Single
nº 2	$Vls = \beta_0 + \beta_1 d + \beta_2 d^2 + \varepsilon$	Single
nº 3	$Vls = \beta_0 + \beta_1 d + \beta_2 d^2 h + \varepsilon$	Multiple
nº 4	$Vls = \beta_0 + \beta 1 d^2 + \varepsilon$	Single
nº 5	$Vls = \beta_0 + \beta_1 d + \beta_2 h + \varepsilon$	Multiple
nº 6	$Vls = \beta_0 + \beta_1 d^2 + \beta_2 h^2 + \varepsilon$	Multiple
nº 7	$Ln\ Vls = \beta_0 + \beta_1 ln\ d + \beta_2 ln\ h + \varepsilon$	Multiple
nº 8	$Ln\ Vls = \beta_0 + \beta_1 ln\ (d^2 h) + \varepsilon$	Multiple
nº 9	$Vls = \beta_0 + \beta_1 V + \varepsilon$	Single
nº 10	$Vls = \beta_0 + \beta_1 V + \beta_2 V^2 + \varepsilon$	Single
nº 11	$Vls = \beta_0 + \beta_1 V + \beta_2 V^2 + \beta_3 V^3 + \varepsilon$	Single
nº 12	$Vls = \beta_0 + \beta_1 V + \beta_2 V^2 + \beta_3 V^3 + \beta_4 V^4 + \varepsilon$	Single
nº 13	$Ln\ Vls = \beta_0 + \beta_1 ln\ d + \beta_2 lnV + \varepsilon$	Multiple
nº 14	$Ln\ Vls = \beta_0 + \beta_1 lnV + \varepsilon$	Single
nº 15	$Vls = \beta_0 + \beta_1 V + \beta_2 d + \varepsilon$	Multiple
nº 16	$Vls = \beta_0 * d \wedge \beta_1 * h \wedge \beta_2 + \varepsilon$	Multiple

In which: β_i = parameters to be estimated; V = volume of log;d = mean diameter of the log; h = log length in meters; Vls = volume sawed in cubic meters; ε = random error; and Ln = logarithm on the neperian basis (e = 2.7128).

which: LL is the log-likelihood and k is the number of model parameters. This criterion penalizes the addition of parameters in the analyzed models. It indicates the quality of fit by the equations. The best equation minimizes the AIC value.

–Adjusted coefficient of determination (R^2_{adj}):

$$R^2_{aj} = R^2 - \left[\frac{k-1}{n-k}\right] \times \left(1 - R^2\right) \tag{5}$$

in which: R^2 = coefficient of determination; k = number of model parameters; and n are the number of observations. By this criterion, the closer the value of the adjusted coefficient of determination is to one (1.0) or 100%, the greater the total variation of the data explained by the equation.

–Root-mean-square error (RMSE):

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(V_i - \bar{V}_i\right)^2}{n}} / \bar{V} \tag{6}$$

in which V_i is the lumber volume of each log (i); $\bar{V}_i$ mean of the lumber volumes; and n is the total number of observations. The root-mean-square error indicates the mean quadratic difference between observed and estimated values. The lower the RMSE, the better the estimate accuracy (Mehtätalo, Maltamo, & Kangas, 2006)

- Bias:

$$Bias = \frac{\sum_{i=1}^{n}\left(V_i - \bar{V}_i\right)^2}{n} / \bar{V} \tag{7}$$

Bias indicates a tendency to under or overestimate; it consists of an error measurement and a quality measure of validated equations. The lower its value, the greater the efficiency in the generalizations.

The best equation for each species was chosen by weighing the statistical criteria in the classification ranking. The weighted value was determined with the purpose of summarizing the results and making the selection process easier. Thus, values or weights were assigned to the calculated statistics for the adjusted equations for each species. The statistics were classified according to their efficiency, with weight 1 being assigned for the most efficient and increasing weights for those less efficient. In the case of selecting an equation among the 16 tested equations and taking into account (for example) the Akaike information criterion (AIC), a value of 1 is assigned to the best statistic (lower value of AIC), and increasing values for the others according to the classification order. The same reasoning was applied for the other statistical criteria, ranking them in ascending order and assigning values or weights according to classification order. The weighted value was obtained according to Equation 7:

$$WV = \sum_{i=1}^{n} N_r \times W_i \tag{8}$$

in which: WV is the weighted value of the equation in the ranking; Wi is the weight of the position i; Nr is the number of records that were obtained for the position i. The best equation is the one that presents the lowest WV.

Results

The total lumber volume obtained for the species was 519.92 m^3 with a mean of 1.04 m^3 and mean standard error of 0.53 m^3 (Table 2).In general, these results are in agreement with the standard error values found, suggesting that the sampling of 50 logs for each species is representative for developing the study. The highest average sawn/lumber volume and mean log volume without hollows were obtained for *D. excelsa*, which justifies its larger dimensions in diameter. The *T. serratifolia*, *D. odorata* and *G. glabra* species presented the lowest lumber volume values. The largest mean standard error was obtained for *H. courbaril*, which may indicate logs with slightly larger volumetric production than the other species, and only being behind *D. excelsa*.

As a rule, 75% of the lumber volume data are concentrated between 0.46 and 2.4 m^3 (Figure 1). Although this dendrometric amplitude differs among species, these results were obtained without the exclusion of outliers. Although the box-plot provides information on location and dispersion, its true value lies in the information it provides on the distribution tail. Outliers can negatively affect the decisions to be made from the data analysis if they are not properly considered.

Corroborating these results and according to the normality test (α = 0.01), symmetrical distributions were observed for *D. excelsa* (p-value = 0.728), *D. odorata* (p-value = 0.079), *G. glabra* (p-value = 0.098), *H. courbaril* (p-value = 0.013); *H. petraeum* (p-value = 0.749), *O. rubra* (p-value = 0.675), *T. serratifolia*: (p-value = 0.259), and *V. guianensis* (p-value = 0.202). The other species suggest a slight deviation from normality with asymmetric distributions, in which the mean and median values of lumber volume are not similar.

The overall results obtained in the model adjustments and the statistical weighting can be seen in the supplementary documents. In general, the equations using log volume as an explanatory variable presented estimates with greater precision. Table 3 shows a summary with the best adjustments obtained for each species. The smaller error measures (RMSE% and Bias), AIC, and the higher R^2adj values justify the inclusion of the length and/or log volume variables as predictors, being combined or not with the diameter in the models.

The final equations selected presented significant coefficients by the t-test (α = 0.05) and normality of residues, for all cases. The equations selected for *G. glabra* (Eq. 10;

Table 2. Descriptive measures and the quantification and volumetry of products obtained in sawing 50 logs of 10 commercial species analyzed in a medium-sized sawmill in Porto Grande, Amapá, Brazil. N = Number of logs measured for each species; n = Number of logs that would be sufficient for each species (α = 0.05; df = 49).

	Mean		Amount		mean volume (m^3) ± standard error	
Species	Diameter (cm)	Length (m)	Logs	Lumber	Logs without hollows	Sawn
L. guianensis	55.17	9.83	N = 50; n = 33	2643	2.39 ± 0.90	0.88 ± 0.40
D. excelsa	103.05	5.11	N = 50; n = 37	4551	3.66 ± 0.52	2.01 ± 0.50
D. odorata	62.23	5.52	N = 50; n = 37	3903	1.68 ± 0.43	0.67 ± 0.24
G. glabra	54.17	8.05	N = 50; n = 45	1994	1.73 ± 0.41	0.69 ± 0.17
H. courbaril	67.35	8.05	N = 50; n = 39	5943	2.91 ± 1.22	1.16 ± 0.53
H. petraeum	62.14	5.93	N = 50; n = 39	5000	1.63 ± 0.37	0.89 ± 0.26
M. huberi	58.69	8.87	N = 50; n = 40	4948	2.44 ± 0.99	0.98 ± 0.41
O. rubra	59.69	9.85	N = 50; n = 41	2655	2.75 ± 0.47	1.23 ± 0.29
T. serratifolia	54.14	7.09	N = 50; n = 38	3143	1.64 ± 0.44	0.63 ± 0.16
V. guianensis	64.84	8.02	N = 50; n = 26	6020	2.63 ± 0.95	1.26 ± 0.49
Total	64.14	7.58		40800	2.35 ± 0.97	1.04 ± 0.53

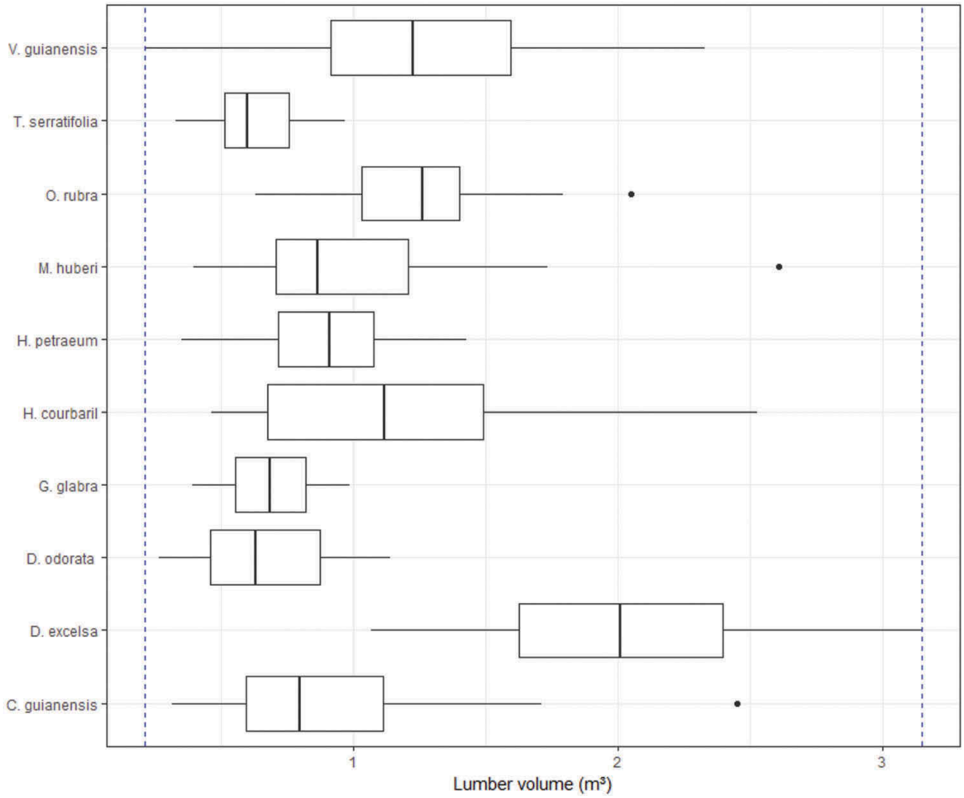

Figure 1. Box-plot of lumber volume for the ten commercial species analyzed in Amapá. The lines inside the boxes indicate the median of the distribution. The dashed lines in blue indicate the lowest and highest quartiles (25% and 75%) of the volumetric data.

Table 3. Coefficients and statistical criteria obtained for the best lumber volume equations obtained for the ten analyzed species in Amapá, Brazil.

Species	Equation	b_0	b_1	b_2	b_3	b_4	AIC	R^2adj	RMSE(%)	Bias	df
L. guianensis	16	5.7E-05	20.068	0.6284	-	-	8.97	0.6116	10.2218	0.0021	2
D. excelsa	13	24.103	−0.6814	10.919	-	-	−59.36	0.7627	5.7295	0.0080	2
D. odorata	5	−16.035	0.0226	0.1560	-	-	−55.71	0.6871	7.6190	0.0370	2
G. glabra	10	−0.1774	0.6416	−0.0785	-	-	−99.52	0.7509	4.7746	0.0136	2
H. courbaril	7	−100.253	18.300	11.702	-	-	−21.90	0.8406	7.9175	0.0168	2
H. petraeum	15	−0.1991	0.6139	0.0015	-	-	−71.02	0.8106	6.7362	0.0267	2
M. huberi	11	−0.5773	10.498	−0.2071	0.0183		−22.56	0.8015	7.1598	0.0417	3
O. rubra	14	−0.8852	10.681	-	-	-	−31.78	0.5439	6.8145	0.0153	1
T. serratifolia	12	−71.347	187.879	−169.570	66.887	−0.9610	−67.72	0.4732	6.6463	0.0324	4
V. guianensis	7	−87.657	19.065	0.4823	-	-	38.16	0.4157	14.9163	0.0624	2

p-value = 0.98), *M. huberi* (Eq. 11; p-value = 0.101), *O. rubra* (Eq. 14; p-value = 0.401) and *T. serratifolia* (Eq. 12; p-value = 0.20) suggest that only the log volume can more accurately estimate the lumber volume (single input model).

The waste versus the adjusted values can be observed In the dispersion graphs, with a smooth curve superimposed mainly on the higher values obtained (Figure 2).

This type of chart shows the curvature (trend or bias) and discrepant values from the confidence interval (Robinson & Hamann, 2011). For all species, there is no evidence which warns about the equation choice due to the low residual amplitude, however it should be considered that the discrepant values suggest a curvature possibly caused by model errors rather than by the data selected in the fit/adjust.

Discussion

Due to their quality of fit, the adjusted logarithmic models compose useful tools to predict the commercial volume of lumber sawed for the different forest species in Amapá. Moreover, the Schumacher and Hall model presented efficient estimates for *H. courbaril* and *V. guianensis* (linear model 7) and it was also most recommended for *L. guianensis* (non-linear model 16). In this case, this result suggests including the variable log length in the estimation of lumber volume, because the models that only use the diameter as a predictive variable assume that trees of different diameters have the same trunk length (Schumacher & Hall, 1933), which is not true for lumber processing of Amazonian commercial species due to the different generated products (Melo, Rocha, Rodolfo Junior, & Stangerlin, 2016; Ribeiro, Gama, & Melo, 2014).

Logarithmic models are often used in Brazil, especially in different forests in the Amazon (Silva & Santana, 2014), although very few studies have applied the transformation back from the log-log scale to the original scale using the corrective factor (Sprugel, 1983; Vibrans, Moser, Oliveira, & de Maçaneiro, 2015). In addition, R^2 is often used to describe the fit quality of the model; however, very few studies have calculated the R^2 for transformed data back (or original scale), evidencing a misleading use of R^2, since it has limitations of use in non-linear models (Anderson-Sprecher, 1994; Tellinghuisen & Bolster, 2011; Vibrans et al., 2015). Other parameters such as RMSE and Bias are rarely calculated based on the original scale of the residues. In addition, robust methods for leveraging the fit quality of models such as the AIC or Bayesian information criterion are rarely used and should be incorporated into lumber volume model fit routines (Zeng, Zeng, & Tang, 2011).This result supports the decision to use regression methods to construct models and estimate their parameters.

Estimates of the parameters associated to each explanatory variable reflect elasticities, showing a proportional change in lumber volume for each percentage change in the respective variable (Silva & Santana, 2014). For example, in equation 13 for *D. excelsa*, for each 1% variation in the log diameter there is an approximate variation of −0.68% for lumber volume, preserving the influence of the fixed log volume. Similarly, there is a 1.09% increase in lumber volume for each 1% increase in the log volume.

However, as shown in the annexes for all species (except for *T. serratifolia*), the inclusion of two or more explanatory variables in model 12 result in effects that were not additive, meaning that no increase in the accuracy of the statistical scores or in the lumber volume estimates were observed. Therefore, it can be assumed that these variables tend to present intercorrelation or collinearity (Scolforo, 2005; Silva, Ferreira, Silva, & Cespedes, 2009; Valente, Queiroz, Pinheiro, & Monteiro, 2011). Although this happened, the Student's t-test becomes important for choosing models with multiple parameters, presenting a value not different from zero and indicating that the variable is not relevant to explain significant variations in the response variable (Mayer & Butler, 1993; Rykiel Jr., 1996; Robinson & Froese, 2004; Adekunle, Nair, Srivastava, & Singh, 2013; Lima et al., 2014; Silva & Santana, 2014).

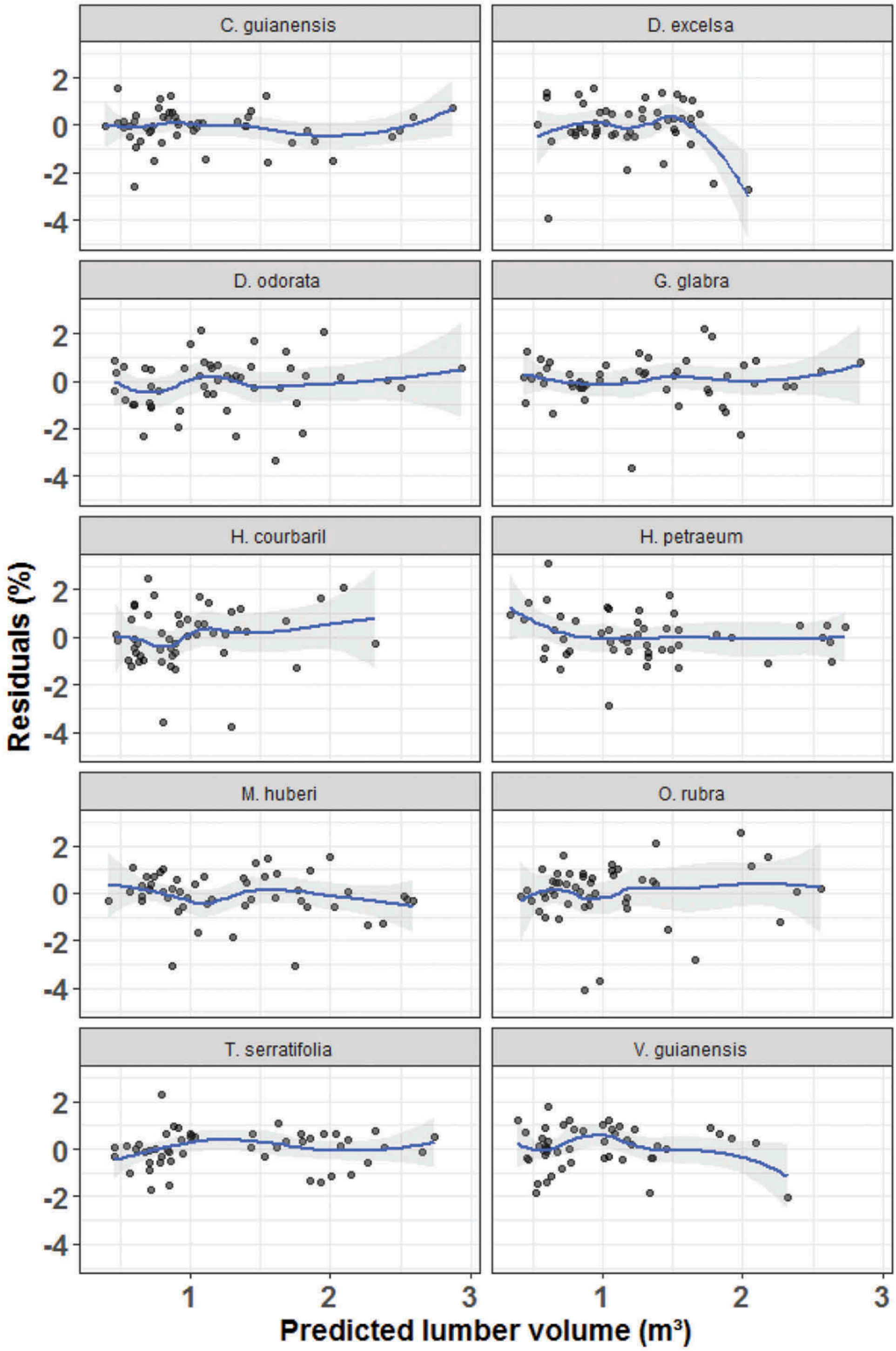

Figure 2. Residual distribution of the best equations for estimating the lumber volume of ten commercial species in Amapá, Brazil.

Equations using log diameter alone as an explanatory variable resulted in adjustments with less statistical precision for all cases. The lower values of R^2_{adj} for these equations highlight a low total variation explained by the regressions. The highest estimate error values and Akaike's information criterion justify the larger bias (RMSE% and Bias) in obtaining the estimated lumber volume, especially for the equations generated by models 1, 2 and 4 for all analyzed cases. Furthermore, the coefficients of these equations were not significant for the t-test ($\alpha = 0.05$), corroborating the worst results in the classification ranking.

It can be seen that the selected equations satisfactorily predict the volume for all species. Lower RMSE and Bias values indicate a small trend of under or overestimations in the generated predictions. These statistics show good measurements of the overall predictive value of the regression equations (Akindele & Lemay, 2006). Draper and Smith (1998) also observed that these criteria are a common measure of quality estimates in regression models, with low values indicating better predictions.

The low residual amplitude and regular distribution of the cluster of points around the regression line suggest variance homogeneity. Moreover, the smaller weights of the regression statistics corroborate the choice of the equations. This analysis highlights the high variability of the dendrometric variables of Amazonian species, reinforcing the use of specific equations for each species since the largest wastes were directly related to larger logs and larger species (Brandeis, Delaney, Parresol, & Royer, 2006; Cysneiros et al., 2017; Lima et al., 2014). It should also be pointed out that the use of longer logs resulting from selected trees does not compromise the adjustment of volumetric models when evaluating different sectioning for cubic measurements and log volume estimations (Ribeiro et al., 2014).

Theoretically, studies on the prediction of lumber volume are crucial for estimating the monetary value of forests, as well as the structuring of production in medium and large sawmills. Pereira et al. (2010) estimated the timber production of the Legal Amazon in 2009 with an average yield of 41% in processing. According to Melo et al. (2016), the quantitative utilization of the transformation of a log into boards, considering a log with bark, occurs in the order of 40% of processed wood, the remaining 60% being allocated: 10% planer shavings, 26% of cutter shavings, 13% of sawdust and 11% of bark.

In the Amazon region, the waste in the timber sector is still very large, despite the technological advances. For every ten cut trees, only five will be used commercially (Mady, 2000). Okai, Frimpong-Mensah, and Yeboah (2004) and Okai and Boateng (2007) also reported that, for each felled tree, almost 50% of the tree volume is left in the forest in the form of branches, crown, and stump. With this loss of wood resources in both exploration and processing, it can be said that most industries are not contributing to their full potential and that environmental compensation services should be developed and applied to native forests.

Thus, new alternatives must be created for the management of the sawn wood production and use of the forest residues from the forest exploitation in several sectors, maximizing their use and minimizing the waste during the production chain, from harvesting to obtaining the product.

Conclusions

Precise estimates of lumber volume should be obtained by models which are adjusted according to the species considered for sawing. Models that use only the log diameter variable suggest less precise estimates. The log volume should be considered as an important predictor variable for obtaining lumber volume of different Amazonian commercial species.

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