EFFECT OF SYSTEMATIC SAMPLING INTENSITY IN THE HYPSOMETRIC RELATIONSHIP OF TEAK STANDS

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- *ABSTRACT: Traditionally in teak stands, systematic sampling is applied to select trees in plots, where their heights are measured to fit hypsometric models, aiming to facilitate its implementation in forest inventories. Therefore, assuming the hypothesis that the hypsometric relationship is affected by selection of trees, the aim of this work was to evaluate the effect of systematic sampling intensities in the hypsometric modeling to estimate the total height, dominant height and total volume in a forest inventory of teak stands. Dendrometric data were collected and hypsometric models were fitted to different systematic sampling intensities: 10%, 20%, 30%, 40% and 50% of the first border trees per plot. Also, 100% of the trees were considered as a control treatment and arranged in a randomized block design. The Dunnett test was used to detect statistical differences between treatment means. It is suggested to measure 40% of tree heights in a plot to obtain statistically appropriate fits of hypsometric models in young teak stands. However, through low systematic sampling intensities of trees in plots, it is possible to obtain average values of dominant heights statistically equal to those of all measured trees.*

- *KEYWORDS: Tectona grandis; hypsometric and volume estimations; systematic sampling.*

1 Introduction

Teak (*Tectona grandis* L. f.) is a native tree species from South and Southeast Asia and cultivated in regions of African, South and Central American continents (NOCETTI et al., 2005). Nowadays, teak wood is considered an alternative to replace native woods in forest-based industries (FERMINO JUNIOR et al., 2009) and, specifically in Brazil, around 68 thousand hectares (ABRAF, 2012) are cultivated with teak stands to produce

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high quality wood to furnishings, factories and for shipping (FIGUEIREDO et al., 2005; NIAMKÉ et al., 2011).

Currently, Brazilian teak stands are considered economically profitable, because teak wood can be sold just after the first thinning, generally harvested between the fourth and fifth years of age. At this phase, it is harvested 40% to 60% of trees, which are used mainly to firewood (PÉREZ & KANNINEN, 2005; CALDEIRA & OLIVEIRA, 2008).

In forest inventories of this stands, the timber volume can be obtained by taking dendrometric data collected of trees, such as diameter and height. However, the mensuration of this last variable oftentimes is not an easy task and, therefore, hypsometric models are essential to estimate the total height as a function of diameter at 1.3 m above ground level (RIBEIRO et al., 2010; ANDRADE & LEITE, 2011; AZEVEDO et al., 2011; SANTOS et al., 2012).

Several factors affect the hypsometric relationship in forest stands, such as forest site, density of trees, tree canopy size, species, sociological position and tree age. Altogether, the height increment in younger trees is faster than in older trees and, consequently, the hypsometric curves are steeper, whose slope decreases with advances in age (BARTOSZECK et al., 2004; MACHADO et al., 2008; PELISSARI et al., 2014).

Considering all those factors related to height estimation, some authors mention that the methodology applied to select trees in the sampling can affect the quality of hypsometric relationship (SILVA et al., 2007; RIBEIRO et al., 2010). Traditionally in teak stands, systematic sampling has been applied to select the first trees that represent 10% to 20% of all trees in the plot, aiming to facilitate the implementation and agility of the field work in the forest inventories.

Even if this sampling procedure can reduce the inventory costs, it may not be appropriated when the concept of statistical consistency is considered, since all diameter classes must be included in the hypsometric modeling. Therefore, assuming the hypothesis that the hypsometric relationship is affected by selection of trees in plots, the aim of this work was to evaluate the effect of systematic sampling intensities in hypsometric modeling to estimate total height, dominant height and total volume in forest inventory of teak.

2 Material and methods

2.1 Study area location

A database of an inventory conducted in teak forest stands of four years old was used to effectuate this research. The forest stands were planted with spacing of 3 m x 3 m between trees in 213 hectares located in Mato Grosso State, Brazil, between the geographical coordinates 16°13'30"S – 16°13'50"S and 56°22'30"W – 56°24'30"W.

2.2 Data collection

For data collection, 30 rectangular sample plots of 15 m x 30 m were randomly allocated in teak stands, comprising the initial density of 50 trees per plot. In each sample unit, the variables diameter at 1.3 m above ground level (d) and total height (h) were measured in all trees, thus composing the database for setting hypsometric mathematical models, whose descriptive statistical analysis is presented in Table 1.

Table 1 - Descriptive statistics of diameter at 1.3 m above ground level (d) and total height (h) in teak forest stands of four years old

Variable	Minimum	Average	Median	Maximum	Standard deviation	CV	*KS*
d (cm)	1.75	12.47	12.73	17.51	1.96	15.7%	0.095^{NS}
h (m)	2.20	11.21	11.50	15.30	1.93	17.2%	0.093^{NS}

Where: CV = coefficient of variation; and NS = normal distribution by Kolmogorov-Smirnov test (*KS*).

Additionally, sampling variations of trees within the sampling units were taken, resulting five data subsets of diameters measured at 1.3 m above ground level (*d*) and total height (*h*) of systematically selected trees such as: (A) 10% of all trees or first five trees; (B) 20%, or first ten trees; (C) 30%, or first fifteen trees; (D) 40%, or first twenty trees and (E) 50%, or first twenty five trees.

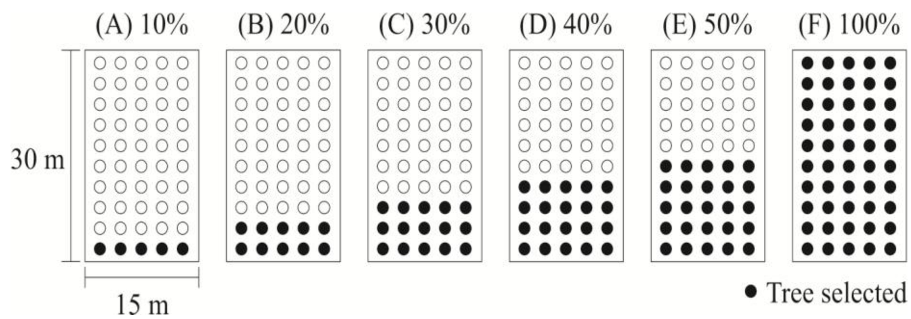

Figure 1 - Systematic sampling intensities of trees in each plot of a forest inventory in teak stands of four years old.

2.3 Data analysis

Ten hypsometric models (Table 2) were fitted to the full dataset, considering all sampled trees. Some statistical criteria were used to evaluate the models, such as lowest standard error of the estimate in percentage (*SEE%*), largest adjusted coefficient of determination ($R^2_{adj.}$), largest *F* test value and the residual tendency in scatter plots. Also, presuppositions of residual analysis were evaluated, such as heteroscedasticity by White test (*W*); autocorrelation between residuals by Durbin-Watson test (*DW*) and normality by Kolmogorov-Smirnov test (*KS*). All tests were evaluated at 95% of probability level.

Curtis (5) and Stoffels (6) models were specified using logarithm in the dependent variable - ln(*h*). For this reason, the bias in the transformations for *h* was corrected applying the Meyer's correction factor (*Mfc*), according to Machado et al. (2008): $Mfc = e^{0,5\,(SEE)^2}$, where: *e* = exponential; and *SEE* = standard error of estimate. Also, the standard error of the estimate in percentage (*SEE*%) and the adjusted coefficient of determination ($R^2_{adj.}$) were recalculated for them.

Table 2 - Hypsometric models fitted in teak stands of four years old

Nº	Model	Equation
1	Linear	$h = \beta_0 + \beta_1 d$
2	Trorey	$h = \beta_0 + \beta_1 d + \beta_2 d^2$
3	Henricksen	$h = \beta_0 + \beta_1 ln(d)$
4	Assmann	$h = \beta_0 + \beta_1 \left(\frac{1}{d}\right)$
5	Curtis	$ln(h) = \beta_0 + \beta_1 \left(\frac{1}{d}\right)$
6	Stoffels	$ln(h) = \beta_0 + \beta_1 ln(d)$
7	Petterson	$\frac{1}{\sqrt[3]{(h-1,3)}} = \beta_0 + \beta_1 \left(\frac{1}{d}\right)$
8	Näslund generic	$h = \frac{d^2}{\beta_0 + \beta_1 d + \beta_2 d^2} + 1,3$
9	Näslund modified	$h = \frac{d^2}{\beta_0 + \beta_1 d^2} + 1,3$
10	Azevedo	$\frac{\sqrt{d}}{h} = \beta_0 + \beta_1 (d)$

Where: d = diameter at breast height (cm); h = total height (m); ln = neperian logarithm; and β_i = coefficients of the models.

After the evaluation of the models based on the mentioned statistical criteria, the best model was selected and fitted to five sub-datasets of trees sampled systematically in different intensities of sampling in each sample plot. In addition, the Graybill identity test (Graybill, 2000) was used to verify the possibility of a single equation to express the hypsometric relationship for all treatments. This test is based on the comparison between the square sum of the residuals in each treatment (completed model) and the square sum of differences for the fitted model with a single database containing all treatments (reduced model). Thus, the rejection of the hypothesis H_0 by F test, at 95% probability, indicates that a single equation cannot be used for estimations.

Then, the selected hypsometric model was fitted for these treatments, whose equations allowed estimating the heights of trees not measured in each one of the sampling intensities. Also, the Assmann dominant height (h_{dom}) was calculated by taking the heights of the one hundred larger trees in diameter at breast height per hectare (ASSMANN, 1970).

Tree volumes (v) were estimated by the equation $v = 0.00256 + 0.00004(d^2h)$, with SEE% of 10% and $R^2_{adj.}$ equals 0,969. After that, the total volume per hectare (V) was calculated for each treatment using measured and estimated heights of different systematic sampling intensity.

The analysis of variance by randomized block design and the Dunnett test were used to detect differences between treatments for total height, dominant height and total volume variables (PALANISWAMY & PALANISWAMY, 2005), at 95% of probability level. For this, the blocks were considered as plots and the treatments were defined as systematic sampling intensities of 10%, 20%, 30%, 40% and 50% of trees. Furthermore, 100% of the trees in the plots (Figure 1F) were used as control treatment.

3 Results and discussion

Coefficients (β_i) and F test values were significant for all models fitted for the full dataset (Table 3). Furthermore, standard error of estimated values (SEE%) have occurred close to 14% and the values of the adjusted coefficient of determination (R^2adj.) in the interval of 0.25 to 0.35. The residuals of Linear (1), Assmann (4), Curtis (5), Stoffels (6) and Petterson (7) models were considered heterogeneous by White test (*W*). However, the residuals of all fits were considered independents by Durbin-Watson (*DW*) test and evaluation of normality by Kolmogorov-Smirnov test (*KS*). Therefore, considering these accuracy statistics (Table 3), the better fit was obtained with Trorey's model (2).

Table 3 - Coefficients and statistics results of the hypsometric relationships of all models fitted to the full dataset in teak stands of four years old

	Model	β_0	β_1	β_2	*SEE*%	$R^2_{adj.}$	*F*	*W*	*DW*	*KS*
1	Linear	4.4172*	0.5452*		14.31	0.307	628.56*	17,87*	0.92^{NS}	0.034^{NS}
2	Trorey	-1.7396*	1.6727*	-0.0496*	13.91	0.345	373.33*	6.50^{NS}	0.83^{NS}	0.032^{NS}
3	Henricksen	-3.1174*	5.7161*		14.02	0.334	711.78*	2.85^{NS}	0.84^{NS}	0.033^{NS}
4	Assmann	14.2316*	-36.1134*		14.73	0.265	512.42*	356.1*	0.75^{NS}	0.036^{NS}
5	Curtis	2.7990*	-4.7890*		14.08	0.329	978.90*	163.6*	0.97^{NS}	0.032^{NS}
6	Stoffels	0.6746*	0.6877*		14.27	0.310	1,040.42*	40.36*	1.15^{NS}	0.035^{NS}
7	Petterson	0.3650*	1.2721*		14.12	0.325	1,788.83*	92.76*	1.22^{NS}	0.032^{NS}
8	Näslund generic	5.3138*	-0.1280*	0.0742*	14.00	0.337	1,196.61*	10.67^{NS}	1.23^{NS}	0.032^{NS}
9	Näslund modif.	4.5733*	0.0731*		14.19	0.318	1,412.59*	7.19^{NS}	1.43^{NS}	0.034^{NS}
10	Azevedo	0.9923*	0.2202*		14.08	0.328	3,049.55*	1.97^{NS}	1.21^{NS}	0.032^{NS}

Where: for β_i and test *F*: * = significant; for White test (*W*): NS = there is no heteroscedasticity and * = there is heteroscedasticity; for Durbin-Watson test (*DW*): NS = independent residues; and for Kolmogorov-Smirnov test (*KS*): NS = residues normally distributed.

High values of *SEE%* and low values of $R^2_{adj.}$ comes from a weak correlation between diameter and height variables in young teak stands. This result occurred because a high variability of heights were observed in a same diametric class, such as commented by Bartoszeck et al. (2004) for *Mimosa scabrella* Benth. and by Donadoni et al. (2010) in tropical pine stands.

As presented in Figure 2A, the Trorey's model has not caused biased height estimates in all diameter classes. Also, in Figure 2B, it was observed the height curve growing and gradually reducing its slope, until stabilizing in diameters greater than 15 cm. However, a high variability of height was observed in all diameter classes, which also was identified by Bartoszeck et al. (2004).

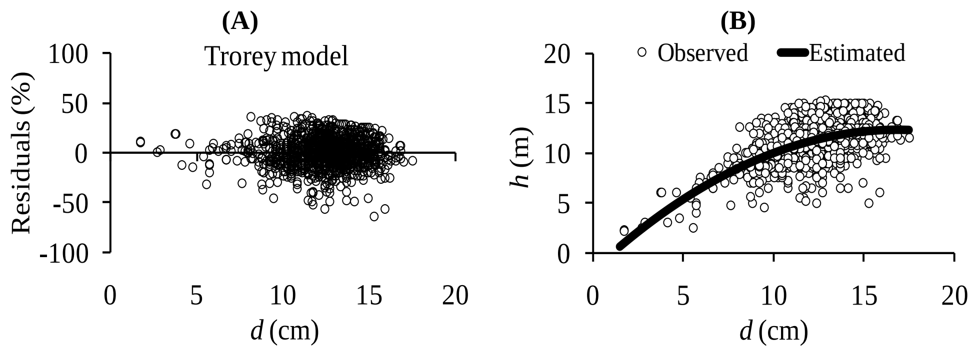

Figure 2 - Total height residuals (A) and hypsometric curve (B) estimated by Trorey's model fitted to full dataset in teak stands of four years old.

Therefore, the Trorey's model was selected to fit all treatments of systematic sampling intensities for teak stands (Table 4). Based on the results of statistical analysis (Table 4), it was not observed a clear tendency in the relationship between the sampling intensities and modeling quality. Thereby, spatial stratification of forest production and tree growth characteristics may reduce the error of estimation in hypsometric modeling.

Table 4 - Statistical parameters of the Trorey's model fitted for systematic sampling intensities in teak stands of four years old

Sampling	β_0	β_1	β_2	*SEE%*	$R^2_{adj.}$	*F*	*W*	*DW*	*KS*
10%	-4.98140*	2.1784*	-0.0712*	12.95	0.331	36.37*	3.72^{NS}	1.14^{NS}	0.056^{NS}
20%	-4.40758*	2.0982*	-0.0689*	13.73	0.288	59.50*	3.03^{NS}	1.27^{NS}	0.076^{NS}
30%	-2.08911*	1.6763*	-0.0495*	13.98	0.388	135.60*	4.49^{NS}	1.05^{NS}	0.068^{NS}
40%	-2.91614*	1.8679*	-0.0583*	14.24	0.353	155.90*	3.46^{NS}	0.89^{NS}	0.059^{NS}
50%	-2.19457*	1.7722*	-0.0551*	13.81	0.348	199.20*	1.86^{NS}	0.87^{NS}	0.057^{NS}

Where: For β_i and test *F*: * = significant; for White test (*W*): NS = there is no heteroscedasticity; for Durbin-Watson test (*DW*): NS = independent residuals; and for Kolmogorov-Smirnov test (*KS*): NS = residuals normally distributed.

Total height residuals as a function of diameter at breast height (Figure 3) were homogeneous when the Trorey's model was fitted for all treatments. Furthermore, the diameter distributions along the x-axis (*d*) increased with higher sampling intensities and inclusion of more diameter classes.

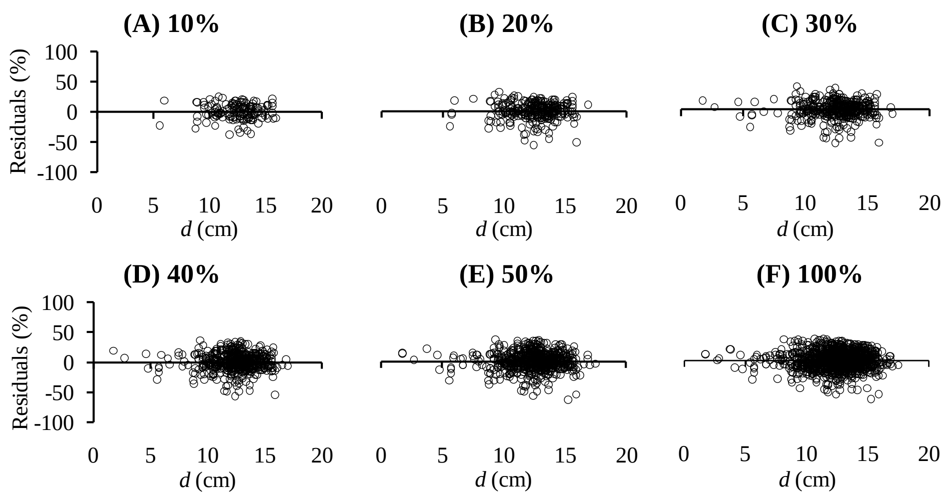

Figure 3 - Total height residuals of the Trorey's model fitted for systematic sampling intensities in teak stands of four years old.

The analysis of variance for Graybill identity test (Table 5) applied for Trorey's model fitted for all treatments, was significant at 95% probability level. This result means that it is impracticable to use the same equation to estimate the total height of trees for different systematic sampling intensities in forest inventories of teak stands.

Table 5 - Identity test for Trorey's model fitted for systematic sampling intensities in teak stands of four years old

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	*F*-test
Completed Model	15	2825.813		
Reduced Model	3	1817.619		
Difference	12	1008.193	84.0161	48.395*
Error	1,402	2433.938	1.7360	
Total	1,417	5259,751		

Where: * = significant at 95% probability level.

As observed in Table 6, the analysis of variance confirms the existence of variability between sampling units, at 95% probability level by F_{block} test, which it was caused by the spatial variability of tree growth and site productivity in the forest. Also, the $F_{treatment}$ test indicated significant differences between the sampling intensities for the variables total height and total volume, but it was not significant for dominant height. Furthermore, the coefficients of variation came out to be less than 4%, which resulted in good experimental precision.

Table 6 - Analysis of variance for systematic sampling intensities in teak stands of four years old

Sampling intensity	Total height (m)	Dominant height (m)	Total volume (m^3 ha^{-1})
10%	10.85*	11.64	77.05*
20%	10.78*	11.49	76.50*
30%	10.94*	11.83	77.64*
40%	11.11	11.84	78.72
50%	11.13	11.79	78.82
100% (control)	11.23	11.74	79.56
F_{Block}	24.79*	8.83*	173.75*
$F_{Treatment}$	7.26*	2.67^{NS}	6.79*
Coefficient of variation (%)	3.25	3.84	3.17

Where: for *F* test: NS and * = non-significant and significant at 95% probability level, respectively; and for Dunnett's test: * = differs significantly from control at 95% probability level.

Dunnett's test (Table 6) indicated significant differences between the control treatment and the systematic sampling intensities of 10%, 20% and 30% of trees, at 95% probability level, for total height and total volume. These results occurred because the height and diameter amplitudes were incompletely covered in the low sampling intensities, which caused the underestimation of these variables.

However, the non-significant differences between the treatments for dominant height (Table 6) occurred because this variable is obtained by sampling the trees in dominant positions classes. Thus, it was demonstrated the possibility to fit site curves using a low number of trees in a plot.

Also, these results showed that the hypsometric modeling was sensible to the sampling intensities lower than 40% of number of trees in plots with up to 50 trees (Table 6), when it was applied to volume modeling in young teak stands with high variability of trees. The lowest intensities provoked underestimations of up to 3.0 m^3 ha^{-1} (Table 6).

Thus, besides the accuracy in hypsometric modeling, additional researches are needed to reach ideal sampling intensity of tree heights in plots. Therefore, it will be possible to optimize the forest inventories through cost evaluation and more efficient field work.

Conclusion

Values of total height and total volume are underestimated when systematic sampling intensities of 10%, 20% and 30% of the number of trees per plot are used in forest inventories. Thus, it is suggested to measure 40% of tree heights in each plot to obtain statistically appropriate fits of hypsometric relationship models in young teak stands.

Through low systematic sampling intensities of trees in plots, it is possible to obtain average values of dominant height statistically equal of that obtained from all measured trees. Consequently, it is ensured to obtain the minimal number of dominant heights, as proposed by Assmann, to fit site index curves in teak stands.

PELISSARI, A. L., DAVID, H. C., PÉLLICO NETO, S., CALDEIRA, S. F., FIGUEIREDO FILHO, A., MARINHESKI FILHO, A. Efeito da intensidade de amostragem sistemática na relação hipsométrica de povoamentos de teca. *Rev. Bras. Biom*., Lavras, v.34, n.1, p.23-32, 2016.

- RESUMO: Tradicionalmente em povoamentos de teca, a amostragem sistemática é aplicada para selecionar árvores em parcelas, as quais terão suas alturas medidas para o ajuste de modelos hipsométricos, visando facilitar sua implantação nos inventários florestais. Com isso, assumindo a hipótese de que a relação hipsométrica é afetada pela seleção de árvores, o objetivo deste trabalho foi avaliar o efeito de intensidades de amostragem sistemática na modelagem hipsométrica para estimar a altura total, altura dominante e o volume total em um inventário florestal de povoamentos de teca. Dados dendrométricos foram coletados e modelos hipsométricos foram ajustados para diferentes intensidades de amostragem sistemática: 10%, 20%, 30%, 40% e 50% da primeira linha de árvores por parcela. Além disso, 100% das árvores nas parcelas foram considerados como o tratamento de controle e estruturados em um delineamento em blocos casualizados. O teste de Dunnett foi usado para detectar diferenças estatísticas entre as médias dos tratamentos. Sugere-se medir as alturas de 40% das árvores nas parcelas para obter modelos hipsométricos estatisticamente adequados em povoamentos jovens de teca. No entanto, por meio de baixas intensidades de amostragem sistemática de árvores nas parcelas, é possível obter valores médios de alturas dominantes estatisticamente iguais aos da mensuração total.
- PALAVRAS-CHAVE: *Tectona grandis*; estimativas hipsométrica e volumétrica; amostragem.

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