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EFFECTIVENESS OF SAMPLING METHODS FOR THINNED AND NON-THINNED *Pinus taeda* L. PLANTATIONS IN THE MOUNTAIN REGION OF SANTA CATARINA, BRAZIL

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Resumo

Eficácia de métodos de amostragem para plantios de Pinus taeda L. desbastado e sem desbaste na região serrana de Santa Catarina. No Brasil, a maioria dos inventários florestais por amostragem utilizam do método de área fixa, mesmo existindo outros métodos alternativos desenvolvidos desde a década de 1940. Pesquisas que demostram a eficácia dos métodos de amostragem de área variável são escassas, principalmente em plantios florestais que preconizam desbastes ao longo do ciclo produtivo. Este trabalho teve como objetivo testar diferentes métodos de amostragem de área fixa (circular com 400 m²) e variável (Bitterlich e Strand) em inventário florestal de plantios de *Pinus taeda* L. aos 9 anos sem desbaste e aos 14 anos com desbaste, comparando-os com a enumeração total das áreas. Os resultados obtidos das variáveis Número de Árvores por hectare (N ha^{-1}), Área Basal por hectare (G ha^{-1}) e Volume por hectare (V ha^{-1}) foram submetidos a um teste de comparação de médias seguindo um delineamento inteiramente casualizado para cada plantio, de modo que as diferenças observadas foram detectadas com o teste de Scott-Knott a 95% de probabilidade. Evidenciou-se que o método de Strand apresentou maior exatidão para estimativa de todas as variáveis analisadas, sobretudo na área com desbaste, porém, necessita-se aumentar a intensidade amostral para garantir a precisão em todos os casos. O método de área fixa apresentou resultados consistentes com o censo para N ha^{-1} e apresentou superestimativas na área sem desbaste e subestimativas na área com desbaste para G ha^{-1} e V ha^{-1}.
Palavras-chave: Área Fixa; Bitterlich; Strand; Inventário Florestal.

Abstract

In Brazil, most forest inventories by sampling use the fixed-area method, even though there are other alternatives methods developed since the 1940s. Research demonstrating the effectiveness of variable-area sampling methods is scarce, especially in forest plantations that advocate thinning throughout the production cycle. This study aimed to test different sampling methods of fixed (400 m² circular) and variable (Bitterlich and Strand) areas in a forest inventory in 9-year-old *Pinus taeda* L. plantations with 9 years without thinning and 14 years with thinning, comparing with the total enumeration of areas. The results obtained from the variables Number of Trees per hectare (N ha^{-1}), Basal Area per hectare (G ha^{-1}) and Volume per hectare (V ha^{-1}) were submitted to a test of average comparison following a completely randomized design for each plantation and the differences observed were detected with the Scott-Knott test at 95% probability. It was evidenced that the Strand method presented greater accuracy for estimating all analyzed variables, especially in the area with thinning, however, it is necessary to increase the sampling intensity to guarantee precision in all cases. The fixed area method showed results consistent with the census for N ha^{-1} and presented overestimates in the area without thinning and underestimations in the area with thinning for Gha^{-1} and Vha^{-1}.
Keywords: Fixed Area; Bitterlich; Strand; Forest inventory.

INTRODUCTION

Planted forests in Brazil occupy an area of 9.55 million hectares, of which 1.7 million hectares belong to species of the *Pinus* genus, mainly concentrated in the states of Paraná (43%) and Santa Catarina (24%) (IBÁ, 2021). *Pinus* plantations in Santa Catarina correspond to an area of 553.6 thousand hectares, which represents 67% of the total area of planted forests in the state (ACR, 2019).

As these plantations represent extensive land areas which have different productive capacities, ages and management regimes, a forest manager's decision-making must be conducted based on reliable information on the forest stock. Thus, the forest inventory serves as a basis for planning forest management, from which quantitative and qualitative data on forest resources in a given area are obtained, in addition to supporting strategies at different administrative levels. According to Sanquetta *et al*. (2014), executing the forest inventory is extremely important to obtain knowledge of the potential of the existing resources of a certain area.

Therefore, due to its speed and lower cost, most forest inventories are done from sampling, meaning the data are only collected from a few sampling units distributed in the area and then the values for the entire population are estimated (Péllico Netto; Brena, 1997).

There are three basic sampling processes according to the need and characteristics of the inventory: random, systematic and mixed sampling (Sanquetta *et al*., 2014). It is possible to use several sampling methods for the quali-quantitative inventories of planted forests, such as the fixed area method considered as a standard method in most studies, the angular count or Bitterlich sampling method, and the in-line sampling method developed by Strand (Péllico Netto; Brena, 1997).

According to Sterba (1986), the fixed area method is considered the oldest and most used, in which the selection criterion is based on the size and shape of the sampling units which are determined according to the size of the population and its characteristics. Sanquetta *et al*. (2014) stated that circular sampling units are currently most used in forest inventories, and the average area should be around 400 to 600 m², comparatively smaller in relation to what is demanded for natural forests (generally above 1,000 m²). The authors also mentioned that the definition of the unit radius is the most important aspect, and radii above 15 m are not feasible because they would impact the survey efficiency, as it requires more time to define the sampling unit. According to Cesaro *et al*. (1994), sampling units with a fixed area have the disadvantage of containing a high number of trees within the unit which vary with the size, age of the stand or with the size of the spacing between the trees, where the measurement time will be longer to obtain smaller volumes than in older stands or with greater spacing and which have greater added economic value.

The Bitterlich method, also known as point sampling or relascopy, has a variable area in a circular format and consists of measuring trees in a 360° rotation; their diameters at breast height are greater than an angular opening, and it is necessary to confer with the limiting value calculation when there are equivalent diameters in order to include the tree in question (Machado; Figueiredo Filho, 2014). However, depending on the value of the angular opening, the number of trees measured in the inventory is significantly lower than in traditional methods without the need to demarcate the sampling units.

Another variable area method is the Strand method, also known as the line method, which is an application of the angular counting technique (Pellico Netto; Brena, 1997; Sanquetta *et al*., 2014). This method selects the trees in the sampling unit with proportionality to height to obtain an estimate of the number of trees and volume per hectare, and in turn the criterion with proportionality to diameter to calculate the basal area and also the number of trees per hectare. The sampling unit consists of a length (L) line taken within the stand, in which all the trees on its left side which qualify for sampling are listed (Miranda *et al.*, 2022).

The conditions and management developed in the forest, the type of relief, and the data collection region (among other characteristics) directly influence the efficiency of the different sampling methods (Corte *et al*., 2013; Farias, *et al*., 2019). Therefore, testing sampling methodologies in different situations becomes a decisive factor when planning the forest inventory, since, according to Ubialli *et al*. (2009), the adequacy of the most effective sampling method will enable maximizing the accuracy of the results and minimize the execution time, reflecting in a cost reduction with field work.

Some studies have compared fixed area methods (Zator Filho *et al*., 2020) with variable area methods in planted forests in Brazil (Druszcz *et al*., 2010, Miranda *et al*., 2015, Santos *et al*., 2016, Farias *et al*., 2019 and Miranda *et al*., 2022). However, studies which used the Strand method are uncommon (Miranda *et al*., 2022), mainly implementing the selection criteria of the basal area factor (BAF) for its proportional-to-diameter approach, which unlike Bitterlich, does not present an ideal number of trees in the sampling unit (Machado; Figueiredo Filho, 2014) for selecting a suitable BAF. Furthermore, there are few studies which compare their performance with the total inventory or census of the area (Miranda *et al*., 2022), and mainly address stands with different management regimes.

Thus, due to the importance and impact of the sampling method choice on the forest inventory result, the objective of this study was to compare the performance and accuracy between the census in two *Pinus taeda* L. plantations (one non-thinned area and one thinned area), with the surveys done with simple random sampling using the Bitterlich, Fixed area with circular format, and Strand methods. It is expected to verify the hypothesis that there are different efficiencies in the estimates of number of trees per hectare, basal Area per hectare and volume per hectare generated by different sampling methods for the evaluated stands.

MATERIALS AND METHODS

The study area is located in the interior of the municipality of Bocaina do Sul, Santa Catarina, Brazil, under the central coordinates 27°44'26.9" South latitude, 49°48'14.8" West longitude, located near the edges of the BR 282 at Km 166 (Figure 1). The municipality is located at approximately 860 meters above sea level and has a Cfb climate according to the Köppen classification, meaning that it is humid mesothermal with mild summers, average temperature of 15.6°C, and average annual precipitation between 1300-1500 mm (Alvares *et al*., 2013).

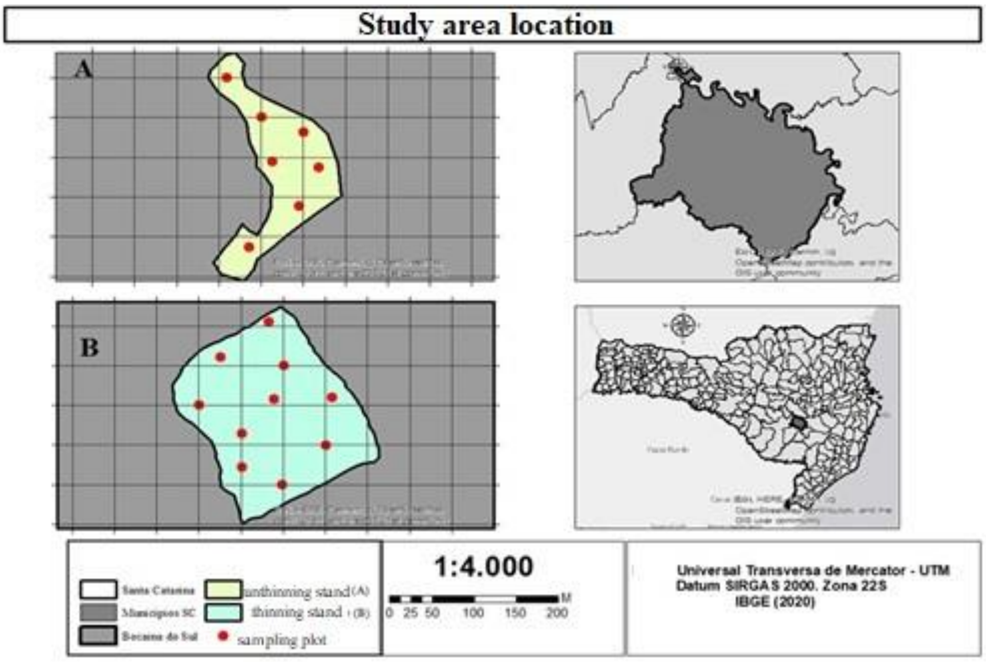

Figure 1. Location of compartment and sampling units in the municipality of Bocaina do Sul, SC, Brazil.
Figura 1. Localização dos talhões e das unidades amostrais no município de Bocaina do Sul - SC.

First, two *Pinus taeda* L. stands were selected to develop this study. The first stand was 9 years old, implanted with a spacing of 2 x 2.5 m, a total area of 2.15 ha and without thinning (Figure 1A). The second plot was 14 years of age, had a total area of 3.88 ha, initial spacing of 2 x 2.5 m (Figure 1B), and at 9 years old it underwent its first mixed thinning, meaning a combination of systematic thinning, harvesting the fifth planting line with selective thinning, harvesting trees which have been suppressed or with quality problems such as: crooked, forked or damaged trees caused by pest attacks.

In the 100% inventory (forest census), the diameters at 1.3 m from the ground (dbh) of all trees in the stands were measured using a sliding T bevel. Furthermore, sampling points were randomly selected in which different sampling methods were established: fixed area method (FA), Bitterlich method (Bi) and Strand method (S1, S2, S3 and SA). In addition, 7 sampling units were installed for the stand without thinning, while 10 sampling units were installed in the stand which had thinning according to the minimum number of repetitions for statistical validation. The installation of each of the sampling points for each method proceeded from the same place of origin, leaving them equally located. The areas were defined with half-spacing distances from the last tree of each stand for the processing of maps in order to demarcate the stand boundaries.

The set of trees for carrying out the height estimation was selected from sampling by the fixed area method. For standardization purposes, the first seven trees of each sampling unit were measured in the stand without thinning, and the first five trees were measured in the stand with thinning, which served as a basis for fitting the hypsometric models for each stand (Table 1). Tree heights were measured with a Vertex IV hypsometer in both areas.

Table 1. Hypsometric models tested for each compartment of the stand under study.
Tabela 1. Modelos hipsométricos testados para cada talhão do povoamento em estudo.

No.	Model
1	$h = \beta_0 + \beta_1 dbh + \varepsilon$
2	$h = \beta_0 + \beta_1 dap + \beta_2 dbh^2 + \varepsilon$
3	$\ln h = \beta_0 + \beta_1 \left({}^{1}/_{dbh^2} \right) + \varepsilon$

In which: h = total height (m); β_n = model coefficients; dbh = diameter at 1.30 m from the ground; and ln = neperian logarithm.

The standard error parameters of the estimate (Syx) and adjusted coefficient of determination (R^2adj) were used in order to determine which are the most suitable models for the plantations, and the homogeneity of the residuals was observed through the analysis of its graphic distribution, in addition to verifying its normality by the Shapiro-Wilks test. The Meyer correction factor was calculated for model 3, which corrects for possible biases in the estimates that underwent a logarithmic transformation.

$$MF = e^{(QMres*0.5)}$$

In which: MF = Meyer Factor; QMres = mean square of the residual presented by the regression ANOVA.

In addition, a t-test at 5% of significance was performed for the hypsometric models to verify the significance of the coefficients. A correlation was also performed between the height and dbh data for each of the stands, observing in which case the correlation of values is greater, justifying the adjusted R^2 values found in the regression of the hypsometric models.

Fixed area method

The sampling units when measuring field data using the fixed-area sampling method were circular in shape with a radius of 11.28 m (400 m²) (Scoloforo; Mello, 2006; Sanquetta *et al*., 2014). The formulas for estimating basal area per hectare, number of trees per hectare and volume per hectare were as follows:

Basal area per hectare:

$$G\ ha^{-1} = \sum gi \times \frac{10000}{400}$$

In which: G ha^{-1} = basal area ($m^2\ ha^{-1}$) and gi = transversal area in m².

Number of trees per hectare:

$$N\ ha^{-1} = n \times \frac{10000}{400}$$

In which: N ha^{-1} = number of trees per hectare and n = number of trees present in the sample unit.

Volume per hectare: The volume per hectare was calculated from the sum of the individual volume of each tree, being obtained through the product of a form factor of 0.45 (as determined for *Pinus taeda* at similar ages by Stepka *et al*. (2017) and Nicoletti *et al*. (2020)), the estimated height and the cross-sectional area. The choice of the form factor for estimating the standing volume was due to the fact that it is the only alternative for estimating the volume per hectare by the Strand method (Péllico Netto; Brena, 1997), and it is interesting that the other methods presented the same methodology for comparison.

$$V\ ha^{-1} = \sum vi \times \frac{10000}{400}$$

In which: V ha^{-1} = volume ($m^3\ ha^{-1}$); and vi = individual volume in m³.

Bitterlich method

Data measurement using the Bitterlich method was obtained using a Criterion RD 1000 digital dendrometer, in which how many trees would be selected were counted from a 360º turn in the center of the sampling unit. The band that computed from 20 to 30 trees per turn was considered adequate to select the basal area factor (BAF), as recommended by Machado; Figueiredo Filho (2014). Thus, it was found that BAF = 2 met these requirements and it was defined as the standard for the other sampling units in both stands. Basal area factor is understood as the conversion in square meters per hectare that each sampled tree represents in the sampling unit, added up for all the trees included in it.

Next, diameter at breast height (dbh) was measured for each tree selected, and the distance from the center of the sampling unit to the tree was measured for trees considered "doubtful" (which had a dbh equal to the size of the band). The measured distance was compared with the calculated value of "R", which was considered as a limiting value for the inclusion of the doubtful tree in question.

$$R = \frac{50 \times dbh}{\sqrt{BAF}}$$

In which: R = calculated distance (m); *dbh* = diameter at breast height (m); and BAF = basal area factor.

The formulas for estimating basal area per hectare, number of trees per hectare and volume per hectare were as follows:

Basal area per hectare:

$$G\ ha^{-1} = n \times BAF$$

In which: G ha^{-1} = basal area (m² ha); n = number of trees presente in the sample unit; and BAF = basal area factor.

Number of trees per hectare:

$$N\ ha^{-1} = \sum \left(\frac{BAF}{gi}\right)$$

In which: N ha^{-1} = number of trees per hectare; gi = transversal area in m²; and BAF = basal area factor.

Volume per hectare:

As in the fixed area method, a form factor of 0.45, total height (m) and cross-sectional area (m²) was used to estimate the individual value for volume.

$$V\ ha^{-1} = \sum \left[\left(\frac{BAF}{gi}\right) \times vi\right]$$

In which: V ha^{-1} = volume (m^3 ha^{-1}); BAF = basal area factor; gi = transversal area in m²; and vi = individual volume in m³.

Strand method

A BAF equal to that used as a reference in the Bitterlich method (BAF = 2) was used for the Strand method. In addition, two additional values were suggested, one lower than the Bitterlich reference (BAF = 1) and one higher (BAF = 3). The use of three basal area factors in the Strand method happened due to the lack of information and references regarding their selection, mainly in relation to the Bitterlich method, which presents an adequate recommendation of the number of trees in the sampling unit for the appropriate definition of BAF. Thus, three selection alternatives were proposed: one equal to the one found in the Bitterlich method and two alternatives (higher and lower than the first).

The unit line length was 15.7 m, equivalent to 5 π (Péllico Netto; Brena, 1997). This line was implemented starting from the center of the previously installed fixed area sampling unit and the Bitterlich, using half of its length (7.85 m) for the North direction and half for the South direction, only considering trees which are located on the west side of the line for the measurement.

Diameters at breast height (dbh) were measured in the trees selected for the diameter and height selections, and only the trees whose distance to the line was equal to or less than half of its height were used as criteria in the height selection (Péllico Netto; Brena, 1997; Sanquetta *et al*., 2014).

The formulas for estimating the basal area per hectare, number of trees per hectare and volume per hectare for the diameter and height selections were as follows:

Diameter selection - basal area per hectare:

$$G\ ha^{-1} = \frac{\sqrt{BAF}}{10} \times \sum dbh$$

In which: G ha^{-1}= basal area (m^2 ha^{-1}); BAF = basal area factor (1, 2 and 3); and *dbh* = diameter at breast height (cm).

Diameter selection – Number of trees per hectare:

$$N\ ha^{-1} = \frac{200\sqrt{BAF}}{L} \times \sum \frac{1}{dbh/100}$$

In which: N ha^{-1} = number of trees per hectare; BAF = basal area factor (1, 2 and 3); L = line length of 15.7m; and dbh = diameter at breast height (cm).

Height selection – Number of trees per hectare:

$$N\ ha^{-1} = \frac{20000}{L} \times \sum \frac{1}{h}$$

In which: N ha^{-1} = number of trees per hectare; L = line length of 15.7m; and h = individual height values (m).

Height selection - Volume per hectare:

$$V\ ha^{-1} = f \times \frac{1}{10} \times \sum dbh^2$$

In which: V ha^{-1}= volume (m^3 ha^{-1}); f = form factor of 0.45; and *dbh* = diameter at breast height (cm).

The statistical summary of the sampling methods was calculated, observing the mean values, coefficient of variation and relative sampling error for each method and its variables (N ha^{-1}, G ha^{-1} and V ha^{-1}). A relative sampling error of at most 10% was considered as a comparison parameter used in planted forests. It was possible to calculate the confidence interval of each variable with the value of the absolute error, and the real error of the estimate was also calculated between the values obtained by the census of the area and the values estimated in the sampling methods, which in turn makes it possible to observe the differences between the observed and estimated value of each of the methods compared to census values.

$$\text{Ere\%} = \frac{\text{Obs}_y - \text{Est}_y}{\text{Obs}_y} \times 100$$

In which: Ere% = Real error of the percentage estimate; Obs_y = Observed value of N ha^{-1}, G ha^{-1} and V ha^{-1} by the census; and Est_y = Estimated value of N ha^{-1}, G ha^{-1} and V ha^{-1}.

Graphs were developed with the mean and the limits of the confidence interval at 95% probability to observe the mean values of each method for each variable studied in comparison with the means obtained by the census of each area.

The data were submitted to a verification test of normality assumption at 5% of significance (Shapiro-Wilks). Then the data were submitted to analysis of variance in a completely randomized design for each stand to identify significant differences for the estimators of the N ha^{-1}, G ha^{-1} and V ha^{-1} variables generated from each sampling method. Due to significant differences by the F-test at 5%, the means were submitted to the Scott-Knott mean test with 5% of significance in the Sisvar statistical program.

RESULTS

Based on the data from the censuses carried out in the areas, the studied stands for the age of 9 years have an average dbh of 18.1 cm, an average total height of 12.7 meters and an average individual volume of 0.1723 m^3. Moreover, the average dbh observed for the age of 14 years was 26 cm, an average total height of 20.4 m and average individual estimated volume of 0.5081 m^3. The stand without thinning showed a basal area of 51.6 m^2 ha^{-1}, density of 1,803 trees ha^{-1}, and a total volume of 310.5 m^3 ha^{-1}, while the stand with thinning showed a basal area of 46.7 m^2 ha^{-1}, density 854 trees ha^{-1}, and 433.8 m^3 ha^{-1} of total volume per hectare. The result of the correlation between height and dbh for the area without thinning was 0.3013, considering a p-value of 0.0354. This correlation for the area with thinning was 0.4059, and a p-value of 0.034 was obtained.

Observing all selection statistics, the hypsometric model which proved to be more efficient for height estimates was model 3 for stands with and without thinning, respectively (Table 2). It is still possible to observe that the coefficients in model 2 in both stands were not significant, which could generate inadequate estimates if they were used.

Table 2. Fitting statistics of hypsometric models of plantations with and without thinning.
Tabela 2. statísticas de ajuste de modelos hipsométricos de plantios com e sem desbaste.

Management	Age	Model	β_0	β_1	β_2	R^2adjust	Syx%	MF	p-value
No thinning	9 years	1	10.3581*	0.1417*	-	0.0714	15.3	-	0.2073
		2	6.8963^{ns}	0.4769^{ns}	-0.0078^{ns}	0.0643	15.4	-	0.1534
		3	2.7855*	-4.1417*	-	0.0762	15.3	1.0123	0.1398
Thinning	14 years	1	16.694*	0.145*	-	0.1474	6.71	-	0.0997
		2	5.716^{ns}	0.942^{ns}	-0.014^{ns}	0.1747	6.60	-	0.3617
		3	22.875*	-1549.22*	-	0.1736	6.60	1.0022	0.1973

In which: β_n = model coefficients; R^2 adjust = adjusted coefficient of determination; and Syx%= standard error of estimate in percentage; MF = Meyer Factor; * = significant coefficients by the t test at 95% probability; ns = Non-significant coefficient; p-value= p-value of the Shapiro-Wilks test to assess the normality of the adjustment residuals.

Figure 2 shows the residual scatter plots of the most representative hypsometric models for each plot, as shown by the results in Table 2. The p-values of the Shapiro-Wilks test performed on the model residuals are shown in the same table, which, show normality according to an α of 5%

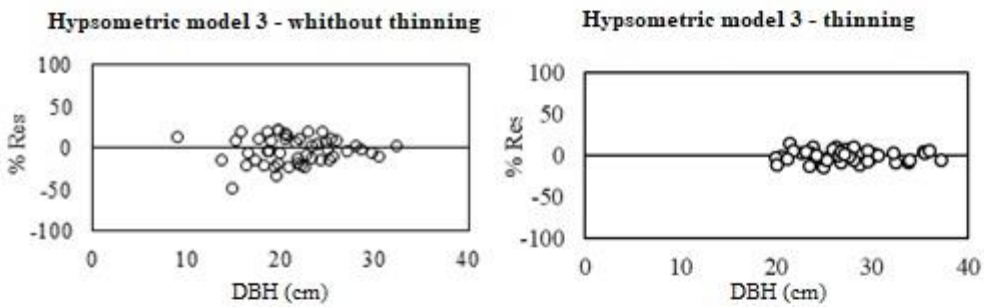

Figure 2. Residual dispersion of the best-fit hypsometric models for the stands with and without thinning.
Figura 2. Dispersão de resíduos dos modelos hipsométricos de melhor ajuste para os talhões com e sem desbaste.

Table 3 presents the statistical summary with mean, coefficient of variation and relative sampling error (Ea%) for the stand with and without thinning, of each sampling method used and each variable analyzed, in addition to the result of the average test by Scott-Knott at 5% significance. The real error of the estimate is also observed (Ere%).

Table 3. Statistics for the N ha^{-1}, G ha^{-1} and V ha^{-1} variables in the two study areas.
Tabela 3. Estatísticas para as variáveis N ha^{-1}, G ha^{-1} e V ha^{-1} nas duas áreas de estudo.

Management	Variable	Method	$\overline{X}$	CV %	Ere%	Ea%
No thinning	G ha^{-1} (m^2 ha^{-1})	FA	62.2 A	17.1	-19.5	15.9
		Bi	55.1 A	10.9	-6.0	10.0
		S1	54.6 A	15.8	-4.9	15.8
		S2	58.1 A	16.7	-11.8	15.5
		S3	60.1 A	15.3	-15.5	15.3
	N ha^{-1} (trees ha^{-1})	FA	1732 B	11.5	3.9	10.7
		Bi	1507 A	10.9	16.4	10.1
		S1	1589 A	22.7	11.8	21.0
		S2	1735 B	20.8	3.7	19.3
		S3	1746 B	22.0	3.1	20.3
		SH	1493 A	24.9	17.2	23.0
	V ha^{-1} (m^3 ha^{-1})	FA	383.3 A	21.4	-23.4	19.8
		Bi	337.9 A	11.5	-8.8	10.6
		SH	315.4 A	19.4	-1.6	17.9
Thinning	G ha^{-1} (m^2 ha^{-1})	FA	43.2 A	9.4	7.5	6.4
		Bi	39.8 A	15.3	14.8	10.3
		S1	45.1 A	17.7	3.3	12.0
		S2	47.0 A	21.3	-0.6	14.4
		S3	45.1 A	21.6	3.4	14.6
	N ha^{-1} (trees ha^{-1})	FA	818 A	14.8	4.3	10.0
		Bi	734 B	21.6	14.0	14.6
		S1	870 A	23.6	-1.9	16.0
		S2	443 C	30.8	48.1	20.6
		S3	279 D	32.2	67.3	21.8
		SH	842 A	26.2	1.4	17.8
	V ha^{-1} (m^3 ha^{-1})	FA	400.0 A	9.1	7.8	6.2
		Bi	369.5 A	14.8	14.8	10.0
		SH	412.3 A	15.6	5.0	10.6

In which: Different letters represent significant difference at a 0.05 level of significance according to Scott-Knott for each variable at each study site. G ha^{-1} = Basal area per hectare (m^2 ha^{-1}); N ha^{-1} = Number of trees per hectare (tree ha-1); V ha^{-1} = Volume per hectare (m^3 ha^{-1}); FA = Fixed area; Bi = Bitterlich; S1 = Strand with basal area factor of 1, S2 = Strand with basal area factor of 2; S3 = Strand with basal area factor of 3; SH = Strand for Height; X = Arithmetic mean; CV% = Coefficient of variation in%; Ere = Actual Error of Estimate (%); and Ea%= Relative sampling error (%).

In the case of the graphical analysis referring to the means and limits of confidence intervals in relation to the census result, shown in Figure 3, the Bitterlich and fixed area methods do not meet the census in some cases among the plots, in contrast to the Strand method.

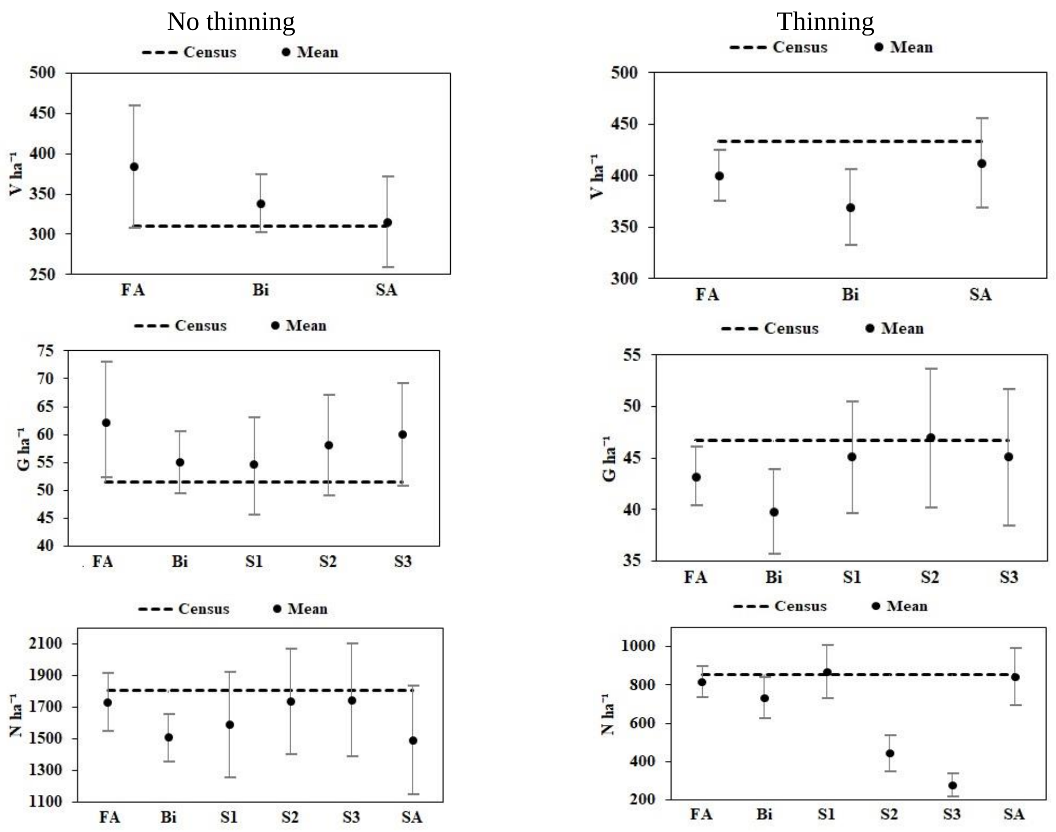

Figure 3. Parametric, estimated means and confinement interval limits at 95% probability for N ha^{-1}, G ha^{-1} and V ha^{-1} in areas with and without thinning.

Figura 3. Médias paramétricas, estimadas e limites de intervalo de confinação a 95% de probabilidade para N ha^{-1}, G ha^{-1} e V ha^{-1}, nas áreas com e sem desbaste.

In which: FA = Fixed area; Bi =Bitterlich; S1 = Strand with basal area factor of 1; S2 = Strand with a basal area factor of 2; S3 = Strand with basal area factor of 3; SH = Strand for Height; G ha^{-1} = Basal area per hectare (m² ha^{-1}); N ha^{-1} = Number of trees per hectare (tree ha^{-1}); and V ha^{-1} = Volume per hectare (m³ ha^{-1}).

DISCUSSSION

The hypsometric models tested for both stands showed coefficient of determination (R^2 adjust) values ranging from 0.0643 to 0.1747, being considered low values, justified by the weak correlation between the height and diameter variables in cases with large diameter variation (Campos; Leite, 2013) as in this case, mainly in the area without thinning, as found herein. The standard error of estimate (Syx%) value was close to 15% for planting at 9 years and 6% for planting at 14 years; both values are also considerably low and demonstrate good precision for the estimation of this variable. This error variation is due to the 14-year-old planting presenting thinning from below, with lower variation in the dbh and heights of the remaining trees.

Nicoletti *et al*. (2020) also observed low values for both parameters (R^2 ajust and Syx%) when testing hypsometric models for *Pinus taeda* L., *Pinus elliottii* Engelm var. elliotti, *Pinus greggii* Engelm and *Pinus patula* Schlechtd. & Cham of 14 years with thinning from below, with these values being associated by Barros (2002) to management issues, site or age of planting, meaning factors which can be modified throughout the rotation and influence the relationship between the forest height and diameter.

Considering the results of the Scott-Knott mean test for the stands, observed in Table 3, there is only a significant difference between the sampling methods for estimating the variable number of trees per hectare (N ha^{-1}). In the case of the stand without thinning, the values in the Fixed Area, Strand with BAF 2 and Strand with BAF 3 methods were closer to the census as shown in Figure 3.

The closest methods to the census to estimate N ha^{-1} for the stand that underwent thinning were the Fixed Area, Strand with BAF 1 and Strand in height selection. It is possible to observe the relative error values between the sampling methods for the different estimated variables in Table 3 and Figure 3, in which it is highlighted that the Bitterlich method was the only one to guarantee sample sufficiency (relative sampling error less than 10% for the three variables observed) (Table 3); however, the census value is outside the confidence interval in some cases.

The accuracy of the Fixed Area method in estimating N ha^{-1} was also demonstrated by Druszcz *et al*. (2010), in which the method usually obtains higher values due to the probability of sampling and frequency of the trees being proportional.

Regarding thinned planting, the Fixed Area, Strand with BAF 1 and Strand methods for height selection present the closest estimates to the value obtained by the census for N ha^{-1}, therefore it is possible to consider them the most accurate methods for this variable. However, when observing the relative sampling error, the Fixed Area method presents the lowest value (6.2%), but the Strand method using height selection showed greater accuracy (1.4%) for the real error of the estimate, while the Fixed Area underestimated it by 4.3%. Moscovich *et al*. (1999) obtained similar results in their study, as did Téo *et al*. (2014), both for an araucaria forest in which the Strand method proved to be more efficient for estimating N ha^{-1}, as well as Miranda *et al*. (2022) for a *Pinus taeda* L. plantation.

The use of BAF 2 and BAF 3 in the Strand method presented the greatest differences for N ha^{-1} in relation to the census and the highest coefficients of variation in relation to the other methods in the area with thinning. Despite the averages obtained by BAFs 2 and 3 being close to the census in the area without thinning, high sampling error values were obtained, resulting in a large amplitude of the confidence interval. Santos *et al*. (2016) obtained similar results and explained that the higher the basal area factor, the lower the number of trees measured, thus increasing the variance between the methodologies.

The methods did not differ for V ha^{-1}, which is the most important commercial variable in forest inventories, resulting in relative sampling errors close to 10% in the thinned area, but the Strand method was the only one in which the census was within the sampling confidence interval. In this perspective, Santos *et al*. (2016), compared the Fixed Area and Bitterlich methods in *Eucalyptus grandis* stands, highlighting that the methods did not differ statistically from each other in both basal area and in volume, thus showing the equivalence of precision methods. However, based on the real error of the estimate, the Strand method with BAF = 2, diameter selection, presented the highest accuracy in the estimation of G ha^{-1}.

Although there was no statistically significant difference between the methods for the G ha^{-1} variable in the thinned plot, the Fixed Area method showed the lowest relative sampling error, followed by Bitterlich and Strand with BAF = 1, but the census was only compatible with the sampling confidence interval for the Strand and Bitterlich methods (only for the area without thinning). According to Péllico Netto; Brena (1997), because the probability of sampling the trees in the Strand method is proportional to the diameter and consequently to the basal area, it tends to be superior to the fixed area method in the estimation of basal area, as also observed in this study, regardless of the BAF used. In addition, Téo *et al*. (2014), found that the Strand method was the most efficient in estimating the G ha^{-1}.

It was found that the relative sampling error in all estimates performed was higher than the real error of the estimate. This feature was also observed by Sydow *et al*. (2017) when comparing the sampling error with the census of a mixed ombrophilous forest fragment; these authors observed an overestimation of the sampling error, as in this work. It is also noteworthy that the sampling error reveals the probability that the sampling can adequately represent the population, but does not ensure the accuracy of the forest inventory estimates.

CONCLUSIONS

- The Strand method showed greater accuracy for estimating all the variables analyzed, especially in the area with thinning, but it is necessary to increase the sampling intensity to guarantee precision in all cases.
- The estimation of N ha^{-1} in the Strand method was efficient with BAF = 1 and for height selection in the two areas, but obtained the highest sampling errors compared to the other methods.
- The fixed area method presented results consistent with the census for N ha^{-1} and presented overestimates in the area without thinning and underestimations in the area with thinning for G ha^{-1} and V ha^{-1}.
- The Bitterlich method presented the smallest sampling error for the same sampling intensity, but the estimates were only consistent with the census for G ha^{-1} and V ha^{-1} in the area without thinning.
- For the choice of a Basal Area Factor for the selection proportional to the diameter of the Strand method, it is recommended that the BAF = 1 regardless of the management performed, or the BAF equivalent to what would be used in a Bitterlich gyrus (mainly for the estimate of G ha^{-1} and V ha^{-1}).

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