PRECISION AND ACCURACY OF SAMPLING METHODS IN THINNED *Pinus taeda* L. STANDS

Rodrigo Otávio Veiga de Miranda[1*], Felipe De Antoni Zarpelon[2], Síntia Valério Kohler[3], Alvaro Augusto Vieira Soares[4], Izabele Domingues Soares Miranda[5], Wilson Cesar Kuchla[6]

[1*] Federal University of Uberlândia, Institute of Agrarian Sciences, Monte Carmelo, Minas Gerais, Brazil – rovmiranda@gmail.com
[2] TTG Brasil Investimentos Florestais LTDA., Guarapuava, Paraná, Brazil – felipeapiaba@hotmail.com
[3] Federal Rural University of Amazônia, Department of Forest Engineering, Parauapebas, Pará, Brazil – sintiakohler@yahoo.com.br
[4] Federal University of Uberlândia Institute of Agrarian Sciences, Monte Carmelo, Minas Gerais, Brazil – alvaroavsoares@gmail.com
[5] Federal University of Uberlândia Institute of Agrarian Sciences, Monte Carmelo, Minas Gerais, Brazil – izabele.soares@gmail.com
[6] Forest Engineer, Irati, Paraná, Brazil –sulguara@hotmail.com

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Resumo

Precisão e acurácia de métodos de amostragem em povoamentos de Pinus taeda L. desbastados. Diferentes métodos de amostragem podem ser utilizados nos levantamentos florestais. É importante conhecer a precisão e acurácia destes métodos amostrais e qual o mais adequado em condições específicas da população florestal. O objetivo deste estudo foi comparar estimativas de um inventário florestal, com resultados provenientes da aplicação de diferentes métodos de amostragem, com resultados do censo florestal. Os métodos de amostragem avaliados foram o de área fixa e os métodos de área variável de Bitterlich, Prodan e Strand. Os dados foram obtidos em um povoamento desbastado de *Pinus taeda* L., com 15 anos de idade, localizado no município de Teixeira Soares, com área total de 12,80 ha. Inicialmente, o censo florestal foi realizado e, em seguida, unidades amostrais para cada método de amostragem foram distribuídas no plantio florestal, tendo em comum um ponto inicial. As variáveis empregadas para a comparação dos resultados amostrais com as médias do censo foram o diâmetro quadrático, número de árvores, área basal e volume, por hectare. A precisão e a acuracidade foram avaliadas respectivamente pelo erro amostral e intervalo de confiança. Os métodos de área fixa e Bitterlich se destacaram em precisão para todas as variáveis analisadas. Os métodos de área fixa, Bitterlich e Strand com proporcionalidade à altura forneceram estimativas com maior acurácia. O método de Prodan forneceu estimativas imprecisas e sem acuracidade para as variáveis sob análise, exceto o diâmetro quadrático.
Palavras-chave: inventário florestal, censo florestal, método de área fixa, métodos de área variável.

Abstract

Different sampling methods can be used in forest surveys. It is important to know the precision and accuracy of these sampling methods, and which one is the most appropriate in specific conditions of the forest population. The aim of this study was to compare estimates of a forest inventory performed by different sampling methods with forest census results. The sampling methods evaluated were the fixed-area method and the variable-area methods of Bitterlich, Prodan, and Strand. The data were obtained in a 15-year-old thinned stand of *Pinus taeda* L., located in the municipality of Teixeira Soares, southern Brazil, with a total area of 12.80 ha. Initially, the forest census was carried out, and subsequently, the sample units for each sampling method were distributed in the stand, with a common starting point. The variables used to compare the sample results with the census means were quadratic diameter, number of trees, basal area, and volume, per hectare. Precision and accuracy were evaluated by sampling error and whether the confidence intervals covered the population means, respectively. The fixed-area and Bitterlich methods stood out in precision for all variables analysed. The fixed-area, Bitterlich and Strand methods with proportion to height provided more accurate estimates. The Prodan method provided inaccurate and imprecise estimates for the variables under analysis, except for the quadratic diameter.
Keywords: forest inventory, forest census, fixed area method, variable area methods.

INTRODUCTION

Forests are essential for human development, representing the sources of numerous resources. Because of this, they have been exploited for a long time, mainly to supply timber and non-timber products. As a way to reduce the suppression of native forests, given the growing demand for wood, commercial plantations play a primary role for society, ensuring the supply of raw materials for the various segments of the forestry sector.

Given the increasing market competition and high demand for natural resources, optimizing the use of forest resources is essential for the sustainability of the sector. For this, the advancement and study of forest measurement techniques for specific situations are important for population estimates to be precisely obtained, which enables the best use of these products (PÉLLICO NETTO; BRENA, 1997; NAKAJIMA *et al*., 1998) and proper planning of their use.

Forest inventory is a widely used technique for gathering information on forest stands for various purposes. This technique provides quantitative and qualitative information (SANQUETTA *et al*., 2014), aiding the decision-making process. To obtain information of a forest population, two techniques can be used: census and sampling. Both provide essential information, and it is up to the professional to choose the most appropriate method according to the objective of the survey (NAKAJIMA *et al*., 1998), the characteristics of the area, and the resources and time available. The forest census is a technique in which all trees in a given area have their characteristics of interest measured (PÉLLICO NETTO; BRENA, 1997). Because of this, in many cases, the census becomes impractical or unfeasible, especially for large populations, due to the time and cost of its execution. Sampling, in which part of the population of interest is sampled (MOSCOVICH *et al*., 1992), is a technique capable of facilitating activities and providing information of interest in a reliable way, with reduced time and costs compared to the census. In Brazil, sampling is the most widespread technique in surveys of commercial plantations.

Although there is always an error associated with the sampling process, it is essential to seek its reduction by the use of the most appropriate sampling method and process to particular situations. According to Péllico Netto and Brena (1997), sampling methods consist of the way of approach and selection of the trees that will make up the sample, and the sampling processes are related to the disposition of the sample units in the population. The accuracy of the estimates of the variable of interest in a forest inventory is directly related to the sampling processes and methods, as well as the sampling intensity (UBIALLI *et al*., 2009; CORTE *et al*., 2013).

Among the known sampling methods, the fixed-area method is the oldest and most widespread one in Brazil; the selection of trees is made according to the frequency in which the trees are arranged in the forest and to the size of the sampling unit (SANQUETTA *et al*., 2014). This method is widely cited in the forest literature and considered, in several cases, as a comparator in different studies, as in the works of Moscovich *et al*. (1992), Druszcz *et al*. (2010), Nakajima *et al*. (2011), Santos *et al*. (2013), Téo *et al*. (2014), Miranda *et al*. (2015), Sydow *et al*. (2017), and Oliveira *et al*. (2019).

Most studies on sampling methods do not bring a population parameter as a comparator, which is obtained through the forest census. Thus, it is essential to conduct research relating different sampling methods with parametric values to indicate the accuracy of the methods for specific situations.

The comparison between estimated values and values considered as real brings a better understanding of different sampling methods, allowing the indication of the sampling method with the greatest accuracy for a given characteristic of interest and population studied. Therefore, it is necessary to perform an in-depth study on sampling methods, evaluating their performance compared to population parameters from the census, in order to evaluate the precision and accuracy of each one.

Under the hypothesis that different sampling methods can provide precise and accurate estimates of a forest stand, this study evaluated the precision and accuracy of forest inventory estimates obtained by the fixed-area sampling method and by the variable area sampling methods of Bitterlich, Prodan, and Strand, with the respective population parameters obtained through census, in a commercial *Pinus taeda* stand.

MATERIAL AND METHODS

The studied area has a size of 12.8 ha and is located in the municipality of Teixeira Soares, state of Paraná, southern Brazil. The local climate is classified as Cfb, according to the Köppen and Geiger classification. The average annual temperature is 18.2 ºC, with an average annual precipitation of 1,474 mm (CLIMATE-DATA.ORG, 2021). The study data were derived from a commercial plantation of *Pinus taeda* L., with an age of 15 years and an initial spacing of 3.0 × 2.0 m, subjected to two thinnings. The first thinning occurred at a stand age of 9 years, in which 20% of the trees were systematically removed, followed by the selective removal of 30% of the remaining trees. The second thinning occurred at the age of 15 years, in which 50% of the trees were selectively removed.

To obtain the comparator parameters, the census of the stand was carried out. All circumferences at breast height (CBH - 1.30 m from the ground) were measured with measuring tapes. Using the CBH values, the values of diameter at breast height (d) were obtained as CBH/π.

In addition to the CAP, the total height of the trees (h) was obtained using the Vertex IV hypsometer. Due to the extent of the area and to optimize the execution time of the census, the total height was measured in one out of every five tree lines, ensuring the representativeness of the stand. At each measuring point, the operator stood at a distance from the tree near its height, never smaller, to avoid measurement errors (SILVA *et al*., 2012; CURTO *et al*., 2013). Because of to the low correlation between d and h in thinned stands (KOHLER *et al*., 2017), which prevents the development of a hypsometric function, the heights of the other trees were estimated by the average of the total heights of the nearest planting lines.

After the census, the sampling of the stand was carried out. Due to its extension, the initial number of five sampling units for the fixed-area method and for the methods of Bitterlich, Prodan, and Strand was established. The distribution of these sample units occurred following the entirely random process.

All sampling units started at the same point. The trees comprising the sampling units were selected by clockwise scanning for the fixed-area, Bitterlich- and Prodan methods and by scanning perpendicular to the line and to the left for the Strand method.

The trees selected in the sample units were numbered and marked with paint, differentiated according to each sampling method, and had their CAP and total height measured. The fixed area sampling units were circular, with a radius of 13.82 m, providing an area of 600 m². Measurement of the individuals was started in the northeast direction, coincident to the alignment of the planting.

The sample units of the Prodan method were determined considering the six trees closest to the central point of the unit. The radius of the sampling unit was defined as the distance between its central point to the center of the farthest tree (sixth tree).

For the selection of trees in the Bitterlich sampling method, a Bitterlich mirror relascope was used with the band (basal area factor) equal to 1, defined in preliminary tests to account for 20 to 30 trees in the 360º sweep. The dubious trees were measured from the calculation of the critical distance (PÉLLICO NETTO; BRENA, 1997; MACHADO; FIGUEIREDO FILHO, 2009).

For allocation of the sample units of the Strand method, a tape measure was stretched perpendicular to the planting lines, the same direction as the beginning of the tree scanning of the fixed area radius and the Bitterlich sweep. The distance of the line was 5 π, equivalent to 15.71 m (MOSCOVICH *et al*., 1992; TÉO *et al*., 2014). This method was performed in two stages.

In the first stage, the trees were selected proportionally to the diameter, using the Bitterlich relascope (basal area factor = 1), along the entire length of the line, observing the trees located perpendicular to the left of the line. For the dubious trees, the same methodology was carried out as for the Bitterlich method. In the second stage, the entire line was selected again, and the trees were selected proportionally to the height; those with a distance to the line less than or equal to half of their total height were selected. To estimate the wood volume by the strand method, a mean form factor was used for the stand, determined with the data from tree scaling.

A diagram of the establishment of the methods is shown in Figure 1. The expressions used for inventory processing for each sampling method can be viewed in Péllico Netto and Brena (1997) and SANQUETTA *et al*. (2014).

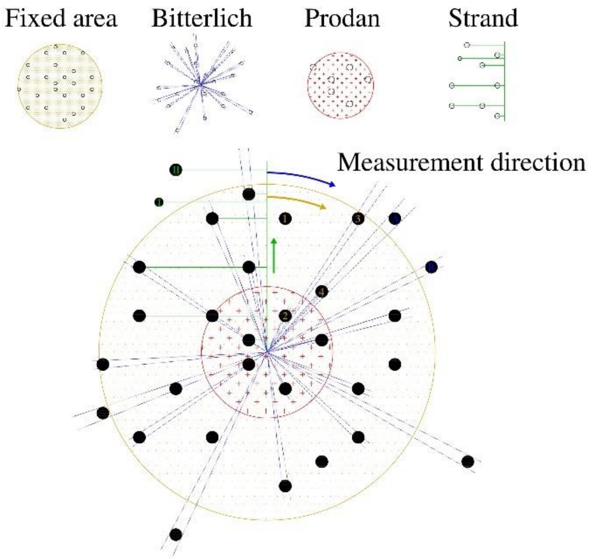

Figure 1. Measurement scheme of the sampling methods evaluated in a *Pinus taeda* stand in Teixeira Soares, Paraná, southern Brazil.

Figura 1. Esquema de medição dos métodos de amostragem avaliados em um povoamento de *Pinus taeda* em Teixeira Soares, Paraná, Brasil.

To obtain the outside bark volume of the stand, 24 trees were scaled according to the Smalian method. These trees were selected according to the diametric distribution of the planting. The diameters were measured at absolute heights of 0.1, 0.3, 0.7, and 1.3 m and at heights relative to 5, 15, 25, 35, 45, 55, 65, 75, 85, and 95% of the total height of the tree. Tip volume was obtained by considering it as a cone (MACHADO; FIGUEIREDO FILHO, 2009).

Due to its great applicability and the generation of acceptable and trend-free results (ANDRADE *et al*., 2019), the linearized Schumacher and Hall (1933) model was used to estimate the total volume outside the bark. This model is expressed as $ln(v) = b_0 + b_1 ln(d) + b_2 ln(h) + \varepsilon_i$I, in which v is the individual volume of the tree (m³), d and h represent the diameter at breast height (cm) and total height (m), respectively, ln is the Neperian logarithm, b_i are the coefficients to be estimated by the ordinary least squares method, and e_i is the random error of the model.

For the evaluation of the equation, the coefficient of determination (R^2), the standard error of the estimate in percentage (Syx%), and the analysis of residual dispersion were used (MACHADO *et al*., 2015). Furthermore, the Meyer's correction factor of logarithmic discrepancy (SANQUETTA *et al*., 2017) was calculated, added to the intercept value by means of the logarithm of this factor.

For the calculation of the ideal sample size, a permissible percentage sampling error of 10% of the volume mean was considered. The sampling fraction (f) was also calculated for each method, in addition to the absolute and relative sampling errors for the quadratic diameter, number of trees, basal area, and volume. Estimates per unit of area of these variables were calculated.

The precision and accuracy of the sampling methods were evaluated by means of sampling error and confidence interval, respectively. The lower the sampling error, the lower the confidence interval and the more precise the sampling method.

The accuracy of the sampling methods was evaluated by the difference between the estimated mean for each method and the mean obtained by the census. For this, the confidence interval was traced for each variable, calculated by the expression $CI = \bar{y} \pm t \times s \times n^{-0,5}$, in which CI represents the confidence interval, $\bar{y}$ is the sample mean, t is the value of the Student distribution for n-1 degrees of freedom at 5% significance ($\alpha \leq 0.05$), s is the standard deviation of the sample, and n is the sample size.

Confidence intervals that cover the population mean indicate the efficiency of the method, demonstrating that there is no statistical difference between the sampled mean and the population mean. The closer the estimate of the respective parametric value, the greater the accuracy of the method.

RESULTS

The volumetric equation obtained was $v = e^{(-12,130465+1,940822\ \ln[d]+1,687150\ \ln[h])}$. The coefficient of determination (R^2) and the standard error of the estimate (Syx) were 0.94 and 10.9%, respectively. The dispersion of the residues indicates the precision of estimates and the absence of a trend, being concentrated in the amplitude between ± 23% (Fig. 2).

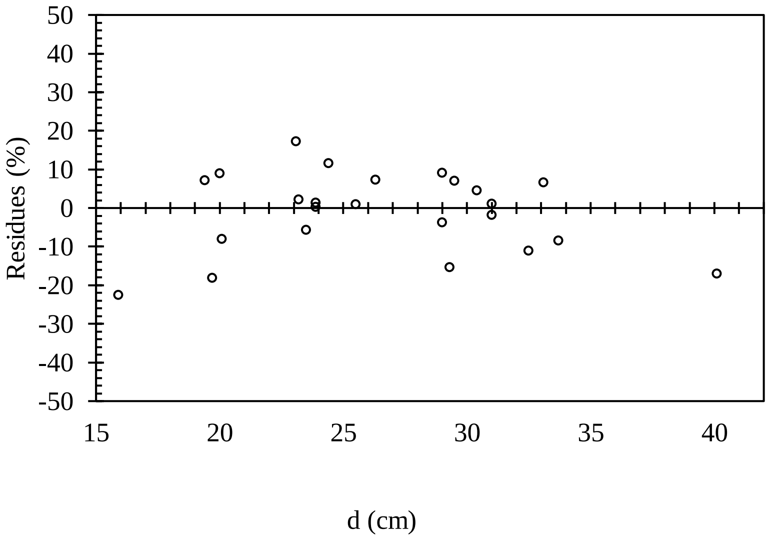

Figure 2. Residual dispersion for the estimates of individual tree volume in a *Pinus taeda* stand in Teixeira Soares, Paraná, southern Brazil.
Figura 2. Dispersão dos resíduos para as estimativas de volume individual da árvore em um povoamento de *Pinus taeda* em Teixeira Soares, Paraná, Brasil.

Observing the descriptive analysis for the main parametric variables of the stand (Table 1), there was a greater variation in the diameter at breast height in relation to height, probably the effect of thinning. The quadratic diameter, number of trees, basal area, and volume, per hectare, represented the values used as comparator between sampling methods, serving as a basis in the evaluation of the accuracy of each one.

Table 1. Amplitude and variation of diameter at breast height and total height and variables obtained with the forest census in a *Pinus taeda* stand in Teixeira Soares, Paraná, southern Brazil

Tabela 1. Amplitude e variação do diâmetro à altura do peito e altura total e variáveis obtidas com o censo florestal em um povoamento de *Pinus taeda* em Teixeira Soares, Paraná, Brasil

Value	d	h	dg	$N.ha^{-1}$	$G.ha^{-1}$	$V.ha^{-1}$
Minimum	16.6	19.5	-	-	-	-
Medium	29.0	24.4	29.33	407	27.51	341.57
Maximum	52.2	27.8	-	-	-	-
CV (%)	15.3	2.8	-	-	-	-

Legend: d = diameter at breast height (1.30 m from the ground) (cm); h = total height (m); d_g = mean quadratic diameter (cm); CV (%) = coefficient of variation; $N.ha^{-1}$ = number of trees per hectare; $G.ha^{-1}$ = basal area per hectare ($m^2.ha^{-1}$); $V.ha^{-1}$ = total volume per hectare ($m^3.ha^{-1}$).

The results of forest inventory processing for each evaluated method can be seen in Table 2. For the fixed-area and Bitterlich methods, the sample size was sufficient for the established precision of 10% for all variables analyzed. For the Prodan method, the initial sample size required was 11 sample units. Thus, six more sample units were added to the sample. However, the resampling provided a sampling error of less than 10% only for the quadratic diameter.

For the Strand method (proportionality to height), considering the volume per hectare, the ideal sample size was nine sample units (Table 2). Thus, four new sampling units were distributed in the population. As expected, the sample size was adequate only for the volume, since it was the variable used in the calculation of the sample size. To jointly meet the accuracy of the other variables, except for the quadratic diameter, it would be necessary to allocate 26 more sample units.

Table 2. Results of the forest inventory for the sampling methods evaluated in a *Pinus taeda* stand in Teixeira Soares, Paraná, southern Brazil

Tabela 2. Resultado do inventário florestal para os métodos de amostragem avaliados em um povoamento de *Pinus taeda* em Teixeira Soares, Paraná, Brasil

Variable	Metric	Fixed Area	Bitterlich	Prodan*	Strand (d)*	Strand (h)*
Dg	Sample size	2	2	2	2	2
	S_y	±0.43	±0.39	±0.34	±0.46	±0.45
	AE	±1.18	±1.07	±0.75	±1.07	±1.05
	RE (%)	±4.06	±3.54	±2.67	±3.54	±3.55
$N.ha^{-1}$	Sample size	3	5	17	35	17
	S_y	±12.10	±14.07	±33.87	±45.22	±28.51
	AE	±33.60	±39.06	±75.47	±104.28	±65.75
	RE (%)	±7.41	±9.08	±12.71	±22.35	±14.69
$G.ha^{-1}$	Sample size	5	2	12	27	-
	S_y	±0.99	±0.67	±1.75	±2.65	-
	AE	±2.74	±1.85	±3.89	±6.11	-
	RE (%)	±9.05	±6.47	±10.64	±19.26	-
$V.ha^{-1}$	Sample size	4	2	14	-	9
	S_y	±10.85	±7.41	±23.01	-	±15.83
	AE	±30.11	±20.56	±51.26	-	±36.51
	RE (%)	±8.22	±5.91	±11.51	-	±9.86

Legend: Sam3ple size = number of sample units required to meet the accuracy of 10%; Sy = Standard deviation of the mean in the variable unit; AE = absolute sampling error in the variable unit; RE (%) = relative sampling error; * = calculations performed after the allocation of new sampling units.

The precision of each method was evaluated by the sampling error. All sampling methods provided precise estimates for the quadratic diameter, with sampling errors close to or less than 4%. The method that presented the highest precision for basal area and volume per hectare was Bitterlich, followed by the fixed-area method (Table 2), whose position was reversed for the estimate of the number of trees per hectare. The Strand method (proportionality to height) met the established precision for the volume per hectare. For the Strand method (proportionality to diameter), the established precision was met only for the mean quadratic diameter.

Regarding the sample fraction (f), the Bitterlich method showed the highest percentage (3.59%), with a mean radius of each unit of 17.05 m (CV_{radius} = 7.8%), followed by the fixed-area method with 2.34%. Even with a larger number of sample units, the Prodan method sampled a smaller area, with a sample fraction of only 0.82%, due to the radius of each unit, whose mean was 5.51 m (CV_{radius} = 8.84%). On the other hand, the nine sample units of the Strand method resulted in a sample fraction of 1.64%.

The evaluation of accuracy for the average estimates of quadratic diameter, number of trees, basal area, and volume, per hectare, in relation to the census results, are presented in Figure 3. Regardless of the sampling method, all variables analyzed were overestimated, except for estimates of quadratic diameter (dg) for the fixed area and Prodan methods (Fig. 3a). For this variable, greater deviations from the parametric value were observed in the Prodan method, followed by the Bitterlich and Strand methods (proportionality to diameter). However, these differences were close to 1 cm. The Prodan method was the only one that did not cover the value of the census in its confidence interval.

To estimate the number of trees per hectare (Fig. 3b), the greatest deviations were observed for the Prodan and Strand methods with proportionality to the diameter. As show by the confidence interval, represented by the vertical lines, the Prodan method and the fixed-area method did not include the census mean. The best results were obtained for the Bitterlich method, followed by the Strand method with proportionality to height.

As well as for estimating the number of trees per hectare, the Bitterlich method presented the greatest accuracy in generating the estimates of basal area per hectare, followed by the methods of fixed area and Strand (proportionality to diameter) (Fig. 3c). On the other hand, the Prodan method did not include the census mean in its confidence interval.

For the estimation of volume per hectare (Fig. 3d), the Bitterlich method was the most accurate one, differing only in 6.21 $m^3.ha^{-1}$ from the parametric value. The second-best method was the fixed-area method, followed by the Strand method, with proportionality to height. The Prodan method overestimated the volume per hectare, and its confidence interval did not include the parametric mean.

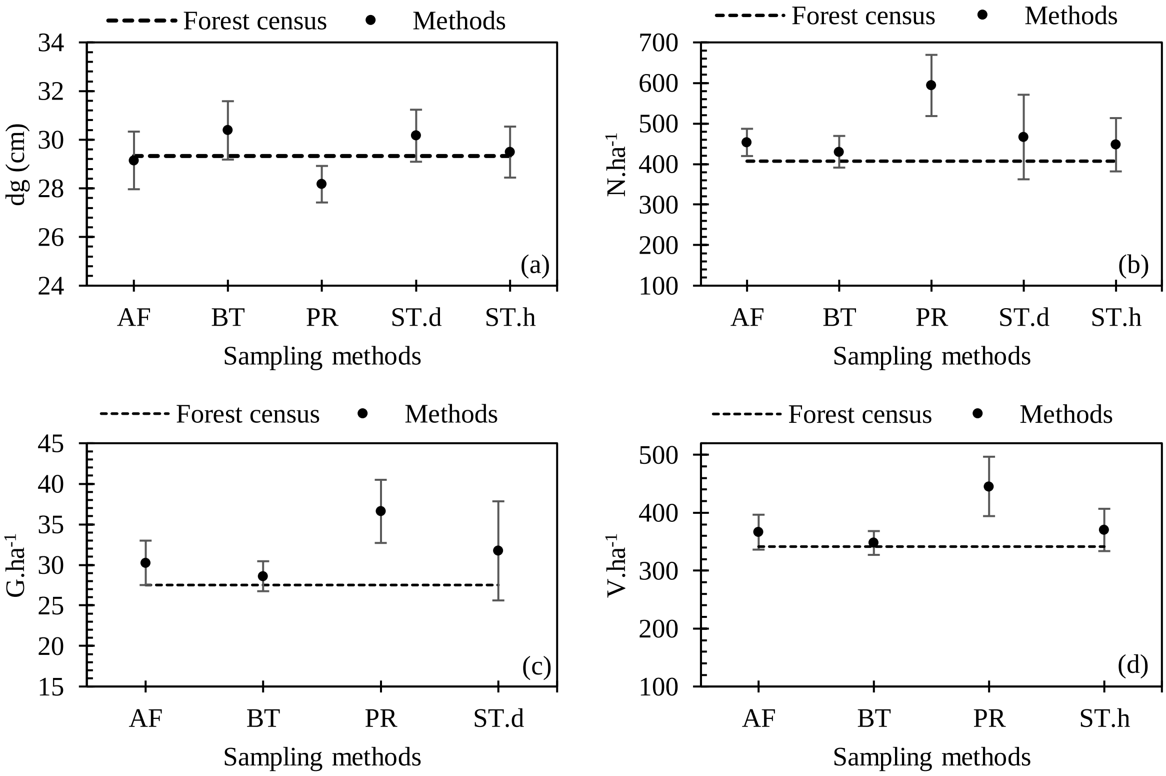

Figure 3. Estimates of the quadratic diameter (a), number of trees (b), basal area (c), and volume (d) per hectare for the fixed-area (AF), Bitterlich (BT), Prodan (PR), and Strand (ST.d or ST.h) sampling methods in relation to the average of the forest census in a *Pinus taeda* stand in Teixeira Soares, Paraná, Brazil.

Figura 3. Estimativas do diâmetro quadrático (a), número de árvores (b), área basal (c) e volume (d) por hectare para os métodos de área fixa (AF), Bitterlich (BT), Prodan (PR) e Strand (ST.d ou ST.h) em relação à média do censo florestal, em um povoamento de *Pinus taeda* em Teixeira Soares, Paraná, Brasil.

DISCUSSION

The estimates generated by the volumetric equation were free of tendency, regardless of the diametric class (Fig. 2). The Schumacher and Hall model was previously used by Druszcz *et al*. (2010), Santos *et al*. (2016), and Araújo *et al*. (2012) for *Pinus taeda*, *Eucalyptus grandis* W. Mill ex Maiden, and *Pinus sp*., in this order.

Even with the allocation of new plots for the Prodan method, the sampling error remained greater than 10%. This result may be a reflection of the initial sample not having contemplated the variability in the population (Table 2). To jointly meet the pre-established precision of the other variables, it would be necessary to allocate six more sample units. Due to logistics and issues involving access to the area, a return to the study area for the allocation of more sample units for the Prodan and Strand methods was not possible.

In the evaluation of inventory precision, based on the sampling error, the Bitterlich and fixed-area methods presented the best results in that the smallest the sampling error, the more precise are the estimates. According to previous studies, the Bitterlich and fixed-area methods present lower sampling errors than other methods.

Santos *et al*. (2013) compared the fixed-area to the Strand method in a 4-year-old *Eucalyptus urophylla* x *Eucalyptus grandis* plantation in the Region of São João Evangelista, Minas Gerais, considering the same number of sample units, and concluded that the fixed-area method was the most precise one. Miranda *et al*. (2015) obtained results similar to those of the current study, evaluating the fixed-area, Bitterlich, and Prodan methods in *Tectona grandis* L stands. According to these authors, the Bitterlich method presented the greatest precision, followed by the fixed-area method, with allocated 30 sample units for each method.

The sampling error of an inventory is related to the size and variability of the sample, as well as to the level of confidence used. The Bitterlich method presented the lowest sampling error (except for the quadratic diameter and number of trees per hectare) and the largest sampling fraction (Table 2). The Prodan method, with the smallest sampling fraction, resulted in sampling errors higher than the pre-established precision, except for the quadratic diameter. Sampling errors tend to decrease as sample size increases, but do not represent directly proportional quantities (PÉLLICO NETTO; BRENA, 1997).

In the analysis of the sampling fraction (f), the Bitterlich method covered a larger sampled area, followed by the fixed-area method. In the Prodan method, more sample units were distributed in the area; however, it promoted a lower percentage of sampled area due to the lower mean radius of each unit.

The accuracy of a sampling method is related to how close to the actual value the method estimates approach and can be calculated only when the actual value of the population parameter is known. The smallest deviations in relation to the parametric value were observed to estimate the quadratic diameter (Fig. 3a), indicating the smallest effect of the sampling method to estimate this variable. For the number of trees per hectare (Fig. 3b), the Prodan method generated low estimates. The confidence interval of the fixed-area method did not include the census mean for the number of trees due, probably because of the low value of the sampling error, reducing the confidence interval. However, its average was very close to that of the census.

The estimates of basal area per hectare obtained by the Bitterlich method were highly accurate (Fig. 3c). The proximity of the estimation of the basal area of the Bitterlich method to the parametric value demonstrates its efficiency to estimate this variable, in which it was idealized (MACHADO; FIGUEIREDO FILHO, 2009), in addition to certifying the choice of band (basal area factor) equal to 1.

The Bitterlich method provided accurate estimates for volume ($V.ha^{-1}$) (Fig. 3d). This method showed the greatest accuracy in the volume estimation, according to Moscovich *et al.* (1992), in a survey of species from a fragment of Mixed Ombrophyllus forest in São Francisco de Paula, state of Rio Grande do Sul. Druszcz *et al*. (2010), when comparing the fixed-area method with a circular plot to Bitterlich for *P. taeda*, at the ages of 7, 9, and 10 years, in Ponta Grossa, Paraná, concluded that the Bitterlich method provided more accurate volumetric estimates in relation to the fixed-area method, although these estimates were not statistically different.

The differences were more expressive for the Prodan method. It is important to highlight that this method was the one that most distanced itself from the sample sufficiency, even with the installation of more sample units in the area. This result is probably due to the greater distance of some trees, caused by thinning, since, according to Péllico Netto and Brena (1997), in conditions in which the trees of the settlement are very close or very distant, the Prodan method may present bias in its estimates.

The effect of thinning is more evident when observing the areas of the Prodan sample units, which ranged from 60.6 to 147.9 m². This variation in the areas may also be due to the planting activity, with deviations to the correct alignment of the seedlings in the field. However, the Prodan method has provided unsatisfactory results, which highlights its low performance in obtaining forest inventory estimates when compared with other sample methods. This fact is corroborated in the works of Moscovich *et al.* (1992), Péllico Netto et al. (2012), Téo *et al*. (2014), Miranda *et al.* (2015), and Nascimento *et al.* (2015).

In view of the results, the hypothesis of this study was rejected since not all sampling methods provided accurate and precise estimates of forest stand. The most satisfactory results were obtained by the Bitterlich and fixed-area methods.

CONCLUSIONS

- The evaluated sampling methods can be used to precisely and accurately estimate the quadratic diameter, except for the Prodan method. The fixed-area and Bitterlich methods provided precise and accurate estimates of basal area per hectare.
- The fixed-area and Bitterlich methods resulted in precise estimates of the number of trees per hectare. The Bitterlich and Strand methods provided accurate estimates of the number of trees per hectare. The fixed-area, Bitterlich, and Strand methods, with proportion to height, provided precise and accurate estimates of volume per hectare.
- The Prodan method presented imprecise and inaccurate estimates for the number of trees, basal area, and volume per hectare. The Strand method, with proportionality to diameter, promoted imprecise estimates for the number of trees and the basal area per hectare.

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