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Comparative Analysis of Sampling Systems in Thinned *Pinus taeda* L. Plantations

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Abstract

The objective of this study was to compare the sampling methods of fixed area, Bitterlich, Strand, and Prodan distributed through random and systematic processes in a 6.3 hectare *Pinus taeda* L. plantation located in the municipality of Lages, in the state of Santa Catarina, subjected to selective and systematic thinning. A 100% inventory (forest census) was carried out, measuring the diameters at 1.3 meters above ground level (d) of all trees in the stand. Additionally, sampling systems (method + process) were designed to estimate the main population parameters (basal area - G, volume - V, and number of trees - N) per hectare. In the random process, the central coordinates (latitude and longitude) of the sample units were selected by random draw, while for the systematic process, only the central coordinate of the first unit was drawn, and the others were distributed at 100 meter intervals. Sampling errors were calculated, and an analysis of variance was performed for the variables G ($m^2 \cdot ha^{-1}$), V ($m^3 \cdot ha^{-1}$), and N ($trees \cdot ha^{-1}$) using a factorial arrangement design, considering the factors: sampling processes (systematic and random) and sampling methods (rectangular fixed area, circular fixed area, Bitterlich, Strand, and Prodan). The results of this study demonstrated that the interaction between the different sampling methods and the random and systematic processes did not result in significant differences. Significant differences were observed only in the volume (V) estimates generated by the random and systematic processes, with the estimates from the random process being closer to the parametric value.

Keywords

Forest Inventory — Sampling Method — Sampling Process — Census

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1. Introduction

The Brazilian forestry sector makes a significant contribution to the country's economy through tax generation and the supply of consumer products for both domestic and export markets. It also plays a key role in creating direct and indirect jobs and in the conservation of natural ecosystems (Ribaski, 2018). Brazil has strong forestry potential, as the country has emerged as a global leader in the supply of forest products—both timber and non-timber—as well as environmental services (Araújo et al., 2017), especially due to the extensive areas planted with *Pinus* and *Eucalyptus* species (Ibá, 2023).

The *Pinus* genus was first introduced in Brazil in 1936 by the Forest Service of the State of São Paulo and has since been widely used in the country's reforestation programs. Currently, the average forest productivity of *Pinus* in Brazil is 30.9 $m^3 \cdot ha^{-1} \cdot year^{-1}$, with productivity in the state of Santa Catarina ranging between 34 and 37 $m^3 \cdot ha^{-1} \cdot year^{-1}$ (Ibá, 2023). Particularly in the southern region, *Pinus* plantations play a significant role in the local economy, covering an area of approximately 1.9 million hectares (Ibá, 2023).

The management of planted forests is essential to ensure balanced and economically viable production, so that harvesting rates remain sustainable over the years (Floriano, 2018). Due to the high demand for *Pinus* wood in the pulp and paper industries, silvicultural practices traditionally employed planting densities ranging from 2,000 to 2,500 trees per hectare. However, with the increasing use of the species for sawmilling and veneer production, the timber industry has shifted toward wider

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spacing, aiming to achieve higher wood volumes in a shorter period and at lower costs, by reducing the number of thinnings (Sanquetta et al., 2003).

Knowledge about forest structure and stock is closely linked to the measurement of forest stands. However, due to the large number of trees that need to be assessed—which typically results in increased inventory costs—it becomes necessary to use sampling techniques to make inferences about population parameters (Pellico Netto & Brena, 1997; Sanquetta et al., 2014).

Sampling systems consist of the methods and procedures used in forest inventories (Pellico Netto & Brena, 1997) and are of great importance for obtaining reliable estimates of variables of interest with acceptable precision and cost. Therefore, different sampling methods and procedures can be employed to increase efficiency and reduce expenses, making the proper selection of the sampling system a key factor for the success of the inventory (Souza et al., 2015).

The random sampling process is widely used in forest inventories due to its simplicity and lack of bias; however, it is susceptible to the uneven distribution of sample units within the forest population. This process is based on the assumption that each sampling unit has an equal chance of being selected (Sharma, 2017; Campos & Leite, 2017). On the other hand, in systematic sampling, the units are not selected randomly but follow an equidistant allocation scheme, resulting in broader coverage and reducing the likelihood of unsampled areas (Van Laar & Akça, 2010).

Among the sampling methods that approach the population based on a single sample unit (Pellico Netto & Brena, 1997), Sanquetta et al. (2014) highlighted the existence of fixed and variable area methods, the latter including those developed by Bitterlich, Strand, and Prodan. Although considered a simple variable-area sampling method, the Bitterlich method provides accurate population estimates for number of trees per hectare, basal area, volume per hectare, mean diameter, and dominant height (Retslaff et al., 2014). It has been used in studies comparing it to the fixed-area method, such as those by Téo et al. (2014), Miranda et al. (2022), Heberle et al. (2022), and Machado et al. (2023).

Another variable-area method is the Strand method, which selects trees within the sample unit in proportion to their height to estimate the number of trees and volume per hectare, as well as in proportion to their diameter to calculate basal area and also the number of trees per hectare (Heberle et al., 2022). It uses 15.7 meter-long lines inside the forest to count the trees that qualify for sampling. However, studies employing this method are relatively uncommon (Miranda et al., 2022).

The fixed-area method is considered the oldest and was recommended by Druszcz et al. (2015) as the most efficient and accurate for surveying stand variables in *Pinus taeda* plantations in the state of Paraná, southern Brazil. The Prodan method, also known as the six-tree method, involves selecting the six trees closest to the central point of the sample unit, including trees proportionally to their distance from the point of origin (Sanquetta et al., 2014). This method is still rarely used in forest inventories in Brazil, mainly due to a lack of awareness about its potential and advantages over the traditional method. Its use has primarily been highlighted in research studies such as those by Péllico Netto et al. (2012), Miranda et al. (2022), and Machado et al. (2023).

In this context, the objective of this study was to select the most appropriate sampling system to obtain per-hectare estimates of basal area, volume, and number of trees in a 24-year-old *Pinus taeda* L. stand subjected to three thinnings, based on the hypothesis that, regardless of the combinations of sampling methods and procedures used, the results should be consistent with those obtained from the forest census.

2. Material and Methods

The data were collected in the municipality of Lages, Santa Catarina, located approximately 229 km from the state capital, at coordinates 27° 48' 42" S and 50° 16' 18" W (Figure 1). The local climate is classified as Cfb according to the Köppen-Geiger system (Alvares et al., 2013), meaning it is temperate, with mild summers, evenly distributed rainfall throughout the year, no dry season, and the average temperature of the hottest month does not exceed 22 °C.

The stand was 24 years old at the time of the survey, established with a 2.5 × 2.5 m spacing, and had undergone three thinning operations (one systematic and two selective), the last of which was carried out in 2018. The total area of the stand is 6.3 hectares. The topography of the site is gently undulating, with no understory, which facilitates movement within the stand.

A 100% inventory (forest census) was conducted, measuring the diameters at 1.3 m above the ground (d) of all trees in the stand. In addition, sampling systems (method + process) were designed to estimate the main population parameters—basal area (G), volume (V), and number of trees (N)—with reference to one hectare.

Two processes were followed: random and systematic, with the selection of 5 sample units in each. In the random process, the central coordinates (latitude and longitude) of the sample units were obtained by lottery using the "Randomize!" app (Higuchi, 2022), and for the systematic process, only the central coordinate of the first unit was randomly selected using the same app, with the others being distributed at 100 m equidistant intervals.

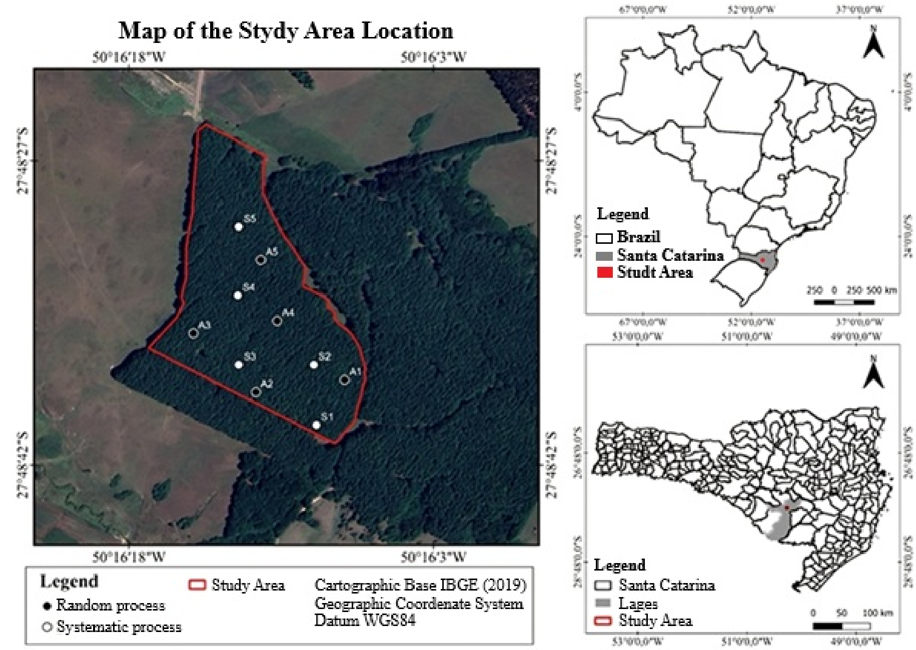

Figure 1. Location of the study area with the respective distributions of sampling units, following the random (An) and systematic (Sn) sampling process.

The data obtained from both processes were subjected to statistical analysis to determine the sampling error for all analyzed variables, with the sampling error of the systematic process calculated using the method of successive differences (Péllico Netto; Brena, 1997).

At the sampling points selected in each process, different sampling methods were applied: fixed area method with 600 m^2 rectangular (20 m × 30 m) and circular plots, Bitterlich method, Strand method, and Prodan method, with the formulas for obtaining G, V, and N presented in Table 1. The installation of each sample point for each method started from the same origin point, ensuring they were equally located. To demarcate the stand boundaries, the areas were defined at a distance of half the spacing (1.25 m) from the last tree of the stand for map processing (Figure 1), as recommended by Machado et al. (2023), to avoid extrapolation errors. Tree measurements in the Bitterlich and Strand methods were obtained using the Criterion RD 1000 digital dendrometer with a basal area factor (BAF) of 2.

The individual tree volumes were obtained by multiplying the individual basal areas, estimated heights, and a form factor of 0.48, as determined for *Pinus taeda* of similar ages by Nicoletti et al. (2020). The choice of the form factor for standing volume estimation was made because it is the only available approach for estimating volume per hectare using the Strand method (Péllico Netto; Brena, 1997), and it was considered appropriate to apply the same methodology to the other methods for comparison purposes.

The set of trees used for height estimation was selected using the fixed area sampling method with rectangular plots. The first 6 trees in each sample unit were measured with a Vertex IV hypsometer and served as the basis for fitting hypsometric models (Table 2).

In order to determine the most suitable model for estimating the heights of the remaining trees, obtained from both the sampling systems and the population census, the following parameters were used: standard error of the estimate in percentage (Syx%), adjusted coefficient of determination (R^2adj), and the normality of the residuals was verified using the Shapiro-Wilk test at a 95% confidence level.

In addition to calculating the sampling errors for the different sampling systems, the real error in percentage (RE%) was also calculated for all dendrometric variables studied (N, G, and V). In this study, RE% was calculated using the following mathematical formula:

$$RE\% = \frac{V_e - V_o}{V_o} \times 100$$

Where: RE% is the real estimation error (%); Vo is the observed value from the census for the variables (volume, basal area, and number of trees); and Ve is the value estimated by the samplings for the same dendrometric variables.

From the 10 treatments (12 for number of trees per hectare) combining method and process, each with five replications, the data for the variables G, V, and N were subjected to Levene's test for homogeneity of variances at a 95% confidence level, as well as the Shapiro-Wilk test for normality at the same significance level. Since the

Table 1. Formulation to obtain dendrometric variables using the sampling methods used.

Method	Varible	Formulas
Fixed Area	Basal Area - G(m².ha^{-1})	G = $\Sigma(g_i) \times (\frac{10000}{600})$
	Volume -V (m³.ha^{-1})	V = $\Sigma(v_i) \times (\frac{10000}{600})$
	Nº of Trees - N(trees.ha^{-1})	N = $n \times (\frac{10000}{600})$
Bitterlich	Basal Area - G(m².ha^{-1})	G = $BAF \times n$
	Volume -V(m³.ha^{-1})	V = $\Sigma[(\frac{BAF}{g_i}) \times v_i]$
	Nº of Trees - N(trees.ha^{-1})	N = $\Sigma(\frac{BAF}{g_i})$
Strand	Basal Area - G(m².ha^{-1})	G = $\frac{\sqrt{BAF}}{10} \times \Sigma(di)$ - Diameter selection
	Volume -V(m³.ha^{-1})	V = $f \times 0,1 \times \Sigma(di^2)$ - Height selection
	Nº of Trees - N(trees.ha^{-1})	N = $\frac{200\sqrt{BAF}}{L} \times \Sigma(\frac{1}{di/100})$ - Diameter selection; N = $\frac{20000}{L} \times \Sigma(\frac{1}{h})$ - Height selection
Prodan	Basal Area - G(m².ha^{-1})	G = $\frac{d_1^2+d_2^2+...+\frac{d_6^2}{2}}{R_6^2} \times 2500$
	Volume -V(m³.ha^{-1})	V = $\frac{v_1+v_2+...+\frac{v_6}{2}}{\pi R_6^2} \times 10000$
	Nº of Trees - N(trees.ha^{-1})	N = $\frac{5.5\times 10000}{\pi \times R_6^2}$

* Where: G = basal area per hectare (m^2·ha^{-1}); V = volume per hectare (m^3·ha^{-1}); N = number of trees per hectare; gi = individual basal area (m^2); n = number of trees in the sample unit; vi = individual volume (m^3); BAF = basal area factor (K) = 2; di = diameter at 1.3 m from the ground (cm, except in the Prodan and Strand methods, which uses meters); h = total height (m); L = 15.7 m line length in the Strand method; f = average form factor (0.48).

Table 2. Hypsometric models tested for the population.

Model	Matematical Expression
1	h = $\beta_0 + \beta_1 d$
2	h = $\beta_0 + \beta_1 d + \beta_2 d^2$
3	h = $e^{\beta_0 + \beta_1 (1/d^2)}$

*Where: h = total height (m); β_n = model coefficients; d = diameter at 1.30 m from the ground in centimeters.

variables N and G did not meet the normality assumption, the data were transformed by extracting the inverse of the square root $(1/\sqrt{x})$ of each value.

When no significance was found in the tests for homogeneity of variances and normality, analysis of variance (at a 95% confidence level) was performed under the hypothesis that there are no significant differences among the sampling systems for the three main dendrometric variables in forest inventory: G (m^2·ha^{-1}), V (m^3·ha^{-1}), and N (trees·ha^{-1}), using a completely randomized design in a factorial arrangement considering the factors sampling processes (systematic and random) and sampling methods (rectangular fixed area, circular fixed area, Bitterlich, Strand, and Prodan). Tukey's test (at a 95% confidence level) was used to highlight possible differences among the treatments (sampling systems).

3. Results

It was observed, in all selection statistics, that hypsometric model 1 proved to be the most efficient for height estimations (Table 3).

Table 3. Statistics and adjustment coefficients for the planting hypsometric models.

Model	β_0	β_1	β_2	β^2adj	Syx%	p-value
1	26.6596*	0.0847*	-	0.0291	5.9	0.0657
2	4.3326^{ns}	1.2751^{ns}	-0.1563^{ns}	0.0507	5.9	0.0131
3	3.4549*	-81.8949*	-	0.0440	5.9	0.0333

*Where: β_n = model coefficients; R^{2}adj = adjusted coefficient of determination; and Syx% = standard error of the estimate in percentage; * = coefficients significant by the t-test at a 95% confidence level; ns = coefficients not significant by the t-test at a 95% confidence level; p-value = p-value from the Shapiro-Wilk test to assess the normality of the model residuals.

In the same Table 3, the p-values obtained from the Shapiro-Wilk test applied to the model residuals are presented, showing normality at a 5% significance level only for model 1.

Based on the census data collected in the area, a total of 2,764 trees were counted, corresponding to 438.7

trees·ha^{-1}. The stand showed an average diameter of 39 cm, an average total height of 30 m, and an average individual volume of 1.766 m^3. The basal area was 53.6 m^2·ha^{-1}, and the volume per hectare was 774.7 m^3·ha^{-1}.

The data from the different sampling systems were processed, and the estimates of G, V, and N are presented in Table 4, where the means of each variable, relative sampling errors, lower and upper bounds of the 95% confidence interval, and the real error can be observed.

From the application of Levene's test to the treatments (methods + process), the presence of homogeneous residual variances was observed, with p-values of 0.4121, 0.791, and 0.075 for G, V, and N, respectively. In addition to homogeneous variances, the Shapiro-Wilk test indicated that the residuals followed a normal distribution, with p-values of 0.0556, 0.2138, and 0.7997 for G, V, and N, respectively.

As the tests for homogeneity of variances and normality were not significant for the three variables at a 5% significance level, the analysis of variance was performed in a factorial design (Table 5).

According to Table 5, it can be observed that all analyzed means were not significant, except for the mean volume between the different sampling processes (random and systematic), indicating independence between the process estimators. The overall mean (considering all sampling methods combined) in the systematic process was 713.2 m^3·ha^{-1}, while in the random process it was 776.4 m^3·ha^{-1}. The parameter obtained for this variable in the census was 774.7 m^3·ha^{-1}, representing an underestimation of 7.9% in the systematic process and an overestimation of 0.2% in the random process.

To illustrate the dispersion behavior of each sampling system used, a box plot graph was developed (Figure 2), where the blue line represents the parametric values obtained in the census.

4. Discussion

In Table 3, it is possible to observe that although Model 2 presented a higher adjusted R^2, its coefficients were not significant, which could lead to inadequate estimates if used (Heberle et al., 2022). It was observed that the adjusted R^2 values presented by the three models were relatively low (ranging from 0.0291 to 0.0507), which was expected (Campos; Leite, 2017). Nicoletti et al. (2020) and Heberle et al. (2022) also observed low values for these parameters when testing height-diameter models for *Pinus* spp. plantations in southern Brazil. However, the estimation errors were low, as in this study. According to Barros et al. (2002), these low values are associated with management practices, site conditions, or plantation age—factors that can modify and influence the relationship between height and diameter in the forest.

The mean values estimated by the different sampling systems for the three analyzed variables (Table 4) were consistent with the census values, especially for the variable ”V”, which is the most important one (Sanquetta et al., 2014) when surveying a production forest. For this variable, the combination of different methods with the random process yielded the most accurate results, overestimating the census values by 2.4% to 4.7%. It is noteworthy that the Bitterlich method, in both the random arrangement (underestimation of 13.6%) and the systematic one (underestimation of 11.7%), was the least accurate. In the study conducted by Machado et al. (2023) in *Pinus taeda* forests, the Bitterlich method was shown to be efficient regardless of the management adopted. However, more accurate results were obtained when using smaller basal area factors (BAFs), which allow more trees to be included in the sample plots something that could have improved the performance of this method in the present study (e.g., using BAF = 1).

For the fixed-area methods, values closer to the census were observed with the rectangular shape compared to the circular one, even though, due to the occurrence of thinning and the fact that circular plots are generally more appropriate under such circumstances (Sanquetta et al., 2014), it was possible to identify the original planting rows and consider the spacing between them for allocating the rectangular sample units. This allowed for the assessment of the effective area occupied by each tree within the sample units, which may have contributed to the improved performance of the estimators. Although generating the most precise estimators, according to Heberle et al. (2022), the fixed-area sampling method is not always considered the most reliable for estimating the same variables in *Pinus taeda* plantations, despite being the most commonly used method in forest inventories.

The least accurate information was obtained from the systems using the Prodan method, where the greatest range in the estimators was observed. Such characteristics were also reported by Miranda et al. (2022). As this method depends on the distance from the sixth tree to the center of the sample unit, the estimators can be heavily influenced by forest management practices (Péllico Netto; Brena, 1997), especially in thinned areas (such as in the present study), where post-intervention forest structure may remain irregular due to selective thinning. However, authors such as Moscovich et al. (1999) advocate for the use of distance-based methods, as they offer advantages over fixed-area plot methods, such as the time savings from not having to install plots; greater speed in the field, which allows for a larger sample size and thus increases

Table 4. Estimates obtained by treatments and precision of estimators for G, V and N.

Var	Est.	Sys.RFA	Sys.CFA	Sys.BIT	Sys.STd	Sys.STh	Sys.PRO	Rnd.RFA	Rnd.CFA	Rnd.BIT	Rnd.STd	Rnd.STh	Rnd.PRO
G	$\bar{x}$	50.8	47.7	53.2	58.1	-	58.2	55.4	55.1	52.0	52.1	-	57.0
	LL	46.0	40.2	46.1	52.3	-	29.7	50.1	48.2	46.2	39.3	-	49.2
	UL	55.6	55.3	60.3	63.9	-	86.8	60.6	62.0	57.8	64.9	-	64.8
	SE%	9.4	15.9	13.4	10.0	-	49.0	9.5	12.6	11.2	24.5	-	13.7
	RE%	5.2	10.9	0.7	-8.3	-	-8.7	-3.3	-2.8	3.0	2.8	-	-6.4
V	$\bar{x}$	729.4	686.6	684.3	-	747.7	766.9	796.3	793.3	669.5	-	811.4	811.4
	LL	660.0	573.6	592.0	-	655.3	453.2	718.7	691.1	593.4	-	717.1	681.1
	UL	798.8	799.6	776.6	-	840.2	1,081	874.0	895.5	745.6	-	905.7	941.8
	SE%	9.5	16.5	13.5	-	12.4	40.9	9.8	12.9	11.4	-	11.6	16.1
	RE%	5.8	11.4	11.7	-	3.5	1.0	-2.8	-2.4	13.6	-	-4.7	-4.7
N	$\bar{x}$	456.7	423.3	476.8	539.2	478.9	577.1	486.7	480.0	463.7	455.2	476.7	510.6
	LL	397.2	368.1	422.5	489.6	373.4	325.3	449.6	437.6	404.1	336.0	418.0	401.2
	UL	516.1	478.6	531.1	588.9	584.4	828.9	523.7	522.4	523.3	574.4	535.5	620.0
	SE%	13.0	13.0	11.4	9.2	22.0	43.6	7.6	8.8	12.9	26.2	12.3	21.4
	RE%	-4.1	3.5	-8.7	-22.9	-9.2	-31.5	-10.9	-9.4	-5.7	-3.7	-8.7	-16.4

*Where: Var. = Variable; Est. = Statistic; Sys.RFA = Rectangular fixed area in systematic process; Sys.CFA = Circular fixed area in systematic process; Sys.BIT = Bitterlich in systematic process; Sys.STd = Strand with diameter-based selection in systematic process; Sys.STh = Strand with height-based selection in systematic process; Sys.PRO = Prodan in systematic process; Rnd.RFA = Rectangular fixed area in random process; Rnd.CFA = Circular fixed area in random process; Rnd.BIT = Bitterlich in random process; Rnd.STd = Strand with diameter-based selection in random process; Rnd.STh = Strand with height-based selection in random process; Rnd.PRO = Prodan in random process; N = Number of trees per hectare; G = Basal area per hectare ($m^2 \cdot ha^{-1}$); V = Volume per hectare ($m^3 \cdot ha^{-1}$); $\bar{x}$ = Arithmetic mean of the variable of interest; LL = Lower limit of the confidence interval for each variable of interest; UL = Upper limit of the confidence interval for each variable of interest; SE% = Sampling error in percentage; RE% = Real error in percentage.

Table 5. P-values obtained in the analysis of variances of variables G, V and N, observing the significances for each factor analyzed (process and sampling method) and the interaction between them.

Factor	p-value		
	G	V	N
Sampling Processes	0.51ns	0.03 *	0.87 ns
Sampling Methods	0.88 ns	0.18 ns	0.64 ns
Process × Method Interaction	0.47 ns	0.69 ns	0.41 ns

*Where: ns = not significant at 95% probability; * = significant at 95% probability.

the precision of estimates; and better spatial coverage of sampling units, which allows for a more representative picture of the forest and a better understanding by those conducting the survey. In this case, since it is the fastest method to implement, a more representative sample with broader spatial coverage could be obtained compared to using fixed-area plots, which theoretically cover larger areas but require lower sampling intensities.

Knowing that most forest inventories are conducted through sampling, estimators are considered reliable when they meet a sampling error limit of 10% with 95% probability (Sanquetta et al., 2014). Floriano (2021) emphasized that, in general, sampling errors tend to be smaller in systematically distributed samples, meaning they are more likely to adequately represent the stand. Meanwhile, in random sampling processes, there is a risk of obtaining a biased sample of the area. Péllico Netto and Brena (1997) also pointed out that systematic sampling provides a good estimate of the mean and total due to the uniform distribution of samples within the population.

One of the main factors contributing to the greater precision of the systematic process lies in the variance of the mean. Due to its specific formulation, which aims to identify differences among the sample units and evaluate them directly, the overall variance of the dataset tends to be reduced. Since this variance is used to calculate the error, it significantly influences the outcome. Additionally, the efficiency of the process is attributed to the uniform and mechanical definition of the sample units, as movement in a fixed and predetermined direction promotes time savings during measurements and, consequently, results in lower costs (Georgin et al., 2015).

However, in the present study, no significant advantage was observed in using systematic sampling compared to random sampling, which may be attributed to the small number of sampling units installed and the limited size of the population. According to Péllico Netto and Brena (1997) and Sanquetta et al. (2014), this process is

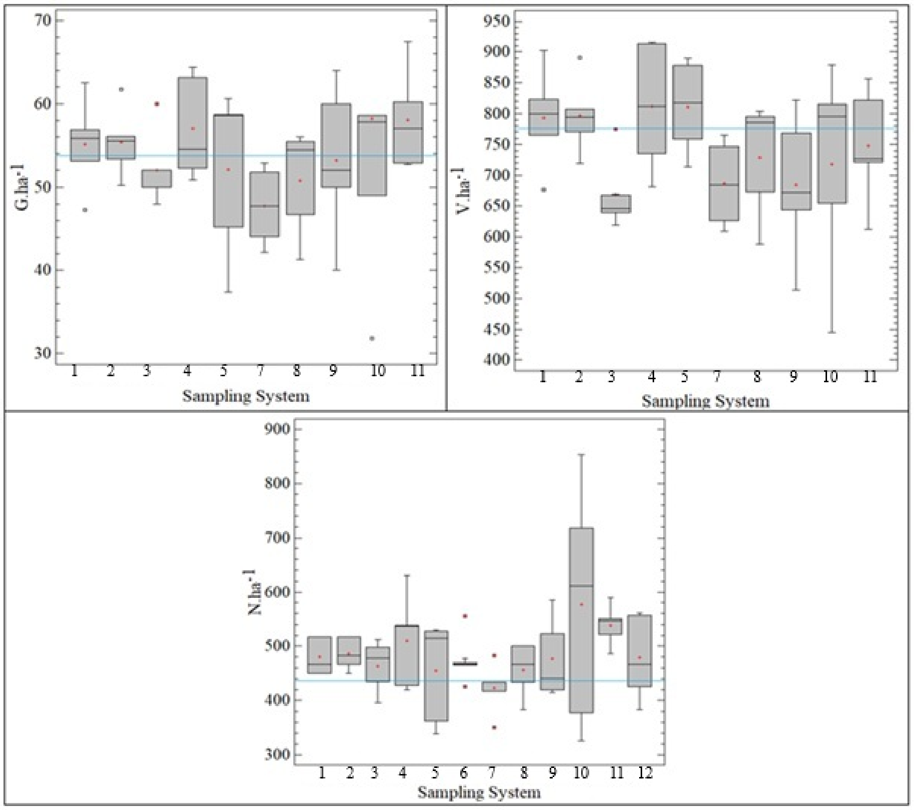

Figure 2. Box-plot graphs of the variables N, G and V demonstrating the variation of the estimators with reference to the census represented by the blue line.

*Where: Rnd.RFA = Random Rectangular Fixed Area; Rnd.CFA = Random Circular Fixed Area; Rnd.BIT = Bitterlich in Random Process; Rnd.PRO = Prodan in Random Process; Rnd.STd = Strand with Diameter Selection in Random Process; Rnd.STh = Strand with Height Selection in Random Process; Sys.RFA = Systematic Rectangular Fixed Area; Sys.CFA = Systematic Circular Fixed Area; Sys.BIT = Bitterlich in Systematic Process; Sys.PRO = Prodan in Systematic Process; Sys.STd = Strand with Diameter Selection in Systematic Process; and Sys.STh = Strand with Height Selection in Systematic Process. (1- Rnd.RFA; 2- Rnd.CFA; 3- Rnd.BIT; 4- Rnd.PRO; 5- Rnd.STd; 6- Rnd.STh; 7- Sys.RFA; 8- Sys.CFA; 9-Sys.BIT; 10- Rnd.PRO; 11- Sys.STd; e 12- Sys.STh). $\bar{x}$ = Arithmetic mean of the variable of interest; LL = Lower limit of the confidence interval for each variable of interest; UL = Upper limit of the confidence interval for each variable of interest; SE% = Sampling error in percentage; RE% = Real error in percentage

recommended for large areas in order to ensure greater control and supervision in field data collection within the sample units, which could be more sensitive to detecting potential discrepancies compared to random sampling.

5. Conclusion

Based on the results obtained in this study, we can conclude that:

The interaction between the different sampling methods and the random and systematic processes did not show significant differences. Although no statistical differences were found between the sampling methods tested, the rectangular fixed-area method was more accurate for estimating volume per hectare, while the Bitterlich method was more accurate for estimating basal area per hectare.

The Prodan method yielded the most discrepant estimates and consequently the highest sampling errors, indicating the need for increased sampling intensity. However, as it is the simplest method, when combined with a systematic layout, it could be a good alternative for faster inventories. No significant differences were observed in the estimators G and N obtained from the random and systematic processes, highlighting that the population is small, homogeneous, and allows for easy movement between sampling units.

It was observed that the V estimators differed statistically between the sampling processes studied, with the estimators from the random process being closer to the census-derived parametric value. The hypothesis established in this study was rejected, since, depending primarily on the sampling process used, the estimators may be inconsistent with the parameter obtained from the forest census.

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