

Evaluation of two sampling methods for even-age *Pinus* forest in northern Mexico

Viridiana S. GALVÁN-MORENO^{1,2}, Jesús M. OLIVAS-GARCÍA^{2*},
Joel RASCÓN-SOLANO^{1,2}, Javier HERNÁNDEZ-SALAS²

¹Autonomous University of Nuevo León, Faculty of Forestry Sciences, Doctoral Program in Science with a Focus on Natural Resource Management, National Highway #85, Km. 145, Linares, Postal Code 67700, Nuevo León, Mexico; viridiana2910@outlook.com; forestal_rascon@hotmail.com

²Autonomous University of Chihuahua, Faculty of Agricultural and Forestry Sciences, 2.5 km on Delicias-Rosales Road, Postcode 33000, Delicias, Chihuahua, Mexico; jolivas@uach.mx (*corresponding author); jhernans@uach.mx

Abstract

The objective was to evaluate and compare the precision of estimation of dasometric variables, survey times and costs of two sampling methods versus a census, applied to a natural even-age mass of *Pinus arizonica* Engelm. in the municipality of Guachochi, Chihuahua, Mexico. Nine fixed-dimension and nine variable-dimension sites were performed with Bitterlich's angular sampling at coincident sample points. Times from start to finish were taken by site and technicians from the State were surveyed to determine sampling costs. ANOVA tests were developed at a significance level of 0.05, comparing both methods with the census. The results indicate that, in both samplings, the number of trees per hectare does not present statistical differences with respect to the census. The basal area by both methods was not statistically different, however, fixed dimensions present an error greater than 5%. Finally, the volume per hectare estimated was similar to that of the census, according to the rates carried out, greater precision was found by the variable area method (error=0.03%). The execution time showed significant differences ($p=0.0001$), the fixed dimension site required a mean time of 44 minutes and the variable dimension one 10 minutes 26 seconds. The total costs are 679.90 and 654.33 Euro to sample nine fixed-dimension and nine variable-dimension sites respectively, showing significant differences ($p=0.0008$). It is concluded that both methods are statistically acceptable for the variables evaluated in the type of forest mass studied.

Keywords: angular sampling; forest sampling; fixed area sampling; sampling costs; sampling times; variable area sampling

Introduction

Forests are the largest terrestrial ecosystem, occupying 30% of the planet's surface area (Food and Agriculture Organization of the United Nations (FAO), 2007). Mexico occupies the twelfth place in forested areas worldwide (FAO, 2010). It has an area under timber harvesting of 6,290,610 hectares (Secretaría del Medio Ambiente y Recursos Naturales (SEMARNAT), 2020).

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Ortiz-Reyes *et al.* (2015) and Martín-García *et al.* (2017) indicate that the most common practice to estimate the population parameters of the dasometric stocks is the forest inventory, and it is supported by sampling tools based on a design and estimators based on models (Ruíz, 1982). The precision of an inventory estimate is determined by the sampling method used (Paula-Neto, 1990). In sampling, a part of a population is selected and used to obtain estimates of the characteristics of that population (Moscovich and Brena, 2006; Köhl and Magnussen, 2016). In this way, and depending on the type of data obtained in the field, it is possible to calculate different levels of precision (Schroeder, 1992).

Some of the objectives, when carrying out a forest inventory through sampling, are to obtain reliable results to know the tree diversity and the density condition of the stands (Aguirre and Jiménez, 1995), calculate the volume (Kramer and Akça, 1987) and plan forestry activities (Schreuder *et al.*, 2006). These parameters are necessary to obtain dasometric estimates of the population of interest (Schreuder *et al.*, 2006; Köhl, Magnussen and Marcheti, 2006; Aguirre-Salado *et al.*, 2009).

Prodan *et al.* (1997) indicate that there are various sampling methods to estimate the variables of a tree population. Sampling through the use of sites of fixed dimensions of 0.1 hectares (ha) is the most used in forest inventories (Aguirre *et al.*, 1995). In this method, the selection of individuals is carried out proportionally to the surface area of the minimum management or sampling unit and, in turn, by the frequency of individuals found within it (Pellico-Netto and Brenna, 1997). On the other hand, the Bitterlich or variable dimensions method (Schreuder *et al.*, 1993) is used only to a limited extent. Finger (1992) mentions that the number of trees in a stand, whose normal diameter ($DN_{1.30}$), from a fixed point, appears greater than a constant alpha angular value, is proportional to the basal area in square meters per hectare (G^{-1}).

Regarding the levels of precision, Schroeder (1992) and Machado and León (2005) mention that in forest inventories it is feasible to obtain different levels of precision. On the other hand, the estimation accuracy of the variables has a direct effect on the quality of the planning, management and evaluation of existing possibilities in the forests (Bettinger *et al.*, 2009). It is important to highlight that, given the importance of the inventory for the development of sustainable forest management strategies, it must be carried out according to the established precision levels, optimizing time, costs and quality of the data collected (Aguirre *et al.*, 1997). Additionally, Lara and Espinosa (1994) mention that the conservation and use of forest resources in a continuous and sustained manner will only be possible when greater precision is achieved in their distribution and quantification.

In this sense, the objective of this research was to evaluate and compare the precision of estimation of dasometric variables, sampling times and costs of two temporal sampling methods based on a census applied to a natural even-age mass of *Pinus arizonica* Engelm. in the municipality of Guachochi, Chihuahua, Mexico. The objective of this study is based on the hypothesis that the sampling methods do not present statistical differences in the precision of estimations of dasometric variables in even-age forests and the execution costs are statistically different between sampling methods.

Materials and Methods

Study location

It was carried out in the municipality of Guachochi, located in the Southwest of the state of Chihuahua, Mexico, in the physiographic province of Sierra Madre Occidental. In the area there is a cold temperate forest of *Pinus arizonica* Engelm (Figure 1). The type of soil is Eutric Regosol, of medium to fine texture (INEGI, 2014), and the predominant climate is C(E)(w2)(x'), humid semi-cold with an average annual temperature between 5 and 12 °C, and an average annual rainfall of 621.3 mm (INEGI, 2008).

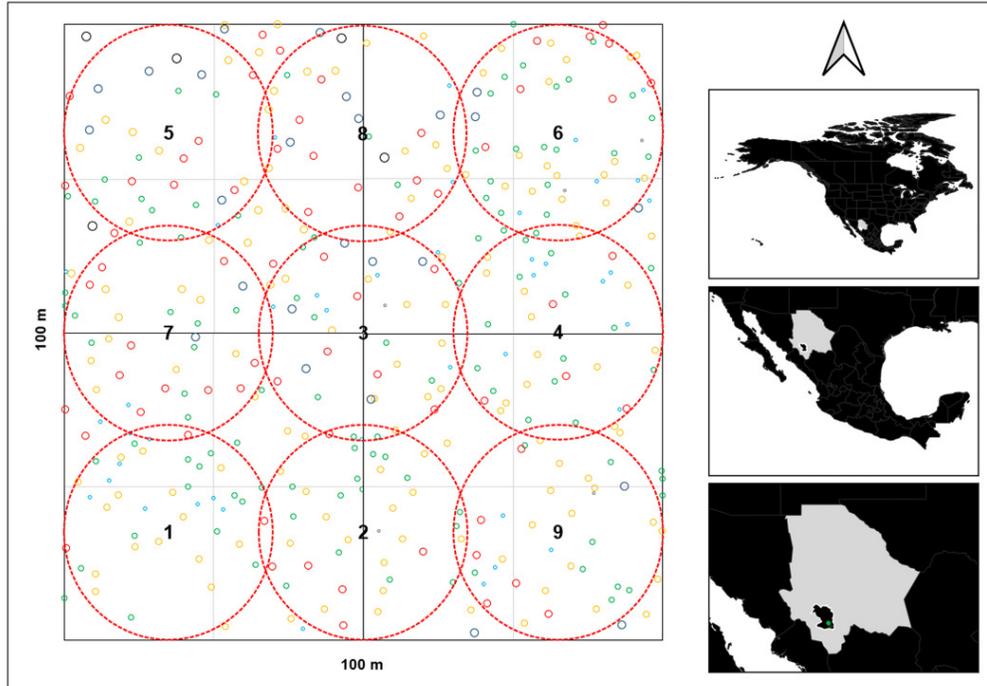


Figure 1. Location of the uniform-age pine forest studied in northern Mexico

Materials and equipment used

The dasometric data for the study were taken from each of the individuals. The database was made up of trees whose normal diameter ($DN_{1.30}$) ≥ 7.6 cm was measured with a 90 cm Hagl \ddot{o} f[®] caliper and the total height with a Suunto[®] PM5-15-20 hypsometer. Additionally, the species to which each individual belongs was recorded. The simple Bitterlich Relascope was used to estimate the basal area in sites of variable dimensions.

Methods

A standard hectare was delimited in a 40-year-old even-aged forest, with flat topography, without a logging program, with coordinates 26° 50' 43.28" N and 107° 04' 55.54" W (Figure 2). The dasometric data of the total trees, species, normal diameter and total height of each of the individuals were recorded.



Figure 2. Individuals identified numerically in an even-aged mass of *Pinus arizonica* within the established type hectare

Within the census area, nine sites of 1,000 m² and nine sites of variable dimensions of Bitterlich were established with a systematic sampling method. These data were collected to determine the statistical precision of each sampling method based on actual stocks. For this, the number of trees per hectare (N arb ha⁻¹) was calculated with the following relationship:

$$N \text{ trees ha}^{-1} = \frac{\sum N \text{ trees}_i}{M} * 10$$

Where:

N trees ha⁻¹ = Number of trees per hectare.

N trees_i = Number of trees in the site i.

M = Number of sites.

The estimation of basal area per hectare (AB m² ha⁻¹) was carried out with the following procedure:

$$AB \text{ m}^2 \text{ ha}^{-1} = \frac{\sum g_i \text{ (m}^2\text{)}}{M} * 10$$

Where:

AB m² ha⁻¹ = Basal area in square meters per hectare.

g_i (m²) = Basal area of site i expressed in square meters.

M = Number of sites.

The volume (Vol m³ ha⁻¹) was determined using the equation developed by the UMAFOR-0807 biometric model (CONAFOR - Chihuahua Government - UMAFOR 0807, 2014), presented below:

$$VTA = 0.000033 * (DN^{1.957172}) * (H^{1.103479}) + 0.000132 * (DN^2)$$

Where:

VTA = Total Tree Volume.

DN = Normal diameter (1.30 m).

H = Total height.

The times from the installation of each of the methods, until the end of data collection, and transfers from site to site were recorded. The comparison of the methods in the efficiency in the estimation of times, was made through the calculation of the Relative Efficiency (RE) by means of the following equation (Silva, 1998).

$$RE = \frac{1}{T_x \cdot CV^2}$$

Where:

RE = Relative efficiency.

T_x = Installation and measurement time.

CV = Coefficient of variation.

To determine fixed costs, variable costs and total costs, the application of 20 structured interviews was carried out with providers of technical forestry services that use or have used sampling both through sites of fixed dimensions and variable dimensions in the municipalities of Madera, Guachochi and Bocoyna, Chihuahua, and the costs of equipment, personnel training, salaries, food, fuel and medical service were considered, mainly.

Statistical analysis

In order to detect if there are statistical differences in the precision of estimates of dasometric variables between methods and in comparison, with the census, data recording times and costs involved in the development of both methods, the homogeneity of the variances of the sampling methods was evaluated employed by Levene's tests at a significance value of $p \leq 0.05$. Analysis of Variance (ANOVA) tests were applied at a significance level of $p \leq 0.05$ to determine the statistical differences between methods with respect to the census in the variables of number of trees per hectare, basal area per hectare and total tree volume per hectare. The statistical package IBM-SPSS® version 25 was used to carry out the analysis of the variables.

Results

Analysis of the number of trees per hectare

The difference in the number of trees per hectare estimated by the fixed dimension method is not significant ($p = 0.8975$) with respect to the census, the same as the variable dimension method ($p = 0.8607$). Figure 3 shows that the sites of fixed dimensions presented absolute ranges from 310 to 540 individuals per hectare, according to the results of the nine established sample units. For its part, the Bitterlich method shows absolute ranges from 291 to 629 trees per hectare. These values indicate that despite the fact that the mass is coetaneous and the estimates are similar in terms of the actual number of trees per hectare, the irregular distribution of the trees may have an effect on the precise calculation of density.

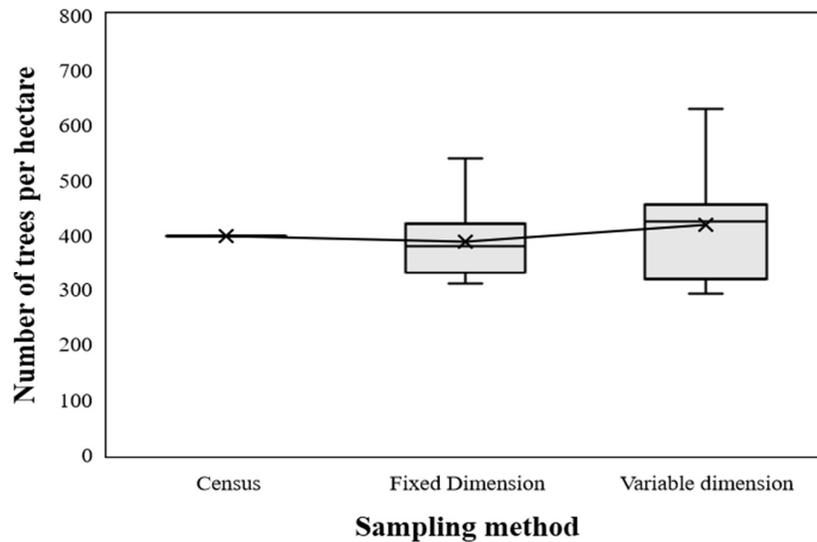


Figure 3. Comparison of ranges to estimate the number of trees per hectare by dasometric sampling method

*Common letter indicates equality in ANOVA test ($p \leq 0.05$).

The analysis of the type or census of the hectare indicates the presence of 398 individuals of *Pinus arizonica*. On the other hand, the estimate product of the sampling of fixed dimensions (nine sites of 0.1 ha) resulted with 388 trees per hectare, which represents an underestimation of -2.57 %. The sampling by variable dimensions method estimates 418 trees per hectare, representing a 5.14% surplus with respect to the result of the census. According to the analysis, this estimation error would have an effect on the sustainable management of the stand; however, the statistical analysis indicates that the difference is not significant as previously mentioned. This indicates that the fixed dimension method is more efficient; but, as mentioned above, the difference between the two methods is not significant.

Analysis of basal area per hectare

The nine sites with fixed dimensions presented ranges from 20.85 to 32.54 $\text{m}^2 \text{ha}^{-1}$ of basal area (Figure 4), the site that presented the highest value represents outlier data. This result indicates the presence of a greater number of individuals, or diametric dimensions greater than the average for the study area. The variable area method shows basal area levels between 22.00 and 38.00 $\text{m}^2 \text{ha}^{-1}$ depending on the nine measurement points. The results found indicate that the distribution of the trees, their diameter, and the density of the mass, generate variability in the estimation of basal area per hectare between sampling sites. However, they do not

represent a significant effect on the estimated mean values. This assertion is supported by a p value = 0.7483 in the comparison of census means and sites of one tenth of a hectare. The variable area sampling method showed similarity with the results obtained from the total count, with a significance of $p = 0.8582$.

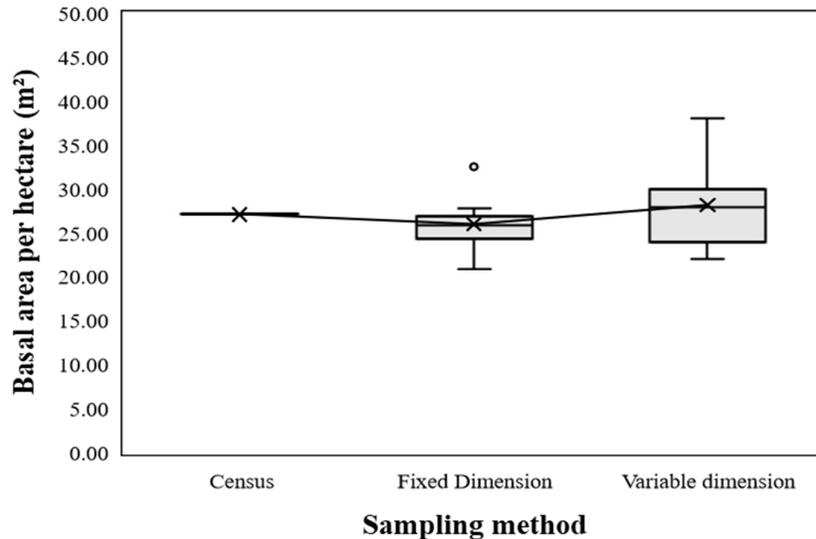


Figure 4. Comparison of ranges for estimation of basal area per hectare by dasometric sampling method
* Common letter indicates equality in ANOVA test ($p \leq 0.05$).

According to the values obtained by the different types of sampling, in basal area estimation (BA), the census or total count recorded $27.13 \text{ m}^2 \text{ ha}^{-1}$, and the fixed dimensions method resulted in a basal area of $26.01 \text{ m}^2 \text{ ha}^{-1}$, therefore, underestimated with -4.12% ; The Bitterlich method resulted in a basal area of $28.22 \text{ m}^2 \text{ ha}^{-1}$, with an overestimation of 4.02% with respect to that estimated by the census of the typical hectare. The Bitterlich method was the one that came closest to the average, which is due to the regular mass structure, which is the type of forest where the study was carried out.

Analysis of total tree volume per hectare

The difference in total tree volume per hectare estimated in the fixed dimension method is not significant ($p = 0.7382$) with respect to that the census. Likewise, the Bitterlich method does not show differences in the estimation of volumetric stocks compared to the total survey ($p = 0.9992$). The sites of fixed dimensions presented volumetric ranges from 179.71 to $366.58 \text{ m}^3 \text{ ha}^{-1}$ in the results of the nine sample units established. For its part, the variable area method shows ranges from 201.42 to $459.43 \text{ m}^3 \text{ ha}^{-1}$. The estimation of the volume of the sites presents variability in the ranges, due in part to the fact that in the sites of variable dimensions a reference tree is taken with representative dasometric characteristics of the sampling point; instead, fixed-size sites take into account the individual volume of trees in the sample area. According to the results obtained by the different types of sampling, in estimation of total tree volume, the census or total count has $287.40 \text{ m}^3 \text{ ha}^{-1}$, the fixed dimensions method resulted in a volume of $265.75 \text{ m}^3 \text{ ha}^{-1}$, therefore, it underestimated the volumetric stocks with -7.53% , in this case, the volume calculated by this method exceeds the expected error of 5.00% , which implies a problem in decision making in the sustainable management of the mass. Using the Bitterlich method, a total tree volume of $287.31 \text{ m}^3 \text{ ha}^{-1}$ was calculated, having an underestimation of -0.03% with respect to that estimated by the census of the typical hectare. The Bitterlich method was the one that came closest to the average (Figure 5), which indicates that it is an adequate method to estimate the volumetric stocks in forests with characteristics similar to those shown in this study.

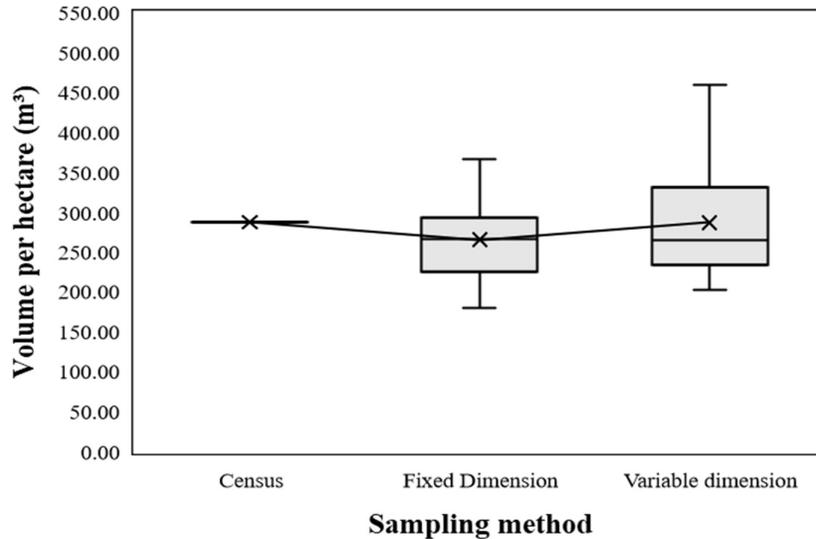


Figure 5. Comparison of ranges for estimation of total tree volume per hectare by dasometric sampling method

* Common letter indicates equality in ANOVA test ($p \leq 0.05$).

The estimates made indicate that both sampling methods are adequate to determine the stocks present in pine forests with regular and even-aged stands. However, the absolute differences presented by the fixed dimension method in the estimation of the number of trees per hectare (5.12 % error) and total tree volume per hectare (7.53 % error) based on the total count, indicate the need for perform deeper analyzes in the sampling methods, because the spatial distribution of the individuals (location and diameter) may affect the values obtained, or even the size of the site may not be the most adequate to obtain a sample accurate in this forest condition.

Inventory data collection time

In the present study, with the fixed sampling method, ranges from 31 to 54 trees per site were obtained. The general data recording and quantification of trees represents an estimated time of 28 to 67 minutes.

With the variable area sampling method, under the basal area factor parameter used (Factor 4), ranges from 6 to 12 individuals per sampling point were obtained. The general record of forest inventory data and the estimation of basal area present survey times of 9 to 12 minutes.

According to the information shown in Figure 6, the sites with fixed dimensions show a significant increase in the time taken to carry out the sampling as a function of the density of trees within the plot. On the other hand, the regression obtained through the relationship of survey time and number of trees registered in the Bitterlich angular count sites, indicates that the density of the trees represents an increase to a lesser degree in the registration time than the sites of fixed dimensions.

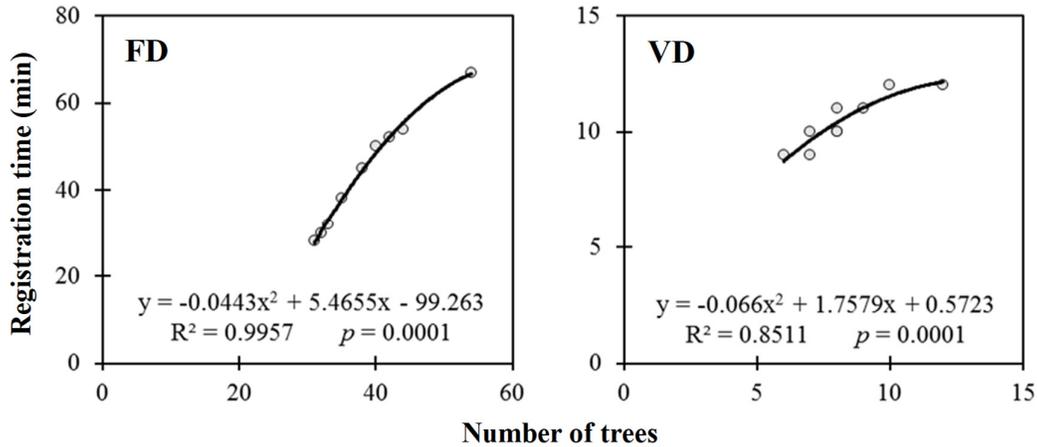


Figure 6. Relation between the number of trees registered and the time involved in the survey of forest sampling sites (FD = Fixed dimensions; VD = Variable dimensions)

Contrast of data collection times

The applied methods presented significant differences ($p = 0.0001$) in the comparison of times in the survey of the sites. The fixed-size sampling method presented an average of 44 minutes, and the Bitterlich method showed greater efficiency, spending less time in the sampling data collection with an average of 10 minutes 26 seconds (Figure 7). Based on the results, it is estimated that according to the average time to execute a site of fixed dimensions, it is possible to make at least four sites of variable dimensions in a forest mass such as the one studied.

According to the maximum range of time for establishing a fixed dimension site, it is possible to make between five and seven variable dimension sites based on their upper and lower limits. Likewise, it is possible to measure two to three Bitterlich sites in the time required to record the trees of a fixed dimension site.

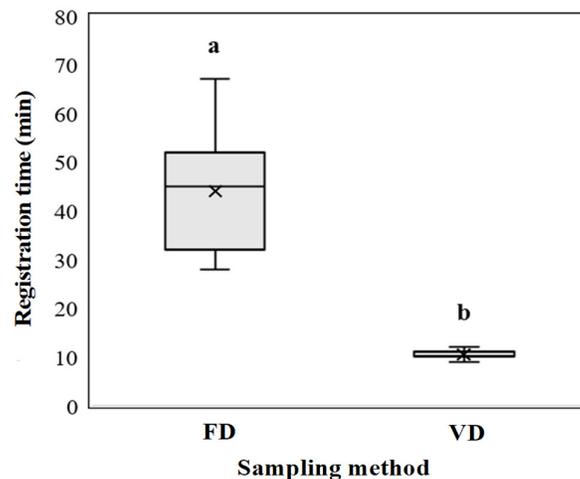


Figure 7. Graphical comparison of ANOVA test results for run time by sampling method (FD = Fixed Dimensions; VD = Variable Dimensions).

* Common letter indicates equality in statistical test ($p = 0.05$).

Estimated cost of sampling

According to the survey applied to providers of technical forestry services in the municipalities of Guachochi, Madera and Bocoyna, Chihuahua, average fixed costs of 48.62 Euro were generated in the concept of medical service, 200.35 Euro is the average cost of training personnel for the two inventory methods, and finally, the cost of forestry inventory equipment, which in the case of fixed dimensions has an average of 394.03 Euro, which includes a pocket diameter tape with an estimated cost of 19.71 Euro; a meter of height by tangent of 23.24 Euro; a bounded cable to delimit the surface of the site at a cost of 24.96 Euro; a satellite geopositioning device (GPS) for 117.48 Euro and an auger for the extraction of increment samples with a value of 211.03 Euro. For its part, Bitterlich sampling requires an investment in equipment of at least 381.09 Euro. In general, the same type of equipment is used as in the previous method, except that in this case the bounded cable is replaced by a simple Bitterlich relascope or a “jalometro” with an approximate cost of 12.02 Euro.

A mean salary of 2.80 Euro per fixed-size site and 1.40 Euro per variable-size site was estimated, with a p value = 0.0001; in food, kitchen equipment and food for the brigade were taken into account, obtaining an average of 1.00 Euro. Regarding the material for data recording, paper, pencil and eraser, an average of 0.08 Euro was obtained. Based on the maximum and minimum distances to the areas where an inventory has been carried out, an average of 0.19 Euro in fuels per site was determined.

According to the analysis of the estimates of the costs of the methods of fixed and variable dimensions through the ANOVA test, it was found that the fixed and total costs present significant differences ($p = 0.0001$ and $p = 0.0008$ respectively) (Figure 8), while for variable costs the difference is not significant ($p = 0.1615$).

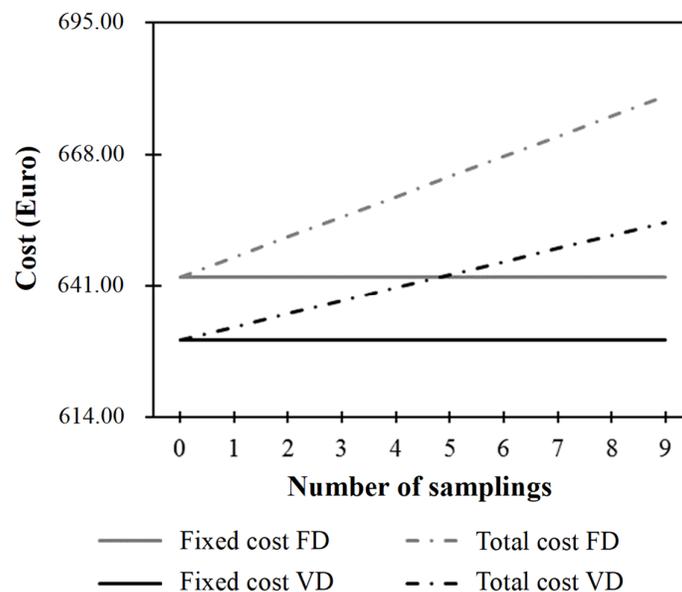


Figure 8. Estimated differences in sampling cost accounting (FD = Fixed Dimensions; VD = Variable Dimensions)

Discussion

Moscovich and Brena (2006) mention that by analysis of variance it was verified that the methods they applied (Fixed area, Strand, Prodan, Bitterlich and Quadrantes), did not show significant differences in the estimation of volume, number of trees per hectare and basal area. This comparison coincides with the results in the present study, since the fixed area and variable area (Bitterlich) methods did not present significant

differences in the estimation of the number of trees per hectare, basal area per hectare and total tree volume per hectare.

Roldán-Cortes *et al.* (2014) determined that in the case of the basal area/volume ratio, it turned out that for each m² of BA in a site, there are approximately 8.05 m³ of standing volume. Like the results obtained in the comparison of stocks in the census and estimates from the Bitterlich method, this relationship can be used to carry out rapid inventories when only the relascope is used to determine the basal area. On the other hand, Ríos *et al.* (2000) indicate that the sampling error, as expected, increases with the increase in the basal area factor, or also with the decrease in the plot area. defined for each factor of basal area and mean diameter.

Corvalán (2019) refers to the fact that the survey time of the sites depends on the area that will be inventoried and the speed of movement within the plots. Similarly, the results of this research indicate that the greater the number of individuals to be recorded in the sampling, the greater the time required to carry out the forest inventory. On the other hand, sites of variable dimensions do not require a large sample of individuals, which means a decrease in the time for collecting dasometric data. Manzanero and Pinelo (2004) determined the variable costs of a silvicultural, remanence, and diagnostic sampling for the Petén Forest in Guatemala, where 500 sites were surveyed (50 sites per day), for ten days, with a budget of \$831.17 dollars (USD), equivalent to 762.34 Euro for salary. According to the information obtained through interviews, the registration of field data requires an investment for the concept of salary of 2.80 Euro per site of fixed dimensions and 1.40 Euro per site of variable dimensions, these amounts being higher and lower respectively compared to the costs registered in Petén, Guatemala.

Finally, Lara and Espinosa (1994) indicate that, in a census carried out in the state of Michoacán, Mexico, it was found that sites with variable dimensions have greater precision in estimating BA than sites with fixed dimensions (1,000 m²). Regarding the time required to register the individuals in the sampling, the Bitterlich angular site requires 3.8 times less time than the fixed dimension sampling. Lastly, the equipment used for measuring sites of variable dimensions tends to be less expensive than that used to survey fixed-dimension sites. In the present study it was found that the variable area method turns out to be more precise (error = 4.02%), however, the precision differences turn out to be non-significant also for the fixed dimension site. Regarding the time taken to record the inventory data, it is estimated that the fixed dimensions site requires 4.19 times more time than the Bitterlich angular sampling.

Conclusions

The methods studied present acceptable statistical precision when estimating the number of trees per hectare, basal area and volume. The time involved in collecting inventory data is more efficient in the application of the Bitterlich method, since it requires only 23.72% of the time used in the fixed dimensions method. The cost per execution of both samplings presents significant differences, being the method of variable dimensions more favorable when taking field data in even-aged forests with absolute presence or dominance of the genus *Pinus*. Although variable-size sampling tends to be cheaper than fixed-size sampling, there is no statistically significant difference.

The differences observed in the fixed dimension method for estimating the number of trees per hectare and total tree volume per hectare compared to the total count, indicate the need to conduct further analyses on sampling methods, due to the random spatial distribution of trees, which can result in biases in the estimations made. The spatial characteristics of the individuals can affect the values obtained, or even the dimension of the site, is not the most adequate to obtain an accurate sample in this forest condition.

The proposed hypothesis is accepted because the sampling methods did not present statistical differences in the precision of the estimates of dasometric variables in natural even-age forests. Likewise, the execution costs of the forest sampling are statistically different between methods, because the variable

dimension method turned out to be less expensive. These results can be applied to carry out larger-scale forest sampling in even-age forests in order to obtain accurate information quickly and at a lower cost.

Authors' Contributions

Conceptualization of the research idea, designing the experiment, and writing-original draft preparation, V.S.G.M.; formal analysis, validation and discussion, J.M.O.G., J.H.S. and J.R.S.; resources, data curation and writing-review and editing, C.M.K.D. and H.T.V.; supervision, V.S.G.M. and J.M.O.G. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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