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STRATIFIED SAMPLING IN FOREST INVENTORY

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Abstract: The paper studies the possibility of using the stratified sampling in forest inventory. The technique of average and total volume assessment is explained in the example of one beech high forest management class. We first observed stands as strata and then homogeneous groups of stands. We concluded that there are numerous possibilities for using stratified sampling in forest inventory. Compared to a simple sample of the same size, the obtained volume assessment has a greater precision. The effect of the performed stratification is significant. In the given example, to achieve the same degree of precision of the assessments, the size of the stratified sample can be 27.2% smaller than the simple sample.

Keywords: stratified sampling, forest inventory, stand, management class

1. INTRODUCTION

Different sampling types (plans) are being applied in modern forest inventory: simple or stratified, blocks, two-stage or multi-stage, two-phase or multi-phase, group sampling etc. (Kangas, A., Maltamo, M. 2006; Laar, V.A., Akça, A. 2007). The main objective of applying different sampling types is to achieve maximum precision and accuracy in the measurement of forest parameters (inventory units) at minimum costs. Simple sampling is used only at stand level, while stratified sampling is more convenient for larger inventory units (compartments, catchments, management classes, forest categories, management units, woodland etc.). In general, the stratified sample is applied to large heterogeneous populations that are or can be subsequently divided into a number of homogeneous subpopulations, called strata.

The primary advantage of the stratified sample compared to the simple one is that if the samples are of the same size, the stratified sample will provide a more precise estimate of the parameters that are measured in an inventory unit. Theoretically speaking, the more homogeneous the elements within each stratum are, (regarding the observed characteristic) and the more heterogeneous they are between the strata, the greater is the effect of the stratification. When the strata differ greatly in their means, a significant effect of the stratified sampling application can be expected for sure (Hadživuković, S., 1975; Koprivica, M., 2004).

Another advantage of stratified sampling over simple sampling is that it provides insight into the estimated parameters both for the whole inventory unit and for its subpopulations - strata. For instance, it measures parameters of one management class per stands or of one forest category per management classes, etc. Although the simple sample is primarily intended for small homogeneous

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populations (stands), in our forestry practice it is often used for the estimates of parameters in large heterogeneous populations (management classes, forest categories, management classes, woodland, etc). It is probably due to unfamiliarity with the advantages of stratified sampling compared to simple sampling and its somewhat more complex statistical procedure of data collection and processing.

This is what Hadživuković says about the problem: `One of the main merits of stratified sampling is the increasing precision of estimates. Therefore, there is a prevailing opinion that it should be always applied. However, it must be stressed that the application of stratification can sometimes result in an insignificant increase of precision that is of small practical value. Namely, the degree of precision depends on the degree of homogeneity between the observations within a stratum and this homogeneity is greatly affected by the way the sample is stratified` (Hadživuković, S., 1975, p. 93).

The task of this paper is to present the technique of estimating average and total volume on the example of one management class of beech high forests (inventory unit), using simple and stratified sampling, as then to evaluate the effect of the stratification. The objective of the paper is to provide forestry experts with better understanding of the technique and possibilities of using stratified sampling in forest inventory or in forestry in general.

2. MATERIALS AND METHOD

A systematic sample of 500 m^2 sample plots, arranged in a square grid of 100 x 100 m, was applied for the stand inventory of one management class of beech high forests. The data required for estimating stand and management class volume (tree diameter and height) were obtained from sample plots. Tree volume was calculated by regression equations (Koprivica, M., Matović, B. 2005). The data for this research were collected within the project "*Method of evaluation of quality and assortment structure of beech high stands in Serbia*", carried out by the Institute of Forestry in Belgrade (from 2005 to 2007), applying specific methodology (Koprivica, M. *et al*., 2005).

The study management class comprises eleven all-aged beech stands. Altogether 242 sample plots were established in the management class and they approximately accounted for the whole area of the management class (241.9 ha). Thus, the sampling intensity accounted for 5% of the measured forest area.

Dendrometric data processing was done using the software SORTIMENT, especially designed to this purpose by Marković, N. *et al*. (2007). The data were then statistically processed. Several methods were applied for this purpose: descriptive statistics, analysis of variance and the methods of simple and stratified sampling (Hadživuković, S., 1991).

3. RESULTS AND DISCUSSION

3.1 Main statistical parameters of the sample

The main statistical parameters of the sample plot sample in the stands and in the management class are given in Table 1.

Table 1 Statistical parameters for the stands and the management class of beech high forests

Stand	F (ha)	n	$\bar{v}$ (m^3/ha)	v_{min} (m^3/ha)	v_{max} (m^3/ha)	s_v (m^3/ha)	$s_{\bar{v}}$ (m^3/ha)	cv (%)	m_v (%)
33a	22.7	23	522.52	298.68	875.00	163.57	34.11	31.30	6.53
42a	17.9	18	379.57	215.07	563.15	88.51	20.86	23.32	5.50
42b	10.4	10	333.23	146.62	441.83	90.18	28.52	27.06	8.56
122a	29.5	29	503.68	246.49	972.84	185.53	34.45	36.83	6.84
27a	20.2	20	350.38	110.10	759.14	170.83	38.20	48.76	10.90
31a	31.6	32	290.89	109.29	511.27	104.48	18.47	35.92	6.35
46a	28.3	28	316.04	68.20	612.28	132.51	25.04	41.93	7.92
8a	16.5	16	385.19	189.73	653.19	117.02	29.25	30.38	7.59
8b	9.8	10	360.83	279.90	453.35	65.10	20.59	18.04	5.70
44a	22.6	23	502.25	265.47	983.92	174.56	36.40	34.75	7.25
116a	32.4	33	289.96	49.96	619.83	122.76	21.37	42.33	7.37
M. class	241.9	242	383.66	49.96	983.92	163.63	10.52	42.65	2.74

Standard formulas for simple random sampling were used to calculate the average volume per hectare and the volume variability. The relative error of volume (m_v%) is expressed as the coefficient of variation divided by the square root of the sample size.

3.2 Use of simple sampling

Simple sampling was applied to estimate the average and the total volume of each stand separately and of the management class as a whole.

For example, a stand 33a estimate is as follows:

$$\bar{v}_{uz} - t \cdot s_{\bar{v}uz} < \bar{V}_{sk} < \bar{v}_{uz} + t \cdot s_{\bar{v}uz} \quad (1)$$

where:

$\bar{v}_{uz}$ - average volume per hectare in the sample,

t - value from *t*-distribution tables for particular probability and degree of freedom *n – 1*,

$s_{\bar{v}uz}$ - error of the average volume per hectare in the sample, and

$\bar{V}_{sk}$ - average volume per hectare in the population (stand)

Some elements of the inequality (1) are defined as follows.

$$\bar{v}_{uz} = \frac{\sum v_i}{n}, \text{ t (95\% and n-1)}, \; s_{\bar{v}uz} = \frac{s_{vuz}}{\sqrt{n}}, \; s_{vuz} = \sqrt{\frac{\sum (v_i - \bar{v}_{uz})^2}{n-1}}$$

where:

v_i - volume per hectare for i^th sample plot, and

s_{vuz} - standard deviation of the volume in a sample of a specific size (n)

Accordingly,

$$522.52 - 2.074 \cdot 34.11 < \overline{V}_{sk} < 522.52 + 2.074 \cdot 34.11$$

$$451.78 < \overline{V}_{sk} < 593.26$$

The actual average volume of stand 33a, with a 95% probability, and degree of freedom 22, is in the range between 451.78 m^3/ha and 593.26 m^3/ha, with a further 5% probability that it may be out of bounds. Practically, this result means that if we established 100 different samples of the same size (n = 23), in this stand, 95 of them would have the average volume per hectare within the defined range and 5 outside the specified limits. The range of confidence interval (of the estimate) is 141.48 m^3/ha, while the sampling error amounts to half of the interval or +/-70.74 m^3/ha or +/-13.54%. It is obvious that the error of the estimated average volume per hectare is high, and in practice it can equal the felling quantity planned in a 10-year long management period, assuming that the planned felling intensity in the stand is 13.54%. This example confirms the conclusion that planning at stand level is usually very unreliable due to the lack of precision (accuracy) of the estimated volume (Koprivica, M., 2006).

The range of the total stand volume i.e. on the whole area (F) of the stand is calculated in the same way.

The formula is as follows:

$$F(\overline{v}_{uz} - t \cdot s_{\overline{v}uz}) < F\overline{V}_{sk} < (\overline{v}_{uz} + t \cdot s_{\overline{v}uz})F \qquad (2)$$

Accordingly,

$$23.7 \cdot 451.78 < F\overline{V}_{sk} < 593.26 \cdot 23.7$$

$$10{,}707.19 < F\overline{V}_{sk} < 14{,}060.26$$

Thus, the total volume of stand 33a is in the interval between 10,707.19 m^3 and 14,060.26 m^3. Sampling error is + / - 1,676.54 m^3 or + / - 13.54%. Of course, here it is assumed that the area of the stand was determined accurately. Otherwise, if there is an error in the stand area calculation, it should be taken into account (Matić, V. 1977; Laar, A.V., Akça, A. 2007).

Average and total volume of the management class (n=242) were estimated in the same manner as for stands. The actual average management class volume, with a 95% probability, and degree of freedom 241, is in the range from 363.06 m^3/ha to 404.26 m^3/ha. Sampling error is +/- 20.62 m^3/ha or +/- 5.37%. It is again assumed that the area of the management class was determined accurately.

For illustration purposes, we will assume that the error in the estimate of the management class area, with a 95% probability, amounted to +/- 1.72%. Applying the law of error transmission, sampling error of the total volume estimate would be as follows

$$m_v\% = \sqrt{(m_{vuz}\%)^2 + (m_{puz}\%)^2} \qquad (3)$$

$$m_v\% = \sqrt{5.37^2 + 1.72^2}$$

$$m_V = +/-5.64\%$$

The error in the estimates of management class volume per hectare and in total is around +/- 5.5%. It means that the felling quantity for the following management period can be planned with greater certainty and more reliable management plans can be developed. If we kept the same sampling intensity and increased the area of the management class, the sampling error would decrease and the precision of the volume estimates would further increase. This would make felling quantity planning more reliable.

3.3 Use of stratified sampling

It is necessary to make a preliminary test of the effects we can expect to have from the application of stratified sampling, i.e. of the management class stratification, with regard to the criterion for strata formation and the number of strata. The main criterion for stratification in the study sample was the size of the average volume per hectare in the stand or in the homogenous group of stands, and the number of strata was determined by the number of stands or the number of homogeneous groups in the management class.

3.3.1 Preliminary assessment of stratification effects

In this case, the management class is first analyzed as a statistical population divided into eleven strata. The strata are stands that are internally homogeneous regarding the variation of volume per area and more or less heterogeneous between them. Whether this type of stratification can significantly reduce the sampling error should be preliminarily tested by applying the method of simple analysis of variance with unequal number of observations (Parde, J., 1961; Hadživuković, S., 1991). In fact, statistical significance of the difference between the sample means taken from different strata (stands) should be tested. If the difference is statistically random, we should not expect a significant effect of the implemented stratification. On the other hand, if the difference is statistically significant (with a 95% or a 99% probability), a significant effect of stratification can be expected. From the theoretical aspect, it is about testing the null hypothesis of equality of the mean values of different strata, at a given probability.

The results of the analysis of variance are given in Table 2.

Table 2 Analysis of variance of the difference between the average stand volumes perhectare

Source of variation	Sum of squares	Degree of freedom	Mean squares	F_0	$F_{0.05}$	$F_{0.01}$
Between the stands	1,931,010	10	193,101.0	9.86	1.83	2.32
In the stands	4,521,820	231	19,575.1			
Total	6,452,830	241	26,775.2			

The result of the analysis of variance shows that there is a statistically significant difference between the average stand volume per hectare, with 99% probability because F_0 is bigger than $F_{0.01}$ (9.86 > 2.32). This supports the hypothesis that significant effect (more precise estimate) can be expected if we use the stratified sample for the purpose of estimating average and total volume of the management class than if we use the simple sampling. If the stratification had not been applied, the standard deviation of the management class volume would have been $s_v = \sqrt{26775,2} = 163.63$ m^3/ha. After the stratification had been applied, it decreased, $s_v = \sqrt{19575,0} = 139.91$ m^3/ha. This decrease in the standard deviation was due to allocation of a portion of the total volume variation to the variation of the stand volume per hectare around the average management class volume per hectare.

In the conducted analysis of variance, the stands were observed as *treatments* in the field experiment analysis, because each stand has a number of specific features concerning its habitat, structure, and management systems. By definition, a management class should be "*a homogeneous part of a forest, comprising stands with similar site and stand characteristics, and ...",* however, in practice, they are most often heterogeneous, which justifies the application of stratified sampling to management classes. Applying the same principle, when we carry out the inventory of all high beech forests in a forest management unit or in woodland, its management classes can be singled out as strata.

Analysis of variance included Bartlett`s test, which is normally used to check the fulfillment of the basic requirement for the proper application of the analysis of variance in the experiment analysis - the homogeneity of variances in the compared treatments (samples). This test showed that the variances in our example were heterogeneous, because the calculated value of the test was greater than the critical value, with a 99% probability. Practically, in this way, we again confirmed that the stratification of the management class was justified. The least significant difference test (LSD) also showed that all stands in the management class could be classified into three homogenous groups:

A - 27a, 31a, 42b, 46a, 116a,

B - 8a, 8b, 42a,

C - 33a, 44a, 122a,

These stand groups statistically represent three strata, characterized by different average volume per hectare:

A - with the average volume 251 - 350 m^3/ha

B - with the average volume 351 - 450 m^3/ha

C - with the average volume 451 - 550 m^3/ha

The results of the analysis of variance with these three strata are given in Table 3.

Table 3 Analysis of variance for the difference of the average volume of stand groups per hectare

Source of variation	Sum of squares	Degree of freedom	Mean squares	F_0	$F_{0.05}$	$F_{0.01}$
Between stand groups	1,857,200	2	928,600.0	48.29	2.99	4.60
In the stand groups	4,595,630	239	19,228.6			
In total	6,452,830	241	26,775.2			

In this case, the difference in the average volume per hectare between homogeneous groups of stands (strata) is again statistically very significant, which means that we can expect more significant effect of stratification compared to simple sampling. Standard deviation of the management class volume is now $s_v = \sqrt{19228,6} = 138.66$ m^3/ha. Compared to the standard deviation obtained in the first type of stratification ($s_v = 139.61$ m^3/ha), there is only an insignificant decrease. Hence, both types of stratification show that the effect of stratification is more significant than the effect of simple sampling, but there is no significant difference between the two types of stratification. Therefore, the first type of stratification would be appropriate enough and in this case management class poststratification is not necessary. Furthermore, the change in the number of strata (from eleven to three) had no significant effect on the results of the analysis of variance. This is a practical confirmation of the statement that the size of the average volume per hectare is the most easily defined criterion for the formation of strata in the forest inventory (Koprivica, M., 2004).

3.3.2 Estimate of average and total management class volume

The estimate of the average and total management class volume by stratified sampling uses similar inequalities as simple sampling. The only difference is in the way certain elements of the inequalities are determined.

The range of the actual average management class volume per hectare is calculated by the following inequality(4),

$$\bar{v}_{st.uz} - t \cdot s_{\bar{v}st.uz} < \bar{V}_{st.sk} < \bar{v}_{st.uz} + t \cdot s_{\bar{v}st.uz} \quad (4)$$

where,

$\bar{v}_{st.uz}$ - average volume per hectare in the stratified sample,

t - value from *t*-distribution tables for particular probability and degree of freedom *n* - *k*, where *k* is the number of strata,

$s_{\bar{v}st.uz}$ - standard error of average volume per hectare in the stratified sample, and

$\bar{V}_{st.sk}$ - average volume per hectare in the stratified population (management class),

It is also necessary to know the relative proportion of individual strata in the population (W_i), where $W_i = F_i/F$ or N_i/N or for the proportional selection n_i/n.

Data necessary for the inequality (4) are given in Table 4,

Table 4 Data for the use of the stratified sample in the beech management class

Stand	n_i	W_i	$W_i \bar{v}_{i.st}$	W_i^2	$s^2_{\bar{v}i.st}$	$W_i^2 s^2_{\bar{v}i.st}$
33a	23	0.0951	49.692	0.009044	1,163.4921	10.5226
42a	18	0.0744	28.240	0.005535	435.1396	2.4085
42b	10	0.0413	13.762	0.001706	813.3904	1.3876
122a	29	0.1198	60.341	0.014352	1,186.8025	17.0330
27a	20	0.0826	28.941	0.006823	1,459.2400	9.9564
31a	32	0.1322	38.456	0.017477	341.1409	5.9621
46a	28	0.1157	36.566	0.013386	627.0016	8.3930
8a	16	0.0662	25.500	0.004382	855.5625	3.7491
8b	10	0.0413	14.902	0.001706	423.9481	0.7233
44a	23	0.0950	47.714	0.009025	1,324.9600	11.9577
116a	33	0.1364	39.550	0.018605	456.6769	8.4965
M.class	242	1.0000	383.664			80.5898

Accordingly,

$$\bar{v}_{st.uz} = \sum W_i \bar{v}_{i.st} = 383.664 \text{ m}^3/\text{ha}$$

$$t\ (95\%\ \text{i}\ n - k) = 1.96$$

$$s_{\bar{v}st.uz} = \sqrt{\sum W_i^2 s^2_{\bar{v}i.st}} = \sqrt{80.5898} = 8.977 \text{ m}^3/\text{ha}$$

When we put the obtained values into the inequality (4), we obtain

$$383.66 - 1.96 \cdot 8.977 < \bar{V}_{st.sk} < 383.66 + 1.96 \cdot 8.977$$

$$366.06 < \bar{V}_{st.sk} < 401.25$$

Actual average volume of the analyzed management class of beech high forests is, at the probability of 95% and degree of freedom 231, in the range between 366.06 m^3/ha and 401.25 m^3/ha. Sampling error is +/- 17.60 m^3/ha or +/- 4.59%.

Total volume of the management class is estimated by the following inequality (5),

$$F(\bar{v}_{st.uz} - t \cdot s_{\bar{v}st.uz}) < F\bar{V}_{st.sk} < (\bar{v}_{st.uz} + t \cdot s_{\bar{v}st.uz})F \qquad (5)$$

Accordingly,

$$241.9 \cdot 366.06 < F\bar{V}_{st.sk} < 401.25 \cdot 241.9$$

$$88{,}549.91 < F\bar{V}_{st.sk} < 97{,}062.37$$

Sampling error is +/- 4,256.23 m^3 or +/- 4.59%, provided that the area of the management class was determined correctly. Otherwise, if there is an error in the management class area calculation, it should be taken into account.

3.3.3 The effect of the use of stratified sampling

The effect of the use of stratified sampling can be estimated from the ratio of the arithmetic mean variance between the stratified and the simple sample (Hadživuković, S., 1991),

$$RE\% = \frac{\sum W_i^2 s_{\overline{v}i.st}^2}{s_{\overline{v}uz}^2} \cdot 100 \tag{6}$$

Accordingly,

RE =(80.5898/110.6395) · 100 = 72.84%

The result shows that in the study example, the size of the simple sample can be reduced by 27.16% or by 66 sample plots (from 242 to 176), if we apply stratified sampling, and the precision of the estimate will remain at the same level as in the simple sample.

Sample plots would be again systematically arranged in a 117.5 x 117.5 m grid. Since the size of the sample is now reduced per stands compared to the initial sample size, the error of the average and total volume estimate would be somewhat higher for each individual stand.

The change in the values of individual statistical indicators can be most easily observed in Table 5.

Table 5 Comparison of simple sample and stratified sample parameters

Sample parameters	Simple sample (1)	Stratified sample (2)	Difference (2) – (1)	Ratio (2)/(1)
Sample size	242	242	-	-
Mean	383.66 m^3/ha	383.66 m^3/ha	-	1.00
Standard deviation	163.63 m^3/ha	139.70 m^3/ha	- 23.93	0.85
Standard error	10.52 m^3/ha	8.98 m^3/ha	-1.54	0.85
Coefficient of variation	42.65%	36.41%	- 6.24	0.85
Relative error, 95%	+/-5.37%	+/-4.59%	- 0.78	0.85

In table 5, it can be observed that the value of the average management class volume per hectare has remained the same, while standard deviation, standard error, coefficient of variation and relative standard error are 15% lower in the stratified sample than in the simple sample of the same size.

Although it has been already shown that the size of the simple sample can be reduced by 66 sample plots or 27.16%, if stratified sample is used instead of simple sample, there is another way to prove that – based on the formula for planning the size of a simple sample,

$$n = \frac{(t \cdot cv\%)^2}{(m_v\%)^2} \tag{7}$$

Thus we obtain $n = (1.96 \cdot 42.65)^2/5.37^2 = 242$ sample plots in the simple sample, or $n = (1.96 \cdot 36.41)^2/5.37^2 = 176$ sample plots in the stratified sample. Again, the number of sample plots in the stratified sample has decreased by 66.

If we want to achieve the level of precision of the stratified sample by using the simple sample, the size of the sample should then be $n = (1.96 \cdot 42.65)^2/4.59^2 = 332$ sample plots.

Compared to the initial size of the simple sample, this sample has increased in size by 37.2% or 90 sample plots. To put it simply, if we want to reduce the sampling error 1.17 times (5.37/4.59), it is necessary to increase the size of the sample 1.17^2 times (1.37) or by 37%.

It would be interesting to see what the size of the stratified sample would be with proportionate and optimal allocation of sample plots, if it was calculated directly by the formulas (Loetsch, F., Haller, K. E., 1964),

$$n = \frac{t^2 \sum W_i s_{vi}^2}{m_v^2} \quad (8)$$

$$n = \frac{t^2 (\sum W_i s_{vi})^2}{m_v^2} \quad (9)$$

where,

$t = 1.96$ ($n > 30$, $P = 95\%$)

$W_i = F_i/F$ or N_i/N or n_i/n

s_{vi} - standard deviation of the stand volume per hectare, and

m_v - absolute error of the average management class volume per hectare, with a 95% probability

Thus we obtain the following result:

$$n = (1.96^2 \cdot 19{,}503.84)/20.62^2 = 176$$

$$n = (1.96^2 \cdot 135.102^2)/20.62^2 = 165$$

The number of sample plots in the optimal stratified sample is smaller by 11 sample plots or by 6.25% compared to the proportionate stratified sample. Similar results can be found in Nyyssonen, A., Vuokila, Y. (1963). It can be also seen that the application of optimal allocation in the stratified sample would reduce the size of the simple sample by 77 sample plots (from 242 to 165) or by 31.82%.

Although the optimal allocation of sample plots would theoretically be the best choice (Hadživuković, S., 1975; Kangas, A., Maltamo, M., 2006; Laar, A. V., Akça, A., 2007), its application in the forest inventory wouldn`t be so easy. The most common reasons are lack of knowledge about the volume variability in individual strata before the sample planning and different spacing between the sample plots (grid density) in the strata. Due to the limited scope of the paper, we cannot analyze the optimal allocation of sample plots with different cost per stratum. That is an issue that needs special attention.

Stratified proportionate sampling has a great advantage compared to the simple and stratified optimal sampling. This is what Hadživuković states about this issue: `Proportionate sampling is often applied because: 1) the sampling method is simple and it doesn`t depend on the cost of sample plot allocation into strata; 2) even when stratification is improperly done, standard error cannot be higher than the standard error of the simple random sample; 3) the use of more complex methods of allocation with the aim of increasing the level of estimate precision does not produce better results; 4) calculations used for parameter estimate and precision are simplified` (Hadživuković, S., 1975. p. 101).

4. CONCLUSION

The task and aim of this study was to inform forestry experts about the possibilities and techniques of applying stratified sampling in forestry, as shown in the example of forest inventory, and to assess its efficiency in comparison to simple sampling. The subject of this paper was a management class of beech high forests with eleven stands. The size of the average and total management class volume was estimated using a simple and stratified systematic sampling. Proportionate sampling was used.

In this particular example, it has been proven that the use of stratified sampling with proportionate sample plot allocation, compared to simple systematic sample, results in decreased standard deviation, standard error, coefficient of variation and relative standard error of the sample by 15%, and the size of the simple sample by 27.2%, provided that the same precision (accuracy) level of estimates is achieved as in simple sampling. If the stratified sample is of the same size as the simple sample, higher precision level is obtained in the estimates of the average and total management class volume. Application of optimal sample plot allocation in the stratified sample leads to a further reduction in the size of the simple sample and increases the estimate precision. However, due to the problems in planning and implementation of optimal stratification, proportionate (systematic) allocation should be primarily used in forest inventory.

If forest inventory deals with inventory units larger than a stand (compartments, catchments, management classes, forest categories, management units, woodland, etc.), stratified systematic sampling with proportionate allocation of sample plots should be used instead of a simple systematic sampling. In fact, most often, in practice, you only need to perform poststratification of large inventory units and then to process data by stratified sampling formulas. However, when there is the possibility that we know or we can estimate variability (of volume, basal area, etc.) by strata in the initial phase of forest inventory planning, the total size of the proportionate or optimal stratified sample and the size of the sample per strata can be planned before we perform forest inventory in the field.

We have shown the possibility and technique of applying stratified sampling in forest inventory, as well as the advantage of this type compared to simple sampling. Everything that relates to stratified sampling in forest inventory can be applied to forestry in general. The technique of stratified sampling is not complicated, and there are numerous possibilities for its application in forestry, because we can always find a suitable criterion for the stratification of an observed population. When it comes to forest inventory, a good criterion for the stratification of the measured forest (inventory unit) is the size of the average volume per hectare.

The paper doesn`t analyze the estimate precision of random and systematic sampling in forest inventory separately. However, it is a well-known fact that systematic sampling is the only practically applicable solution for forest inventory. It has been empirically proven that if the sample size is the same, systematic samples produce better estimates than random samples, although the whole sampling theory is based on the probability calculations with a random allocation of population units into a sample. The possibility and technique of estimating the proportion of a specific property of a population unit (inventory unit) using a simple and stratified sampling have not been considered. In general, when estimating the proportion, there is no significant difference related to the arithmetic mean of the population, since proportion is actually a specific type of arithmetic mean.

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STRATIFIED SAMPLING IN FOREST INVENTORY

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Summary

The paper analyzes the possibility and technique of using stratified sampling in forest inventory. The research was carried out in a management class of beech high forests. It was first stratified into stands (eleven in total), and then into homogenous groups of stands (three in total). The focus was on estimating the average and total management class volume. The anticipated effects of stratification were preliminarily checked by using the method of simple analysis of variance. It was concluded that there was a statistically significant difference in the values of the average volume per hectare between the stands. In other words, we can expect a significant effect of the stratification performed in estimating the management class volume. The result was confirmed with the homogeneous groups of stands as strata. Statistical data processing referred to the volume that was determined by establishing 500 m2 sample plots, systematically arranged in a 100 x 100 grid across the stands. At stand level, the estimate of the average and total volume was done by the simple random sampling formulas, while the simple and stratified random sampling formulas were used at the level of the management class.

In this particular case, it was found that the stratified sample of the same size provides a much more precise estimate of average and total management class volume than the simple sample. In the first case, the relative error of volume, with a 95% probability, is + / - 5.37% and in the second + / - 4.59%. To achieve the same level of precision of management class volume estimates obtained using a simple sample, we can use a stratified sample that is smaller by 27.2%. Instead of 242 sample plots in the simple sample, 176 sample plots would be enough in the stratified sample or 66 sample plots fewer than in the simple sample. Compared to the proportionate stratified sample, the optimal stratified sample provides an even greater reduction in the size of the applied simple sample (by 77 sample plots). However, this paper gives the preference to the stratified sample with proportionate allocation of sample plots (systematic arrangement) for the purposes of forest inventory of units larger than a stand. Simple systematic sample should be used for stands. However, we should not insist on achieving a high level of precision of volume estimates at stand level, but at the level of management classes and inventory units larger than stands, because if we use an economically justified size of a sample, we can achieve the necessary level of precision (accuracy) and develop reliable management plans.