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THE OPTIMIZATION IN FOREST INVENTORY ON REGIONAL LEVEL IN BOSNIA AND HERZEGOVINA

OPTIMIZACIJA U INVENTURI ŠUMA NA REGIONALNOJ RAZINI U BOSNI I HERCEGOVINI

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The present study is made to determine optimal sampling plan for growing stock estimation in forest inventory on regional level. The method is based on anticipated variance with lack of fit (Mandallaz 2001). For research object is chosen one forest economic management unit in Bosnia and Herzegovina. On database of most recent forest inventory is applied tree selection plan optimization and sample size optimization. Alternate optimal sample plans are developed and compared.

Key words: forest inventory, optimization, optimal sampling plan, growing stock, regional level

INTRODUCTION
UVOD

Forest inventory presents a basis of information on natural resources of forested areas. Recently there are certain efforts to optimize all activities that are done within the forest inventory (Stahl 1998). Also, there are two especially important, and comparatively researched approaches in sampling theory for forest inventory in large areas: standard (classical) approach and model based approach. In the standard approach the key is probabilistic nature of sampling plan (Gregoire 1998). Besides, extensive researches quoted the possibility to make conclusions on population parameters based on the population model (Arvanitis & O'Regan 1967, Särndal 1978, Mackisack & Wood 1990, Penttinen *et al.* 1992, Kangas 1994, Schröder & Williams 1995, Eriksson 1995, Rao 1997, Gregoire 1998, Mandallaz 1991, 1995, 1997, Mandallaz & Ye 1999).

In the last decade new technologies and development of scientific approaches in sampling theory have certainly lead to the improvement of previously used sampling plans for forest inventories. Special attention is paid to the sampling plans for taxation recording that would provide the required information with necessary precision. In order to make a decision on the sampling plan for the next forest inventory, it is necessary to analyze the existing plan and prepare alternate plans. At the forest inventory in large areas, the selection of alternate plans should be based on a number of factors. The factors of primary importance are a precision of the estimated most important taxation elements and cost efficiency. In other words, interesting items are the alternatives that provide desired precision of estimate with minimal costs, or vice versa, minimal costs for desired precision of estimate. These solutions can be reached by making optimal sampling plans, i.e. determination of optimal size of alternate samples. Besides of sample size optimization, models of general optimization of sampling plans have been developed in the last few years (Lanz 2001, Mandallaz 2001). Kuliesis & Kasperavicius (1998) made the optimization of the sampling plan parameters for national forest inventory in Lithuania. Reich & Arvanitis (1992) analyzed the relations between the size of sample plot and sample variance, depending on the regional distribution of trees, volume and basal area of trees. Jonsson, et al. (1992) and Hočevar (1989) investigated alternate plans for forest inventory. Köhl & Scott (1993) presented a method for comparison of alternate sampling plans for extensive inventories. Stamellos & Blioumis (1997) have proposed the optimization of growing stock estimate with plot-double sampling plan.

Sampling plan for forest inventory on regional level in Bosnia and Herzegovina is based on research done by Matić (1964, 1971, 1977). Also Stojanović & Drinić (1974) investigated elements for efficient sampling. Koprivica (1984) suggested regression models for sample plan parameters.

Now, using database of previous forest inventory it is possible to improve existed sampling plan according to new developed method of general optimization.

FORMULATION OF THE RESEARCH AIM
FORMULACIJA ISTRAŽIVAČKOGA CILJA

To discuss possibilities for planning an sample for terrestrial measurements in the next forest inventory on the regional level (forest economic management unit), in this paper were established next aims of research:

I. To develop alternate optimal sample plans:
   1. To optimize tree selection plan according to PPS for tree volume;
   2. To determine optimal sample size using criteria:
      — Minimize variance of estimator for fixed costs, or conversely
      — Minimize costs for given precision;
   3. To determine alternate optimal plan parameters;

II. To compare developed alternate optimal sample plans mutually and with previous sample plan.

This research may provide an alternative to the current sampling plan in forest inventory. The results of this study could be useful to open the possibility to develop multivariate sampling plan (the growing stock, the growth, the volume of marked trees, the regeneration). Additionally, the study may serve as a basis for the development of improved and statistically complex sampling plans (multi-stage multi-phase).

METHODS AND MATERIALS
METODE I MATERIJALI

FOREST ECONOMIC MANAGEMENT REGIONS
ŠUMSKOGOSPODARSKA PODRUČJA

In the Federation of Bosnia and Herzegovina, forested area is 1135931 ha, with 56,3% high forests with natural regeneration. The area of 895104 ha of state owned forests is managed by thirty-two forestry enterprises. Average forested area of forestry enterprises is about 39000 ha. Average volume of the growing stock in high forests with natural regeneration is 251 m³/ha (Golob 2001). Analyzing the available information, it was concluded that for this research the most complete documentation could be provided by JP Šume Tuzlanskoga Kantona Tuzla ŠG Konjuh Kladanj.

FOREST ECONOMIC MANAGEMENT UNIT KONJUH KLADANJ
ŠUMSKOGOSPODARSKO PODRUČJE "KONJUH" KLADANJ

The area of study is forestry economic management unit (FEMU) Konjuh Kladanj with forested area of about 26000 ha.

The last forest inventory was done between 1989-1990. The objectives of this forest inventory were multiple. Here will be considering the estimate of the volume of the growing stock in high forest with natural regeneration as a main objective.

The pedological and typological mapping for the FEMU Konjuh Kladanj was done in 1980. Based on this classification, forest stratification was done and the whole area was divided into thirty-four basic classification units (management classes) considered as strata. Assuming that there was no significant changes in the boundaries of forestry area, nor in the structure of the forest recently, data and information gained in the previous inventory were considered as reliable for making conclusions on the current state of the forest.

APPLIED SAMPLING PLAN
PRIMIJENJENI PLAN UZORKA

The sampling scheme used in recent forest inventory in forestry area FEMU Konjuh Kladanj can be signed as two-phase one-stage sampling with stratification.

The first phase of sample was related to the separation of the strata and to the allocation of sample plots to each of divided strata (allocation of sample plots into management classes).

Terrestrial measurements conducted on these sample plots were marked as second phase of sample.

Taxation recording were done in concentric circles in high forests with natural regeneration, systematically distributed in square network 100x100 m (Stojanović & Drinić 1974). Tree selection plan was the system of concentric circles with joint centre and different radiuses, depending on the diameter at breast height of trees and nature of gathered data (Table 1).

Table 1. Tree selection plan (Stojanović & Drinić 1974)
Tablica 1. Plan selekcije stabala (Stojanović & Drinić 1974)

Threshold (cm)	5–10	10–15	15–20	20–30	30–50	50–80	>80.0
Radius (m)	2.2	3.5	4.5	5.5	9.0	15.0	25.0

The following taxation elements were recorded in the sample plots: canopy, tree species, tree diameter at breast height and tree height on every fourth sample plot.

Volumes of individual trees were determined using volume tables for individual (or similar) species: "Tables of taxation elements of high and coppice forests" (Drinić et al. 1980). Input variables in these tables are: tree species, site quality, and diameters at breast height with bark included. For determination of site quality, heights of sample trees were measured in the smaller part of sample (on ¼ of all sample plots). Recorded heights, therefore, did not participate in the determination of volume of individual trees numerically. As determination of the volumes of individual trees is based numerically only on the values of diameter at breast height, estimation of timber volume per area unit is considered to be one-stage.

Taxation recording was done in the total of 19269 circular sample plots within the taxation recording in high forests with natural regeneration of 19269 ha. That sample plots were used to collect the data on diameter at breast height for 134467 trees.

In the same forest category, data of height were recorded for 30533 trees in 5735 detailed sample plots.

Data gained during the taxation measuring done within recent forest inventory were registered by RC Šipad Sarajevo.

APPLIED STATISTICAL ESTIMATION PROCEDURE
PRIMIJENJENA STATISTIČKA PROCEDURA PROCJENE

Considering the fact that the stratification of forest area into management classes was previously completed, and that the allocation of sample plots in management classes was known, statistics were determined using formulas for simple random and stratified sampling.

COSTS
TROŠKOVI

In the forest inventory costs of taxation recording include financial means or time required for the planned taxation recording.It is more practical to express the costs as time. As the information for evaluation of the cost function were not noticed at the taxation recording, it was necessary to do this, according to method used for the previous inventory.

Two forest compartments were selected randomly. Compartment 17, of 52.0 ha was selected in Management unit Gostelja (Figure 2(A)). Compartment 93a, of 34.2 ha was selected in Management unit Gornja Drinjača (Figure 2(B)).

In the field were determined:

- travelling between sample plots (travelling time),
- Time for the installation of sample plots (marking of the centre of sample plot in the field, registration of the sample plot in the manual, and canopy estimate), and
- Time for measuring of diameter at breast height (testing of the distance of the tree from the centre of the sample plot, and two cross-measuring of diameter at breast height).

A B

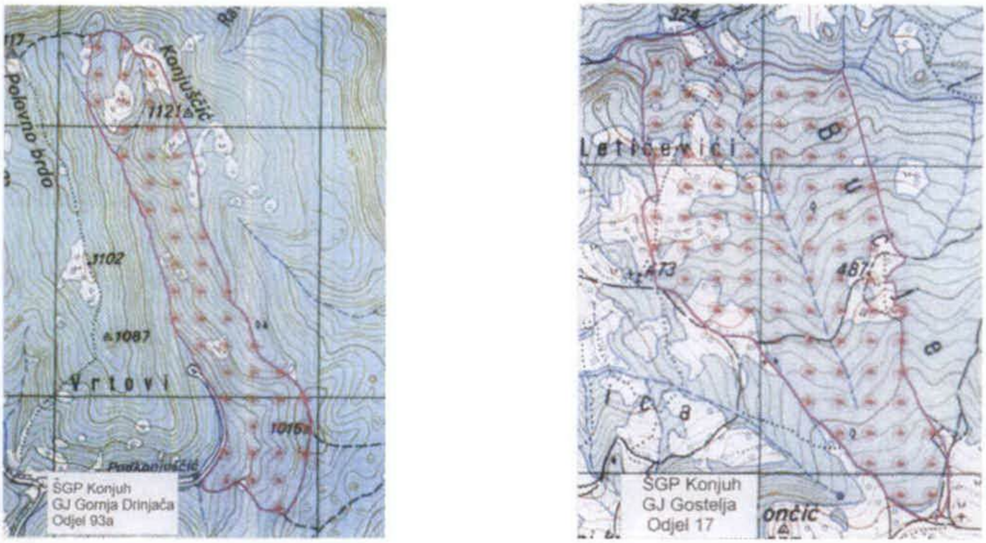


Figure 2. MU Gornja Drinjača Forest compartment 93a (A) and MU Gostelja Forest compartment 17 (B)

Slika 2. GJ Gornja Drinjača, odjel 93a (A), i GJ Gostelja, odjel 17 (B)

METHOD
METODA

Here were applied optimization techniques within the linear programming framework. The optimization problem is presented in the following form: to minimize or to maximize the objective function for anticipated constrains (Beale 1997).

Given the fact that it was intended to use the general optimization of the sampling plan, it was necessary to analyze the methods of trees selection plan optimization and the sample size optimization. In this research the Mandallaz method was used (2001). Discrete approximation for PPS is applied for optimal threshold optimization (Mandalay 2001). The optimization model based on the concept of anticipated variance within local Poisson's model for spatial distribution of trees is used.

OPTIMIZATION - MINIMAL ANTICIPATED VARIANCE FOR GIVEN COST
OPTIMIZACIJA – MINIMALNE PREDVIDLJIVE VARIJANCE ZA DANE TROŠKOVE

Mandallaz (2001) presented the optimization as classical problem of the linear optimization:

1. minimize the anticipated variance for the given costs, or
2. minimize the costs for corresponding anticipated variance.

The objective function (the anticipated variance) expresses timber volume per unit area variability. It depends on sample size (n), forested area $\lambda(F)$, tree volume (Y_i), inclusion probability (π_i) and lack of fit (Δ).

The constrain function is expressed as cost function deepening on travelling cost $\phi(n)$, installation cost (c_1), unit cost per tree $(c_2)$and inclusion probability .

The anticipated variance $\left(\mathrm{AV}\left(\overline{\mathrm{Y}}\right)\right)$ defined by:

$$AV\left(\bar{Y}\right)=\frac{1}{n\lambda^2(F)}\sum\frac{Y_i^2}{\pi_i}+\frac{1}{n}\Delta^2$$

Should be minimized within the constrain:

$$\phi(n)+nc_1+nc_2\sum_{i=1}^{N}\pi_i\leq C$$

It is important to define the sample size for the lowest limit of the anticipated variance $\left(\mathrm{MAV}\left(\overline{\mathrm{Y}}\right)\right)$, with the given sample size:

$$MAV\left(\bar{Y}\right)=\frac{\left(\bar{Y}\left(\sqrt{c_{21}}\gamma_g\right)\right)^2}{C-nc_2-\phi(n_2)}+\frac{\Delta^2}{n}$$

The lowest limit of the anticipated variance $\left(\mathrm{MAV}\left(\overline{\mathrm{Y}}\right)\right)$ is function of average timber volume per unit area $(\bar{Y})$, corrected unit cost per tree (c_{21}), PPS factor (γ), cost function, lack of fit and sample size.

OPTIMAL SAMPLE SIZE
OPTIMALNE VELIČINE UZORKA

The optimal sample size $(n_{u,opt})$ is depending on average timber volume per unit area, relative lack of fit (υ), travelling cost (c_2) and PPS factor. It could be reached through differentiation of the lowest limit of the anticipated variance by value of the sample size:

$$n_{opt} = \frac{\widetilde{C}\Delta}{\sqrt{c_2}\left(\gamma\sqrt{c_{21}} + \upsilon\sqrt{c_2}\right)}$$

For the optimal sample size, the absolute lowest limit of the anticipated variance could be evaluated by:

$$\min_n MAV(Y) = \frac{\left(\bar{Y}\left(\gamma\sqrt{c_{21}} + \upsilon\sqrt{c_2}\right)\right)^2}{\widetilde{C}}$$

Evaluated anticipated variances could be used as the foundation for the analysis of the alternate sampling plans deducted by the optimization technique. The optimization evaluated using alternate criteria – to minimize costs for given precision – leads to the same solution for optimal sample size (Mandallaz 2001).

Minimal cost for given precision is:

$$C_{\min} = \frac{\left(\bar{Y}\left(\gamma\sqrt{c_{21}} + \upsilon\sqrt{c_2}\right)\right)^2}{W}$$

RELATIVE EFFICIENCY ALTERNATE SAMPLING PLANS
RELATIVNA UČINKOVITOST ALTERNATIVNIH PLANOVA UZORAKA

Relative efficiency could be used in the decision-making between the two alternate plans. Relative efficiency (precision) of the alternate plans is determined as a relative relation of previous (VarB) and planed variances of the estimates (VarA) (Cochran 1977):

$$\mathrm{RE} = \frac{\mathrm{VarA}}{\mathrm{VarB}}$$

If the relative efficiency is between 0.95 and 1.05, it is considered that the optimal plans of approximate efficiency are completed and the choice for one of the two plans should be based on other essential criteria.

COST EFFICIENCY ALTERNATE SAMPLING PLANS
UČINKOVITOST TROŠKOVA ALTERNATIVNIH PLANOVA UZORAKA

According to the method used, minimization of costs for given (desired) precision, result in the same optimal sample size. For determined cost of alternate optimal plans, the cost efficiency (EC) can be expressed as percentage differences between the costs of the alternate sampling plans.

OPTIMAL SAMPLE PLAN PARAMETERS
PARAMETRI OPTIMALNOGA PLANA UZORKA

Sampling plans remain on the measures of the sample parameters as: number of units (sample plots) in a sample, their spatial distribution, shape and size.

Previous research and practice showed that the square distribution of sample plot centres was the most acceptable in the forest inventory. Keeping the square distribution of sample plot centres, the distance from one centre to another (R_u) is determined by:

$$R_u = \sqrt{\frac{\lambda(F)}{n_{u,opt}}}$$

The surface size of the concentric circles $(S_{u,p})$ are evaluated as (Mandallaz 2001):

$$S_{u,p} = \frac{C - n_1 c_1 - \phi(n_2)}{\overline{Y} c_{21} \gamma} \frac{g(Y)}{n_2}$$

RESULTS AND DISCUSSION
REZULTATI I DISKUSIJA

THE TREE SELECTION PLAN OPTIMIZATION
OPTIMIZACIJA PLANA SELEKCIJE STABALA

Using the method discrete approximation for PPS, optimal threshold values for tree volume classes for one, two and three optimal concentric circles were determined (Čabaravdić 2002). Also, here was determined PPS factor for previous sampling plan (6*). The determination was done on Chair for forest inventory and planning ETH Zurich. Table 2 summarizes the results on PPS factors, optimal thresholds, improved volume expectations in diameter classes and their variability.

Table 2. Optimal diameter threshold and γ_u factor for tree volume

Tablica 2. Optimalni debljinski intervali i faktori za volumen stabala

u	$N_{u,p}$	γ_u	p	$d_{u,p}$	$g^v_{u,p}$	$sd_{u,p}$	$V^-_{u,p}$	$V^+_{u,p}$
1	95	2.4595	I	>5	0.4067	0.0882	0.0072	10.8449
2	27	1.3689	I	5 - 30	0.2408	0.0339	0.0072	0.7827
	68		II	>31	2.6665	0.0746	0.8462	10.8449
3	17	1.1692	I	5 – 20	0.1103	0.0165	0.0072	0.2953

3	23		II	21 – 44	0.8613	0.0406	0.3322	1.8211
	55		III	> 45	4.0433	0.0571	1.9201	10.8449
6	1	1.1288	I	5 – 10	0.0186	0.0000	0.0186	0.0186
	2		II	11 – 20	0.1157	0.0272	0.0679	0.1608
	2		III	21 – 30	0.4237	0.0443	0.3113	0.5329
	4		IV	31 – 50	1.4119	0.0985	0.8289	2.1593
	6		V	51 – 80	3.8432	0.0803	2.7541	6.7189
	4		VI	> 80	8.2342	0.7470	7.4074	10.844

Legend: u – diameter classes number, $N_{u,p}$ – count, γ_p – PPS factor, p – diameter class rang, $d_{u,p}$ – optimal threshold, $V_{u,p}$ – volume expectation, $g^{v}_{u,p}$ –improved volume expectation, $sd_{u,p}$ – standard deviation, $V^{-}_{u,p}$ – minimal value, $V^{+}_{u,p}$ – maximal value

Legenda: u – *broj debljinskih intervala,* $N_{u,p}$ – *broj vrijednosti,* γ_p – *PPS faktor, p – rang debljinskoga intervala* $d_{u,p}$ – *optimalni prag,* $V_{u,p}$ – *volumno očekivanje,* $g^{v}_{u,p}$ – *korigirano volumno očekivanje,* $sd_{u,p}$ – *standardna devijacija,* $V^{-}_{u,p}$ – *minimalna vrijednost,* $V^{+}_{u,p}$ – *maximalna vrijednost*

OPTIMIZATION
OPTIMIZACIJA

OPTIMIZATION PARAMETERS
PARAMETRI OPTIMIZACIJE

It is necessary to know some parameter population to carry out the optimization. Here it is necessary to have: number of trees of previous sample, diameter distribution of sample, previous sample size, estimated values of the volume of the growing stock for every sample plot, number strata and allocation sample plots in that strata.

First, it is necessary to express the volume of the growing stock variability in local Poisson forest. Basic database of previous inventory was consisted of values for estimated local densities for 19269 sample plots under the forested area distributed in eighteen management units (strata) in high forest with natural regeneration. On the base allocation of sample plots into management units, in order to determine necessary optimization parameters, it was carried out analyses of variance for working-strata (Table 3).

Table 3. ANOVA for working strata

Tablica 3. ANOVA za radne stratume

Sources	df	Sum square	Expected values
Model	17	57883091	3003.949
Residual	19252	451510510	23431.96
Total	19269	509393601	26435.91

Here was found low determination (0.1136) what pointed out that applied stratification criteria had not reached result what was possible when a volume of the growing stock estimation was in a consideration (Table 4).

Mostly, stratification achieves minimal coefficient of determination about 0.20. But, in management praxis, stratification criteria are complex, so, here found such a value of determination was accepted for further analyses, although it stayed a question about stratification criteria related to more precise the growing stock estimation.

Table 4. Population parameters
Tablica 4. Parametri populacije

$\overline{Y}$ (m³/ha)	R^2(%)	ε^2	Δ	υ(%)
241.62	0.1136	12268.03	105.65	0.4372

Legend: $\overline{Y}$ – volume of growing stock in m³/ha, R^2 – determination in %, ε^2 – pure error, Δ – lack of fit, υ – relative lack of fit

Legenda: $\overline{Y}$ – *drvna zaliha u (m³/ha),* R^2 – *determinacija u %,* ε^2 – *čista greška,* Δ – *nedostatak izravnanja,* υ – *relativni nedostatak izravnanja*

Using previous tree selection plan, here is determined value of puree error and evaluated lack of fit . Puree error value showed on high variability for the volume of the growing stock in strata.

It was left to express overall costs in local Poisson forest and means of particular costs. Table 5 summarizes values for cost coefficients.

Table 5. Costs coefficients
Tablica 5. Koeficijenti troškova

Costs	Mean	Standard error	Confidence interval (95%)	Sample size
c_0	3.5581	0.1198	0.2383	84
c_1	1.0504	0.0656	0.1304	86
c_2	0.4982	0.0401	0.0797	86
c_2^h	0.6794	0.0921	0.2006	13

Legend: c_0 – travelling time in min/plot/crew member, c_1 – installation time in min/plot/crew member, c_2 – unit cost per tree diameter in min/tree, c_2^h – unit cost per tree height in min/tree

Legenda: c_0 – *vrijeme prelaza u min/premjernoj površini/članu sekcije,* c_1 – *vrijeme instalacije u min/premjernoj površini/članu sekcije,* c_2 – *vrijeme mjerenja prsnoga promjera u min/stablu,* c_2^h – *vrijeme mjerenja visine min/tree*

Figure 3 shows percentage structure of particular activities in terrestrial measurement.

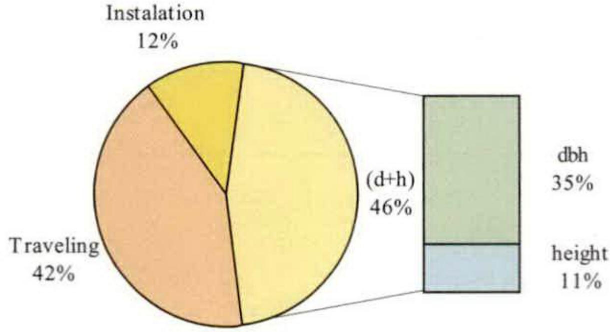
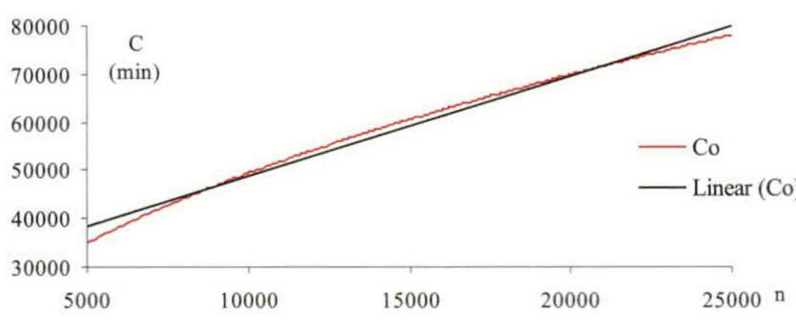


Figure 3. Cost structure in %
Slika 3. Struktura troškova u %

Empirical experience showed that travelling costs follow square root function (Figure 4). In optimization purpose it was determined travelling cost model as a linear function:

$$\phi(n) = 27797 + 9.44n$$



Legend: Co: travelling cost in *min, Linear (Co)*: linearized travelling cost in *min*, n number of terrestrial plots

Legenda: Co: *troškovi prijelaza u min, Linear (Co): linearizirani troškovi prijelaza u min, n broj premjenih površina*

Figure 4. Travelling costs
Slika 4. Troškovi prijelaza

Finally, overall costs for growing stock estimation for 19269 sample plots was 445091 minutes (Table 6).

Table 6. Average and total costs

Tablica 6. Prosječni i totalni troškovi

Intercept a	Slope b (min)	c_{21} (min)	C (min)	$\tilde{C}$ (min)
27797	9.44	1.9574	445091	417294

Legend: a – intercept for travelling cost, b – slope for travelling cost, c_{2t} – unit cost per tree, C – total cost, $\tilde{C}$ – variable cost

Legenda: a – *koeficijent funkcije troškova prijelaza, b – korak funkcije troškova prijelaza,* c_{21} *– trošak mjerenja po stablu,* C *– ukupni troškovi,* $\tilde{C}$ *– varijabilni troškovi*

OPTIMIZATION – OPTIMAL SAMPLING PLAN FOR GIVEN COST
OPTIMIZACIJA – OPTIMALNI PLAN UZORKA ZA DANE TROŠKOVE

First, it was optimized sample size for given cost. It meant, anticipated variance was minimized for different number concentric circles for tree selection, for given budget of variable cost in previous forest inventory. Using a criteria to minimize anticipated variance for given cost, here were determined optimal sample size and minimal anticipated variance using optimal one, two, three and six concentric circles (Table 7).

Table 7. Minimal anticipated variances

Tablica 7. Minimalne predvidljive varijance

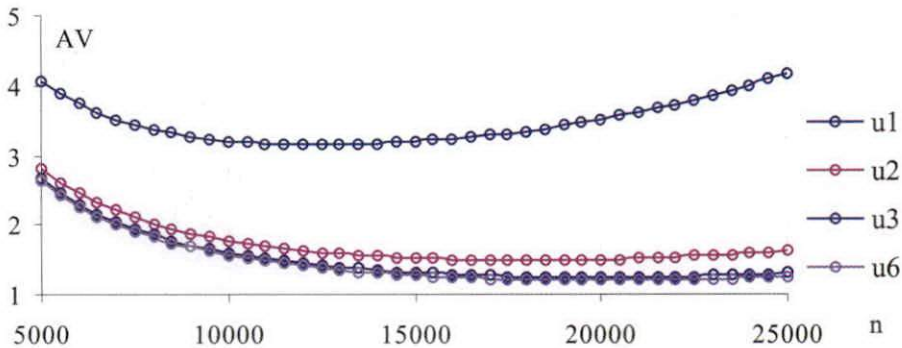
u	$(n_{u,opt})$	(MAV_u)	$2RE_{u,opt}$ (%)
1	12525	3.1462	1.4684
2	18231	1.4849	1.0088
3	19934	1.2420	0.9226
6	20323	1.1950	0.9050
6*	19269	1.2180	0.9136

Legend: u – concentric circle number for tree selection, $(n_{u,opt})$ – optimal sample size, (MAV_u) – minimal anticipated variance, $2RE_{u,opt}$ (%) – double relative error

Legenda: u *– broj koncentričnih krugova za selekciju stabala,* $(n_{u,opt})$ *– optimalna veličina uzorka,* (MAV_u) *– minimalna predvidljiva varijanca,* $2RE_{u,opt}$ *(%) – dvostruka relativna greška*

When concentric circle number for tree selection increase, optimal sample size also increase. That cause anticipated variance decrease. It could be seen that precision expressed by double relative error also decrease. Optimal sample plan with tree selection in one circle, for fixed cost, overestimates desired precision (double relative error of 1%). Also, optimal sample plan with tree selection in two concentric circles, for fixed cost, overestimates desired double relative error slightly. Results show that optimal sample plan with tree selection in tree and six concentric circles, for fixed cost, could provide desired precision.

Minimizing anticipated variance in range from 5000 to 25000 sample plots, it could be seen that optimal sample sizes correspond with minimal anticipated variances (Figure 5). Also it could be noticed that values of anticipated variances differ slightly in the wide interval around minimal anticipated variance (optimal sample size).



Legend: AV – anticipated variance, *u* – concentric circle number for tree selection, γ_u – *n* – sample size

Legenda: AV – *predvidljiva varijanca,* u – *broj koncentričnih krugova za selekciju stabala,* γ_u – n – *veličina uzorka*

Figure 5. Anticipated variance, C const
Slika 5. Predvidljiva varijanca, C konstatno

In narrow interval, values of anticipated variance are almost equal, so it is possible to consider sample size freely. There are wide range sample size where could be chosen other sample parameters without large deviation from expected precision.

It means it could be chosen small number of larger circles or inversely, without significant influence on precision.

Also, it is possible to notice that minimal anticipated variance for optimal tree and six concentric circles overlap almost. Here could be achieved very small difference in expected precision. Even sampling in two optimal concentric circles achieves good result.

RELATIVE EFFICIENCY ALTERNATE OPTIMAL SAMPLING PLANS
RELATIVNA UČINKOVITOST ALTERNATIVNIH PLANOVA UZORAKA

Table 8 shows relative efficiency for developed optimal alternate sampling plans with different number of concentric circles for tree selection.

Table 8. Relative efficiency alternate sampling plans

Tablica 8. Relativna učinkovitost alternativnih planova uzoraka

u \REf	(u|2)	(u|3)	(u|6)	(u|6*)
1	0.69	0.63	0.62	0.62
2		0.91	0.90	0.91
3			0.98	0.99
6				1.01

Legend: u: concentric circle number for tree selection, *REf*: relative efficiency
Legenda: u: broj koncentričnih krugova za selekciju stabala, REf: relativna učinkovitost

As referent sample plan it is signed previous sampling plan with six concentric circles. Relative efficiencies for alternate plans with one and two concentric circles are less then 0.91. They could be considered as enough efficient. Relative efficiency between alternate plan with tree and six concentric circles (0.98 and 0.99) pointed out close precision. Also, there is not significant precision difference between optimal plan with six concentric circles and previous sample plan (1.01).

OPTIMAL PLAN PARAMETERS
PARAMETRI OPTIMALNIH PLANOVA

Table 9 summarizes parameters of optimal plans with tree selection in three and six concentric circles. Optimal plan with three concentric circles is related to tree selection on concentric circles with radii of 3.86 m (dbh > 5 cm), 10.66 (dbh > 22 cm) and 23.10 m (dbh > 45 cm).

Table 9. Optimal sampling scheme with three and six concentric circles

Tablica 9. Optimalni plan uzorka s tri i šest koncentričnih krugova

u	$(n_{u,opt})$	R_u (m)	p	$d_{u,p}$ (cm)	$S_{u,p}$ (m²)	$P_{u,p}$ (m)
3	19934	98.32	I	5 – 20	23.5	2.7
			II	21 – 44	179.0	7.5
			III	> 45	840.2	16.4
6	20323	97.37	I	5 – 10	4.1	1.1
			II	11 – 20	25.9	2.9
			III	21 – 30	95.6	5.5
			IV	31 – 50	286.4	9.5
			V	51 – 80	801.4	16.0
			VI	> 80	1753.6	23.6

Legend: u – concentric circle number for tree selection, R_u – distance between terrestrial plots, p – diameter class, $d_{u,p}$ – optimal threshold, $S_{u,p}$ – surface areas of optimal circles, $P_{u,p}$ – optimal radii of concentric circles

Legenda: u – *broj koncentričnih krugova za selekciju stabala,* R_u – *rastojanje između premjernih površina,* p – *debljinski interval,* $d_{u,p}$ – *optimalni intervali prsnih promjera,* $S_{u,p}$ – *optimalne površine koncéntričnih krugova,* $P_{u,p}$ – *optimalni radijusi koncentričnih krugova*

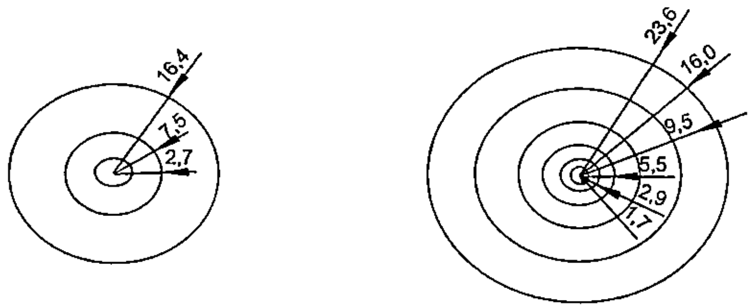


Figure 6. Optimal inclusion surfaces

Slika 6. Površine optimalnih koncentričnih krugova

On Figure 6 are presented surface areas of concentric circles according to tree diameter and volume, using optimal tree (A) and six circles (B).

OPTIMIZATION FOR GIVEN PRECISION
OPTIMIZACIJA ZA DANU PRECIZNOST

Application the second criteria, minimizing costs for given precision, gave optimal sample sizes and relative efficiency corresponding to optimal sample sizes and relative efficiency determined using criteria minimizing anticipated variances.

Table 10. Minimal costs for given precision

Tablica 10. Minimalni troškovi za danu preciznost

u	1	2	3	6	6*
Min C (min)	1078796	509249	425959	409828	417294

Legend: u: concentric circle number for tree selection

Legenda: u: *broj koncentričnih krugova za selekciju stabala*

For given precision, optimal sample plans with one, two and three concentric circles are more expensive then previous sample plan (Table 10). But, optimal sample plan with six concentric circles for tree selection is not. It means that the same precision could be achieved using mentioned optimal plan providing cost reduction.

OPTIMIZATION FOR DESIRED PRECISION
OPTIMIZACIJA ZA ŽELJENU PRECIZNOST

Beside the optimization for given costs, it was found that it was important to evaluate optimal sample sizes for desired precision. Desired precision is expressed by variance W derived from empirical double relative error for investigated forest category of 1%. The value of such determined variance was 1.4595.

It was applied criteria minimizing costs for desired precision to develop optimal sampling plans. Table 11 summarizes optimal sample sizes and minimal costs of determined alternative optimal plans.

Table 11. Optimal sample size (W=1%)
Tablica 11. Optimalna veličina uzorka (W=1%)

u	$n^{W}_{u,opt}$	$C^{W}_{u,MIN}$ (min)
1	27031	900215
2	18572	424949
3	16985	355447
6	16661	341986

Legend: u – concentric circle number for tree selection, γ_u – PPS factor, $n^{W}_{u,opt}$ – optimal sample size, $C^{W}_{u,MIN}$ – minimal cost

Legend: u – *broj koncentričnih krugova za selekciju stabala,* γ_u – *PPS faktor,* $n^{W}_{u,opt}$ – *optimalna veličina uzorka,* $C^{W}_{u,MIN}$ – *minimalni troškovi*

For desired precision, optimal sample plan with one circle for tree selection should have 27031 sample plots. If concentric circle number for tree selection increase, optimal sample size decrease as minimal cost too.

Cost efficiency alternative optimal plans are presented in Table 12.

Table 12. Cost efficiency
Tablica 12. Učinkovitost troškova

*u**EC*	(*u*|2)	(*u*|3)	(*u*|6)	(*u*|6*)
1	111.84	153.26	163.23	115.73
2		19.55	24.26	1.83
3			3.94	-14.82
6				-18.05

Legend: u – concentric circle number for tree selection, *EC* – cost efficiency
Legend: u – *broj koncentričnih krugova za selekciju stabala,* EC – *učinkovitost troškova*

It could be noticed that optimal sample plan with two concentric circle for tree selection excel referent cost slightly (1.83 %). Cost reduction could be assured using optimal plans with tree and six concentric circles. Optimal sample plan with tree concentric circles could provide 14.82 % cost reduction. Also, optimal sample plan with six concentric circles could provide 18.05 % cost reduction.

COMPARISON TO RESULTS OF OTHER AUTHORS
POREDBA S REZULTATIMA DRUGIH AUTORA

TREE SELECTION PLAN
PLAN SELEKCIJE STABALA

Determined radii for tree selection in six concentric circles (A) are in the same range as radii of current tree selection plan (B) (Table 13). The first and the second concentric circles could be smaller due to huge number of trees with diameter of breast height less then 20 cm. Following radii are larger with last one of 25 m.

Table 13. Concentric circles radii (m)
Tablica 13. Radijusi koncentričnih krugova u m

u	$(n_{u,opt})$	R_u (m)	p	$d_{u,p}$ (cm)	$P_{u,p}$(A) (m)	$P_{u,p}$(B) (m)	$P_{u,p}$(C) (m)
6*	19269	100.00	I	5 – 10	1.0	2.5	2.2
			II	11 – 20	3.0	4.5	4.6
			III	21 – 30	6.0	5.5	6.0
			IV	31 – 50	10.0	9.0	7.0
			V	51 – 80	17.0	15.0	14.0
			VI	> 80	25.0	25.0	20.0

Compared with Matić tree selection plan (C), plan (A) has larger tree selection radii. We found plan (A) more appropriate for concrete investigated forest area.

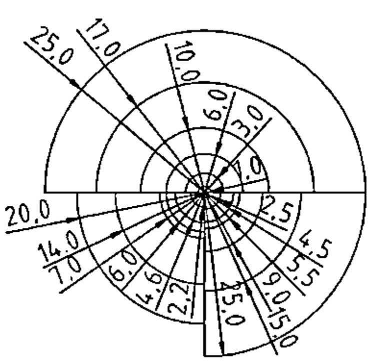
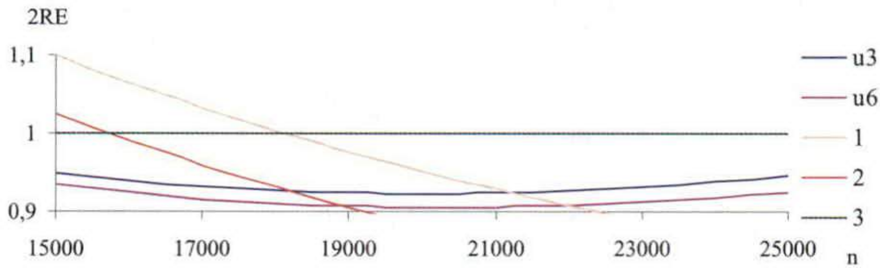


Figure 7. Concentric circles radii (m)
Slika 7. Radijusi koncentričnih krugova u m

SAMPLE SIZE
VELIČINA UZORKA

Figure 8 shows double relative error depending on sample size. Results achieved using sample random sampling (1), regression model (2) developed by Koprivica (1984) conformed that it could be chosen sample size on the optimization base (u3, u6) which could provide desired precision (3) in a range up to 18000 sample plots.



Legend: *2RE* – double relative error in %, u – concentric circle number for tree selection, *1* – sample random sampling, *2* – regression model (Koprivica 1984), *3* – double relative error of 1%, *n* – sample size.

Legend: 2RE – *dvostruka relativna greška u %,* u – *broj koncentričnih krugova za selekciju stabala,* 1 – *slučajni izbor,* 2 – *regresijski model (Koprivica 1984),* 3 – *dvostruka relativna greška od 1%,* n – *veličina uzorka.*

Figure 8. Precision depending on sample size

Slika 8. Preciznost u zavisnosti od veličine uzorka

CONCLUSIONS
ZAKLJUČCI

1. Related to tree selection plan, it could be concluded that tree selection in one circle deviates form exact PPS significantly.
2. Optimal threshold for two concentric circles are 5 cm and 31 cm. Here is noticed tree volume precision increase.
3. Optimal threshold for tree concentric circles are 5 cm, 21 cm and 45 cm.
4. PPS factor for six concentric circles points out tree selection the closest to exact PPS.
5. Relative difference between PPS factor for tree and six concentric circles could be considered as negligible.
6. Considering the optimization for fixed cost, developed alternate optimal plans show differences in sample sizes. There is wide range of sample size around optimal sample size without significant changes in precision. Then, relative efficiency of alternate optimal plans point out close precision for sample plans with tree selection in three and

six circles.

7. Optimal sample plan with three concentric circles has 19934 sample plots with radii for tree selection of 2.7 m, 7.5 m and 16.4 m.
8. Optimal sample plan with six concentric circles has 20323 sample plots with radii for tree selection of 1.1 m, 2.9 m, 5.5 m, 9.5 m, 16.0 m and 23.6 m.
9. For desired precision, the optimization showed that optimal sample plan with tree selection in three optimal concentric circles could provide cost reduction of 14.82 % having 16985 samples plots. Optimal sample plan with six concentric circles could provide cost reduction of 18.05 % with 16661 sample plots.

The evaluated optimization results are related to investigate forest area only, due to model, which was developed here, used characteristic of concrete forest on investigated area. For optimal sampling plans for other economic forest management units it is necessary to know characteristics of their forests. Particular cost expressed in time are not usually registered in forest inventory measurement in forest inventories recently. If forests and stands characteristics of two forests economic regions are similar, it is possible to use similarity law travelling cost to develop cost model.

Using this optimization model, it was found that there is significant cost reduction. Also, cost reduction could be achieved introducing new stratification criteria, new instruments for forest inventory measurements or with two-member crew.

Further improvement in planning is development advanced sampling plans (two-phase two-stage) what uses all available auxiliary information (maps, air-photos, previous databases, GPS, GIS) and technological improvement (new instruments).

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OPTIMIZACIJA U INVENTURI ŠUMA NA REGIONALNOJ RAZINI U BOSNI I HERCEGOVINI

SAŽETAK

Cilj je rada primjena nove metode planiranja uzorka za taksacijska snimanja (procjenu drvne zalihe) u inventuri šuma na regionalnoj razini.

Metoda se temelji na predvidljivoj varijanci uz nedostatak izravnanja (Mandallaz 2001).

Za objekt istraživanja odabrano je jedno šumskogospodarsko područje u Bosni Hercegovini.

Plan opće optimizacije proveden je uz upotrebu baze podataka prethodne inventure šuma. Pri tome je provedena optimizacija plana selekcije stabala i optimizacija veličine uzorka. Izvedeni su alternativni planovi uzoraka i međusobno uspoređeni.

Optimizacija plana selekcije stabala upućuje na mogućnost redukcije broja koncentričnih krugova za selekciju stabala sa šest na tri koncentrična kruga uz zanemarljiv gubitak na preciznosti procjene. Optimalni planovi uzoraka sa selekcijom stabala u tri i šest koncentričnih krugova, za dane troškove, pokazuju približnu relativnu učinkovitost (0,98). Planiranje optimalnih uzoraka za željenu preciznost izraženu dvostrukom relativnom greškom od 1 % pokazuje da bi se optimalnim planovima sa selekcijom stabala u tri i šest koncentričnih krugova mogla ostvariti redukcija troškova od 15 % i 18 % u odnosu na prethodni plan uzorka.

Plan uzorka mogao bi se dalje unaprijediti analizom stratifikacije, primjenom složenijih planova uzoraka, te uvođenjem novih tehnologija.

Ključne riječi: inventura šuma, optimizacija, optimalni plan, drvna zaliha, regionalna razina