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RELIABILITY OF THE STAND REGRESSION MODELS DEVELOPED ON THE BASIS OF SAMPLE PLOTS

Miloš KOPRIVICA, Bratislav MATOVIĆ[1]

Abstract: *The paper addresses the problem of reliability of the stand regression models developed on the basis of sample plots as basic sample units. The aggregate values of estimation elements, determined on sample plots are usually extrapolated per hectare before they are used for the estimation of stand elements or as variables in the construction of regression models. Other sample plot estimation values, which are not aggregate, are used in these models as individual values or as average values of the sample plots established in the stands. We tested the reliability of the models for estimating form factor, form height and volume of high beech stands in Serbia. It was concluded that the stand models obtained on the basis of a large sample of sample plots were always sufficiently reliable. When regression models used stands as basic units of the sample, instead of sample plots, the obtained models did not have a significantly greater degree of reliability.*

Key words: model, stand, sample plot, beech, sample, reliability

POUZDANOST SASTOJINSKIH REGRESIONIONIH MODELA RAZVIJENIH NA BAZI PROBNIH POVRŠINA

Apstrakt: U radu je razmatran problem pouzdanosti sastojinskih regresionih modela razvijenih na bazi probnih površina kao osnovnih elemenata uzorka. Naime, agregatne veličine taksacionih elmenata utvrđene na probnim površinama se obično prvo ekstarpoliraju na hektar a zatim služe za procenu taksacionih elemenata sastojine ili kao promenljive prilikom konstrukcije regresionih modela. Ostale taksacione veličine utvrđene na probnim površinama, koje nisu agregatne, koriste se u modelima kao individualne veličine ili kao prosečne veličine probnih površina postavljenih u sastojini. Proverena je

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pouzdanost modela za procenu zapreminskog koeficijenta, oblikovisine i zapremine visokih sastojina bukve u Srbiji. Zaključeno je da su u svim slučajevima sastojinski modeli dobijeni na bazi velikog uzorka probnih površina dovoljno pouzdani. U slučaju kada su osnovne jedinice uzorka korišćenog za dobijanje regresionih modela bile sastojine, a ne probne površine, nisu dobijeni značajno pouzdaniji modeli.

Ključne reči: model, sastojina, probna površina, bukva, uzorak, pouzdanost

1. INTRODUCTION

This paper includes a thorough analysis of the reliability of the sample plot based models, previously constructed for the estimation of the form factor, form height and volume of high beech stands in Serbia (Koprivica, M., Matovic, B. 2009; Koprivica, M. et al. 2010). In fact, this research poses the following question: Can the stand models developed on the basis of sample plots be applied on stands or they can be used only for sample plots?

It is considered that the models, based on data on trees, sample plots and stands, can be in practice applied only to these observation units, while the independent variables have to be determined in the same way they were determined in the construction of the model. However, in the construction of these stand models in Serbia, we assumed that the models based on sample plot data could be successfully used to estimate the elements of beech high stands: form factor, form height and volume. This assumption was based on strong internal heterogeneity of beech high stands and on the smaller error of the average values of independent variables, or stand estimation elements in comparison to the individual values of independent variables of the sample plots.

Because of a small number of stands in the sample, it was assumed that the sample plot characteristics (estimation elements and site characteristics) can be provisionally equated with the characteristics of hypothetical stands. In our opinion, this is statistically justified because the variability of the individual values of all elements in the plot sample is higher than the variability of the average values of the same elements in the stand sample.

This attitude is confirmed by the papers dealing with theoretical analysis of the sample structure intended for modelling in forestry (Box, G.E.P. and Draper, N.R., 1987, Vancelay, J.K. *et al*. 1993, Rennolls, K. 1997). Among other things, these papers study the issue of optimal data collection, assuming that the regression method will be used in modelling. It can be concluded that the best results of modelling can be achieved if the variables include different magnitudes within the scope of their variation, taking into account the extreme magnitudes, not only those that slightly deviate from the average. Furthermore, the data needed for the stand-level modelling should be collected on sample plots.

2. MATERIAL AND METHOD

The same method and material was used in the construction of these new regression models based on a stand sample as in the earlier construction of regression models based on a plot sample (Koprivica, M., Matović, B. 2009;

Koprivica, M. *et al*. 2010). Stand models used the average values of the variables (estimation elements), obtained on the basis of the sample plots that were established within them. Furthermore, separate regression models were constructed for each stand, based on their sample plots. The comparison of the models was done using the indices, calculated as the ratio of the estimation element predicted value, as obtained in a specific model, and its empirical value obtained in the sample.

The research material consists of numerous data on high uneven-aged beech stands and their site, collected within the project "Method of evaluation of quality and assortment structure of beech high stands in Serbia". The selection of the study stands, as well as the methods of data collection and processing are described in detail in Koprivica, *et al.* (2005). The characteristics of the investigated stands are also described in several papers (Koprivica, M., Matovic, B. 2006, Koprivica, M. *et al*. 2006 i 2007). The research covered eleven representative high stands of beech, selected in six forest regions: Severno Kučajsko, Podrinjsko-Kolubarsko, Jabaničko, Golijsko, Donje Ibarsko and Rasinsko. A systematic sample of circular sample plots was established in all stands. Altogether 241 sample plots of 500 m^2, spacing 100 m were established. The data were processed separately for each sample plot, as average or aggregate values converted into a hectare. The aplication programme SORTIMENT (Markovic, N. *et al*. 2007) was used for this purpose. The regression models were developed by using the programme STATGRAPHICS, version 5.0.

3. RESULTS AND DISCUSSION

3.1. Models for estimating beech stand elements obtained in earlier studies

Our earlier studies (Koprivica, M., Matovic, B. 2009; Koprivica, M. *et al.* 2010) provide regression models for estimating form factor, form height and volume of beech high stands in Serbia:

$$F=1,1948 - 0,0136869H_L - 2,31108/H_L - 0,0320255TN - 4,1527/D_g$$
$S_e = 0,01301$ $R^2 = 0,7849$ $n = 241$

$$H_LF=15,5566 + 0,176377H_L - 0,929592TN - 115,761/D_g$$
$S_e = 0.3823$ m $R^2 = 0,9800$ $n = 241$

$$V = -113,725 - 2,47698G + 8,93191H_L - 0,17812H_L^2 + 0,592762GH_L$$
$S_e = 16,74\ m^3/ha$ $R^2 = 0,9897$ $n = 241$

These models were obtained on the basis of all sample plots (n=241), measured in eleven selected representative beech stands. The reliability of the models was tested and it was concluded that they can be successfully applied in practice.

New regression models for stands were produced in this research and their reliability was tested. We first used the sample plots of each stand separately (n=10-33) and then the respective stands (n=11) as sample elements.

3.2 Models for estimating the form factor and the form height of each beech stand separately

The general form of the model obtained in earlier researches was used for stands,

$$F = a + bH_L + c/H_L + dTN + e/D_g \quad (1)$$

$$H_LF = a + bH_L + cTN + d/D_g \quad (2)$$

where:
F – stand form factor,
H_LF – stand form height,
H_L – Lorey`s mean height of a stand,
TN – stand tariff series and
D_g – stand quadratic mean diameter

The obtained results are presented in Tables 1 and 2.

Table 1. *Statistical parameters of the model for estimating the stand form factor (F)*

Stand.	n	a	b	c	d	e	R^2	S_e
33a	23	1,6298	-0,026247	-7,69154	-0,0360115	-5,42466	0,837	0,0105
42a	18	2,1025	-0,032807	-13,5006	-0,0305938	-3,76320	0,492	0,0177
42b	10	1,6147	-0,023360	-4,23753	-0,0522183	-3,60243	0,921	0,0083
122a	29	0,5592	-0,004225	+7,40660	-0,0254734	-3,47685	0,642	0,0120
27a	20	0,9725	-0,009613	+0,12913	-0,0219942	-4,39587	0,611	0,0136
31a	32	1,2711	-0,015342	-3,08991	-0,0328527	-4,35832	0,962	0,0089
46a	28	0,9510	-0,008879	+0,17846	-0,0299203	-3,68993	0,804	0,0133
8a	16	1,4704	-0,020863	-0,44285	-0,0515007	-7,45019	0.901	0,0067
8b	10	5,2032	-0,094348	-50,1793	-0,0381785	-5,43781	0,866	0,0096
44a	22	1,3763	-0,017479	-2,69444	-0,0387479	-5,20886	0,915	0,0086
116a	33	1,1910	-0,013013	-4,12448	-0,0267675	-3,00477	0,817	0,0120

Table 2. *Statistical parameters of the model for estimating the stand form height (H_LF)*

Stand	n	a	b	c	d	R^2	S_e
33a	23	21,1459	+0,076076	-1,200300	-180,834	0,974	0,345
42a	18	12,2661	+0,240807	-0,718457	-93,7982	0,829	0,433
42b	10	16,2097	+0,175545	-1,158860	-80,5615	0,986	0,169
122a	29	15,9923	+0,154575	-0,811108	-108,806	0,920	0,433
27a	20	12,5666	+0,247172	-0,622988	-110,310	0,972	0,388
31a	32	17,1870	+0,127288	-0,961311	-127,231	0,991	0,274
46a	28	12,5581	+0,248259	-0,783059	-96,6339	0,984	0,317
8a	16	24,1729	-0,024457	-1,338050	-189,259	0,991	0,137
8b	10	16,1490	+0,096465	-0,666206	-104,888	0,846	0,270
44a	22	22,8011	+0,021667	-1,287620	-165,173	0,968	0,289
116a	33	11,7725	+0,262541	-0,781075	-85,8152	0,983	0,363

3.3 Models for estimating the form factor and the form height of all beech stands together

The general form of the model is the same as in the first case. By applying the multiple regression with fixed independent variables, the following regression equations were obtained,

$$F = -0{,}104732 + 0{,}0116884H_L + 4{,}93375/H_L + 0{,}00872387TN + 2{,}13421/Dg \quad (3)$$

$S_e = 0{,}00488$ $R^2 = 0{,}805$ $n = 11$

$$H_LF = -6{,}68446 + 0{,}653604H_L + 0{,}307627TN + 39{,}8059/D_g \quad (4)$$

$S_e = 0{,}165$ m $R^2 = 0{,}995$ $n = 11$

Since only the value of the parameter *b* is statistically significant in equations (3) and (4), the method of stepwise multiple regression was applied too (Hadzivukovic, S. *et al*. 1982).

A simpler forms of regression equation were obtained,

$$F = 0{,}449008 + 0{,}00162813H_L \quad (5)$$

$S_e = 0{,}00630$ $R^2 = 0{,}512$

$$H_LF = -1{,}32257 + 0{,}542605H_L \quad (6)$$

$S_e = 0{,}18$ $R^2 = 0{,}993$

There is a linear dependence of the form factor (5) and the form height (6) of beech high stands on Lorey`s mean stand height. The difference in the values of the parameter *b*, i.e. in the inclination of the lines that represent the graphic expression of these equations, is great. The stand form factor slightly increases with the increase of Lorey's mean stand height (with the coefficient of variation $CV_F = 1.73\%$). The form height of the stands rapidly increases with the increase of Lorey's mean stand height (with the coefficient of variation $CV_{HF} = 14.84\%$). The relatioship is extremely strong and the standard error of regression is small.

It follows that the application of regression equations (5) and (6) enables us to derive new formulas for approximate estimation of the beech stand volume per hectare from the basic stand volume formula $V = G\,H_L\,F$:

$$V = 0{,}449008\,GH_L + 0{,}00162813\,GH_L^2 \quad (7)$$

$$V = -1{,}32257\,G + 0{,}542605\,GH_L \quad (8)$$

For the practical implementation of these formulas, it is necessary to determine the stand basal area (G) and Lorey`s mean stand height ($H_L$). In order to do this, either classical or *relascopy method* should be applied to establish 3 to 5 competently selected sample areas and measure the diameter at breast height of all trees above the estimation limit (10cm). The accuracy of the basal area and Lorey`s mean stand height determination directly affects the accuracy of the estimated stand volume per hectare. Distribution of the stand volume per diameter degrees is similar to the basal area distribution, i.e. the relative proportion of the basal area per diameter degrees in the stand basal area roughly corresponds to the relative proportion of the volume per diameter classes in the stand volume (Koprivica, M., Matović, B. 2010).

3.4 Comparison of the empirical value of the form factor and the form height of beech stands with the values calculated by different models

For the purpose of this comparison, the following models were used:

- Models based on sample plots for all stands together,
- Models based on sample plots for each separate stand,
- Models based on stands with three independent variables,
- Models based on stands with one independent variable

The comparison is shown in Tables 3.1, 3.2 and 4.1 and 4.2

Table 3.1. *Beech stand form factor (F) – empirical and model values*

Stand	n	*F_0	F_1	F_2	F_3	F_4
33a	23	0,50369	0,50235	0,49617	0,49734	0,49955
42a	18	0,48993	0,49170	0,48883	0,48673	0,48885
42b	10	0,48687	0,47442	0,49993	0,48773	0,48435
122a	29	0,50509	0,50003	0,49510	0,50918	0,50493
27a	20	0,50236	0,49315	0,48965	0,50135	0,49823
31a	32	0,48199	0,50919	0,50803	0,48592	0,49461
46a	28	0,49421	0,48388	0,47582	0,49849	0,49386
8a	16	0,48386	0,49453	0,48398	0,48730	0,49111
8b	10	0,49828	0,49696	0,51226	0,49474	0,48904
44a	22	0,50332	0,49416	0,51075	0,50019	0,50132
116a	33	0,48875	0,50043	0,49511	0,48871	0,49250

Tabela 3.2. *Form factor index (F) of the beech stands - modelled/empirical*

Stand	n	F_0/F_0	F_1/F_0	F_2/F_0	F_3/F_0	F_4/F_0
33a	23	1,000	0,997	0,985	0,987	0,992
42a	18	1,000	1.004	0,998	0,993	0,998
42b	10	1,000	0,974	1,027	1,002	0,995
122a	29	1,000	0,990	0,980	1,008	1,000
27a	20	1,000	0,982	0,975	0,998	0,992
31a	32	1,000	1,056	1,054	1,008	1,026
46a	28	1,000	0,979	0,963	1,009	0,999
8a	16	1,000	1,022	1,000	1,007	1,015
8b	10	1,000	0,997	1,028	0,993	0,981
44a	22	1,000	0,982	1,014	0,994	0,996
116a	33	1,000	1,024	1,013	1,000	1,008

F_0 – empirical value of the stand form factor
F_1 – value of the form factor calculated by the model of all sample plots together (n = 241)
F_2 – value of the form factor calculated by the model of the sample plots for each separate stand (n = 10 - 33)
F_3 – value of the form factor calculated by the multiple model for all stands (n = 11)
F_4 – value of the form factor calculated by the simple model for all stands (n = 11)

The most accurate model for estimating the beech stand form factor is the one in which the index value has the slightest deviation from the index 1.000. As can be seen from the data in Table 3.2, Model F_3 is the most efficient, because it has the greatest number of accurate results (the smallest deviation of the empirical values F_0 from the estimated values F_3). However, it is of special importance to compare the accuracy of Model $F_{3,}$ or the model obtained on the basis of all sample plots (n = 241) with the accuracy of the model that is based on all stands (n=11). There is no significant difference between these two models, although the model F_3 is slightly more accurate. However, Model F_1 has a better practical application because of the small number of stands in the sample.

On the whole, it can be concluded that none of the models for estimating the stand form factor show a systematic deviation. The deviations are randomly distributed.

Table 4.1. *Form height (H_LF) of beech stands – empirical and modelled*

Stand	n	*H_LF_0	H_LF_1	H_LF_2	H_LF_3	H_LF_4
33a	23	15,634	15,543	15,319	15,536	15,520
42a	18	11,991	12,062	11,920	11,970	11,955
42b	10	10,568	10,321	10,837	10,453	10,457
122a	29	17,350	17,157	17,062	17,340	17,316
27a	20	15,185	14,890	14,894	15,179	15,080
31a	32	13,500	14,257	14,235	13,682	13,876
46a	28	13,615	13,309	13,193	13,818	13,626
8a	16	12,512	12,803	12,505	12,644	12,709
8b	10	12,254	12,311	12,095	12,045	12,020
44a	22	16,173	15,864	16,404	16,020	16,111
116a	33	13,057	13,374	13,179	13,154	13,170

Table 4.2. *Form height index (H_LF) of beech stands – modelled/empirical*

Stand	n	HF_0/HF_0	HF_1/HF_0	HF_2/HF_0	HF_3/HF_0	HF_4/HF_0
33a	23	1,000	0,994	0,980	0,994	0,993
42a	18	1,000	1,006	0,994	0,998	0,997
42b	10	1,000	0,977	1,025	0,989	0,989
122a	29	1,000	0,989	0,983	0,999	0,998
27a	20	1,000	0,981	0,981	1,000	0,993
31a	32	1,000	1,056	1,054	1,013	1,027
46a	28	1,000	0,978	0,969	1,015	1,001
8a	16	1,000	1,023	0,999	1,010	1,016
8b	10	1,000	1,005	0,987	0,983	0,981
44a	22	1,000	0,981	1,014	0,991	0,996
116a	33	1,000	1,024	1,009	1,007	1,009

HF_0 – empirical value of the stand form height
HF_1 – value of the form height calculated by the model of all sample plots together (n = 241)
HF_2 – value of the form height calculated by the model of the sample plots for each separate stand (n = 10 - 33)
HF_3 – value of the form height calculated by the multiple model for all stands (n = 11)
HF_4 – value of the form height calculated by the simple model for all stands (n = 11)

As can be seen from the data in Table 4.2, Models HF_3 and HF_4 are the most efficient, because they have the greatest number of accurate results. However, it is of great importance to compare the accuracy of Models HF_3 and HF_4 ,i.e. the model obtained on the basis of all sample plots (n = 241) and the model obtained on the basis of all stands (n = 11). There is no significant difference between these two models, although Model HF_3 is slightly more accurate. However, Model HF_1 has a better practical application because of the small number of stands in the sample.

Again, it can be concluded that none of the models for estimating the stand form height show a systematic deviation, but the deviations are randomly distributed.

3.5 Models for estimating volume of each beech stands separately

The general form of the model, developed in earlier investigations, was used for stands,

$$V = a + bG + cH_L + dH_L^2 + eGH_L \quad (9)$$

The obtained results are presented in Table 5.

Table 5. *Statistical parameters of the model for estimating beech stand volume per hectare (V)*

Stand	n	a	b	c	d	e	R^2	S_e
33a	23	-701,940	-4,59352	48,9302	-0,839607	0,652192	0,981	24,814
42a	18	768,021	-5,00893	-56,3465	1,04262	0,674438	0,963	19,518
42b	10	185,023	-0,80250	-20,2999	0,455949	0,582039	0,989	12,434
122a	29	-485,939	3,17787	29,0765	-0,441584	0,424898	0,992	17,579
27a	20	74,656	-0,03031	-6,41145	0,124742	0,507891	0,995	13,487
31a	32	170,106	-8,97200	-6,54878	0,011962	0,817302	0,986	13,118
46a	28	118,315	-4,95033	-8,04861	0,126982	0,681550	0,994	10,858
8a	16	34,0822	-34,3601	40,5958	-1,64826	1,83144	0,990	13,581
8b	10	2420,12	-30,0461	-149,138	2,0776	1,70767	0,979	12,697
44a	22	198,223	-1,20807	-12,6801	0,159614	0,588235	0,990	19,386
116a	33	-81,3943	-3,24981	6,91556	-0,140404	0,609576	0,993	11,369

3.6 Models for estimating volume of all beech stands together

The general form of the model is still the same as in the first case. By applying the multiply regression with fixed independent variables, the following regression equation was produced,

$$V = 6,00118 + 0,108797G – 2,40954H_L + 0,0632384H_L^2 + 0,505875GH_L \quad (10)$$

S_e= 4,861 m^3/ha R^2 = 0,998 n = 11

Since some of the parameters in equation (10) are not statistically significant, the method of stepwise multiply regression was applied to develop the following equation,

$$V = -26,7355 + 0,0173008H_L^2 + 0,512172GH_L \quad (11)$$

S_e= 4,261 m^3/ha R^2 = 0,998 n = 11

For practical implementation of equations (10) and (11), it is necessary to determine the basal area (G) and Lorey`s mean height (H_L) of the stand for which the volume (V) has to be estimated. In that case, the derived simple formulas (7) and (8) can be used.

3.7 Comparison of the empirical values of the beech stand volume with the values calculated by different models

For the purpose of this comparison, the following models were used:
- models based on sample plots for all stands together,
- models based on sample plots for each stand separately,
- models based on stands with four independent variables,
- models based on stands with two independent variables

The comparison is shown in Tables 6.1 and 6.2.

As can be seen from the data in Table 6.2, Models V_3 and V_4 are the most efficient because they have the greatest number of accurate results. However, it is again of great importance to compare the accuracy of Models V_1 and V_3 , or the model obtained on the basis of all sample plots (n = 241) and the model obtained on the basis of all stands (n = 11). There is no significant difference between these two models, although Model V_3 is slightly more accurate. However, Model V_1 has a better practical application because of the small number of stands in the sample.

Table 6.1. *Beech stand volume per hectare (V) – empirical and modelled*

Stand	n	*V_0	V_1	V_2	V_3	V_4
33a	23	522,52	524,03	530,96	520,56	521,25
42a	18	379,57	379,11	377,59	380,42	380,58
42b	10	333,22	323,89	332,32	333,21	332,01
122a	29	503,68	502,10	507,82	505,52	504,46
27a	20	350,38	349,76	348,40	346,32	346,33
31a	32	290,89	301,13	295,98	295,75	295,92
46a	28	316,04	318,70	313,88	313,63	313,91
8a	16	385,19	393,72	381,85	392,04	392,56
8b	10	360,83	354,52	360,51	354,47	354,56
44a	22	502,25	499,83	504,99	501,99	502,15
116a	33	289,90	294,27	293,80	290,54	290,71

Table 6.2. *Beech stand volume index, per hectare (V) – modelled/ empirical*

Stand	n	V_0/V_0	V_1/V_0	V_2/V_0	V_3/V_0	V_4/V_0
33a	23	1,000	1,003	1,016	0,996	0,998
42a	18	1,000	0,999	0,995	1,002	1,003
42b	10	1,000	0,972	0,997	1,000	0,996
122a	29	1,000	0,997	1,008	1,004	1,002
27a	20	1,000	0,998	0,994	0,988	0,988
31a	32	1,000	1,035	1,017	1,017	1,017
46a	28	1,000	1,008	0,993	0,992	0,993
8a	16	1,000	1,022	0,991	1,018	1,019
8b	10	1,000	0,983	0,999	0,982	0,983
44a	22	1,000	0,995	1,005	0,999	1,000
116a	33	1,000	1,015	1,013	1,002	1,003

V_0 – empirical value of the stand volume
V_1 – the value of the volume calculated by the model of all sample plots together (n = 241)
V_2 – the value of the volume calculated by the model of sample plots for each separate stand (n = 10 - 33)
V_3 – the value of the volume calculated by the model with four independent variables for all stands (n = 11)
V_4 – the value of the volume calculated by the model with two independent variables for all stands (n = 11)

On the whole, it can be concluded that none of the models for estimating the beech stand volume per hectare show a systematic deviation, but the deviations are randomly distributed.

3.8 Average values of form factor, form height and volume of all beech stands together

Average values of form factor, form height and volume of all beech stands together (management classes) were obtained as weighted values of these estimation elements determined in the stands (weight – the number of sample plots in a stand).

The results are presented in Table 7.

Table 7. *Average values of form factor, form height and volume of all beech stands together, per hectare*

Model	F	Index	H_LF	Index	V	Index
Original	0,49442	1,0000	14,1580	1,0000	382,88	1,0000
Model 1	0,49636	1,0039	14,1923	1,0024	384,99	1,0055
Model 2	0,49536	1,0019	14,1481	0,9993	385,09	1,0058
Model 3	0,49483	1,0008	14,1816	1,0017	383,54	1,0017
Model 4	0,49463	1,0004	14,1852	1,0019	383,57	1,0018

The data in Table 7 show that there is no significant difference between the average values of form factor, form height and volume when they refer to a set of all study beech stands (management class). Yet, the most accurate results are achieved in Models 3 and 4, i.e. the models with stands as sample elements. However, we must bear in mind that the sample of the study beech stands was very small and that the models used the average values of all investigated stand estimation elements obtained from the data set on sample plots. Therefore, the best practice is to use the models derived on the basis of all sample plots (Model 1).

4. CONCLUSION

The main purpose of this paper was to resolve the crucial issue of construction and application of the regression models and tables intended for fast volume estimation in high beech stands in Serbia. These models and tables were previously constructed on the basis of a sample with sample plots as basic observation units, instead of stands. As a matter of fact, a lot of authors agree that if the models are constructed using a sample of trees, sample plots or stands, they should be applied at the respective level of observation. However, a stand model would be both money and time consuming and it would require extensive measurements. It is rarely feasible in investigations that are time limited and have modest financial resources. Therefore, when developing these regression models in Serbia, sample plot characteristics were extrapolated (converted) into a hectare and then observed as characteristics of hypothetical stands.

Beech stands are proved to have strong internal heterogeneity and it is assumed that within beech high forests in Serbia, there are stands with average estimation and site characteristics similar to the estimation and site characteristics of randomly selected sample plots. Model efficiacy testing showed that the initial hypothesis was justified. Namely, there is no significant difference between the estimated average values of stand form factor, form height and volume per hectare, calculated by the models based on the characteristics of a great number of sample areas (n = 241) and the models based on the characteristics of a small number of stands (n = 11).

The main question of this study – whether the plot-based stand models can be practically applied on stands, or they are limited to sample plots only – is resolved. The final answer is that they can. It is ascertained by comparing the values calculated by the models for all sample plots and for all stands with the empirical values of form factor, form height and volume per hectare for each separate stand and for all stands together (management class).

There are differences between the studied models in all cases. However , they are not systematic, but random and their magnitude cannot have a significant influence on the final result when estimating stand volume either per hectare or on its whole area. It was proved in two ways: indirectly, through the models for stand volume elements (form factor and form height) and directly, through the models for stand volume. Thus, the obtained models can be applied in practice and their accuracy will primarily depend on the accuracy of the estimated stand elements, needed for model implementation, not on the accuracy of the model parameters, because they are determined as accurately as possible.

Finally, the models based on the sample of all plots established in beech high stands should be favoured. In our opinion, these models are flexible and they can include all variations of beech high stand characterictics that might occur in practice.

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RELIABILITY OF THE STAND REGRESSION MODELS DEVELOPED ON THE BASIS OF SAMPLE PLOTS

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Summary

This paper addresses the problem of reliability of previously constructed stand regression models for beech high forests in Serbia, based on sample plots as basic sample elements. A lot of authors agree that stand models should use stands as basic sample elements, not sample plots, because in practice they are usually applied at that level. The main hypothesis of this study is that stand models based on sample plots are reliable enough. This hypothesis is based on strong internal heterogeneity of beech high stands, so that characteristics of sample plots can provisionally be equated with characteristics of hypothetical stands. It is well-known that in forest inventories, the aggregate values of estimation elements, determined on the sample plots, are usually extrapolated per hectare before they are used for the estimation of stand elements or as variables in the construction of regression models. Other estimation values determined on the sample plots, which are not aggregate, are used in these models as individual values or as average values of the sample plots established in the stands.

The reliability of the models for estimating form factor, form height and volume of beech high stands in Serbia was tested by comparing their empirical values obtained in the sample with the values obtained in different models: (1) models based on sample plots for all stands together, (2) models based on sample plots for each stand separately, (3) models based on stands with several independent variables and (4) models based on stands with one or two independent variables. It was concluded that the stand models constructed on the basis of a great number of sample plots were in all cases sufficiently reliable. In the cases where the basic units of the sample, which was used for obtaining regression models, were stands instead of sample plots, the resulting models were not significantly more reliable. Therefore, previously constructed stand models for estimating form factor and form height (Koprivica, M., Matović, B. 2009) or directly volume per hectare (Koprivica, M. *et al*. 2010) are recommended to be used in practice.

POUZDANOST SASTOJINSKIH REGRESIONIONIH MODELA RAZVIJENIH NA BAZI PROBNIH POVRŠINA

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Rezime

U radu je razmatran problem pouzdanosti ranije razvijenih sastojinskih regresionih modela za visoke bukove šume u Srbiji, na bazi probnih površina kao osnovnih elemenata uzorka. Prema mišljenju mnogih autora sastojinski modeli bi trebali biti razvijeni na bazi uzorka sastojina kao osnovnih elemenata uzorka, a ne probnih površina, jer se u praksi obično primenjuju na tom nivou. Osnovna hipoteza u ovom istraživanju bila je da su i sastojinski modeli dobijeni na bazi probnih površina dovoljno pouzdani. Hipoteza je zasnovana na velikoj unutrašnjoj heterogenosti visokih sastojina bukve, tako da se

karakteristike probnih površina uslovno mnogu izjednačiti sa karakteristikama hipotetičkih sastojina. Naime, poznato je da se u inventuri šuma agregatne veličine taksacionih elmenata utvrđene na probnim površinama prvo ekstrapoliraju na hektar a zatim koriste za procenu taksacionih elemenata sastojine ili kao promenljive prilikom konstrukcije regresionih modela. Ostale taksacione veličine utvrđene na probnim površinama, koje nisu agregatne, koriste se u modelima kao individualne veličine ili kao prosečne veličine probnih površina postavljenih u sastojini.

Proverena je pouzdanost modela za procenu zapreminskog koeficijenta, oblikovisine i zapremine visokih sastojina bukve u Srbiji, upoređenjem njihovih stvarnih veličina dobijenih u uzorku sa veličinama dobijenim po različitim modelima: (1) - modeli na bazi probnih površina za sve sastojine zajedno, (2) - modeli na bazi probnih površina za svaku sastojinu posebno, (3) - modeli na bazi sastojina sa više nezavisno promenljivih, i (4) - modeli na bazi sastojina sa jednom ili dve nezavisno promenljive. Zaključeno je da su u svim slučajevima sastojinski modeli dobijeni na bazi velikog uzorka probnih površina dovoljno pouzdani. U slučaju kada su osnovne jedinice uzorka korišćenog za dobijanje regresionih modela bile sastojine, a ne probne površine, nisu dobijeni značajno pouzdaniji modeli. Zbog toga su za primenu u praksi preporučeni ranije konstruisani sastojinski modeli za procenu zapreminskog koeficijenta i oblikovisine (Koprivica, M., Matović, B. 2009) ili direktno zapremine po hektaru (Koprivica, M. et al. 2010).

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