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SUSTAINABLE FORESTRY ODRŽIVO ŠUMARSTVO

COLLECTION
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STAND VOLUME TABLES FOR BEECH IN SERBIA

Miloš KOPRIVICA¹, Bratislav MATOVIĆ²,
Vlado ČOKEŠA¹, Snežana STAJIĆ¹

Abstract: *The study results are a regression model and two-way stand volume tables intended for practical application. The Model and the tables resulted from a large data-set collected in beech high forests in Serbia. Eleven all-aged beech high stands were selected in six forest areas and measured using a simple systematic sample. Altogether 241 circular sample plots of 500 m² were distributed using the square grid network design, spacing 100 m. The models were constructed by the method of stepwise multiple regression. The model accuracy was tested on the material that was used for the construction of tables. However, the true reliability and efficacy of the models can be evaluated only after their practical implementation.*

Key words: beech stand, stand volume, model, stand tables

SASTOJINSKE ZAPREMINSKE TABLICE ZA BUKVU U SRBIJI

Apstrakt: *Rezultat ovog rada je regresioni model i dvoulazne sastojinske zapreminske tablice namenjene za primenu u praksi. Model i tablice su dobijeni na bazi obimnog materijala prikupljenog u visokim bukovim šumama na području Srbije. U šest šumskih područja odabrano je i premereno jedanaest raznodobnih sastojina bukve. Primenjen je jednostavni sistematski uzorak. Postavljena je 241 probna površina, oblika kruga i veličine 500 m², u kvadratnom rasporedu na rastojanju 100 m. Za konstrukciju modela i tablica primenjen je metod postepene (stepwise) višestruke regresije. Proverena je tačnost modela i tablica na materijalu koji je poslužio za izradu tablica. Međutim, ocena stvarne efikasnosti dobijenog modela i tablica biće moguća tek posle njihove primene u praksi.*

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² Institute of Lowland Forestry and Environment, Novi Sad

1. INTRODUCTION

In forest management planning, one of the most significant estimation elements is stand volume (growing stock) per hectare and over the entire area. The same applies to larger forest management or forest classification units (e.g. management class). The main goal of forest inventory is to estimate the size of growing stock and its distribution per diameter degrees or classes, as accurately as possible both for the principal tree species and in total. The methods used to this purpose must be accurate and economic, i.e. efficient. The most frequently implemented methods both in the world and in our country are based on the sample, i.e. on partial stand measurement. The *method of stand volume tables* is one of many stand inventory methods. These tables have been used for a long time in the forestry of the USA, Canada and some countries in Europe (Scandinavian countries). The interest in the construction of stand volume tables for different tree species particularly increased after the invention of relascope and the development of relascopy method (Bitterlich, R. 1948, after Mirković, D., Banković, S. 1993). As it is known, the relascopy can determine the basal area of a stand (primarily even-aged) per hectare and its distribution per diameter degrees or classes relatively quickly and precisely enough.

The tables are constructed based on the dependence of the stand volume per hectare on other stand estimation elements (most often basal area per hectare and mean height). The examples for the construction of stand volume tables for pure and mixed all-aged and even-aged stands of our principal tree species, were produced only for the area of Bosnia and Herzegovina (Matić, V. *et al.*, 1963, Stojanović, O. *et al.*, 1987). There are no tables of this type for natural stands in Serbia. There are only tables for artificially established stands of Austrian pine up to fifty years of age (Koprivica, M. 1995). In all the above cases, stand tables were calculated by the method of multiple regression analysis.

The aim of stand volume table construction is to provide the data on stand volume per hectare and total area with relatively little stand measurement and hence with minimal forest inventory costs. This is most easily performed in pure and even-aged stands. The main disadvantage of this method is that it is not accurate enough and that it does not encompass the distribution of stand volume per diameter degrees or classes. However, rough volume distribution can be estimated based on the percent distribution of stand basal area per diameter degrees or classes (Koprivica, M., Matović, B. 2010).

The task of this paper is to define the regression model and to construct tables for volume estimation in all-aged beech high stands in Serbia. Therefore, three aspects should be analysed construction, accuracy and implementation.

2. MATERIAL AND METHOD

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 in the period from 2005 to 2007. Eleven all-aged high stands of beech were selected under the predetermined criteria in six forest regions: Severno Kučajsko, Podrinjsko-Kolubarsko, Jablaničko, Golijsko, Donje Ibarsko, and Rasinsko. Altogether 241 circular sample plots of 500 m² were established. The simple systematic sample of sample plots i.e. the square grid network with a 100 m spacing was used in all stands. The selection intensity accounted for 5% of the stand area. The data were processed using the application programme “SORTIMENT”, especially designed to this purpose (Marković, N. *et al.*, 2007). More detailed information on the method of data collection and processing had been previously reported by Koprivica, M. *et al.* (2005).

The main characteristics of the sample of selected plots are presented in Table 1.

Table 1: *Statistics of the elements in beech high forests in the sample (n = 241)*

Element	Statistical indicators							
	X _{aver.}	X _{min.}	X _{max.}	S	CV%	m%	α ₃	α ₄
V	382.88	49.96	983.92	163.52	42.71	5.50	0.93	4.25
G	26.95	6.91	54.00	9.10	33.78	4.35	0.30	2.66
N	298.34	60.0	1200.0	145.55	48.78	6.28	1.72	10.04
H _l	28.42	13.73	40.33	4.77	16.78	2.16	0.07	2.62
H	23.79	11.7	39.4	5.02	21.08	2.72	0.43	2.94
D _g	35.76	17.95	61.26	8.31	23.23	2.99	0.47	3.02
D	32.66	17.50	60.20	8.35	25.58	3.30	0.64	3.16
SK	0.84	0.14	1.00	0.163	19.41	2.50	-1.54	5.40
TN	3.34	1.0	8.0	1.47	44.16	5.69	0.34	1.95
NV	846.5	406.0	1370.0	255.53	30.19	3.89	0.13	2.17

Legend:

V - stand volume per hectare	D - arithmetic mean stand diameter
G - stand basal area per hectare	SK - stand canopy
N - number of trees per hectare	TN - tariff series (site class)
H _l - Lorey's mean height	NV - stand altitude
H - arithmetic mean stand height	NT - stand slope
D _g - stand quadratic mean diameter	EK - stand aspect

Because of a small number of stands in the sample, further analyses had to start from the assumption that the sample plot characteristics (estimation elements and site) can be conditionally equated with the characteristics of hypothetical stands. From the statistical aspect, this can be justified because the variability of all elements in the plot sample is higher than the variability 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). The above papers also deal with the issue of optimal data collection, assuming that the regression method will be used in modelling. It is concluded that the best results of modelling can be achieved if the variables include different values within the domain of their variation, taking into account extreme values, not only those with

minor deviations from the average. Also, the data for the modelling at the stand level should be collected on sample plots.

The method of stepwise multiple regression was applied for the definition of the statistical relations between stand volume (V) as dependent variable and the selected stand and site elements (G, N, H_L, H, D_g, D, SK, TN, NV, NT, EK) as independent variables (Hadživuković, S. 1991). The data were processed using STATGRAPHICS, ver. 5.0. From the formal – statistical aspect, the analysis includes not only eleven original independent variables, but also thirty-five independent variables obtained by the transformation of the original independent variables.

3. RESULTS AND DISCUSSION

The study result is the regression model (1) which is applied in the volume estimation of beech high stands per hectare. The model has only two original independent variables (G and H_L) and it is the best practical solution of the problem.

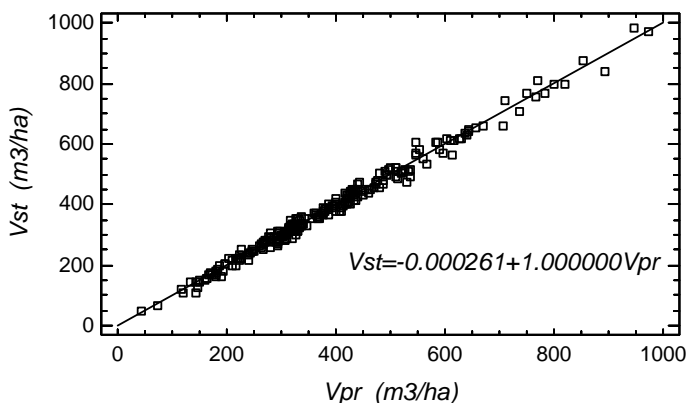
$$V = - 113.725 - 2.47698G + 8.93191H_L - 0.17812H_L^2 + 0.592762GH_L \quad (1)$$

In equation (1), all partial regression coefficients are statistically significant at the risk level $p < 0.001$, as well as the whole regression. Standard error of regression is $\pm 16.74 \text{ m}^3/\text{ha}$, and mean absolute deviation is $12.70 \text{ m}^3/\text{ha}$. Coefficient of multiple determination is 98.97%. The stand volume tables (TABLE I) constructed by this Model are graphically illustrated (Graphs 2a and 2b).

The Model reliability was tested in several ways: by the analysis of residual deviations of original values of stand volume per hectare from the values estimated by this Model (analysis of residuals), by the graphic illustration of the linear correlation between the original and the estimated values of volume per hectare (method of linear correlation) and by the analysis of percent deviations of the estimated values from the original values of stand volume per hectare.

The analysis of standardised residuals shows that the residuals are distributed almost completely by the probability law of normal distribution. Of the total number of all residuals, there are 12 or 4.98% standardised residuals of absolute value above 2.0 and only 3 or 1.24% above 3.0. This practically means that it can be expected at the probability of 95% that the error of the estimated stand volume per hectare will not exceed $\pm 33.50 \text{ m}^3/\text{ha}$.

The linear correlation between original and estimated values of stand volume per hectare is presented in Graph 1.



Graph 1: *Correlation between original and estimated values of beech stand volume per hectare*

In the ideal case, that is at the complete congruence of data, the values of straight line equation parameters are $a = 0$ and $b = 1$ (Stojanović, O., 1976). From the statistical aspect, true values of parameters of linear regression differ accidentally from the expected, so it can be concluded that the obtained regression model is reliable for the estimation of the beech stand volume per hectare. This is confirmed by a very narrow dispersion interval along the correlation line.

In our previous research study of the use of regression models to estimate the volume of beech stands (same material) a slightly better regression model was obtained, but only theoretically (Koprivica, M. *et al.*, 2010).

TABLE I: STAND VOLUME TABLES FOR BEECH IN SERBIA (volume of wood above 3.0 cm)

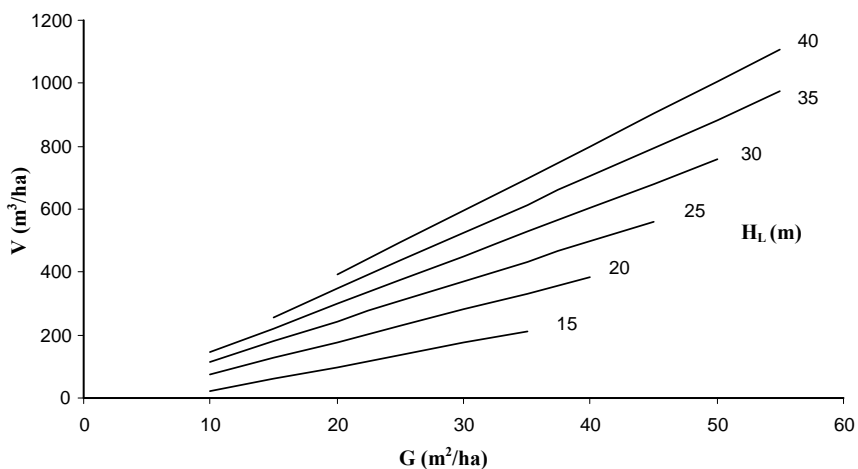
m ³ /ha		Stand basal area (m ² /ha)															
		10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
Lorey's mean stand height (m)	15	44.32	50.74	57.15	63.56	69.98	76.39	82.81	89.22	95.64	102.05	108.47	114.88	121.29	127.71	134.12	
	16	53.66	60.67	67.67	74.68	81.69	88.70	95.70	102.71	109.72	116.72	123.73	130.74	137.75	144.75	151.76	
	17	62.64	70.24	77.84	85.44	93.04	100.64	108.24	115.84	123.44	131.04	138.64	146.24	153.84	161.44	169.04	
	18	71.27	79.46	87.65	95.84	104.04	112.23	120.42	128.62	136.81	145.00	153.19	161.39	169.58	177.77	185.96	
	19	79.53	88.32	97.11	105.89	114.68	123.46	132.25	141.03	149.82	158.60	167.39	176.18	184.96	193.75	202.53	
	20	87.45	96.83	106.20	115.58	124.96	134.34	143.72	153.10	162.47	171.85	181.23	190.61	199.99	209.37	218.74	
	21	95.00	104.98	114.95	124.92	134.89	144.86	154.83	164.80	174.77	184.74	194.71	204.69	214.66	224.63	234.60	
	22	102.20	112.77	123.33	133.90	144.46	155.02	165.59	176.15	186.72	197.28	207.84	218.41	228.97	239.53	250.10	
	23	109.05	120.21	131.36	142.52	153.68	164.83	175.99	187.14	198.30	209.46	220.61	231.77	242.93	254.08	265.24	
	24	115.54	127.29	139.04	150.78	162.53	174.28	186.03	197.78	209.53	221.28	233.03	244.78	256.53	268.28	280.03	
	25	121.67	134.01	146.35	158.69	171.04	183.38	195.72	208.06	220.41	232.75	245.09	257.43	269.77	282.12	294.46	
	26	127.44	140.38	153.31	166.25	179.18	192.12	205.05	217.99	230.92	243.86	256.79	269.73	282.66	295.60	308.53	
	27	132.86	146.39	159.92	173.45	186.97	200.50	214.03	227.56	241.08	254.61	268.14	281.67	295.19	308.72	322.25	
	28	137.93	152.05	166.17	180.29	194.41	208.53	222.65	236.77	250.89	265.01	279.13	293.25	307.37	321.49	335.61	
	29	142.63	157.35	172.06	186.77	201.49	216.20	230.91	245.62	260.34	275.05	289.76	304.48	319.19	333.90	348.62	
	30	146.98	162.29	177.59	192.90	208.21	223.51	238.82	254.12	269.43	284.74	300.04	315.35	330.65	345.96	361.27	
	31	150.98	166.88	182.77	198.67	214.57	230.47	246.37	262.27	278.17	294.07	309.96	325.86	341.76	357.66	373.56	
	32	154.62	171.11	187.60	204.09	220.58	237.07	253.56	270.06	286.55	303.04	319.53	336.02	352.51	369.00	385.49	
	33	157.90	174.98	192.07	209.15	226.23	243.32	260.40	277.49	294.57	311.65	328.74	345.82	362.91	379.99	397.08	
	34	160.82	178.50	196.18	213.85	231.53	249.21	266.88	284.56	302.24	319.91	337.59	355.27	372.95	390.62	408.30	
	35		181.66	199.93	218.20	236.47	254.74	273.01	291.28	309.55	327.82	346.09	364.36	382.63	400.90	419.17	
	36			203.33	222.19	241.05	259.92	278.78	297.64	316.50	335.37	354.23	373.09	391.95	410.82	429.68	
	37				225.83	245.28	264.74	284.19	303.65	323.10	342.56	362.01	381.47	400.92	420.38	439.83	
	38					249.15	269.20	289.25	309.30	329.35	349.39	369.44	389.49	409.54	429.59	449.63	
39						273.31	293.95	314.59	335.23	355.87	376.51	397.15	417.80	438.44	459.08		
40							298.30	319.53	340.76	362.00	383.23	404.46	425.70	446.93	468.16		

TABLE I: STAND VOLUME TABLES FOR BEECH IN SERBIA (volume of wood above 3.0 cm) (continued)

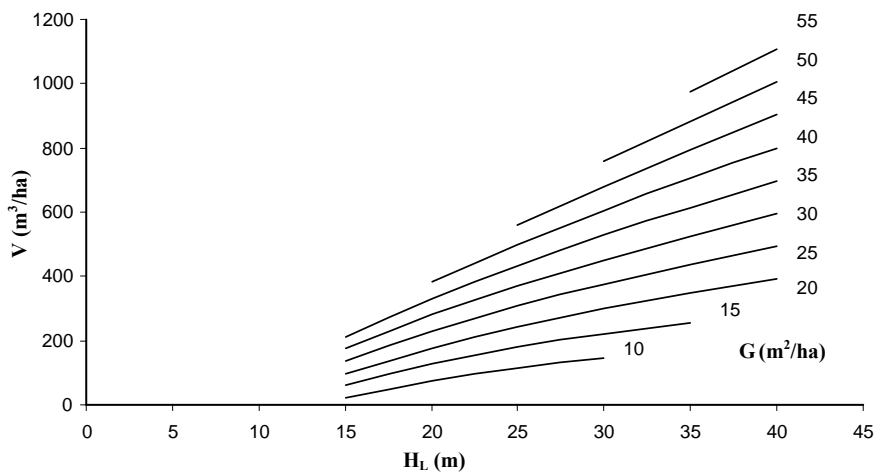
m ³ /ha		Stand basal area (m ² /ha)																			
		25	26	27	28	29	30	31	32	33	34	35	36	37	38	39					
Lorey's mean stand height (m)	15	140.54	146.95	153.37	159.78	166.20	172.61	179.02	185.44	191.85	198.27	204.68	211.10								
	16	158.77	165.77	172.78	179.79	186.80	193.80	200.81	207.82	214.82	221.83	228.84	235.85	242.85							
	17	176.64	184.24	191.84	199.44	207.04	214.64	222.24	229.84	237.44	245.04	252.64	260.24	267.84	275.44						
	18	194.16	202.35	210.54	218.74	226.93	235.12	243.31	251.51	259.70	267.89	276.08	284.28	292.47	300.66	308.86					
	19	211.32	220.10	228.89	237.67	246.46	255.24	264.03	272.82	281.60	290.39	299.17	307.96	316.74	325.53	334.31					
	20	228.12	237.50	246.88	256.26	265.63	275.01	284.39	293.77	303.15	312.53	321.90	331.28	340.66	350.04	359.42					
	21	244.57	254.54	264.51	274.48	284.45	294.42	304.40	314.37	324.34	334.31	344.28	354.25	364.22	374.19	384.16					
	22	260.66	271.23	281.79	292.35	302.92	313.48	324.04	334.61	345.17	355.74	366.30	376.86	387.43	397.99	408.55					
	23	276.40	287.55	298.71	309.87	321.02	332.18	343.34	354.49	365.65	376.81	387.96	399.12	410.28	421.43	432.59					
	24	291.78	303.53	315.28	327.02	338.77	350.52	362.27	374.02	385.77	397.52	409.27	421.02	432.77	444.52	456.27					
	25	306.80	319.14	331.48	343.83	356.17	368.51	380.85	393.19	405.54	417.88	430.22	442.56	454.90	467.25	479.59					
	26	321.47	334.40	347.34	360.27	373.21	386.14	399.08	412.01	424.94	437.88	450.81	463.75	476.68	489.62	502.55					
	27	335.78	349.30	362.83	376.36	389.89	403.41	416.94	430.47	444.00	457.53	471.05	484.58	498.11	511.64	525.16					
	28	349.73	363.85	377.97	392.09	406.21	420.33	434.45	448.57	462.69	476.81	490.93	505.06	519.18	533.30	547.42					
	29	363.33	378.04	392.76	407.47	422.18	436.90	451.61	466.32	481.03	495.75	510.46	525.17	539.89	554.60	569.31					
	30	376.57	391.88	407.18	422.49	437.79	453.10	468.41	483.71	499.02	514.32	529.63	544.94	560.24	575.55	590.85					
	31	389.46	405.36	421.25	437.15	453.05	468.95	484.85	500.75	516.65	532.54	548.44	564.34	580.24	596.14	612.04					
	32	401.99	418.48	434.97	451.46	467.95	484.44	500.93	517.43	533.92	550.41	566.90	583.39	599.88	616.37	632.87					
	33	414.16	431.24	448.33	465.41	482.50	499.58	516.66	533.75	550.83	567.92	585.00	602.09	619.17	636.25	653.34					
	34	425.98	443.65	461.33	479.01	496.68	514.36	532.04	549.71	567.39	585.07	602.75	620.42	638.10	655.78	673.45					
35	437.44	455.71	473.98	492.25	510.52	528.79	547.06	565.32	583.59	601.86	620.13	638.40	656.67	674.94	693.21						
36	448.54	467.40	486.27	505.13	523.99	542.85	561.72	580.58	599.44	618.30	637.17	656.03	674.89	693.75	712.62						
37	459.29	478.74	498.20	517.66	537.11	556.57	576.02	595.48	614.93	634.39	653.84	673.30	692.75	712.21	731.66						
38	469.68	489.73	509.78	529.83	549.87	569.92	589.97	610.02	630.07	650.11	670.16	690.21	710.26	730.31	750.35						
39	479.72	500.36	521.00	541.64	562.28	582.92	603.56	624.20	644.84	665.48	686.12	706.77	727.41	748.05	768.69						
40	489.40	510.63	531.86	553.10	574.33	595.56	616.80	638.03	659.26	680.50	701.73	722.97	744.20	765.43	786.67						

TABLE I: STAND VOLUME TABLES FOR BEECH IN SERBIA (volume of wood above 3.0 cm) (continued)

m ³ /ha	Stand basal area (m ² /ha)														
	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
15															
16															
17															
18															
19															
20	368.80														
21	394.14	404.11													
22	419.12	429.68	440.25												
23	443.75	454.90	466.06	477.21											
24	468.02	479.77	491.51	503.26	515.01										
25	491.93	504.27	516.61	528.96	541.30	553.64									
26	515.49	528.42	541.36	554.29	567.23	580.16	593.10								
27	538.69	552.22	565.75	579.27	592.80	606.33	619.86	633.38							
28	561.54	575.66	589.78	603.90	618.02	632.14	646.26	660.38	674.50						
29	584.03	598.74	613.45	628.17	642.88	657.59	672.30	687.02	701.73	716.44					
30	606.16	621.47	636.77	652.08	667.38	682.69	697.99	713.30	728.61	743.91	759.22				
31	627.94	643.84	659.73	675.63	691.53	707.43	723.33	739.23	755.13	771.02	786.92	802.82			
32	649.36	665.85	682.34	698.83	715.32	731.81	748.31	764.80	781.29	797.78	814.27	830.76	847.25		
33	670.42	687.51	704.59	721.67	738.76	755.84	772.93	790.01	807.10	824.18	841.26	858.35	875.43	892.52	
34	691.13	708.81	726.48	744.16	761.84	779.51	797.19	814.87	832.55	850.22	867.90	885.58	903.25	920.93	938.61
35	711.48	729.75	748.02	766.29	784.56	802.83	821.10	839.37	857.64	875.91	894.18	912.45	930.72	948.99	967.26
36	731.48	750.34	769.20	788.07	806.93	825.79	844.65	863.52	882.38	901.24	920.10	938.97	957.83	976.69	995.55
37	751.12	770.57	790.03	809.48	828.94	848.39	867.85	887.30	906.76	926.21	945.67	965.13	984.58	1004.0	1023.5
38	770.40	790.45	810.50	830.55	850.59	870.64	890.69	910.74	930.79	950.83	970.88	990.93	1011.0	1031.0	1051.1
39	789.33	809.97	830.61	851.25	871.89	892.53	913.17	933.81	954.45	975.10	995.74	1016.4	1037.0	1057.7	1078.3
40	807.90	829.13	850.37	871.60	892.83	914.07	935.30	956.53	977.77	999.00	1020.2	1041.5	1062.7	1083.9	1105.2



Graph 2a: *Dependence of beech stand volume on its basal area and mean height*



Graph 2b: *Dependence of beech stand volume on its mean height and basal area*

Percent deviation of the estimated values of beech stand volume from their true values is obtained by the equation (2),

$$p = 100 (V_{pr.} - V_{st.})/V_{st.} \tag{2}$$

The accuracy of the estimated volume was checked for all eleven beech stands analysed in this research separately and for all stands together, starting from

the assumption that the stands belong to the same management class. The results are presented in Table 2.

Table 2: Accuracy of the beech stand volume estimated by the Model

Stand	n	$V_{st.}$ (m ³ /ha)	$V_{pr.}$ (m ³ /ha)	Δ (m ³ /ha)	Δ (%)
33a	23	522.52	524.03	+1.51	+0.29
42a	18	379.57	379.11	-0.46	-0.12
42b	10	333.22	323.89	-9.33	-2.80
122a	29	503.68	502.10	-1.58	-0.31
27a	20	350.38	349.76	-0.62	-0.18
31a	32	290.89	301.13	+10.24	+3.52
46a	28	316.04	318.70	+2.66	+0.84
8a	16	385.19	393.72	+8.53	+2.21
8b	10	360.83	354.52	-6.31	-1.75
44a	22	502.25	499.83	-2.42	-0.48
116a	33	289.90	294.27	+4.37	+1.51
All	241	382.88	383.50	+0.62	+0.16

Percent deviation for individual stands varies from -2.80% to +3.52%, and for all stands together it accounts for +0.16%. Absolute deviations of the estimated from the true volume range from -9.33 m³/ha to +10.24 m³/ha and they are much lower than the standard error of regression (+/-16.74 m³/ha). This result confirms our original hypothesis in the Model construction - that sample plot characteristics can conditionally be equated with the characteristics of hypothetical stands.

All methods of checking the accuracy of the Model show that the Model is highly reliable, which means that the obtained stand volume tables are reliable too. However, the accuracy of the Model and the tables will in practical application depend exclusively on the accuracy of the calculated stand basal area per hectare and Lorey's mean height. In the study material, the basal area and the mean height were determined with extremely high accuracy. In each sample plot, the height and the diameter at breast height were measured for all trees. Furthermore, volume and basal area were calculated separately for each tree and then extrapolated per hectare. Of course, this level of accuracy cannot be achieved in the practical application of the Model, so the error of the estimated stand volume will be significantly higher.

4. APPLICATION OF THE STUDY RESULTS

The obtained stand volume tables are intended for practical application. The regression equation (1), or the Model can be used as well. Table or regression equation inputs can be determined most readily using the *relascopy method*.

The procedure is in short as follows. First the stand structure should be evaluated (per tree diameter and per stand area) and then the tree enumeration factor should be selected, so that the average number of trees per sample plot is 20 - 25. The number of sample plots should be 3 - 5, and their location should be determined by a competent professional so that they represent the stand volume as well as possible. Each selected tree in the sample plot (when sighting from the center of the sample plot tree diameter at breast height is wider than scope of the

measuring scale) should be enumerated and its height and diameter at breast height should be measured. Stand height curve can be constructed and Lorey's mean height (H_L) can be calculated based on the collected data. Stand basal area per diameter degrees ($G_1, G_2, \dots G_k$) and total basal area (G) per hectare are estimated based on the classification of the measured trees per diameter degrees. Of course, the tree enumeration factor should be used if it is different from factor 1 (1 : 50 scale).

When stand basal area (G) and Lorey's mean height (H_L) are determined in the above way, stand volume (V) can be read in the tables or calculated by the Model. The distribution of stand volume per diameter degrees or diameter classes can be approximated based on the relative distribution of stand basal area, because the difference between the relative (percent) distribution of basal area and volume in the study beech stands is not great (Koprivica, M., Matović, B. 2010).

If the calculation accuracy of beech stand volume per hectare is to be increased, an additional number of sample plots can be established for the determination of basal area, without measuring the tree diameters and heights. This can be theoretically justified, because the coefficient of variation of basal area in the applied sample is twice higher than the coefficient of variation of Lorey's mean height ($CV_G = 33.78\%$, $CV_H = 16.78\%$). Taking into account the method of sample plot selection in the stand, this is a two-phase sample type (Kangas, A., Maltamo, M., 2006., Koprivica, M., Maunaga, Z. 2012).

Example: In stand 122a, based on the detailed measurement of 29 sample plots, it was calculated that the average volume amounted to 503.68 m³/ha, average basal area 29.03 m²/ha, and Lorey's mean height 34.35 m. In the same stand, 5 sample plots were randomly selected out of 29 sample plots and it was determined that $G = 30$ m²/ha and $H_L = 32$ m. The average stand volume for these inputs in the tables was 484.44 m³/ha. The difference in the average stand volume was -19.24 m³/ha or -3.82%. Based on the basic sample amounting to 29 sample plots, the real average stand volume (resulting from the complete measurement) ranged between 434.62 m³/ha and 572.73 m³/ha, with the probability of 95%. The average stand volume calculated using the tables based on five randomly selected samples also ranges within these values.

In exceptional cases, when a fast assessment of beech stand volume per hectare is necessary, the described procedure should be maximally simplified. In other words, stand basal area (G) per hectare should be determined using the relascope based on 2-3 representative sample plots, without the measurement of tree diameters, and Lorey's mean height (H_L), should be estimated by measuring the height of a small number of dominant and codominant trees. However, this requires a high professional experience of the taxator.

5. CONCLUSION

The volume of beech high stands per hectare depends on numerous factors. However, the resulting regression model in this research study shows that stand basal area per hectare and Lorey's mean height are the most significant factors in the estimation of stand volume. The effect of basal area on stand volume is linear, and the effect of mean height is curvilinear.

When the Model (1) is applied to the concrete beech stands used in this research, it results in an exceptionally high accuracy. Percent deviation of stand volume per hectare varies from -2.80% to +3.52%, that is in absolute amounts from -9.33 m³/ha to +10.24 m³/ha. However, so high accuracy cannot be expected in practice, because the accuracy of the estimated stand volume will depend exclusively on the accuracy of the calculated basal area and stand mean height.

The true reliability and efficacy of the resulting regression Model and stand volume tables can be evaluated only after their practical implementation. In fact, it is difficult to foresee the magnitude of the error which can occur in volume estimation of individual stands, but a satisfactory accuracy of volume of the management class comprising the estimated beech stands can be expected with high dependability.

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STAND VOLUME TABLES FOR BEECH IN SERBIA

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Summary

This paper deals with the issue of the construction of stand volume tables for beech in Serbia. There are no tables of this type for natural stands of the principal tree species in this region. The regression model and tables resulted from a set of data collected in six forest regions. The study comprised 241 circular sample plots of 500 m². They were distributed using the square grid network design, spacing 100 m. On all sample plots, a complete measurement of the stand estimation elements was carried out on all trees with diameters above 10 cm and their site characteristics were determined. The data were processed using an application programme especially designed to this purpose. For each sample plot, the estimation elements were determined as aggregate values and extrapolated to hectare (number of trees, basal area, volume, volume increment) as well as mean values (diameter, height, stand canopy), and site characteristics (tariff series, altitude, slope, aspect). The method of multiple regression or the method of stepwise multiple regression was applied on the sample plot data. We assumed that the characteristics of the sample plots can be equalised with the characteristics of hypothetical beech stands. It later proved to be justified. The obtained regression model (1) has the greatest practical significance. This model was used to construct two-way stand volume tables for beech in Serbia (TABLE I). The two variables are Lorey's mean height (H_L) and stand basal area per hectare (G). The table contains the values for the volume of beech stands per hectare (V). The accuracy of the regression model and tables was tested. When the Model (1) is applied to the stands used in this research, the percent deviation of the model stand volume per hectare from the stand volume determined based on all sample plots distributed in the stand

varies from -2.8% to +3.5%, that is in absolute amounts from -9.3 m³/ha to +10.2 m³/ha. It is also concluded that the standardized residuals are distributed almost completely by the probability law of normal distribution. All regression parameters are statistically significant at the risk level $p < 0.001$. Standard error of regression is +/-16.74 m³/ha, and coefficient of multiple determination is 98.97%. The true reliability and efficacy of the resulting regression Model and stand volume tables can be evaluated only after their practical implementation, because the accuracy of the beech stand volume determination will depend solely on the accuracy of the determined basal area and mean stand height.

SASTOJINSKE ZAPREMINSKE TABLICE ZA BUKVU U SRBIJI

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Rezime

U radu je razmatran problem izrade sastojinskih zapreminskih tablica za bukvu u Srbiji. Na ovom području za prirodno nastale sastojine glavnih vrsta drveća nisu ranije izrađivane tablice ovog tipa. Regresioni model i tablice su dobijeni na bazi podataka prikupljenih u šest šumskih područja. Istraživanjem je obuhvaćeno jedanaest visokih raznodobnih sastojina bukve, u kojima je postavljena 241 probna površina, oblika kruga i veličine 500 m². Probne površine su bile raspoređene u kvadratnom rasporedu na rastojanju 100 m. Na svim probnim površinama izvršen je potpun premer taksacionih elemenata stabala prečnika iznad 10 cm i uzeti su podaci o staništu. Obrada podata izvedena je po posebnom aplikativnom programu izrađenom za ove svrhe. Za svaku probnu površinu, polazeći od izmerenih stabala, utvrđeni su taksacioni elementi kao agregatne veličine prevedene na hektar (broj stabala, temeljnica, zapremina, zapreminski prirast) i prosečne veličine (prečnik, visina, sklop), kao i karakteristike staništa (tarifni niz, nadmorska visina, nagib terena, ekspozicija). Na podatke o probnim površinama primenjen je metod višestruke regresione analize, odnosno metod postepene (stepwise) višestruke regresije. Pretpostavljeno je da karakteristike probnih površina mogu biti istovremeno i karakteristike hipotetičkih sastojina bukve. To se kasnije pokazalo kao opravdano. Dobijen je regresioni model (1) koji ima najveći značaj za primenu u praksi. Po ovom modelu izrađene su dvoulazne sastojinske zapreminske tablice za bukvu u Srbiji (TABELA I). Ulazi u tablice su srednja visina sastojine određena po Lorajevoj formuli (H_L) i temeljnica sastojine po hektaru (G). U polju tabele nalazi se zapremina sastojine bukve po hektaru (V). Ispitana je tačnost regresionog modela i tablica. Kada je Model (1) primenjen na sastojine korišćene za ovo istraživanje procentualno odstupanje zapremine sastojine po modelu u odnosu na zapreminu sastojine koja je utvrđena na bazi svih probnih površina postavljenih u sastojini varira od -2,8% do +3,5%, odnosno u apsolutnom iznosu od -9,3 m³/ha do +10,2 m³/ha. Takođe, konstatovano je da su standardizovani reziduali raspoređeni skoro u potpunosti po zakonu verovatnoće normalnog rasporeda. Svi parametri u regresionom modelu statistički su značajni na nivou rizika $p < 0,001$. Standardna greška regresije je +/- 16,74 m³/ha, a koeficijent višestruke determinacije 98,97%. O stvarnoj valjanosti i efikasnosti dobijenog regresionog modela, odnosno izrađenih sastojinskih zapreminskih tablica, može se sigurnije zaključivati tek posle njihove primene u praksi, jer će tačnost utvrđene zapremine sastojine bukve zavisiti isključivo od tačnosti sa kojom će biti utvrđena temeljnica i srednja visina sastojine.