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APPLICABILITY OF DIFFERENT REGRESSION MODELS FOR ESTIMATION OF MERCHANTABLE WOOD VOLUME OF SESSILE OAK (*Quercus petraea* (Matt.) Liebl.) IN BOSNIA AND HERZEGOVINA

PRIMJENJIVOST RAZLIČITIH MODELA REGRESIJE ZA PROCJENU VOLUMENA KRUPNOG DRVA STABALA HRASTA KITNJAKA (*Quercus petraea* (Matt.) Liebl.) U BOSNI I HERCEGOVINI

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SUMMARY

In Bosnia and Herzegovina, there are tariff tables used for estimating the volume of sessile oak trees in high forests, which were created on the basis of two-entry volume tables for oak trees from the area of Germany, authored by Schwappach in 1905. There are indications that the application of the aforementioned tariffs in forest management practice results in certain differences in the estimated amount of merchantable wood volume compared to the real situation. The material for creation of volume tables was the data concerning the measurement of 2,413 model trees in different habitat and stand conditions. A large number of widely used regression models was tested to equalize the volume of merchantable wood volume as a dependent variable in terms of the diameter at breast height and height of the tree as independent variables. Regression models such as Schumacher-Hall and Spurr II provide satisfactory accuracy, that is, they can be used to estimate the merchantable wood volume of sessile oak trees in high forests (pure and mixed) in the territory of Bosnia and Herzegovina, with a permissible deviation. By introducing the third variable into the model, diameter at seven meters height, the accuracy of the tree volume estimation increases significantly, but due to the significant increase in the volume of work on collecting the necessary data, this model is not suitable for use in forest inventories.

KEY WORDS: sessile oak, Smalian's formula, merchantable wood volume, regression model, nonlinear regression

INTRODUCTION
UVOD

Volume tables have been used to estimate the volume of standing trees since the second half of the 18th century. The first volume tables were made by Cotta for birch in Germany, back in 1804 (Clark 1902). The first modern volume tables were the Bavarian tables published in 1846, which, according to Emrović (1960), proved to be usable not only

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in Bavaria, but also in other parts of Germany and neighboring countries. From that time, the wider application of volume tables in forestry practice begins. The Association of German Forest Research Institutes adopted a plan on the basis of which new tables were created, starting from model trees felled throughout the whole of Germany in pure and even-aged forests (Grundner and Schwappach 1922).

In previous periods, the volume tables have been made by means of graphical or analytical method in the form of hardcopy tables, and now the tables are made exclusively analytically in the form of regression equations. According to Laar and Akca (2007), an early volume equation was introduced during the 1930s by Schumacher and associates. Especially since the 1960s, when computers became readily available to allow regression analyses to be carried out, forest scientists have developed many volume functions for various tree species in many parts of the world, and they continue to do so (West 2009). Zianis et al. (2005) gave a detailed overview of the equations that were developed to estimate the volume and biomass of trees in Europe. The determined number of obtained equations for biomass estimation was 607, and 230 for tree volume estimation. They stated that a relatively small number of equations had been developed for southern Europe, to which Bosnia and Herzegovina belongs.

Until now, measuring the volume of trees directly using conventional tools has been impossible. However, with the advancements made in technologies such as terrestrial laser scanners (TLS) over the past decade, this has changed. TLS has evolved from experimental tools to established instruments in forest mensuration, offering the potential to measure tree volume directly (Calders et al. 2020; Demol et al. 2022; Abegg et al. 2023; An and Froese 2023).

A relatively small number of volume tables have been developed for the territory of Bosnia and Herzegovina. In the previous period, two-entry volume tables for Norway spruce and silver fir have been made, as well as tariff tables and two-entry volume tables for estimating the volume of trees (European beech, sessile oak, common hornbeam and manna ash) in coppice forests. (Drinić et al. 1990). In recent times, tariff tables for estimating the volume of oak and beech in coppice forests in Bosnia and Herzegovina (Koprivica and Maunaga 2004, 2004a), and two-entry volume tables, for estimating the merchantable wood volume of spruce trees in the area of Canton 10 in the Federation of Bosnia and Herzegovina, have been created in the form of functions (Balić et al. 2020).

In Bosnia and Herzegovina, tariff tables are used to estimate wood volumes during the preparation of forest management plans and implementation of annual felling plans (Drinić et al. 1990). Tariff tables that are applied in practice contain tabulated quantities for which parameters of mathematical models of equalization functions are not known because they are mostly obtained by graphical equalization. Furthermore, the measures of reliability of volume estimation are not known. According to Balić et al. (2020) there are indications that the application of the aforementioned tariff tables in forest management practice in Bosnia and Herzegovina results in certain differences in the amount of wood mass of merchantable wood in relation to the actual state of those volumes.

According to the data of the second national forest inventory (2006-2009) in Bosnia and Herzegovina, the total area of forests and forest land is 3,231,000 ha, and the area of sessile oak forests (high and coppice forests) is 356,000 ha (Čabaravdić et al. 2016). In the Republic of Srpska, the area of sessile oak forests is 257,600 ha, or 70% of the total area of these forests in Bosnia and Herzegovina. Of that area, high forests cover only 76,900 ha or 30% (Dukić 2014). For the purpose of estimating the volume of oak trees in high forests, there are tariff tables (Drinić et al. 1990) used, which were created on the basis of two-entry volume tables for oak from the area of Germany authored by Schwappach from 1905 (Schwappach 1905; Grundner and Schwappach 1922), that is, tariff tables were made based on the constructed site index curves for the area of Bosnia and Herzegovina (Vukmirović 1963) and the aforementioned two-entry volume tables for the area of Germany. Tariff tables for other main types of trees (silver fir, Norway spruce, European beech, Scots pine and Austrian pine) were created in the same way. No data or written traces were found that show the applicability of the aforementioned two-entry volume tables in our conditions. The German tables do not differentiate between sessile oak and pedunculate oak, that is, they show the volume for both tree species. According to Špiranec (1975), given that the above tables were created by measurements on felled trees from pure, even-aged stands, it has been noticed long since that the above tables do not correspond to our stands (for the area of Croatia), and the need to create our tree-volume tables is evident. In particular, it is important to emphasize that in Bosnia and Herzegovina the sessile oak dominantly occurs in uneven-aged and mixed stands, in contrast to Croatia and Germany. The management of sessile oak forests in Bosnia and Herzegovina is atypical and is characterized by selection cuttings.

The issue of volume tables that are in use is always a topical one, which must be given special attention, that is, work on checking existing and creating new tables must be a continuous activity. Based on that, according to the methodology introduced by Danilović et al. (2013), the collection of data for the production of volume and assortment tables for sessile oak was started. Volume tables are made by tree species, considering the fact that the ecological conditions and silviculture treatment of the stand affect the shape of the tree for each type of tree tables are made for a smaller or larger part of the area and for silvicultural systems. The goal of this research was to obtain regression models that can be efficiently used to estimate the merchantable wood volume in high forests (pure and mixed) in the territory of Bosnia and Herzegovina, with a permissible deviation. According to Balić et al. (2020), volume values in the tables as such are not suitable for automated computer data processing, so for these reasons, there is a need to find mathematical models for estimating the tree volume.

MATERIAL AND METHODS
MATERIJAL I METODE

The starting material for the creation of the tables was measurement data of model trees in 2020 and 2021 in different sites and stands conditions. The measurement of model trees was carried out by trained teams composed of forestry workers (chainsaw operator) and forestry engineers. On site, after determining the data that spatially determines the selected tree (Forest management area, forest management unit, compartment, etc.) and measuring diameter at breast height, the tree was felled. After felling, the branches were pruned and sectioned, andthen the measurement of the following parameters was made: the height of the stump, the total length of the trunk, the length of the clean trunk, that is, the length to the beginning of the tree crown (base of the live crown), and the length of the trunk to the spot with a diameter of 7 cm. The trunks were measured by being subdivided into sections (section-wise measurements) with a fixed length of 1.0 m along the entire trunk of the tree, by measuring two mutually perpendicular diameters (d_{i1} and d_{i2}) with millimeter precision (over bark). Smalian's formula was used to determine the volume of the trunk (v_{trunk}). The volume of the branches ($v_{large\ branches}$) was determined as the sum of the volumes of individual pieces ($v_{large\ branch}$) whose volume was determined using simple Huber's formula (Banković and Pantić 2006; Pranjić and Lukić 1997). Smalian's formula in this case gives accurate volumes due to the small length of the section. According to Kershaw et al. (2016), Smalian's formula should not be used unless it is possible to measure sections of the tree in short lengths (maximum lengths of about 1 m). For longer lengths, such as 3 or 6 m, Newton's or Huber's formula will give more accurate results. The volume of the top end (v_t), that is the last section shorter than one meter, was determined by

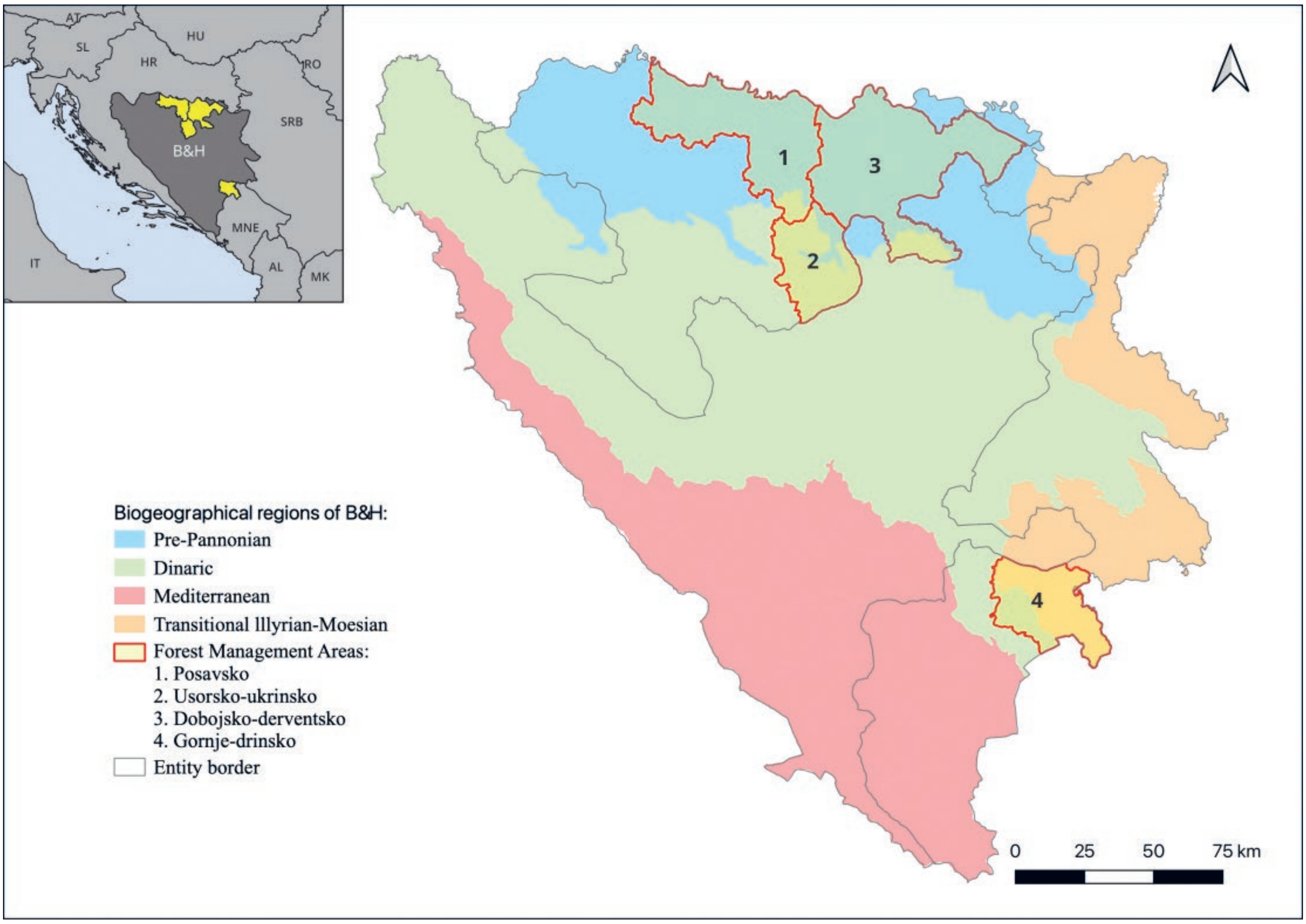

Figure 1. Research area
Slika 1. Područje istraživanja

applying Smalian's formula. The real merchantable wood volume of the tree (v_r) is obtained by summing the volume of the trunk and large branches.

$$v_r = v_{trunk} + v_{large\ branches}$$

$$v_{trunk} = l \cdot \left(\frac{g_0 + g_n}{2} + g_1 + g_2 + ... + g_{n-1} \right) + v_t$$

– Smalian's formula/trunk subdivides into n sections (wood + bark)

$$v_t = \frac{g_n + 0{,}0033}{2} \cdot l_t \quad \text{– Smalian's formula}$$

$$v_{large\ branches} = \sum_{i=1}^{n} v_{large\ branch}\ (wood + bark)$$

$$v_{large\ branch} = g_{1/2} \cdot v_{large\ branch} \quad \text{– Huber's formula}$$

Note: g_0, g_1, g_2… g_n is a cross-sectional area at the lower and upper end (m^2); $g_{1/2}$ is cross-sectional area at the midpoint; 0.0033 is a cross-sectional area for a diameter of 7 cm (m^2); l is a section length (l = 1 m); l_t is the length of top section; v_r is the real merchantable wood volume of tree (m^3); v_{trunk} is the volume of the trunk (m^3); v_t is the volume of top section (m^3) and $v_{large\ branches}$ is the volume of part of the branches (m^3).

Before processing the data, a detailed analysis of the sample was undertaken, checking each tree individually. The trees without visible damage are considered for modeling volume tables. The trees with severely deformed trunks and forked trees are not considered for modeling. In addition to logical control of data, visual control based on the photos of trees and the methods of statistical analysis were also used. After the first stage of sample control, the data was entered into the created database in Excel. Logical control of the entered measurement data was carried out and the necessary corrections were made. In the end, a final sample of 2,413 trees was obtained for the development of regression models.

Model trees for the creation of regression models were felled in the following forest management areas: „Posavsko", „Dobojsko-derventsko", „Usorsko-ukrinsko" and „Gornjedrinsko". In the aforementioned forest management areas, the trees were felled in 19 stands or sub-compartments, which were distributed in 7 forest management units (Figure 1). With a focus on the distribution of oak forests, it is evident that the sample is representative in terms of the spatial distribution of model trees.

When it comes to management classes or types of forests, there are three types of forests in the aforementioned areas (Table 1):

– Forest type A: High sessile oak and European beech forests on deep acidic brown and ilimerised soils on acidic silicate and silicate-carbonate rocks,

– Forest type B: High sessile oak forests on deep soils on peridotite and serpentinite, and

– Forest type C: High sessile oak forests on predominantly deep distric brown soils on limestone and dolomite.

According to the chemical composition of the bedrock and the reaction of the soil, there are both acidophilic and basophilic sessile oak forests in the aforementioned areas. It can be concluded that the sample is not completely representative when the data is compared with the typological classification of forests in Bosnia and Herzegovina (Stefanović et al. 1977), because trees from mixed sessile oak and Scots pine forests are missing.

Table 1 also shows the distribution of the number of model trees by altitude. The distribution of model trees by altitude coincides with the distribution of high forest areas by altitude according to the data of the state forest inventory in the period from 2006 to 2009, according to Dukić (2014).

According to Laar and Akca (2007), the standard volume table uses both diameter at breast height and tree height as table entries. Several studies, however, indicate that the addition of a third predictor variable, such as a height above the ground of the base of the live crown (Nåsslund 1947) or stem diameter at 30% of the tree height (Pollanschütz 1965) or at a height of 7m (Winzeler 1986) reduces the amount of unexplained variation and makes it possible to estimate the tree volume more accurately. A larger number of independent variables ensures greater accuracy of the data in the tables, but also complicates their practical application. A large number of models have been tested that has a wide application for equalizing the merchantable tree wood volume as a dependent variable in terms of a diameter at breast height and height of the tree as independent variables [1-6]. In addition to the two-entry models, three three-entry models were tested, namely the model [7] for equalization of the merchantable oak wood volume depending on diameter at breast height, tree height, and diameter at seven meters high used in Switzerland, and two models [8-9] for equalization of the merchantable wood volume of trees depending on diameter at breast height, the height of the tree, and a height above ground at the base of the live crown

Table 1. Distributions of the number of model trees by type of forest and by altitude

Tablica 1. Distribucija broja modelnih stabala po tipovima šuma i po nadmorskoj visini

Number of model trees/*Broj modelnih stabala*			
Type of forest/*Tip šume*			
A	B	C	Total/*Ukupno*
1218	329	866	2.413
Altitude/*Nadmorska visina* (m)			
do 300	od 300 do 600	preko 600	Total/*Ukupno*
962	585	866	2.413

Table 2. Regression models for merchantable wood volume estimation.
Tablica 2. Regresijski modeli za procjenu volumena krupnog drveta

No *Br.*	Model name *Naziv modela*	Mathematical form of the model *Matematički oblik modela*	No. of coefficient *Br. koeficijenata*
Two predictor variables/*Dvije prediktorske varijable*			
[1]	Schumacher-Hall	$v = a_0 + d_{1.3}^{a_1} h^{a_2}$	3
[2]	Meyer	$v = a_0 + a_1 d_{1.3} + a_2 d_{1.3} h + a_3 d_{1.3}^2 + a_4 d_{1.3}^2 h$	4
[3]	Spurr I	$v = a_0 + a_1 d_{1.3}^2 h$	2
[4]	Spurr II	$v = a_0 (d_{1.3}^2 h)^{a_1}$	2
[5]	Takata	$v = (d_{1.3}^2 h) / (a_0 + a_1 d_{1.3})$	2
[6]	Newham	$v = a_0 + a_1 d_{1.3}^{a_2} h^{a_3}$	2
Three predictor variables/*Tri prediktorske varijable*			
[7]	Swiss NFI	$v = a_0 + a_1 d_7^2 h + a_2 d_{1.3}^2 + a_3 d_{1.3}^3 + a_4 d_{1.3}^3 h$	5
[8]	Eriksson	$v = a_0 d_{1.3}^2 + a_1 d_{1.3}^2 h + a_2 d_{1.3} ch + a_3 d_{1.3} h + a_4 h + a_5 d_{1.3}^3$	6
[9]	Johansson	$v = a_0 + d_{1.3}^{a_1} + h^{a_2} + ch^{a_3}$	4

Note: $d_{1.3}$ is diameter at breast height/*promjer na prsnoj visini* (cm); d_7 is diameter at 7 meter height/*promjer na 7 metara visine* (cm); h is height/*visina* (m); ch is height above ground at the base of the live crown/*visina iznad tla do baze krošnje* (m); a_0, a_1, a_2, a_3, a_4, a_5 are parameters to be estimated in this study/*parametri koji se procjenjuju u ovoj studiji*.

(Schumacher and Hall 1933; Meyer 1941; Newnham 1967; Spurr 1952; Laar and Akça 2007; Pranjić and Lukić 1997; Takata 1958; Emrović 1960; Banković and Pantić 2006; Kaufmann 2001; Eriksson 1973; Johansson 2005). The tested models are shown in Table 2.

To compare and analyze the usability of regression models, the criteria (Draper and Smith 1997; Wackerly et al. 2008; Chicco et al. 2021; Burnham and Anderson 2002; Symonds and Moussalli 2011) shown in table 3 were used. In addition to the criteria listed in table 3, the significance of the differences were tested using the paired sample *t*-test (the dependent sample *t*-test) between the real and estimated merchantable wood volumes of the trees, by diameter classees and in total. The percentages of deviations estimated from the real volumes by diameter classes and in total were determined as an important indicator of the applicability of the model, according to the formula (Bruce 1920, according to Pranjić and Lukić 1997):

$$p\% = \frac{v_f - v_r}{v_f} \times 100$$

v_f - tree volume estimated by function
v_r - real tree volume

RESULTS AND DISCUSSION
REZULTATI I RASPRAVA

The diameter at breast height ($d_{1.3}$) ranged from 10.15 to 79.60 cm and height (h) from 8.38 to 38.65 m. Based on the distribution of trees, according to diameter classes (5-centimeter-wide diameter classes), it can be stated that there is a relatively small number of trees that are thicker than 70 cm. In other diameter classes, the number of trees is greater than 100, that is, in the interval from 111 to 316, with an average of 200 trees. According to Banković and Pantić (2006), based on some research (Germany, Czech Republic, Slovakia, Romania, Russia...), it was concluded that the optimal number of measured trees in each diameter class should not be less than 100 and more than 350. This is completely fulfilled, except in the highest diameter classes (> 70 cm). Based on the forest inventory data on large areas in Bosnia and Herzegovina (2006 - 2009), it is evident that there is a relatively small number of sessile oak trees with a thickness of 70 cm to 80 cm in high forests, which is expected, considering the way of management. The real volume of trees is in the interval from 0.04 to 8.99 m³. The variation of tree volume as a dependent variable is significantly greater than the variation of diameter at breast height, diameter at 7 meters height, crown height above ground, and tree

Table 3. Criteria for regression models comparison.
Tablica 3. Kriteriji vrednovanja različitih regresijskih modela

No *Br.*	Criterion *Kriterij*	Formula *Jednadžba*	Optimum value *Optimalna vrijednost*
1.	Absolute mean error *Srednja apsolutna greška* (MAE)	$\sum_{i=1}^{n}\frac{\lvert v_i-\check{v}_i\rvert}{n}$	0
2.	Root mean squared error *Korijen prosječne kvadratne pogreške* (RMSE)	$\sqrt{\frac{\sum_{i=1}^{n}\left(v_i-\check{v}_i\right)^2}{n-p}}$	The smallest value
3.	Coefficient of determination *Koeficijent determinacije* (R^2)	$1-\frac{\sum_{i=1}^{n}\left(v_i-\check{v}_i\right)^2}{\sum_{i=1}^{n}\left(v_i-\bar{v}\right)^2}$	1
4.	Akaike Information Criterion *Akaike informacijski kriterij* (AIC)	$AIC=n\times\ln\left(\frac{\sum_{i=1}^{n}\left(v_i-\check{v}_i\right)^2}{n}\right)+2p$	The smallest value
5.	AIC differences *AIC razlike* (Δ_i)	$\Delta_i=AIC_i-AIC_{\min}$	0

Note:
v : observed values of volume/izmjereni volumen
$\hat{v}_i$: estimated values of volume from the regression model/volumen procijenjen regresijskim modelom
n : number of observations/broj mjerenja
p : number of regression coefficients/broj regresijskih koeficijenata
$\bar{v}$: average of estimated volumes/srednji procijenjeni volumen

height as independent variables. The smallest variation is the form factor (f), which in this case was obtained as the ratio of the calculated volume of the merchantable wood of the trees in the previously described manner and the volume of the cylinder based on the breast diameter and height of the tree. The variation in the volume of trees belonging to the same diameter and height classes is the largest when it comes to the thinnest trees, that is, trees thinner than 25 cm, and the smallest when it comes to the trees thicker than 45 cm and higher than 22 m (Table 4 and Figure 2).

The estimated coefficients of functions (a_0–a_5) are shown in table 5. All regression coefficients of all functions differ from zero at the 95% level (t - statistic). The function co-

Table 4. Descriptive statistics of the sampled trees.
Tablica 4. Opisna statistika uzorkovanih stabala

Variable *Varijabla*	Mean *Prosjek*	Std.Dev.	Coef.Var.	Min.	Max.	Confidence interval *Interval pouzdanosti* –95%	 +95%
$d_{1.3}$ (cm)	37.10	15.53	41.85	10.15	79.60	36.48	37.72
d_7 (cm)	30.07	13.94	46.35	1.85	68.50	29.51	30.62
h (m)	22.53	6.32	28.06	8.38	38.65	22.28	22.78
ch (m)	9.57	3.83	40.03	1.50	22.20	9.41	9.72
v_r (m^3)	1.74	1.71	97.92	0.04	8.99	1.68	1.81
f	0.522	0.067	12.79	0.285	0.792	0.519	0.524

Note: *f* is form factor/*oblični broj*

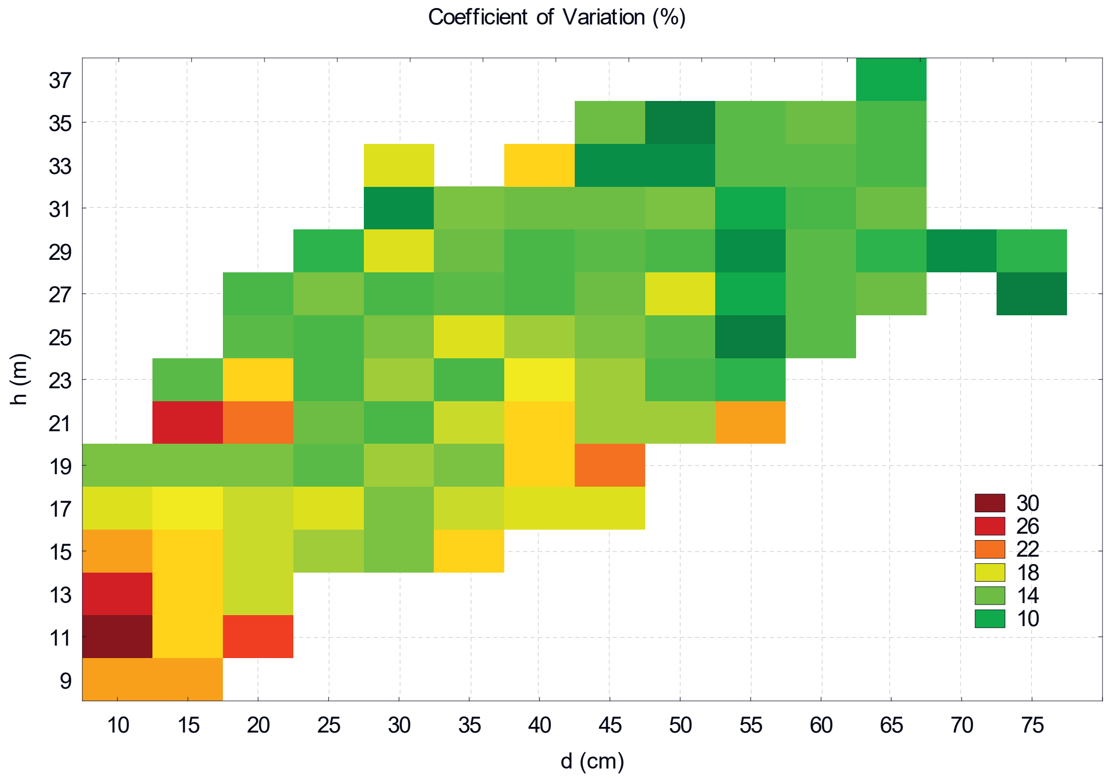

Figure 2. Coefficients of variation of merchantable wood volume of trees according to diameter and height classes
Slika 2. Koeficijenti varijacije volumena krupnog drveta stabala prema debljinskim i visinskim klasama

efficients were estimated using nonlinear regression (Gauss-Newton method) in the Statistica software package.

The comparison of regression models based on the criteria shown in Table 6 indicates approximately the same estimation accuracy, that is, the usability of the tested regression models with two and three independent variables, except for the Swiss NFI model (with $d_{1.3}$, h, and d_7 as independent variables). Due to approximately same values of the presented criteria for comparing the tested regression models, except for the mentioned Swiss NFI model, the ranking of the models was not performed. Based on the observed criteria, the Swiss NFI model enables greater accuracy in estimating the volume of the tree, but at the same time implies a greater scope of field work when collecting the necessary data. In addition to measuring diameter at breast height and tree height, it is necessary to measure the diameter at the height of seven meters with special instruments (Finnish parabolic caliper, Bitterlich's mirror relascope, Bitterlich's telerelascope, Wheeler's pentaprism, etc). Regarding the accuracy of the obtained model with the diameter at 7 meters high as the third variable, the fact that in this research the specified diameter was measured with a standard diameter on a felled tree must be taken into account. It is to be expected that the same accuracy of the survey cannot be

Table 5. Coefficients of the regression models
Tablica 5. Koeficijenti regresijskih modela

Coefficients *Koeficijenti*	Regression models / *Regresijski modeli*								
	Schumacher-Hall	Meyer	Spurr I	Spurr II	Takata	Newham	Swiss NFI	Eriksson	Johansson
	Two predictor variables *Dvije prediktorske varijable*						Three predictor variables *Tri prediktorske varijable*		
a_0	0.00003669	0.08261267	-0.02414723	0.000032798	26004.03598175	0.010142005	0.0001089105	-0.00000183	0.000037453
a_1	2.09995631	-0.00433865	0.00004176	1.020427984	-32.19153832	0.000035196	0.0000418131	0.00004019	2.112073253
a_2	0.91632624	-0.00016771				2.103979308	0.0002269454	0.00008886	0.879647098
a_3		0.00013176				0.921910804	0.0000011166	-0.00020103	0.023212295
a_4		0.00004163					0.0000000309	0.00262124	
a_5								0.00000173	

Table 6. Regression models comparison - Criteria for regression models comparison
Tablica 6. Usporedba regresijskih modela - Kriteriji za usporedbu regresijskih modela

Regression models *Regresijski modeli*	Criterion / *Kriterij*				
	Absolute mean error *Srednja apsolutna greška* (MAE)	Root mean squared error – *Korijen prosječne kvadratne pogreške* (RMSE)	Coefficient of determination *Koeficijent determinacije* (R^2)	Akaike Information Criterion *Akaike informacijski kriterij* (AIC)	AIC differences *AIC razlike* (Δi)
Schumacher-Hall	0.1628	0.2776	0.9736	-6165	1764
Meyer	0.1642	0.2780	0.9736	-6158	1771
Spurr I	0.1667	0.2802	0.9731	-6120	1809
Spurr II	0.1647	0.2796	0.9732	-6131	1798
Takata	0.1638	0.2787	0.9734	-6148	1781
Newham	0.1627	0.2776	0.9736	-6166	1763
Swiss NFI	0.1081	0.1932	0.9872	-7929	0
Eriksson	0.1640	0.2786	0.9866	-6162	1767
Johansson	0.1636	0.2779	0.9867	-6175	1754

achieved with the aforementioned instruments on the living trees. According to Kaufmann (2001), the function with a diameter at 7 meters height gives more accurate estimates of volume than the function with a diameter at breast height and tree height, even when the diameter at 7 meters is measured with a larger random error than diameter at breast height.

According to Johansson (2005), to estimate the volume of grey alder (*Alnus incana* (L.) Moench.) and common alder (*Alnus glutinosa* (L.) Gaertn.) in Sweden, functions including diameter and height and functions including diameter, height and height of the crown base were tested. The analysis showed that no model including the height of the crown base improved the estimation of grey alder tree volume, while the estimation accuracy increased for common alder. The result with grey alder is explained by the fact that the stands were not thinned, which resulted in a reduction in the crown length. As already mentioned, in the territory of Bosnia and Herzegovina, the oak forests do not have adequate management adapted to the ecological requirements and biological properties of this type of tree, which is reflected in the form of the crown, that is, the dependence of the volume of the tree on the height of the tree crown base. As a consequence, the introduction of the crown base

Table 7. Regression models comparison - deviations estimated from the real volumes of trees by diameter classes
Tablica 7. Usporedba regresijskih modela - odstupanja procijenjenih od stvarnih volumena stabala po debljinskim stupnjevima

Diameter *Promjer* (cm)	n	Regression models / *Regresijski modeli*								
		Schumacher-Hall	Meyer	Spurr I	Spurr II	Takata	Newham	Swiss NFI	Eriksson	Johansson
		Two predictor variables *Dvije prediktorske varijable*							Three predictor variables *Tri prediktorske varijable*	
		P% – Percent deviation / *Postotak odstupanja* (%)								
12.5	198	-0.62	20.16	-20.77	0.28	1.85	13.71	-1.34	15.31	-0.35
17.5	194	-6.92	0.00	-13.11	-6.92	-6.11	-0.34	-3.20	-0.51	-6.71
22.5	214	-8.28	-6.94	-8.70	-7.70	-7.64	-5.61	-1.57	-5.38	-8.14
27.5	232	-4.47	-4.60	-3.09	-3.75	-4.12	-3.54	0.46	-3.26	-4.28
32.5	302	-1.42	-1.70	0.28	-0.80	-1.37	-1.19	0.60	-1.18	-1.37
37.5	316	1.80	1.61	3.12	2.02	1.44	1.75	0.77	1.60	1.80
42.5	240	1.42	1.37	2.66	1.72	1.12	1.23	-0.32	1.15	1.38
47.5	182	1.91	1.95	2.63	1.91	1.44	1.71	0.77	1.63	1.90
52.5	146	-1.72	-1.64	-1.26	-1.69	-2.05	-1.88	-0.72	-1.91	-1.68
57.5	141	-1.42	-1.35	-1.52	-1.66	-1.78	-1.52	-0.90	-1.56	-1.46
62.5	120	0.92	0.95	0.59	0.79	0.89	0.91	-0.08	0.91	0.93
67.5	111	0.35	0.31	-0.38	0.12	0.51	0.44	0.89	0.44	0.34
72.5	8	-1.82	-2.18	-3.86	-3.22	-2.27	-1.67	-1.13	-1.63	-1.90
77.5	9	-1.05	-1.54	-3.69	-2.89	-1.61	-0.84	-1.95	-0.61	-1.04
Total	2413	-0.17	0.00	0.00	-0.17	-0.32	0.00	0,00	-0.02	-0.17

height as a third variable does not increase the accuracy of the tree volume estimation.

For the usability analysis and comparison of regression models, in addition to the standard criteria shown in Table 5, the deviations estimated from the real volumes of trees by diameter classes were calculated (Table 7) and the significance of the differences was tested using a t-test of pairs between the real and estimated volumes of merchantable trees, also by diameter classes (Table 8). Based on the obtained results, with the applied regression models, larger deviations and statistically significant differences of real and estimated values are observed for thinner trees, which can be explained by the determined coefficients of volume variation by diameter and height classes shown in Figure 2.

As is the case with the previously analyzed criteria, the Swiss NFI model with three variables stands out. According to Kaufmann (2001), the volumes of individual trees can be more precisely estimated with the aforementioned three variables ($d_{1.3}$, h and d_7), because the differences in the shape of the tree can be easier distinguished with the measurement of the upper diameter. Statistically significant deviations occur only in the trees thinner than 25 cm. Concerning the specified model, the maximum deviation of the estimated values from the real ones is in the diameter degree of 17.5 cm, which makes 3.20%. In most diameter classes, the deviation is less than 1%. It is to be expected that the influence of the diameter at 7 m height on the accuracy of determining the volume of the tree is less pronounced

Table 8. Regression models comparison – Results of testing the significance of differences by t-test of pairs between real and estimated merchantable wood volumes by diameter classes

Tablica 8. *Usporedba regresijskih modela – Rezultati testiranja značajnosti razlika pomoću t-testa parova između stvarnih i procjenjenih volumena krupnog drveta po debljinskim klasama*

$d_{1.3}$ (cm)	n	t- test	Regression models / *Regresijski modeli*								
			Schumacher-Hall	Meyer	Spurr I	Spurr II	Takata	Newham	Swiss NFI	Eriksson	Johansson
			Two predictor variables *Dvije prediktorske varijable*						Three predictor variables *Tri prediktorske varijable*		
12.5	198	t	0.664	-26.969	18.720	0,300	2,036	-9.408	2.347	-18.618	0.370
		p	0.507	0.000	0.000	0,764	0,043	0.000	0.020	0.000	0.712
17.5	194	t	7.693	-0.918	14.097	-7,839	-6,983	3.490	5.361	0.603	7.526
		p	0.000	0.360	0.000	0,000	0,000	0.001	0.000	0.547	0.000
22.5	214	t	9.756	8.077	9.628	-8,683	-8,716	8.019	2.753	6.200	9.498
		p	0.000	0.000	0.000	0,000	0,000	0.000	0.006	0.000	0.000
27.5	232	t	5.964	6.118	3.988	-4,817	-5,338	5.285	-0.945	4.339	5.736
		p	0.000	0.000	0.000	0,000	0,000	0.000	0.346	0.000	0.000
32.5	302	t	2.155	2.612	-0.384	-1,173	-2,024	2.058	-1.430	1.758	2.068
		p	0.032	0.009	0.702	0,242	0,044	0.040	0.154	0.080	0.039
37.5	316	t	-2.547	-2.209	-4.394	2,830	2,021	-2.324	-1.555	-2.256	-2.540
		p	0.011	0.028	0.000	0,005	0,044	0.021	0.121	0.025	0.012
42.5	240	t	-1.593	-1.539	-3.008	1,932	1,248	-1.257	0.510	-1.282	-1.548
		p	0.113	0.125	0.003	0,055	0,213	0.210	0.611	0.201	0.123
47.5	182	t	-2.042	-2.054	-2.843	2,057	1,538	-1.653	-1.288	-1.737	-2.019
		p	0.043	0.041	0.005	0,041	0,126	0.100	0.199	0.084	0.045
52.5	146	t	1.569	1.511	1.159	-1,544	-1,866	1.928	1.008	1.735	1.526
		p	0.119	0.133	0.249	0,125	0,064	0.056	0.315	0.085	0.129
57.5	141	t	1.629	1.550	1.726	-1,882	-2,019	2.093	1.429	1.791	1.691
		p	0.106	0.123	0.086	0,062	0,045	0.038	0.155	0.075	0.093
62.5	120	t	-0.809	-0.842	-0.531	0,704	0,791	-0.462	0.105	-0.805	-0.823
		p	0.420	0.402	0.597	0,483	0,430	0.645	0.917	0.423	0.412
67.5	111	t	-0.349	-0.314	0.370	0,118	0,505	0.032	-1.268	-0.444	-0.349
		p	0.728	0.754	0.712	0,907	0,614	0.975	0.207	0.658	0.728
72.5	8	t	0.616	0.721	1.245	-1,031	-0,737	0.753	0.440	0.547	0.631
		p	0.557	0.494	0.253	0,337	0,485	0.476	0.673	0.601	0.548
77.5	9	t	0.346	0.495	1.241	-0,998	-0,559	0.481	0.771	0.202	0.341
		p	0.738	0.634	0.250	0,347	0,591	0.644	0.463	0.845	0.742
Total	2413	t	0.533	0.397	0.001	-0,514	-0,977	1.090	0.002	0.068	0.510
		p	0.594	0.691	0.999	0,607	0,329	0.276	0.998	0.946	0.610

in the case of thinner and, subsequently, shorter trees. Regarding the models with two variables, the Spurr II model is the most favorable. In four diameter classes, the deviation is greater than 3% (Max=-7.70%), that is, the deviations are not random ($p < 0.05$) in five diameter classes. The results are similar for the Schumacher-Hall model, in three diameter classes the deviation is greater than 3% (Max=-8.28%), that is, the deviations are not random ($p < 0.05$) in six diameter classes.

A study on the volume functions of spruce trees in Switzerland showed that, by creating regional volume functions with two variables ($d_{1.3}$ and h), the gain in precision is negligible, so the regional functions were not derived, but the aforementioned general functions with three inputs (Kaufmann 2001). It is to be expected that even in the conditions of Bosnia and Herzegovina, given the large variations in habitat and stand conditions even in small areas, the creation of regional volume functions with two variables ($d_{1.3}$ and h) would not result in great accuracy.

CONCLUSION
ZAKLJUČAK

The development of regression equations (volume tables) for the estimation of the volume of sessile oak trees in the territory of Bosnia and Herzegovina, which is characterized by the specific habitat conditions and the method of management of the sessile oak forests, is necessary because in practice, for the estimation of the volume, tariff tables are used, which are made on the basis of two-entry volume tables for oak from Germany by Schwappach from 1905. A particularly significant fact for the estimation of the volume of trees in the observed area is the atypical way of managing the sessile oak forests. Selection cutting is applied and, as a consequence, uneven-aged and dominantly mixed stands are formed. The tested models with two variables that have a wide application for equalizing the volume of merchantable wood of a tree depending on the diameter at breast height and height of the tree, such as Spurr II (MAE = 0.1647, RMSE = 0.2796 and $R^2 = 0.9732$) and Schumacher-Hall (MAE = 0.1628, RMSE = 0.2776 and $R^2 = 0.9736$) functions, give satisfactory accuracy, considering the fact that these are general models intended for estimating the volume of trees in the entire area of Bosnia and Herzegovina. By introducing a third variable into the model, diameter at seven meters height, the accuracy of the tree volume estimation increases significantly (MAE = 0.1081, RMSE = 0.1932 and $R^2 = 0.9872$). Due to the measurement of the diameter at a height of seven meters, the volume of work in the field to collect the necessary data increases significantly, so this model is not suitable for use in forest inventories.

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Conflict of interest – *Sukob interesa*

The authors declare that they have no competing interests

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SAŽETAK

U Bosni i Hercegovini za procjenu volumena stabala hrasta u visokim šumama koriste se uređajne tarife, koje su izrađenene na temelju dvoulaznih volumnih tablica za hrast s područja Njemačke autora Schwappach iz 1905. godine. Postoje indicije da se primjenom navedenih tarifa u uređajnoj praksi dobivaju određene razlike u količini procijenjenog volumena krupnog drva u odnosu na stvarno stanje. Materijal za izradu volumnih tablica odnosno modela regresije predstavljali su podaci izmjere i izračuna stvarnog volumena drva 2.413 modelnih stabala u različitim stanišnim i sastojinskim uvjetima. Na osnovi raspodjele stabala po debljinskim stupnjevima možemo zaključiti da je relativno mali broj stabala koja su deblja od 70 cm, u ostalim debljinskim stupnjevima broj stabla veći je od 100, odnosno u intervalu od 111 do 316. Testirani su modeli koji imaju široku primjenu za izjednačenje volumena krupnog drva stabla kao zavisne varijable u ovisnosti o prsnom promjeru i visini stabla kao nezavisnim varijablama. Za usporedbu i analizu upotrebljivosti modela regresije korišten je veći broj kriterija (Srednja apsolutna greška, Korijen prosječne kvadratne pogreške, Koeficijent determinacije i Akaike informacijski kriterij). Uz navede kriterije, testirane su značajnosti razlika pomoću t-testa parova uzoraka između stvarnih i procijenjenih volumena krupnog drveta stabala te utvrđeni postoci odstupanja procijenjenih od stvarnih volumena, po debljinskim stupnjevima i ukupno. Modeli kao što su Schumacher-Hall i Spurr II daju zadovoljavajuću točnost, s obziron na to da su u pitanju općeniti modeli namijenjeni za procjenu volumena stabala na području cijele Bosne i Hercegovine. Uvođenjem u model i treće varijable, promjer debla na sedam metara visine, povećava se značajno točnost procjene volumena stabala. Zbog izmjere promjera na sedam metara visine povećava se značajno i količina rada na terenu na prikupljanju potrebnih podataka, pa ovaj model nije pogodan za primjenu u operativnim inventurama šuma. Uvođenjem visine baze krošnje stabla kao treće varijable, nije se povećala točnost procjene volumena stabla u odnosu na analizirane dvoulazne modele.

KLJUČNE RIJEČI: hrast kitnjak, Smalianova formula, volumen krupnog drva, regresijski model, nelinearna regresija