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REGRESSION MODEL FOR ASSESSMENT OF VOLUME OF MERCHANTABLE WOOD OF EVEN-AGED NOT-TENDED FOREST PLANTATIONS OF SCOTS PINE ON CARBONATE SUBSTRATES IN B&H

Regresioni model za procjenu zapremine krupnog drveta jednodobnih nenjegovanih šumskih zasada bijelog bora na karbonatnim supstratima u BiH

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Abstract

As the result of sporadic afforestation of not-grown forest land in the past, today in B&H we have significant areas of even-aged forest plants of Scots pine of different ages. Estimate of yield capabilities of habitats/sites of these stands is one of very real issues in even-aged management planning for this tree species. In order to get the clear idea on the value of yield of even-aged stands, it is necessary to conduct long-term researches on permanent experimental plots. Considering that for the results of those researches it is necessary to wait approximately for the duration of production periods for specific tree species, to gain orientation solutions of the problem we can apply short-term researches – using temporary experimental plots set in stands of different ages. Members of the Forest Management Department of Forestry Faculty in Sarajevo in a period from 1985 to 1990 gathered data on temporary experimental plots in existing even-aged forest plantations of spruce, Scots pine and black pine in order to research their growth, structural and production characteristics. Part of those data for Scots pine is used for making of this document. Objective of this research was, based on data on measurement of 77 experimental plots positioned in even-aged not-tended plantations of Scots pine Bosnia-wide, to reach relevant information on the value of wood volume depending on their age and site quality, and to create the most favourable regression model for assessment of volume of large wood value based on known values of the stand taxation elements that could be easily and quickly determined. Besides this, in this document by comparing gained results with appropriate data from other authors we have evaluated productivity of even-aged not-tended forest plantations of Scots pine in B&H.

Key words**:** *even-aged forest plantations of Scots pine, volume of large wood of the stand, yield, multiple regression analysis, net correlation.*

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INTRODUCTION – *Uvod*

Parts of not-grown forest land in B&H in the past were afforested with seedlings of spruce, Scots and black pine, so today we have significant areas of even-aged forest plantations of these tree species of different ages. It is assumed that their total area in 1985 was approximately 150,000 hectares. (PAVLIČ, 1999). Plantations of Scots pine within even-aged stands cover significant areas with tendency of further increase in size. This was foreseen by long-term forestry development program in B&H for period 1986-2000 (IZETBEGOVIĆ, 1986) which, due to past war, was not completely implemented. For those reasons, as necessity we have the need to research these stands in terms of determining the values of individual taxation elements, as first, the value of wood volume per hectare. In other words, in general we have a problem of managing even-aged stands because forest management companies on whose territory those even-aged stands are located do not have available basic findings and data about when to start with thinning, what type and intensity of thinning to use, how long production period should be and what yield could be produced, etc. We can get reliable answer to these questions through long-term researches on permanent experimental plots. Considering that for the results of those researches it is necessary to wait approximately for the duration of production periods for specific tree species, to gain orientation solutions of the problem we can apply short-term researches – using temporary experimental plots set in stands of different habitat conditions and different ages. Such researches were started by Forestry Faculty in Sarajevo in 1985, more precisely Forest Management Department (PAVLIČ, 1999). Gathered data served as basic scientific background for making of this document.

MATERIAL AND METHODS – *Materijal i metode*

Selection of stands in which temporary experimental plots are positioned and gathering of necessary data was done using previously developed methodology (PAVLIČ, 1999). In a period from 1986-1990, basic and taxation data on 88 temporary experimental plots in plantations of Scots pine all over Bosnia in the age interval from 10 to 138 years of age were collected. However, since stands in age interval from 55 to 100 years of age were not included in the sample, all considerations and analysis were conducted for 77 experimental plots positioned in plantations from 10 to 54 years of age. Additional to this, we have uncertainty in projection of received average values of taxation elements for stands older than 55 years.

Basic material was gathered on temporary experimental plots of circular shape whose area depended on the age of the stand. Areas and diameters of experimental plots for stands of different age are presented in Table 1.

Table 1. Areas and diameters of experimental plots depending on the age of the stand
Tabela 1. Površine i radijusi oglednih ploha u zavisnosti od starosti sastojine

Age of the stand (year)	Diameter of experimental plot (m)	Area of experimental plot (ha)	Age of the stand (year)	Diameter of experimental plot (m)	Area of experimental plot (ha)
10 – 15	4,0	0,0050	66 – 75	12,5	0,0491
16 - 25	5,0	0,0079	76 – 85	14,5	0,0661
26 – 35	6,5	0,0133	86 – 95	16,5	0,0855
36 – 45	7,5	0,0177	96 – 105	18,0	0,1018
46 – 55	9,5	0,0284	106 – 115	19,5	0,1195
56 – 65	10,5	0,0346	116 i više	21,0	0,1385

On selected temporary experimental plots, we gathered more various data which were recorded in manuals prepared in advance. Data were inserted separately for each experimental plot for which we later also determined the values of taxation elements of the stand.

Method of taxation element calculation for trees and stands - *Metode obračuna taksacionih elemenata stabala i sastojina*

On basis of taxation elements that were measured (and determined) in the field directly by method of simple and multiple correlation and regression, we have determined the most probable values of volume of large wood of trees and stands. For interconnections analysis and dependence between individual taxation elements we used method of multiple regression, while method of net-correlation was used to determine and analyse "pure" relations between the value of larger timber volume of the stand and each individual taxation element taken for the analysis. Overall calculation and statistical procedure of data processing, graphical interpretation of results and individual table overviews were done using statistical software „*Statistica 8.0*" and statistical „package" in „*Microsoft Excel*".

Determination of the volume of trees and stands per hectare - *Određivanje zapremine stabala i sastojina po hektaru*

Before creating model for assessment of the stand volume we have determined the value of volume of large wood for each experimental plot. In the process volume of large wood (7 cm and more) of each tree on experimental plot was taken from two-entry volume tables of BEZAK, (1992). These tables were selected because of most probably "the smallest" difference in climate, edaphic and other conditions between habitats/sites of even-aged stands of Scots pine (between Croatia and Bosnia), as well as because of possibility to accurately calculate tree volume per determined function for assessment based on diameter at breast height (DBH) and height. Actually, based on parameters of Schumacher-Hall function (KRAMER & AKÇA, 1995, CALDERON, 1989) that was used

for assessment of tree volume in development of mentioned tables, we can calculate the value of tree volume for each combination of data pairs (DBH and tree height). Equation of the model used to calculate volume of large wood is:

$$V_7 = 0,0000383293 d_{1,3}^{2,087561} h^{0,875764} 1,004013 \quad (1)$$

where:

V_7 - volume of large wood of trees (above 7 cm),

$d_{1,3}$ - diameter at breast height (DBH),

h – tree height,

a,b,c – parameters of the function.

Stand volume per ha was determined as product (multiplication) of volume of all trees on the plot and reduction factor (reciprocal value of plot area F ha):

$$V_{7(\frac{m^3}{ha})} = V_{7(\frac{m^3}{plot})} \frac{1}{F_{(ha)}} \quad (2)$$

RESULTS AND DISCUSSION - *Rezultati i diskusija*

After calculating typical values of taxation elements for each experimental plot, we have created regression model for assessment of volume of large wood value of even-aged stands (dependent variable) and for analysis of "net" impact of individual independent variables.

Model of the function of multiple regression for assessment of volume of large wood value of even-aged stands and impact analysis of individual independent variables - *Model funkcije višestruke regresije za procjenu veličine zapremine krupnog drveta jednodobnih sastojina i analizu uticaja pojedinih nezavisnih varijabli*

After testing multiple models, while sticking to criteria that there is no correlation connection between independently changeable values or that it is expressed in as smaller measure as possible (KOPRIVICA, 1997; STOJANOVIĆ, 1966), we have chosen (determine) the regression model in which as independent variables the following taxation elements of the stand were selected:

α - age of the stand,

β - site quality class[1],

δ - degree of land coverage by forest stand canopy.

[1] Issue of assessing quality of even-aged not-tended forest plantations og Scots pine in B&H is described in published document of Balić, B. (2003): „Bonitiranje jednodobnih zasada bijelog bora (*Pinus sylvestris* L.) na karbonatnim supstratima u Bosni" („Assessing quality of even-aged plantations of Scots pine (*Pinus sylvestris* L.) on carbonate substrates in Bosnia". I Simposium of agriculture, veterinary and forestry. Neum. Collection of papers of Forestry Faculty in Sarajevo. page 67-79.

Function of selected regression model is:

$$V_k = a + b\left(1 - exp^{(-c\alpha)}\right)^d + e\beta + f\delta + g\delta^2 + h\beta\delta \quad (3)$$

In determined regression model the impact of age on volume of large wood value is expressed using Chapman-Richard function (KRAMER & AKÇA, 2003; CALDERON, 1989), impact of site quality is expressed in linear manner, while impact of degree of land coverage by forest stand canopy is expressed by second-order polynomial form. Besides four elements of determined model, which summarises the impact of independent variables, the model has one more element in which impacts of site quality and degree of land coverage by forest stand canopy are mutually multiplied. Based on assessed values of statistic parameters of multiple regression equation presented in Table 3 one can get an insight in what amount the changes in values of volume of large wood of the stand could be attributed to overall action of all factors covered by the regression model. Average values of variables taken into regression model are presented in the following table.

Table 2. Basic statistical parameters of independent variables in regression model
Tabela 2. Osnovni statistički parametri nezavisnih varijabli u regresionom modelu

Variables	Average	Standard deviation	Minimum	Maximum
Age (year)	24,65	9,18	10	54
Site quality class	3,00	1,10	1	5
Degree of land coverage by forest stand canopy	0,87	0,08	0,58	1,00
Volume of large wood (m^3/ha)	196,78	114,25	7,88	512,61

Assessed values of parameters with basic statistical indicators of determined regression model are presented in Table 3.

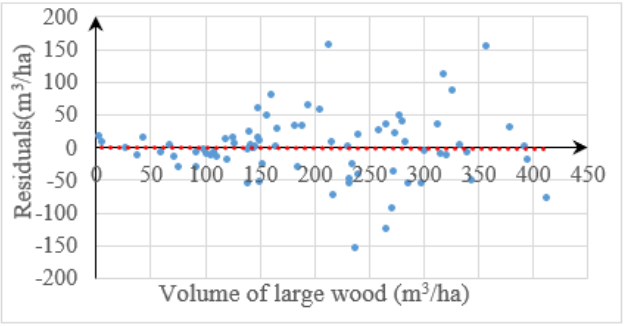
Table 3. Basic statistical indicators of regression function
Tabela 3. Osnovni statistički pokazatelji funkcije regresije

Label parameter	*Estimated value*	Multiple correlation coefficient	Determination coefficient	Standard error of assessment
a	*40,6657*	$R = 0,90$	$R^2 = 0,81$	$S_{ey} = 52,33 m^3 / ha$
b	*541,857*			
c	*0,05311*			
d	*2,70291*			
e	*7,59204*			
f	*-241,833*			
g	*271,915*			
h	*-33,4267*			

According to determined value of determination coefficient (R^2), relative statistical indicator of assessment precision, chosen independent variables and chosen regression model explain 81% of varying in the value of volume of large wood of Scots pine stand, while the rest is attributed to other not covered impact factors.

Pretty large value of standard error of assessment (Sey) in amount of 52.33 m^3/ha, (absolute statistical measure of assessment precision) is the result of large variation of volume of large wood of individual experimental plots/areas (from 7.88-512.61 m^3/ha).

Quality of the regression model was checked also with analysis of residuals (deviation of assessed compared to empirical data). Based on diagram of dispersion of residuals we can conclude on the character of residual distribution, i.e. whether they are systematically (or non-systematically) distributed around assessment line, which indicates the potential systematic error of regression model (EKINOVIĆ, 1997). Diagram of dispersion of residuals of selected model is represented in Graph 1.



Graph 1. - Diagram of dispersion of residuals around regression model

Grafikon 1. - Dijagram rasturanja reziduala oko regresionog modela

On presented diagram of dispersion of residuals (Graph 1) we can notice their approximately symmetric distribution around regression, i.e. absence of systematic distribution, and can conclude that the selected model is adequate to present analysed dependences.

Based on assessed parameters of regression model (3) and average values of independent variables, we have analysed individual (net) impacts of independent variables on the value of volume of large wood as dependable variable, in order to gain insight into character and intensity of the connection between dependable variable and individual included independent variables (VUKMIROVIĆ et al., 1966). In the process, in regression model (3) we include different values (in the variation interval) of independent variable whose impact is examined, and to others we assign average values (KOPRIVICA, 1997).

Net correlation between the volume of large wood and the age of even-aged Scots pine stands - *Neto korelacija između veličine zapremine krupnog drveta i starosti jednodonih sastojina bijelog bora*

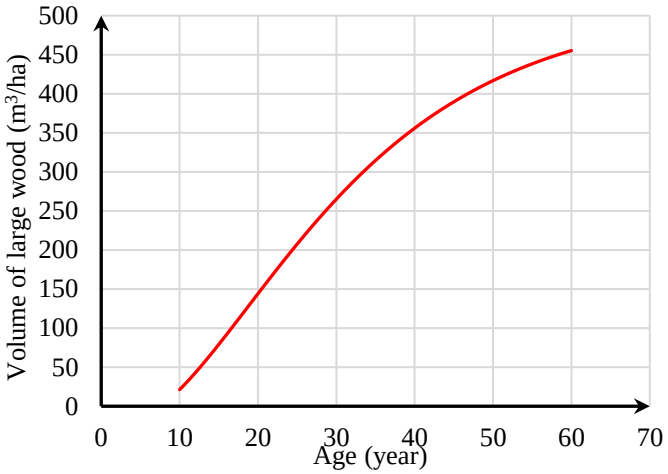
By including average values of site quality and degree of land coverage by forest stand canopy into determined regression model (3) we have reached an equation

of net correlation between volume of large wood and age of even-aged Scots pine stands:

$$V_k = -28{,}1699 + 541{,}85654794\left(1 - exp^{(-0{,}05311435x)}\right)^{2{,}70290864} \quad (4)$$

This equation shows how the volume of large wood changes with the change in age of the stand with average values of other independent variables.

Graphical form of gained equation of net regression is shown in Graph 2.



Graph 2. Net correlation between volume of large wood and age of even-aged Scots pine stands

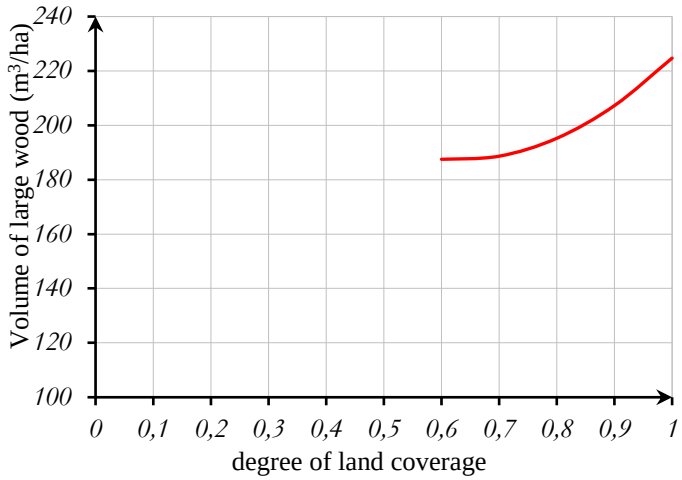
Grafikon 2. Neto korelacija između zapremine krupnog drveta i starosti jednodobnih sastojina bijelog bora

Based on given graphical depiction we can conclude that the value of volume of large wood of Scots pine stands with average habitat/site conditions and average degree of land coverage by forest stand canopy with age is increasing as per extended "S-shaped" curve. This is general characteristic of growth curves of all taxation elements of trees and stands, i.e. all living organisms.

Net correlation between the volume of large wood value and degree of land coverage by canopy of even-aged stands of Scots pine - ***Neto korelacija između veličine zapremine krupnog drveta i stepena zastrtosti zemljišta krošnjama stabala jednodobnih sastojina bijelog bora***

Net correlation equation, of impact of degree of land coverage by forest stand canopy onto the value of volume of large wood of even-aged stands of Scots pine, is:

$$V_k = 294{,}8603 - 342{,}0716319\delta + 271{,}91457458\delta^2 \quad (5)$$



Graph 3. Net correlation between the volume of large wood value and degree of land coverage by canopy of even-aged stands of Scots pine

Grafikon 3. Neto korelacija između veličine zapremine krupnog drveta i stepena zastrtosti zemljišta krošnjama stabala jednodobnih sastojina bijelog bora

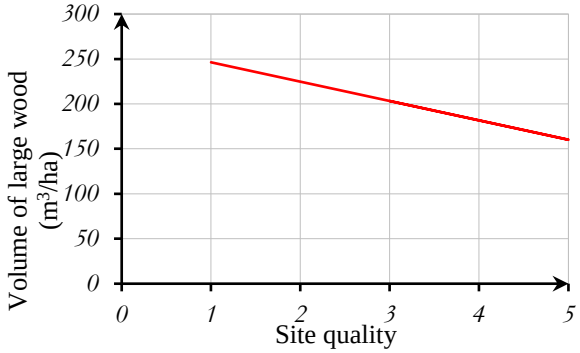
Graphical depiction of this equation is provided in Graph 3- Value of the volume of large wood of even-aged stands of Scots pine is, with average age and average site quality, larger with larger degree of land coverage by forest canopy. This is logical relation, while progressive increase in value of stand volume with increase of degree of land coverage by forest canopy points out that the larger degree is most probably the consequence of larger number of trees per unit of stand area.

Net correlation between value of volume of large wood and site quality of Scots pine even-aged stands - *Neto korelacija između veličine zapremine krupnog drveta i boniteta staništa jednodobnih sastojina bijelog bora*

Net correlation equation between value of volume of large wood and site quality is:

$$V_k = 267,84203 - 21,53694044\,\beta \quad (6)$$

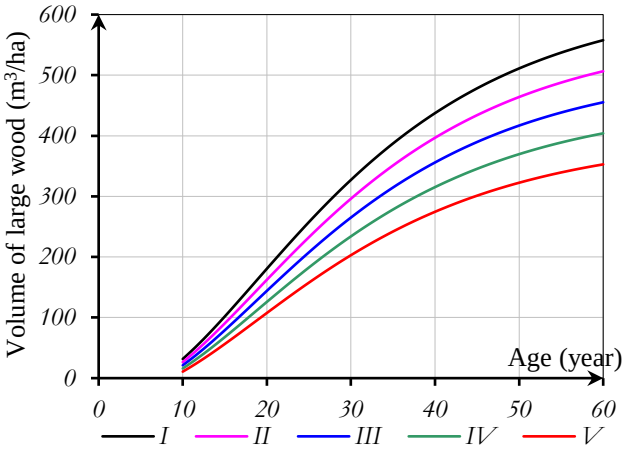
According to mathematical presentation of net correlation, values of parameters and graphical depiction (Graph 4), the value of volume of large wood of Scots pine stands is decreasing with worsening of habitat/site conditions with average age and average degree of land coverage by forest canopy.



Graph 4. - Net correlation between value of volume of large wood and site quality of Scots pine even-aged stands
Grafikon 4. - Neto korelacija između veličine zapremine krupnog drveta i boniteta staništa jednodobnih sastojina bijelog bora

That is quite understandable if one has in mind the expressed statement that the complex of all conditions for tree growth is more favourable on better habitats/sites than on bad ones and that it causes faster increase in values of all taxation elements of trees, and indirectly the volume of large wood of the stands as complex and additive taxation element.

On Graph 5 we have presented graphical presentation of dependences of assessed values of volume of large wood with the age of even-aged stands of Scots pine per site quality classes, while in Table 3 we present absolute values.



Graph 5. – Dependence of value of volume of large wood and age and site quality of even-aged stands of Scots pine
Grafikon 5. - Zavisnost veličine zapremine krupne drvne mase od starosti i boniteta staništa jednodobnih sastojina bijelog bora

Curves of growth of large wood mass volume as per site quality classes were determined by a method of equal relative changes (MATIĆ, 1980). This method is based on position that within site quality classes we cannot expect the same absolute differences in values of volume of large wood of the stands of different age, but those differences are larger in older age.

Table 3 – Assessed values of volume of large wood of even-aged not-tended forest plantations on carbonate substrates in Bosnia depending on site quality and age of plantations
Tabela 3 – Procjenjene veličine zapremina krupnog drveta jednodobnih nenjegovonih šumskih zasada na karbonatnim supstratima u Bosni u zavisnosti od boniteta staništa i starosti zasada

Age of stand (year)	Volume of large wood *(m^3/ha)*				
	Bonitet class				
	I	**II**	**III**	**IV**	**V**
10	31,6	26,4	21,2	15,9	10,7
15	101,8	90,4	79,1	67,7	56,3
20	180,5	162,2	144,0	125,8	107,5
25	257,5	232,5	207,5	182,5	157,6
30	327,2	296,1	265,0	234,0	202,9
35	387,2	350,9	314,6	278,3	241,9
40	437,4	396,7	355,9	315,2	274,5
45	478,3	434,0	389,7	345,4	301,1
50	511,1	464,0	416,8	369,6	322,5
55	537,2	487,7	438,3	388,9	339,4
60	557,7	506,5	455,2	404,0	352,8

Based on assessed values of volume of large wood of even-aged not-tended stands of Scots pine in Bosnia (Graph 5 and Table 3) one can say that existing plantations have very high productivity and their forming and growth is quite justified. High productivity is most likely the consequence of favourable conditions of the habitat/site on which these plantations were raised.

Comparison of results with data from yield and increment tables - *Upoređenje rezultata s podacima prirasno-prinosnih tablica*

In order to make close assessment on productivity of researched stands, as well as assessment of justification of their existence and future creation, the determined values in this document were compared with the data in existing increment and yield tables. For comparison we used indexes that were calculated as quotients (relations) of values of other tables and appropriate estimated values of Scots pine stands in Bosnia (appropriate age and quality class) multiplied by 100. We this we achieved that the indexes for all compared data have the same basis.

Since for even-aged stands of Scots pine in Bosnia we lack data on wood volume of cut trees since creation to the moment of stand measurement, and that we are dealing with stands that lacked application of silviculture measures, we can ask the question of soundness of mentioned comparison procedure. Because of this it is important to emphasise that this comparison for its objective has orientation knowledge on yield capabilities of habitats of even-aged forest plantations of Scots pine in Bosnia. Determined values of volume of large wood of Scots pine stands in Bosnia were compared to the appropriate data of yield tables from WIEDEMANN, (1943), LEMBCKE

et al. (2000) and GERHARDT, (1921). Table 4 represents values of indexes of comparison of value of even-aged stands for the best, medium and worst habitats/sites.

Table 4.- Indexes of comparison of value of Scots pine even-aged stands volume
Tabela 4.- Indeksi poređenja veličine zapremine jednodobnih sastojina bijelog bora

Age (year)	Indexes of volumes								
	WIEDEMANN			*GEHRHARDT*			*LEMBCKE ET AL.*		
	I	*III*	*V*	*I*	*III*	*V*	*MEN28*	*MEN20*	*MEN12*
25	**62**	**22**					**115**		
30	**68**	**34**		**72**	**45**	**-**	**104**	**61**	
35	**71**	**40**	**6**				**99**	**62**	
40	**73**	**43**	**11**	**65**	**46**	**17**	**97**	**62**	
45	**75**	**46**	**15**				**96**	**64**	
50	**77**	**49**	**18**	**61**	**45**	**21**	**97**	**66**	**26**
55	**79**	**51**	**21**				**98**	**68**	**29**
60	**81**	**53**	**24**	**60**	**46**	**24**	**100**	**70**	**31**

Values of comparison indexes, which are mainly significantly lower than 100, point out the significantly larger value of volume of large wood of Scots pine stands in Bosnia compared to used table data. The exception is comparisons with data from tables from LEMBCKE et al. (2000) for the best habitat/site conditions which points out to insignificant differences. Differences in value of volumes are smallest with better habitat/site conditions and larger age of stands. According to the results of comparison the even-aged Scots pine stands in Bosnia could be assessed as highly productive, and is most likely conditioned by habitat/site conditions on which even-aged plantations that suit the Scots pine, were created.

CONCLUSIONS - *Zaključci*

On the basis of conducted researches, we can make the following conclusions:

- For assessment of value of volume of large wood of even-aged plantations of Scots pine in Bosnia as best regression model we have chosen the model in which independent variables are the age of the stand, site quality class and degree of land coverage by forest canopy. Mathematical presentation of this model is:

$$V_7 = 40{,}6654706 + 541{,}8565479\left(1 - e^{(-0{,}0531143\alpha)}\right)^{2{,}702903811} + 7{,}592038\beta - 241{,}83288\delta + 271{,}91457\delta^2 - 33{,}426699\alpha\beta\delta$$

- For chosen regression model we have assessed that is of high quality regardless of large standard error of assessment (52.33 m^3/ha) because values of volume of large wood of even-aged plantations of Scots pine in Bosnia vary in very wide interval, from 7.88 to 512.61 m^3/ha. Besides this, selected regression model is of quality because with included independent variables in the model it explains 81% of variations in value of

volume of large wood in Scots pine stand, while the rest is attributed to other not included impact factors.

- With net correlation analysis between value of volume of large wood and age of even-aged plantations of Scots pine in Bosnia, we have determined a typical S-shaped curve of dependence between value of the volume and age of the stand.
- With net correlation between value of volume of large wood and site quality we have determined that the value of volume in linear form increases with improvement of habitat/site conditions.
- With net correlation between value of volume of large wood and degree of land coverage by forest stand canopy it has been determined that progressive increase in value of volume with increase of degree of coverage conditioned by increase of number of trees per unit of stand area.
- With determined model one can calculate the most likely (assessed) values of volume of large wood of even-aged plantations of Scots pine with existing management manner up to the age of 60 years. Having in mind that planned production periods for even-aged stands of Scots pine are longer than 60 years there is a need for new researches with samples that cover stands older than 60 years. This would check the validity and usability of created regression model.
- By comparison of results gained from this research with appropriate data of other yield tables we can conclude that even-aged stands of Scots pine in Bosnia are highly productive; that their existence is quite justified and that in the future much more attention should be focused on them. High productivity of these stands is most likely conditioned by habitat/site conditions which suit Scots pine.
- In this document we could not get the value of totally produced wood volume which is the only real indicator of yield capabilities of the habitat/site of even-aged stands, because we did not have available data on the value of harvested/cut trees. Considering that in the sample we chose stands (experimental plots) where "there was no harvest", because of which these stands were characterised as not-tended, we can assume that volume of harvested trees was not big and that only mortality was in effect.

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SAŽETAK

U radu je predstavljen regresioni model za procjenu veličine zapremine krupnog drveta jednodobnih nenjegovanih šumskih zasada bijelog bora na karbonatnim supstratima u Bosni za koji je ocijenjeno da je najbolji od više prethodno testiranih. U ovom modelu su kao nezavisne varijable korišteni starost sastojine, bonitetni razred staništa i stepen zastrtosti zemljišta sastojine krošnjama stabala. Model je ocijenjen kao kvalitetan jer se njime opisuje 81% varijabiliteta veličine zapremine krupnog drveta jednodobnih nenjegovanih šumskih zasada bijelog bora na karbonatnim supstratima u Bosni. U radu su provedene i analize neto korelacione veze između veličine zapremine krupnog drveta predmetnih zasada i odabranih nezavisnih varijabli. Utvrđeno je da se veličina zapremine krupnog drveta analiziranih zasada sa starošću povećava prvo progresivno, a zatim degresivno, sa poboljšanjem uslova staništa povećava se linearno, dok se sa povećanjem stepena zastrtosti povećava progresivno. Zaključeno je da se po utvrđenom regresionom modelu veličine zapremine krupnog drveta jednodobnih nenjegovanih šumskih zasada bijelog bora u Bosni mogu procjenjivati za starosti do 60 godina, a da su za prevazilaženje ovog ograničenja potrebna nova istraživanja na uzorcima koji obuhvataju i starije sastojine kojim bi se provjerila i valjanost utvrđenog modela. Osim toga, na osnovu poređenja rezultata utvrđenih u ovom radu sa odgovarajućim podacima drugih autora jednodobni nenjegovani šumski zasadi bijelog bora u Bosni su ocijenjeni kao visoko produktivni, da je njihovo postojanje i uzgajanje opravdano i da im u budućnosti treba posvetiti mnogo više pažnje.

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