UDK 630* 516 + 524.2 (*Pinus halepensis* L.) (001)

TREE VOLUME MODEL ESTIMATES AND NEAREST NEIGHBOR ANALYSIS IN THE STANDS OF SCOTS PINE (*Pinus sylvestris* L.) IN THE CENTRAL PART OF RODOPE MOUNTAIN

Modeli procjene volumena stabala te analiza strukturnih odnosa metodom najbližih susjeda u sastojinama običnog bora (*Pinus sylvestris* L.) u središnjem masivu Rodopa

Kyriaki Kitikidou[1], Elias Milios[1], Ioannis Lipiridis[1]

Summary:

Scots pine (*Pinus sylvestris* L.) is a native species of Europe and Asia, important for its timber. The aim of this study was to develop volume estimation models for the Scots pine in the central part of the Rhodope mountains (Northeastern Greece). For each sampled tree the three nearest trees were examined, applying nearest neighbor analysis. For the Scots pine of the central part of the Rhodope mountains, regression models, which estimate the volume using breast height diameter and total height as predictor variables, were fitted. In addition, nearest neighbor analysis was applied to examine possible effects on form factor of nearest trees and their distances to sampled trees. Three site types were distinguished in the research area, A, B, C (good, medium, and poor site qualities). For the site type C it wasn't possible to develop a volume estimation model. For the rest of the sites the selected models are: For site type A: $\hat{v} = 0.328 + 0.255D^2H$, $R^2 = 0.7653$, standard error = 0.3096, for site type B: $\hat{v} = 0.343D^2H$, $R^2 = 0.8146$, standard error = 0.3379, for the total area: $\hat{v} = 0.318D^2H$, $R^2 = 0.8377$, standard error = 0.3039. There is not a clear effect of the distance of the nearest trees on the form factor of sampled trees. This study lead to the development of volume estimation models for site types A, B, and for the whole study area. Nearest neighbor analysis showed that the species and dimensions of the nearest trees had different influence in the form of trees.

KEY WORDS: *Pinus sylvestris*, Greece, volume model estimation, nearest neighbor analysis.

1. INTRODUCTION
UVOD

Scots pine (*Pinus sylvestris* L.) is a native species of Europe and Asia, spreading west to Scotland, Ireland and Portugal, east to eastern Siberia, south to the mountains of Caucasus and far north, as well as inside the Arctic Circle in Scandi-navia. In the North appears in altitude 0-1000 m, while in South orientation is at higher altitudes, 1200–2600 m (Mirov 1967, Farjon 2005). The species is easily recognized, based on quite short, turquoise needles and orange bark. The tree wood is known as red wood, is reddish and hard and used for paper pulp, building construction and ship-building (Mirov 1967, Farjon 2005).

[1] Dr. Kyriaki Kitikidou, Dr. Elias Milios, Mr. Ioannis Lipiridis,
Democritus University, Department of Forestry and Management of the Environment and Natural Resources, Pandazidou 193, 68200, Orestiada, Greece.
Corresponding author: Kyriaki Kitikidou <kkitikid@fmenr.duth.gr>

Given that the objective of "timber management" type of forestry is to provide the optimal combination of quantity and quality of timber products that will maximize economic profit, the development of accurate and flexible models is necessary to provide the information required. The variable used in decision-making regarding timber management is volume. The total volume of trees is commonly estimated from regression models using the breast height diameter and the total height as predictors (Van Laar and Akça 2007).

In this study, randomly selected Scots pine trees from the central part of the Rhodope Mountains were measured. Data collected were used as input for the development of regression models that estimate the total tree volume. Development of such models is particularly important, because there are no other models for Scots pine for that area. Also, the effect of nearest trees to sample trees was examined, in an attempt to uncover possible relation between distance and species of the nearest trees and form factor of the sampled trees.

2. MATERIALS AND METHODS
MATERIJALI I METODE

2.1 Study area – Područje istraživanja

The study area was in the central part of the Rhodope Mountains, which is under the management of the Forest Service of Xanthi, Greece. Data covered an area about 3100 ha (longitude 41º19'N and latitude 24º43'E), where altitude range from 1200 to 1500 m. (Figure 1).

In the wider region, stands of *Fagus sylvatica* L. s.l., *Pinus sylvestris – F. sylvatica*, *Abies borisii-regis – F. sylvatica – P. sylvestris, and F. sylvatica – A. borisii-regis* and are mainly occurred (Milios 2000a, 2000b, 2004, Milios et al. 2008). Scots pine species occurs mainly in mixed stands with beech in three productivity sites. The age of Scots pine trees in several cases exceeds 120 years (Milios 2000a, 2000b).

In the scots pine – beech stands, the basal area of scots pine ranges from 17.00 to 41.15 m^2/ha and in beech ranges from 0.39 to 26.38 m^2/ha. In almost all cases scots pine appears mainly in the overstory. On the other hand, in a rather small totally area beech appears with many trees in the overstory (Milios 2000a, 2000b).

2.2 Data collection – Uzorkovanje

Raw data were collected in the framework of a Master thesis prepared at the Department of Forestry and Management of the Environment and Natural Resources, of Democritus University of Thrace, in Greece (Lipiridis 2013). Sampled trees were selected applying Neyman's random stratified sampling, with optimum distribution of sampled units to strata (Neyman 1934). Stratification was applied by distinguishing three site types (A, B, C) in the study area (Milios 2000a). Site type A represents the best sites (good site quality), B the intermediate sites (medium site quality) and C the worst sites (poor site quality). The distinction of site types was based on a combination of site attributes and the growth performance of predominant trees, using plots of 500 m^2. The site distinction was referred mainly to *F. sylvatica* that is the main (abundant) late successional species
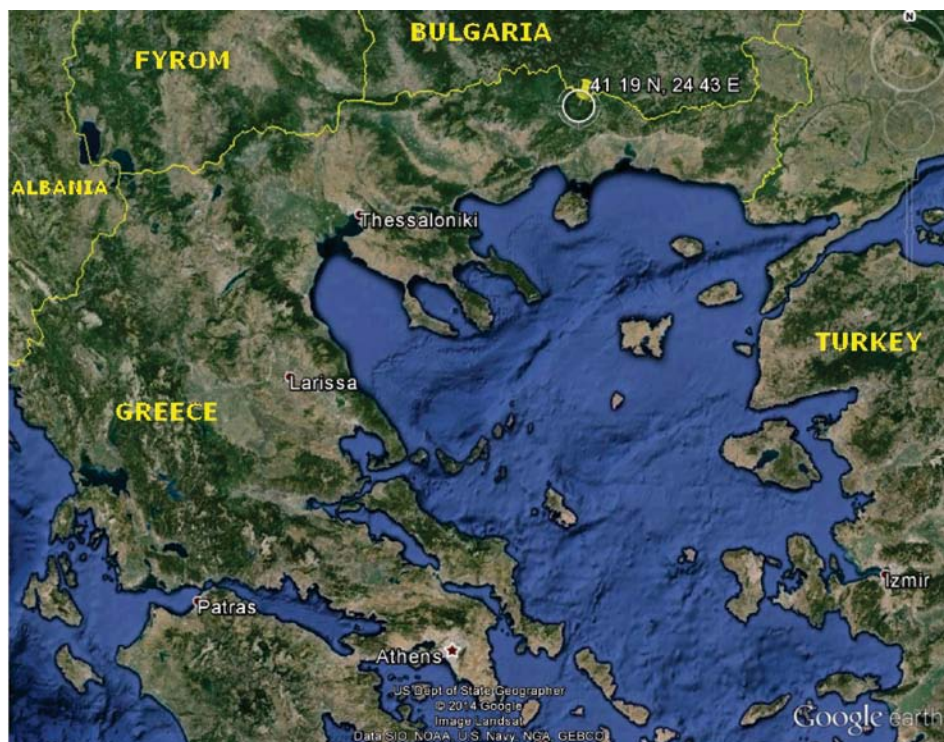

Figure 1. Location of the study area (white circle).
Slika 1. Područje istraživanja (bijela kružnica).

of the area (Milios 2000a). By applying Neyman's method, which achieves minimum variation in the sample assuming that the cost is the same for each sampling unit (tree), 60 trees were selected randomly from the site type A, 53 from B, and 45 from C.

Sampled trees were measured as follows:

- Breast height diameter D (in meters with 2 decimals) was measured with a calliper
- Total height H (in meters with 0.5m precision) was estimated with a Blume-Leiss altimeter
- Form factor f was estimated with a Bitterlich's Spiegel relaskop.

Total volume v (m³) of each tree was calculated using the formula (Van Laar and Akça 2007): $v = \frac{\pi}{4} D^2 fH$.

For each sampled tree, distance of the three nearest trees was measured and species of these trees was determined, in an attempt to relate nearest trees establishment to form factor.

2.3 Regression models – Modeli regresije

The regression models that were tested for fitting to data are given in Table 1. These models were fitted for each site type separately and for the whole study area. In each case, approximately 80% of the data were used for fitting and the remaining 20% for validation (Ezekiel and Fox 1959, Marquardt and Snee 1975).

Regression analysis was performed using the statistical package SPSS v.19.0 (Kitikidou 2005, IBM 2010). The criteria used for comparing the five regression models were (Table 2):

Table 1. Regression models for total volume estimation.
Tablica 1. Modeli regresije za procjenu ukupnog volumena stabala

No Br.	Name Regresijski model	Equation form Jednadžba	References Izvori
1	Logarithmic	$\hat{v} = b_0 + D^{b_1} H^{b_2}$	Schumacher and Hall, 1933
2	Constant form factor	$\hat{v} = b_0 D^2 H$	Gevorkiantz and Olsen, 1955
3	Combined variable	$\hat{v} = b_0 + b_1 D^2 H$	Spurr, 1952 Burkhart, 1977
4	Generalized combined variable	$\hat{v} = b_0 + b_1 D^2 + b_2 H + b_3 D^2 H$	Romancier, 1961
5	Generalized logarithmic	$\hat{v} = b_0 + b_1 D^{b_2} H^{b_3}$	Newham, 1967

$\hat{v}$: volume estimates
procijenjeni volumen
b_i: regression coefficients
regresijski koeficijent

Table 2. Criteria for regression models comparison.
Tablica 2. Poredbeni kriteriji vrednovanja različitih modela regresije

No Br.	Criterion Kriterij	Formula Jednadžba	Optimum value Optimalna vrijednost	References Izvori
1	Absolute mean error (bias, B)	$\sum_{i=1}^{n} \frac{\|v_i - \hat{v}_i\|}{n}$	0	Mayer and Butler, 1993; Janssen and Heuberger, 1995; Wackerly et al., 2008
2	Standard error of the estimate, se	$\sqrt{\dfrac{\sum_{i=1}^{n}(v_i - \hat{v}_i)^2}{n-p}}$	min	Ezekiel and Fox, 1959; Mathews, 1987; Wackerly et al., 2008; Draper and Smith, 1997
3	Coefficient of determination R^2	$1 - \dfrac{\sum_{i=1}^{n}(v_i - \hat{v}_i)^2}{\sum_{i=1}^{n}(v_i - \overline{v})^2}$	1	Draper and Smith, 1997; Everitt and Skrondal, 2010

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

2.4 Nearest neighbor analysis – Analiza metodom najbližih susjeda

Nearest neighbor analysis is a method for classifying cases based on their similarity to other cases. In machine learning, it was developed as a way to recognize patterns of data without requiring an exact match to any stored patterns, or cases. Similar cases are near each other and dissimilar cases are distant from each other. Cases that are near each other are called "neighbors" (Weber et al. 1998). In our study, nearest neighbor analysis was performed using the statistical package SPSS v.19.0 (IBM 2010), using the Euclidean metric for distance transformation. The number of nearest neighbors k was set equal to 3, i.e. for each sampled tree (case) the three nearest trees were examined. Three new (theoretical) cases were used as focal identifiers, corresponding to three trees with mean v, D, H and f for each site type.

3. RESULTS
REZULTATI

3.1 Exploratory data analysis – Preliminarna analiza podataka

Descriptive statistics of the sampled trees, for each site type and for the study area as a whole, are given in Table 3. Mean volume was statistically significantly different between site

Table 3. Descriptive statistics of the sampled trees.
Tablica 3. Deskriptivna statistika dimenzija uzorkovanih stabala

Variable *Varijabla*	Site type A *Stanište "A"*			
	Mean *Sredina*	Standard deviation *Standardna devijacija*	min	max
v (m³)	1.87	0.59	0.91	4.19
D (m)	0.46	0.07	0.32	0.65
H (m)	27.37	4.05	22.00	41.00
f	0.41	0.01	0.30	0.61
Variable *Varijabla*	Site type B *Stanište "B"*			
	Mean *Sredina*	Standard deviation *Standardna devijacija*	min	max
v (m³)	1.41	0.81	0.38	3.83
D (m)	0.39	0.11	0.22	0.72
H (m)	23.91	2.01	18.00	28.00
f	0.47	0.02	0.29	0.89
Variable *Varijabla*	Site type C *Stanište "C"*			
	Mean *Sredina*	Standard deviation *Standardna devijacija*	min	max
v (m³)	0.92	0.46	0.21	2.12
D (m)	0.35	0.08	0.19	0.49
H (m)	19.87	2.45	17.00	26.00
f	0.45	0.01	0.33	0.59
Variable *Varijabla*	Whole area *Sva tri staništa ukupno*			
	Mean *Sredina*	Standard deviation *Standardna devijacija*	min	max
v (m³)	1.45	0.75	0.21	4.19
D (m)	0.41	0.10	0.19	0.72
H (m)	24.07	4.29	17.00	41.00
f	0.44	0.01	0.29	0.89

types, ($F = 28.214$, $p = 0.000$), justifying the development of volume estimation models for each site type separately.

Summary statistics for the nearest neighbors to the sampled trees (distances and species) are given to tables 4 and 5, respectively.

Table 4. Descriptive statistics of the distances of the neighbor trees.
Tablica 4. Deskriptivna statistika udaljenosti susjednih stabala

Distance *Udaljenost*	Trees of site type A *Stabla na staništu "A"*			
	Mean *Sredina*	Standard deviation *Standardna devijacija*	min	max
1	2.13	1.31	0.10	5.00
2	3.04	1.11	0.50	5.00
3	3.90	1.29	0.50	8.00
Distance *Udaljenost*	Trees of site type B *Stabla na staništu "B"*			
1	1.57	0.94	0.01	4.00
2	2.45	1.12	0.20	5.00
3	3.17	1.09	1.00	5.00
Distance *Udaljenost*	Trees of site type C *Stabla na staništu "C"*			
1	2.71	1.45	0.30	7.00
2	3.33	1.71	0.50	8.00
3	4.15	1.86	0.30	10.00

Distance 1: distance of the first closest tree (m)
Udaljenost 1: udaljenost do prvog najbližeg stabla (m)
Distance 2: distance of the second closest tree (m)
Udaljenost 2: udaljenost do drugog najbližeg stabla (m)
Distance 3: distance of the third closest tree (m)
Udaljenost 3: udaljenost do trećeg najbližeg stabla (m)

3.2 Selection of the best regression model and validation for site type A – Odabir najpovoljnijeg modela regresije za lokaciju A

Based on the results of Table 6, for site type A, model 2 should be rejected, because, although is adequately fitted, has negative R^2 for validation data. Also, models 4 and 5 should be rejected, because, although they have fairly good values for comparison criteria, both for fitting and validation data, some of their regression coefficients are not statistically significant at the level p<0.05 (Table 7). Moreover, Model 1 is inappropriate, because regression coefficients are not statistically significant at the level p<0.05, for validation data (Table 7). Regression coefficients and their 95% confidence intervals are given in Table 7. Therefore, the selected model is:

3. Combined variable $\hat{v} = 0,328 + 0,255D^2H$

One should note that R^2 for validation data is quite small, which means that, by taking a new sample, regression coefficients of the selected model might be different.

3.3 Selection of the best regression model and validation for site type B – Odabir najpovoljnijeg modela regresije za lokaciju B

Values for tested models gave satisfactory values for comparison criteria, both for fitting and validation data (Table 8). However, we should reject models 1, 4 and 5, in which

Table 5. Descriptive statistics of the species of the neighbor trees.
Tablica 5. Opisna statistika analize udaljenosti susjednih (najbližih) stabala prema vrstama drveća

		Trees corresponding to site type *Stabla prema staništim tipovima*					
		A		B		C	
		Count *Broj stabala*	%	Count *Broj stabala*	%	Count *Broj stabala*	%
species 1 Vrsta 1	1: *Pinus sylvestris*	12	19.7	9	16.7	31	67.4
	2: *Fagus sylvatica*	44	72.1	45	83.3	14	30.4
	3: *Abies borisii-regis*	5	8.2	0	0.0	1	2.2
	4: *Betula pendula*	0	0.0	0	0.0	0	0.0
species 2 Vrsta 2	1: *Pinus sylvestris*	19	31.1	22	40.7	28	60.9
	2: *Fagus sylvatica*	41	67.2	32	59.3	14	30.4
	3: *Abies borisii-regis*	0	0.0	0	0.0	4	8.7
	4: *Betula pendula*	1	1.6	0	0.0	0	0.0
species 3 Vrsta 3	1: *Pinus sylvestris*	16	26.2	23	42.6	30	65.2
	2: *Fagus sylvatica*	42	68.9	31	57.4	15	32.6
	3: *Abies borisii-regis*	3	4.9	00	0.0	0	0.0
	4: *Betula pendula*	0	0.0	0	0.0	1	2.2

Species 1: first closest species
Vrsta 1: prvo najbliže susjedno stablo
Species 2: second closest species
Vrsta 2: drugo najbliže susjedno stablo
Species3: third closest species
Vrsta 3: treće najbliže susjedno stablo

Table 6. Regression models comparison for site type A.
Tablica 6. Usporedba regresijskih modela za stanišni tip A

	Fitting data *Uklapanje podataka*		
	Statistic (optimum value) *Statistika (optimalne vrijednosti)*		
Model *Model*	Absolute mean error *Srednja apsolutna pogreška* (0)	Standard error of the estimate *Standardna pogreška procijenjene vrijednosti* (min)	Coefficient of determination R^2 *Koeficijent determinacije R^2*
1	0.2411	0.3159	0.7607
2	0.2487	0.3255	0.7351
3	0.2435	0.3096	0.7653
4	0.2393	0.3098	0.7748
5	0.2366	0.3089	0.7761
	Validation data *Provjera valjanosti*		
	Statistic (optimum value) *Statistika (optimalne vrijednosti)*		
Model *Model*	Absolute mean error *Srednja apsolutna pogreška* (0)	Standard error of the estimate *Standardna pogreška procijenjene vrijednosti* (min)	Coefficient of determination R^2 *Koeficijent determinacije R^2*
1	0.1483	0.2366	0.4522
2	0.2670	0.3141	-0.2412
3	0.1558	0.2301	0.4080
4	0.1540	0.2598	0.4340
5	0.1432	0.2500	0.4761

Rejections are highlighted in grey.
Odbačeni modeli označeni sjenčanjem.

some regression coefficients do not differ significantly from zero, both for fitting and validation data, and model 3, for which regression coefficients do not differ significantly from zero, for validation data (Table 7). Therefore, the selected model is:

2. Constant form factor $\hat{v} = 0{,}343D^2H$

3.4 Selection of the best regression model and validation for site type C – Odabir najpovoljnijeg modela regresije za lokaciju C

As for site type C, all models have negative values for R^2, either for fitting or validation data, so we cannot choose one.

3.5 Selection of the best regression model and validation for the study area as a whole – Odabir najpovoljnijeg modela regresije za sve tri lokacije zajedno

Analysis of data as a whole, i.e. without distinguishing site types, gave highly satisfactory results, both for fitting and validation data (Table 9). After rejecting models 4 and 5, because some of their regression coefficients for fitting data are not statistically significant at the level p<0.05 (Table 7) and models 1, 3, 4 and 5, because their regression coefficients for validation data are not statistically significant at the level p<0.05 (Table 7), the following model was selected:

2. Constant form factor $\hat{v} = 0{,}318D^2H$

3.6 Nearest neighbour analysis – Analiza najbližih susjeda

Sampled trees of site type C had the most distant neighbours (Table 4), while the majority of their neighbours were *Pinus sylvestris* trees (Table 5).

Table 7. Regression coefficients and their significances for all models.
Tablica 7. Koeficijenti regresije i njihova značajnost za sve modele

Site type A – fitting data *Stanišni tip "A" – uklapanje podataka*					
Model *Model*	Parameter *Parametar*	Estimate *Procjena*	Std. Error *Standardna pogreška*	95% Confidence Interval *Interval pouzdanosti 95%*	
				Lower bound *Donja granična vrijednost*	Upper bound *Gornja granična vrijednost*
1	b_0	0.290	0.143	0.002	0.579
	b_1	1.651	0.159	1.330	1.971
	b_2	0.941	0.140	0.660	1.222
2	b_0	0.303	0.007	0.289	0.317
3	b_0	0.328	0.133	0.061	0.595
	b_1	0.255	0.020	0.214	0.296
4	b_0	1.846	1.241	−0.652	4.344
	b_1	−6.953	5.188	−17.397	3.490
	b_2	−0.053	0.045	−0.143	0.037
	b_3	0.498	0.186	0.123	0.872
5	b_0	0.888	0.304	0.277	1.499
	b_1	0.043	0.055	−0.067	0.153
	b_2	2.932	0.774	1.375	4.489
	b_3	1.604	0.429	0.741	2.466

Site type B – fitting data *Stanišni tip "B" – uklapanje podataka*					
Model *Model*	Parameter *Parametar*	Estimate *Procjena*	Std. Error *Standardna pogreška*	95% Confidence Interval *Interval pouzdanosti 95%*	
				Lower bound *Donja granična vrijednost*	Upper bound *Gornja granična vrijednost*
1	b_0	0.105	0.172	−0.242	0.453
	b_1	1.630	0.131	1.366	1.894
	b_2	1.286	0.495	0.286	2.287
2	b_0	0.343	0.012	0.319	0.366
3	b_0	0.213	0.095	0.020	0.406
	b_1	0.302	0.021	0.259	0.345
4	b_0	−0.838	1.170	−3.207	1.531
	b_1	3.246	8.103	−13.158	19.650
	b_2	0.046	0.049	−0.053	0.144
	b_3	0.161	0.324	−0.496	0.817
5	b_0	−0.496	0.584	−1.679	0.686
	b_1	0.324	0.500	−0.688	1.337
	b_2	1.279	0.351	0.568	1.990
	b_3	0.931	0.473	−0.027	1.889

Site type A – validation data *Stanišni tip "A" – provjera valjanosti podataka*					
Model *Model*	Parameter *Parametar*	Estimate *Procjena*	Std. Error *Standardna pogreška*	95% Confidence Interval *Interval pouzdanosti 95%*	
				Lower bound *Donja granična vrijednost*	Upper bound *Gornja granična vrijednost*
1	b_0	0.585	0.744	−1.173	2.343
	b_1	0.798	0.386	−0.116	1.712
	b_2	0.529	0.401	−0.418	1.477
2	b_0	0.312	0.018	0.272	0.352
3	b_0	0.990	0.331	0.226	1.753
	b_1	0.139	0.059	0.003	0.275
4	b_0	−1.313	5.401	−14.530	11.903
	b_1	10.850	28.022	−57.717	79.418
	b_2	0.092	0.213	−0.430	0.614
	b_3	−0.297	1.111	−3.015	2.422
5	b_0	−140.246	106732.848	−261306.117	261025.624
	b_1	140.118	106724.358	−261004.979	261285.215
	b_2	0.010	7.593	−18.570	18.590
	b_3	0.007	4.965	−12.142	12.155

Site type B – validation data *Stanišni tip "B" – provjera valjanosti podataka*					
Model *Model*	Parameter *Parametar*	Estimate *Procjena*	Std. Error *Standardna pogreška*	95% Confidence Interval *Interval pouzdanosti 95%*	
				Lower bound *Donja granična vrijednost*	Upper bound *Gornja granična vrijednost*
1	b_0	5.139	24.581	−51.545	61.822
	b_1	1.943	0.384	1.058	2.828
	b_2	0.140	1.443	−3.187	3.467
2	b_0	0.329	0.022	0.280	0.379
3	b_0	0.135	0.242	−0.411	0.682
	b_1	0.307	0.046	0.204	0.410
4	b_0	1.286	5.892	−12.647	15.218
	b_1	2.099	27.732	−63.476	67.674
	b_2	−0.050	0.242	−0.623	0.522
	b_3	0.244	1.109	−2.378	2.867
5	b_0	0.164	0.675	−1.431	1.760
	b_1	5.882	33.307	−72.876	84.639
	b_2	2.166	1.102	−0.440	4.772
	b_3	0.118	1.702	−3.907	4.142

Site type C – fitting data
Stanišni tip "C" – uklapanje podataka

Model / *Model*	Parameter / *Parametar*	Estimate / *Procjena*	Std. Error / *Standardna pogreška*	95% Confidence Interval / *Interval pouzdanosti 95%*	
				Lower bound / *Donja granična vrijednost*	Upper bound / *Gornja granična vrijednost*
1	b_0	0.279	0.176	−0.079	0.636
	b_1	1.794	0.144	1.501	2.086
	b_2	1.010	0.189	0.626	1.394
2	b_0	0.346	0.008	0.329	0.362
3	b_0	0.060	0.054	−0.049	0.169
	b_1	0.327	0.018	0.291	0.364
4	b_0	−0.029	0.554	−1.154	1.096
	b_1	0.281	3.675	−7.179	7.742
	b_2	0.005	0.029	−0.054	0.064
	b_3	0.309	0.186	−0.067	0.686
5	b_0	−0.169	0.253	−0.682	0.343
	b_1	0.384	0.258	−0.140	0.907
	b_2	1.518	0.382	0.741	2.294
	b_3	0.870	0.237	0.389	1.351

Total area – fitting data
Sva tri staništa zajedno – uklapanje podataka

Model / *Model*	Parameter / *Parametar*	Estimate / *Procjena*	Std. Error / *Standardna pogreška*	95% Confidence Interval / *Interval pouzdanosti 95%*	
				Lower bound / *Donja granična vrijednost*	Upper bound / *Gornja granična vrijednost*
1	b_0	0.415	0.135	0.149	0.681
	b_1	1.677	0.082	1.515	1.839
	b_2	0.848	0.091	0.667	1.029
2	b_0	0.318	0.005	0.307	0.328
3	b_0	0.221	0.050	0.122	0.320
	b_1	0.279	0.010	0.260	0.299
4	b_0	−0.326	0.337	−0.993	0.341
	b_1	2.841	1.801	−0.723	6.405
	b_2	0.024	0.015	−0.005	0.053
	b_3	0.162	0.073	0.017	0.306
5	b_0	−0.099	0.190	−0.476	0.278
	b_1	0.479	0.194	0.095	0.863
	b_2	1.577	0.197	1.186	1.968
	b_3	0.798	0.125	0.551	1.046

Site type C – validation data
Stanišni tip "C" – provjera valjanosti podataka

Model / *Model*	Parameter / *Parametar*	Estimate / *Procjena*	Std. Error / *Standardna pogreška*	95% Confidence Interval / *Interval pouzdanosti 95%*	
				Lower bound / *Donja granična vrijednost*	Upper bound / *Gornja granična vrijednost*
1	b_0	5.15E-005	0.000	−0.001	0.001
	b_1	1.908	0.527	0.230	3.585
	b_2	3.921	2.158	−2.945	10.788
2	b_0	0.349	0.031	0.268	0.430
3	b_0	0.111	0.232	−0.533	0.755
	b_1	0.312	0.084	0.080	0.545
4	b_0	9.216	0.217	8.282	10.151
	b_1	−78.393	1.454	−84.649	−72.137
	b_2	−0.447	0.011	−0.492	−0.401
	b_3	4.205	0.072	3.896	4.514
5	b_0	Run stopped after 400 model evaluations and 174 derivative evaluations because it reached the limit for the number of iterations. *Nastavak obrade prekinut nakon 400 evaluacija modela i 174 derivacija, jer je dostignut maksimum iteracija*			
	b_1				
	b_2				
	b_3				

Total area – validation data
Sva tri staništa zajedno – provjera valjanosti podataka

Model / *Model*	Parameter / *Parametar*	Estimate / *Procjena*	Std. Error / *Standardna pogreška*	95% Confidence Interval / *Interval pouzdanosti 95%*	
				Lower bound / *Donja granična vrijednost*	Upper bound / *Gornja granična vrijednost*
1	b_0	0.502	0.593	−0.722	1.726
	b_1	1.705	0.214	1.263	2.147
	b_2	0.797	0.353	0.069	1.525
2	b_0	0.322	0.013	0.297	0.348
3	b_0	0.208	0.135	−0.071	0.487
	b_1	0.285	0.027	0.229	0.341
4	b_0	−0.181	1.706	−3.709	3.348
	b_1	2.477	9.615	−17.414	22.367
	b_2	0.016	0.072	−0.133	0.165
	b_3	0.184	0.395	−0.633	1.002
5	b_0	0.055	0.443	−0.861	0.972
	b_1	0.462	0.673	−0.931	1.855
	b_2	1.773	0.594	0.544	3.002
	b_3	0.828	0.465	−0.133	1.790

Rejections are highlighted in grey.
Odbačeni modeli označeni sjenčanjem

Table 8. Regression models comparison for site type B.
Tablica 8. Usporedba modela regresije za stanišni tip "B"

	Fitting data *Uklapanje podataka*		
	Statistic (optimum value) *Statistika (optimalne vrijednosti)*		
Model *Model*	Absolute mean error *Srednja apsolutna pogreška* (0)	Standard error of the estimate *Standardna pogreška procijenjene vrijednosti* (min)	Coefficient of determination R^2 *Koeficijent determinacije R^2*
1	0.2480	0.3127	0.8490
2	0.2698	0.3379	0.8146
3	0.2622	0.3225	0.8352
4	0.2572	0.3254	0.8407
5	0.2406	0.3114	0.8540
	Validation data *Provjera valjanosti*		
	Statistic (optimum value) *Statistika (optimalne vrijednosti)*		
Model *Model*	Absolute mean error *Srednja apsolutna pogreška* (0)	Standard error of the estimate *Standardna pogreška procijenjene vrijednosti* (min)	Coefficient of determination R^2 *Koeficijent determinacije R^2*
1	0.2972	0.4206	0.8420
2	0.2885	0.3896	0.8305
3	0.2896	0.4039	0.8360
4	0.2865	0.4476	0.8434
5	0.2887	0.4480	0.8431
Rejections are highlighted in grey. *Odbačeni modeli označeni sjenčanjem*			

Table 9. Regression models comparison for the whole dataset.
Tablica 9. Usporedba modela regresije za ukupni uzorak.

	Fitting data		
	Statistic (optimum value) *Statistika (optimalne vrijednosti)*		
Model	Absolute mean error (0)	Standard error of the estimate (min)	Coefficient of determination R^2
1	0.2174	0.2807	0.8638
2	0.2270	0.3039	0.8377
3	0.2222	0.2841	0.8593
4	0.2194	0.2833	0.8623
5	0.2165	0.2814	0.8641
	Validation data		
	Statistic (optimum value) *Statistika (optimalne vrijednosti)*		
Model	Absolute mean error (0)	Standard error of the estimate (min)	Coefficient of determination R^2
1	0.2429	0.3208	0.8159
2	0.2559	0.3234	0.7972
3	0.2467	0.3154	0.8146
4	0.2457	0.3283	0.8151
5	0.2433	0.3276	0.8160
Rejections are highlighted in grey.			

4. DISCUSSION
RASPRAVA

At least thirty four volume models are reported in Europe for Scots pine, from which more than half were developed for Scandinavian countries (Zianis et al. 2005). Comparing our models with the ones developed by Näslund (1947) (breast height diameter ranges between 5 and 49.9 cm, and total tree height between 3 and 32.9 m), we can demonstrate that volume - dimensions (D, H) relationship of the forest studied in the present research and of the forest studied in Sweden are comparable. Näslund's models are:

$$\hat{v} = 0.1028D^2 0.02705D^2 H + 0.005215DH^2 \qquad (1)$$

$$\hat{v} = 0.1072D^2 + 0.02427D^2 H + 0.007315DH^2 \qquad (2)$$

where total volume $\hat{v}$ is in dm³, breast height diameter D in cm and total tree height H in m.

For the common D and H ranges of both studies (Näslund's and the present): $0.32 \leq D \leq 0.499$ m and $22 \leq H \leq 28$ m,

volume is $0.795 \leq v \leq 2.346$ m³ for model (1), $0.770 \leq v \leq 2.245$ for model (2), $0.902 \leq v \leq 2.106$ for site type A of the central part of the Rhodope Mountains, $0.773 \leq v \leq 2.391$ for site type B and $0.716 \leq v \leq 2.217$ for the studied area as a whole. The central part of Rhodope and the Swedish forest appear to have similar volumes for the same tree dimensions (D, H).

In an attempt to examine possible effects of distance between trees on form factor, we applied nearest neighbor analysis, a method used in forestry to assess animal damage to trees (Pepper 1998) and cavity tree abundance (Temesgen et al. 2008). Form factor is related to stand density (competition between neighbor trees) (Philip 1994) Nearest neighbor analysis revealed that trees of site type C are more isolated, compared with trees of site types A and B; based on the analysis, neighbor trees of the sampled trees were more distant than those of the site types A and B. This fact did no led to a lower form factor in the sampled trees of site type C compared with the trees of site type A, where a lower form factor and smaller distances between sampled trees and their neighbors were observed. This happened because the nearest trees to the sampled trees in site type A were beech trees with small dimensions. In most cases, in the mixed *P. sylvestris – F. sylvatica* stands of the study area, beech appears in the understory and in the middle story as a small tree. As a result, the competition imposed to pine trees was not significant, as well as the influence of beeches on the form factor of pines. The main influence on the form

factor of pine trees is induced by overstory pine trees. According to Milios (2000a), the density of overstory pines in the development stages where beech trees have been established under the shade of pines (and grow in the understory and middle story) is the lowest in site type A (143 trees/ha) and seems to be the highest in site type B (290 trees/ha in the first development stage and 640 trees/ha in the second). In site type C the density of overstory trees is 335 trees/ha. These data explain the values of form factors of sampled pine trees in the different site types; 0.41 for site type A, 0.47 for site type B and 0.45 for site type C (Table 3).

In conclusion, from the central part of the Rhodope Mountains, selecting 158 *Pinus sylvestris* trees from 3 site types, by applying Neyman's random stratified sampling, we developed volume estimation models for each site type and for the whole study area. Selected models were:

For site type A: $\hat{v} = 0.328 + 0.255D^2H$, $R^2 = 0.7653$, standard error = 0.3096

For site type B: $\hat{v} = 0.343D^2H$, $R^2 = 0.8146$, standard error = 0.3379

For the total area: $\hat{v} = 0.318D^2H$, $R^2 = 0.8377$, standard error = 0.3039.

For site type C none of the tested models was selected. There is not a clear effect of the distance of the nearest trees on the form factor of sampled trees since the species and dimensions of the nearest trees have different influence in the form of trees. As for site types A and B and for the study area as a whole, they seem to be analogous regarding volume – dimensions (*D*, *H*) relationship with a similar study in Sweden.

REFERENCES
LITERATURA

- Burkhart, H., 1977: Cubic-foot volume of Loblolly pine to any merchantable top limit. Southern Journal of Applied Forestry 1: 7-9.

- Draper, N., Smith, H., 1997: Applied regression analysis. 3rd edition. Whiley and Sons, USA. 736 p.

- Everitt, B., Skrondal, A., 2010: Cambridge Dictionary of Statistics. 4th edition. University Press, Cambridge UK. 478 p.

- Ezekiel, M., Fox, K., 1959: Methods of correlation and regression analysis. John Wiley and Sons, New York. 548 p.

- Farjon, A., 2005: Pines: Drawings and Descriptions of the Genus *Pinus*. 2nd edition. Brill Academic Pub., the Netherlands. 236 p.

- Gevorkiantz, S., Olsen, L., 1955: Composite volume tables for timber and their application in the Lake States. U.S. Dep. Agric. Tech. Bull. 1104.

- Google Earth, 2013: http://www.google.com/earth/index.html

- IBM, 2010: SPSS Regression 19. 51 p.

- Janssen, P., Heuberger, P., 1995: Calibration of process-oriented models. Ecological Modelling 83: 55-66.

- Kitikidou, K., 2005: Applied statistics using the statistical package SPSS. Tziola publications, Thessaloniki, Greece.

- Lipiridis, I., 2013: Volume tables for the Scots pine (*Pinus sylvestris* L.) in the central part of the Rhodope mountains. MSc thesis. Department of Forestry and Management of the Environment and Natural Resources, Democritus University of Thrace, Greece. 25 p.

- Marquardt, D., Snee, R., 1975: Ridge regression in practice. The American Statistician 29(1): 3–20.

- Mathews, J., 1987: Numerical methods for computer science, engineering and mathematics. Prentice-Hall, Englewood Cliffs, New Jersey. 507 p.

- Mayer, D., Butler, D., 1993: Statistical validation. Ecological Modelling 68: 21-32.

- Milios, E., 2000a: Dynamic development and evaluation of mixed stands in Rhodope, prefecture of Xanthi, Greece. PhD thesis. Department of Forestry and Natural Resources, Thessaloniki, Greece. 345 p.

- Milios, E., 2000b: Dynamics and development patterns of *Pinus sylvestris* L. - *Fagus sylvatica* L. stands in central Rhodope. Silva Gandavensis 65: 154–172.

- Milios, E., 2004: The influence of stand development process on the height and volume growth of dominant *Fagus sylvatica* L. s.l. trees in the central Rhodope Mountains of north- eastern Greece. Forestry 77: 17–26.

- Milios, E., Pipinis, E., Smiris, P., Aslanidou, M., 2008: The influence of overhead shade on the shade mortality of *Abies* x *borisii* – *regis* Mattf. seedlings and saplings in the central Rhodope mountains of North-eastern Greece. Plant Biosystems 142: 219–227.

- Mirov, N., 1967: The Genus *Pinus*. Ronald Press, New York. 602 p.

- Näslund, M., 1947: Funktioner och tabeller för kubering av stående träd. Meddelanden från Statens skogsforskningsinstitutet 36(3): 1–81.

- Newnham, R., 1967: A modification to the combined-variable formula for computing tree volumes. Journal of Forestry 65: 719-720.

- Neyman, J., 1934: On the two different aspects of the representative method: The method of stratified sampling and the method of purposive selection. Journal of the Royal Statistical Society 97(4): 557–625.

- Pepper, H., 1998: Nearest neighbour method for quantifying wildlife damage to trees in woodland. Forestry Commission Practice Note no1, Edinburgh, UK.

- Philip, M., 1994: Measuring trees and Forests, second edition. CAB International, Cambridge. 310 p.

- Romancier, R., 1961: Weight and volume of plantation-grown loblolly pine. USDA For. Serv. Southeast. For. Exp. Stn. Res. Note 161.

- Schumacher, F., Hall, F., 1933: Logarithmic expression of timber-tree volume. Journal of Agricultural Research 47: 719–734.

- Spurr, S., 1952: Forest inventory. Ronald Press, New York. 476 p.

- Temesgen, H., Barrett, T., Latta, G., 2008: Estimating cavity tree abundance using Nearest Neighbor Imputation methods for western Oregon and Washington forests. Silva Fennica 42(3): 337–354.

- Van Laar, A., Akça, A., 1997: Forest Mensuration. Cuvillier Verlag, Göttingen, Germany. 418 p.

- Wackerly, D., Mendenhall, W., Scheaffer, R., 2008: Mathematical statistics with applications. 7th edition. Duxbury Press. Belmont. 944 p.
- Weber, R., Schek, H., Blott, S., 1998: A quantitative analysis and performance study for similarity-search methods in high-dimensional spaces. Proceedings of the 24th VLDB Conference, New York, USA, pp.194-205.
- Zianis, D., Muukkonen, P., Raisa Mäkipää, R., Mencuccini, M., 2005: Biomass and stem volume equations for tree species in Europe. Silva Fennica Monographs 4. 63 p.

Sažetak

Obični bor (*Pinus sylvestris* L.) euroazijska je vrsta drveća, ekonomski važna radi vrijednosti i iskoristivosti drva. Cilja istraživanja bio je razviti modele procjene volumena drva stabala običnog bora u mješovitim borovo-bukovim sastojinama u središnjem masivu Rodopa (sjeveroistočna Grčka). Primijenjeni regresijski modeli koriste prsni promjer i ukupnu visinu stabala običnog bora kao predikcijske varijable. Za svako uzorkovano stablo te njegova tri neposredna susjedna stabla analizirani su strukturni odnosi primjenom metode najbližih susjeda. Nadalje, metoda najbližih susjeda primijenjena je kako bi se analizirao učinak udaljenosti između stabala i pripadnosti vrsti drveća na njihov oblik. Istraživanje je provedeno na tri stanišna tipa, "A", "B" i "C" (dobri, srednji i slabi stanišni uvjeti). Za stanište "C" nije bilo moguće izvesti model procjene volumena. Na preostala dva staništa odabrani modeli bili su kako slijedi: na staništu "A": $\hat{v} = 0.328 + 0.255 D^2 H$, $R^2 = 0.7653$, standardna pogreška = 0.3096, na staništu "B": $\hat{v} = 0.343 D^2 H$, $R^2 = 0.8146$, standardna pogreška= 0.3379, te sveukupno, za sva tri staništa $\hat{v} = 0.318 D^2 H$, $R^2 = 0.8377$, standardna pogreška= 0.3039. Nije utvrđen utjecaj udaljenosti među susjednim stablima na oblik analiziranih stabala. Istraživanje je pridonijelo razvoju volumnih prediskcijskih modela na staništima "A" i "B" kao i na sva tri staništa zbirno. Analiza sastojinskih strukturnih odnosa metodom najbližih susjeda ukazala je da vrsta drveća i udaljenost među stablima imaju različit utjecaj na oblik stabla.

KEYWORDS: *pinus sylvestris*, Grčka, modeli procjene volumena, metoda najbližih susjeda.