UDK 630* 537 + 238 (001)
doi:10.31298/sl.142.11-12.4

Izvorni znanstveni članci – Original scientific papers
Šumarski list, 11–12 (2018): 601–610

PREDICTING CROWN FUEL BIOMASS OF TURKISH RED PINE (*Pinus brutia* Ten.) FOR THE MEDITERRANEAN REGIONS OF TURKEY

PROCJENA GORIVA IZ BIOMASE KROŠANJA BORA (*Pinus brutia* Ten.) U MEDITERANSKIM PODRUČJIMA TURSKE

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SUMMARY

Accurate fuel load estimation is an important prerequisite for effective forest fire management. The aim of this study was to develop empirical allometric equations for the estimation of crown fuel loading of Calabrian pine (*Pinus brutia* Ten.) trees of Southwestern Mediterranean region of Turkey using dendrometric variables. For this study, 84 trees were sampled destructively. Branch samples of crown fuel biomass were classified as foliage and as branches within the following diameter ranges: very fine (≤0,3 cm), fine (0,31–0,6 cm), medium (0,61–1.0 cm), thick (1,01–2,5 cm) and active fuels. To estimate the crown biomass, the diameter at breast height, tree height, crown length, and crown width were used as the independent variables. Stepwise function and logarithmic linear regression models were used to analyze the relationships between the fuel biomass and properties of the sampled trees. Among all of the obtained allometric equations, the variation in fine branches was explained the most by crown width and crown length which together explained R^2_{adj} of 90.2 of the variation in fine branches. The variation in very fine branches was explained the least by tree height, which only explained R^2_{adj} of 60.4% the variation in very fine branches. The total crown fuel loading of Calabrian pine in present study compared with studies distributed in Greece and Turkey indicate, the fuel biomass of Calabrian pines can differ between regions.

KEY WORDS: crown biomass, fuel load, Calabrian pine, Mediterranean regions

INTRODUCTION
UVOD

Although fires are an important and natural part of Mediterranean ecosystems, there has been a notable increase over the past decades in the number and total area of forest fires in the European Mediterranean Basin, which has resulted in significant damage (Martínez et al,. 2008; Tampakis et al., 2005). Since the 1950s, the relationships between socio-economic and geophysical factors played an important role in increasing the risk of forest fires in the region (Viedma et al., 2017).

Fire plans need to be effective in preventing potential fires and minimizing possible damages, while also offering a useful method for fighting fires (Vasconcelos et al., 2001). An important prerequisite for successful fire management is the accurate estimation of the fuel load (Bond-Lamberty et

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al., 2002). Fuel load models are an important basis for determining fire behavior, fire hazard risks, fire management plans, and decision-supporting system for fire management (Alexander, 2007; Sandberg et al., 2001). An important prerequisite for successful fire management is the accurate estimation of the fuel load (Bond-Lamberty et al., 2002). Equations for estimating fuel load are an important basis for determining fire behavior, fire hazard risks, fire management plans, and decision-supporting system for fire management (Alexander, 2007; Sandberg et al. 2001). The amount of data required for the development of fire propagation models in fire estimation systems is gradually increasing (Sandberg et al., 2001). Estimations of typical forest fire features such as fire propagation ratio, fuel consumption, fire intensity, and flame size utilize fuel loading values (Dimitrakopulos, 2002), as well as spatial heterogeneity, which affects these factors (Fernandes, 2009; Hiers et al., 2009). Predicting tree biomass based on fuel inventories provide important modeling data for fire managers and researchers to determine aboveground primary production and so to estimate the fuel load characteristics (Bond-Lamberty et al., 2002; Küçük et al., 2008). Allometric relationships related to structural components of tree species are generally used for predicting intensity and rate of spread of crown fires (Cruz et al., 2003; Gray and Reinhardt, 2003). As independent variables, most allometric equations for measuring tree biomass use either the diameter at breast height (DBH, 1,3 m) (Zianis and Mencuccini, 2004), or the DBH value along with the tree height (H) (Poudel and Temesgen, 2015). DBH is a commonly used and preferred parameter, owing to the fact that it has high correlation with tree biomass (Jiménez et al., 2013), and can be easily obtained from forest inventories (Mitsopoulos and Dimitrakopoulos, 2007a). RCD (root collar diameter) is usually used in allometric equations for estimating biomass of young trees below 1.3 m in DBH (Annighöfer et al., 2016). It is also used to estimate the fuel biomass of young forest areas Küçük et al., 2008). Aside from DBH, H and RCD, crown length (CL) and crown width (CW) have also been used as independent factors to estimate crown biomass in homogeneous stands of many coniferous tree species (Cruz et al., 2003; Mitsopoulos and Dimitrakopoulos, 2007b).

In DBH-based allometric equations, errors in biomass stock measurements generally stem from their usage on larger diameter trees, rather than on the faster growing, smaller diameter trees for which they are more appropriate (Singh et al., 2011). In fact, an increasing number of papers are being published on crown fuel characteristics of trees with DBH values above 8 cm in diameter (Jiménez et al., 2013; Molina et al., 2014; Zianis et al., 2011). On the other hand, problems in estimating the fuel biomass properties of saplings and seedling in fire-prone forests render the estimation of fire behavior even more difficult (Küçük et al., 2008).

In Turkey's Mediterranean biogeography, the proper and sufficient assessment of fuel loads for trees with varying diameters is of strategic importance in fighting fires in this region, which is characterized by a variable topography and stand type. The aim of this study was to develop empirical allometric equations for the estimation of crown fuel loading of Turkish red pine (*Pinus brutia* Ten.) trees of Southwestern Mediterranean region of Turkey using dendrometric variables. Estimated crown fuel loads could be used in fire behaviour models. Calabrian pine forests cover a total area of 5,85 million ha in Turkey, and constitute 27% of the country's forests (OGM, 2015). These forests are distributed on the Mediterranean coasts of Turkey, between 1,200 to 1,400 m (supra-Mediterranean stratum) from sea level (Boydak et al., 2006). Calabrian pine forests of Turkey's Mediterranean, Aegean, and Marmara regions are designated as first-degree fire sensitive (i.e. fire prone) areas by Turkey's competent forestry authority (OGM, 2013).

METHODS
METODE

Study Site – *Područje istraživanja*

This study was conducted in Turkish red pine forests distributed in the Antalya province, which is located on Turkey's Southwestern Mediterranean coast (Figure 1). The Antalya province of Turkey is in the country's Southwestern Mediterranean region; its climate is described by Iyigun et al. (2013) as a dry summer subtropical humid coastal Mediterranean climate. This type of Mediterranean climate is characterized by high levels of winter precipitation, as well as hot and dry long-summer season mainly associated with

Figure 1. Locations of data sampling sites
Slika 1. Lokalitet mjesta prikupljanja podataka

Table 1. The distribution of Turkish red pine crown fires within forest fires in the Antalya province between 1979 and 2012.

Tablica 1. Distribucija požara krošnji kalabrijskog bora u sklopu šumskih požara u Antaliji između 1979. i 2012. godine

	Total Ukupno	Turkish red pine Krošanja bor	%
Burnt area (ha) Opožareno površina (ha)	57.041,8	50.116,49	87,86
Number of fires Broj požara	6.875	5.825	84,73
Area of crown fires (ha) Površina požara krošanja (ha)	43.891,8	39.095,79	89,07
Number of crown fires Broj požara krošnji	2.107	1.673	79,40

the large-scale weather systems, both of which are influenced by seasonal and inter-annual variations.

The total area of the study was 598.051,31 ha, while the total forest area was 255.748,82 ha. Turkish red pine forests constitute 192.501,79 ha of this area, which corresponds to 75.26% of the forested areas within the studied region. An evaluation of forest fires in Antalya between 1979 and 2012 revealed that although crown fires occurred less often, 89.07% of the burnt areas in Turkish red pine forests were the crown fires (Table 1).

Data Collection and Sampling – *Prikupljanje i uzorkovanje podataka*

In this study, 7 saplings and 77 trees were sampled destructively. Trees were randomly sampled only in fire prone areas of Antalya province. H, CW, CL, age, RCD and DBH were measured as independent variables. Vertex IV was used for the H and CL measurements. Following these measurements, the trees were cut in order to measure their crown fuel load. After all the trees were cut, the fuel biomass in their crowns were destructively sampled. Different sampling methods were used to sample the fuel load of the crowns of large and young trees. The first method was used for large trees with a DBH greater than 8 cm and a crown length of at least 3 m. In this method, the live crown (CL) of the cut trees were measured and divided equally into 21 sections. All living and dead fuel materials originating in sections 1, 6, 11, 16, and 21 were removed and separated by fuel size classes (foliages and fuel branches), and then weighed. Weight values obtained through this method were then multiplied with a factor of 4,2 to sample the crown fuel load (Küçük et al. 2008; Robichaud and Methven 1992). In the second method, all fuel crown biomass of young trees with a DBH less than 8 cm and a crown length below 3 m were removed, and then separated by fuel size classes. The removed and classified material was then weighed. Dead fuel branches were not included in the analyses.

Branch samples of crown fuel biomass were separated into standard fuel size classes (Scott and Reinhardt, 2002). Crown fuel biomass classes are foliage, <0,3 cm very fine branches, 0,3–0,6 cm fine branches, 0,6–1,0 cm medium branches and 1,0–2,5 cm thick branches. The main reason to use this classification that the finest fuels are the first to be consumed before the crown fuel biomass are entirely consumed in the flaming front of a crown fire. In fact, only the finest fuels burn in the short duration of a crown fire (Mitsopoulos and Dimitrakopoulos, 2007b; Stocks et al., 2004). In this way, a separate class designated as "active fuels" (Küçük et al., 2008) and foliage and branches thinner than 0,6 cm were added to the crown fuel biomass classification, to indicate materials that are more predisposed to be consumed. Total fuel biomass was determined by weighing the foliage and different fuel branches classes of each tree. Foliage and branches by diameter classes were taken as samples and weighed once again. In this study, we have used oven-drying of fuel samples to determine fuel moisture content (Matthews, 2010). These samples were dried in 103 ± 2°C ovens for 24 ±1 hours to obtain oven-dried samples. The oven-dried samples were then weighed. Based on the ratio between the live weight and oven-dried weight of the samples, the oven-dried weight of the foliage and fuel branches on every tree was determined. In the study, oven-dried weights were used as fuel load values in tables and figures.

Statistical Data Analysis – *Statistička analiza podataka*

Correlation and regression analyses were used to examine the relationships between tree properties and crown fuel biomass. Stepwise function and logarithmic linear regression models were used to analyze the relationships between fuel biomass and the measured tree properties. Logarithmic regression is commonly used to estimate the relationships between crown fuel load and the different properties of trees and crown (Mitsopoulos and Dimitrakopoulos, 2007a; Molina et al., 2014). The equation used was [$ln(Y) = a + bln(x) + \varepsilon$], where, Y is the dependent variable (needle, branch or total biomass), *ln* is the natural logarithm, x is the independent variables, *a* is the constant, *b* is the regression coefficients, and ε is the error term. The residual variance of dependent and independent variables is both used in the analysis of allometric relationships. For this reason, logarithmic transformation is necessary to remove residual heteroscedasticity (Socha and Wezyk, 2007).

All selected equations were significant at least at P=0,05 significance level. Regression and correlation analyses were performed using IBM SPSS 20.0 for Windows. The measured tree properties H, CL, CW, RCD and DBH were used as independent variables, while the foliage and branch biomasses were used as the dependent variables. Before the variables were analyzed, there were tested for normality.

RESULTS
REZULTATI

In this study, the tree properties exhibited high variation. RCD of saplings varied from 1 cm to 5 cm, while H of RCD saplings varied from 1,25 m to 1,65 m . DBH varied from 1,5 cm to 42 cm, while H varied from 1,9 m to 26,7 m. Other descriptive statistics are provided in Table 2. The results of the correlation analysis are shown in Table 3. In general, the crown fuel components were found to be significantly correlated to H, RCD, DBH, CW, and CL. All of the crown fuel components had a strong relationship with CL. According to Table 3, all the crown fuel components had a strong relationship (p=0,01) with all the tree properties.

To develop allometric equations that allow estimating the biomass of crown fuel components, the measured tree properties were used as independent variables in different allometric equations. All allometric relationships identified between the dependent and independent variables are shown in Table 4. Among the different allometric equations, the variation in fine branches was explained the most by CW and CL, which together explained 90% of the variation in this parameter (P<0.001). On the other hand, the variation in very fine branches was explained the least by H, which could only explain 60.4% of the variation (P<0.001). The variation in total fuels was explained the most by CW and CL, which together explained 89.8% of the variation in this parameter (P<0.001). On the other hand, the variation in total fuels was explained the least by H, which could only explain 78.4 % of the variation (P<0.001). The variation in active fuels was explained the most by H, CW, and CL, which together explained 86.8% of the variation (P<0.05). This trio of properties also explained 81.6% of the variation in foliage (P<0.001).

The mean fuel load distribution of the crown fuel components show that thick branches were the most common, representing 31.43% of the components, followed by foliage mass, representing 29.98% of the components. Active fuels constituted 56.6% of the total crown biomass (Figure 2). The relationship between by DBH estimated and actual val-

Table 2. Descriptive statistics on tree properties and fuel biomass types (s.d.: standard deviation; S.E.E.: standard error of the estimate)
Tablica 2. Deskriptivna statistika značajki stabala i tipova goriva iz biomase (s.d. standardna devijacija; S.E.E: standardna greška procjene)

Statistic *Statistika*	Age *Starost*	RCD (cm)	DBH (cm)	H (m)	CW (m)	CL (m)	Foliage *Iglice* (kg)	Branch (kg) – *Grane* (kg)				Total fuels *Ukupno gorivo* (kg)
								Very fine *Vrlo tanko* (0–0,3 cm)	Fine *Tanko* (0,3–0,6 cm)	Medium *Srednje* (0,6–1 cm)	Thick *Debelo* (1–2,5 cm)	
N	84	7	77	84	84	84	84	84	84	84	84	84
Min.	5	1	1,5	1.25	0.53	1	0.113	0.035	0.039	0.010	0.068	0.280
Max.	93	5	42	26.7	8.6	15	20.45	5.939	8.958	8.188	17.694	53.988
Mean	25.131	2,13	14.73	9.313	3.389	6.053	4.227	1.228	2.525	1.688	4.431	14.098
S.E.E.	2.008	1,062	1.046	0.637	0.196	0.350	0.415	0.126	0.245	0.195	0.442	1.310
s.d.	18.401	1,36	9.315	5.840	1.798	3.210	3.804	1.155	2.250	1.791	4.054	12.008

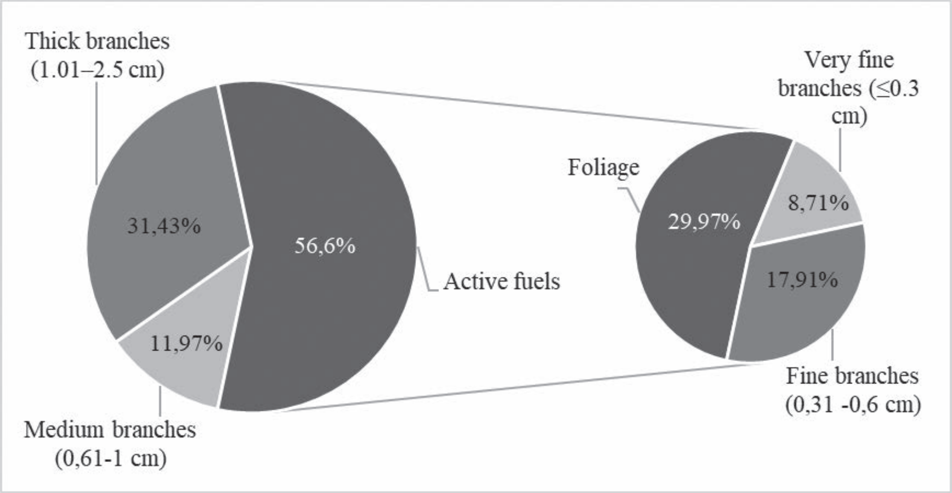

Figure 2. Percentage distribution of the crown fuel component's mean fuel loads
Slika 2. Postotna distribucija srednjih količina goriva iz komponenti goriva u krošnji

Table 3. Correlation matrix of the variables used in the analyses
Tablica 3. Korelacijska matrica varijabli korištenih u analizi

n=84	H	DBH	CW	CL	Foliage *Iglice*	Branch – *Grane* (kg)				Active fuels	Total fuels *Ukupno gorivo*
						Very fine *Vrlo tanko*	Fine *Tanko*	Medium *Srednje*	Thick *Debelo*		
H	1										
DBH	.948**	1									
CW	.851**	.928**	1								
CL	.898**	.886**	.847**	1							
Foliage Iglice	.601**	.619**	.639**	.728**	1						
Very fine Branches Vrlo tanke grane	.496**	.515**	.585**	.585**	.701**	1					
Fine branches Tanke grane	.765**	.788**	.773**	.794**	.834**	.746**	1				
Medium branches Srednje debeke grane	.711**	.732**	.732**	.790**	.780**	.640**	.842**	1			
Thick branches Debele grane	.804**	.773**	.745**	.846**	.791**	.699**	.889**	.836**	1		
Active fuels Aktivna goriva	.682**	.702**	.721**	.778**	.966**	.818**	.935**	.833**	.865**	1	
Total fuels Ukupna goriva	.759**	.764**	.764**	.839**	.924**	.789**	.949**	.898**	.947**	.976**	1

** Correlation is significant at the 0.01 level (2-tailed). H (tree height), DBH (diameter at breast height), CW (crown width), CL (crown lenght)
Korelacija je značajna na razini od 0.01 (dvosmjerni). H (visina stabla), DBH (prsni promjer), CW (širina krošnje), CL (duljina krošnje)

n=84	H	RCD	DBH	CW	CL	Foliage *Iglice*	Branch – *Grane* (kg)				Active fuels	Total fuels *Ukupno gorivo*
							Very fine *Vrlo tanko*	Fine *Tanko*	Medium *Srednje*	Thick *Debelo*		
H	1	,481										
RCD	,481	1										
DBH	.940**	x	1									
CW	.821**	,865*	.918**	1								
CL	.876**	,619	.870**	.813**	1							
Foliage Iglice	.548**	,996**	.572**	.590**	.693**	1						
Very fine branches Vrlo tanke grane	.430**	.994**	.457**	.530**	.529**	.671**	1					
Fine branches Tanke grane	.732**	.900**	.760**	.741**	.766**	.816**	.718**	1				
Medium branches Srednje debeke grane	.682**	.977**	.706**	.706**	.775**	.760**	.608**	.828**	1			
Thick branches Debele grane	.777**	.623	.744**	.710**	.828**	.768**	.667**	.876**	.821**	1		
Active fuels Aktivna goriva	.634**	.350	.662**	.678**	.745**	.962**	.799**	.927**	.818**	.849**	1	
Total fuels Ukupna goriva	.723**	.999**	.731**	.728**	.817**	.916**	.766**	.943**	.889**	.940**	.973**	1

** Correlation is significant at the 0.01 level (2-tailed). H (tree height), RCD (root collar diameter), DBH (diameter at breast height), CW (crown width), CL (crown lenght), x, cannot be computed

Table 4. Fuel load equations developed for the estimation of foliage, branch diameters, active fuels, and total crown biomass.
Tablica 4. Jednadžbe količine goriva za procjenu lišća, promjera grana, aktivnih goriva i ukupne biomase krošnji

	Model Model	Constant Konstanta	Coefficients Koeficijenti			F	Adj. R^2	s.e.e.	$P<$
		a	b	c	d				
Foliage Iglice	LnY=a+bLnH	-1.441	1.201			154.005	0.648	0.693	0.001
	LnY=a+bLnDBH	-1.391	1.019			164.118	0.663	0.679	0.001
	LnY=a+bLnH+cLnCW+dLnCL	-0.997	-0.863	1.2	1.468	123.722	0.816	0.501	0.001
	LnY=a+bLnCW	-0.766	1.62			281.936	0.772	0.558	0.001
	LnY=a+bLnCW+cLnCL	-1.194	0.963	0.689		159.697	0.793	0.532	0.05
	LnY=a+bLnCL	-1.571	1.545			253.794	0.753	0.581	0.001
Very fine branches Vrlo tanke grane	LnY=a+bLnH	-2.561	1.146			127.783	0.604	0.727	0.001
	LnY=a+bLnH+cLnDBH+dLnCL	-2.638	-0.966	0.664	1.691	65.612	0.7	0.632	0.05
	LnY=a+bLnH+cLnCW+dLnCL	-2.041	-0.684	1.349	1.041	86.262	0.755	0.572	0.05
	LnY=a+bLnDBH	-2.529	0.98			140.216	0.626	0.706	0.001
	LnY=a+bLnCW	-1.934	1.564			232.075	0.736	0.594	0.001
	LnY=a+bLnCL	-2.651	1.454			178.712	0.682	0.652	0.001
Fine branches Tanke grane	LnY=a+bLnH	-2.925	1.621			362.019	0.813	0.611	0.001
	LnY=a+bLnH+cLnDBH	-2.944	0.771	0.746		205.23	0.831	0.580	0.05
	LnY=a+bLnDBH	-2.835	1.366			374.107	0.818	0.603	0.001
	LnY=a+bLnDBH+cLnCW	-2.191	0.332	1.635		329.491	0.888	0.473	0.05
	LnY=a+bLnCW	-1.912	2.092			626.324	0.883	0.483	0.001
	LnY=a+bLnCW+cLnCL	-2.396	1.351	0.778		382.713	0.902	0.442	0.001
	LnY=a+bLnCL	-2.924	1.978			457.174	0.846	0.554	0.001
Medium branches Srednje debele grane	LnY=a+bLnH	-3.554	1.693			318.661	0.793	0.680	0.001
	LnY=a+bLnH+cLnDBH	-3.568	1.026	0.585		168.555	0.801	0.665	0.05
	LnY=a+bLnDBH	-3.423	1.411			295.094	0.78	0.701	0.001
	LnY=a+bLnH+cLnCW	-2.839	0.415	1,729		303.815	0.879	0.518	0.05
	LnY=a+bLnCW	-2.512	2.2			572.209	0.873	0.532	0.001
	LnY=a+bLnCW+cLnCL	-3.048	1.378	0.863		351.647	0.894	0.486	0.001
	LnY=a+bLnCL	-3.587	2.087			444.378	0.842	0.593	0.001
Thick branches Debele grane	LnY=a+bLnH	-2.903	1.829			371.663	0.817	0.680	0.001
	LnY=a+bLnH+cLnDBH	-2.924	0.86	0.849		211.969	0.836	0.645	0.05
	LnY=a+bLnH+cLnCW	-2.264	0.686	1.547		299.003	0.878	0.556	0.001
	LnY=a+bLnDBH	-2.803	1.542			386.186	0.823	0.669	0.001
	LnY=a+bLnDBH+cLnCW	-2.186	0.551	1.567		285.658	0.873	0.567	0.05
	LnY=a+bLnCW	-1.724	2.325			512.719	0.86	0.594	0.001
	LnY=a+bLnCW+cLnCL	-2.399	1.288	1.088		338.389	0.89	0.526	0.001
	LnY=a+bLnCL	-2.904	2.233			474.408	0.851	0.614	0.001
Active fuels Aktivna goriva	LnY=a+bLnH	-1.025	1.311			221.316	0.726	0.631	0.001
	LnY=a+bLnH+cLnCW+dLnCL	-0.533	-0.569	1.292	1.154	182.739	0.868	0.439	0.05
	LnY=a+bLnDBH	-0.969	1.112			238.704	0.741	0.614	0.001
	LnY=a+bLnCW	-0.264	1.747			443.143	0.842	0.480	0.05
	LnY=a+bLnCW+cLnCL	-0.662	1.136	0.641		254.026	0.859	0.453	0.001
	LnY=a+bLnCL	-1.107	1.65			344.808	0.806	0.532	0.001
Total Ukupno	LnY=a+bLnH	-0.851	1.477			303.118	0.784	0.608	0.001
	LnY=a+bLnH+cLnDBH	-0.868	0.683	0.696		169.412	0.802	0.582	0.05
	LnY=a+bLnDBH	-0.771	1.246			314.908	0.791	0.599	0.001
	LnY=a+bLnCW+cLnCL	-0.446	1.177	0.791		365.054	0.898	0.419	0.001
	LnY=a+bLnCL	-0.906	1.837			465.815	0.848	0.510	0.001
	LnY=a+bLnCL+cLnDBH	-0.965	1.336	0.382		252.109	0.858	0.493	0.05

H (tree height), DBH (diameter at breast height), CW (crown width), CL (crown lenght)
H(visina stabla) DBH (prsni promjer), CW (širina krošnje), CL (duljina krošnje)

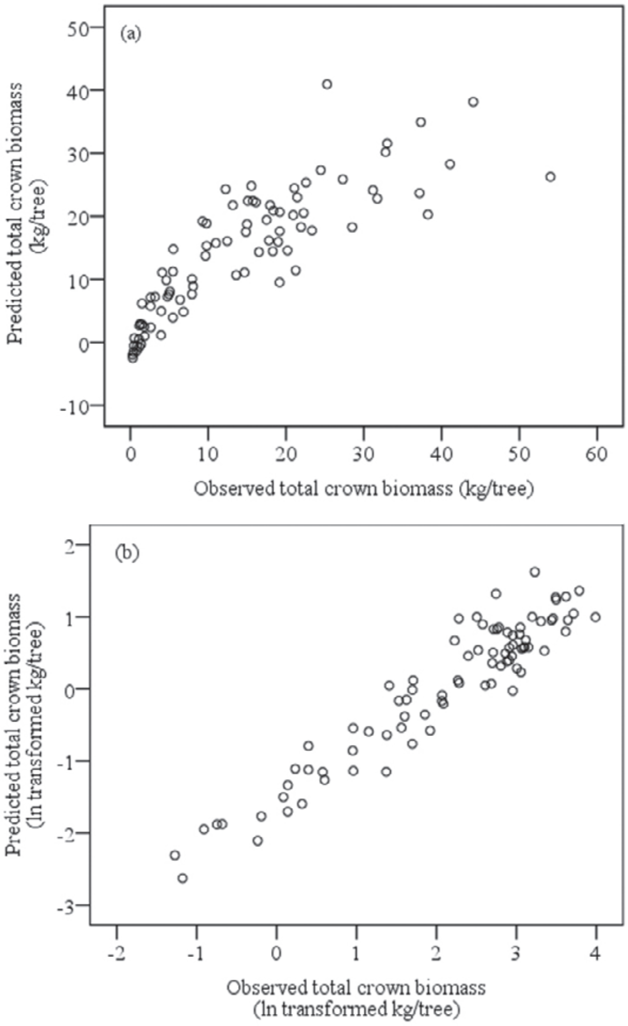

Figure.3. (a) Actual and (b) logarithmic relationship between predicted and observed total crown biomass

Slika 3. (a) Stvarni i (b) logaritamski odnosi između predviđene i utvrđene ukupne biomase krošnji

ues of total crown biomass, and the relationship between their estimated values and logarithmically converted values are shown in Figure 3. The use of fitting linear models on logtransformed data can cause the results that are biased in geometric rather than arithmetic space (Mascaro et al., 2011). Therefore, it was necessary to perform a logarithmic transformation for variables to account the heteroscedasticity. Systematic biases in estimates for total crown fuel are increasing in this study towards the large diameter trees of the small diameters, especially, trees with > 10 cm diameter are strongly heteroscedastic (Figure 3a). This is indicated for ideal allometry data to show increasing variation in tree biomass with increasing diameter (Chave et al., 2005; Mascaro et al., 2011).

The mean diameter of the trees included in this study was 13.68 cm (s.d. 9.58, mean S.E.E. 1.05). Sixty-seven of the trees had a DBH below 20 cm. The distribution of active fuels in DBH proportions displayed that the biomass of trees with DBH values greater than 10 cm tended to increase with notably greater than trees with smaller DBH values (Figure 4). Foliage mass was the largest component of active fuels, constituting 52.97%, as a mean. We considered it necessary to identify the relationship between the crown ratio (CR=CL/H×100) of the sampled tree and their DBH. As the DBH of the trees increased, we noted that their CRs also began to decrease disproportionately. On the other hand, as the DBH increased, the foliage fuels of the trees began to

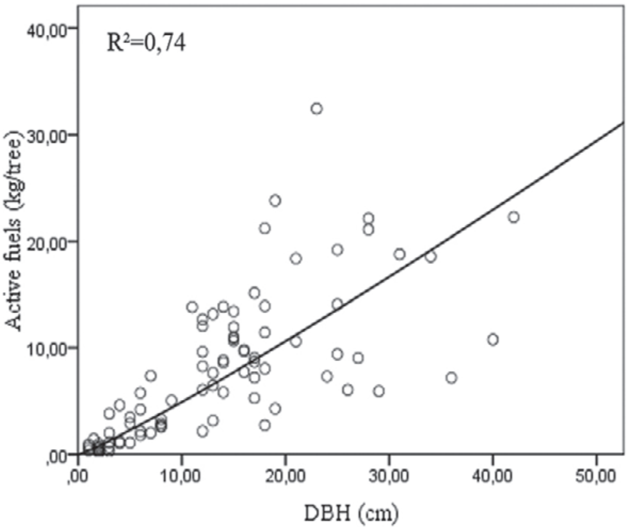

Figure 4. Active fuels as a function of diameter at breast height (DBH)

Slika 4. Aktivna goriva kao funkcija prsnog promjera (DBH)

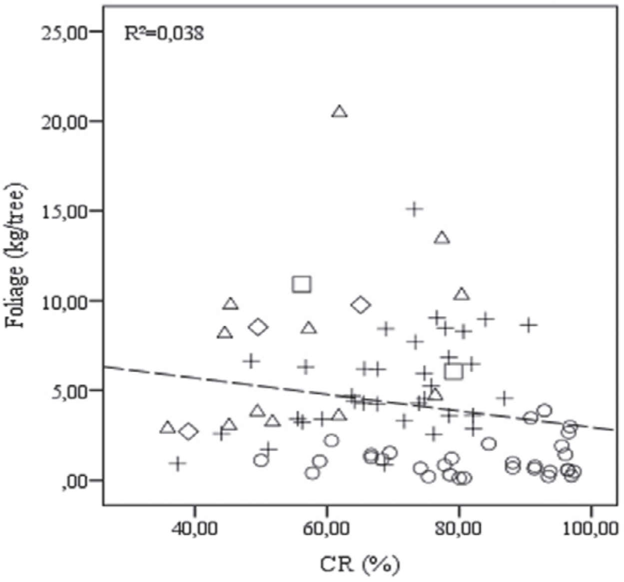

Figure 5. The proportional distribution of DBH in CR and foliage fuels. ○, trees whose DBH was < 10 cm ; + , trees whose DBH was between 10 and 20 cm; Δ, trees whose DBH was between 20 and 30 cm; ◊, trees whose DBH was between 30 and 40 cm; □, trees whose DBH was >40 cm

Slika 5. Proporcionalna distribucija DBH u CR i gorivu iz lišća.○, stabla čiji DBH je < 10 cm ; + , stabla čiji DBH je između 10 i 20 cm; Δ, stabla čiji DBH je između 20 i 30 cm; ◊, stabla čiji DBH je između 30 i 40 cm; □, stabla čiji DBH je >40 cm

Table 5. Descriptive statistics of foliage fuels according to DBH classes.
Tablica 6. Deskriptivna stastistika goriva iz iglice prema stupnjevima DBH.

DBH (cm)	Number of Trees Broj stabala	Foliage (kg/tree) – Iglice (kg/stablo)				
		Min.	Max.	Mean	SEE	s.d.
<10	20	0.65	3.88	1.65	0.213	0.951
10 - 20	35	0.89	15.1	5.36	0.482	2.849
20 - 30	12	2.88	20.45	7.65	1.54	5.336
30 - 40	3	2.71	9.76	7.00	2.174	3.766
>40	2	6.06	10.91	8.48	2.426	3.431

DBH (diameter at breast height)
DBH (prsni promjer)

increase disproportionately (Figure 5). These changes can be easily understood from the s.d. and S.E.E. of the foliage fuel distributions in the DBH proportions (Table 5).

DISCUSSION AND CONCLUSIONS
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Regression models were developed to assess the foliage, branch, and active and total fuel biomass of 84 Turkish red pine. The regression models aimed to describe the relationship between fuel biomass components and tree properties (H, DBH, CW, CL). When the adjusted coefficient of determination (R^2_{adj}) values were evaluated, it was observed that fine branches had the highest explanation percentage with 90%, while total fuels had second highest with 89,8%, and thick branches had third highest with 89%. The lowest R^2_{adj} value was observed with fine branches, at 60.4%, followed by foliage, at 64.8%. Although the R^2_{adj} value was generally high in equations involving both CW and CL, and generally low in equations involving H, it was still understood that all tree properties could be used for determining crown fuel loads in Calabrian pines. Comparisons with other studies on crown fuel load in Calabrian pines indicate that H, DBH, CW, and CL are all important predictive variables for this tree (Küçük et al., 2008; Zianis et al., 2011).

In a study performed by Küçük et al. (2008) on Turkish red pine forests across northwestern Turkey, the mean oven-dried weight of total crown fuel biomass for trees and saplings together, and its properties was 2.47 kg/tree (n= 324, mean DBH= 15.49 cm., mean H= 2.27 m., mean CW=1.1 m., mean CL= 1.6, s.d.= 5557.2, S.E.E.= 319.781, R^2_{adj}= 0.944). The mean value of total crown fuel biomass for trees and saplings in our study was 14,098 kg/tree (Table 2). Another study performed by Küçük and Bilgili (2008) found results similar to our study. In the said study, the mean oven-dried weights of fuel biomass was 16.54 kg/tree (n= 35, mean DBH= 15.91 cm, mean H= 10.25 m., mean CW=3.74 m, mean CL= 5.75, R^2_{adj}= 0.799). In a study performed by Zianis et al. (2011) in the Turkish red pine forests of Greece's island of Crete and Lesvos. The total fuel load results on island Create were closer to the findings of Küçük et al. (2008). In this study performed in Crete, the mean oven-dried weight of the total crown fuel biomass (T_1+T_2) was determined as 3.83 kg/tree (n= 12, mean DBH= 18 cm, mean H= 8 m). T1 is dry biomass of needles and twigs up to 0.63 cm in diameter and T_2 is dry biomass of branch wood 0.64-2.5 cm in diameter. As these comparisons indicate, the fuel biomass of Calabrian pines can differ between regions. In this study, an increase in DBH did not inevitably result in an increase in foliage fuel biomass, while CR was generally found to scatter disproportionately. However, this does not mean that trees with high DBH values consistently have lower foliage fuel biomass than trees with low DBH values. It must be considered that such a generalization might lead to erroneous and inaccurate assessments. A study performed by Affleck et al. (2012) to characterize the crown profile and crown mass of conifer forests showed that the total crown fuel biomass distributed disproportionately from the relationship between CR and DBH. The same study concluded that in crown biomass studies, large conifer trees are generally present in smaller number, while their effect on overall biomass per unit area is disproportionate. In fact, the species included in the study of Affleck et al. (2012), which was conducted in the Interior Northwest of USA, are quite different from Calabrian pine. The similar results compared with our study regarding to same tree species appeared in the study of Zianis et al. (2011). The distribution of average total crown fuel biomass to the DBH sizes (7,3 – 30 cm) in their study were disproportionately and differentiated in each site. The variability between biomass equations are generally due to the increasing size between the independent variables (Zianis and Mencuccini, 2004).

Although fuel characterization and classification is a mathematical modelling (Alexander 2007), the differences in these models is generally due to the distinguishing features of individuals in nature, and the complex compositions that stem from structural and spatial distributions (Affleck et al., 2012; Fernandes, 2009). In addition, it is believed that the hazard, risk, and severity of forest fires are also associated with the ecological context, which includes components such as historical natural fire regimes, time, space, and process (Hardy 2005). For this reason, there is a need to simply and constantly renew and develop fuel classification approaches (Sandberg et al., 2001). Although fuel characterizations and classifications have great importance in fire behavior modelling, using them on their own is not sufficient for fire decision support systems. Especially in large administrative areas, fuel loads will not be unique due to the reasons mentioned above, and there is consequently a need for different fuel load standards rather than a single fuel load standard. In decision-making processes for fire management, it is important to take into account standards that will include factors other than fuel appraisal (Alexander, 2007). In addition to its variable topography and forest structures, the Mediterranean region of Turkey is also seeing a considerable demand for tourism, agriculture, and settlement. For this reason, fuel-loading studies should be enriched by also taking human intervention, canopy structures, and site conditions into account. Doing so will allow forest fire behavior analyses to be more effective, thus enabling decision-makers dealing with forest fires in the region to obtain far more accurate data and results.

ACKNOWLEDGEMENT
ZAHVALA

This study has been supported by the General Directorate of Forestry connected to The Turkish Ministry of Forestry and Water Affairs as a research-development project with number: 19.9200/2012-2014-2015.

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SAŽETAK

Točna procjena količine goriva je važan preduvjet za učinkovito upravljanje šumskim požarima. Ovo je istraživanje imalo za cilj razviti empirijske alometrijske jednadžbe za procjenu količine goriva iz krošnji stabala kalabrijskog bora (*Pinus brutia* Ten.) u jugozapadnom mediteranskom području Turske korištenjem dendrometrijskih varijabli. Destruktivnom metodom uzorkovana su 84 stabla. Uzorci grana u gorivu iz biomase krošnji klasificirani su kao iglice i kao grane prema sljedećem rasponu promjera: vrlo tanke (≤0,3 cm), tanke (0,31–0,6 cm), srednje (0,61–1,0 cm), debele (1,01–2,5 cm) i aktivno gorivo. Za procjenu biomase krošnjanja korištene su prsne visine, visine stabala, visine krošnji i širine krošnji kao neovisne varijable. Za analizu odnosa između goriva iz biomase i značajki uzorkovanih stabala korišteni su *stepwise* funkcija i modeli logaritamske linearne regresije. Od svih dobivenih alometrijskih jednadžbi, varijacija u tankim granama najbolje je objašnjena širinom krošnji i visinom krošnji, koje zajedno objašnjavaju R^2_{adj} od 90.2 varijacije u tankim granama. Varijacija u vrlo tankim granama objašnjena je najslabije visinom stabla, koja samo objašnjava R^2_{adj} od 60.4% varijacije u vrlo tankim granama. Ukupna količina goriva iz krošnji kalabrijskog bora u ovom istraživanju u usporedbi s istraživanjima u Grčkoj i Turskoj pokazuje da se gorivo iz biomase kalabrijskog bora može razlikovati od regije do regije.

KLJUČNE RIJEČI; biomasa krošnje, šumsko gorivo, kalabrijski bor, mediteranska područja