Comparison of tree volume equations for brutian pine stands in Eğirdir district

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Abstract: In this study, tree volume equations have been developed for Brutian pine (*Pinus brutia* Ten.). The data was obtained from the natural brutian pine stands in Eğirdir region. Totally of 405 trees are sampled and randomly separated into the two groups. Since there is no real independent dataset, two-fold evaluation scheme was applied and the prediction performance of 18 models was evaluated. For this purpose, four different criteria values were used: mean error (*MD*), mean absolute error (*MAD*), coefficient of determination (R^2) and root mean square error (*RMSE*). The prediction performances of the models were evaluated on the basis of relative ranking. As a result of the evaluations, the most successful results were obtained with Model 4, while the most unsuccessful results were obtained with model 6. The obtained results suggested that Model 4 should be used to more reliable volume predictions for natural brutian pine stands in Eğirdir Region
Keywords: Brutian pine, Volume prediction, Nonlinear models, Diameter, Relative rank

Eğirdir yöresi kızılçam meşcereleri için ağaç hacim denklemlerinin karşılaştırılması

Özet: Bu çalışmada, Kızılçam (*Pinus brutia* Ten.) için ağaç hacim denklemleri geliştirilmiştir. Veriler, Eğirdir yöresi doğal kızılçam meşcerelerinden elde edilmiştir. 405 örnek ağaç ölçülmüş ve tesadüfi olarak iki gruba ayrılmıştır. Gerçek anlamda bağımsız veri setine sahip olunmadığı için çapraz geçerlilik testi uygulanarak, 18 modelin ortalama hata (MD), ortalama mutlak hata (MAD), belirtme katsayısı (R²) ve hata kareler ortalamasının karekökü (RMSE) değerleri hesaplanmıştır. Modellerin tahmin performansları, bu dört ölçüt değeri esas alınarak hesaplanan model nisbi sıralarına göre değerlendirilmiştir. Yapılan değerlendirmeler sonucunda, en başarılı sonuçlar Model 4 ile elde edilirken, en başarısız sonuçlar model 6 ile elde edilmiştir. Elde edilen sonuçlar, Eğirdir yöresi doğal kızılçam meşcerelerinde güvenilir hacim tahminleri için Model 4'ün kullanılmasını önermektedir.
Anahtar kelimeler: Kızılçam, Hacim tahmini, Nonlinear models, Çap, Nisbi sıra

1. Introduction

Tree volume prediction is an key tool for estimating volume at different merchantable heights (Dieguez-Aranda et al. 2006), estimating woody biomass and assessment of carbon stocks (Zianis et al., 2005; Castedo-Dorado et al. 2012), forest management and planning (Rodríguez et al. 2014), monitoring forest health and productivity (Gómez-García et al., 2015), and future projections of the forest products industry (de-Miguel et al. 2012). Thus, flexible and reliable volume estimation methods that also can be easily integrated to any growth and yield models are needed in order to estimate the single tree and stand volumes in Turkey (de-Miguel et al., 2012).

Tree volume equations and tree volume tables are the most popular methods for estimating the tree stem and timber volume since the past. Single, double and multi-entry tree volume models have been used to generate tree volume tables (Burkhart and Tome, 2012). It is seen that a large number of different types of models are used in the studies to develop tree volume equations (Ritchie and Hann, 1984; Hjelm and Johansson, 2012; Rachid et al., 2014). In Turkey, tree volume equations have been developed by various researchers on a regional basis (Bozkuş and Carus, 1997; Yavuz, 1999; Özkurt, 2000; Sakıcı and Yavuz, 2003; Mısır

and Mısır, 2004; Kahriman et al., 2017; Özçelik and Çevlik, 2017; Özçelik and Kalkanlı, 2018; Sakıcı et al. 2018).

Brutian pine is one of the most important commercial tree species in Turkey. According to the latest forest inventory data, Brutian pine covers more than 5.7 million hectares and has about 270 million m^3 growing stock in our country (OGM, 2018). On the other hand, brutian pine forests play a key tool in important environmental issues such as protecting biodiversity, protection of soil and water resources, and reducing the negative impact of climate change.

Therefore, in the development of strategies for the management and planning of Brutian pine forests, wide geographic distribution, and related ecological conditions must be taken into consideration. However, in forest management plans, it is often observed that the same volume tables are used in large geographical regions without considering the differences in the growing environment. As a result of this, large and unacceptable errors can occur in volume predictions when applying a tree volume equation to trees in different areas (Brooks et al., 2008). Pillsbury et al. (1995) indicated that when volume tables or equations used by foresters without verification of their appropriateness, this practice can lead to errors in volume estimates of 40% or more. Therefore; tree volume

tables should be generated by considering regional differences (Brooks and Wiant, 2008).

In recent years, Turkey has adopted the principles of multipurpose and ecologically-based forest management. Therefore, the General Directorate of Forestry needs to develop growth and yield prediction models for the management of forest resources. As indicated by Klos et al. (2007), one of the essential building blocks in forest growth and yield modeling are the equations for estimating individual tree volume of different tree species. However, individual tree volume equations for major tree species have not been developed in different local environmental conditions of Turkey. Since accurate volume estimations depend heavily on local environmental conditions. Therefore, successful implementation of ecosystem-based functional planning studies for brutian pine stands necessitated the development of tree volume equations for different ecological regions or local environmental conditions. On the other hand, developed individual stem volume models could help forest managers to account for regional variations in tree volume and sustainable forest management applications.

The primary objectives of this study were to develop and compare eighteen different volume equations for more accurate tree volume estimates for natural Brutian pine stands in Eğirdir Region.

2. Material and methods

2.1. Material

Data were obtained from the natural Brutian pine stands in Eğirdir Region, Isparta. Sample trees were obtained throughout the area of distribution of Britian pine in the Eğirdir Region. Total of 405 sample trees was selected for this study. The trees also were subjectively selected to ensure a representative distribution by diameter and height classes within stands. Trees possessing multiple stems, broken tops, obvious cankers or crooked boles were not included in the sample. Diameter (*d*-diameter at breast height) of the trees were measured by the electronic caliper with the precision of 0.1 cm before cutting and the height (*h*) of the trees were measured by the tape measure with the precision of 0.05 cm. Actual cubic volume for each tree was estimated using overlapping bolts method described by Bailey (1995).

The data were randomly divided into two groups as Group I and Group II, each containing 203 and 202 trees, respectively. Distributions of the dataset for Group I and Group II by diameter and height classes and descriptive statistics were given in Table 1, 2, and 3, respectively. Figure 1 present scatter plots of dbh versus height and dbh versus volume for Group I and Group II.

2.2. Methods

Based on previously published papers, in forestry studies, many tree volume equations are used in different forms in order to develop tree volume equations (Saraçoğlu, 1988; Bi and Hamilton, 1998; Yavuz, 1999; Mısır and Mısır, 2004; Teshome 2005; Akindele and LeMay, 2006; Perez, 2008; Alegria and Tome, 2011; Hjelm and Johansson, 2012; Stolarikova et al., 2014; Malata et al., 2017; Lee et al., 2017; Özçelik and Çevlik 2017; Kitikidou et al., 2017; Sakıcı et al., 2018). In this study, following eighteen volume models in different forms obtained from the above-mentioned references are used.

Table 1. Distribution of sample trees by diameter and height classes for Group I

Diameter (cm)	5	7	9	11	13	15	17	19	21	23	25	27	Σ
8	4	11	7										22
12		3	20	11	4								38
16			7	17	7	3							34
20				5	3	4		1					13
24					2	3	2	1					8
28					3	6	11	7	2				29
32					1	3	3	4	4	1			16
36						1		3	4	1		1	10
40							1	2	5	3	1	1	13
44								2	3	1	2		8
48								1	2	1	2	1	7
56										2	1	1	4
60										1			1
Σ	4	14	34	33	20	20	17	21	20	10	6	4	203

Table 2. Distribution of sample trees by diameter and height classes for Group II

Diameter (cm)	5	7	9	11	13	15	17	19	21	23	25	27	Σ
8	2	4	6	1									13
12		7	19	11	2								39
16		1	4	11	6	3							25
20				4	6	2							12
24					4	7	4	1	1				17
28						6	8	5	3				22
32						5	2	9	5	1			22
36						2	3	5	6	2			18
40							1	3		3	1		8
44								4	4	6			14
48							1			2	4		7
56										1	1		2
60										2			2
Σ	2	12	29	27	18	25	19	27	19	17	5	2	202

Table 3. Descriptive statistics for used trees by groups

Variables	Group I (n = 203)				Group II (n = 202)			
	Mean	Min.	Max.	S.D.	Mean	Min.	Max.	S.D.
DBH (cm)	25.05	7.50	58.00	12.40	23.13	6.00	60.50	12.66
THT (m)	15.12	5.50	26.50	5.21	14.48	4.82	26.50	5.37
V (m³)	0.4989	0.0148	2.6827	1.20	0.4375	0.0083	2.7128	0.5510

DBH: diameter at breast height; *THT*: total tree height; *V*: tree volume.
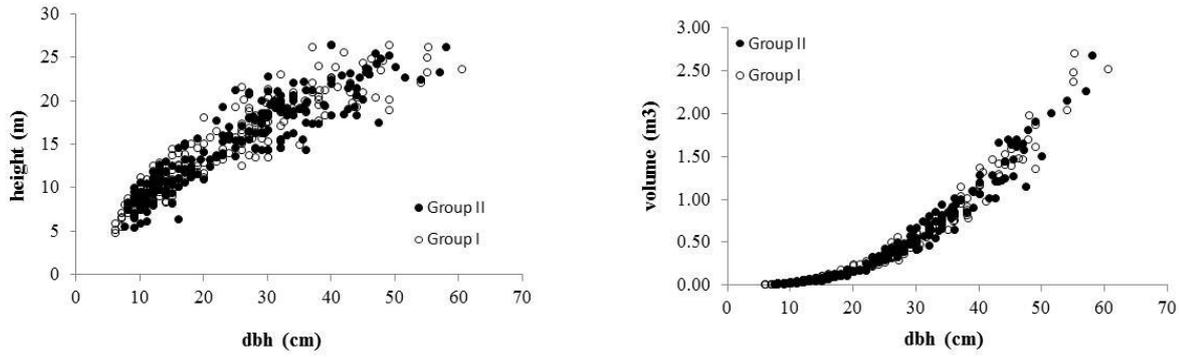
Figure 1. Scatter plots of dbh versus height and dbh versus volume for Group I and Group II

$$v = \beta_0 + (\beta_1 d^2 h) \qquad\qquad \text{(Borset, 1954)} \qquad (1)$$

$$v = (\beta_0 + \beta_1 d)^2 \qquad\qquad \text{Perez and Kanninen (2003)} \qquad (2)$$

$$v = \beta_0 d^2 h \qquad\qquad \text{(Spurr, 1952)} \qquad (3)$$

$$v = \beta_0 d^{\beta_1} h^{\beta_2} \qquad\qquad \text{(Schumacher-Hall, 1973)} \qquad (4)$$

$$v = \frac{d^2}{\beta_0 + \beta_1 h^{-1}} \qquad\qquad \text{(Honer, 1967)} \qquad (5)$$

$$v = \beta_0 + \beta_1 d^2 h + \beta_2 h \qquad\qquad \text{(Rachid-Casnati et al., 2014)} \qquad (6)$$

$$v = \frac{d^2 h}{\beta_0 + \beta_1 d} \qquad\qquad \text{(Takata, 1958)} \qquad (7)$$

$$v = \beta_0^{\left(2+\frac{d}{h}\right)} + \beta_1 h^2 + \beta_2 dh^2 \qquad\qquad \text{(Hjelm and Johansson, 2012)} \qquad (8)$$

$$v = \beta_0 + \beta_1 (h/d)^{\beta_2} d^2 h \qquad\qquad \text{(Teshome, 2005)} \qquad (9)$$

$$v = d^2 (\beta_0 + \beta_1 h) \qquad\qquad \text{(Ogaya, 1968)} \qquad (10)$$

$$v = \beta_0 d^2 + \beta_1 d^2 h - \beta_2 d^2 h^2 - \beta_3 dh + \beta_4 dh^2 \qquad\qquad \text{(Eriksson, 1973)} \qquad (11)$$

$$v = \beta_0 + \beta_1 d^2 h + \beta_2 d^3 h + \beta_3 d^2 h^2 + \beta_4 h \qquad\qquad \text{(Bi and Hamilton, 1998)} \qquad (12)$$

$$v = \beta_0 (d^2 h)^{\beta_1} \qquad\qquad \text{(Malata et al., 2017)} \qquad (13)$$

$$v = \beta_0 (d^2)^{\beta_1} h^{\beta_2} \qquad\qquad \text{(Malata et al., 2017)} \qquad (14)$$

$$v = \beta_0 + \beta_1 d^2 + \beta_2 d^2 h^2 \qquad\qquad \text{(Alegria and Tome, 2011)} \qquad (15)$$

$$v = \beta_0 + \beta_1 d + \beta_2 d^2 + \beta_3 d^2 h^2 \qquad\qquad \text{(Alegria and Tome, 2011)} \qquad (16)$$

$$v = \beta_0 + \beta_1 dh + \beta_2 dh^2 + \beta_3 d^2 h^2 \qquad\qquad \text{(Alegria and Tome, 2011)} \qquad (17)$$

$$v = \beta_0 + \beta_1 d + \beta_2 dh^2 + \beta_3 d^2 h^2 \qquad\qquad \text{(Alegria and Tome, 2011)} \qquad (18)$$

The models were fitted Marquardt method using PROC NLIN procedure in SAS 9.4 software (SAS Institute Inc. 2010).

2.2.1. Model evaluation

The accuracy of stem volume predictions for each model was judged by numerical and graphical assessment of the residuals. As suggested by Kozak and Kozak (2003), validation of the models must be tested using an independent data set. In the absence of independent data, different methods are suggested. Therefore, we used the two-fold evaluation scheme to evaluate the performance of models (Bohora and Cao, 2014; Özçelik et al., 2018) in which parameters of volume equations fitted to one group was applied to predict for the other group. The predictions from both groups were then used to calculate evaluation statistics for different volume equations..

The eighteen tree volume equations were evaluated using the following error statistics:

$$Mean\ Difference\ (MD) = \frac{\sum_{i=1}^{i=n}(y_i - \hat{y}_i)}{n} \qquad (19)$$

$$Mean\ absolute\ difference\ (MAD) = \frac{\sum_{i=1}^{i=n}|y_i - \hat{y}_i|}{n} \qquad (20)$$

$$R^2 = 1 - \left[\frac{\sum_{i=1}^{i=n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{i=n}(y_i - \bar{y})^2}\right] \qquad (21)$$

$$Root\ Mean\ Square\ Error\ (RMSE) = \sqrt{\frac{\sum_{i=1}^{i=n}(y_i - \hat{y}_i)^2}{n-p}} \qquad (22)$$

where, y_i, $\hat{y}_i$, and $\bar{y}$ are the observed, predicted, and average values of the dependent variable, respectively; n is the observation numbers, and p is the number of model parameters.

As indicated by Poudel and Cao (2013), the traditional standard or ordinal ranks show the order of the methods but fail to exhibit the exact positions of the methods compared with another one. Therefore, the relative rank, introduced by Poudel and Cao (2013), used in this study to show the relative position of the different models. The relative rank of model i is defined as:

$$R_i = 1 + \frac{(m-1)(S_i - S_{\min})}{S_{\max} - S_{\min}} \qquad (23)$$

where R_i is the relative rank of model i ($i=1,2,\ldots,m$), m is the number of methods evaluated, S_i is the error statistics produced by model i, S_{min} is the minimum value of S_i, and S_{max} is the maximum value of S_i.

In the rank system, the best and the worst models have relative ranks of 1 and m, respectively. Ranks of the remaining models are expressed as real numbers between 1 and m. Because the magnitude, and not only the order of the S_i's are taken into consideration, this ranking system should provide more information than the traditional ordinal ranks. After a relative rank was computed separately for each error statistics (MD, MAD, R^2, and RMSE) of each method, a final rank was calculated based on the sum of all ranks for each method.

3. Results and discussion

In this study, stem volume prediction models were developed for natural brutian pine trees in Eğirdir Region using eighteen nonlinear models. Parameters for each model estimated from the entire dataset are presented in Table 4. All t-statistics for parameters of the eighteen models were significant at $\alpha=0.0001$ except for some models.

Four error statistics computed to compare and evaluate of stem volume estimation models using two-fold evaluation schemes (Table 5). The results showed that, except for model (6), more than 97% of the variation in volume predictions was explained by all models. The mean difference ranged from -0.002 to 0.0095, MAD values ranged from 0.0410 to 0.0749, and RMSE values ranged from 0.0744 to 0.1190 for tested models.

The relative ranks were obtained from the means of the error statistics for the eighteen methods are shown in Table 6. Model 4 produced fitting statistics that were better than those from the rest of the models. As a result, the Model 4 took part as the most successful model among all 18 models analyzed in this study, whereas Model 6 was the poorest performer. The results also indicated that model 1, 5, 3, 14, and 17 performed quite well for brutian pine trees.

Table 4. Parameter estimates of eighteen volume equations for all dataset

Model no	Parameters					
	β_0	β_1	β_2	β_3	β_4	β_5
1	0.016037 ****	0.000034 ****				
2	-0.17497 ****	0.030688 ****				
3	0.000032 ****					
4	0.000076 ****	2.039836 ****	0.67574 ****			
5	421.3998 ****	21550,34 ****				
6	-0.00092 NS	0.000032 ***	0.001542 NS			
7	26836.09 ****	90.71855 ****				
8	0.504665 ****	-0.00158 ****	0.000097 ****			
9	0.019895 ***	0.00003 ****	-0.0648 *			
10	0.000179 ****	0.000024 ****				
11	0.000376 *	0.000021 *	2.49x10^{-7} NS	0.00053 **	0.000023 **	
12	-0.0348 *	0.000289 ****	2.243049 ****	0.001482 ****	-135.017 ****	-19.3492 ****
13	0.000058 ****	0.945777 ****				
14	0.000076 ****	1.019908 ****	0.675667 ****			
15	-0.003088 ****	0.000483 ***	4.99x10^{-7} ****			
16	-0.02213 NS	-0.0009 NS	0.000506 ****	4.87x10^{-7} ****		
17	-0.10603 ****	0.001867 ****	-0.00008 ****	1.35x10^{-6} ****		
18	-0.19175 ****	0.020497 ****	-0.00002 ****	1.18x10^{-6} ****		

NS:non significant $p>0.05$; *: $p<0.05$; **: $p<0.01$; ***: $p<0.001$; ****: $p<0.0001$

Table 5. The two-fold evaluation for tested models

Model no	MD	MAD	R^2	RMSE
1	0.0018	0.0412	0.9808	0.0753
2	0.0002	0.0464	0.9799	0.0773
3	0.0001	0.0457	0.9797	0.0775
4	0.0022	0.0410	0.9813	0.0744
5	0.0018	0.0421	0.9811	0.0749
6	0.0079	0.0749	0.9522	0.1190
7	0.0029	0.0431	0.9812	0.0746
8	0.0022	0.0447	0.9802	0.0766
9	0.0023	0.0516	0.9752	0.0857
10	0.0048	0.0447	0.9812	0.0746
11	0.0022	0.0516	0.9752	0.0857
12	0.0095	0.0428	0.9796	0.0777
13	0.0008	0.0439	0.9798	0.0773
14	0.0002	0.0469	0.9800	0.0770
15	0.0017	0.0445	0.9812	0.0745
16	0.0017	0.0441	0.9812	0.0745
17	0.0022	0.0529	0.9784	0.0800
18	0.0024	0.0557	0.9774	0.0819

Table 6. Relative ranks for eighteen methods

Model no	Relative rank				Sum of Ranks	Overall Rank
	MD	MAD	R^2	RMSE		
1	4.07447	1.10029	1.29210	1.34305	7.80991	1.00334
2	1.18085	3.70796	1.81787	2.10538	8.81207	1.28122
3	1.00000	3.35693	1.93471	2.18161	8.47325	1.18727
4	4.79787	1.00000	1.00000	1.00000	7.79787	1.00000
5	4.07447	1.55162	1.11684	1.19058	7.93351	1.03761
6	15.10638	18.00000	18.00000	18.00000	69.10638	18.00000
7	6.06383	2.05310	1.05842	1.07623	10.25158	1.68038
8	4.79787	2.85546	1.64261	1.83857	11.13451	1.92520
9	4.79787	6.31563	4.56357	5.30717	20.98426	4.65640
10	9.50000	2.85546	1.05842	1.07623	14.49011	2.85566
11	4.79787	6.31563	4.56357	5.30717	20.98426	4.65640
12	18.00000	1.90265	1.99313	2.25785	24.15363	5.53522
13	2.26596	2.45428	1.87629	2.10538	8.70190	1.25068
14	1.18085	3.95870	1.75945	1.99103	8.89003	1.30284
15	3.89362	2.75516	1.05842	1.03812	8.74532	1.26271
16	3.89362	2.55457	1.05842	1.03812	8.54473	1.20709
17	4.79787	6.96755	2.69416	3.13453	17.59411	3.71636
18	5.15957	8.37168	3.27835	3.85874	20.66835	4.56881

Relative rankings of the 18 models are presented as a radar graph in Figure 2. Each method is represented by a quadrilateral, whose area is smallest for the best method and largest for the worst method. The largest area in Figure 2 belongs to model 6 which ranked last in all four evaluation statistics. The radar chart shows that the eighteen models can be grouped into three general groups. The successful methods include models 4, 1, 5, 3, 14, 16, 2, 13, 14, 7, and 8. The areas of these models are almost indistinguishable from one another. The intermediate groups consist of models 12, 17, and 18, 11, 9 and 12. The last group, which produced higher values for error statistics, consisted of model 6 with model 6 being ranked last in three statistics and next to last in another. These visual results are consistent with the overall rankings presented in Table 6.

Figure 3 shows residual plots for the estimated volume values for the three most successful and poorest models in terms of their relative ranking values. Considering the Loess regression line, the residual plots for successful models are obtained relatively more accurately, but for unsuccessful models are relatively inaccurate. It is seen that the Loess regression line of Model 6 and Model 12, which are the most unsuccessful models in particular, is quite distinct from the zero line. On the other hand, the Loess regression line of the most successful model, Model 4 and Model 1, seems to be close to the zero line.

Figure 4 shows the distribution of the measured volume values for the best (models 4, 1, and 5) and the worst (models 6, 13 and 9) versus to the estimated volume values. As indicated by Huang et al. (2000), *observedVol= a+b*PredictedVol*, was fitted on the data in Figure 4 using a simple linear model. If significant estimation errors are present, the model intercept will not equal zero $(a \neq 0)$ and slope will not equal one $(b \neq 1)$. Estimated values were regressed against observed values to look for possible prediction error in the model. Confidence intervals were obtained for the model intercept and slope. The best models (Model 4, Model 1 and Model 5) not showed a biased estimation for diameters. For example; using the Model 4, confidence interval ranged from -0.01568 to 0.0036 and from 0.99359 to 1.02073 for the model intercept and slope, respectively. These results exhibited that the intercept was

not significantly different from zero and the slope was not significantly different form one. Similar results were obtained for Model 1 and 5. The worst models (Model 6, Model 9 and Model 12) showed a biased estimation for diameters. For example; using the Model 12, confidence interval ranged from 0.00627 to 0.002585 and ranged from 0.97198 to 0.99943 for the model intercept and slope, respectively. The results exhibited that the intercept and the slope were significantly different from zero and form one, respectively. Similar results were found for the other models. In general, for all models, separation from the 1:1 line is relatively higher for large volumes.

To evaluate the models' performance for different tree sizes, models further evaluated by dbh and height classes. Figures 5 show the error distribution of some models by diameter and height classes. Successful models tend to produce negative residuals in the thin and middle diameter classes, whereas unsuccessful models produce a positive residual. However, error variance of all models is increased for thick diameter classes. A similar situation can be seen in Figure 5 in the distribution of errors for height classes. The error variance increases as the tree height increases.
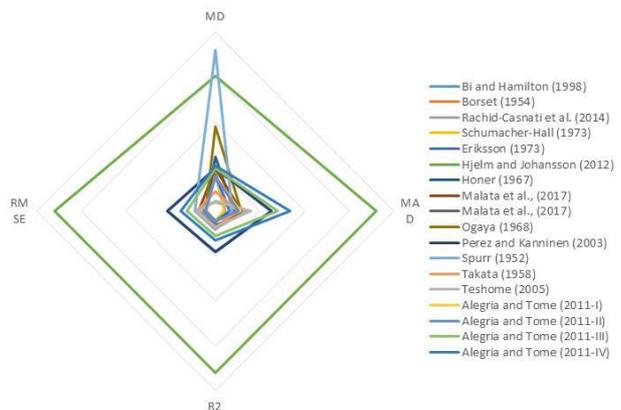

Figure 2. Relative ranks for eighteen volume equations. Method resulting in the smallest area inside the box represents the best method
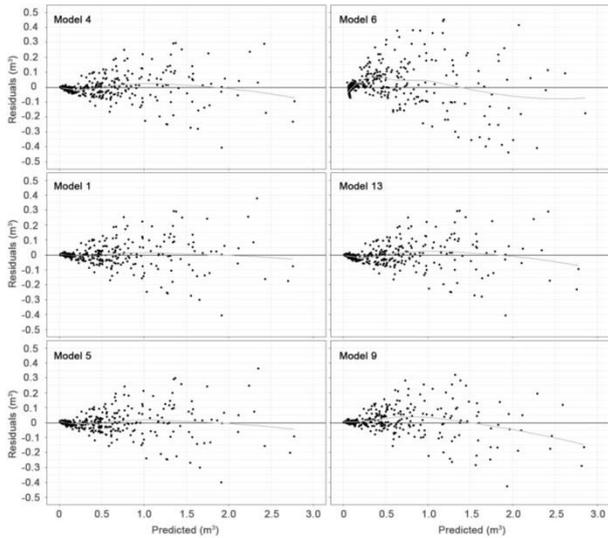
Figure 3. Residual plots of developed volume models (the best models in the left column and the worst models in the right column). Blackline is loess line for natural brutian pine trees
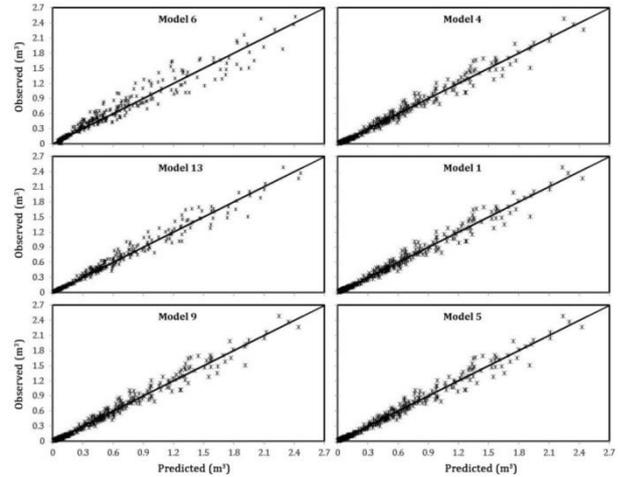

Figure 4. The 45° line plots for the best models (right column) and the worst models (left column)
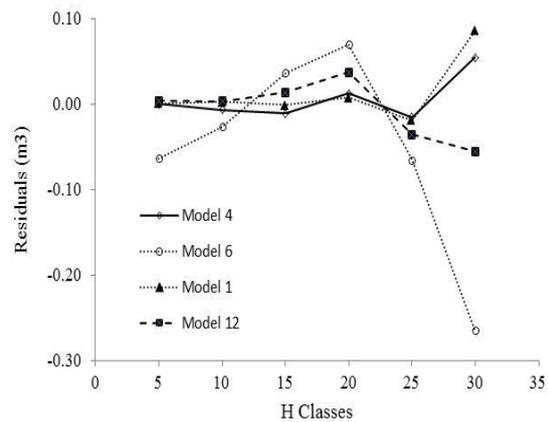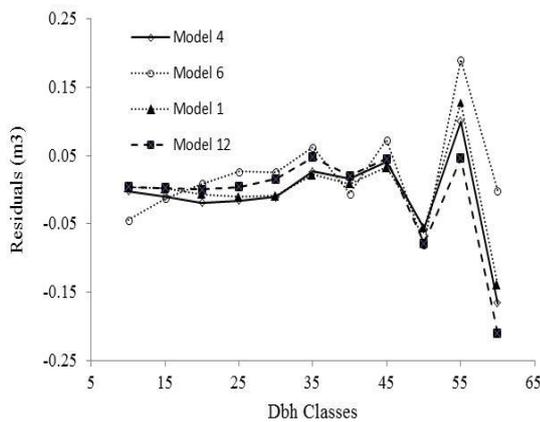

Figure 5. Residuals by dbh and height classes of some developed volume models

According to the results of this study, Model 4, which is proposed as the most successful model are compared with the other researchers' equations (Alemdağ, 1962; Çatal 2009; Kahriman et al., 2017) in terms of the volume estimation success. The results of these comparisons are shown in Table 7. It is seen that Model 4 is more successful than other models in this comparison of mean error and RMSE values. This clearly reveals the importance of localization in tree volume estimations. Because models proposed by Çatal (2009), Kahriman et al. (2017) and Alemdağ (1962) were developed with the data collected from Western Mediterranean Region, Antalya, and Mersin Regional and wide entire distribution range of Brutian pine respectively, it is quite normal for these models to produce higher errors. Local ecological conditions have a significant effect on the tree stem form and accordingly the diameter and height growth of the trees. Tree volume equations developed for larger geographic regions are not sufficient to explain the variation in tree form, unlike the regional tree volume equations.

Table 7. Comparison of results obtained from different volume equations

Volume equation	MD (m^3)	RMSE (m^3)
Model 4	-0.0047	0.0721
Alemdağ (1962)	0.0046	0.0748
Çatal (2009)	0.0455	0.0976
Kahriman et. al., (2017)	-0.0159	0.0764

As a result; since the model 4 is a widely used model for tree volume estimations in forestry studies and contains fewer parameters compared to many other model forms, this model can be suggested for estimating single tree and stand volumes in natural brutian pine stands for Eğirdir Region. On the other hand, the results of paired t-test concluded that the Model 4 (Schumacher-Hall, 1973) could be used safely in regional aspect at the significance level $p > 0.05$

4. Conclusions

In this study, stem volume equations are developed and compared for natural brutian pine stands in Eğirdir region. For this purpose, 18 different tree volume equations are tested using relative ranks of models, based on 4 different performance criteria. Total of 405 trees are sampled and randomly separated into the two groups and these groups are used to parameter estimations and calculate to error statistics. Based on statistical evaluations and graphical examination, Model 4 is the best model to predict tree volume for brutian pine in Eğirdir Region. Considering the relative ranking of the models, there are no significant differences between the Model 4, 1, 3, 5, 7, 14 and 17. However, Model 4 is a well-known and widely used model and it is preferred to other models because it allows comparison with other studies.

Measuring the tree height and breast height diameter will be sufficient to estimate tree volume with the equation developed in the relevant area. Tree volume can be estimated as m^3 by replacing these values in the related tree volume equation.

In this study, Model 4, the suggested equation for the Brutian pine volume estimation, is compared with the volume estimations obtained from the two-entry volume tables that are developed by Alemdağ (1962), Çatal (2009) ve Kahriman et al.. (2017). The results showed that these models gave a higher residual in volume estimation. This situation suggests that the regional conditions should be taken into consideration while developing the tree volume equations.

As a result, tree volumes can be estimated for natural brutian pine stands using model 4 (Schumacher-Hill, 1973). However, as a rule, as long as the possibilities can be given and a sufficient amount of sample trees can be measured, the development of separate volume equations for each region and tree species will be more useful to explain the variability in tree form and to make more accurate the volume estimates.

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