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DIAMETER AT BREAST HEIGHT ESTIMATED FROM STUMPS IN *QUERCUS FRAINETTO* IN THE REGION OF EVROS IN NORTHEASTERN GREECE

Keywords:
Diameter at breast heigh
Diameter at stump height
Regression estimation

ABSTRACT: For foresters, it is sometimes required to estimate the diameter at breast height of tree that has been cut, though it is often only the stump that is available as an indicator of size, after illegal logging and quick removal of the cut trees from the forest. In this study, equations for predicting the diameter at breast height, were fit specifically for Quercus frainetto in the region of Evros in northeastern Greece. The selected equations (quadratic model) were: $\hat{d}$ for pure stands (R^2 = 0.94), $\hat{d} = -0.359 + 0.869d_{st} - 0.001d_{st}^2$ for mixed stands (R^2 = 0.92), and $\hat{d} = -1.571 + 0.993d_{st} - 0.004d_{st}^2$ for the whole forest (R^2 = 0.94), where $\hat{d} = -0.880 + 0.915d_{st} - 0.002d_{st}^2$ is the estimated diameter at breast height d (cm), and dst is the measured diameter at stump height (cm).

Histórico:
Recebido 25/06/2016
Aceito 13/09/2016

DIÂMETRO À ALTURA DO PEITO ESTIMADA A PARTIR DE TOCOS DE QUERCUS FRAINETTO NA REGIÃO DE EVROS NO NORDESTE DA GRÉCIA

Palavras chave:
Diâmetro à altura do peito
Diâmetro à altura do toco
Estimativa por regressão

RESUMO: Para silvicultores, às vezes é necessário estimar o diâmetro à altura do peito de árvores cortadas, embora muitas vezes é somente o toco que está disponível como um indicador do tamanho, após a extração ilegal de madeira e remoção rápida das árvores cortadas da floresta. Neste estudo, equações para estimar o diâmetro à altura do peito foram ajustados especificamente para Quercus frainetto na região de Evros no nordeste da Grécia. As equações selecionadas (modelo quadrático) foram: $\hat{d} = -0,359 + 0,869d_{st} - 0,001d_{st}^2$ para talhões puros (R^2 = 0.94); $\hat{d} = -1,571 + 0,993d_{st} - 0,004d_{st}^2$ para talhões mistos (R^2 = 0.92); $\hat{d} = -0,880 + 0,915d_{st} - 0,002d_{st}^2$ para a floresta toda (R^2 = 0.94), onde $\hat{d}$ é o diâmetro estimado na altura do peito (cm), e d_{st} é o diâmetro medido na altura do toco (cm).

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DOI:
10.1590/01047760201622032193

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INTRODUCTION

The most important variable to take into consideration regarding to forestry is tree diameter at breast height. Not only it is used to estimate the volume of the tree, but also as a way to describe the stand structure and to select an inventory sample. When a tree has been cut down, and the only thing that remains to indicate its former size is the stump, it becomes necessary to use these dimensions to predict the diameter and volume. Examples include (1) when the timber has already been harvested in the final cut or thinned, (2) when checking the harvesting practices after tree removal, (3) determining the loss of volume due to illegal cutting, (4) assessing the damage that results from environmental disturbances, and (5) tracing history of the cutover stands (MCCLURE 1968, BYLIN 1982, KOZAK and OMULE 1982, WHARTON 1984, KHATRY CHHETRI and FOWLER 1996, CORRAL-RIVAS et al. 2007, ÖZÇELÍK et al. 2010).

Current studies estimating diameter at breast height, and trees' volume from stump dimensions, are based on charts, equations, or tables. (BYLIN 1982, KOZAK and OMULE 1982, MCCLURE 1968, WHARTON 1984, KHATRY CHHETRI and FOWLER 1996, CORRAL-RIVAS et al. 2007, ÖZÇELÍK et al. 2010). Tree volume estimate is done in two steps. Firstly, diameter at breast height is measured; then, tree volume is estimated generally by using a one-entry volume table. However, when one-entry volume tables are unavailable, or cannot be elaborated upon (e.g. often when cutting trees in an isolated area); as such, in order to predict the volume of the trees that have been removed, other methods may be required.

Quercus spp. forests comprise the 22.6 % of the area of all Greek forests (MINISTRY OF AGRICULTURE 1992). One of the most common *Quercus* species of the mainland country that dominates in most oak forests is *Q. frainetto* (BERGMEIER and DIMOPOULOS 2008, KORAKIS, 2015). It expands from the Balkans to central Europe, while it is also found in south Italy and Anatolia (CHRISTENSEN, 1997). It is considered a significant species for timber (CHRISTENSEN, 1997), which forms pure and mixed deciduous forests, while also it is found in open woodlands (BORATYNSKI, et al. 1992; CHRISTENSEN, 1997). *Quercus frainetto* is usually appears at altitudes between 200 and 1,200 m (BORATYNSKI, et al. 1992; CHRISTENSEN, 1997). However it can be found in lowland degraded forests (MILIOS, et al. 2014, BATZIOU, et al. 2016). It is an intermediate shade tolerant species (ATHANASIADIS 1986). Even though it has the ability to appear and grow in low productive sites (KITIKIDOU, et al. 2015; KORAKIS, 2015), it exhibits the best growth in fertile sites (KORAKIS , 2015). Moreover, *Q. frainetto* is considered as a drought tolerant species (ABBATE, et al. 1990; RAFTOYANNIS, et al. 2006)

Current equations estimating diameter at breast height from diameter at stump height developed for *Q. frainetto* in the south Evros region are presented. These equations can serve as an indicator of size, especially for trees removed from the forest due to illegal logging; in that case, the stump is the only available part left for diameter measurements.

MATERIAL AND METHODS

Study area

The study was carried out in northeastern Greece, in the southern part of the region of Evros (Figure 1). It covers an area of approximately 1,118 ha between the altitudes of 364 and 1,072 m. Mean annual air temperature, according to the data of the closest

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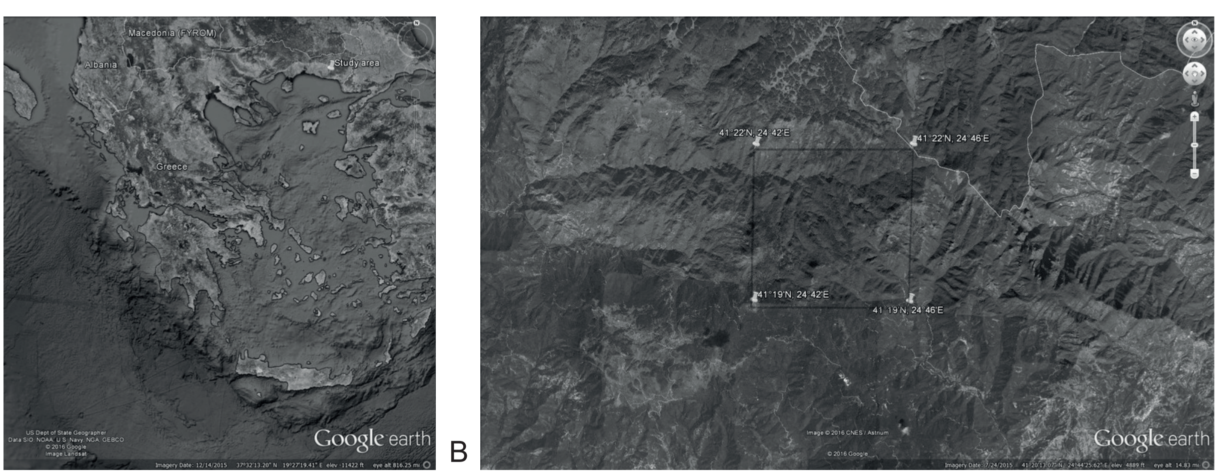

FIGURE 1 Study area (northeastern Greece (A), southern part of the region of Evros (B).

meteorological station is 14.8 °C and the total annual precipitation is 558.9 mm (ANTHOPOULOS, et al. 2008). The trees used in this study were selected from pure and mixed *Q. frainetto* stands. The mixed stands involved *Q. frainetto*, *Fagus sylvatica* or *Quercus pubescens* or *Q. coccifera*.

Data

Equations to predict diameter at breast height from stump diameter were developed using data of 135 trees selected from pure stands, and 250 trees from mixed stands. Eighty four trees (SP trees), growing more or less freely, were selected in sparse pure stands, while 51 trees (DP trees) were selected in dense pure stands of the species. On the other hand, 111 (SM trees) trees, growing more or less freely, were selected in sparse mixed stands, and 139 trees (DM trees) were selected in dense mixed stands. In order for a tree to be classified as a SP or a SM, the closest distance between its crown and the crowns of adjacent trees had to be more than 0.5 m. The rest (being closer to a adjacent tree) were classified as DP and DM trees. However, the crown of almost all selected DP and DM trees touched the crown of adjacent trees in a great part of its circumference. The trees documented covered an existing range of site qualities, and were selected in stands located within the study location. Trees were randomly selected, ensuring that there was a representative distribution among the diameters and height classes. Perimeter *p* at breast height 1.3 m, *d* (in cm), and the perimeter at stump height 0.2 m d_{st} (in cm) were measured in each tree, using a measurement tape of 1 cm precision. Diameter was calculated applying the equation 1.

$$d = \frac{p}{\pi} \qquad [1]$$

Relationships between diameter at stump height and diameter at breast height were examined by visually comparing scatter plots of stump diameter against diameter at breast height (Figure 2). Outliers weren't present in this study. The summary statistics of these final datasets, used to develop the equations to predict the diameter at breast height from the stumps, as shown in Table 1.

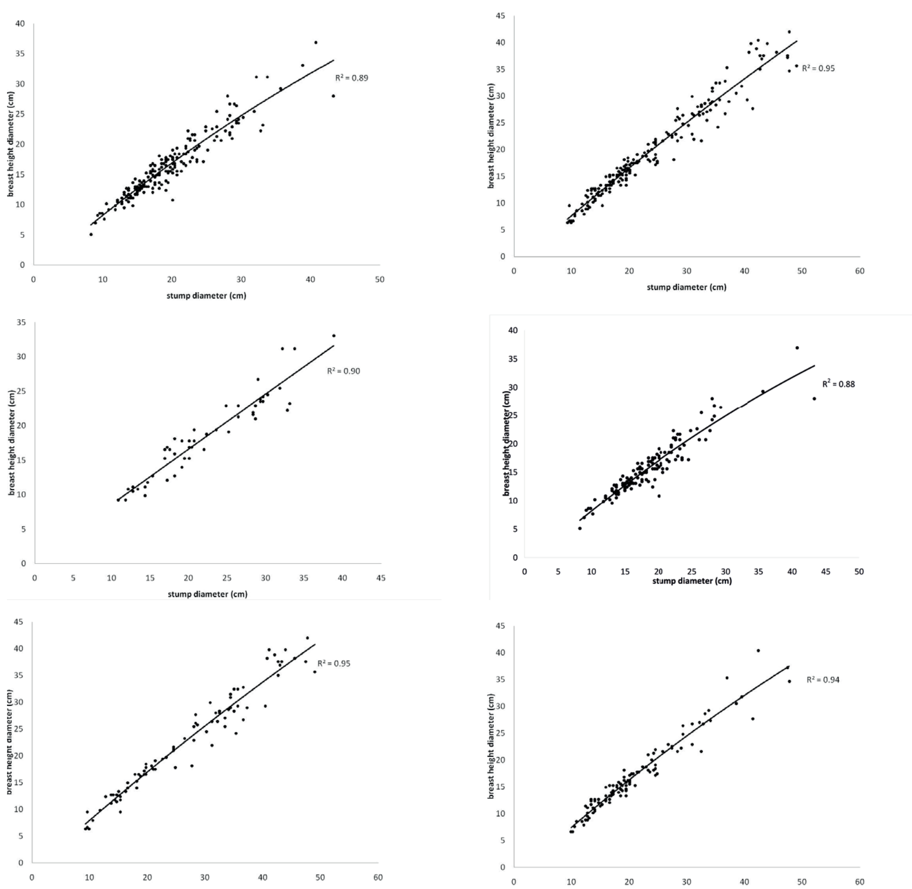

FIGURE 2 Scatter plots breast height diameter - stump height diameter of subsamples (beginning from the upper left corner: dense stands, sparse stands, pure dense stands, mixed dense stands, pure sparse stands, mixed sparse stands).

TABLE 1 Statistic summaries for sampled trees, for each measured variable (breast height diameter d and stump height diameter dst), and subsample (whole forest, dense stands, sparse stands, pure dense stands, mixed dense stands, pure sparse stands, mixed sparse stands).

	Mean (cm)	Standard deviation (cm)	Minimum (cm)	Maximum (cm)
all_d	17.96	7.12	5.09	42.02
all_dst	21.55	8.31	8.28	49.02
dense_d	16.49	5.18	5.09	36.92
dense_dst	19.64	6.09	8.28	43.29
sparse_d	19.39	8.37	6.37	42.02
sparse_dst	23.40	9.67	9.23	49.02
pure_dense_d	18.35	5.91	9.23	33.10
pure_dense_dst	22.16	7.04	10.82	38.83
mixed_dense_d	15.81	4.72	5.09	36.92
mixed_dense_dst	18.72	5.44	8.28	43.29
pure_sparse_d	22.51	9.38	6.37	42.02
pure_sparse_dst	26.59	10.80	9.23	49.02
mixed_sparse_d	17.03	6.64	6.68	40.43
mixed_sparse_dst	20.99	7.96	9.87	47.75

Models Analyzed

Eleven different models were tested, each available in the Curverfit command of SPSS v.21 (IBM 2012), to help develop the equations used for predicting the parameters. Stump diameter was measured at 20 cm height (above ground level), and thus the stump height was not included as a covariate in the models. The models tested are shown in Table 2, where $\hat{d}$: estimated diameter at breast height d (cm), b_i: regression coefficients, d_{st}: measured diameter at stump height (cm), u: upper boundary value (max d rounded up).

TABLE 2 Evaluated mathematical expressions for the models tested for breast height diameter estimation from stump diameter.

1. Linear	$\hat{d} = b_0 + b_1 d_{st}$
2. Logarithmic	$\hat{d} = b_0 + b_1 \ln d_{st}$
3. Inverse	$\hat{d} = b_0 + \frac{b_1}{d_{st}}$
4. Quadratic	$\hat{d} = b_0 + b_1 d_{st} + b_2 d_{st}^2$
5. Cubic	$\hat{d} = b_0 + b_1 d_{st} + b_2 d_{st}^2 + b_3 d_{st}^3$
6. Power	$\hat{d} = b_0 \left(d_{st}^{b_1}\right)$
7. Compound	$\hat{d} = b_0 \left(b_1^{d_{st}}\right)$
8. S-curve	$\hat{d} = e^{b_0 + \frac{b_1}{d_{st}}}$
9. Logistic	$\hat{d} = \frac{1}{\frac{1}{u} + b_0\left(b_1^{d_{st}}\right)}$
10. Growth	$\hat{d} = e^{b_0 + b_1 d_{st}}$
11. Exponential	$\hat{d} = b_0 e^{b_1 d_{st}}$

Comparing Models

When judging the performance criteria of the functions, a numerical and graphical base was used to analyze the residuals. The two statistics that were calculated were the root mean square error (*RMSE*) and the coefficient of determination (R^2) (KITIKIDOU, 2005).

The statistical expressions are as follows [2] and [3], where d_i, $\hat{d}_i$ and $\overline{d}$ are the observed, the predicted and mean values, respectively, of the dependent variable, and *n* is depicted as the total number of observations used to fit the model.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(d_i - \hat{d}_i\right)^2}{n}} \qquad [2]$$

$$R^2 = 1 - \frac{\sum_{i=1}^{n}\left(d_i - \hat{d}_i\right)^2}{\sum_{i=1}^{n}\left(d_i - \overline{d}_i\right)^2} \qquad [3]$$

In order to compare the predictive capabilities of the models, one should take into account that the residuals (the *RMSE* criterion in our study) and the measurements of quality (the R^2 criterion in our study) do not determine the quality of future prediction (MYERS ,1990). To this end, the model must be verified for this process, and only a newly collected dataset will be viable in this instance. However, as such data are scarce, several other methods have been proposed, though they seldom provide additional information when compared with the statistics that have been obtained directly from other complete datasets (KOZAK and KOZAK, 2003). Hence, validations can only be performed once new data have been collected and have become available.

RESULTS - DISCUSSION

Model selection

The statistics for each of the different models tested for diameter estimation are shown in Table 3 (all contained significant parameters). Optimal values are highlighted. The quadratic model performed best (Figure 3).

The R^2 values of both selected models are high. However, in the trees which grow in sparse stands (SP, SM trees) the R^2 values (0.9500, 0.9426, respectively) of the selected models are higher than the R^2 values of the corresponding trees (DP, DM trees) growing in dense stands (0.9022, 0.8810, respectively). The relationship between basal and breast height diameter of a tree is determined by the taper of the tree. Growth conditions (competition regime) affect form factors of trees (PHILIP 1994, KITIKIDOU et al. 2014). The form of trees is affected by the stand density. Higher tree taper is the result of low stand densities (PHILIP, 1994; SMITH et al., 1997, MILIOS and AKRITIDOU, 2002). On the other hand, a free growing tree or a robust dominant tree puts more wood in its base, while trees with low vigor, suppressed trees, or trees growing in dense stands without being dominant add lower wood width in their base (compared to that of the other bole heights) (FRITTS, 1976, WILSON, 1984, SMITH et al., 1997). So, high variability of tree tapers can be found in stands according to tree density and social position. Thus, in the present study the trees from the dense stands (DP, DM trees) can exhibit a high variability of form factors. However, this is not the case for the trees from sparse stands (SP, SM trees) which grow freely without intense competition from the adjacent trees. This is the reason for the lower estimation ability (lower R^2 values) of the selected models for DP and DM trees compared to the selected models for SP and SM trees. Furthermore, high variability of form factors influences the volume prediction models (KITIKIDOU, et al. 2016).

Nevertheless, in the present study the model selected for all measured trees (Figure 4) had a R^2 of 0.94, which is relatively high (Table 4). As a result, it is recommended for general use for simplicity as well as for accuracy reasons. More research is needed in order to be developed analogue models for more species. Moreover, use of competition indices may increase the accuracy of the models, through more accurate stem form predictions, especially when simple models are not accurate.

TABLE 3 Comparison statistics (root mean square error (RMSE) and coefficient of determination R^2), for pure and mixed stands, for the eleven models tested for breast height diameter estimation from stump diameter.

Variables	Pure stands		Mixed stands	
Model	RMSE	R^2	RMSE	R^2
1	2.00	0.94	1.66	0.91
2	55.68	<0	44.48	<0
3	3.70	0.79	2.76	0.76
4	2.00	0.94	1.63	0.92
5	29.68	<0	224.57	<0
6	12.66	<0	8.79	<0
7	2.01	0.94	1.67	0.91
8	2.65	0.89	2.10	0.86
9	3.03	0.86	2.71	0.77
10	3.04	0.86	2.72	0.77
11	2.14	0.93	1.66	0.91

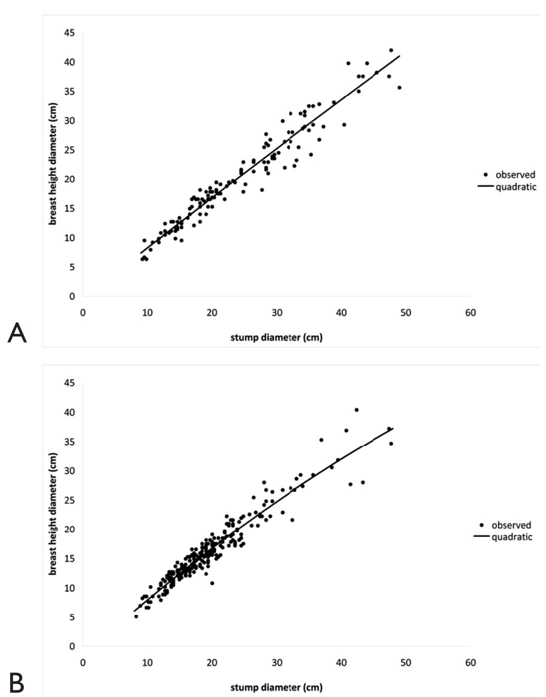

FIGURE 3 Fitting of the quadratic model estimating breast height diameter from stump diameter - (A) pure stands ($\hat{d} = -0.359 + 0.869 d_{st} - 0.001 d_{st}^2$); (B) mixed stands ($\hat{d} = -1.571 + 0.993 d_{st} - 0.004 d_{st}^2$).

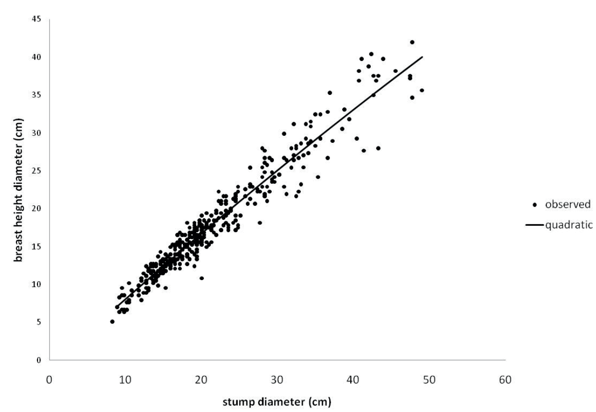

FIGURE 4 Fitting of the quadratic model estimating breast height diameter from stump diameter - whole forest ($\hat{d} = -0.880 + 0.915 d_{st} - 0.002 d_{st}^2$).

TABLE 4 Comparison statistics (root mean square error (RMSE) and coefficient of determination R^2), for the eleven models tested for breast height diameter estimation from stump diameter - whole forest (pure and mixed stands).

Model	RMSE	R^2
1	1.03	0.94
2	963.15	<0
3	5.98	0.78
4	0.99	0.94
5	1944.85	<0
6	20.89	<0
7	1.00	0.94
8	1.39	0.88
9	2.13	0.85
10	2.13	0.85
11	1.16	0.93

In the models tested, stump height was not considered as covariate, as each of the trees had been measured at the same stump height (20 cm). While prior studies have revealed that, for species having more or less the same stump height, this variable (i.e. stump height) did not significantly improve the variability explained by the regression equations that were developed for predicting diameter at breast height from diameter at stump height (e.g. BYLIN, 1982), this limitation suggests that further work and data is needed to be evaluated before adapting the equations to test stumps resulting from trees that have been cut at heights different from 20 cm.

CONCLUSION

In this study, equations to predict diameter at breast height from diameter at stump height, were developed. Fittings for pure *Quercus frainetto* stands, mixed stands, and for the whole forest were tested. These equations are useful for direct calculations of the volume of cut trees. This is particularly interesting for the prediction of the volume of trees that have been illegally cut down. Even if logs have been removed from the forest, one will still be able to obtain their diameter at breast height by employing these models. The selected equations (quadratic model) were: $\hat{d} = -0.359 + 0.869 d_{st} - 0.001 d_{st}^2$ for pure stands (R^2 = 0.94); $\hat{d} = -1.571 + 0.993 d_{st} - 0.004 d_{st}^2$ for mixed stands (R^2 = 0.92); $\hat{d} = -0.880 + 0.915 d_{st} - 0.002 d_{st}^2$ for the whole forest (R^2 = 0.94), where $\hat{d}$ is the estimated diameter at breast height d (cm), and d_{st} is the measured diameter at stump height (cm).

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