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Technical note

Volume Equations for Abies borisii-regis Mattf. and Fagus sylvatica L. in central Greece

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ABSTRACT In the mixed stands of *Fagus sylvatica - Abies borisii-regis* in Aspropotamos (central Greece), 90 fir trees and 87 beech trees were randomly selected. Breast height diameter, total tree height and form factor were measured to the sampled trees, while 14 single-entry and 18 double-entry volume models were fitted to data. No double-entry model is selected for either species. The selected single-entry models for the estimation of the *A. borisii-regis* and *F. sylvatica* volume fit very well (R^2>0.8), while the comparison of the two volume estimation curves reveals that fir has a larger volume than beech, when their diameter is the same. Fir has a mean form factor of 0.331, while beech has a mean form factor of 0.315. The observed form factor differences and different patterns in form factors between the two species can be the result of the differences in their growth (form and ecology).

KEYWORDS: Bulgarian fir, European beech, single-entry volume tables, double-entry volume tables.

Introduction

Fir forest type constitutes the 8.34 % of the forests of Greece (Ministry of Agriculture 1992). A great part of these fir forests is created by *Abies borisii-regis* Mattf. (Bulgarian fir). *A. borisii-regis* is endemic in the Balkans; as *A. alba* Mill. gradually spread to southern Europe, it arrived in Greece, where it coexisted with *A. cephalonica* Loud. and they hybridized (Korakis 2015). The biological requirements of the hybrid are between those of the parental species (Athanasiadis 1986). It is a very shade tolerant species that can endure shade for many decades exhibiting extremely low growth rates (Milios et al. 2008).

Abies spp. provide the 31.23 % of the merchantable wood volume in Greece (Ministry of Agriculture 1992), while a great part of it is from *A. borisii-regis* forests. According to Zagas and Smiris (1993) the forests of fir are among the most wood productive forests in Greece.

The forest type of *Fagus sylvatica* L. covers the 5.17 % of the Greek forests, while beech provides the 20.05 % of the merchantable wood volume in Greece (Ministry of Agriculture 1992). According to Dafis (1990), *F. sylvatica* forests occupy the most productive sites in the mountainous areas in Greece, but they confronted mistreatment (intense grazing, illegal logging) in the past.

In many cases *F. sylvatica* and *A. borisii-regis* form mixed forests in Greece.

Volume estimation models are essential for any forest inventory, as the standing tree volume is a basic dendrometric variable dealing with timber yield, i.e. a variable of great economic interest (Marchi et al. 2020). Standing tree volume is estimated, commonly, via its diameter at breast height and its height (Picard et al. 2012). This study is aiming at developing volume estimation models, for *F. sylvatica* L. and A. *borisii-regis* Mattf. in mixed stands in a forest of central Greece.

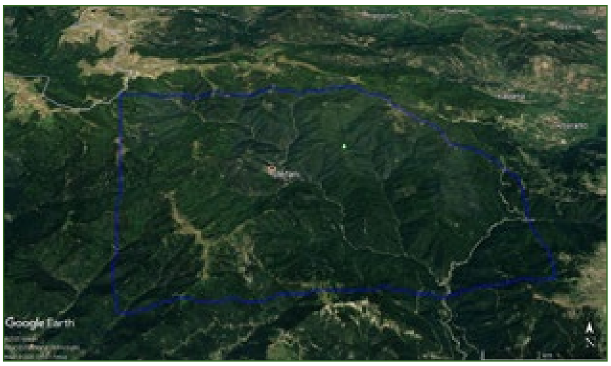
Modelling stem taper and volume is crucial in many forests management and planning systems dealing with economic aspects. Forest planning and management activities require timber volume estimations with adequate accuracy; to this end, taper functions are developed to improve timber volume estimation, particularly to improve timber volume estimation for logs.

Materials and methods

Study area

The study was conducted in the mixed stands of *F. sylvatica - A. borisii-regis* of the Aspropotamos area that is located in the central Greece (coordinates of the mid-point 39°38'28.0793"N, 21°17'17.7420"E, Fig. 1).

Figure 1 - Study area of Aspropotamos (Google Earth n.d.). The blue line is the boundaries of the study area. The green tree is the mid-point of the formed polygon.



This study covers an area of 20,168 ha. The elevation ranges from 795 to 2,279 m. The parent materials

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of the studied stands are Pindos flysch (sandstone – margaic type - fo) (Poulianidis 2019). In areas adjacent to the research area, the soils that come from flysch in which sandstone layers dominate, exhibit sandy-loamy to silty-loamy texture (Chrysopolitou and Dafis 2014).

In the *F. sylvatica - A. borisii-regis* stands of the study area, an uneven-aged silvicultural system is followed, where in the even-aged groups selective thinning (a type of positive selection) is applied and the regeneration is made using the shelterwood method (Poulianidis 2019).

According to the data of the closest meteorological station, which is located near the study area, the mean temperature in the area is 8.75 °C and the annual rainfall is 874.86 mm (Poulianidis 2019).

Measurements were taken in 2014.

Field Measurements

In the mixed stands of *F. sylvatica - A. borisii-regis* of the study area, 90 fir trees and 87 beech trees were randomly selected. These trees were randomly selected from 30 plots of 20 m x 50 m, which were established randomly in the mixed stands. These plots were established in the context of another study on the stand structure and growth of *F. sylvatica - A. borisii-regis* stands. From each plot, three trees from each species were randomly selected. Among the 90 beech trees, three of them were considered as outliers, regarding the height – diameter ratio, and they were excluded from the statistical analysis.

For each of the 177 trees, the following measurements or estimations were recorded:

- Breast height diameter D (in meters with 2 decimals, accurate to 0.5 cm), which was measured with a calliper.
- Total height H (in meters with 0.5 m accuracy), which was estimated with a Blume-Leiss altimeter.
- Form factor f, which was estimated with a Bitterlich's Spiegel relaskop, using the formula (Van Laar and Akça 2007):

$$v = \frac{2}{3}\frac{L_2 - L_1}{L_3 - L_1} \qquad \text{(eq. 1)}$$

where L_1, L_2, and L_3 are the relaskop's measurements at the breast height, at the height where the diameter is half of the breast height diameter, and at the top, respectively.

The total volume v (m^3) of each tree was calculated using the formula (Van Laar and Akça 2007):

$$v = \frac{\pi}{4} D^2 \cdot f \cdot H \qquad \text{(eq.2)}$$

Summary statistics for the sampled trees are given in Table 1.

Statistical Analysis

14 single-entry volume models $v = function(D)$, and 18 double-entry volume models $v = function(D,H)$ were fitted to data (Kitikidou 2008). Of the 32 models, the ones for which it was ensured that all explanatory variables were significant in explaining the variation in the response variables at 0.05 significance level by applying the *t*-test, were further examined. The coefficient of determination R^2, the Standard Error of the Estimate (SEE), and the Root of the Mean Squared Error (RMSE) were calculated for the models that had passed the *t*-test. Departure of error term from normality was explored with the Jarque-Bera test, which tests the skew and kurtosis of data to see if it matches the expected from a normal distribution (Jarque 2011). Graph of distribution of error term next to the observed values was considered for this purpose. Finally, the autocorrelation of the error term, was checked by using Durbin Watson (DW) statistic. Values under 1 or more than 3, would cause rejection of the corresponding model (Field 2009).

Results

A. borisii-regis volume models

Regarding the *A. borisii-regis* single-entry volume models, where diameter at breast height (D) was the only explanatory variable, 9 models from the initial 14 passed the regression coefficients's *t*-test. As for the double-entry volume models, where diameter at breast height (D) and total height (H) were the explanatory variables, 4 models from the initial 18 passed the regression coefficients's *t*-test. The models's comparison criteria (R^2, SEE, RMSE, DW) are given in Table 2. The best values for R^2, SEE, and RMSE, for the two groups of models (single-entry

Table 1 - Statistical description of the sample.

Variables	*Abies borisii- regis*	*Fagus sylvatica*	*Abies borisii- regis*	*Fagus sylvatica*	*Abies borisii- regis*	*Fagus sylvatica*	*Abies borisii- regis*	*Fagus sylvatica*
	Mean		**Standard deviation**		**Min**		**Max**	
D (cm)	36.32	29.41	12.02	12.24	9.00	8.00	86.00	73.00
H (m)	22.77	23.30	5.59	5.28	7.00	11.00	32.00	31.50
f	0.331	0.315	0.077	0.083	0.155	0.037	0.556	0.513
v (m^3)	0.95	0.64	0.86	0.61	0.01	0.01	6.08	3.52

and double-entry) are shaded. The Durbin Watson statistics that indicate significant residuals's autocorrelation, are marked in bold.

For the proposed models (the shaded ones in Tab. 2), the residuals's heteroscedasticity does not differ much from the other models of each group (Tab. 3).

Table 2 - Statistical comparison of the *A. borisii-regis* volume models (criteria used: coefficient of determination R2, Standard Error of the Estimate SEE, Root of the Mean Squared Error RMSE, Durbin Watson statistic DW).

Model nº	Model	R²	SEE	RMSE	DW
1	$v = b_1 D^2$	0.8925	0.28433	0.6188	**0.5335**
2	$v = b_0 + b_1 D^2$	0.8925	0.28433	0.6625	**0.4654**
3	$v = b_0 + b_1 \frac{\pi}{4} D^2$	0.8925	0.28433	0.2823	1.5977
4	$v = b_1 D + b_2 D^2$	0.8959	0.27985	0.2942	1.4809
5	$\ln v = b_0 + b_1 \ln D$	0.8877	0.29060	0.3245	1.7867
6	$\ln v = b_0 + b_1 \ln D + b_2 D$	0.8928	0.28392	0.2812	1.5392
7	$\frac{v}{D^2} = b_0 + b_1 \frac{1}{D}$	0.8948	0.28128	0.3986	**0.9459**
8	$\frac{v}{D^2} = b_0 + b_1 \frac{1}{D^2}$	0.8925	0.28433	0.5781	**0.6113**
9	$\frac{v}{D^2} = b_0 + b_1 \frac{1}{D} + b_2 \frac{1}{D^2}$	0.8962	0.27941	0.2772	1.5671
1	$v = b_1 D^2 H$	0.9050	0.26730	0.2645	1.2009
2	$\ln v = b_0 + b_1 \ln\left(D^2 H\right)$	0.9050	0.26732	0.2670	1.1961
3	$\ln v = b_0 + b_1 \ln\left(DH\right)$	0.8782	0.30270	0.3223	1.2913
4	$\ln v = b_0 + b_1 \ln D + b_2 \ln H$	0.5496	0.58205	1.5343	**0.3760**

Table 3 - Residuals's Jarque-Bera normality test for the *A. borisii-regis* volume models.

Model nº	Jarque-Bera p-value	Jarque-Bera test value
1	0.3408	2.1532
2	0.3408	2.1532
3	0.2392	2.8609
4	0.2745	2.5857
5	0.3238	2.2550
6	0.2755	2.5783
7	0.3356	2.1837
8	0.3408	2.1532
9	**0.3048**	**2.3760**
1	**0.2319**	**2.9226**
2	0.2538	2.7423
3	0.3707	1.9847
4	0.3423	2.1440

From all this we conclude that the models that could be chosen for the estimation of the *A. borisii-regis* volume are:

$$\frac{v}{D^2} = 0.001 - 0.016\frac{1}{D} + 0.082\frac{1}{D^2}$$ (single-entry model) (eq.3)

$$v = 0.00002573 D^2 H$$ (double-entry model) (eq.4)

F. sylvatica volume models

Regarding the *F. sylvatica* single-entry volume models, where diameter at breast height (*D*) was the only explanatory variable, 8 models from the initial 14 passed the regression coefficient's t-test. As for the double-entry volume models, where diameter at breast height (*D*) and total height (*H*) were the explanatory variables, 6 models from the initial 18 passed the regression coefficients's *t*-test. The models's comparison criteria (R^2, SEE, RMSE, DW) are given in Table 4. The best values for R^2, SEE, and RMSE, for the two groups of models (single-entry and double-entry) are shaded. The Durbin Watson statistics indicate that there is no significant residuals's autocorrelation, for all models.

Regarding the double-entry models, the model nº 3 has the best values for R^2 and SEE; however, its RMSE value is the worst of all 6 double-entry models. On the other hand, the model nº 2 has the best RMSE value, while its values for R^2 and SEE are not far from the corresponding values of model 3. Therefore, both models are proposed. For all 3 proposed models (the shaded ones in Tab. 4), the residuals's heteroscedasticity does not differ much from the other models of each group (Tab. 5).

Table 4 - Statistical comparison of the *F. sylvatica* volume models (criteria used: coefficient of determination R2, Standard Error of the Estimate SEE, Root of the Mean Squared Error RMSE, Durbin Watson statistic DW).

Model n°	Model	R^2	SEE	RMSE	DW
1	$v = b_1 D^2$	0.8437	0.2436	0.5575	1.1143
2	$v = b_0 + bD + b_2 D^2$	0.2321	0.2341	1.5790	**0.8165**
3	$v = b_0 + b_1 D + b_2 \ln D$	0.8667	0.2250	2.0775	1.6135
4	$\ln v = b_0 + b_1 \ln D$	0.7955	0.2787	0.3634	1.8616
5	$\ln v = b_0 + b_1 \ln D + b_2 \frac{1}{D}$	0.8379	0.2481	0.2595	1.6553
6	$\ln v = b_0 + b_1 \ln D + b_2 D^2$	0.8707	0.2216	0.2211	1.6357
7	$\frac{v}{D^2} = b_0 + b_1 \frac{1}{D}$	0.8389	0.2474	0.4352	1.4457
8	$\frac{v}{D^2} = b_0 + b_1 \frac{1}{D^2}$	0.8437	0.2436	0.5296	1.2344
1	$v = b_1 D^2 H$	0.8173	0.2635	0.2867	1.2880
2	$v = b_0 + b_1 D^2 H$	0.8173	0.2635	0.2637	1.5224
3	$v = b_0 + b_1 D^2 + b_2 H$	0.8532	0.2361	0.6229	1.0207
4	$\ln v = b_0 + b_1 \ln\left(D^2 H\right)$	0.8131	0.2664	0.2806	1.6895
5	$\ln v = b_0 + b_1 \ln\left(DH\right)$	0,7966	0.2780	0.2764	1.6972
6	$\ln v = b_0 + b_1 \ln D + b_2 \ln H$	0.8113	0.2677	0.2824	1.6874

Table 5 - Residuals's Jarque-Bera normality test for the *F. sylvatica* volume models.

Model n°	Jarque-Bera p-value	Jarque-Bera test value
1	0.1875	3.3476
2	0.9332	0.1383
3	0.9550	0.0921
4	0.1179	4.2759
5	0.4582	1.5610
6	**0.8711**	**0.2759**
7	0.1519	3.7691
8	0.1875	3.3476
1	0.8872	0.2394
2	**0.8872**	**0.2394**
3	**0.2607**	**2.6887**
4	0.1122	4.3749
5	0.7948	0.4594
6	0.1163	4.3037

From all this we conclude that the models that could be chosen for the estimation of the *F. sylvatica* volume are:

$$\ln v = -10.334 + 2.919 \ln D - 0.0002 D^2$$ (single-entry model) (eq.6)

$$v = 0.087 + 0.00002 D^2 H$$ (double-entry model) (eq.7)

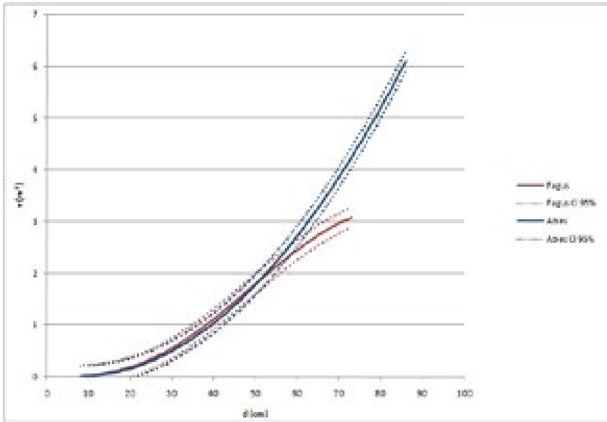
$$v = -0.287 + 0.001 D^2 + 0.015 H$$ (double-entry model) (eq.8)

Despite the addition of height as an explanatory variable in the two proposed double-entry models, the single-entry model gives better values for all its comparison statistical criteria than the double-entry models (Tab. 4). Therefore, the single-entry model is preferred.

When comparing the single-entry volume estimation curves of the two species, we observe that fir has a larger volume than beech, when their diameter is the same. In fact, this happens beyond the 54 cm diameter. In greater diameters fir exhibits larger volumes compared with beech, and this volume difference between the two species increases as the diameter increases (Fig. 2).

Fir has a mean form factor of 0.331, while beech has a mean form factor of 0.315 (Tab. 1), meaning that fir trees are more cylindrical (less tapered) than beech trees. Even though the dispersion of the form factor values of both species measured trees is rather high (Fig. 3), in the group of measured trees having a diameter greater than 24 cm, up to the largest measured tree, i.e. 24.73 cm for beech and 24.86 cm for fir, fir trees exhibit larger mean form factor than that

Figure 2 - Volume estimation curves for *A. borisii-regis* Mattf. and *F. sylvatica* L. (single-entry models), with their 95% Confidence Intervals CI.



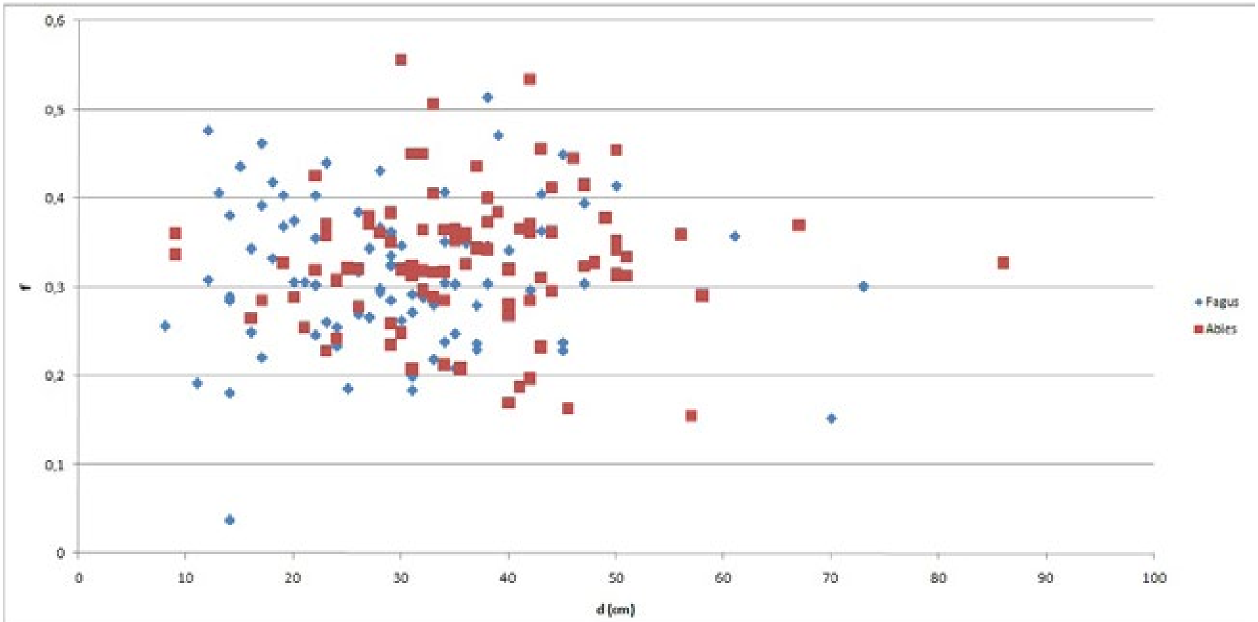
to a larger error than the diameter. With these two issues in mind (the small differences regarding the comparison statistical criteria, and the error in variables estimated from a distance), the single-entry model is preferred.

It has been found that diameter at breast height, which is an easily measurable variable as opposed to height, explains the most amount of variation in tree volume (Husch et al. 1982). As a result, single-entry volume estimation models occur more often, while double-entry volume estimation models come in second place (Husch et al. 1982). With this in mind, and in conjuction with the results in Tables 2 and 4, we recommend the use of the single-entry models for both species's volume estimation.

The volume of trees is determined by their form factor, in the sense that, for the same breast height diameter and total height, the larger the form factor, the larger the volume of the tree (Van Laar and Akça 2007). The form factor is strongly related to the density of the stand (Smith et al. 1997, Milios et al. 2016). Tall trees growing alone with large crown have lower form factor, compared to those with the same height growing in dense stands having small crown (Philip 1994, Smith et al. 1997). However, the underlying process is the competition, as a result of stand density, that affects taper leading to more tapered dominant trees that are the winners of competition, and to more cylindrical trees that are under the influence of competition (Smith et al. 1997, Kitikidou et. al. 2014). Taper is affected by the distribution of annual growth ring thickness along the tree bole (Fritts 1976, Wilson 1984, Smith et al. 1997, Milios and Akritidou 2002).

The form factor differences and patterns of the measured trees, as illustrated in Figure 3, affected the developed volume models.

Figure 3 - Form factor - Diameter scatter plots for *A. borisii-regis* Mattf. and *F. sylvatica* L.



of beech trees (mean of beech trees = 0.313, mean of fir trees = 0.334). On the other hand, in the group of measured trees having a diameter lower than or equal to 24 cm, i.e. 8.24 for beech and 9.24 cm for fir, the two species have, more or less, the same mean form factor (mean of beech trees = 0.320, mean of fir trees = 0.312).

Discussion

Regarding the selected models for *A. borisii-regis* volume estimation, even though the proposed double-entry model is expected to give better volume estimations than the proposed single-entry model, based on their values for the comparison statistical criteria in Table 2, we note that these values do not differ much between the two proposed models. Height is a variable that in standing trees is estimated from a distance and is not measured directly like the breast height diameter, so it is subject

Accepting that, more or less, the trees of the two species grew under the same competition regime, the main reason for the observed form factor differences and different patterns in form factors between the two species (Fig. 3) can be the differences in their growth (form and ecology). Theses differences in form factor patterns are, possibly, the result of the different apical dominance, which is observed in the two species. According to Carron (1968), in conifers, usually apical control is strong, while in broadleaf trees, in most cases, a weak apical control is observed after a young age, and the tree stem does not exhibit a continuous form from the base to the treetop.

Conclusions

In this work, volume estimation models were developed to estimate the volume of A. *borisii-regis* and *F. sylvatica*, in Aspropotamos (central Greece). Considering the expected errors in explanatory variables, and the results of the comparison statistical criteria, single-entry models are suggested for both species's volume estimation. Fir has a mean form factor of 0.331, while beech has a mean form factor of 0.315. The observed form factor differences and different patterns in form factors between the two species can justify their differences in volume estimation curves.

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