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Technical notes

Single-entry volume table for *Pinus brutia* in a planted peri-urban forest

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Abstract - Brutia pine is a Mediterranean tree species of high ecological value, widely planted for soil protection, windbreaks and timber, both in its native area and elsewhere in the Mediterranean region. However, there is not yet enough information relating its growth dynamics and yield. The aim of this study was to evaluate the volume of Pinus brutia in a planted peri-urban forest (reforested area) in Greece. A single-entry, individual tree volume model has been developed using data from 18 permanent experimental plots, in the context of a research project regarding recovery of degraded coniferous forests..

Keywords - Pinus brutia; volume equation; volume estimation; volume table

Introduction

Brutia pine, also known as red pine, Turkish pine and Calabrian pine, is a widely distributed species, native to the eastern Mediterranean / western Asia regions. *Pinus brutia* is a fast-growing conifer, often associated with the related Aleppo pine (*Pinus halepensis*), extensively used in reforestations, in many degraded areas in Greece.

The wood of *Pinus brutia*, though resinous, can be successfully sawn and has higher density than *Pinus radiata* or *Pinus pinaster* (Raymond et al. 2004), while appropriate silviculture and genetic improvement can increase its growth rates and augment merchantable volume through improved stem form and branching (Arnold et al. 2005).

Pinus brutia is a drought-tolerant species, with fire resistant cones allowing it to successfully colonize dry, abandoned and burnt areas, particularly adapted to dry and cold sites and shallow, calcareous soils (Arnold et al. 2005). It has a remarkable adaptation to recurrent and severe fires, because it is an obligate seeder (Keeley et al. 2011), so knowledge about post-fire growth is useful for assessing not only current management practices, but also growth rate changes under climate warming (Sugihara et al. 2006). Climate affects forest fire regimes, in the short term, because weather rules fire ignition and propagation, and in the long term, because climate determines primary productivity, thus potential fuel and global fire patterns (Dale et al. 2000 and 2001, Urbieta et al. 2015). Moreover, research on the species yield dynamics and its impact on climate change via carbon storage, can contribute to the implementation and development of management strategies for climate change mitigation. Forest management practices should focus on maximizing increments, not stocks, in order to be more efficient under different climate scenarios. Volume dynamics are related to biomass increments, which should be maximized instead of standing biomass, since many regions in Europe have already high carbon stocks in forests (Kindermann et al. 2013).

The most usual way of estimating yield is through the use of volume tables (volume equations). Secondary variables such as diameter and height are used when it becomes difficult to measure volume directly in the field. Volume equations relating the tree volumes and auxiliary variables are applied to quicken this process. In developing volume tables, two variables can be used as dependent: individual tree volume or stand volume. Individual tree-based tables predict volume per tree, whereas stand volume tables predict volume per unit area (Philip 1994). The individual tree volume tables are further divided into three categories: local/single-entry, standard/double-entry, and form class/multiple-entry volume tables (Husch et al. 1982).

Local volume tables estimate tree volume using only the diameter at breast height, while standard tables are using diameter at breast height and height. Local volume tables are supposed to be restricted to

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a local area. However, the terms “local” and “standard” do not in any way connote that one is better than the other. Both table categories are normally developed for a single species and specific region. The main difference between them is that local volume tables don’t consider the height-diameter relationship. When this relationship is known, then a double-entry volume equation can be transformed to a single-entry volume equation (Husch et al. 1982). The form-class/multiple entry tables are different from the previous two, as they provide the volume in terms of some measure of form in addition to diameter and height. Examples of such form are the Girard form class and the absolute form quotient (Spurr 1952, Husch et al. 1982, Avery and Burkhart 1994).

Despite the ecological importance of Brutia pine, there is still a knowledge gap about the growth and yield properties of the species. This research is a preliminary investigation to assessing the productivity potential of *Pinus brutia*, providing a basis for future studies. The purpose of this study is to develop an individual tree volume table for the Brutia pine as simple as possible, i.e. a single-entry volume equation.

Materials and Methods

Study area

The peri-urban forest of Xanthi (41º 09' 27.33'' N - 24º 54' 09.80'' E) is located northern of Xanthi city, in northeastern Greece, and it covers an area of 2.366,137 ha (Theodoridis 2016) (Fig. 1).

The topography of the area varies, due to many hills, gorges and streams. Slopes vary from 5% to 80%, while the minimum altitude is 100 and the maximum 630 m above the sea level (information from Forest Service).

In 1936, planting activities began and took place periodically up to 2007, even though most of them were made till 1973. In 2006, the forest was designated as protective. The main species that were used for reforestation were mainly *Pinus brutia*, and secondarily *Pinus pinaster*, *Pinus pinea*, *Pinus nigra*, and *Cupressus spp*. A few broadleaves such as *Robinia pseudoacakia* were used as well (Theodoridis 2016).

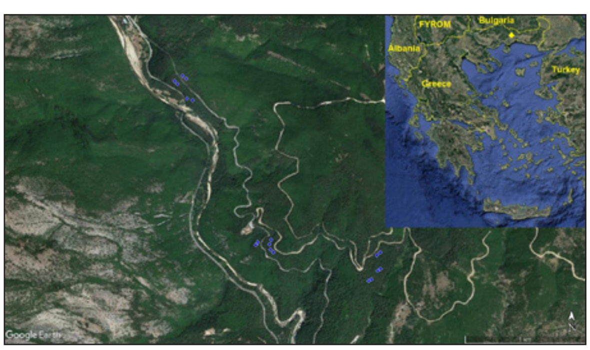

Figure 1 - Plot centers in the peri-urban forest of Xanthi, northeastern Greece.

According to the meteorological data from the closest meteorological station to the peri-urban forest (in the city of Xanthi), the mean annual temperature is 15.5 ºC and the mean annual precipitation is 675 mm. The xerothermic period lasts from July till the middle of October (Papaioannou 2008). The soil is classified as alkaline with poor humus (Theodoridis 2016).

Experimental plots and data used

The most reliable sources of data for the estimation and modeling of growth and yield are the Permanent Sample Plots - PSPs. PSPs are classified into two groups: passive monitoring PSPs and experimental PSPs. The major difference between the two groups lies in the scope of their use; passive PSPs are used for monitoring only existing conditions, whereas the experimental plots are used for monitoring treatments like varying intensities of thinning (Alder and Synott 1992, Vanclay et al. 1995).

In the context of the LIFE14 CCM/IT/000905 project entitled "recovery of degraded coniferous FOrests for environmental sustainability, REStoration and climate change MITigation" (FORESMIT), 18 circular experimental PSPs with 13 m radius were placed in the study area in February 2016. The following measurements are used in the present work:

- diameter at breast height (d) of each tree, with caliper, in cm
- total height (h) of each tree, with Haglöf Vertex laser hypsometer, in m
- form height (fh) of the trees with $d \geq 15$ cm, with Bitterlich's Spiegel relaskop (first measurement with the relaskop at breast height).

The total volume v (m^3) of each tree with $d \geq 15$ cm was derived following the formula (Van Laar and Akça 1997):

$$v = \frac{\pi}{4} d^2 1,3 + \frac{\pi}{4} d^2 fh$$

For each tree with d<15 cm its volume was calculated as a cylinder:

$$v = \frac{\pi}{4} d^2 h$$

Tree volume estimation

The mean tree method is one method for estimating stand volume and yield – there are various others. This method, and that of volume tables, shall be briefly discussed in this section.

The mean tree method of stand volume estimation

In the simplest of terms, in this method, the stand volume is obtained by carefully measuring the tree of mean volume and multiplying this volume by the total number of trees in the stand or plot (Spurr 1952).

The usual way of doing this is by getting the average volume of sub-sampled trees in each plot as the mean tree volume. The volume per hectare and the volume of each plot are calculated using this value and the number of trees.

This method involves two stages of sampling, with the sub-sampled trees being the second stage sample. For a precise estimate of the mean tree volume, the minimum sub-sampled size ought to be about 20 trees per plot (Philip 1994). This same postulation proposes pooling of the sub-sampled trees in all plots, to obtain a pooled tree of mean volume. However, this proposal comes with a warning: a serious bias can come out, if different plots provide different numbers of trees in the sub-sample and have different sized trees.

A common issue with this method is that the sub-sampled size is normally small, especially when there is a need for felling the sub-sampled trees to get detailed measurements. A substitute to this approach is founded on the assumption that the tree of mean volume is the one with the mean basal area (Spurr 1952, Crow 1971). Though this substitute approach offers some fairly positive results, a fallacy has been observed in the assumption (Spurr 1952). In this case, the mean tree is the tree that has a diameter approximately equal to the quadratic mean diameter of a sample of trees from the target stand.

Following this step the (mean) tree must be isolated in order to properly obtain the volume. After this, the plot volume estimate can be obtained by multiplying the total basal area of the plot by the ratio of the volume to the basal area of the mean tree (Schreuder et al. 1993).

Stand volume estimation using volume tables

The most usual way of estimating yield is through the use of volume tables. Secondary variables, such as diameter and height, are used when it becomes impossible to measure the individual tree volume in the field (Murchison 1984). In preparing volume tables, two variables can be used: single tree or stand volume. Single tree-based tables predict volume per tree, whereas stand volume tables predict volume per unit area (Philip 1994).

The single tree volume tables are further divided into three (3): local/single entry, standard/double entry, and form class/multiple entry volume tables (Husch et al. 1982).

Local volume tables present tree volume in terms of only the diameter at breast height (dbh). Tables that are restricted to a local area fall in this division. However, the terms "local" and "standard" do not in any way connote that one is greater than the other. Both table categories are normally prepared for single species or a group of species and specific localities. The main difference between these two divisions is that local volume tables don't generally consider the total height-dbh relationship. When the relationship is considered, then a standard volume table is the result (Husch et al. 1982).

The form-class/multiple entry tables are different from the previous two in that they provide the volume in terms of some measure of form in addition to dbh and total height. Examples of such form are the Girard form class and the absolute form quotient (Spurr 1952, Husch et al. 1982, Avery and Burkhart 1994).

One of the most common problems encountered in constructing volume tables is heteroscedasticity of residuals. Cunia (1964) proposed a solution to this problem. The proposed solution is through the use of weighted least squares when constructing the tables.

There are basically three methods that can be used for preparing a single tree volume table. The graphical method is the oldest and requires less mathematical techniques (Spurr 1952). The downside to this method is that it is prone to errors and subjectivity (Philip 1994, Spur 1952).

The next method is the alignment chart method for correcting curve linearity in multiple regression equations (Spurr 1952). A usual drawback of this method is the fact that prepared base charts are required – which are rarely available. Also, the charts cannot be read accurately as they are prone to errors associated to changes in paper dimensions (Spurr 1952).

A more modern and better method is the group of regression methods (Husch et al. 1982). Here, mathematical models and functions are used for preparing the tables. The advantage of this approach is the improved accuracy of the estimates. This method is applied in the present study.

Results

Data (v-d scatterplot) suggest that volume increases as diameter increases, following a trend that could be either linear or curve, with a constant term, as shown in Fig. 2. This was the reason for testing the following ten regression models ([1] to [10]) for fitting (Arlinghaus 1994):

Linear $$\hat{v} = b_0 + b_1 d \quad [1]$$

Logarithmic $$\hat{v} = b_0 + b_1 \ln d \quad [2]$$

Inverse $$\hat{v} = b_0 + \frac{b_1}{d} \quad [3]$$

Quadratic $$\hat{v} = b_0 + b_1 d + b_2 d^2 \quad [4]$$

Cubic $$\hat{v} = b_0 + b_1 d + b_2 d^2 + b_3 d^3 \quad [5]$$

Compound $$\hat{v} = b_0 \; b_1^{\,d} \quad [6]$$

Power $\hat{v} = b_0 \; d^{b_1}$ [7]

S-curve $\hat{v} = e^{b_0 + \frac{b_1}{d}}$ [8]

Growth $\hat{v} = e^{b_0 + b_1 t}$ [9]

Logistic $\hat{v} = \dfrac{1}{\frac{1}{u} + b_0 \; b_1^{t}}$

where u = upper boundary value = max h rounded up = 5.00 [10]

where:

$\hat{v}$: estimated volume (m^3)

d: diameter at breast height (cm)

b_i (i = 1,2): regression coefficients.

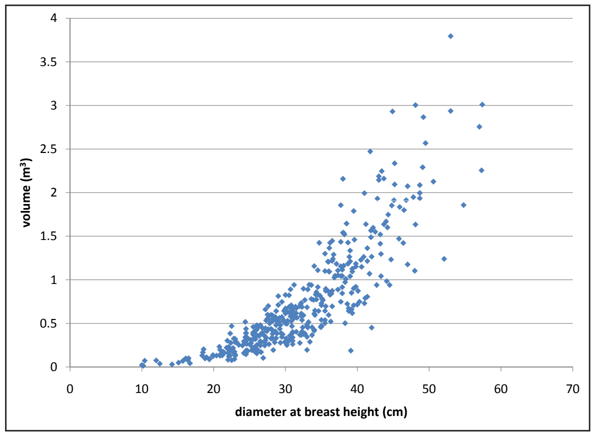

Figure 2 - Volume - diameter at breast height scatterplot.

Table 1 - Comparison criteria for tested regression models.

No	Criterion	Formula	Optimum value
1	Absolute mean error	$\dfrac{\sum_{i=1}^{n} \lvert v_i \quad \hat{v}_i \rvert}{n}$	0
2	Standard error of the estimate	$\sqrt{\dfrac{\sum_{i=1}^{n} (v_i \quad \hat{v}_i)^2}{n \quad p}}$	min
3	Coefficient of determination R²	$1 \quad \sum_{i=1}^{n} (v_i \quad \hat{v}_i)^2 \Big/ \sum_{i=1}^{n} (v_i \quad \bar{v})^2$	1
4	Root of the mean squared error	$\sqrt{\dfrac{\sum_{i=1}^{n} (v_i \quad \hat{v}_i)^2}{n}}$	min
5	Sum of squared errors	$\sum_{i=1}^{n} (v_i \quad \hat{v}_i)^2$	0

where:

v: measured volume (m^3)

$\hat{v}$: estimated volume (m^3)

$\bar{v}$: average measured volume (m^3)

$\bar{\hat{v}}$: average estimated volume (m^3)

p: number of regression coefficients

n: number of observations (404 trees).

We tested the assumptions for the Least Squares Method, in order to fit regression equations to data, i.e.: autocorrelation, homoscedasticity and normality of residuals. Five criteria were used for model comparison (Draper and Smith 1998) (Tab. 1). Firstly, we checked the significance of regression coefficients; then we calculated the comparison criteria and selected the best regression model for volume estimation.

A summary of the statistics for the measured and calculated variables are given in Tab. 2.

Regression coefficients of all models were significant (p<0.05), except for the cubic model [5],

Table 2 - Summary statistics of individual tree variables.

Variable	Mean	Standard deviation	Minimum	Maximum
diameter at breast height d (cm)	32.19	8.37	10.00	57.40
total height h (m)	19.74	4.58	2.80	31.40
form height fh	6.39	3.21	.26	17.73
form factor $f = \frac{fh}{h}$	0.3185	0.1327	0.0147	0.7802
volume v (m^3)	0.7464	0.6172	0.0148	3.7946

which had p=0.097 for the coefficient b_3 (all other coefficients had p<0.05). Therefore, the cubic model was excluded from further assessment. Comparison criteria values for the nine remaining models are given in Tab. 3 (best values for each criterion are highlighted).

Table 3 - Values for comparison criteria for tested regression models.

Criterion Optimum	1 0	2 min	3 1	4 min	5 0
Model					
[1] Linear	0.229	0.324	0.741	0.323	42.229
[2] Logarithmic	0.269	0.384	0.637	0.383	59.275
[3] Inverse	0.326	0.463	0.473	0.462	86.119
[4] Quadratic	**0.192**	**0.291**	**0.792**	**0.290**	**34.030**
[6] Compound	0.233	0.432	0.540	0.431	75.117
[7] Power	0.197	0.298	0.781	0.298	35.780
[8] S-curve	0.234	0.379	0.647	0.378	57.674
[9] Growth	0.233	0.432	0.540	0.431	75.117
[10] Logistic	0.199	0.301	0.777	0.300	36.328

The quadratic model clearly excels over the other regression models. The selected volume-diameter model for *Pinus brutia* is $\hat{v}$= 0.201 0.032d+0.001d^2, with R^2=0.792 and standard error of the estimate=0.291.

Regarding the assumptions for the Least Squares Method, in residuals autocorrelation check, by applying the Durbin-Watson test, DW value was equal to 1.494, which is a value fairly within the confidence interval [1.5,2.5]; therefore, residuals are considered non-autocorrelated. Homoscedasticity was checked with the Kruskal-Wallis test (p=0.058>0.05). Finally, normality of residuals was checked with the Q-Q plot (Fig. 3); points are fairly close to the normal line.

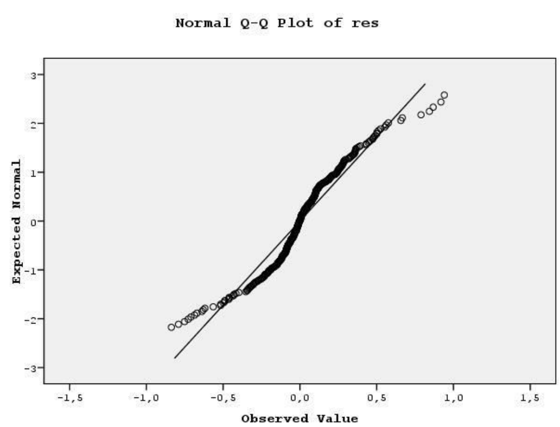

Figure 3 - Normality Q-Q plot of the residuals of the volume table.

Discussion

With this work, we have developed a single-entry equation for individual tree volume estimation, using a large sample size (404 trees from 18 permanent sample plots). Comparing this volume table with the equation of Özçelik et al. (2010) for *Pinus brutia* created for Burdur in Turkey, for the stands of the Bucak Forest Enterprise (Fig. 4), we observe that the peri-urban forest in Xanthi has higher individual tree volume, with the same diameter, than that of Turkey. In Fig. 4, the curve of Özçelik et al. (2010) $\hat{v} = 0.428753 d^{2.054628} h^{0.843735}$ was drawn using actual pairs of d and h from the database of the present work.

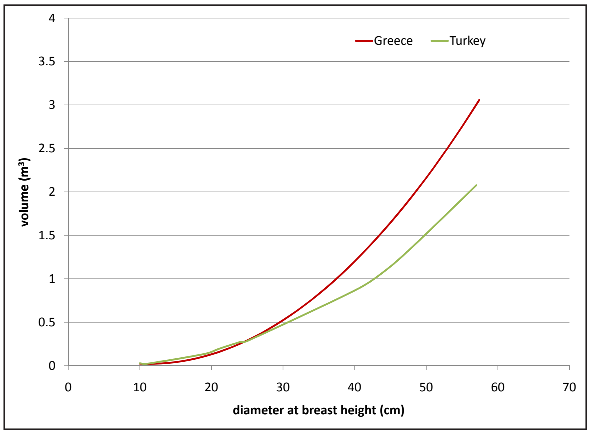

Figure 4 - Comparison of the two volume curves for *Pinus brutia* from Greece and Turkey.

In both areas stands were even-aged. Additional future research, based on climatic, geopedological, and stand structural conditions in Burdur, is essential before extracting conclusions regarding differences between the volume tables of Xanthi and Bucak.

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