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Estimates of the Bark Thickness in Bole Profiles of Oak in Northern Mexico

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ABSTRACT

The accurate estimate of the oak bark has economic and ecological implications. Operationally simple techniques are required without reducing its statistical reliability. The aim of this study was to estimate the total bark volume and thickness at different sections of the bole of the genus *Quercus* in forests of Northern Mexico through allometric relationships of diameter and partial heights. A sample of 206 trees with 1064 data pairs was collected and fitted to 5 models empirically proposed. The goodness of fit was examined from the comparison of the fitted coefficient of determination, bias and root mean square error. Statistical techniques were included to verify and correct the heteroscedasticity and autocorrelation problems associated with regression procedures. The results showed that to estimate the total volume of bark and its thickness, diameter and height are the most important explanatory variables ($R^2_{adj}\geq 0.81$) and generate a good relationship between simplicity and approximation. It is also advisable to apply the proposed equation, due to the complexity that represents the direct measurement of the bark at different heights to 1.3 m.

Key words: Allometric relationships, volume, *Quercus*, oak bark

INTRODUCTION

The oaks are a group of widely distributed species in the forests of temperate-cold climate (Valencia, 2004), this same author reports that the specific diversity for *Quercus* in Mexico is equivalent to nearly a third with regard to that of the world and are the second most important group because of its abundance after the pines. The forest region in the state of Chihuahua has an area of approximately 5 million hectares and there oaks belong to group of broad-leaved species most important in terms of commercial value, ranges of distribution as well as volume harvested. Its integral use provides substantial revenue in the region of study where the primary economic activity is the forest management (Pompa and Solis, 2008).

The accurate estimate of the volume of bark has implications for the economy of the forest sector as it constitutes a major source of raw material for power generation (Shah *et al*., 2007). With industrial purposes products such as tannins, methanol and absorbents of oil residues are used (Andrensek *et al*., 2004; Jansen and Kuiper, 2004; Elkhalifa *et al*., 2005; Nwafor *et al*., 2007; Oluwole *et al*., 2007). Ecologically, trees quantification is essential to understand the structure and function of a community. Especially in mature trees, the bark plays an important role in biodiversity conservation (Larsen *et al.*, 2006; Parsakhoo and Hosseini, 2009) and as an energy source for animals (Gasmi-Boubaker *et al.*, 2007; Elahi, 2010).

Traditionally, information about the content of bark has been obtained through direct measurement of the thickness. Otherwise, bark content is obtained through the difference of volumes of trees with and without bark using existing scaling equations. This however implies different errors of estimation notable in sections of the bole distant to the normal diameter where complexity of its direct measurement increases proportionally. In addition, estimates of the bark thickness along the bole allow a posteriori calculation of its volume in whole or in sections, providing particular application in the optimization of volume bark before their industrialization.

Allometric functions constitutes an alternative of reliable quantification. Under the assumption that the bark thickness decreases along the bole (Trincado and Burkhart, 2006), it is possible to model that attribute in function of variables such as diameters and relative heights, relieving the complexity of direct measurement at different heights to 1.3 m.

Several studies have been developed to estimate the content of bark, especially the studies of conifers, through estimates of artificial neural networks (Diamantopoulou, 2005); taper curves fitted with cubic spline functions (Laasasenaho *et al.*, 2005) and regression models with random effects and a mixed-effects modeling approach (Li and Weiskittel, 2011). As for the genus *Quercus*, the European studies of Vazquez and Pereira (2008) have been distinguished, they make a thorough review of the useful models on estimates of bark emphasizing the advantages of empirical models. Additionally, Vazquez *et al.* (2009) tested exogenous variables and though they result explanatory, require serious efforts for their measurement. Recently in western Iran, Valipour *et al.* (2009) evaluated the interrelationship of bark thickness and geographic variables, based on data on heights and diameters which helped to improve forest management strategies. However in Mexico, there is a paucity of studies to make estimates of standing oak bark.

Thus, this study aimed to estimate the total bark volume and thickness to different sections of the bole of the genus *Quercus* and to establish its relationships in diameter and partial heights.

MATERIALS AND METHODS

Description of the study area: The study area corresponded to the Ejido “El Largo y Anexas”, the largest Ejido of the Mexican Republic, located in the northwestern region of the State of Chihuahua, covering an area of 251,960 ha. The area is geographically located at coordinates 108°15' and 108°45' West longitude and 28°45' and 30°00' North latitude (Fig. 1). Politically it is located in the municipality of Madera, situated high in the Sierra Madre Occidental, being a fairly rough terrain with irregular elevations and depressions. The vocation of the land use is for forest management, the forest in this region is composed of tree vegetation mainly of temperate and semi-cold regions and with varying degrees of moisture; In general, the tree species are of *Pinus, Quercus, Pseudotsuga, Juniperus,* among others (Pompa-Garcia *et al.*, 2009).

Description of data: Data corresponded to a sample of 206 trees of various species of commercial use of the genus *Quercus* in uneven-aged mixed forests, randomly selected, covering the existing range of ages, stand densities and sites of the study area. The field data were obtained through a destructive sampling utilizing the cut areas, for which it was measured: normal diameter with bark/normal diameter over-bark at a height above ground of 1.3 (D) in cm, diameter with bark (d)

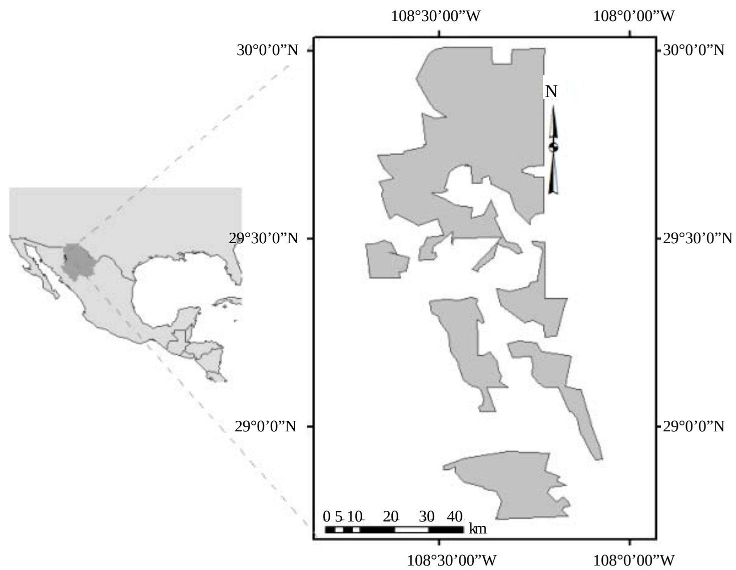

Fig. 1: Location of the study area

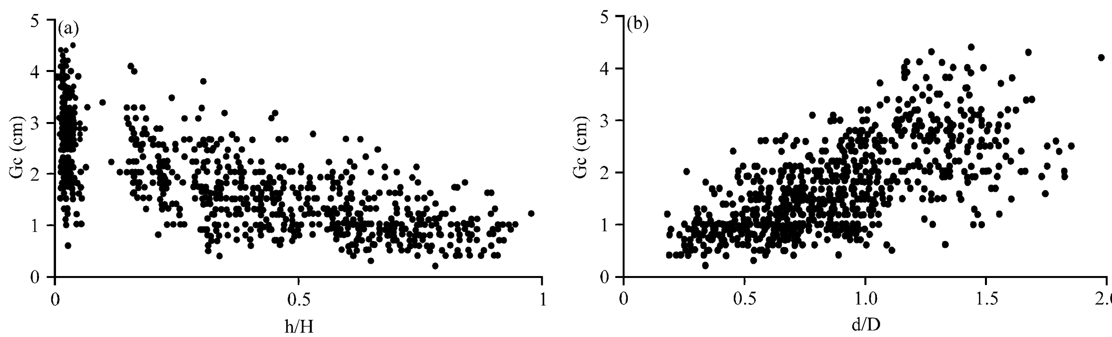

Fig. 2(a-b): Dispersion of observations Gc with relative (a) Heights and (b) Diameters of the 206 trees used in the fit

in cm, for each section to the height (h) in m which is above ground, total height (H) in m, as well as bark thickness for each section (Gc) in cm. Each section measurements were made from the stump in intervals of 1.2 m to reach the upper-bole height and then every 3 m. Volumes with over-bark and under bark of logs were calculated in cubic meters with the Smalian's formula, while for the top log the cone formula was used. The bark volume (Vc) was estimated by the difference between over-bark and under-bark volume. Descriptive statistics of data used in this study are reported in Table 1. Figure 2 shows scattered plots between the bark thickness and relative heights and diameters to the trees considered. The width of the distribution of the data reflect the size and shape of the trees forming the sample.

Evaluated models: To model the volume and thickness of bark, given the trends observed in Fig. 2, the following models were tested:

Table 1: Descriptive statistics of the trees used

Variable	No. of observatious	Min. value	Max. value	Mean	Standard deviation
D	206	10.00	81.0	36.90	16.18
H	206	4.00	32.0	13.04	4.92
h	1064	0.11	32.0	6.15	5.00
d	1064	4.90	101.6	25.28	19.67
Gc	1064	0.20	4.4	1.38	1.02

D: Normal diameter with bark/normal diameter over-bark (cm), H: Total height (m), h: Partial height from the base of the tree (m), d: Diameter over bark at height h (cm), Gc: Thickness with bark/over bark at height h and diameter d (cm)

$$Vc = \beta_0+\beta_1 \cdot (D^2H)+\varepsilon \tag{1}$$

$$Gc = \beta_0+\beta_1 \cdot (d)+\beta_2(h)+\varepsilon \tag{2}$$

$$Gc = \beta_0+\beta_1 \cdot \left(\frac{h}{H}\right)+\beta_2 \cdot (h)+\left(\frac{d}{D}\right)+\varepsilon \tag{3}$$

$$Gc = \beta_0+\beta_1 \cdot \left(\frac{h}{H}\right)+\varepsilon \tag{4}$$

$$Gc = \beta_0+\beta_1 \cdot \left(\frac{d}{D}\right)+\varepsilon \tag{5}$$

Where:

Vc : Volume of total bark m^3
Gc : Bark thickness in the diameter (d) and height (h) (cm)
D : Normal diameter with bark/normal diameter over-bark (cm)
d : Diameter with bark/over bark at height (h) (cm)
h : Height from the base of the stump to where it reaches the diameter (d) (m)
H : Total height of tree (m)
β_0, β_1, β_2 : Regression coefficients to be determine by fit

Fitting of models: Fit of the models was performed by regression using the ordinary least squares method (SAS, 2004). In these procedures it is common to verify heteroscedasticity and autocorrelation problems for applications in forest biometrics (Kozak, 1997). In the first case the Park "P" (Park, 1966) test was used to examine that variance of errors be homogeneous over the entire range of observations, while to prove the absence of correlation the Durbin and Watson statistic "DW" was applied (Durbin and Watson, 1951).

The criterion for evaluating the goodness of fit of the models was based on a numerical analysis involving the comparison of three statistics frequently used in forest modeling: (1) the bias ($\bar{E}$) which evaluates the deviation of the model with respect to the observed values, (2) the Root Mean Square Error (RMSE) which examines the accuracy of the estimates, (3) the fitted coefficient of determination R^2_{adj} which represents the part of the variance explained by the model, taking into account the number of parameters in it. Their expressions are:

$$\text{Bias}\left(\overline{E}\right) = \sum_{i=1}^{n}\left(y_i - \hat{y}_i\right)/n$$

$$\text{Root mean square error}\left(\text{REMC}\right) = \sqrt{\sum_{i=1}^{n}\left(y_i - \hat{y}_i\right)/\left(n-p\right)}$$

$$\text{Fitted coefficient of determination}\left(R^2_{adj}\right) = 1-\left(n-1\right)\cdot\sum_{i=1}^{n}\left(y_i - \hat{y}_i\right)/\left(n-p\right)\cdot\sum_{i=1}^{n}\left(y_i - \overline{y}_i\right)^2$$

where, y_i, $\hat{y}_i$ and $\overline{y}_i$ are the value observed, estimated and mean of the dependent variable; n is the total number of observations used to fit the model; p is the number of parameter of the model.

The experimental data and the residuals after the fitting of the models were graphically represented. These plots are a useful tool to detect errors or abnormal behavior (Neter *et al.*, 1990; Yang *et al.*, 2009).

Due to the fact that the database contains multiple observations for each tree (i.e. as hierarchical data), it is reasonable to expect that there is correlation between the residuals of the same individual, violating the assumption of independence of errors in the regression model, seriously affecting standard errors of the parameters and thus the efficiency of their estimates. Consequently this condition invalidates the tests using distributions t or F and by extension confidence intervals (Neter *et al.*, 1990). To correct this problem an error structure was used which was expressed as a continuous autoregressive model (CAR (x)), suitable for non-equidistant and unbalanced data (Zimmerman and Nunez-Anton, 2001). The autocorrelation of order k can be corrected by a model CAR(x) that expands the term of the error of the following form (Zimmerman and Nunez-Anton, 2001):

$$e_{ij} = \sum_{k=1}^{k=x} I_k \rho_k^{h_{ij}-h_{ij-k}} e_{ij-k} + \varepsilon_{ij}$$

where: e_{ij} is the residual jth of the individual i, e_{ij-k} is the residual j-kth of the individual i, $I_k = 1$ for $j > k$ and 0 for $j \le k$, ρ_k is the parameter autoregressive of the order k to estimate and $h_{ij}-h_{ij-k}$ is the distance that separates the observations jth and j-kth within each individual i, being $h_{ij} > h_{ij-k}$. In this cases ε_{ij} is the term of the error under independence conditions.

RESULTS AND DISCUSSION

All equations show that the thickness of the bark decreases as the sectional diameter and its corresponding height are reduced. However, the combined effect of both variables as predictors in the same expression (Eq. 2) improved the bark thickness estimation along the bole, unlike when adjusted from separate models for relative diameters and heights (Eq. 3, 4 and 5). Both the bias as the root mean square error and the fitted coefficient of determination resulted better than the rest of the models (Table 2). These results are consistent with Sunmez *et al.* (2007) and Valipour *et al.* (2009). For Sherrill *et al.* (2008) this correlation is linked to genetic causes, since the diameter is highly correlated with the thickness of bark.

Table 2: Results of the fitting of models generated all with a level of significance Pr> |t|<0.0001

Model	Parameter	Estimation	Standard error	Statistics of fit Ē (cm)	RMSE	R^2_{adj}
$Vc = \beta_0+\beta_1 \cdot (D^2H)+\varepsilon$	β_0	0.0759	0.0038	0.008	0.094	0.83
	β_1	7.38×10^{-6}	1×10^{-7}			
$Gc = \beta_0+\beta_1 \cdot (d)+\beta_2(h)+\varepsilon$	β_0	0.6822	0.0400	0.196	0.443	0.81
	β_1	0.0389	0.0008			
	β_2	-0.0457	0.0033			
$Gc = \beta_0+\beta_1 \cdot \left(\frac{h}{H}\right)+\beta_2 \cdot (h)+\left(\frac{d}{D}\right)+\varepsilon$	β_0	2.2762	0.1644	0.276	0.526	0.73
	β_1	0.2488	0.1207			
	β_2	-2.2264	0.1667			
$Gc = \beta_0+\beta_1 \cdot \left(\frac{h}{H}\right)+\varepsilon$	β_0	2.6104	0.0278	0.277	0.526	0.73
	β_1	-2.556	0.0472			
$Gc = \beta_0+\beta_1 \cdot \left(\frac{d}{D}\right)+\varepsilon$	β_0	1.7941	0.0314	0.323	0.568	0.69
	β_1	0.1156	0.0368			

All parameters were significant at $\alpha = 0.05$

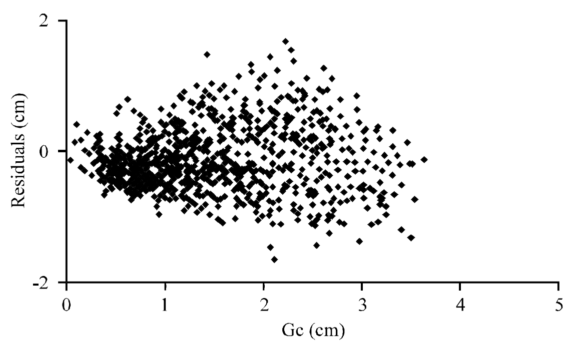

Fig. 3: Residuals facing predicted values of the model used to estimate thickness of bark, Gc: Function of the diameter over-bark d at the height h

According to Vazquez and Pereira (2008), the regression procedures used for estimating bark reported in the literature are usually linear and consider the independent variables of single form or, rarely, exponential as that used by Fonseca and Parresol (2001) whose model accounted for 86% of the observed variation, although the residuals showed scarce heteroscedasticity. In order to reduce heteroscedasticity and autocorrelation Ribeiro and Tome (2002), carried out the logarithmic transformation of the independent variables; however, they do not appreciate advantages over the models without transforming despite using, in part, the same data.

With regard to heteroscedasticity, the residual plots against the values predicted by the model (Fig. 3) and test of Park (1966) show that there is equality of variance and was not significantly relationship of residuals with the explanatory variables ($R^2 = 0.162$). To test the hypothesis of independence of residues, the Durbin and Watson statistic was close to 2 (DW = 1.18). Therefore, the existence of auto-correlation between residues with an α of 0.05

was rejected (Durbin and Watson, 1951). Thus, leads to an unbiased estimate of the residual variance and an efficient estimation of the parameters obtained.

After expanding trends in the residuals disappeared, as it is observed in Fig. 3. The sole purpose of correcting the autocorrelation was to improve the interpretation of the statistical properties of the models.

As can be seen, after expanding the error structure trends in residual plots are not observed, as happened with the reduced model (Fig. 3).

The production of bark at individual level depends heavily of two sources of variation: tree size and silvicultural treatments. According to Vazquez and Pereira (2008) the vast majority of models are based on election and measurement of dendrometric attributes which define tree as bark producer, although sometimes soil and climatic variables are included (Vazquez *et al.*, 2009).

Once known the thickness of bark, it is possible to estimate its total or partial content by sections. Several authors have found that for the genus *Quercus* the bark volume/total volume ratio is 15% (Sarikhani, 2001; Zobeiry, 2005; Namiranian, 2007); similar results were reported for *Sterculia setigera* in the Guinea Savanna (Oluwafemi and Tunde, 2008). However, estimations in percentage terms are relative and therefore inaccurate, given the multiplicative error generated by pre-calculate the volume of tree that usually presents polymorphism, while those made from woodland dendrometric variables produce direct and accurate estimates. Statistics reported in Table 2 for equation 1, give evidence of this and result according to studies on bark estimations (Montero *et al.*, 1996; Ribeiro and Tome, 2002) where it has been shown that the diameter and height (in that order) are the most important explanatory variables and they generate a good relationship between simplicity and approximation, ignoring the volume of the tree as a variable that improves competitively the bark estimation.

Although, these results constitute a contribution to knowledge in the estimates of bark, one must be careful when trying to generalize to other geographical areas. Ferreira and Oliveira (1991) analyzed the variability of bark in various regions of Portugal, concluding that the estimates should be specific to local predictions and even they recommend doing a grouping according to the size of trees in the confidence intervals.

When the main purpose is to obtain the thickness of bark, it is useful to obtain several models simultaneously, classified according to the difficulty of measuring the independent variables which allow for choosing the most suitable as the primary objective (inventory or research), such as those presented in this study.

CONCLUSION

Agricultural populations depend on the production of bark so it is necessary to have accurate estimates. The generated tool provides an advantage over direct estimation using the bark gauge, particularly at different heights than 1.3 m and when there is no adequate experience in its use. Instead, the facility that represents to measure heights and diameters along the bole without the need to scale them makes that found equation adequately estimates the thickness of bark, reduces operational problems in its measurement.

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