The Adjustment of Global and Partial Dry Biomass Models for *Pinus pinaster* in the North-East of Portugal

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Abstract. Ecosystems net primary production quantification can be done by means of allometric equations. Carbon sequestration studies also involve the quantification of growth dry biomass, knowing the carbon percentage of dry biomass. Fieldwork complexity to collect these kind of data are often limitative for obtaining these mathematical models.

Allometric equations were adjusted to estimate dry biomass of individual *Pinus pinaster* trees, using data from 30 trees. Statisticals form the final equations have shown that biomass estimation could be made under an accuracy of around 95%.

All mathematical models were calculated using diameter at breast height (dbh) as independent variable and enable to estimate biomass (in Kg) for: stem (R^2_{adj}=97.9); crown (R^2_{adj}=88.4) and roots (R^2_{adj}= 93. 5).

KeyWords: *Pínus pinaster*, total biomass, stem biomass, crop biomass, roots biomass

Introduction

Allometric equations are important for a wide range of ecological studies (Cao and Woodward, 1998; Lopes *et al*., 2003; Lopes and Aranha, 2004; and Lopes *et al*., 2004), including the quantification of the net primary production of ecosystems and the quantification of atmospheric carbon sequestered by vegetation, among others. Independently of its importance, the difficulties of fieldwork to collect these data are often limitative to obtain these models.

As allometric equations for estimation of net primary production for the *Pínus pinaster* were not available for the Northern of Portugal, thirty casual trees were destructively sampled – there trees were dig up by violent storms that took place in Portugal along 2001 Winter - in order to adjust models for the estimation of total and partial dry biomass. The sampled trees were distributed along all the dbh classes available for collection. The extreme dbh values were 7.5 and 35.7 cm.

This way was possible to adjust equations which have a wide range of applications.

Methodology

Trees were cut in parts (roots, stem, branches, etc.) and total tree height and live crown were measured.

Then some points along the tree merked in order to identify places for further cutoff of thick stem disks: at 10 to 15 cm from the base of the soil (base), at dbh and then at intervals of 10%, beginning at 10% of the total height and ending at 90% of the height (Figure 1). In each tree at each level previously identified, diameters and bark were measured and a thick disk was removed from the base of each stem section and preserved in a plastic bag to be weighed in the laboratory.

Remaining stems were cut into small sections to facilitate weighing on scales with a precision of

0.5 kg (Figure 2).

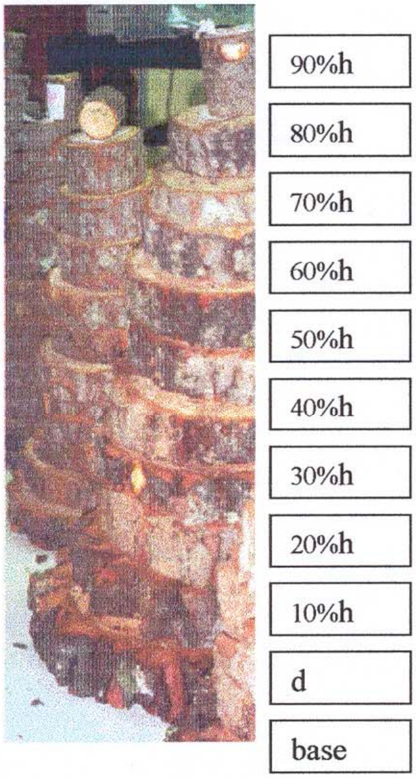

Figure 1 - Stem samples

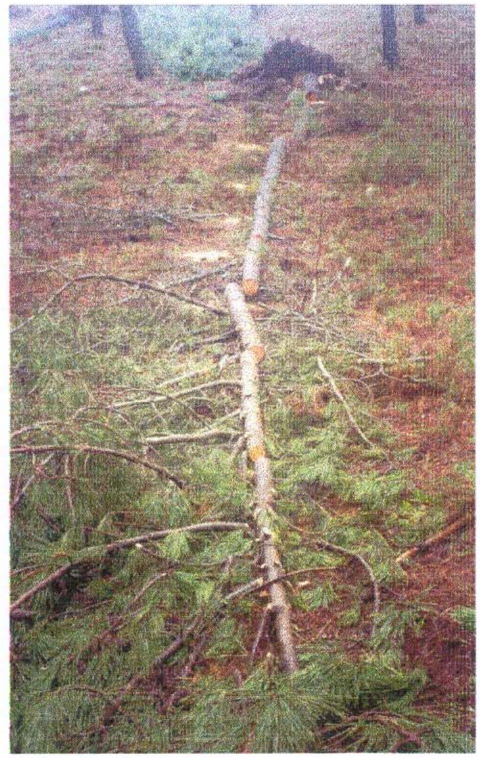

Figure 2 - Weighing the stems

In terms of canopy, each dead or alive branch was separated from the stem and fresh mass of each component was measured using scales with 1kg precision (Figure 3). Two live branches from the middle of the canopy were randomly selected for laboratory measurements later on.

Figure 3 - Weighing the branches

The central nucleus of each root system was identified, and whenever possible roots were carefully removed from the soil so that they could be extracted as possible to be weighed (Figure 4). This proved to be a difficult and time-consuming process.

Figure 4 - A root from a *Pinus pinaster* tree

At the laboratory each stem sample disk was weighed on electronic scales and volume was determined using Arquimedes method. In practice the volume was obtained by the immersion of the slices in a pail of water, without touching the sides of the pail, and weight was obtained for each slice (Figure 5). The volume coincides with the obtained weight and is given in cm^3. It was then possible to estimate green density.
Samples were then kept inside a stove at 100ºC for four to five days until weight measurement was constant. At that moment wood contained no moisture and each slice was again weighed in order to determine oven dry density.
In each sample branch, leaves, logs and fruits were separated to obtain the relative contribution of each component for the total weight of the branch (Figure 6). After that, some shoots were taken from each subsample to proceed with weight and volume measurements following the same

methodology applied for stem disk samples (Figure 7), to determine density of each component when the wood was both completely dry and wet. The methodology was also repeated for a subsample of each root.

Figure 5 - Volume calculations

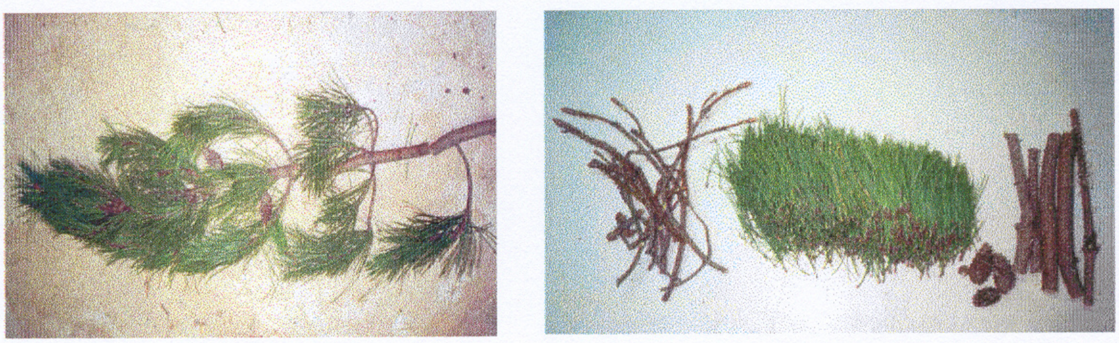

Figure 6 - A sample branch of components

Figure 7 - Subsamples of each component from the sample branch

Methodology used to adjust biomass estimation models

The approaches followed to estimate the total biomass of a *Pínus* tree involved the adjustment of partial model for stem, crop and roots. That way, total dry biomass was obtained trough the sum of each partial estimation.

In a previous stage of the adjustment models, the correlation matrix was analyzed to enable the detection of which tree variables presented a better correlation with each partial dry biomass. These variables could constitute the best independent variables for the models to be built. Following that, a more exhaustive study was undertaken to allow identification of the variables which should in fact be used as prediction variables.

Therefore, some transformations (e.g. logarithms, exponential) of the initial variables were tested.

In the next stage mathematical models were adjusted. Later a multicollinearity study and an analysis of the previous assumption of the heterogeneous variance, through analysis of FIV and the graph of the residuals were conducted.

In the selection stage, models were divided into three large groups: linear models with just one independent variable, which are easier to use; linear models with more than one independent variable and intrinsic linear models linear models.

Firstly, the best model from each of these groups was selected using the following statistics: Simple coefficient of determination (R^2); Adjusted coefficient of determination (R^2_{adj}); Medium square of the residuals (MSR); Mean absolute deviation (MAD); and standard deviation error (s_{yx}), as described by Fonseca (1998).

Here, the easier applicability of a model, as biomass would de determined at different ages to evaluate biomass variation and NPP, was also considered. That way, all independent variables should be easily obtained. For present measurements, diameter at breast height (dbh), crown height and width can all be easily measured. Although, while for previous time periods dbh can still be easily obtained, using a drill, the other variables are no so easily obtainable, specially crown width. Unlike for dbh, reconstruction of figures for height is impossible. However, due to its frequent measurement past figures for dbh can easily be found. As far as crown width is concerned the situation is different and is not so easily available.

Results

Analysis of the global correlation matrix for each specie showed that the best correlated variables with partial and total dry biomass were diameter at breast height (dbh), diameter at base level (d_{base}), total height (h) and crown width (CW). The dbh constituted almost always the best variable, except for root biomass (and even there the correlation coefficient is high).

The best models for each group (linear with one independent variable to estimate dry biomass, linear with more than one independent variable and intrinsic linear) are further presented (from equations 1 to 9).

Pre-selected equations to estimate stem dry biomass of a *Pinus pinaster* tree

Eq. 1	B=-128.264+1168.689dbh	R^2=83.8%;	R^2_{adj}.=83.2%
Eq. 2	B=36.775+53.359dbh*h	R=96.0%;	R^2_{adj}.= 95.9%
Eq. 3	Log(B)=3.769+2.7061og(dbh)	R^2=98.6%;	R^2_{adj}.=97.9%

Pre-selected equations to estimate crop dry biomass of a *Pinus pinaster* tree

Eq. 4	B=-44.192+307.597dbh	R^2=71.2%;	R^2_{adj}.=70.1%

Eq. 5	$B=8.192+40.159d*CW$	$R=88.2\%$;	$R^2_{adj.}=87.7\%$
Eq. 6	$Log(B)=2.911+2.130log(dbh)$	$R^2=76.5\%$;	$R^2_{adj.}=75.6\%$

Pre-selected equations to estimate root dry biomass of a *Pinus pinaster* tree

Eq. 7	$B=-4.562+71.248\ d\ d_{base}$	$R^2=93.3\%$;	$R^2_{adj.}=93.0\%$
Eq. 8	$B=-4.673+53.308\ d_{base}+0.399h$	$R=95.6\%$;	$R^2_{adj.}=95.3\%$
Eq. 9	$Log(B)=1.972\pm1.221\ 1og(dbh)$	$R^2=93.7\%$;	$R^2_{adj.}=93.5\%$

Table 1 presents the best standard error estimation for the best possible combinations of the two best models for stem and root components and equation b and h for dry crop biomass estimation. In this case, equation e was excluded considering that crown width is the most difficult variable to obtain.
The best combination would be the one that uses equation 3 to estimate stem biomass, equation 6 to estimate crop biomass and equation 8 to estimate root biomass. Nevertheless, the most practical methodology is the one which uses only dbh as a prediction variable as its measurement is the easiest, at any time. For estimations of past time points information can be gathered from drillings.

Table 1 - The standard error deviation (kg) for the best NPP estimation approaches

Some tested combinations taking into consideration the previously selected models for the stem, the crop and the root biomass estimation							
2-4-7	2-4-8	2-6-9	2-6-8	3-4-7	3-4-8	3-6-7	3-6-8
30.9	28.3	27.6	28.3	28.3	27.7	27.5	26.9

Discussion and final comments

The adjustment of the allometric equations to estimate *Pinus* NPP was a extremely important, otherwise NPP only could be measured based on the physiological procedures, which can be even more laborious and complex. Furthermore, it also provides an invaluable tool for the Portuguese scientific community and for any kind of study requiring biomass quantification. Final results showed that biomass can accurately be estimated based only dbh which is a very simplified approach.

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