

PBRAVO Model

BRIEF DESCRIPTION, EQUATIONS & SOFTWARE

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Background Introduction

Eucalyptus globulus Labill. planted forest is of crucial importance for the Portuguese economy being the main source for high quality raw material for the pulp and paper industries. Portugal has a long experience in developing empirical growth models for eucalyptus even-aged stands for which the planting date is known. Age is one of the most important variables in growth and yield modelling of even-aged stands. However, plantation date is often unknown for Portuguese eucalyptus stands and stand age is especially hard to assess for fast growing species with no well defined tree rings like is the case of Eucalyptus. In order to solve the problem of unknown stand age, GYMMA model Growth and Yield Model Missing Age, was developed and is at present being applied to project uneven-aged stands ([Barreiro et al. 2004](#)). Additionally, a set of biomass functions per component was included to complement the model ([Oliviera xxxx](#)).

Model Description

In whole stand models, such as the GLOBULUS 3.1 model, state variables are all defined at stand level: (e.g. dominant height (h_{dom}), number of trees per ha (N), basal area (G)). In turn, diameter distribution models apart from some stand level variables (e.g. stand density) often require other variables that are needed for the simulation of diameter distribution. These models are based on a particular probability distribution function, and the PBRAVO diameter distribution model is based on the Weibull probability distribution function (eq 1):

$$F(x) = 1 - e^{-\left(\frac{x-a}{b}\right)^c} \quad (\text{Eq. 1})$$

Where x corresponds to the upper limit of the diameter class, and a , b and c are the Weibull parameters estimated with the following equations:

$$a = 0.9 d_{\min} \quad b = \frac{(x_p - a)}{\left[-\ln(1 - P_{95})\right]^{1/c}} = \frac{(P_{95} - a)}{\left[2.99573\right]^{1/c}}$$

Where d_{\min} represents the minimum diameter of the stand/plot and P_{95} the percentile 95. After a and b are estimated, the c parameter is estimated by resolution using numerical methods following the non-linear equation.

$$a^2 + 2a(x_p - a) \frac{\Gamma\left(1 + \frac{1}{c}\right)}{-\ln(1-p)^{1/c}} + (x_p - a)^2 \frac{\Gamma\left(1 + \frac{2}{c}\right)}{-\ln(1-p)^{2/c}} - E(x^2) = 0$$

The Weibull function has the inconvenience of having one of its parameters difficult to estimate (c). Thus, for practical applications the parameter is either provided or the user is recommended to use the PBRAVO software developed by (Pascoa xxx). The model was programmed in *fortran* and a user friendly interface was developed. Before moving to a description of the interface let us look at an example of how these type of models work in the following example.

Knowing the values of the 3 Weibull parameters and the stand density (N), the accumulated probabilities of trees that occur under each dbh class can be estimated. Suppose a=2.6, b=9.0, c=3.2 and N=878.

classe d	dcentral (cm)	dsup (cm)	Weibull P(d<=dsup)
[2.5, 7.5]	5	7.5	0.137
]7.5, 12.5]	10	12.5	0.751
]12.5, 17.5]	15	17.5	0.994
]17.5, 22.5]	20	22.5	1.000
]22.5, 27.5]	25	27.5	1.000
]27.5, 32.5]	30	32.5	1.000
]32.5, 37.5]	35	37.5	1.000

Weibull function to estimates the accumulated frequency of trees per dbh class

$$F(12.5) = 1 - e^{-\left(\frac{12.5-2.6}{9.0}\right)^{3.2}}$$

Nacum is obtained by multiplying the accumulated probabilities by N=878. The number of trees in each dbh class is obtained subtracting the Nacum between consecutive dbh classes and the corresponding G by dbh class is obtained as shown.

dcentral (cm)	Weibull P(d<=dsup)	Nacum (ha ⁻¹)	N (ha ⁻¹)	G (m ² ha ⁻¹)
5	0.137	120	120	0.2
10	0.751	659	539	4.2
15	0.994	873	214	3.8
20	1.000	878	5	0.2
25	1.000	878	0	0.0
30	1.000	878	0	0.0
35	1.000	878	0	0.0
Stand			878	8.4

$$\Rightarrow = \left(\frac{\pi}{4} (10/100)^2\right) 539$$

The next step is predicting the height and volume of the average tree of each dbh class, volume per dbh class is obtained by multiplying the average tree volume by the number of trees.

dcentral (cm)	N (ha ⁻¹)	h (m)	v (árvore)	V (m ³ ha ⁻¹)
5.0	120	1.4	0.003848	0.5
10.0	539	4.6	0.021739	11.7
15.0	214	6.8	0.060050	12.8
20.0	5	8.4	0.119334	0.6
25.0	0	0.0	0.000000	0.0
30.0	0	0.0	0.000000	0.0
35.0	0	0.0	0.000000	0.0
878				25.6

Stand volume is estimated by summing up these values

$$\Rightarrow = (0.021739) 539$$

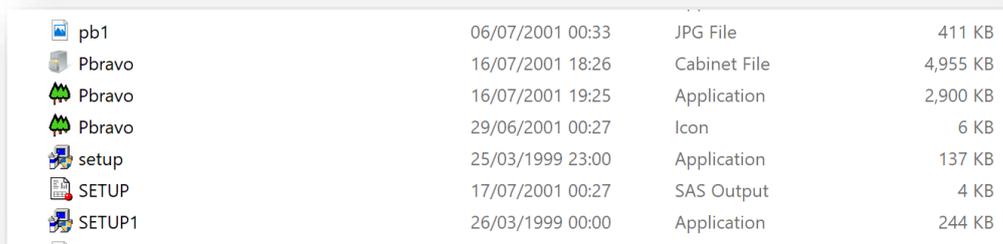
The growth and prediction functions that make up the PBRAVO model are presented in **Table 1**.

Table 1. PBRAVO model functions by module.

	Initialization Module	Projection/prediction Module	
G	$G = 0.000984 h_{dom}^{2.103402} N^{0.797707} e^{-\frac{8.702327}{t}}$	$G_2 = G_1 e^{\left(\frac{h_1}{t_2} - \left(\frac{h_1}{t_1}\right)^4\right) (4.178774 + 0.039053 h_{dom})}$	
P 95%	$P_{95} = 2.754927 h_{dom}^{1.445365} N^{-0.161445}$	$P_{95} = 154.155144 \left(\frac{G_1^{t_1/2}}{N_1}\right)^{\frac{1}{2}} e^{-0.009172(t_2-t_1)\left(\frac{h_1}{t_2}\right) (2.919335 - 0.034485 h_{dom})}$	
d _{min}	$d_{min} = 12.302998 h_{dom}^{1.617991} N^{-0.687786}$	$d_{min_2} = 44.995291 \left(\frac{G_1^{t_1/2}}{N_1}\right)^{\frac{1}{2}} e^{0.062039(t_2-t_1)\left(\frac{h_1}{t_2}\right) (-6.721703 - 0.039053 h_{dom})}$	
N	$N = Npl^{(1-0.00400588 t)}$	$N = 1324.485 G^{-0.23156} h_{dom}^{-0.382656} e^{5.407995 t^{-1}}$	
Calculus Module			
h _{dom} & S	$h_{dom} = S 10^{\left(0.380999 - 2.694076 t^{-\frac{1}{2}}\right)}$		$S = h_{dom} 10^{\left(-0.380999 + 2.694076 t^{-\frac{1}{2}}\right)}$
Height DBH curve	$h = 1.891036 h_{dom}^{0.890695} G^{-0.146749} N^{0.075548} e^{\left(\frac{2.000723}{t} - \frac{11.96184}{d}\right)}$		
Total volume	$v = 0.336 g h^2 e^{\left(\frac{0.94}{d} - \frac{d+3.79}{h}\right)}$	Merchantable volume	$di = d \sqrt{1.0080 e^{\left(\frac{0.94}{h} - \frac{3.79}{d}\right)} \left(1 - 2\frac{hi}{h} + \frac{hi^2}{h^2}\right)}$
Thinning Module			
Residual d _{min}	1st thinning $d_{min_{res}} = 0.438034 + 1.047001 d_{min}$	Following thinnings	$d_{min_{res}} = 0.684456 + 1.07904 d_{min}$
Residual P 95%	1st thinning $P_{95_{res}} = 0.121887 + 1.000760 P_{95}$	Following thinnings	$P_{95_{res}} = 1.22143 + 0.981559 P_{95}$
Residual N	1st thinning $N_{res} = N \left[1 - \left(1 - \frac{G_{res}}{G}\right)^{0.896268}\right]^{0.882856}$	Following thinnings	$N_{res} = N \left[1 - \left(1 - \frac{G_{res}}{G}\right)^{0.715054}\right]^{0.820574}$

Using the PBRAVO model

Copy the folder PBRAVO from the memory stick, go to PBRAVO\PBRAVO-FPFP, then click on the setup (NOT on the SETUP1). After installing the setup, click on the PBRAVO application (**Figure 1**).



File Name	Date	Type	Size
pb1	06/07/2001 00:33	JPG File	411 KB
Pbravo	16/07/2001 18:26	Cabinet File	4,955 KB
Pbravo	16/07/2001 19:25	Application	2,900 KB
Pbravo	29/06/2001 00:27	Icon	6 KB
setup	25/03/1999 23:00	Application	137 KB
SETUP	17/07/2001 00:27	SAS Output	4 KB
SETUP1	26/03/1999 00:00	Application	244 KB

Figure 1. Location of the PBRAVO application within the folder.

Once installed, the PBRAVO model shows a very simple interface (**Figure 2**) with 4 buttons: 1) the Model Options (Opções do Modelo); 2) the Run (simulação); 3) The Help; and 4) the Exit (Sair).

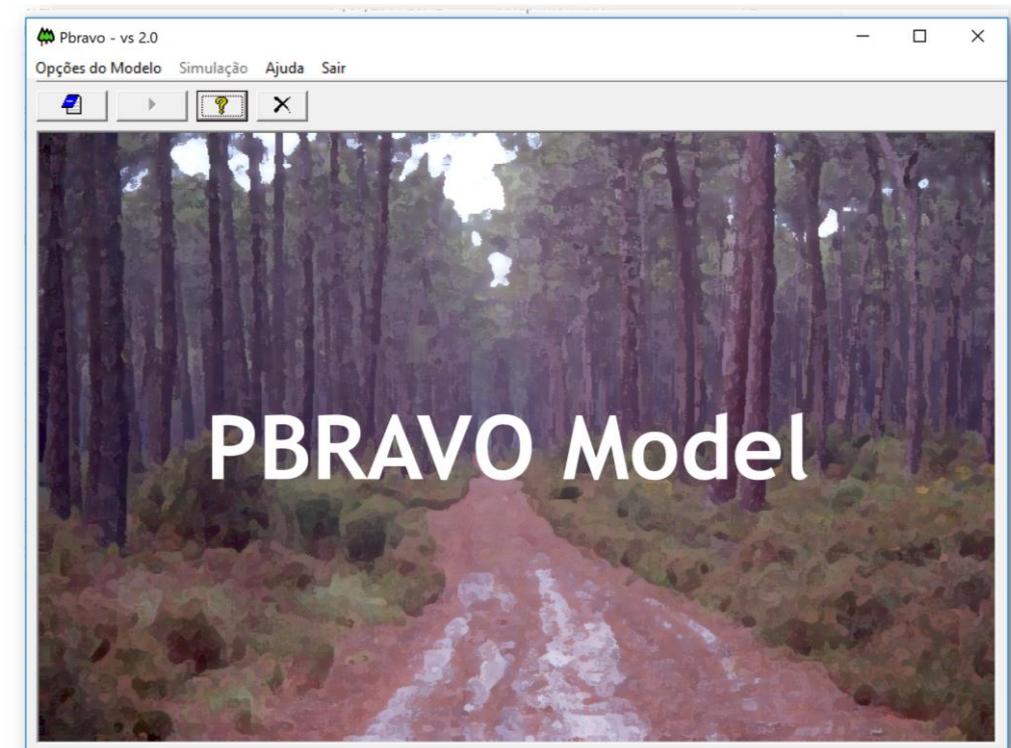


Figure 2. PBRAVO interface.

By Clicking on the Model Options button, a new window shows (**Figure 3**). Here the user is asked to provide some details about the simulation, such as:

- the current year, which should be consistent with the stand's age;
- whether to simulate underbark or overbark volume (since the bark of maritime pine trees represents 20-30% of stem volume);
- some details about the assortment dimensions (**Figure 4**).

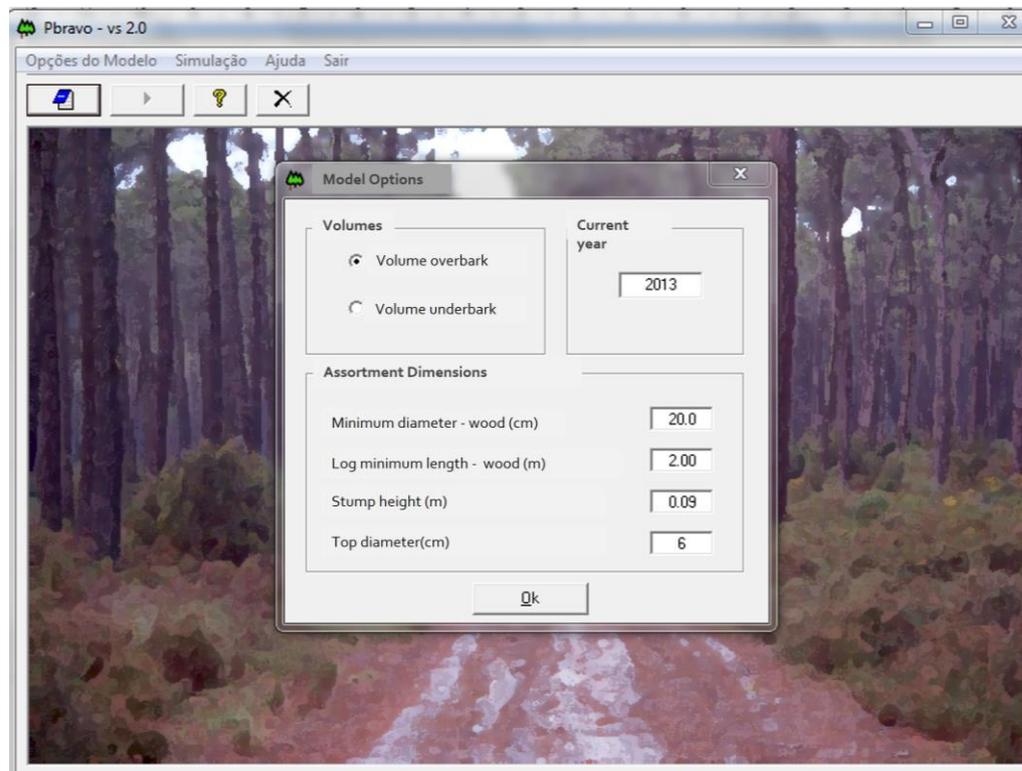


Figure 3. PBRAVO model options window 1.

For the example on the right, the inputs should be:

- Minimum diameter of wood (cm) = 20 cm
- Log minimum length (m) = 2 m
- Stump height (m) = 9 cm
- Top diameter (cm) = 6 cm

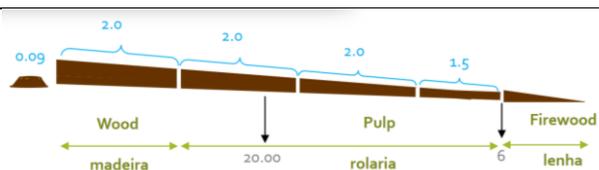


Figure 4. Example of the assortment dimensions requested by PBRAVO model.

Moving to the next step, the user will be asked to decide whether he wants to run the model for one of the 3 situations (**Figure 5**):

- stands that have the dominant height (hdom) measured, and then fill the hdom value;
- stands with no information on dominant height, and in this case the site index class is required;
- unthinned stands, ie young stands. Please note that, projections are not so good for old stands that have never been thinned.

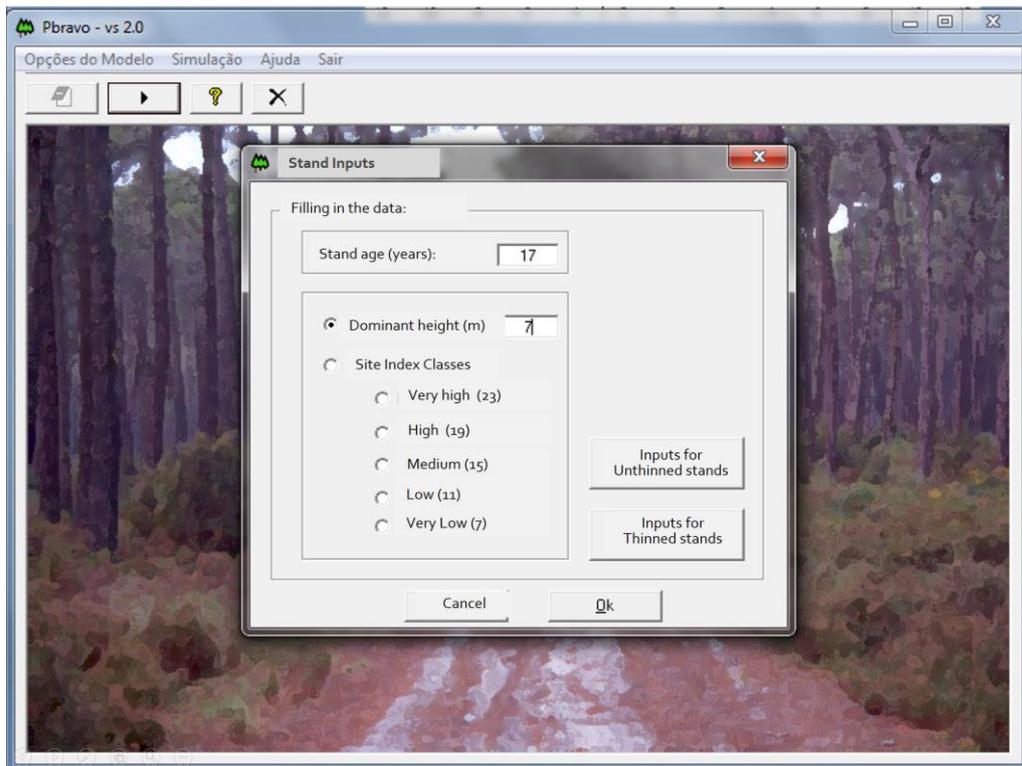


Figure 5. Example of a 17 year old stand with dominant height measured.

For young stands, the user has to provide either the number of standing trees (ha^{-1}) or the number of trees planted (ha^{-1}). In the latest case, a mortality model is applied to express the death of trees due to competition in early stages of stand development. The model runs in 5-year time-steps, stopping at each step allowing the user to (re-)define the management for the next 5-years period. For older stands (already thinned), the user has to provide either the number of trees by diameter class or the required stand variables so that the Weibull parameters (a , b , c) can be obtained (**Figure 6**). Before filling in the information the user has to remember to check which of the 2 options he prefers.

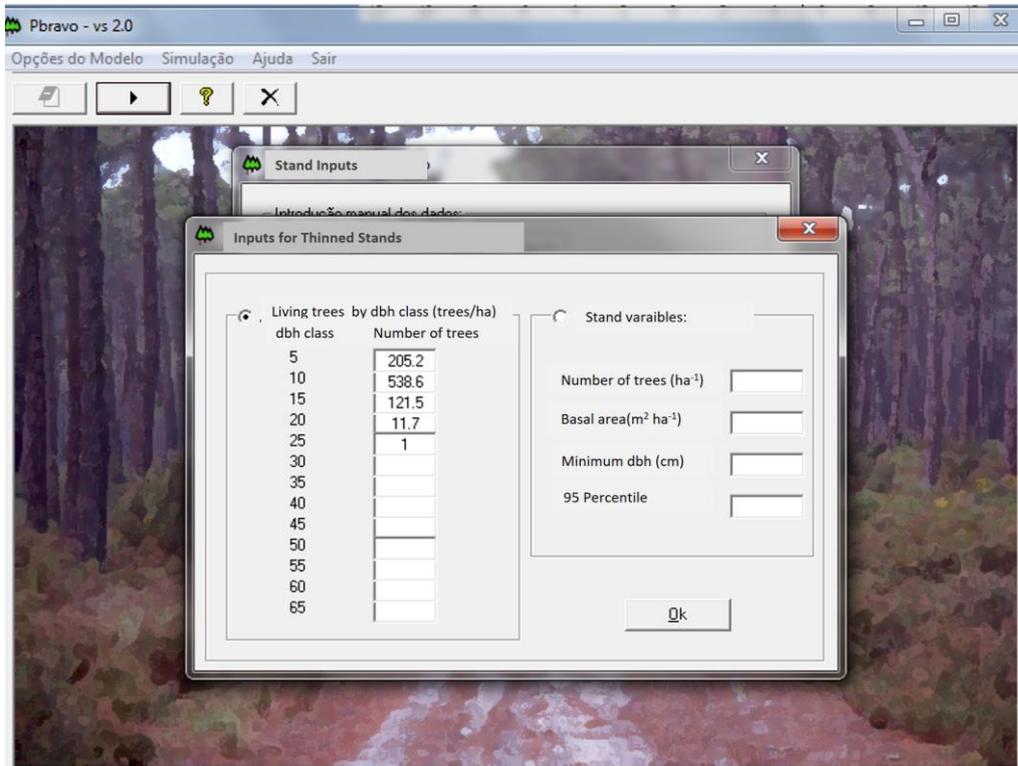


Figure 6. Example of a simulation run for which it was chosen to provide the number of trees by diameter class instead of the stand variables.

Making a bridge to what has been previously explained; the dbh class value represents the midpoint of the diameter class. In case the stand has trees with dbh values greater than 67.5 cm these should be grouped under the 65 class. Likewise, dbh class 5 includes not only the trees with dbh [2.5, 7.5[but also those with dbh < 2.5 cm.

After the stand has been described, by clicking the OK button a new window showing a summary table with the estimated diameter distributions is displayed (**Figure 6**). Among the information provided, the user will see the values of the Weibull parameters and the volume by assortments for each dbh class. To move forward the user will have to choose whether to carry out a thinning or not. If he chooses not to thin, then growth is projected by diameter class for a 5 years period and an updated table is displayed (**Figure 7**).

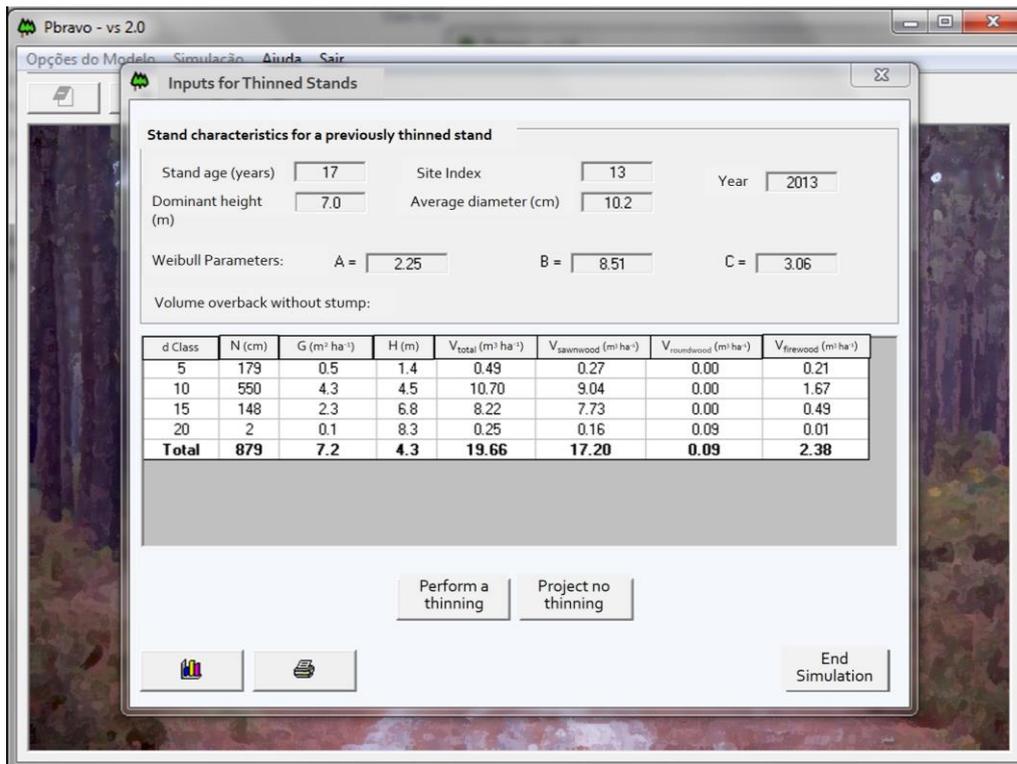


Figure 6. Example of a summary table characterizing the stand at the beginning of simulation (following the examples in previous figures).

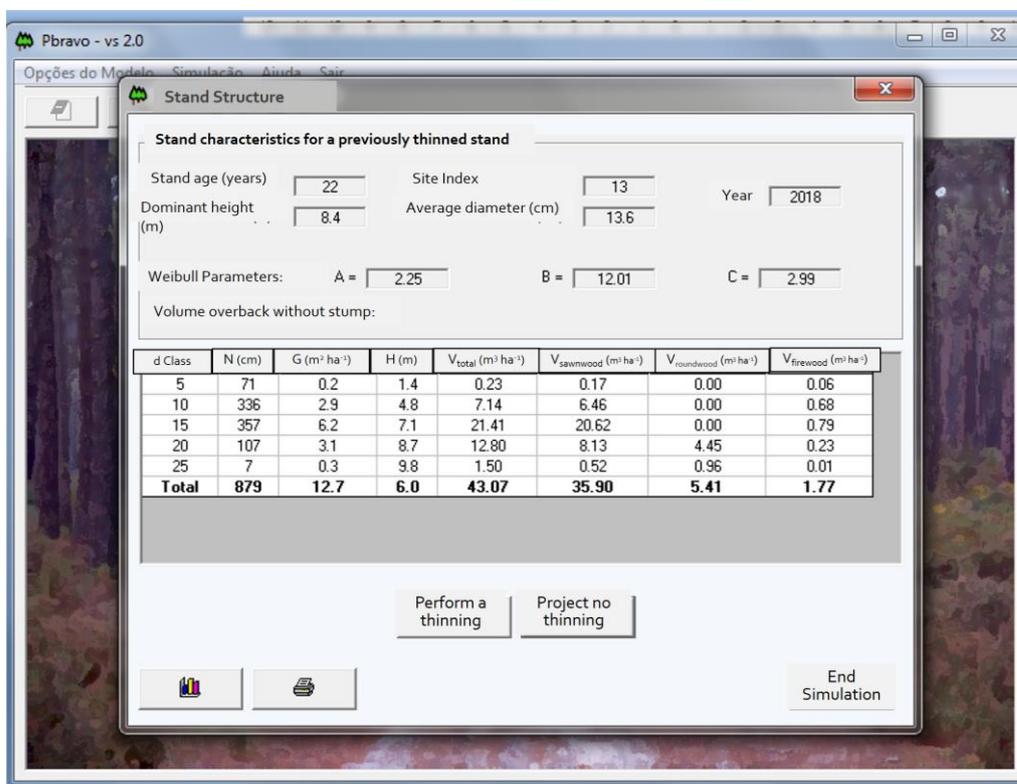


Figure 7. Example of the summary table characterizing the stand after the first 5-years simulation run.

On the other hand, if the user chooses to thin, he has to click on “Project thinning” so that a new window requesting the thinning details is displayed (**Figure 8**). In this window the user has to choose whether to thin by removing a percentage of trees or defining the residual basal area (the standing basal area).

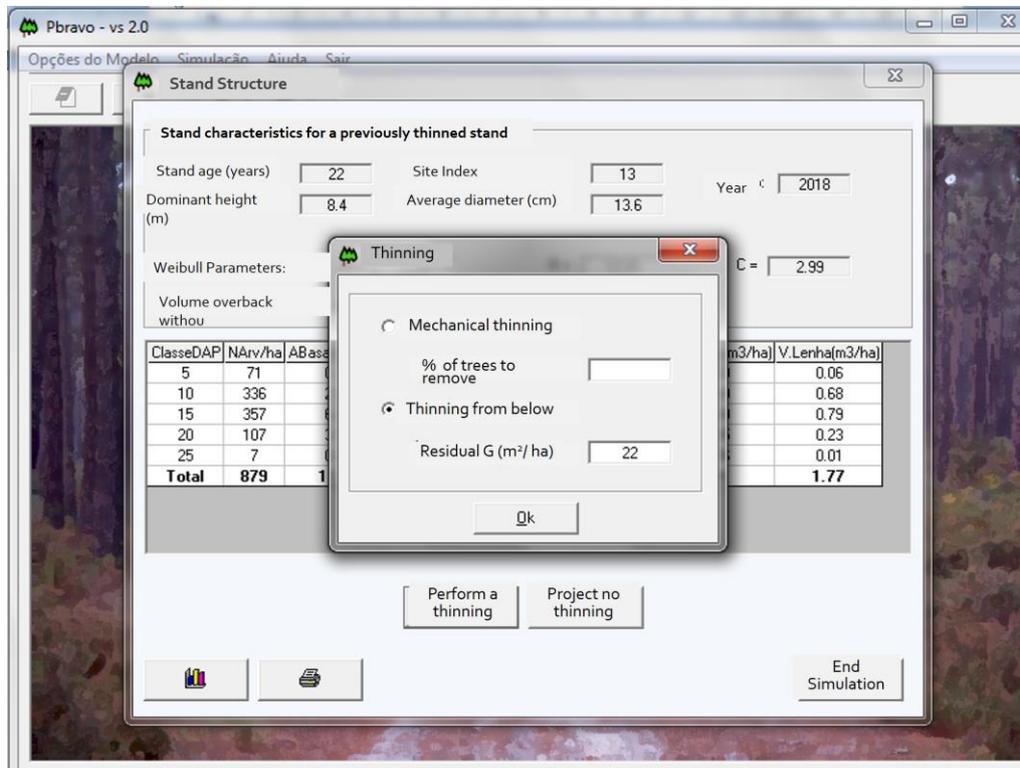


Figure 8. Example of the thinning details window assuming a thinning from below leaving a basal area of 22 m²ha⁻¹.

If the user decides to perform a thinning leaving a residual basal area greater than the stand basal area, a message is displayed (**Figure 9**). Please note that the stand basal area was 12.7 m²ha⁻¹ (**Figure 7**) and when the thinning was defined a residual basal area of 22 m²ha⁻¹ (**Figure 8**). In such situation, the user is left with the option to project growth without thinning until the stand basal area is greater than the predefined value or decreasing the residual basal area. However the user should be aware that the PBRADO model was programmed with a restriction that only allows thinning to take place if the amount of basal area removed is above a certain threshold to avoid that the thinned wood would pay off the for the thinning costs. For this reason, even after reaching a basal area of 23.6 m²ha⁻¹, a warning message is still displayed for a residual basal area of 22 m²ha⁻¹ (**Figure 10**). Whenever a thinning takes place two tables are displayed characterizing the stand before and after thinning. At any point of the simulation the user can click on the graphs button on the lower left part of the window and a smaller window opens displaying a summary of stand characteristics and a graphic comparing the situation before and after thinning (**Figure 11**). Alternatively, the user can choose to print the results.

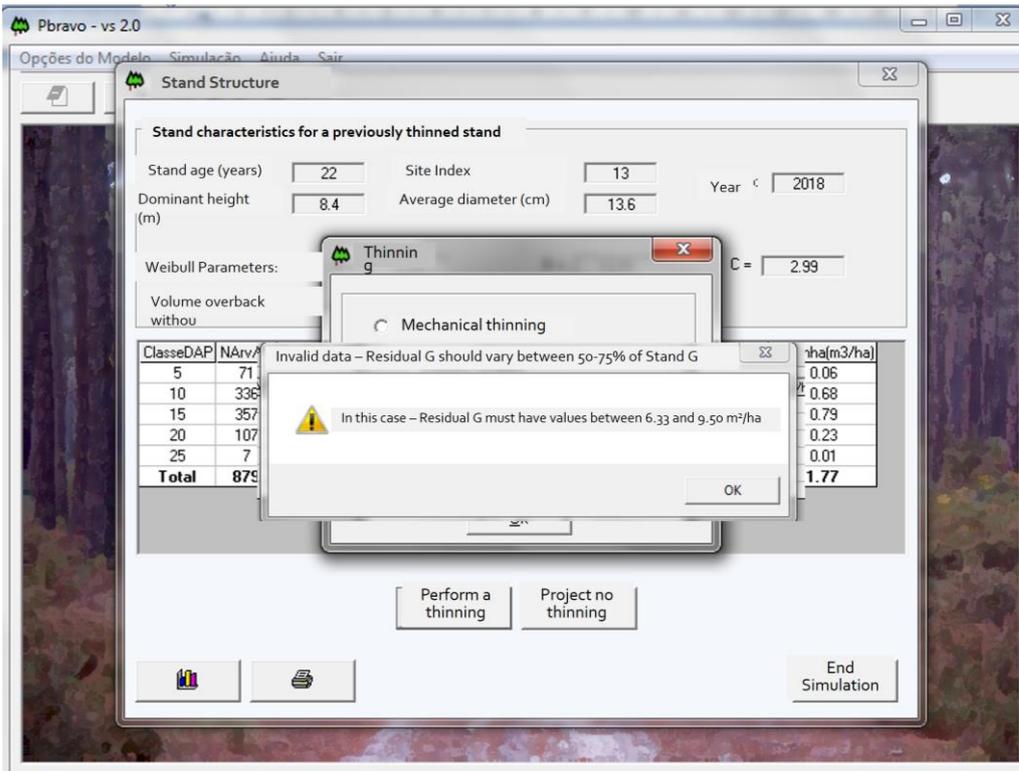


Figure 9. Warning message stating the interval of residual basal area values that would allow a thinning to take place for this stand.

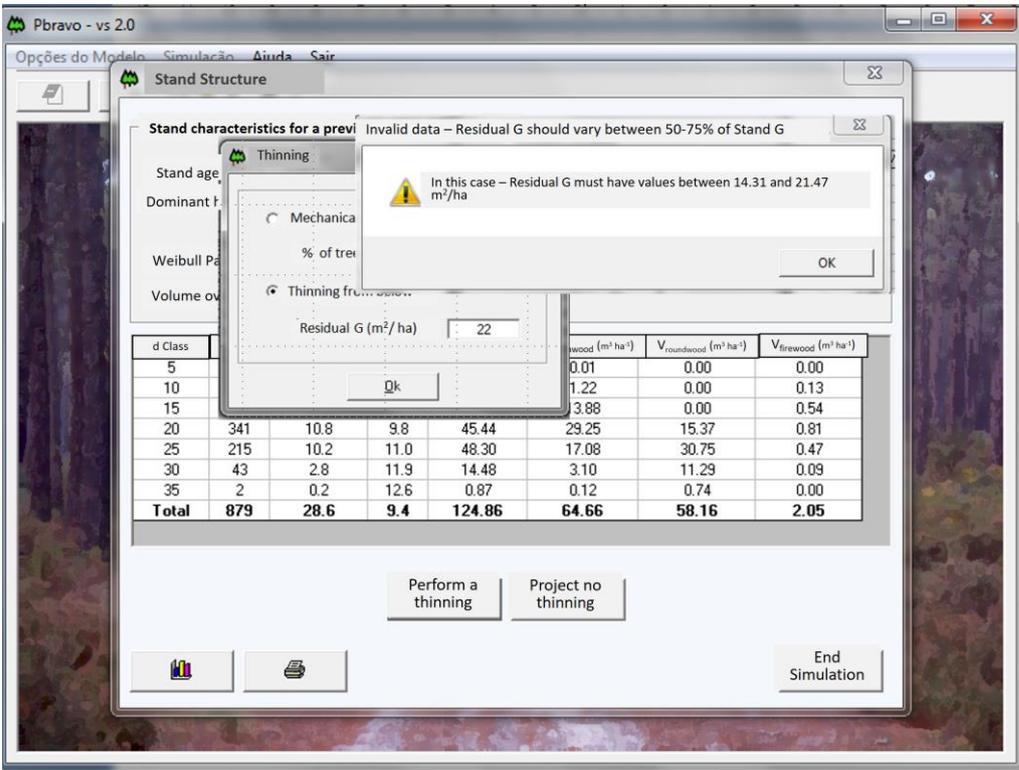


Figure 10. Warning message stating the interval of residual basal area values that would allow a thinning to take for this stand even when the stand has a basal area greater than the residual basal area.

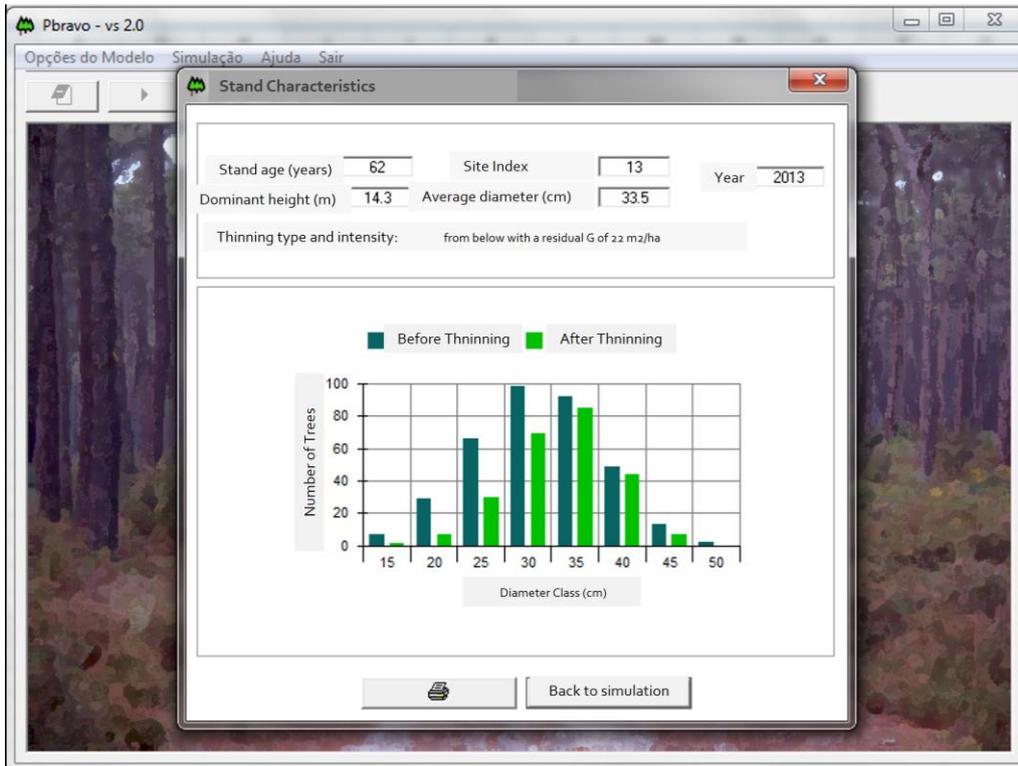


Figure 11. Graphical display of stand characteristics comparing the before and after thinning situations.

When the simulation is terminated, the user can click on the “End Simulation” button on the lower right and the last window is displayed. At this stage, the user can choose to visualize results in graphical or tabular form, save the simulation results in a text file, print the simulation outputs or carry put another simulation (**Figure 12**).

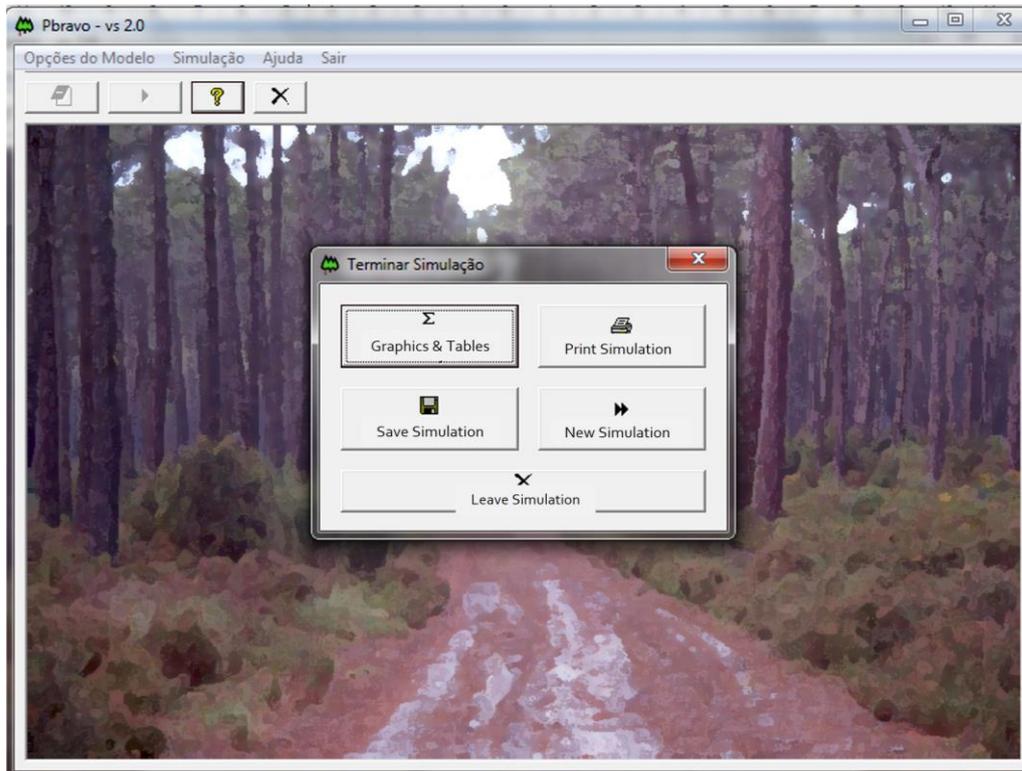


Figure 1. Interface giving the user the option to run a new simulation, visualising, printing or saving results.