



# FlorNExT<sup>®</sup>, a cloud computing application to estimate growth and yield of maritime pine (*Pinus pinaster* Ait.) stands in Northeastern Portugal

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## Abstract

**Aim of the study:** To introduce and describe FlorNExT<sup>®</sup>, a free cloud computing application to estimate growth and yield of maritime pine (*Pinus pinaster* Ait.) even-aged stands in the Northeast of Portugal (NE Portugal).

**Area of study:** NE Portugal.

**Material and methods:** FlorNExT<sup>®</sup> implements a dynamic growth and yield modelling framework which integrates transition functions for dominant height (site index curves) and basal area, as well as output functions for tree and stand volume, biomass, and carbon content.

**Main results:** FlorNExT<sup>®</sup> is freely available from any device with an Internet connection at: <http://flornext.esa.ipb.pt/>.

**Research highlights:** This application has been designed to make it possible for any stakeholder to easily estimate standing volume, biomass, and carbon content in maritime pine stands from stand data, as well as to estimate growth and yield based on four stand variables: age, density, dominant height, and basal area. FlorNExT<sup>®</sup> allows planning thinning treatments. FlorNExT<sup>®</sup> is a fundamental tool to support forest mobilization at local and regional scales in NE Portugal.

**Keywords:** forest management; maritime pine; forest modelling; knowledge transfer tool.

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## Introduction

The ability to predict growth and yield is a fundamental requirement for forest management and planning, therefore of utmost importance for the forest sector in any country or region. Forest growth is usually approached through mathematical modelling at the individual tree or forest stand level, according to a specific period of time and the silvicultural practices followed (Bravo *et al.*, 2011). The equations used for this purpose are, however, often dependent on a particular environmental context. In addition, forest growth equations are difficult to apply in practice when the end user lacks adequate knowledge or experience in forest modelling. In northeastern Portugal there is a high heterogeneity of biophysical conditions and forest management practices

which makes it difficult to estimate standing volume. At the same time, there are no tools to facilitate the use of regionally adjusted forest growth and yield models for managers and stakeholders in general.

There are currently numerous forest growth and yield computational applications (Packalen *et al.*, 2013). Although most of them have been developed as desktop tools, e.g., ModisPinaster for maritime pine in the Tâmega river valley (Fonseca, 2004), GesMO for several species in Galicia (Diéguez-Aranda *et al.*, 2009), there are now platforms that take advantage of the available cloud computing capabilities that enhance data update and potentiate real time interactions with users, such as Web-Globulus 3.0 (Palma, 2016).

As part of an ongoing research effort to increase forest mobilization across Europe we developed a cloud

computing application (FlorNExT<sup>®</sup>) to make forest growth and yield simulations accessible to any forest manager or stakeholder in northeastern Portugal to support management and to stimulate forest supply regionally. FlorNExT<sup>®</sup> has modelling capabilities for both maritime pine (*Pinus pinaster*) and Pyrenean oak (*Quercus pyrenaica*) although, for convenience, we centred this communication on maritime pine only. For that, we selected and analysed several forest growth models for maritime pine with potential application in the region and tested them with data from the region and against the PBRAVO model (Páscoa, 2001). In the development of FlorNExT<sup>®</sup> we followed as key principles user friendliness, simplicity, scalability, and self-explainability.

## Specifications

FlorNExT<sup>®</sup> was programmed in Visual Studio Web 2013 Express, using MVC technology. The languages used were C# and XML for models, drivers and configuration and Razor, HTML, JavaScript and CSS for displays. There are Portuguese, Spanish and English versions of the application.

## System description

### Structure and models

The maritime pine module of the application uses a set of models from different authors (Table 1).

The dynamic forest growth models used in the application were:

- Projection of dominant height: Tomé (2001)
- Projection of basal area: Páscoa (1987)

- Initialization of basal area: Páscoa (1987)
- Mortality: self-thinning line equation of Luis & Fonseca (2004)
- Stand volume: Luis & Fonseca (2004)
- Biomass: Diéguez-Aranda *et al.* (2009)
- Carbon: Diéguez-Aranda *et al.* (2009)

The tree equations used for thinning were:

- Average diameter: quadratic mean diameter relationship of Fonseca (2004)
- Generalized height–diameter relationship: Almeida (1999)
- Tree volume over bark: Nunes *et al.* (2010).

The dynamic growth models project key stand variables over time and when thinning is applied, FlorNExT<sup>®</sup> computes the respective diameter distribution using a bi-parametric Weibull probability density function whose parameters are related to the projected stand variables. The intensity of thinning is defined using the Wilson Factor, computed as  $F_w = 100 / (\sqrt{N} \cdot H_{dom})$ . The volume extracted in a particular thinning is computed using the individual-tree volume and the height-diameter equations.

For the validation of FlorNExT<sup>®</sup>, total volume estimated by the set of equations in the tool was tested against estimates produced by PBRAVO (Páscoa, 2001) based on 5 cm diameter classes data (Table 2). Differences between volume estimates are small for most stand conditions. For a smaller diameter class amplitude (1 cm), individual-tree volume equation estimates are close to those of the stand volume equation (Table 2).

Also, stand and individual-tree volume and generalized height-diameter equations were evaluated with inventory data. All equations showed consistent behaviour producing adequate estimates when compared with measurements in IFN5 (IFN, 2005) plots (see e.g. height-diameter in Table 3). In addition, for a total of 916 pairs

**Table 1.** Summary characteristics of data in the models tested

|                        | Stand models           |                            |             |                                     |               |
|------------------------|------------------------|----------------------------|-------------|-------------------------------------|---------------|
|                        | Luis & Fonseca (2004)  | Fonseca (2004)             | Tomé (2001) | Diéguez-Aranda <i>et al.</i> (2009) | Páscoa (1987) |
| t (years)              | 7 – 80                 | 12 – 65                    | 9 – 45      | 9 – 45                              | 10 – 80       |
| H <sub>dom</sub> (m)   | 3.2 – 29.8             | 5.6 – 25.9                 | 3.5 – 23.0  | 4.6 – 20.4                          | 8.9 – 23.9    |
| G (m <sup>2</sup> /ha) | 0.3 – 52.9             | 6.0 – 56.9                 | —           | 5.1 – 72.5                          | <7.5 – >27.5  |
| N (trees/ha)           | 60 – 8480              | 200 – 7680                 | —           | 654 – 3142                          | <251 – 3333   |
|                        | Individual tree models |                            |             |                                     |               |
|                        | Almeida (1999)         | Nunes <i>et al.</i> (2010) |             |                                     |               |
| d (cm)                 | 3.0 – 47.5             | 5.5 – 77.4                 |             |                                     |               |
| h (m)                  | 2.3 – 25.2             | 5.6 – 36.0                 |             |                                     |               |

t – Age; H<sub>dom</sub> – Dominant height; G – Basal area; N – Density; d – Dbh; h – Total height

**Table 2.** Comparison of FlorNExT® and PBRAVO volume estimates for variable stand structure conditions (input data)

| Input data   |                 |                         |                           | Volume estimates             |                               |                               |                               |
|--------------|-----------------|-------------------------|---------------------------|------------------------------|-------------------------------|-------------------------------|-------------------------------|
|              |                 |                         |                           | FlorNExT®<br>Stand           | FlorNExT®<br>Tree (DC 1 cm)   | PBRAVO<br>Tree DC 5 cm        | FlorNExT®<br>Tree DC 5 cm     |
| t<br>(years) | N<br>(trees/ha) | H <sub>dom</sub><br>(m) | G<br>(m <sup>2</sup> /ha) | Vob*<br>(m <sup>3</sup> /ha) | Vob**<br>(m <sup>3</sup> /ha) | Vob**<br>(m <sup>3</sup> /ha) | Vob**<br>(m <sup>3</sup> /ha) |
| 10           | 1500            | 5.46                    | 5                         | 14.79                        | 13.26                         | 10.46                         | 10.2                          |
| 12           | 1800            | 6.18                    | 8.7                       | 24.97                        | 26                            | 20.15                         | 16.87                         |
| 13           | 1404            | 7                       | 9.8                       | 35.51                        | 32.52                         | 26.75                         | 20.91                         |
| 14           | 2700            | 6                       | 12.5                      | 39.49                        | 37.2                          | 27.71                         | 24.64                         |
| 15           | 1100            | 9                       | 14.9                      | 66.27                        | 61.36                         | 54.68                         | 43.27                         |
| 25           | 1500            | 16                      | 35                        | 233.07                       | 228.26                        | 195.39                        | 172.14                        |
| 29           | 1000            | 18                      | 32                        | 236.16                       | 232.95                        | 202.78                        | 181.21                        |
| 32           | 900             | 16                      | 40                        | 277.84                       | 269.54                        | 230.74                        | 220.72                        |
| 35           | 550             | 19                      | 40                        | 320.04                       | 312.34                        | 262.46                        | 262.66                        |
| 48           | 510             | 21                      | 40                        | 346.7                        | 345.9                         | 296.89                        | 295.38                        |

t – Age; N – Density; H<sub>dom</sub> – Dominant height; G – Basal area; Vob – Volume over bark; \* – Stand volume equation estimate; \*\* – Individual-tree volume equation estimate; DC 1 cm – 1 cm diameter class; DC 5 cm – 5 cm diameter class.

of  $h$  and  $d$  measurements made by the authors in plots recently established in the region, the Almeida (1999) equation presented a mean of prediction residuals (Bias) of 0.05 m, a mean of absolute prediction residuals (MAR) of 0.75 m and a modelling efficiency of 0.88.

### Using FlorNExT®

FlorNExT® is organized in four sections: i) Home page, ii) Growth simulator, iii) Thinning simulator, and iv) About FlorNExT®. In the “Home page” the user is introduced to the basics of the application and has the possibility of choosing between the “Growth simulator” and the “Thinning simulator” sections. The “Growth simulator” allows the user to obtain stand growth data

over time based on a small set of inputs and predefined thinning schemes. This section is suited for users who want to project stand growth and yield in the future considering thinning, either predefined or customized. No thinning is also a possibility. The “Thinning simulator” section, on the other hand, is directed to managers who want to define and apply instantaneously a particular thinning operation to a particular stand, although stand growth can be simulated after thinning.

The “Growth simulation” section (Fig. 1) estimates volume, biomass, carbon content, average and current annual volume increments, and site index based on the following inputs: stand age (years), density (number of trees/ha), dominant height (m), and growth projection (years). Stand basal area (m<sup>2</sup>/ha) can be provided by the user but it will be estimated if unknown, although this

**Table 3.** Residuals of tree height estimates with Almeida (1999) and IFN (2005) equations as compared with measured trees in inventory plots in the Nordeste region. Only estimates for plots with more than five measurements are shown

| Stand structure |                         |            |                          | t<br>(years) | Bias (m)           |             | MAR (m)            |             |
|-----------------|-------------------------|------------|--------------------------|--------------|--------------------|-------------|--------------------|-------------|
| N<br>(trees/ha) | H <sub>dom</sub><br>(m) | Dg<br>(cm) | D <sub>dom</sub><br>(cm) |              | (Almeida,<br>1999) | (IFN, 2005) | (Almeida,<br>1999) | (IFN, 2005) |
| 840             | 12.82                   | 20.55      | 30.51                    | 29.50        | 0.77               | 0.03        | 1.16               | 1.12        |
| 300             | 12.90                   | 23.20      | 29.20                    | 31.00        | 0.47               | -0.05       | 1.44               | 1.31        |
| 900             | 6.29                    | 10.40      | 13.60                    | 14.50        | -0.02              | -0.14       | 0.28               | 0.34        |
| 160             | 11.03                   | 24.57      | 27.00                    | 30.00        | 0.16               | -0.36       | 0.51               | 0.48        |
| 1199            | 8.90                    | 13.43      | 16.90                    | 16.50        | -0.23              | -0.21       | 0.46               | 0.40        |
| 3658            | 11.10                   | 11.42      | 18.38                    | 30.00        | -0.24              | -0.23       | 0.46               | 0.35        |
| 260             | 8.20                    | 14.20      | 19.80                    | 18.00        | -0.25              | -0.25       | 0.81               | 0.72        |
| 200             | 6.70                    | 15.70      | 17.80                    | 14.70        | -0.23              | -0.54       | 1.03               | 1.18        |
| 840             | 5.90                    | 11.10      | 11.60                    | 13.50        | 0.18               | 0.19        | 0.51               | 0.52        |
| 840             | 15.50                   | 23.60      | 27.30                    | 26.50        | 1.01               | 1.00        | 1.43               | 1.32        |

N – Density; H<sub>dom</sub> – Dominant height; Dg – Quadratic mean diameter; D<sub>dom</sub> – Dominant diameter; t – Age; Bias – mean of prediction residuals; MAR – mean of absolute prediction residuals.

Portuguese | Español | English

Home page | Growth simulator | Thinning simulator | About FlorNExT®

Good afternoon! I'm your forestry consultant and I will help you to estimate growth and yield in your forest stand. Simply complete the form next.

**How is your woodland?**

*Pinus pinaster*  
 *Quercus pyrenaica*

Age: 20 years  
 Dominant height: 15 m  
 Density: 1500 trees/ha  
 Basal area: 20 m<sup>2</sup>/ha

Define a thinning plan (Optional)

Weak  Moderate  
 Moderate to strong  Strong

Age of first thinning: 20 years  
 Number of thinnings: 3  
 Frequency: 10 years  
 Growth projection: 40 years

Simulate

Increase accuracy (It may take longer)

**Frequently asked questions:**  
 Can I use these models in my woodland?

**Models used in FlorNExT®:**

**Model**  
 Transition dominant height  
 Transition basal area  
 Mean density/mortality  
 Individualization of basal area  
 Volume with bark  
 Biomass  
 Carbon

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 Pinheiro F. (1987) Estrutura, Crecemento e Produción en Posseamentos de Pinheiro Bravo. Un Modelo de Simulación. Tese de Doutoramento. ISA/ULP, Lisboa (241 pp.)  
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Figure 1. The FlorNExT® “Growth simulator” section.

might result in large errors. It is, therefore, strongly recommended that basal area is inputted in the application. The user is able to choose among thinning intensity levels (weak, moderate, moderate-strong, and strong) based on the Wilson Factor (0.16, 0.20, 0.23 and 0.28, respectively). In addition, the user can choose the age of first thinning, frequency, and number of thinnings. Growth without thinning can also be estimated. The default thinning is moderate from below (first thinning at age 20 years, 10 years frequency, maximum 3 thinnings). The user can also increase the precision level of the estimates using the check box at the end of the inputs form. Volume in this case is calculated yearly based on the stand structure, the diametrical distribution, and the individual tree volume equation (Nunes *et al.*, 2010). When uncheck, the simulation process uses the stand volume equation of Luis & Fonseca (2004). The former process can result in longer processing time.

The output of the growth simulator is a table with stand variables for each year of the simulation period

and the result of the application of the prescribed thinning plan. For each thinning in this table a graph and a detailed table of the distribution of standing trees and trees to be removed by thinning are produced.

The “Thinning simulator” section requires as inputs stand age (years), number of trees/ha, dominant height (m) and, optionally, basal area (m<sup>2</sup>/ha), such as for the previous section. The user can define the thinning method (from below or systematic) and the number or percentage of trees in the stand to extract. When this number or percentage is not known, the user can check the “I don’t know” option for which the system applies the moderate thinning Wilson Factor.

The outputs of the thinning simulators include the volume to extract and the graphical distribution of standing trees per diameter class (d) with indication of trees to be removed by systematic or thinning from below (Fig. 2).

Credits, contact information, and a disclaimer are shown in the section “About FlorNExT®”. In addition,

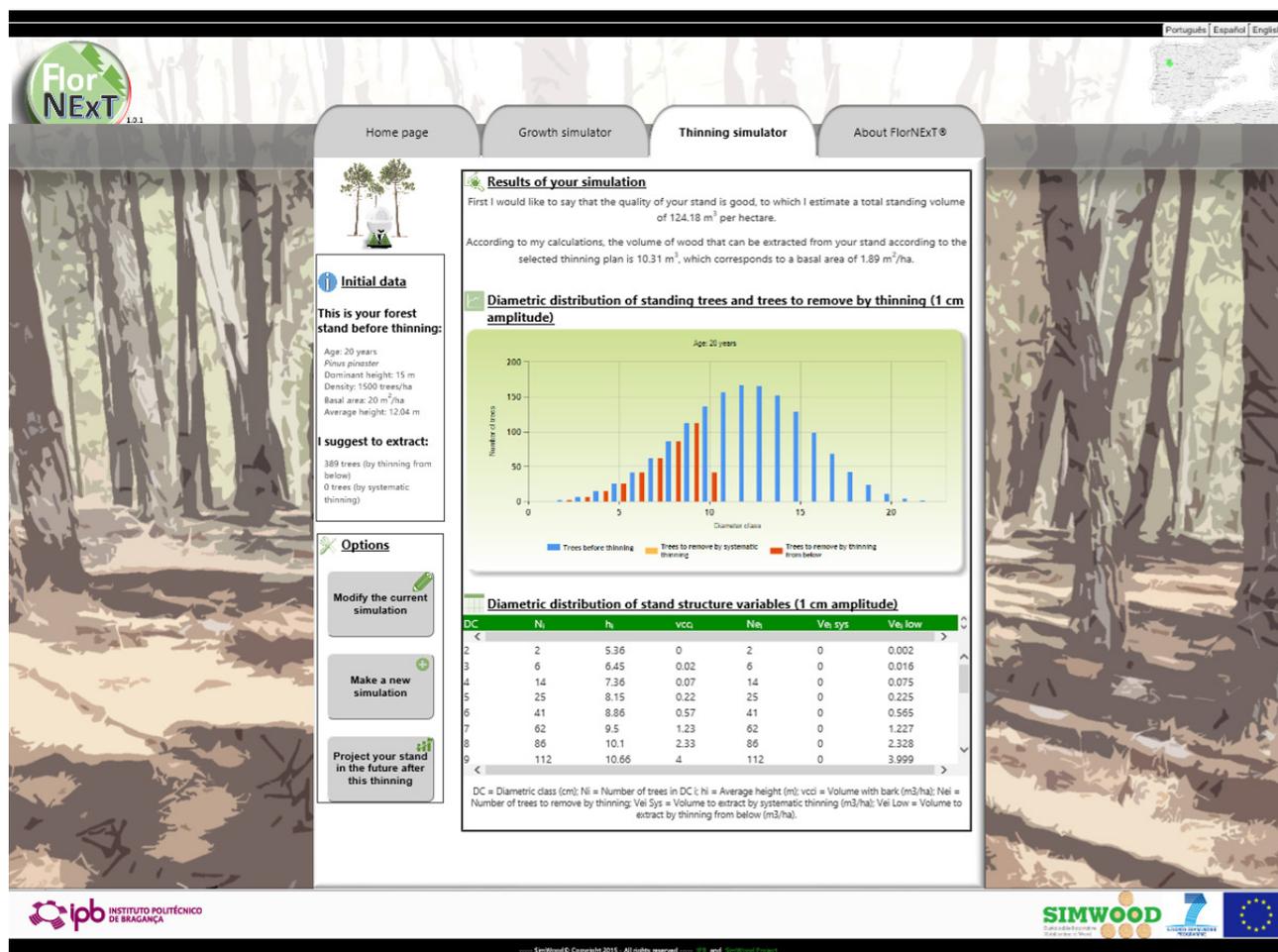


Figure 2. Output of the FlorNExT® “Thinning simulator” section.

User’s guides in Portuguese and English are available from the application’s website.

## Access

FlorNExT® was developed as a public cloud application, i.e., to be accessible via the Internet. Therefore, no specific installation is required and it can be freely accessed from any Internet-connected device (desktop, laptop, mobile phone, smartphone, tablet, etc.) from the address <http://flornext.esa.ipb.pt/>. FlorNExT® is compatible with the most common browsers. FlorNExT® is hosted in a server owned by the Polytechnic Institute of Bragança (<http://www.ipb.pt>).

## FlorNExT® conditions of use

The application is provided “as is” without any warranty, express or implied. In addition, FlorNExT® developers reserve for themselves the right to make changes and to translate it to other languages without notice.

FlorNExT® use is open to the forestry community but the authors are not responsible for use or interpretation of the results obtained by the application.

## Final considerations

The development of tools like FlorNExT® is required to translate complex model equations into simple applications easy to operate by any end user. Cloud computing improves the capability of development of user-friendly tools and simplifies the process of updating them. These kinds of tools are valuable resources for regions where forest mobilization is constrained by lack of usable information and models to support sustainable forest management.

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