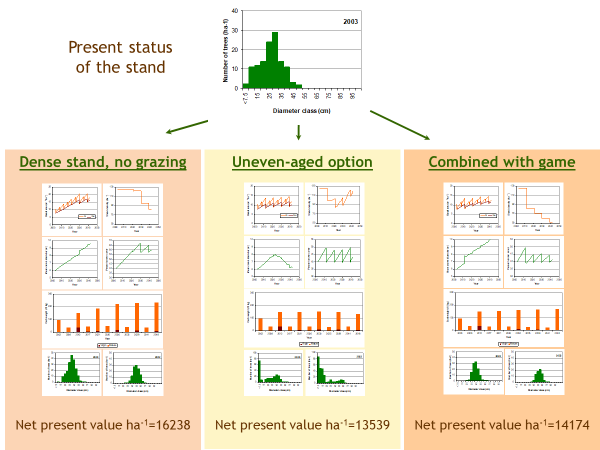
**Universidade de Lisboa – Instituto Superior de Agronomia Centro de Estudos Florestais**

**FOREST MODELS**

**Exercises notebook – 4rd edition**

**Margarida Tomé, Susana Barreiro and Joana Amaral Paulo**



**Comparison of alternative forest mamangement approaches using the SUBER model**

Textos Pedagógicos TP 1/2023



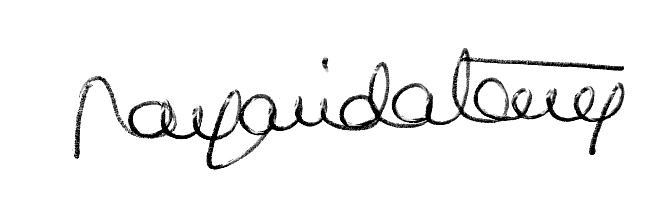
***FOREWORD***

*This volume consists of a set of exercises related to different topics of Forest Modelling. The exercises were selected using real data and are intended to help the students to understand the application of the acquired concepts in the Forest Models course.*

*This volume is complemented with the Study Material available in the Forest Models course webpage (Fénix -* [*https://fenix.isa.ulisboa.pt/courses/mrf-1-283463546570857*](https://fenix.isa.ulisboa.pt/courses/mrf-1-283463546570857)*), namely a selection of exercises that have been resolved (students must solve the remaining exercises). Most of the exercises use input files that can be downloaded from the section “Data files” of the Forest Models course webpage (Fénix).*

*.*

*Lisbon, October 2023*

**

**CONTENTS**

[LIST OF FIGURES iii](#_Toc149744301)

[LIST OF TABLES iv](#_Toc149744302)

[1. Overview of forest models and simulators as a support to sustainable forest management in a global change context 1](#_Toc149744303)

[2. Data for the development and validation of forest models 1](#_Toc149744304)

[2.1 Permanent plots – effect of site index on growth and yield of eucalyptus stands 1](#_Toc149744305)

[2.2 Permanent plots – effect of stand density at planting (spacing) on growth and yield of eucalyptus stands 1](#_Toc149744306)

[2.3 Stand table projection – uneven-aged stand of maritime pine in the Chamusca county 2](#_Toc149744307)

[2.4 Stand table projection – uneven-aged stands of maritime pine in the Coruche county 2](#_Toc149744308)

[2.5 Stand table projection – pine stand 3](#_Toc149744309)

[2.6 Stem analysis of a 29 years old maritime pine tree 4](#_Toc149744310)

[3. Introduction to R and R studio 5](#_Toc149744311)

[3.1 Reading data and exploratory analysis 5](#_Toc149744312)

[3.2 Reading large data sets and more exploratory analysis 6](#_Toc149744313)

[3.3 Reading and preparing data organized in several EXCEL worksheets/files 7](#_Toc149744314)

[3.4 Exploratory data analysis with graphics 8](#_Toc149744315)

[4. Allometric relationships 9](#_Toc149744316)

[4.1 Allometric equations to estimate biomass in young eucalypt tree biomass 9](#_Toc149744317)

[4.2 Allometric equations for generalized use to estimate eucalypt tree biomass in seminal stands 10](#_Toc149744318)

[4.3 Allometric models to estimate, at stand level, total aboveground biomass and biomass per tree component from the usual stand variables (hdom, G, N, S) 11](#_Toc149744319)

[4.4 Analysis of the shape of the Lundqvist-Korf function for different values of the parameters. 11](#_Toc149744320)

[4.5 Analysis of the shape of the Lundqvist-Korf function for different values of the parameters. Using the “Forest functions playground” illustrate the shape of the Richards function: 11](#_Toc149744321)

[4.6 Analysis of the shape of the Richards function for different values of the parameters. Using the “Forest functions playground” illustrate the shape of the Richards function: 11](#_Toc149744322)

[4.7 Analysis of the shape of the Hossfeld IV function for different values of the parameters. Using the “Forest functions playground” illustrate the shape of the Hossfeld IV function: 12](#_Toc149744323)

[4.8 Formulate the Lundqvist-Korf growth function as difference equations 12](#_Toc149744324)

[4.9 Formulate the Richards growth function as difference equations 12](#_Toc149744325)

[4.10 Formulate the Hossfeld growth function as difference equations 12](#_Toc149744326)

[4.11 Use the volume growth data from one permanent plot of eucalyptus from the EXCEL file Ec\_ StandGrowthData\_1.xlsx 12](#_Toc149744327)

[4.12 Use the growth data from permanent plots of eucalyptus from the EXCEL file Ec\_ StandGrowthData\_2.xlsx: 12](#_Toc149744328)

[5. Forest productivity evaluation 13](#_Toc149744329)

[5.1 The Richards function was fitted to a data set corresponding to the measurement of temporary plots in cork oak stand. The following function was obtained: 13](#_Toc149744330)

[5.2 The difference formulation of the Lundqvist-Korf growth function with the k parameter as the free parameter was fit to a data set coming from permanent plots established in eucalyptus stands. The following function was obtained: 13](#_Toc149744331)

[5.3 Illustrating the site index curves for the most important Portuguese tree species 14](#_Toc149744332)

[5.4 Developing a model to estimate site index from site and stand variables for cork oak 15](#_Toc149744333)

[6. Management oriented process-based models 16](#_Toc149744334)

[6.1 Become familiar with the 3PGpjs27.xlxs simulator 16](#_Toc149744335)

[6.2 Impact of different climatic scenarios in the productivity of eucalyptus in the Chamusca county 16](#_Toc149744336)

[6.3 Impact of different climatic scenarios in the productivity of eucalyptus in two regions with contrasting climates 17](#_Toc149744337)

[References 18](#_Toc149744338)

[ANNEXE 1 – Example of cork prices 19](#_Toc149744339)

[ANNEXE 2 – Description of data files used as support to the course 20](#_Toc149744340)

# LIST OF FIGURES

**No table of figures entries found.**

# LIST OF TABLES

[Table 1. Diameter distribution and current 5 years increment in a maritime pine stand in the Chamusca county 2](#_Toc149744341)

[Table 2. Diameter distributions and current annual increments in dbh in two uneven-aged maritime pine stands. 4](#_Toc149744342)

[Table 3. Diameter distributions and current annual increments in dbh in pure pine stand. 4](#_Toc149744343)

[Table 4. Dominant height growth curves for the most important Portuguese tree species 14](#_Toc149744344)

[Table 5. Mean, minimum and maximum values for the site index of the most important Portuguese tree species 15](#_Toc149744345)

# Overview of forest models and simulators as a support to sustainable forest management in a global change context

1. Write FCTOOLS in your web browser or, alternatively, use the link <http://www.isa.ulisboa.pt/cef/forchange/fctools/>. Make your registration in the FCTOOLS website that will give you access to the forest models and simulators developed within the ForChange – Forest Ecosystem Management under Global Change – research group of the Forest Research Centre (CEF)
2. Explore the FCTOOLS site to get acquainted with the forest models and simulators that are available in the site
3. Try to use the webGLOBULUS simulator (no need to download, it is available on the web)
4. Download the SUBER and standsSIM simulators. Later on during the course you will become familiar with them, you can now try to use them but it requires some work (there are manuals available on the HELP e on the study material)
5. Look for other sites where you can find forest simulators available in other countries and try to explore at least one of those (examples: CAPSIS <https://capsis.cirad.fr/capsis/models>; BwinPro 6.0 <https://forestsimulator-bwinpro.software.informer.com/>)
6. Explote the ForModels database

(<https://www.plantedforests.org/formodels_database_forest_modeles_liste/>)

# Data for the development and validation of forest models

## Permanent plots – effect of site index on growth and yield of eucalyptus stands

File “2.1.PermanentPlots-Ec-S-data.xls” contains data from some permanent plots established in eucalyptus plantations in Portugal. All the stands were established at a 3x3 spacing.

1. Illustrate, for each plot, the evolution of dominant height, basal area and volume as well as the mean and current annual increments in volume (plot the two increments in the same graphic)
2. Find the site index (base age 10) for each one of the plots
3. Analyze the location of the maximum of the mean annual increment in volume and relate it with the site index
4. Plot the evolution of the variables referred in a) considering all the plots in the same graphic

## Permanent plots – effect of stand density at planting (spacing) on growth and yield of eucalyptus stands

File “2.2.PermanentPlots-Ec-Npl-data.xls” contains data from the plots of one block of a spacing trial established in eucalyptus plantations in Portugal. Being a block from an experiment, all the plots have a similar site index.

1. Illustrate, for each plot, the evolution of dominant height, basal area and volume as well as the mean and current annual increments in volume (plot the two increments in the same graphic)
2. Find the site index (base age 10) for each one of the plots
3. Analyze the location of the maximum of the mean annual increment in volume and relate it with the initial stand density (spacing)
4. Illustrate, for each plot, the evolution of the biomass per tree component as well as the total biomass
5. Plot the evolution of the variables referred in a) considering all the plots in the same graphic

## Stand table projection – uneven-aged stand of maritime pine in the Chamusca county

Table 1 contains data (available at the EXECL file “2.3. StandTableProjection-Pb-data”) that were obtained during a forest inventory made in an uneven-aged stand of maritime pine located in the Chamusca county.

|  |  |  |
| --- | --- | --- |
| Table 1. Diameter distribution and current 5 years increment in a maritime pine stand in the Chamusca county | | |
| diameter class j (5 cm) | Nj1996 after mortality | d increment id5 (cm) |
|
| ingrowth |  |  |
| 5 | 102 | 3.80 |
| 10 | 59 | 3.80 |
| 15 | 53 | 3.85 |
| 20 | 59 | 3.85 |
| 25 | 58 | 3.85 |
| 30 | 22 | 3.90 |
| 35 | 1 | 3.90 |
| 40 | 0 |  |
| 45 |  |  |
| Total | 354 |  |

1. Assuming an ingrowth of 100 trees per hectare, compute the stand table for the year 2001
2. Using the equations below, estimate the volume at the time of measurement and in 2001 and, from those, the current annual increment in volume for the 5 years period

|  |  |
| --- | --- |
| Height-diameter curve | h=d/(0.64212+0.01874\*d) (units: d – cm; h-m) |
| Volume equation | v = 0.00005126 d2.0507 h0.8428 (units: d – cm; h-m; v – m3) |

## Stand table projection – uneven-aged stands of maritime pine in the Coruche county

Table 2 represents the diameter distribution and the measured annual increments in dbh in two uneven-aged stands, a pure and a mixed stand, located in the Coruche county, Portugal. (Hidrotécnica Portuguesa, 1965).

1. Using the stand table projection method and assuming a mortality rate of 5% in every diameter class and an ingrowth of 50 trees per hectare, obtain the stand table for the two stands 5 years after the measurement
2. Using the following equations:

|  |  |
| --- | --- |
| Height-diameter curve |  |
| Volume equation |  |

estimate the volume at the time of measurement and 5 years later and, from those, the current annual increment in volume for the 5 years period.

## Stand table projection – pine stand

Table 3 presents the diameter distribution and the measured annual increments in dbh for the past 10 years.

1. Using the stand table projection method and assuming mortality has already been discounted and ingrowth is inexistent, obtain the stand table for this stand 10 years after the measurement
2. Using the same equations given for the previous exercise (2.4 b)) estimate the volume at the time of measurement and 10 years later and, from those, the current annual increment in volume for the 10 years period.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Table 2. Diameter distributions and current annual increments in dbh in two uneven-aged maritime pine stands. | | | | |
| Diameter class (dj) | Pure stand | | Mixed-stand dominated by Pb | |
| Nj (ha-1) | id (cm year-1) | Nj (ha-1) | id (cm year-1) |
| 10 | 135 | 0.735 | 86 | 0.965 |
| 15 | 139 | 0.810 | 64 | 1.100 |
| 20 | 114 | 0.870 | 52 | 1.200 |
| 25 | 59 | 0.910 | 20 | 1.200 |
| 30 | 40 | 0.930 | 14 | 1.100 |
| 35 | 26 | 0.915 | 6 | 0.995 |
| 40 | 13 | 0.885 | 2 | 0.970 |
| 45 | 4 | 0.840 | 1 | 0.940 |
| 50 | 1 | 0.790 | - | 0.900 |
| 55 | - | - | - | 0.860 |

|  |  |  |
| --- | --- | --- |
| Table 3. Diameter distributions and current annual increments in dbh in pure pine stand. | | |
| Diameter class (dj) | Pure stand | |
| Nj (ha-1) | id (cm year-1) |
| 6 | 313 | 2.2 |
| 8 | 229 | 2.3 |
| 10 | 134 | 2.4 |
| 12 | 70 | 2.2 |
| 14 | 34 | 2.4 |
| 16 | 10 | 2.6 |
| 18 | 9 | 2.1 |
| >20 | 6 | 1.8 |
| total | - | - |

## Stem analysis of a 29 years old maritime pine tree

During the harvest of some of the permanent plots from a thinning trial estbalished in maritime pine stands in the North of Portugal, some of the dominant trees were selected for stem analysis. File “2.4-StemAnalysis-Pb-data.xls” contains, in the first sheet, the data gathered at harvest in one of those trees. The discs extracted at several heights were analyzed in the laboratory and the tree rings at dbh level were measured along 4 radii. Each radii was measured twice, starting from the pith to the outer ring and then from the outer ring to the pith. Data from tree rings measurements are also in the same file, organized in different sheets, one sheet per disc.

1. Make a graph with the evolution of the tree dominant height using Carmean’s method to estimate each one of the tree tips
2. Make a graph with the evolution of the tree profile (stem analysis graphic), using Carmean’s method to estimate each one of the tree tips
3. Estimate the evolution of the variables dbh, tree basal area, tree height and tree volume and make the respective graphics
4. Make the graphic of the mean and current annual increments in volume

# Introduction to R and R studio

## Reading data and exploratory analysis

Data file used: “Pb\_PP&Trials.xlsx”

Script: “4.1\_PlayWith\_Pb\_GrowthData”

1. Use the function *getwd()* to find out to which directory/forder R is pointed and the function *setwd()* to change the workspace to the folder where you stored the “Pb\_PP&Trials” file. Check with the command *getwd* that the change was succesfull
2. In order to read EXCEL files, there is the need to install, for instance, the *xlsx* package. If you have it already installed, just go to the following alinea, otherwise you must install it. The best way to learn how to install packages in R is just google “R install packages” (or something similar); you can also use the R help that is on the “files” window or type ?install in the console. Another package very useful for data manipulation is the “dplyr”.

The script “0\_installPackages” exemplifies the installation of the two packages with the *install.packages()* command. You just need to install a package once. You can also install the packages diretly in the RStudio.

1. You must load the packages that will be needed for the data manipulation (“xlsx” or “readxl” and “dplyr”) with the *library()* function.

The packages need to be loaded in every R session.

1. You are now ready to read (with the *read.xlsx()* or *read\_xlsx()* commands) the data on the worksheet that contains the data (there is another worksheet with the description of the variables).
2. The file Pb contains the stand biomass per plant component (Ww-wood, Wb-bark, Wbr-branches, Wl-leaf). Compute total aboveground biomass (Wa)
3. R has several functions to describe and summarize data that is available in one dataframe or in each one of the component vectors, for instance: *head()*, *summary()*, *apply()*, *length()*, *tapply()*. Use the R help and/or make a search on the web about these commands and try them with the dataframe that you just built (name it Pb).
4. Create a variable of type *factor* using the variable ID\_plot (a *factor* can only take a limited number of values)
5. The R functions of the *apply* family are very usefull to summarize data classified according to the values of a *factor*. Use the *tapply* function (use the help to learn about the sintax of the function) to compute the average value of the variable N for each one of the plots. Save the results in a variable named Navg\_plot. Repeat the calculation but for the standard deviation.
6. Use the *count* function to count how many measurements were made in each plot.
7. Use the *plot* function to plot dominant height over age
8. Now explore the *ggplot* function, more powerfull than *plot*, to make some alternative plots of dominant height over age:

* By connecting the measurements of each plot (one line per plot)
* By connecting the measurements of each plot and use a different color for each Trial
* By connecting the measurements of each plot and use a different color for each Trial and adding a legend

1. Use the *filter* function to create a dataset that is a subset of the original one by considering just the plots with Cod\_Trial=”SS” and use the *ggplot* function to plot dominant over age for each plot using a different color for each plots and a legend to identify the plots
2. Use the *ggplot* function to plot wood biomass (Ww) over total volume (V) and add a linear tendence line
3. Use the *ggplot* and *boxplot* functions to make a box-plot graph of domint height over Cod\_Trial
4. Use the *par*() function with the argument mfrow to plot the biomass of each tree component over total aboveground biomass in a 2x2 matrix of graphs

## Reading large data sets and more exploratory analysis

Data files used: “IFN5\_Pb.xlsx” or “IFN5\_Ec.xlsx” (generic name “IFN5\_Sp.xlsx”)

Script: “4.2\_NFIData\_LargeDataset”

1. Use the function *getwd()* to find out to which directory/forder R is pointed and the function *setwd()* to change the workspace to the folder where you stored the IFN\_Sp.xlsx file. Check with the command *getwd* that the change was successful
2. In order to read large EXCEL files, there is the need to use the library (*readxl*). You can also use the library *(RODBC) (ImportExport)*. To read the file you need to use the *odbcConnectExcel2007()* and *sqlFetch()* commands.
3. Now just use the commands that you already learned in the previous exercise to characterize and explore the data.
4. Create a data frame with the names of the variables changed for the names in your native language.
5. Create a file with a subset of the initial variables: id\_plot, d, dclass, d0, h, hc, sample\_tree
6. Calculate the tree basal area (g) for each tree and a variable with value=1 named n (each trees represents 1 tree within the plot)
7. Use the aggregate() function to compute plot basal area (Gplot) and number of trees per plot (Nplot)
8. Read the information in the Plot\_Sp sheet and keep the information on the plot area. Merge the two data.frames (with tree and plot information) by Id\_plot and expand the values of basal area and number of trees in the plot to the ha
9. Create a file filtering just the trees that are sample trees and that have a measurement of tree height.
10. It is often usefull to have an equation that allows to estimate diameter at breast height as a function of stump diameter (for instance if we need to estimate stand variables after the stand being harvested). Use the file created in the previous alinea to fit a simple linear model that estimates the diameter at breast height as a function of the diameter measured at the tree base.

## Reading and preparing data organized in several EXCEL worksheets/files

Data file used: “Ec\_StandGrowthData.xlsx”

Script: “4.3\_PlayWith\_Ec\_GrowthData”

1. Use the function *getwd()* to find out to which directory/forder R is pointing and the function *setwd()* to change the workspace to the folder where you stored the Ec\_StandGrowthData. Check with the command *getwd* that the change was succesfull
2. Start by loading the packages that will be needed for the data manipulation (“xlsx” and “dplyr”) with the *library()* function.
3. Read (with the *read.xlsx()* or *read\_xlsx()* commands) the data from each one of the 4 worksheets, each worksheet into one dataframe (AV, AV\_plot, EPE and EPE\_plot).
4. Use the R functions *head()*, *summary()*, *apply()*, *length()*, *tapply()* to get familiar with the 4 dataframes you that you just built.
5. Using the *rbind()* function, create two dataframes, Ec (AV+EPE) and Ec\_plot (AV\_plot+EPE\_plot), that make an union (add the rows of both dataframes in a unique dataframe)
6. Using the *merge()* function, create a dataframe (Ec) that merges the dataframes euca and Ec\_plot by adding the variables available in Ec\_plot to the dataframe Ec (merge), using the ID\_plot and ID\_rot variables to make the merge. Calculate the variable age (t) for each plot at time of measurement.

Use the functions *head()* and *str()* to analyse the structure of the euca\_all dataframe.

1. Write the data in the dataframe Ec in an EXCEL file and in an R file.
2. Study something about the %>% R function and how it can be used to simplify the R scripts.
3. Use the functions:
   1. *select()*, to select just some variables
   2. *rename()*, to rename some variables
   3. *filter()*, to select some individuals (rows)
   4. *mutate()*, to add variables computed from existing variables
4. As an alternative to the *mutate()* function, use just an assignment to add a variable dg to the dataframe euca\_all. For that
5. Use the *aggregate()* function to calculate the means and standard deviations of the hdom and G variables by the combination (ID\_plot,ID\_rot) and place the results in a dataframe.
6. Use the *lag()* function to create a dataframe with variables that are lagged, as it is needed to fit growth functions in the form of difference equations.
7. Repete the previous exercise with the *lead()* function.
8. Split the data in the dataframe Ec in two datasets, to fit and to validate the models, each with approximately 50% of the plots (not of the data points).

## Exploratory data analysis with graphics

The best way to start a data analysis is by explore the relationships that exist in the data set by displaying them in appropriate graphics.

Data file used: “Ec\_StandGrowthData.xlsx”

Script: “GraphicalDataAnalysis\_Ec\_GrowthData”

1. Prepare a R data file by:
   * reading the the data from each one of the 4 worksheets, each worksheet into one dataframe (AV, AV\_plot, EPE and EPE\_plot)
   * make the union of the data from the two data sets that contain stand data information (AV and EPE) and the same for the two data sets that contain plot data information (AV\_plot and EPE\_plot)
   * merge the information available in the two files previously created using ID\_plot and ID\_rot to make the merge and calculate plot age using the data of measurement and the data of regeneration
   * delete the variables that, in your opinion, are not relevant for the data analysis
2. Suppose that you want to develop a model to estimate the total aboveground biomass (Wa) and the biomass per tree component (stem, stem wood, stem bark, branches and leaves, respectively Ws, Ww, Wb, Wbr and Wl) from the stand variables that are usually available from forest inventories. In order to have an idea of the relationships between variables make an exploratory graphical analysis by ploting:
   * Plot Wa, Ws, Ww, Wb, Wbr and Wl over each one of the stand variables t, hdom, N, G and V
   * Plot graphs among the variables Wa, Ws, Ww, Wb, Wbr and Wl
   * Plot Ww, Wb, Wbr and Wl over G with colors by rotation
   * Plot Ww, Wb, Wbr and Wl over G with colors by N classes (N<1000,1000>=N<2000, N>2000)

# Allometric relationships

## Allometric equations to estimate biomass in young eucalypt tree biomass

Data file used: “BiomassData\_Ec\_trees\_clonesXspacings.xlsx” – contains data from the destructive sampling of eucalyptus young trees in a spacing trial with 3 clones (split-plot design), from which one block is represented in Figure 1.

Figure 1. Block1 from the Agolada spacing trial, showing the sub-plots (clones) inside each plot (spacing)

* 1. Plot total aboveground biomass over diameter at 0.5 m, using different symbols according to the clone. Discuss the results
  2. The same as a) but according to the spacing. Discuss the results, comparing them with the results obtained in a)
  3. Prepare an R script to fit the allometric model (*wa=k da*) to obtain models to estimate aboveground biomass (*wa*)
  4. Fit now the multiple allometric model (*wa=k da hb*)and check if it is better than the simple allometric model
  5. Repeat the alineas a) to d) for the other tree biomass components by substituting *wa* by other tree components in the previous script
  6. Repeat the alineas a) to d) for the other tree biomass components by writing a new script with a cycle that fits one tree component in each step and keep all the results in the same EXCEL file
  7. Test if the information about the spacing and/or the clone increase the predictive ability of the models developed in f) by expressing the *a* and/or *b* parameters as a function of clone and/or spacing
  8. EXTRA: Fit the equations for all the tree biomass components as a system of equations that guarantee the property of additivity for total tree biomass

## Allometric equations for generalized use to estimate eucalypt tree biomass in seminal stands

Data file used: “BiomassData\_Ec\_trees.xlsx”

Contains data from the destructive sampling of a large set of eucalyptus trees sampled in the area of distribution of eucalyptus in Portugal and covering stands with different values of site index and stocking

It is a subset of the data used in the paper:

António, N., Tomé, M., Tomé, J., Soares, P. & Fontes, L. 2007. Effect of tree, stand and site variables on the allometry of *Eucalyptus globulus* tree biomass. Canadian Journal of Forest Research 37: 895-906

* 1. Read the data into a R data.frame and filter it to keep just the trees that are not clones
  2. Plot total biomass and biomass per tree component over diameter at breast height
  3. Prepare an R script to fit the allometric model to obtain models to estimate each one of the tree biomass components (ww, wb, wbr and wl)
  4. Test if the information about the stocking and/or other tree or stand variables increase the predictive ability of the models developed
  5. EXTRA: Fit the equations developed in c) and d) as a system of equations that guarantee the property of additivity for total tree biomass

## Allometric models to estimate, at stand level, total aboveground biomass and biomass per tree component from the usual stand variables (hdom, G, N, S)

Data file used: “Ec\_StandGrowthData.xlsx”

Scripts:

In exercise 3.4 you must have saved the “Ec” data.frame as a .Rdata file. You will now use this file in order to fit the allometric models.

1. Start by “looking” at the data through some plots of the biomass variables (Wa, Ww, Wb, Wbr and Wl) over the stand variables
2. Fit the multiple allometric model for each one of the biomass components using dominant height and basal area as predictors. Check the regression assumptions and take corrective measures if needed and assess the respective fitting ability
3. Evaluate the prediction ability of the models obtained (bias and precision) using several statistics based on the press residuals
4. Evaluate now the prediction ability of the models obtained (bias and precision) using several statistics based on cross validation
5. Check if adding other variables to the models will improve their fitting and/or prediction ability

# Growth functions

## Analysis of the shape of the Lundqvist-Korf function for different values of the parameters.

Write “Forest functions playground” on Google and explore the Forest Growth functions Playground to learn more about the role of each parameter on the shape of the growth functions

## Analysis of the shape of the Lundqvist-Korf function for different values of the parameters. Using the “Forest functions playground” illustrate the shape of the Richards function:

1. Varying the asymptote A and keeping parameters k and m constant (suggestion: A=40,…,100; k=3; m=0.7)
2. Varying parameter k and keeping both the asymptote A and the parameter m constant (suggestion: A=90; k=1,…,7; m=0.5
3. Varying parameter m and keeping the asymptote A and the parameter k both constant (suggestion: A=90; k=3; m=0.2,…,0.89
4. Assuming the values of A=70; k=3; m=0.5, estimate the evolution of dominant height for the plot data from exercise 3.2 and comment the performance of the model.

## Analysis of the shape of the Richards function for different values of the parameters. Using the “Forest functions playground” illustrate the shape of the Richards function:

a) Varying the asymptote A and keeping the parameters k and m constant (suggestion: A=40,…,100; k=0.05; m=0.2)

b) Varying parameter k and keeping both the asymptote A and the parameter m constant (suggestion: A=90; k=0.2,…,0.08; m=0.2)

c) Varying parameter m and keeping the asymptote A and the parameter k both constant (suggestion: A=90; k=0.05; m=-0.6,…,0.6)

## Analysis of the shape of the Hossfeld IV function for different values of the parameters. Using the “Forest functions playground” illustrate the shape of the Hossfeld IV function:

1. Varying the asymptote A and keeping parameters c1 and k constant (suggestion: A=40,…,100; c1=0.20; k=1.20)
2. Varying parameter c1 and keeping the asymptote A and parameter k constant (suggestion: A=90; c1=0.10,…,0.70; k=1.20)
3. Varying parameter k and keeping the asymptote A and parameter c1 constant (suggestion: A=90; c1=0.40; k=0.90,…,1.50)

## Formulate the Lundqvist-Korf growth function as difference equations

1. Formulate the difference equations solving the function for A, K and n
2. Formulate the age independent difference equation form for the Lunqvist-Korf growth function

## Formulate the Richards growth function as difference equations

1. Formulate the difference equations solving the function for A, K and n
2. Formulate the age independent difference equation form for the Richards growth function

## Formulate the Hossfeld growth function as difference equations

1. Formulate the difference equations solving the function for A, c1 and k
2. Formulate the age independent difference equation form for the Hossfeld growth function

# Forest productivity evaluation

## Site index curves using the guide curve method

The Richards function was fitted to a data set corresponding to the measurement of temporary plots in cork oak stand. The following function was obtained:



1. Compute the site index (*S*) for this guide-curve, using a base age (*tb*) equal to 80 years
2. Using this guide-curve derive the general expression for a dominant height growth curve for a particular *S*
3. Using the expression derived in b), create a graphic with the site index curves for the following site index values: 8, 10, 12, 14, 16.

## Using site index curves based on growth functions expressed as a difference equation

The difference formulation of the Lundqvist-Korf growth function with the k parameter as the free parameter was fit to a data set coming from permanent plots established in eucalyptus stands. The following function was obtained:



1. Consider a stand with 5 years of age and a dominant height of 10 m. Estimate the site index (*S*) for this stand considering a base age equal to 10
2. Using this function derive the general expression for the dominant height growth curve for a particular *S*
3. Using the function obtained in b), create a graphic graphic with the site index curves for the following site index values: 13, 16, 19, 22, 25.

## Illustrating the site index curves for the most important Portuguese tree species

Use the equations on Table 4 to create site index curves for the most important Portuguese tree species. Table 5 indicates the minimum and maximum values of *S* for each species

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Table 4. Dominant height growth curves for the most important Portuguese tree species | | | | | | | |
| **Models** | | | | | | | |
| (1)  (2) | | | | | | | |
| (3)  The model uses the age at dbh level, it has been assumed that the tree takes 4 years to achieve this height | | | | | | | |
| **Species** | **Model** | **A** | **n** | **k** | **p** | **tb** | **Source** |
| Maritime pine | 1 | 69 | 0,458203 | - | - | 50 | Tomé, 2001 |
| Eucalyptus | 1 | 61,1372 | \* | - | - | 10 | Tomé, et. al, 2001 |
| Cork oak | 2 | 20.7216 | 1.4486 | - | - | - | González et al., 2005 |
| Pyrenean Oak | 3 | - | -0.0210 | 0.915 | - | 40 | Carvalho, 2000 |
| Chestnut | 2 | 34,8559 | 1,6160 | - | - | 45 | Patrício, 2006 |
| |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | | **\* n =** | **Region** | **1NL** | **2NC** | **3CL** | **4SL** | **5VT** | **6NI** | **7SI** | **8VD** | | **1ª rotação** | 0.5225 | | 0.4805 | 0.4407 | 0.4780 | 0.4805 | 0.3955 | | | **Talhadia** | 0.4384 | | 0.3964 | 0.2826 | 0.3199 | 0.3964 | 0.2374 | |   S – site index (m); hdom – dominant height (m); hdomd – dominant height above dbh level; t – age (years); tb – base age (years).  The correspondence between the Portuguese counties and the 8 climatic regions defined for the eucalyptus can be seen in the original publication (Tomé et al., 2001) | | | | | | | |

|  |  |  |
| --- | --- | --- |
| Table 5. Mean, minimum and maximum values for the site index of the most important Portuguese tree species | | |
| **Species** | **Minimum** | **Maximum** |
| Maritime pine |  |  |
| Eucalyptus | 13 | 25 |
| Cork oak | 8 | 16 |
| Pyrenean Oak |  |  |
| Chestnut |  |  |

## Developing site index curves with the difference equations approach

Data files used: Ec\_ StandGrowthData.xlsx; Pb\_PP&Trials.xlsx

Scripts:

1. Plot the evolution of dominant height for the different plots
2. Fit the different formulations of the Lundqvist function as difference equations to the dominant height growth data and compare the three formulations to select one to adopt as site index curves for the species
3. Plot the estimated values together with the original data
4. Repeat b) and c) with the Richards functions and decide which one of the functions performs better

## Developing site index curves with the parameter prediction method

Data files used: Ec\_ StandGrowthData.xlsx; Pb\_PP&Trials.xlsx

1. Plot the evolution of dominant height for the different plots
2. Use R to fit the Lundqvist function to dominant height data of each plot and plot the estimated values together with the original data
3. Estimate de site index (S) for each plot
4. Fit the Lundqvist function for dominant height with the A parameter expressed as a linear function of the site index and plot the estimated values together with the original data
5. Repeat d) but expressinh ther parameters expressed as a function of site index

## Developing a model to estimate site index from site and stand variables for cork oak

Data file used: “g)\_Sb\_SiteIndex&SiteData.xlsx”

Scripts: “0\_Sb\_SiteIndex\_DataPrep” – a) to e)

“1\_Sb\_SiteIndex\_ExploratoryAnalysis”

“2\_Sb\_SiteIndex\_SelectingSubsetsOfVar”

“3\_Sb\_SiteIndex\_AnalysingOneModel”

“4\_Sb\_SiteIndex\_ComparingCandidateModels”

1. Read all the worksheets available in the file
2. Use the R function “merge” to obtain a unique data set with all the information available
3. Estimate the site index for each plot with the site index curves:
4. Analyse the frequency of observations per category in categorical variables and recode some if needed
5. Save the final data set as an R datafile for future use
6. Create dummy variables for each categorical variable: c1) using the *ifelse()* function; c2) automatically with the *dummy\_cols()* function (requires library *fastDummie*); c3) check the frequency of data points in each category
7. Use the *summary()* function to “look” at the variables and find out that there are some variables with missing values (NA). Create a dataframe that deletes the data points with missing values
8. Estimate the correlation coefficient between S and each one of the site and climate continuous variables available
9. Plot the site index (S) over the several site and climate continuous variables available and see the type of relationship that exists (positive, negative, linear, non-linear, strong, weak)
10. Fit a linear regression between S and each continuous variable and find out which variables give a better prediction of S
11. Fit a linear regression between S and the set of dummy variables defined for each categorical variable and find out which variables/categories give a better prediction of S
12. Fit a linear regression between S and each categorical variable defined as a factor and compare the results with those obtained in the previous question. Try to find out the main difference between the two regressions (answer: with the dummies you can use just some of the categories, which is not possible if you use the categorical variable)
13. Use stepwise algorithms (e.g. functions of the family *ols\_step\_method\_p()* ou *ols\_step\_method\_aic()*, ou *step()*, ou *stepAIC()*) to select subsets of variables to e used as candidate models to estimate cork oak site index from environmental variables
14. Use now all possible regressions algorithms (e.g. *ols\_step\_all\_possible()*, *ols\_step\_best\_subset()*) and select some more candidate models
15. Compare the candidate models previously selected using the fitting and prediction statistics that can be used to characterize: the fitting; the prediction bias; the prediction precision. Check also if the models fulfil the regression assumptions. Propose one or, if justified, two models to be used for the estimation of cork oak stands

# Growth and yield models – whole stand models

## Xxxx

a) a) Repeat d) but for stand basal area, testing the impact of expressing the parameters as a function of stand and site variables:

f.1) A as a function of site index

f.2) m as a function of stand density

f.3) k as a function of stand density

f.4) A as a function of site index and k as a function of stand density

f.5) A as a function of site index and m as a function of stand density

Repeat e) for stand basal area, testing the impact of expressing the parameters as a function of stand and site variables:

g.1) A as a function of site index

g.2) m as a function of stand density

g.3) A as a function of site index and m as a function of stand density

# Management oriented process-based models

## Become familiar with the 3PGpjs27.xlxs simulator

1. Explore the 3PGpjs27.Data EXCEL file and learn how to use this simulator.
2. Explore the templates that were provided to you in Fenix.

## Impact of different climatic scenarios in the productivity of eucalyptus in the Chamusca county

Use the 3PG model to study the impact of different climatic scenarios in the eucalyptus productivity in the Chamusca county. You should go through the following steps:

1. Get climatic data for the Chamusca county: averages of the last 30 years and at least two future scenarios for the next 30 years. For that you can use the climate picker tool of the FCTOOLS web site.
2. Obtain the range of site indices for the Chamusca county. You can use the WebGlobulus tool available from the FCTOOLS website or use Figure 1 that has been extracted from the forest inventory that took place in Chamusca in 1999 (Tomé 1999).
3. Run the WebGlobulus tool for the range of site indices (at least 5: very low, low, average, high, very high) to find the values of biomass that correspond to each one of these site classes.
4. Test different combinations of: soil texture, fertility rating and maximum available soil water to reproduce, using the average climate of the last 30 years, the biomass production for each one of the site classes defined in c)
5. Repeat the simulations for each one of the site classes selected in c) but using the two climatic scenarios selected in a).
6. Prepare a small report describing the work undertaken and discussing the results obtained.

|  |  |
| --- | --- |
| Percentage of plots |  |
|  | Site index (base age 10) |

Figure 2. Site indices range in the Chamusca county

## Impact of different climatic scenarios in the productivity of eucalyptus in two regions with contrasting climates

Use the 3PG model to study the impact of different climatic scenarios in the eucalyptus productivity in two contrasting regions: Braga and Odemira counties. You should go through the following steps:

1. Get climatic data for the Braga and Odemira counties: averages of the last 30 years and at least two future scenarios for some 30 years period (for instance 2030-2060 and 2060-2090). For that you can use the climate picker tool of the FCTOOLS web site.
2. Obtain the average site index for each of the counties. You can use the WebGlobulus tool available from the FCTOOLS website.
3. Run the WebGlobulus tool for the average site index of each one of the counties to find the values of biomass that correspond to each one of them.
4. Test different combinations of: soil texture, fertility rating and maximum available soil water to reproduce, using the average climate of the last 30 years, the biomass production for each one of the counties
5. Repeat the simulations for each one of the counties but using the two climatic scenarios selected in a).
6. Prepare a small report describing the work undertaken and discussing the results obtained.

# References

Bevan KJ, Kirkby MJ, 1979. A physically based, variable contributing area model of basin hydrology. Hydrol Sci Bull Sci Hydrol 24:43–69.

Paulo JA, Palma JHN, Gomes AA, Faias SP, Tomé J, Tomé M, 2015. Predicting site index from climate and soil variables for cork oak (*Quercus suber* L.) stands in Portugal. New Forests 46(2): 293-307. Doi: 10.1007/s11056-014-9462-4.

Sánchez-González M, Tomé M, Montero G, 2005. Modelling height and diameter growth of dominant cork oak trees in Spain. Ann For Sci 62:633–643.

Tomé, M., Ribeiro, R. P., Marques, M., 1999. Inventário Florestal do concelho da Chamusca. Relatórios técnico-científicos do GIMREF, nº 1/1999, Instituto Superior de Agronomia, Lisboa, Portugal.

Tomé, M., Oliveira, T., Soares, P., 2006. O modelo Globulus 3.0. Publicações GIMREF - RC2/2006. Departamento de Engenharia Florestal, Instituto Superior de Agronomia, Lisboa.

# ANNEXE 1 – Example of cork prices

If you do not have information about cork prices, you can use the values in the following table:

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| caliber class | Cork quality | | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | refugo |
| <=14 | 11.75 | | | 0.7 | | | |
| ]14,18] |
| ]18,23] | 11.65 | 6.5 | | 0.7 |
| ]23,27] |
| ]27,41] | 88.25 | | | 51.5 |
| >41 |
| Virgin cork, burnt cork and small pieces: 0.7 | | | | | | | |

NOTE: When inserting the information for cork prices please be aware that you must use the same caliber and quality classes as in the SUBER window regarding the default distributions for the NUT II region – Centre.

# ANNEXE 2 – Description of data files used as support to the course

Before solving each exercise, be sure that you are familiar with the data files needed for the exercise, that are described in the following items.

1. Pb\_PP&Trials.xlsx

This file includes stand level variables of a set of permanent plots and trials – thinning and pruning trials, spacing trials – established in maritime pine stands.

1. IFN5\_Arv\_Pb.xlsx

This file was extracted from the Portuguese National Forest Inventory data base (IFN5) and includes measurements undertaken in plots pure or dominated by maritime pine.

1. IFN5\_Arv\_Ec.xlsx

This file was extracted from the Portuguese National Forest Inventory data base (IFN5) and includes all the measurements undertaken in plots pure or dominated by eucalyptus.

1. SinglePlotVolumeData.xlsx

Volume growth data for an eucalypt plot

1. Ec\_ StandGrowthData\_1.xlsx

This file includes the evolution of volume for an eucalypt plot over time in the first spread-sheet and a set of permanent plots with the evolution of basal area and dominant height over time on the second spread-sheet.

1. Ec\_StandGrowthData\_2.xlsx

This file is a sub-set of the data used to develop the GLOBULUS 3 model (Tomé et al. 2006).

The file includes stand level data from trials and permanent plots established in eucalyptus plantations in Portugal.

The same file includes several sub-sets, one for the permament plots (EPE) and the others each corresponding to one trial (AV, QP). The data from each sub-set includes two worksheets, one with the plot level information and another with the values of the stand variables over time. Variables names are according to the IUFRO standards.

1. File “3.1. BiomassData\_Ec\_trees.xlsx” contains data from the destructive sampling of eucalyptus young trees representing different spacings and clones

* Plot total biomass over diameter at 0.5 m, using different symbols according to the clone. Discuss the results
* The same as a) but according to the spacing. Discuss the results, comparing them with the results obtained in a)

1. Sb\_SiteIndex&SiteData.xlsx

This data file is a sub-set of the data used by Paulo et al. (2015) to develope a model to estimate site index in cork oak stands in Portugal.

The file includes several worksheets: 1) Property – with the cod and name of the properties (Cod\_property and property) where the plots are installed and the code of the closest metereologic station (Cod\_Meteo); 2) StandVariables – with the information, for each plot, of the dominant diameter and height (dudom and hdom) and of stand age (t); 3) Soil\_twi – with the information on soil and litology characteristics and topographic wetness index (Bevan and Kirkby 1979); 4) Climate – with information on several climate variables for each metereologic station.

It was not possible to open a soil pit in some of the plots, therefore the variables Soil\_depth and Soil\_depth\_A are not available for all the plots.

| **Soil, litology and topographic variables:** | |
| --- | --- |
| **Variable** | **Description** |
| **Data from the Portuguese Agency for the Environment website**  **(http://sniamb.apambiente.pt/webatlas/).** | |
| Litology | Litology according to Silva(1983) |
| Soil\_FAO | FAO soil group according to the IUSS Working Group WRB (2006) classification |
| **Observation of the soil profile (soil pit)** | |
| Soil\_depth | Soil depth until the R/C or C/R horizon was reached |
| Soil\_depth\_A | Thickness of the A horizon |
| **Observation of the soil** | |
| Soil\_texture | Soil textural class (fine, medium and coarse) |
| Soil\_texture\_ A | Soil textural class (fine, medium and coarse) of the A horizon |
| **Computed from the Jarvis et al. (2008) digital terrain model** | |
| Twi | topographic wetness index developed by Bevan and Kirkby (1979) |

| **Climate variables (average monthly data over the 30-year period 1961–1990:** | |
| --- | --- |
| **Variable** | **Description** |
| Tmin | minimum temperature (ºC) |
| T | mean temperature (ºC) |
| Tmax | maximum temperature (ºC) |
| HR\_9 | relative humidity at 9 hours |
| HR\_15\_18 | relative humidity at 15-18 hours |
| P | mean monthly precipitation (mm) |
| NdaysP | number of days with precipitation per month |
| Evap | monthly evaporation with Piche evaporimeter (mm) |
| Ndays\_Tmin<0 | number of days with Tmin < 0 |
| Ndays\_Tmin>20 | number of days with Tmin > 20 |
| Ndays\_Tmin>25 | number of days with Tmin > 25 |
| NdaysFog | mean number of days with fog per month |
| NdaysDew | mean number of days with dew per month |
| NdaysFrost | mean number of days with frost per month |
| Martonne | Martonne climatic index (De Martonne 1925) (M=Pannual/T+10) |

1. NFI\_plots\_WithFireInformation (não sei se arranjo estes dados, se não arranjar terão de ser dados da árvore para fazer a regressão logística ou talvez dados do IFN com ataque de pragas)