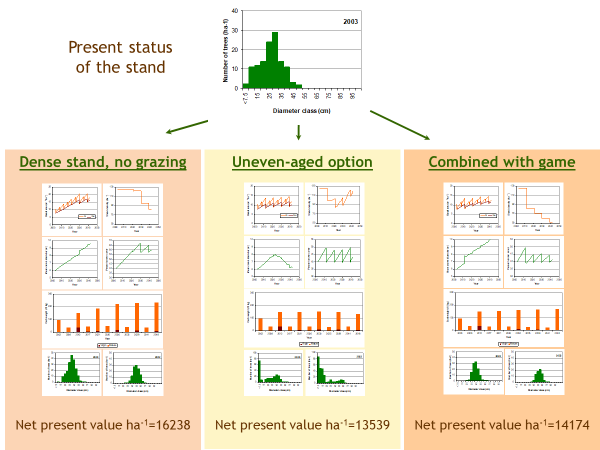
**Universidade de Lisboa – Instituto Superior de Agronomia Centro de Estudos Florestais**

**FOREST MODELS**

**Exercises notebook – 2nd edition**

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



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

Textos Pedagógicos TP 1/2021



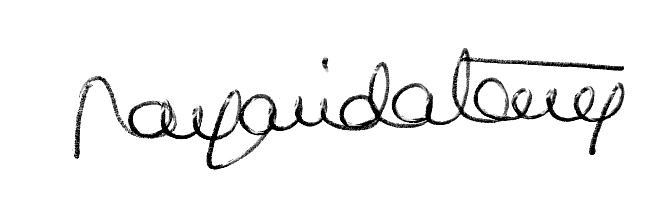
***FOREWORD***

*This volume is part of the notes of the FOREST MODELS course. It consists of a set of exercises related to the different chapters. The exercises were selected using real data and are intended to help the students to understand the application of the acquired concepts.*

*This volume is complemented with 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” in the Forest Models webpage (Fénix)*

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*Lisbon, September 2020*

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# 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 and on the study material)

# Data for the development and validation of forest models

1. 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
5. 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
6. 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) |

1. 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.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 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 |

1. 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 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 | - | - |

1. 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

## Description of data files used

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. 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. 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 and includes all the measurements undertaken in individual trees of maritime pine.

1. Ec\_StandGrowthData\_2.xlsx

This file is 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)

## Reading data and exploratory analysis

Data file used: “Pb\_PP&Trials”

Script: “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 IFN\_TM\_Arv\_Pb. Check with the command *getwd* that the change was succesfull
2. In order to read EXCEL files, there is the need to install 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 exemplifies the installation of the two packages with the *install.packages()* command. You just need to install a package once.

1. You must load the packages that will be needed for the data manipulation (“xlsx” 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()* command) 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 plots 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 file used: “IFN\_Arv\_Pb”

Script: “2\_Pbtrees\_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\_TM\_Arv\_Pb. Check with the command *getwd* that the change was succesfull
2. In order to read large EXCEL files, there is the need to 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.

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

Data file used: “Ec\_StandGrowthData”

Script: “PlayWith\_Ec\_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 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()* command) 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, euca (AV+EPE) and euca\_plot (AV\_plot+EPE\_plot), that make an union (add the rows of both dataframes in a unique dataframe)
6. Using the *inner\_join()* function, create a dataframe (euca\_all) that merges the dataframes euca and euca\_plot by adding the variables available in euca\_plot to the dataframe euca (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 euca\_all in a EXCEL 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 variable
   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. Find alternative ways of calculating the means and standard deviations of the hdom and G variables by the combination (ID\_plot,ID\_rot)
7. 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.
8. Repete the previous exercise with the *lead()* function.
9. Split the data in the dataframa euca\_all in two datasets, to fit and to validate the models, each with 50% of the plots (not of the data points).

## Exploratory data analysis with graphics

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

Data file used: “Ec\_StandGrowthData”

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 and growth functions

## Analysis of the shape of the Lundqvist-Korf function for different values of the parameters. Using the EXCEL illustrate the shape of the Lundqvist-Korf 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 EXCEL, 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 EXCEL, 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)

## Go to the link http://home.isa.utl.pt/~joaopalma/modelos/fgfp/index2.html and use the Forest Growth functions Playground to learn more about the role of each parameter on the shape of the growth functions.

1. Formulate the Lundqvist-Korf growth function as difference equations
2. Formulate the difference equations solving the function for A, K and n
3. Formulate the age independent difference equation form for the Lunqvist-Korf growth function
4. Formulate the Richards growth function as difference equations
5. Formulate the difference equations solving the function for A, K and n
6. Formulate the age independent difference equation form for the Richards growth function
7. Formulate the Hossfeld growth function as difference equations
8. Formulate the difference equations solving the function for A, c1 and k
9. Formulate the age independent difference equation form for the Hossfeld growth function

## Fitting the Lundqvist-Korf function to data from one and several permanent plots

Data file used: “Ec\_StandGrowthData\_1”

Scripts: “3B\_VolumeGrowthCurves”, “3C\_VolumeGrowthCurves”, “3D\_VolumeGrowthCurves”

1. Use the EXCEL to fit the Lundqvist-Korf function to the data in the worksheet “OnePlot”. Start by making a “trial and error” fitting and, finally, use the SOLVER tool.
2. Write a R script to fit the Lundqvist-Korf function to the data in the worksheet “OnePlot”. Compare the results with the solution obtained in EXCEL.
3. Fitting a family of curves – Write a R script to fit the Lundqvist-Korf function expressed as a difference equation to the data in the worksheet “SeveralPlots”.

Lundqvist-k: 

1. Fitting a family of curves – Write a R script to fit the Lundqvist-Korf function with some of the parameters expressed as a function of stand variables to the data in the worksheet “SeveralPlots”.

## Fitting growth curves to data from permanent plots of eucalyptus with some parameters expressed as a function of stand variables

Data file used: “Ec\_StandGrowthData”

Script: “GraphicalDataAnalysis\_Ec\_GrowthData”

1. Fit the Lundqvist function to the data from basal area the A parameter expressed as a linear function of the site index and plot the estimated values together with the original data and the k parameter expressed as a function of number of trees at planting

## Fitting growth curves to data from permanent plots of eucalyptus using the difference equations methods:

1. Fit the Lundqvist function expressed as a difference equation to the basal area growth
2. Repeat the fitting for stand basal area but test the impact of expressing the parameters as a function of stand and site variables:

* A as a function of site index
* m as a function of stand density at planting
* A as a function of site index and m as a function of stand density at planting

## 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 9.2 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

# Forest productivity evaluation

## 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.

## 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 3 to create site index curves for the most important Portuguese tree species. Table 4 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 |  |  |

## Fitting site index curves using the difference equations model to data from permanent plots of eucalyptus:

1. Plot the evolution of dominant height for the different plots
2. Write an R script to fit a set of site index curves using different formulations of the Lunqvist-Korf function as a difference equation (If needed, you can fix the asymptote to an acceptable value)
3. Plot the fitted site index curves and compare them with the plot observed data (evaluation of the fitted site index curves)

## Model to estimate site index from topographic, soil and climate variables

Data file used: “Sb\_SiteIndex&SiteData.xlsx”

Scripts: “0\_Sb\_SiteIndex\_DataPrep”; “1\_Sb\_SiteIndex\_ExploratoryAnalysis”; “2\_Sb\_SiteIndex\_SelectingSubsetsOfVAR”; “3\_Sb\_SiteIndex\_AnalysingOneModel”; “4\_Sb\_SiteIndex\_ComparingCandidateModels”

Using the data in the data file “Sb\_SiteIndex&SiteData.xlsx”, develop a model to estimate the site index of cork oak stands from site and climate variables. You must follow the following steps:

1. Build a R data file where you merge, for each plot, the information from the 4 worksheets in the file “Sb\_SiteIndex&SiteData.xlsx”
2. Use the site index curves from Sánchez-González et al. (2005) to estimate the site index (base age 80 years) for each one of the plots
3. 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
4. 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
5. Estimate the correlation coefficient between S and each one of the site and climate continuous variables available
6. 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)
7. Fit a linear regression between S and each continuous variable and find out which variables give a better prediction of S
8. 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
9. 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 dimmies you can use just some of the categories, which is not possible if you use the categorical variable)
10. 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
11. Use now all possible regressions algorithms (e.g. *ols\_step\_all\_possible()*, *ols\_step\_best\_subset()*) and select some more candidate models
12. 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 stans

# The standsSIM.md simulator

Using the Generator of Forest Management Approaches (FMAs) available in sIMfLOR build FMAs for the different tree species.

***Eucalyptus globulus***

## *Eucalyptus globulus* plantation managed for pulp production considering 3 consecutive rotations and describing the operations for a maximum age of 10 years:

|  |  |  |
| --- | --- | --- |
| **Ages** | **Operation** | **Details** |
| Plantation: |  |  |
| 1 | Harrowing and ripping (1 tooth) |  |
| 1 | Planting | 1250 trees per ha |
| 1 | Fertilizing at planting |  |
| 1 | Beating up/filling in | 10% of the plants |
| 2, 4, 6, 10 | Weed control | Disk arrow |
| 2, 4 | Fertilization |  |
| Coppice: | | |
| 3, 5 | Fertilization |  |
| 3, 5 | Shoots selection | 1.6 shoots per stool |

## *Eucalyptus globulus* plantation managed for pulp production considering 3 consecutive rotations and describing the operations for a maximum age of 14 years:

|  |  |  |
| --- | --- | --- |
| **Ages** | **Operation** | **Details** |
| Plantation: |  |  |
| 1 | Harrowing and ripping (1 tooth) |  |
| 1 | Planting | 1100 trees per ha |
| 1 | Fertilizing at planting |  |
| 1 | Beating up/filling in | 15% of the plants |
| 2, 4, | Weed control | Disk arrow |
| 2, 4, 6 | Fertilization |  |
| Coppice: | | |
| 3, 5 | Fertilization |  |
| 3 | Shoots selection | 1.4 shoots per stool |
| 3, 5 | Weed control |  |

## Compared to exercises 5.1 and 5.2 would you have to change something in the FMA generation process if you wished to apply these FMAs for only 1 coppice? Justify.

## Would you be able to use the FMAs described in exercises 5.1 and 5.2 (for maximum ages of 10 and 14, respectively) to simulate eucalyptus growth considering an harvest age of 12 years? Justify and describe any inconvenience you might see in that.

## Would you be able to apply any of these FMAs if you only wished to simulate consecutive plantations (without benefiting from *E. globulus* resprouting ability)? Justify.

## Describe how you to proceed if you were asked to generate an FMA similar to 5.1, but considering a stump destruction operation had to be performed before planting.

## Suppose a forest owner decides to manage *E. globulus* for sawlog production. Propose an FMA considering a rotation cycle of 40 years.

***Pinus pinaster***

## Build an FMA for a *Pinus pinaster* plantation for a maximum age of 50 years consisting of the following operations:

|  |  |  |
| --- | --- | --- |
| **Ages** | **Operation** | **Details** |
| 1 | Harrowing, ripping (1 tooth) |  |
| 1 | Planting and fertilizing at planting | 2500 trees per ha |
| 1 | Beating up/filling in | 15% of the plants |
| 3, 7, 11, 17, 27, 37, 47 | Weed control | Disk arrow |
| 6, 15 | Prunning |  |
| 15, 20, 25, 30, 35, 40, 45 | Thinning from below | Wilson factor of 0.25 |

## Build an FMA for a *Pinus pinaster* plantation for a maximum age of 50 years consisting of the following operations:

|  |  |  |
| --- | --- | --- |
| **Age** | **Operation** | **Details** |
| 1 | Harrowing, ripping (1 tooth) |  |
| 1 | Planting and fertilizing at planting | 2500 trees per ha |
| 1 | Beating up/filling in | 15% of the plants |
| 3, 7, 11, 17, 27, 37, 47 | Weed control | Disk arrow |
| 6, 15 | Prunning |  |
| 15, 20, 25, 30, 35, 40, 45 | Thinning from below | Residual basal area of 25 cm2 ha-1 |

## Consider a *Pinus pinaster* uneven-aged stand. Build an FMA that can be applicable for 80 years consisting of the following operations:

|  |  |  |
| --- | --- | --- |
| **Age** | **Operation** | **Details** |
| - | Weed control every 5 years (assume the last las carried out 2 years ago) | Disk arrow |
| - | Thinning from below every 5 years | Residual basal area of 10 cm2 ha-1 |

## Build an FMA for a *Pinus pinaster* plantation for a maximum age of 80 years consisting of the following operations:

|  |  |  |
| --- | --- | --- |
| **Age** | **Operation** | **Details** |
| 1 | Harrowing, ripping (1 tooth) |  |
| 1 | Planting and fertilizing at planting | 2500 trees per ha |
| 1 | Beating up/filling in | 15% of the plants |
| 3, 7, 11, 17, 27, 37, 47, 57, 67, 77 | Weed control | Disk arrow |
| 6, 15 | Prunning |  |
| *considering the occurrence of selfthinning* | | |

***Quercus suber***

## Build an FMA for a *Cork oak* plantation for a maximum age of 100 years and a debarking cycle of 10 years consisting of the following operations:

'1»\_extraccao' 10

'outras\_extraccao' 10

'coef\_descort\_virgem' 2

'coef\_descort\_secundeira' 2.2

'coef\_descort\_amadia' 2.5

'silvicultura' 1

'diametro\_max' 90

|  |  |  |
| --- | --- | --- |
| **Age** | **Operation** | **Details** |
| 1 | Harrowing, ripping (1 tooth) |  |
| 1 | Planting and placing protectors | Spacing (8x4) |
| 1 | Beating up/filling in | 20% of the plants |
| 5 | Formation pruning (manual) | 50% of the trees |
| 5 | Manual fertilization |  |
| 36 | Formation pruning (mixed) | 50% of the trees |
| 5, 15, 25 | Weed control | Disc harrow |
| 46, 56, 66, 76, 86, 96 | Mature cork debarking every 10 yrs |  |
| 36, 46, 56, 66, 76, 86, 96 | Virgin cork debarking every 10 yrs |  |
| 36 | Prunning |  |
| 36, 46, 56, 66, 76, 86, 96 | thinning | Leaving a crown cover of 50% |

## Build an FMA for a *Cork oak* plantation for a maximum age of 100 years and a debarking cycle of 8 years consisting of the following operations:

'1»\_extraccao' 8

'outras\_extraccao' 8

'coef\_descort\_virgem' 2

'coef\_descort\_secundeira' 2.2

'coef\_descort\_amadia' 2.5

'silvicultura' 1

'diametro\_max' 90

|  |  |  |
| --- | --- | --- |
| **Age** | **Operation** | **Details** |
| 1 | Harrowing, ripping (1 tooth) |  |
| 1 | Planting and placing protectors | Spacing (8x4) |
| 1 | Beating up/filling in | 20% of the plants |
| 5 | Formation pruning (manual) | 50% of the trees |
| 5 | Manual fertilization |  |
| 36 | Formation pruning (mixed) | 50% of the trees |
| 5, 15, 25 | Weed control | Disc harrow |
| 44, 52, 60, 68, 76, 84, 92, 100 | Mature cork debarking every 10 yrs |  |
| 36, 44, 52, 60, 68, 76, 84, 92, 100 | Virgin cork debarking every 10 yrs |  |
| 36 | Prunning |  |
| 36, 44, 52, 60, 68, 76, 84, 92, 100 | thinning | Leaving a crown cover of 50% |

# Whole stand models and diameter distribution models

## **GLOBULUS.** Simulating a new plantation

A forest owner owns some land and wants to know how much standing volume of eucalyptus he will obtain over the next 30 years if he made a plantation in his property. Build a yield table for a eucalyptus considering the following information:

* Location: Coruche municipality
* Altitude: 14 m (if you don’t know the altitude you can use the webGLOBULUS stand simulator to obtain it)
* Site index: 15 m (base age 10 years)
* Plantation spacing: 4 x 2.5 (the interface requires the number of trees per hectare)

1. Define a suitable forest management approach (FMA) considering a prescription composed of 3 cycles with 10 years each (one plantation followed by two coppices).
2. Suppose he reconsidered and wants you to repeat the simulation delaying the harvest age of the plantation to 12 years and anticipating the harvest age of the coppices to 9 years. Compare both simulations and discuss the results.

## **GLOBULUS**. Comparing alternative prescriptions

For a planning horizon of 60 years compare the following prescriptions:

1. 6 cycles for each the plantation is harvested at age 10, followed by 5 coppices always harvested at age 10,
2. 6 ciclos all harvested at age 10 anos, but considering a replantation in the 4th cycle. Please note that soil preparation when replanting is different which implies the definition of 2 different FMAs.

## **GLOBULUS.** Simulating an existing stand

Suppose that another landowner wants you to simulate his existing stand:

* Location: Coruche municipality
* Age: 7 years
* Dominant height: 12 m
* Stand density: 980 trees ha-1
* Altitude: 14 m (if you don’t know the altitude you can use the webGLOBULUS stand simulator to obtain it)

Define a suitable FMA and consider the same prescription as before: 3 cycles with 10 years each (one plantation followed by two coppices). You will likely get the message: “*terminated before the planning horizon – check prescriptions*” because the 3 cycles only cover 23 years (3 years for the plantation and 10+10 for coppice). Therefore, in order to run the simulation, you will have to define another cycle or change the planning horizon. Having more than the required number of cycles represents no problem for StandsSIM.

## **GLOBULUS.** Build yield tables for a range of site indices

For the same county (Coruche) build a set of yield tables for site indices ranging from 15 to 25 m (base age 10 years), considering 3 cycles of 10 years. Select a forest management approach for all of them.

## **PBRAVO.** Solving a simulation in EXCEL

Using the equations that make up the model that are listed in the word file PBRAVO, program the model in EXCEL, with the exception of the estimation of the parameter c from the Weibull distribution. Using the observed data from stand nº 32 in the National Forest of Leiria (Figure 1) try to reproduce the results obtained with the PBRAVO stand simulator. Use, in each year, the estimates of the c parameter given by the PBRAVO.



**Figure 1. Data from the continuous forest inventory of the National Forest of Leiria – stand nº 2**

## **PBRAVO.** Comparing two management alternatives

Consider the stand nº 2 of the Mata Nacional de Leiria in the year 1970 and simulate its growth and yield till the age of 82 years with the following management alternatives:

1. Apply the first thinning at the age of 22 years and every 10 years after that until the age of 82 years. The residual basal area (after thinning) must be around 22 m2 ha-1
2. Apply the first thinning at the age of 22 years and every time the basal area gets a value higher than 18 and try to maintain it close to 18 m2 ha-1. The last thinning should occur at the age of 62 years and final harvesting at 82 years
3. Compare the two management alternatives above using the net present value. The prices are 40 Є for round wood, 15 Є for pulp and 5 Є for firewood. You don’t need to use costs for the comparison as they will be the same in both alternatives. Use a discount rate of 0.04.
4. Suppose that you want to define a management alternative with the first thinning at the age of 20 years. Is it possible with this simulator?

## **PBRAVO.** Simulating a new plantation

Suppose that a landowner is planning to plant a pine stand using 2500 plants per ha. In order to get support from the National Agriculture Services he needs to present a project including the proposed management and an estimate of the revenues. He estimates that the productivity of his site is representative of the average in the country. Use the PBRAVO model to support this landowner by comparing two alternatives for the thinnings (assume that other silvicultural operations are the ones presented in table 1)

1. Apply the first thinning at the age of 20 years and every 10 years after that until the age of 80 years. The residual basal area (after thinning) must be around 22 m2 ha-1
2. Apply the first thinning at the age of 20 years and every time the basal area gets a value higher than 18 and try to maintain it close to 18 m2 ha-1. The last thinning should occur at the age of 50 years and final harvesting at 60 years

## **PBRAVO.** Analysis of weak points and proposal of improvements

Are you able to propose some improvements to this simulator? And to the model?

# Individual tree models

## **PINASTER.** Simulating a new plantation

Consider a planning horizon of 50 years and build a yield table for maritime pine using the following information:

* Location: São Pedro de Moel municipality
* Altitude: 31 m (if you don’t know the altitude you can use the webGLOBULUS stand simulator to obtain it)
* Site index: 18 m (50 years)
* Plantation spacing: 2 x 2 (the interface requires the number of trees per hectare)

1. Define a suitable forest management approach (FMA) considering thinning from bellow to take place every 10 years based on a Wilson factor of 0.25 and final harvest at 50 years. Alternatively, import the FMA file *FMA41\_Pb\_025\_REGular.csv*.
2. Repeat the previous exercise considering a residual basal area basal of 25 m2 ha-1. You can obtain the FMA file by editing the file file *FMA41\_Pb\_025\_REGular.csvI*

## **PINASTER.** Simulating a new stand without thinning (self-thinning)

And now repeat the simulations delaying the final harvest age up to 80 years and not carrying out any thinning (the stand will reach self-thinning). You can impor the FMA file *FMA41\_Pb\_SelfThin\_REGular.csv*

## **PINASTER.** Simulating an existing even-aged stand

Simulate the growth of the following existing stand:

* Location: São Pedro de Moel municipality
* Stand structure: even-aged
* Age: 15 years
* Dominant height: 12 m
* Number of trees in the plot: 49 trees
* Plot area: 500 m2
* Altitude: 31 m (if you don’t know the altitude you can use the webGLOBULUS stand simulator to obtain it)
* Tree data file: “Pb\_inv\_t15\_arv.csv”

Define a suitable FMA considering a presciption composed of 4 cycles of 50 years each. Consider a planning horizon of 80 years. You can use the FMA from file *FMA41\_Pb\_025\_REGular.csv*.

## **PINASTER.** Simulating an existing uneven-aged stand – transition to even-aged

Simulate the growth of the following existing uneven-aged maritime pine stand:

* Location: Alcácer do Sal municipality
* Stand structure: uneven-aged
* Age: NA
* Dominant height: 12 m
* Number of trees in the plot: 23 trees
* Plot area: 500 m2
* Altitude: 100 m (if you don’t know the altitude you can use the webGLOBULUS stand simulator to obtain it)
* Tree data file: *Pb\_inv\_irreg\_arv.csv*

Build a prescription with 2 cycles as described below:

* cycle 1: uneven-aged management for 35 years with final harvest in the end of the cycle;
* cycle 2: planting (even-aged management) and final harvest at 35 years.

A planning horizon of 70 years is required. Please not that 2 different FMAs need to be considered (suggestion: use “FMA31\_Pb\_Gres\_Irreg.csv for the uneven-aged cycle and “FMA41\_Pb\_025\_REGular.csv” for the plantation).

## **PINASTER.** Simulating an existing even-aged stand – transition to uneven-aged

Simulate the growth of the following maritime pine even-aged stand:

* Location: São Pedro de Moel municipality
* Stand structure: even-aged
* Age: 15 years
* Number of trees in the plot: 49 trees
* Plot area: 500 m2
* Altitude: 31 m (if you don’t know the altitude you can use the webGLOBULUS stand simulator to obtain it)
* Tree data file: *Pb\_inv\_t15\_arv.csv*

Build a prescription with 2 cycles as described below:

* cycle 1: even-aged management for 35 years with final harvest in the end of the cycle;
* cycle 2: uneven-aged management for 35 years.

A planning horizon of 70 years is required. Please not that 2 different FMAs need to be considered (suggestion: use *FMA41\_Pb\_025\_REGular.csv* for the even-aged cycle and *FMA31\_Pb\_Gres\_Irreg.csv* for the uneven-aged one).

## **PINASTER.** Building a series of yield tables for a range of site indices

For the county of S. Pedro de Moel, build a set of yield tables for site indices ranging from 15 to 25 m (base age 50 years), considering final harvest at 80 years. Consider the same FMA for all site indices.

## **PINEA-tree.** Simulating an existing even-aged stand

Suppose that you were given the task of simulating the growth of the following existing stand:

* Location: Alcácer do Sal municipality
* Stand structure: even-aged
* Age: 10 years
* Number of trees in the plot: 136 trees
* Plot area: 5000 m2
* Altitude: 100 m (if you don’t know the altitude you can use the webGLOBULUS stand simulator to obtain it)
* Tree data file: “*inv\_Pm\_reg\_arv.csv*”

Define a FMAs/prescriptions considering even-aged management corresponding to a thinning regime that maintains the basal area around 12 m2 ha-1 yr-1. Simulate for a planning horizon of 100 years.

## **PINEA-tree.** Comparing two alternative management approaches

Simulate for a planning horizon of 100 years the following existing stone pine stand:

* Location: Évora municipality
* Stand structure: even-aged
* Age: 18 years
* Number of trees in the plot: 34 trees
* Plot area: 2000 m2
* Altitude: 275 m (if you don’t know the altitude you can use the webGLOBULUS stand simulator to obtain it)
* Tree data file: “*inv\_Pm\_arv\_n34.csv”*

Define 2 FMAs/prescriptions considering even-aged management considering 2 different regimes corresponding to two different stockings (thinning intensities) and compare the results (suggestion: *FMA41\_Pm\_15\_REGular.csv* and *FMA41\_Pm\_25\_REGular.csv*).

## **SUBER.** Simulating a new plantation

Suppose that you work in a Forest Owners Association and that you are addressed by a landowner to help him to prepare a forest management plan (PGF) for the cork oak stands in his property located in Chamusca. There is no information regarding the soil type. To support his decisions you must run the SUBER model to build an yield table for the new stands, by using the available tools from sIMfLOR platform. Consider a planning horizon of 100 years and build an yield table using the following forest management alternative (FMA):

|  |  |  |
| --- | --- | --- |
| **Silvicultural operations** | **Year** | **Details** |
| Soil preparation: Mechanical operation for ripping (1st line) | 1 | - |
| Plantation (plants in container) | 1 | 666 trees/ha |
| Weed control for young stands (Manual operation) | 5 |  |
| Weed control with harrowing (Mechanical operation) | 18 |  |
| Thinning using the crown cover as parameter | When debarking | 50% |
| 1st Debarking (Manual operation – virgin cork) | 18 |  |
| Debarking rotation (Manual operation – virgin and mature cork) |  | 9 years |

|  |  |
| --- | --- |
| **Silvicultural details** |  |
| The debarking coefficients:  1st extraction, 2nd extraction and mature extraction | 2; 2.5; 3 |

## **SUBER.** Simulating an existing even-aged stand

Use now the SUBER model to predict the evolution of an existing stand in the same property located in the Chamusca region. The stands are mainly cork oak characterized as pure and even-aged stands, but age is unknown. There is no information regarding the soil type. The last forest inventory took place in 2002, immediately after the debarking, and used 30 circular plots with an area of 2827.43 m2. In each plot the following variables were measured in every tree: *d*, *ct*, *h*, *hs*, *hdv*, *nbru1*, debarking year and debarking type (virgin, second cork or mature cork).

The tree data is provided, organized as required by the SUBER simulator interface, in the EXCEL file *inv\_Sb\_Chamusca\_arv.xlsx*.

1. Use the SUBER model to compare different alternatives for the cork rotation length
2. Solve again the same exercise but considering all the plots joined in a unique plots with an area equal to 30\*2827.43

## **SUBER.** Comparing different ages to start the debarking in a new plantation

Consider a planning horizon of 100 years and build a yield table with the SUBER simulator using the following information:

* Location: Mora municipality
* Site index: average for the county
* FMA: use the Generator to build the forest management approach described in the table below (suggestion *FMA\_Sb\_YieldTable\_CC35\_R9.csv*)

|  |  |  |  |
| --- | --- | --- | --- |
| **Year of 1st occurrence** | **Periodic (Y-yes; N-no)** | **Periodicity** | **Operation** |
| 0 |  |  | Plantation (spacing 8x4) |
| 1 | Y | 4 | Manual weed control |
| 1 | N |  | Beating-up (20% of the trees) |
| 4 | N |  | Formation pruning (80% of the trees) |
| 5 | Y | 4 | Application of fertilizer (manual) |
| 8 | N |  | Formation pruning (30% of the trees) |
| 10 |  |  | Thinning (% crown cover = 35) |
| 12 | N |  | Formation pruning (10% of the trees) |
| 15 | N |  | Thinning (% crown cover = 35) |
| td [19;40] | Y | 9 | First debarking |
| td | N |  | Formation pruning (10% of the trees) |
| td | Y | 9 | Thinning (% crown cover=35) |
|  |  |  |  |

Start by running SUBER without selecting the debarking operation to find the age at which the dug is close to 17 cm and use it as one possible age to start cork debarking.

Run the SUBER for several alternative FMAs that differ among them by the age of the first debarking (td) and compare the results.

## **SUBER.** Comparing different periodicities of debarking in an existing cork oak stand

Consider a planning horizon of 100 years and use the SUBER to simulate the growth of the following existing stand:

* Location: Herdade da Bolota, Coruche municipality
* Age: 10 years
* Plot area: 2000 m2
* Tree data file: *inv\_Sb\_HBolota\_t10\_arv.csv*
* FMA: use the Generator to build the forest management approach described in the table below (suggestion *FMA\_Sb\_Existing\_CC35\_R9.csv*)

|  |  |  |  |
| --- | --- | --- | --- |
| **Year of 1st occurence** | **Periodic (Y-yes; N-no)** | **Periodicity** | **Operation** |
| 5 | Y | 4 | Manual weed control and Application of fertilizer |
| 8 | N |  | Formation pruning (30% of the trees) |
| 10 |  |  | Thinning (% crown cover = 35) |
| 12 | N |  | Formation pruning (10% of the trees) |
| 15 | N |  | Thinning (% crown cover = 35) |
| td [19;40] | Y | 9 | First debarking |
| td | N |  | Formation pruning (10% of the trees) |
| td | Y | 9 | Thinning (% crown cover=35) |
|  |  |  |  |

Start by running SUBER without selecting the debarking operation to find the age at which the dug is close to 17 cm and use it as the age to start cork debarking.

Run the SUBER for several alternative FMAs that differ among them by the periodicity of debarking and compare the results.

# Management oriented process-based models

## **3PG.** 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.

## **3PG.** 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 1. Site indices range in the Chamusca county

## **3PG.** 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.

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# 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.