

EFORWOOD  
Tools for Sustainability Impact Assessment

**Report describing the regional simulators and the European simulator**

Margarida Tomé and Sónia Faias



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## Preface

This report is a deliverable from the EU FP6 Integrated Project EFORWOOD – Tools for Sustainability Impact Assessment of the Forestry-Wood Chain. The main objective of EFORWOOD was to develop a tool for Sustainability Impact Assessment (SIA) of Forestry-Wood Chains (FWC) at various scales of geographic area and time perspective. A FWC is determined by economic, ecological, technical, political and social factors, and consists of a number of interconnected processes, from forest regeneration to the end-of-life scenarios of wood-based products. EFORWOOD produced, as an output, a tool, which allows for analysis of sustainability impacts of existing and future FWCs.

The European Forest Institute (EFI) kindly offered the EFORWOOD project consortium to publish relevant deliverables from the project in EFI Technical Reports. The reports published here are project deliverables/results produced over time during the fifty-two months (2005–2010) project period. The reports have not always been subject to a thorough review process and many of them are in the process of, or will be reworked into journal articles, etc. for publication elsewhere. Some of them are just published as a “front-page”, the reason being that they might contain restricted information. In case you are interested in one of these reports you may contact the corresponding organisation highlighted on the cover page.

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Sustainability Impact Assessment  
of the Forestry - Wood Chain



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EFORWOOD

Tools for Sustainability Impact Assessment

## **Description of the regional forest simulators and the European simulator**

**Editors:** Margarida Tomé, Sónia Faias

**Abstract:**

This report describes forest simulators that were developed under EFORWOOD. According to the terminology agreed in PD2.5.2 “Framework for the description of forest modelling tools currently available with identification of their ability to estimated sustainability indicators” (Tomé et al., 2007) a forest simulator is a computer tool that, based on a set of forest models, makes long term predictions of the status of the forests within a well defined region under a certain scenario of climate, forest policy and/or management alternatives. Forest simulators usually predict, at each point in time, wood and non-wood products from the forest. Forest simulators can be developed for different levels of spatial resolution, from a single stand to a large region or even a continent. One of the objectives of EFORWOOD was the design and implementation of simulators at different levels of spatial resolution, including in the output a list of selected sustainability indicators. This report describes the regional and European simulators: i) SIMPLOT, a regional simulator for the Portuguese forests that is implement into an interface that includes several simulators for the Portuguese forests (SIMFLOR); ii) REGWISE, a regional simulator for Swedish forests; iii) SYLVOGENE, simulator of the Maritime pine forests in Aquitaine (South West France); iv) EFISCEN-space, the spatialized European forest simulator. Each simulator is presented as a working paper with the respective authors, and some flexibility was allowed in the descriptions so that each author’s team was able to organize the description of the simulator in a way appropriate to the specificity of the simulator.

**Keywords:** Forest models, forest resource simulators, stand simulators, regional simulators, and sustainability indicators



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## 1 INTRODUCTION

This report describes the regional and European forest simulators that were developed under EFORWOOD. According to the terminology agreed in PD2.5.2 “Framework for the description of forest modelling tools currently available with identification of their ability to estimated sustainability indicators” (Tomé et al., 2007) a forest simulator is a computer tool that, based on a set of forest models, makes long term predictions of the status of the forests within a well defined region under a certain scenario of climate, forest policy and/or management alternatives. Forest simulators usually predict, at each point in time, wood and non-wood products from the forest. An objective of EFORWOOD is that simulators include in the output a list of selected sustainability indicators.

There are several types of forest simulators depending on the spatial scale to which they apply and to the connection/or not to geo-referenced information:

1. Stand simulator  
Forest simulator focused on the simulation of a stand
2. Landscape simulator  
Forest simulator focused on the simulation of all the stands included in a certain well defined region in which the stands are spatially described in a GIS. The simulation is made on a stand by stand basis but outputs for the whole landscape are also provided, namely sustainability indicators. It allows for the testing of the effect of spatial restrictions such as maximum or minimum harvested areas or maximization of edges.
3. Regional/National simulator – not spatialized  
Forest simulator focused on the simulation of a large region, based on forest inventory data, without individualizing each stand, not connected to a GIS. Outputs are usually given by forest type but focused on the whole region.
4. Regional/National simulator – spatialized through a grid  
Forest simulator focused on the simulation of a large region, based on forest inventory data aggregated according to a spatial grid connected to a GIS. Outputs are also usually given by forest type but focused on the whole region. Due to the connection to a GIS it is possible to compute indicators that include spatial relationships. It is also possible to include spatial conditions in the implementation of the drivers, for instance to include distance to the mills in the harvesting algorithms or ecological conditions in the areas that are abandoned or planted.

There were several simulators developed under EFORWOOD, from stand simulators to a European simulator. The following chapters present a detailed description of each one of the regional and European simulators that are briefly characterized on Table 1.

Each simulator is presented as a working paper with the respective authors, and some flexibility was allowed in the descriptions so that each author’s team was able to organize the description of the simulator in a way appropriate to the specificity of the simulator.



Table 1. Regional and European forest simulators that were developed under EFORWOOD.

Name	Type of simulator	Partner responsible	Applicability			
			Region	Species	Stand types	FMA <sup>1</sup>
sIMfLOR	Stand + Regional	ISA	Portugal	Eucalyptus	Pure even and uneven-aged	DB EAF (COF)
RegWise	Regional/National	SLU	Sweden	Scots Pine, Norway Spruce, Birch, Oak, Beech, Aspen, Other Deciduous	Even and uneven-aged	EAF COF CN NC
Sylvogene	Stand + Regional	INRA FCBA	South West France	Maritime pine	Pure even aged	DB EAF (COF)
EFISCEN-space	European	ALTERRA	Europe	Several species <sup>1</sup>	Pure and mixed, even- and uneven-aged	DB EAF COF CN NC

<sup>1</sup>Abies spp., Alnus spp., Betula spp., Carpinus betulus, Castanea sativa, Eucalyptus spp., Fagus sylvatica, Fraxinus spp., Larix spp., other broadleaves, other conifers, other Pinus spp., other Quercus spp., Picea spp., Pinus pinaster, Pinus sylvestris, Populus spp., Pseudotsuga menziesii, Quercus robur/petraea, Robinia pseudoacacia

<sup>2</sup>DB – dendrobiomass; EAF – even-aged forestry; COF – combined objective forestry; CN – close to nature; NC – nature conservation



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## **2 SIMPLOT: regional simulator for the analysis of sustainability of eucalyptus forests in Portugal.**

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### **Abstract:**

SIMPLOT is a forest simulator for eucalyptus and maritime pine mainly driven by wood and biomass demand. AT present it is working for eucalyptus but it is prepared to work for any species provided that the functions of the respective stand growth model are implemented. It was designed for long-term simulation of the Portuguese forest development using National forest inventory data as input and taking into account the effect of different drivers such as wood demand, hazards occurrence, percentage of land use changes and changes between different forest management alternatives. This report describes the present status of the simulator and the improvements that are expected in the short term. The use of the simulator is illustrated by two simulation runs for two main scenario lines. In the first one, increasing wood demand rates are combined with a low severity fire scenario, whereas the second one considers an increasing number of high severity wildfires for a given wood demand rate as well as the impacts of different scenarios of use of burnt wood by the industry. These simulations provide some insight on the impact of increasing wood demand combined with an increasing number of severe wildfires. As higher the wood demand rate is the more drastically carbon stocks decrease. The 5% wood demand rate scenario shows a 67% reduction in carbon stock throughout the analyzed period, against a 17% reduction for the 4% rate scenario and a 55.5% increase for the 2% one. The impact of an increasing number of severe wildfires for a wood demand rate of 4% results in carbon stock depletions that can reach a 50% loss for the more severe wildfire scenario. If less burnt wood is used by industry, only allowing burnt stands near the rotation age to be harvested and dropping the percentage of these stands that are used with industrial purposes, the situation can get even worse with carbon stocks shortening in 60% when compared with the beginning of the simulation period. Holding all other variables constant and varying wood demand and wild fires once at a time, despite the impact of the number of wildfires occurrence, wood demand is still the crucial driver with the major impact on changing forest conditions.

**Key words:** Portugal, forest simulator, eucalyptus, carbon sequestration, carbon stock, wood demand, forest fires.



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## **2.1 INTRODUCTION**

The SIMPLOT is a forest simulator for the Portuguese forests designed for large-scale and long term analysis. SIMPLOT is suitable for assessments of the future state of the forest under assumptions of future wood and biomass demand, hazards occurrence and land use changes. The model simulates the state of the forest under different conditions defined by the user, although it does not comprise any optimization module. At present it just considers eucalyptus stands but it is prepared to include any other species provided that the functions corresponding to the stand growth model are implemented.

The model has the advantage of not being too demanding in terms of input data. It requires inventory data usually available for National Forest Inventories as is the case of eucalyptus in Portugal. The basic output of the model consists of the state of the forest in one year intervals: growing stock, harvested area and volume, burnt area and a wide set of social, economic and environmental indicators.

The simulator is still under constant development at Instituto Superior de Agronomia (ISA). This paper describes the first prototype of the simulator. The only hazard taken into account so far is forest fire but it is planned to add the impact of the most important pests and diseases that affect the eucalyptus and maritime pine in Portugal. The present version of the simulator allows simulating two different forest management alternatives: even-aged forestry and short rotation forestry or dendro biomass production forestry. In order to illustrate the present abilities of the simulator it is used to analyze the impact of different scenarios of fire and wood demand on carbon sequestered and carbon stock.

## **2.2 SIMPLOT - THE SIMULATOR CONCEPTION**

SIMPLOT has been conceived to simulate all the stands in a region, but it also allows the user to simulate the growth of an individual stand providing an yield table as output as well as a large set of sustainability indicators and an economic analysis. This possibility is highly appreciated by the users as a way to follow the future development of individual stands and, in this way, gain confidence on the simulator. When running the simulator for different scenarios, it starts with forest inventory information to characterize the forest resources in a region (e.g. NUT, country) and uses forest growth models to predict long-term development of forest resources in the region taking into account the influence of a certain number of external variables – the drivers. For each year of the simulation it computes a set of sustainability indicators that directly relate to forest resources.

## **2.3 SIMPLOT - THE SIMULATION UNIT**

The basic simulation unit is a “fictitious” stand from here on designated by stand. Each stand has the characteristics of a NFI plot and represents an area corresponding to the total area of a certain species in the country divided by the respective number of NFI plots. The simulator allows the user to divide the stand in as many parts as desired in order to adjust the area to which harvest and forest operations are applied.

## **2.4 SIMPLOT - THE STRUCTURE**

The main objective of short-rotation forestry's is to produce the highest amount of wood biomass without major environmental concerns. The resulting wood biomass will be used as solid bio-energy. Forest biomass used for energy production can be allocated from three different sources:

Biomass from forest residues (Source <sub>Residues</sub>)

To include forest residues as an output of SIMPLOT biomass functions for estimation of biomass residues were incorporated into the respective growth module. This biomass source contemplates



biomass deriving from burnt stands not used by industry, biomass from tree tops resulting from harvesting and biomass of selected shoots in thinning operations of coppice stands.

Biomass from plantations specifically planted for bio-energy (Source<sub>Energy</sub>)

So that the option of managing stands as short-rotation forests could be included in the simulator, the afforestation/reforestation with this type of plantations with stockings closer to those expected to exist for short-rotation forestry (much higher than those practiced for the wood production forest management alternative – WPF), was added. The simulator, mainly driven by wood demand, has now two demands to be met for the horizon of simulation: the wood demand for pulp and paper production and the biomass demand for bio-energy production.

Biomass from plantations planted for wood production (Source<sub>Wood</sub>)

In case the biomass demand is not met using the biomass from the previous sources, there is still the possibility to do so by harvesting stands planted originally for pulp. This alternative will only be considered if there are stands in condition to be harvested after the wood demand is met and there is still a deficiency in biomass for energy.

To integrate these three sources of biomass for energy in the simulator different methodologies were applied according to the source.

Figure 2. shows the current structure of the simulator including the new modules and each module contribution to meet the wood and biomass demands. The same “philosophy” is applied to each species. The simulator can run more than one species at the same time but the drivers are applied by species. The first three boxes represent the input files. The next level of boxes deriving from the scenario and simulation parameters input files show the total amount of each driver needed as input for each of the drivers’ modules. The cascade boxes represent the modules and the arrows indicate the order by which each of the modules run: first the growth module followed by the modules related to the drivers: fire, harvest dendrobiomass plantations for energy (DB/E), harvest even-aged forest for wood production (WPF/W), harvest even-aged forest for energy production (WPF/E), land use changes (LUC) and forest management alternatives (FMA).

There is an amount of biomass residues resulting from harvested stands which is estimated and assumed to be used for bio-energy production and that represents one of the three sources of biomass. In order to calculate the biomass of tree tops, tree biomass ratio equations depending on the top diameter used in the harvesting operation are used (Fontes et al 2008). The biomass of tops is estimated per tree component: wood, bark, branches and leaves. The equations are applied to the mean tree and the total biomass of residues is then estimated from the number of trees per hectare. To be able to implement the biomass ratio equations there was the need to determine the height of the mean tree (Tome et al 2008), the height up to the crown base (Soares and Tomé 2003), the diameter of the dominant trees (Tome et al 2007a) and the top height. The diameter at the base of each log ( $d_i$ ), assumed to be 2 meters long, along the stem is calculated until the top diameter planed for harvesting is surpassed. The diameters ( $d_i$ ) were calculated over bark with existing taper equations (Tome et al 2007b). The top height was selected from the bottom and the top of the last log so that a top diameter as close as possible from the one planned could be obtained. All the equations used can be seen in

**Table 1.** This allows the simulator to contemplate different harvesting systems from more to less intensive depending on the amount of residues removed from the site.

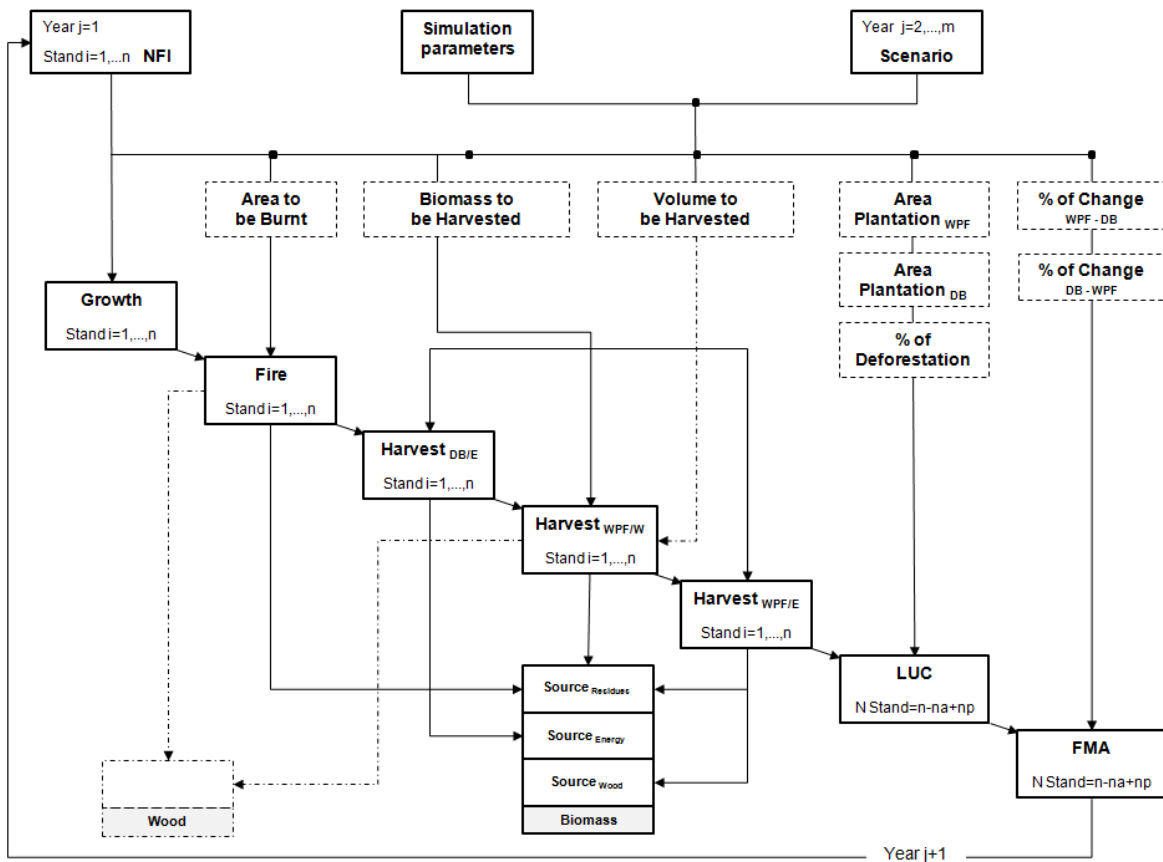


Figure 2.1. Structure of the SIMPLOT regional simulator.

At the start of the simulation the area of energy plantations was set equal to zero and from this year onwards stands which were planted for energy production according to the planted areas defined in the scenario input file were classified as dendro-biomass production (DB). All other stands were classified as wood production forest (WPF).

The growth module was modified in order to correct the estimates obtained with GLOBULUS when DB stands are simulated. After running this module to update forest resources for the first year of simulation, the fire module is run originating volume of wood and biomass of residues which will be used by the pulp and paper industry and by bio-energy production plants, respectively. This biomass corresponds to the first source of biomass for energy (**Figure 2.1**).

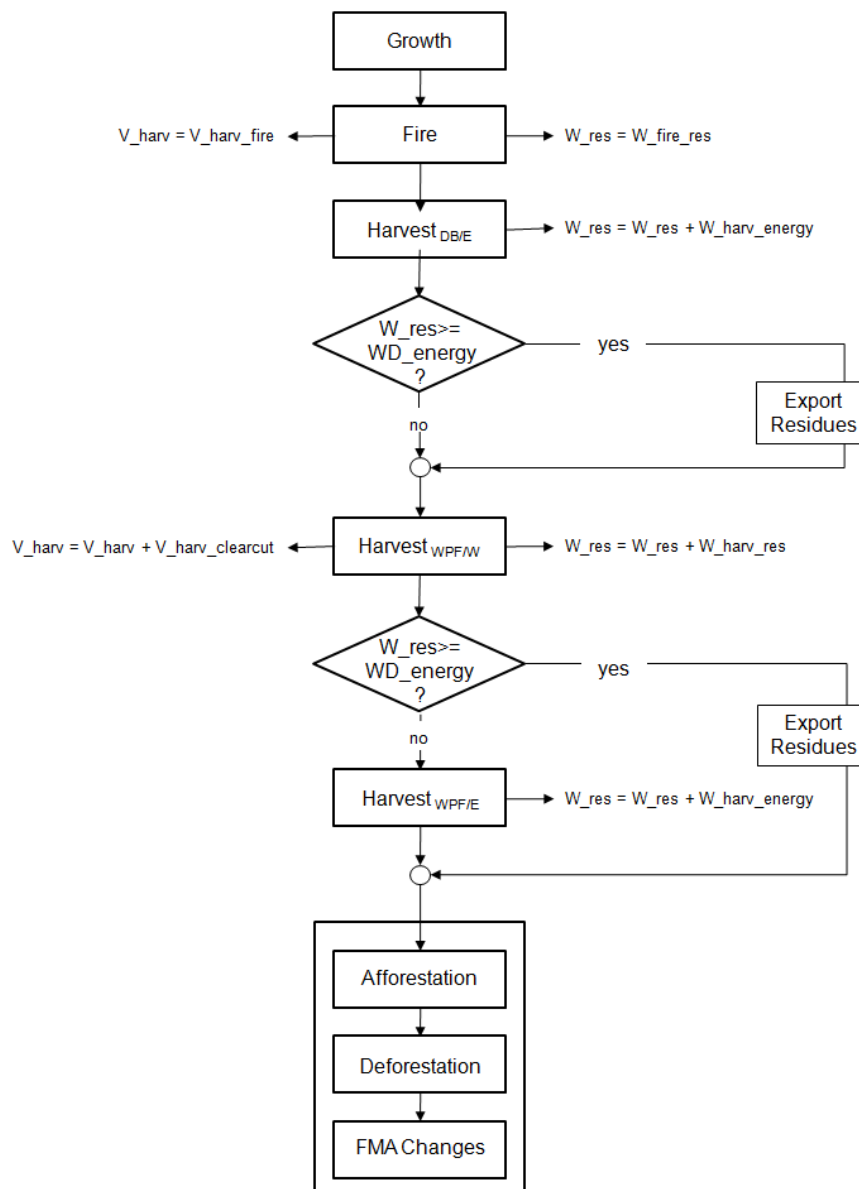
The next three modules in **Figure 2.1** are harvesting modules. The first one, harvest DB/E module, is completely new and is responsible for harvesting dendro-biomass stands. Its output consists of the second source of biomass for energy. This module is followed by the one responsible for harvesting stands for pulp production (harvest WPF/W module) producing two outputs: wood, which is added to the volume of salvage wood that resulted as an output from the fire module, and biomass of residues. This biomass output, also contributes to the first source of biomass. The last harvesting module is designated as harvest PF/E module and is responsible for harvesting pulp stands to be used for energy production.

Despite both demands have not been met, the next module to run is the land use module which integrates 2 sub-modules: the afforestation and the deforestation. The major differences in this module when compared to the previous version of the simulator refer to the double inputs concerning each



FMA. The afforestation sub-module has to plant two different kinds of stands: wood production stands (WPF) and short-rotation bio-energy production stands (DB). The deforestation module has not been changed.

Finally, the last module to run is the forest management alternatives (FMA), which defines the percentage of change between FMAs for each year of the scenario. Only harvested plots can be abandoned or converted to a different FMA. The percentage of change is defined in the scenario input file. **Figure 2.2** intends to give a more detailed view over the structural and functional changes in the drivers that have been made in the simulator as a consequence of including another FMA.



**Figure 2.2.** Schematic view of SIMPLOT's functioning.

It starts by calling in the growth module for all the stands at year  $j$  in order to update the forest resources to year  $j+1$ . After growth has been updated the fire module is called in and analyses all the





stands in order to decide if they burn. Each stand can either burn or not according to a  $P_{fire}$  probability. On one hand, if the stand burns it is assumed that the whole stand will be harvested. It is up to the user to define the conditions under which it is possible to use the harvested burnt wood. The user can define a minimum age to allow harvesting the burnt stand with industrial purposes ( $t_{minfire}$ ) as well as the quantity of burnt wood that will have an industrial use ( $\%UseFire$ ). The amount of wood to be used by industry ( $V_{di\_fire}$  Industry Used) is “stored” in a  $V_{harvest}$  variable. After the fire module runs the modules for each one of the pests will be called (not yet implemented). Once a stand is attacked the intensity of the attack will have to be taken into account. Different pests will have different consequences on growth and on the silvicultural operations that will follow. Therefore, if the attack comes from a borer sanitary thinning or clear cut will take place depending on the intensity of the attack. Similarly to what happens when a fire takes place, part of the wood deriving from an attacked stand can be used by the industry ( $V_{di\_pests}$  Industry Used), “stored” in the  $V_{harvest}$  variable.

Finally the harvesting module will be called in and according to a user defined probability ( $P_{harv}$ ) each stand can be harvested or not. If harvesting takes place the volume will be “stored” in the  $V_{harvest}$  variable.

After each stand is analysed in the harvest module,  $V_{harvest}$  will be compared to the wood demand and in case it is greater or equal the simulator is ready to move to the next year of simulation calling in the afforestation module, planting as many new stands as the total amount of afforestation defined by the user for that year. In case the volume harvested is greater than the wood demand (which is usually the case because the unit of simulation is a stand), the exceeding volume is stored to be used in the next year of simulation.

## **2.5 SIMPLOT – THE SIMULATION PARAMETERS**

Simulation runs depend on a series of parameters that can be modified by the user. The parameters include the first year of simulation and the number of years to simulate, information needed to run the different modules. Top-diameter ( $TopDiameter$ ) considered in the computation of merchantable wood and the percentage of death occurring between rotations ( $\%deathRot$ ) are simulation parameters of the growth module. The fire module simulation parameters are the minimum age that allows the industrial use of trees after a fire ( $t_{minFire}$ ) and the percentage of salvage wood used by the industry ( $\%UseFire$ ), while the parameter for the harvest module is the minimum age that allows a stand to be harvested ( $t_{minHarv}$ ). The percentages of non-industrial stands ( $\%HarvNI$ ) and uneven-aged stands ( $\%HarvUEA$ ) that can be harvested are also simulation parameters that can be user defined. The probability of an even-aged stand to be harvested ( $P_{harv}$ ) is defined as a function of age and stand type, while the probability of a stand to be abandoned ( $P_{aband}$ ) is function of stand productivity. The simulation parameters concerning the specifications of each FMA were also taken into account: starting densities, the rotation age and the number of rotations. The harvesting methodology has been considered as well as.

## **2.6 SIMPLOT – THE DRIVERS**

The simulator comprises 5 types of main drivers: i) the wood demand ii) the biomass demand which have implications on the amount of harvest per year; iii) the occurrence of hazards that takes into account the burnt area per forest type and per year and the area affected by each of the most important pests per year as well as the intensity of the attack; iv) the changes in management intensity expressed as the percentage of area changing from one forest management alternative (there are 5 FMAs: dendro-biomass, even-aged, combined objective, close to nature and nature conservation) to another and finally v) the land use changes (LUC) to and from other uses: the afforested area per year and the deforested area per year. The changes in the forest management alternatives module is not yet





implemented in the simulator and therefore will not be described in this report. The hazards module, as mentioned before, whereas it has been implemented for fire does not yet include pests.

The implementation of the drivers takes into account two main points: the total amount of each driver and the probability of occurrence of the event for each stand. The total amount of one driver for each year can be given as an area or a proportion of an existing area, whereas the probability of occurrence of the event is estimated according to a probability function (user defined or following some logistic function) and implemented with Monte-Carlo simulation. In case the event occurs the simulator takes a specific action depending on the event.

### 2.6.1 Hazards occurrence

The hazards occurrence is the first driver to be “called in”. This driver comprises different types of hazards such as fire, pests and diseases and storms. So far, only the fire algorithm has been implemented in the simulator. The model for prediction of probability and intensity of attack by *Phoracantha semipunctata* in eucalyptus stands is still under development as well as an algorithm to simulate its impact. The other pest that will be considered in eucalyptus is *Gonipterus scutellatus*.

At present the amount of area burned every year (A<sub>fire</sub>) has to be provided by the user in the scenario input file and the selection of stands that are burnt is based on Monte-Carlo simulation assuming an equal probability of being burnt for all the stands (P<sub>fire</sub>). Wildfire behaviour is influenced by weather, in the short and the long-term, as well as by topography and fuels. Therefore, forest conditions combined with extreme fire weather conditions can lead to high severity fires (USDA Forest Service, 2004). The fact that an equal probability of burning is assumed for every stand might seem unrealistic, but it has been shown that a very high percentage of the burnt area per year results from big fires of high intensity which occur concentrated in only a few days (Oliveira, 2008). When this type of fire occurs there are no characteristics related to the stand (slope, age, vertical structure, species, management, etc) or the landscape (species mixture, proximity to populated areas) that can be said to regulate the fire, therefore in reality the burnt area is almost randomly set. An alternative to assuming an equal value of P<sub>fire</sub> for all the stands is to use a logistic function that predicts fire ignition probability using the distance of the stand to the nearer different land uses as well as the azimuth as predictors (Vasconcelos et al., 2001)

The simulator starts with a burnt area equal to zero and selects the stands that are burned by Monte-Carlo simulation. The burnt area is summed up to the so far existing one and the fire algorithm will run until the burnt area meets the total amount of burnt area defined in the scenario.

After a fire it is assumed that the stand is harvested and that part of its wood can be industrially used contributing to meet the wood demand, while the other part will be used as residues contributing to meet the biomass demand. At the same time as it decides which stands are burnt (Monte Carlo simulation), it separates the volume of salvage wood to be used for pulp from the biomass of residues for bio-energy production. Two types of biomass are taken into account: the biomass of residues resulting from harvesting a certain proportion of burnt wood for industrial use and the total biomass in the stands with no industrial use. Thus, before the harvest DB/E module starts running, the harvested biomass is already greater than zero.

Therefore, apart from the total amount of the driver there are other user defined driver options taken into account. One is the minimum age that allows the industrial use of trees after a fire (t<sub>minFire</sub>) while the other is the percentage of these stands which is actually used by the industry (%UseFire).

### 2.6.2 Biomass demand

The harvest DB/E module operates in a very simple way harvesting all stands planted for energy production that have reached the rotation length (rot<sub>length</sub>) defined as a simulation parameter for this management alternative. After a stand has reached the number of rotations defined by the used (rot<sub>max</sub>) it can be either abandoned or replanted and, in this case, it may continue as the same FMA



or change to WPF. The aboveground biomass resulting from this harvest operation is summed up to the burnt biomass previously harvested and the sum is compared with the biomass demand. In case the biomass demand has been met the exceeding residues are considered to be exported, if not the harvested biomass variable will continue being increased by biomass outputs from the subsequent modules.

### 2.6.3 Wood demand

The following module to run is the harvest WPF/W module. As the unit of harvesting is the stand, with a fixed area, the volume harvested at the end of each year of simulation is usually slightly higher than the wood demand. The difference is kept for the following year as a stock (Vstock). Before the wood demand driver is “called” the harvested volume is already greater than the Vstock because there is a percentage of the burnt stands (%UseFire) that will be used by the industry. Similarly to what has been described for the fire driver it is up to the user to define the total amount of volume harvested in each year of the simulation (Vharvest) in the scenario input file. Just like for hazards, there is also a user defined age threshold that keeps non-burnt stands under a certain age to be harvested (tminHarv) regardless of fire occurrence. It is also the user’s responsibility/choice to define the percentage of harvest in non-industrial stands (%HarvNI). The harvesting algorithm gives an increasing harvesting priority to older stands up to the user defined age limit (tminHarv), a harvesting probability to non-industrial stands (%HarvNI) and keep on harvesting until wood demand is met (Vharvest). A random number is drawn for each stand and compares it to the harvesting probability (P\_harv) which is pre-defined by the user according to the age class.

In terms of biomass residues, the biomass resulting from the shoots selection operation in coppice stands has been accounted for in the present version. [Alves G.R. \(1996\)](#) has determined that the amount of dry biomass removed compared to the total standing dry biomass has an average value of 53.24%. This percentage was used to account for this pool of biomass. The module runs until the wood demand is met and as it runs, biomass residues are produced. Another improvement consists in allowing for the removal of biomass residues resulting from the clear cut in case the biomass demand for energy has not been met so far. Otherwise, it is assumed to be left on the site to compensate for the nutrient removal resulting from harvesting. This biomass output, together with the biomass resulting from burnt stands, contributes to the second source of biomass.

At this point, the total harvested biomass is compared to the biomass demand and in case it has not reached the amount defined in the scenario there is the possibility to turn to another harvesting module. Existing WPF stands are the last option to gather more biomass. The simulator will only run this module in case the biomass demand has not been met but the wood demand has. The reason for this lays in the fact that if there is no need for more biomass for energy, then there is no point in harvesting, for energy, stands planted for pulp. Moreover, if the wood demand has not been met then there will not be stands to be harvested for energy production either.

In case the harvest WPF/E module runs, it selects the stands to be harvested with Monte Carlo simulation based on the methodologies used in the previous module. In fact the only difference between this module and the previous one is that the first produces a harvested volume as its main output and this one will only produce aboveground biomass that makes of the third source of biomass. After running the modules that allow meeting both demands, the modules responsible for land use have to run: afforestation, deforestation and change between forest management alternatives.

### 2.6.4 Land use changes

The land use changes module includes an algorithm for the new areas planted where land use used to be other than forest. These areas represent the afforestation per year. The other algorithm part of this



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driver is the one for the abandoned areas per year. The simulator assumes that part of the forest area is abandoned and converted to other land uses, which corresponds to deforestation.

The first step in the afforestation sub-module is to determine the number of stands that correspond to the total amount of new planted areas for energy production (DB) and of new planted areas for wood production (WPF) for each year of simulation defined in the scenario file (APlantE and APlantW, respectively).

Afterwards, a random number is drawn for each of the new stands in order to set them with a climatic region (Ribeiro and Tomé, 2001) which will be used to estimate each stand site index according to the observed distribution of site indices for the species in that particular climatic region.

However, before these stands are ready to be simulated the forest management alternative has to be defined, through Monte Carlo simulation according to the areas to be planted and managed as WPF and DB.

The first step in the afforestation algorithm is to determine the number of stands that correspond to the total amount of new planted area per year of simulation (APlant) that is defined by the user in the scenario file.

In the deforestation algorithm the main input information is the total amount of forest land with each species being converted to a different land use (%LandChange) given as a proportion of the respective area. Thus, the first step is to determine the abandoned area in hectares as well as the number of stands that correspond to that same area. The next step is drawing a random number for each harvested stand and considering that each stand has 50% chance of being abandoned. This is not realistic, because it is more likely that stands located in less productive areas will be abandoned than stands located in highly productive ones. Thus this is a subroutine to be improved.

### **2.6.5 FMA changes**

The last module to run is the FMA changes. Only stands that have been harvested and which have not been abandoned can be considered to have their management altered. The main input information in the FMAs algorithm is the percentage of transition from one management alternative to another. Thus, the next step is to determine the area in hectares and the corresponding number of stands that are converted from WPF to DB and from DB to WPF for each year of simulation. Monte Carlo simulation is used to decide which stands are converted to a different management alternative.

## **2.7 SIMPLOT – THE FOREST MODELS FOR EUCALYPTUS**

SIMPLOT uses two growth models to simulate the WPF: the GLOBULUS 3.0 model for even-aged stands and the GYMMAnlin models for uneven-aged stands. Unlike what has happened for other species in other countries, the increasing demand for renewable energy sources, has not yet led to the study of *E. globulus* as a potential species for energy production in Portugal. Stands planted with this purpose would be expected to have extremely high densities as for other species used with energy production purposes. Common densities found in literature vary per region and per species: 20400 trees per hectare for willow (Noronha-Sannervik and Kowalik 2003); densities ranging from 8000 trees per hectare (Manzone et al 2009) up to densities of 18000 (Labrecque and Teodorescu 2005) in poplar studies; a density of 20000 trees per hectare was also found in a recent study of *Eucalyptus nitens* in Galicia (AFG 2007). In the absence of eucalyptus energy study trials and of a growth model specifically developed for extremely high stockings, a possible way to simulate growth in these stands is to use the existing model. Therefore, the GLOBULUS model was used to simulate growth and production of spacing trials with densities ranging from 4000 up to 10000 trees per hectare. Its performance to simulate growth of stands with high stockings was evaluated and corrected.



### **Globulus 3.0 - eucalyptus whole stand model**

The Globulus 3.0 model is a stand level growth and yield model developed for pure even-aged stands. It gathers all the available information on eucalyptus growth and yield in Portugal and represents the combined efforts between industry and universities, which have been involved in several co-operative research projects over the past decades.

Globulus 3.0 previous version – Globulus 2.1 - was parameterized for 8 different climate regions (Ribeiro and Tomé, 2000). A set of 7 dummy variables was defined in order to assess the need to parameterize each model component for the different regions which allowed obtaining different growth curve shapes for different soil and climatic conditions. Descriptions of the previous versions of the model can be found in Tomé et al. 1998, Tomé 1999, Tomé et al. 2001a and Tomé et al. 2001b.

Most of the components of the Globulus 3.0 model were already available in the previous version, but some of them were improved and some of the parameters of the model are now expressed as a function of climatic variables: the number of days with rain, the altitude, the total precipitation, the number of days with frost and the temperature. New components were developed for stand parameters before the thinning of the shoots takes place. The new version allows simulating the transition between rotations by simulating growth for coppice stands before the thinning of the shoots usually occurring during the 3<sup>rd</sup> year after the final harvest. Therefore, the following equations were developed for the first time and introduced into the model:

- a growth function for the number of stools per year
- a prediction function for the number of sprouts before the thinning of the shoots
- a prediction function for the number of sprouts by the age of three years after an operational thinning of the shoots

Another improvement is related to the biomass functions, which were rather incipient in Globulus 2.1. Thus, new biomass functions for total and per plant components were also developed.

The development of the Globulus 3.0 model was based on a large amount of information deriving from various sources: permanent plots, experimental trials and continuous forest inventory plots from the pulp and paper companies was compiled and exhaustively analyzed to build up a database (Soares et al., 2006). The amount of data stored is impressive but the coverage of the data on the control variables still has some weaknesses:

- Even though the number of planted and coppiced stands is pretty close they are not equally distributed all over the country. Coppice stands are mainly located by the Tagus River basin, while the planted stands are spread out over Portugal.
- A small number of stands is found in extreme density classes (below 600 ha<sup>-1</sup> and above 1800 ha<sup>-1</sup>). For density classes between these thresholds the number of planted stands decreases with stand density, while the inverse relation is observed for coppice.
- About 45% of the stands are found in the Site Index (SI) class that goes from 18 up to 22, around 25% fall in the SI class of 14 to 18 while nearly 20% of the stands have a SI class from 22 to 26. The remaining 10% are more or less equally distributed between the classes from 10 to 14 and from 22 to 26.
- The great majority of stands have 8 to 10 years of age. There are barely any stands over 14 and the remaining ones are distributed in the age classes below 6 and between 10 to 14 with the singularity that the proportion of coppices in the younger age class is higher than the one of planted stands, while the opposite is observed for the class of 10 to 14.

Globulus 3.0 includes two types of variables – state variables and control variables – and three main modules – initialization, projection and prediction.



The variables that define the state of the stand over time (state variables) can be divided into principal variables in case they are directly predicted from a growth function or derived variables when their values are predicted from allometric or other equations that relate them to the principal variables and other previously derived variables. On the other hand, the control or external variables control the development of the state variables and can be of three different sub-types: environmental, cultural or intrinsic to the stand. Table 1 lists all variables currently included in the model.

The overall structure of the Globulus 3.0 model is shown in Figure 2.3.

The model includes state variables and control variables. Table 2.1 lists all variables currently included in the model. Globulus 3.0 is composed of three main modules: the initialization module, the projection module and the prediction module.

The initialization module predicts each stand variable as a function of the control variables that characterize the stand.

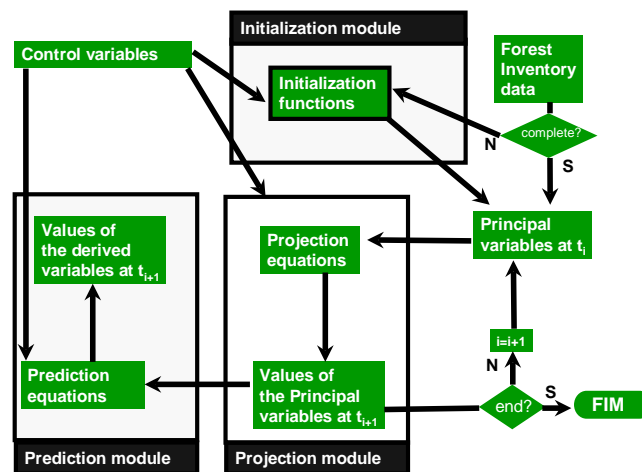


Figure 2.3. Structure of Globulus 3.0 model.

The projection module consists of a system of compatible growth functions for each principal variable as a function of its starting value, control variables and other principal or derived variables. All the sub-models are growth functions formulated as first order non-linear difference equations. On the prediction module, derived variables are predicted as a function of principal variables as well as of control variables.

The initialization module is essential because it allows initializing a new stand either by planting or coppice.

The equations included in the Globulus 3.0 model are shown in tables of **annex I**, as well as the list of symbols used in the equations.





Table 2.1. Variables currently included in the model Globulus 3.0

<b>State variables</b>	<b>Control variables</b>
<p><u>Principal variables</u></p> <ul style="list-style-type: none"> <li>Dominant height</li> <li>Stand basal area</li> <li>Number of trees per ha</li> <li>Total volume without bark</li> <li>Stump volume</li> <li>Bark volume</li> </ul> <p><u>Derived variables</u></p> <ul style="list-style-type: none"> <li>Number of sprouts per ha before the shoots selection</li> <li>Number of sprouts per ha after the shoots selection</li> <li>Merchantable volume</li> <li>Aboveground biomass and biomass per tree component and respective C and nutrients</li> <li>Roots biomass and respective C and nutrients</li> <li>Total biomass and respective C and nutrients</li> </ul>	<p><u>Environmental</u></p> <ul style="list-style-type: none"> <li>Number of days with rain in a year</li> <li>Altitude</li> <li>Number of days with frost in a year</li> <li>Total precipitation</li> <li>Temperature</li> <li>Site Index (base age =10)</li> </ul> <p><u>Cultural</u></p> <ul style="list-style-type: none"> <li>Initial stand density (planted stands)</li> <li>Number of sprouts per ha after shoots selection (coppice)</li> <li>Rotation age</li> </ul> <p><u>Stand</u></p> <ul style="list-style-type: none"> <li>Rotation</li> <li>Age</li> <li>% of stools that die in the transition between rotations</li> </ul>

**The GYMMAnlin model**

Existing growth and yield models were developed for even-aged stands in which the planting date is known. However, when plantation date is unknown like often happens in Portuguese eucalyptus stands and only an estimate of age class can be provided age dependent growth and yield models became useless. The three-parameter growth functions used in the Globulus model as difference equations - with two common parameters and a free parameter - were formulated as three parameter difference equations for annual periods, which are independent of stand age (Barreiro et al., 2004), the GYMMAnlin model - Growth and Yield Model Missing Age – Non Linear Regression. As the GLOBULUS model it includes a projection and an initialization module that include the same variables as the GLOBULUS model. In the projection module the growth functions are formulated as age-independent growth functions (Tomé et al., 2006) with some of the parameters expressed as a function of climatic variables. The GYMMAnlin equations can be found in **Annex II. Figure 2.4** show an overview of the model structure.

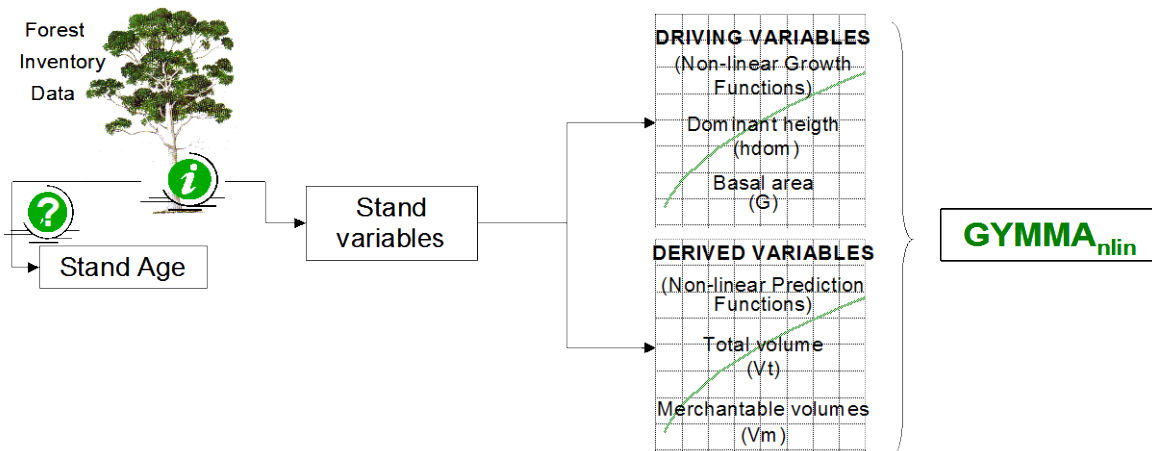


Figure 2.4. Structure of GYMMAnlin model.

### The adapted Globulus model

In the absence of eucalyptus energy study trials and of a growth model specifically developed for extremely high stockings, a possible way to simulate growth in these stands is to use the existing model. Therefore, the GLOBULUS model was used to simulate growth and production of spacing trials with densities ranging from 4000 up to 10000 trees per hectare. Its performance to simulate growth of stands with high stockings was evaluated.

In the 90s several spacing trials were installed in Portugal either by pulp companies, by Universities or by the joint effort of them both (Soares and Tomé 2000). The data set used to evaluate the estimates of the GLOBULUS model for high density plantations was selected from the trials that included spacings with more than 4000 trees per hectare at planting. The data from these trials was gathered in a database and harmonized to become the input for the GLOBULUS model that was used to simulate the evolution of each plot within each trial. The residuals for each stand variable were calculated as the difference between the observed values and the correspondent simulated values. Using the simulation output runs with stand variables' estimates, residues were calculated.

Residuals were plotted against stand variables expressed as classes in order to detect possible relationships, namely with stand density. This analysis was carried out both for the initialization and projection modules of the GLOBULUS model (Soares et al 2006).

The residuals were modelled as a function of stand variables with the objective to develop a correction that could be applied when using the GLOBULUS model to simulate energy plantations. Stand variables such as age and dominant height, as well, as their interactions with stand density were tested as possible regressors. The models were developed using the stepwise regression (Reg procedure, SAS Institute 1993).

The stand variables estimated were then obtained as:

$$Y^{\wedge}_{corr} = Y^{\wedge} + \text{modeled residue}$$

Where  $Y^{\wedge}_{corr}$  represents the corrected estimate and  $Y^{\wedge}$  the estimate obtained with GLOBULUS model. The residuals obtained with the corrected estimates were calculated and its mean values and confidence interval plotted by each of the previously used classes of stand variables in order to access how effective the proposed corrections were. In the selection of the models to predict the residuals as a function of stand variables, the models with clear evidence of multicollinearity among the regressors, evaluated by the variance inflation factors (Myers 1986), were discarded. The overall performance of the models was assessed with modeling efficiency or the proportion of variation explained by the model which should be close to 1 (Soares et al 1995). The variance inflation factor, used to quantify



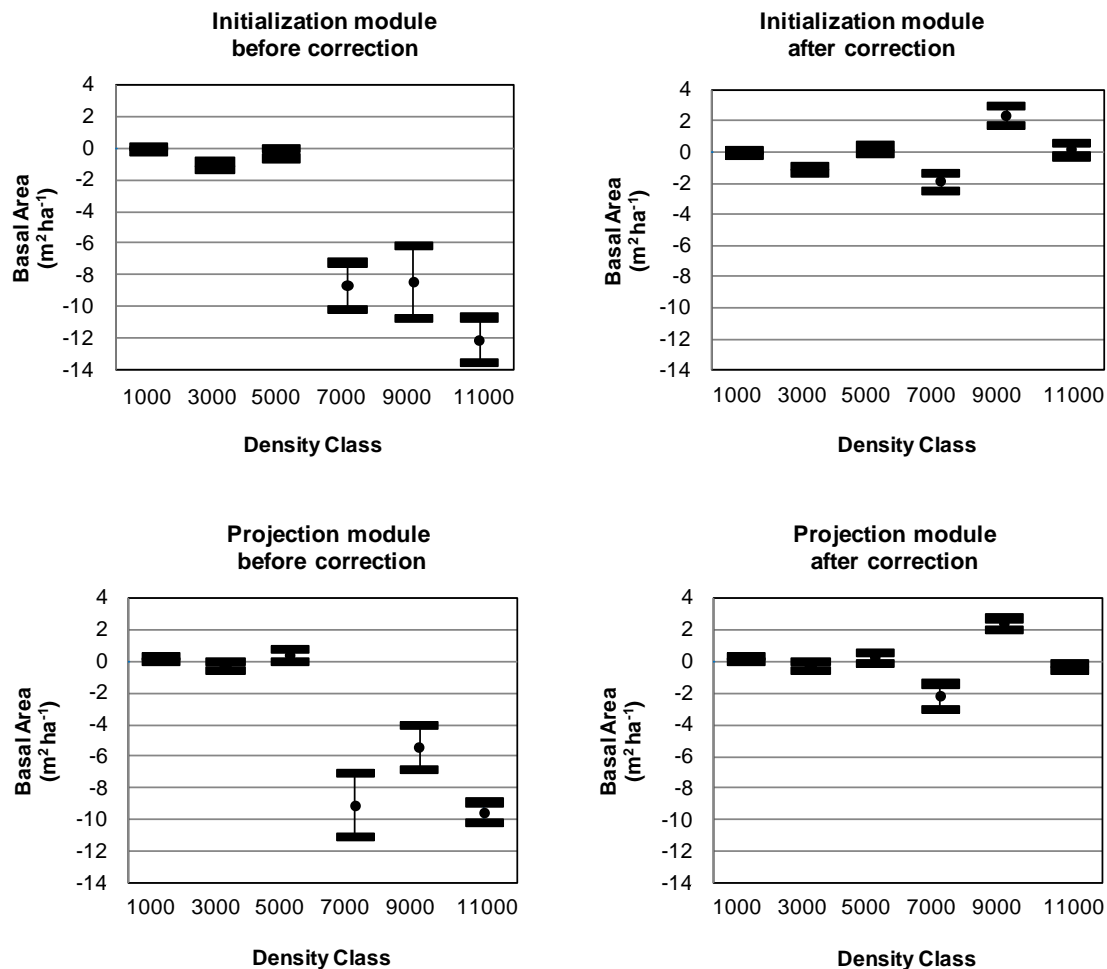
the severity of multicollinearity in a regression analysis was also determined. It provides an index that measures how much the variance of an estimated regression coefficient is increased because of collinearity (Myers 1986).

The residues were modelled as a function of stand variables in order to allow the use of GLOBULUS for short-rotation stands. The aboveground biomass ( $W_a$ ) in the model results from the sum of the biomass of the components ( $W_i$ ): wood ( $W_w$ ), branches ( $W_{br}$ ), bark ( $W_b$ ) and leaves ( $W_l$ ). The biomass of the components is a function of basal area and dominant height. If the residues of these variables are modelled, more accurate basal area and dominant height estimates can be produced resulting in better aboveground biomass estimates. Therefore, only residues from dominant height, basal area and stand density were considered in this modelling exercise.

The mean value and the standard error were calculated and the confidence intervals were plotted by class for dominant height, basal area and density. The set of graphics by density class showed a clear need for corrective measures for the higher density classes (number of trees per hectare greater than 4000) in terms of basal area and number of trees per hectare estimates, while for the other classes considered - site quality, age and initial age of simulation - the need for a correction was not so evident. Out of all the stand variables and products of different stand variables considered when fitting the models to predict residuals, the most significant were stand age ( $t$ ), site index ( $S$ ), the product of age by stand density ( $tN$ ) and the product of site index by stand density ( $SN$ ). Table 3 shows the linear models developed as corrective measures to be applied to the estimates of the GLOBULUS model (initialization and projection modules) for high density plantations. The modelling efficiency (Mod eff.) and the maximum variance inflation factor (MaxVif) of the models can also be found in **Annex III**. As can be seen, there is no important correlation of residuals with stand variables in dominant height prediction, but the correlation of residuals from the basal area and the stand density models are quite relevant.

Corrections were applied to stand densities greater than 4000 trees per hectare. This threshold was defined based on the fact that above these densities stands were too dense for pulp production. Figure 3 shows the confidence intervals by density class for basal area before and after correction for initialization and projection modules. As can be seen the model is slightly biased for very high densities. Before the correction was applied, the three more dense classes had mean errors ranging from 8 to 12  $m^2ha^{-1}$  and from 5 to 10  $m^2ha^{-1}$  for initialization and projection, respectively. The plots on the right hand side of Figure 3 show that basal area estimates considerably improved after the correction was applied.





**Figure 2.5.** Basal area estimates before and after corrections were made for the initialization and projection modules.

A similar situation was found for the number of trees per hectare whose residuals were higher as denser the class was, but for which the correction was able to reduce the error estimates in 300 trees per hectare for the density class of 11000.

In terms of dominant height the models were only capable of explaining 7% of the variance in estimates and for this reason it was decided not to correct dominant height estimates.

For the other three classes the need for correction was not as clear as for the density class.

## 2.8 SIMPLOT - THE INPUT FILES

There are different types of input files:

- Base year plot input file - Input file characterizing the forest resources for the first year of simulation.
- Scenario input file - Input file describing the scenario to be simulated.
- FMA input file - Input file describing the different forest management alternatives



- Costs input file - Input file listing costs
- Simulation parameters input file – Input file generated based on the simulation parameters defined by the user.

The base year plot input file contains the list of forest inventory plots to be simulated. The file structure has to have descriptive information on each plot as well as the stand variable information listed on **Table 2.4** (principal variables).

Table 2.4. List of stand variables needed as input for the simulator.

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<u>Stand variable information</u>	
hdom	dominant height (m)
Nst	Number of trees ( $\text{ha}^{-1}$ ) in planted stands and number of stools in coppice stands
N	Number of sprouts in coppice stands (Nst=N in planted stands)
G	Stand basal area ( $\text{m}^2$ )
Vu	Stand volume under-bark with stump ( $\text{m}^3 \text{ha}^{-1}$ )
Vb	Stand volume of bark ( $\text{m}^3 \text{ha}^{-1}$ )
Vs	Stand volume of stump ( $\text{m}^3 \text{ha}^{-1}$ )

---

If not available from the forest inventory, all these variables can be predicted in the initialization module based on the site index and forest management alternative specifications. If site index is not available it can be simulated on the basis of the site index distribution of the NUTIII in which the stand is located.

The scenario input files define the scenario by describing the values of the drivers. There is one scenario input file per species. The file has the structure shown in **Table 2.6**. The default values of the simulation parameters are shown in Table 2.5.



Table 2.5. Structure of the simulation parameters input file for the SIMPLOT simulator.

Initial year :	1997
Nr of years to project:	15
tminHarv:	8
tminFire:	5
%UseFire:	60
%HarvNI:	10
TopDiameter:	5
%deathRot:	20
Stand density_wood	997
Stand density_energy	5000
Rotation length_wood	12
Rotation length_energy	5
Number_rotations_wood	3
Number_rotations_energy	5

Table 2.6. Structure of the scenario input files for the SIMPLOT

'Ano'	V_harvplan (103 m3)'	Wa_harvplan (Mg ha-1)	'Aardida (ha)'	A_plant Wood(ha)'	A_plant Energy	'Aband (%)'	shift_WE	shift_EW
1998	4096	6000000	4817	4800	960	0.0012	0	0
1999	4523	6005000	2353	4800	960	0.0012	0	0
2000	4632	6010250	7326	4800	960	0.0012	0	0
2001	4907	6015763	4836	4800	960	0.0012	0	0
2002	5368	6021551	6954	4800	960	0.0012	0	0
2003	6038	427628	30526	4800	960	0.0012	0	0
2004	6038	434010	5988	4800	960	0.0012	0	0
2005	6136	440710	13312	4800	960	0.0012	0	0
2006	6151	447746	3897	4800	960	0.0012	0	0
2007	6120	155133	248	4800	960	0.0012	0	0
2008	6061	162889	6036	4800	960	0.0012	0	0
2009	6101	171034	6837	4800	960	0.0012	0	0
2010	6151	179586	2109	4800	960	0.0012	0	0
2011	6102	188565	1559	4800	960	0.0012	0	0
2012	6189	197993	8637	4800	960	0.0012	0	0
2013	6283	207893	31991	4800	960	0.0012	0	0

## 2.9 SIMPLOT - THE OUTPUT FILES

The simulator has 3 types of outputs: output per plot and year (output\_plot.prn), output of area distribution per age class and year (output\_clt.prn) and output of different areas and stand variables per year for each species and stand type (output\_year.prn). In SIMPLOT a stand type is originated by a FMA.



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The main output is given in the file `output_year` that encloses information regarding what has happened for each year of simulation. It allows to compare the volume of wood that is planned to be harvested in each year (total amount of wood demand) with the total volume that was available to be harvested in that year under the user defined restrictions (the actual harvested volume). It shows the total standing volume in the beginning of each year of simulation with the existing standing volume after all drivers have been called in and the total volume harvested due to fire occurrence. The equivalent information regarding biomass can also be found in this output file. It also holds the information on areas, such as existing forest area before the drivers have been called in, total forest area after calling in the drivers, the area that corresponds to the actual harvested volume and the area that was burnt per year.

On its turn, the `output_clt` file includes the area distribution per age class contains the existing forest area per year allocated to one year age classes. This output is an area transition matrix that illustrates the evolution of forest area between different age classes along the simulation period.

On the other hand, the `output_plot` file allows tracking the history of a given stand throughout the simulation period by analyzing the values of several stand variables.

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**Annex I – Globulus 3.0 Equations**

Table I.1. Site Index and dominant height projection functions.

<b>Models</b>			
$(1) SI = A \left( \frac{hdom}{A} \right)^{\left( \frac{t}{t_p} \right)^n} \quad (2) hdom_2 = A \left( \frac{hdom_1}{A} \right)^{\left( \frac{t_1}{t_2} \right)^n} \quad A = a_0 + a_1 DR$			
<b>model</b>	<b>a<sub>0</sub></b>	<b>a<sub>1</sub></b>	<b>n</b>
(1) and (2)	29.0669	0.2880	0.4890

Table I.2. Basal area: initialization function (1) and growth projection function (2).

<b>Models</b>										
$(1) G = A_G e^{-k_G \left( \frac{1}{i} \right)^{\left( n_{Gp} + n_{GN} \right)}} \quad (2) G_2 = A_G \left( \frac{G_1}{A_G} \right)^{\left( \frac{t_1^{n_{GN1}}}{t_2^{n_{GN2}}} \right)^{\left( \frac{t_1}{t_2} \right)^{n_{Gp}}}}$										
$A_G = (a_{G0} + a_{G1} DR) \quad K_G = k_{G0} + k_{G1} SI + k_{G2} \frac{100}{SI \sqrt{Npl}} + k_{G3} rot$										
$n_{Gp} = n_{G0} + \frac{n_{G1}}{\left( 1 - \left( \frac{\cot a}{2000} \right) \right)} + n_{G2} rot \quad n_{GNi} = n_{G3} \frac{N_i}{1000}$										
<b>model</b>	<b>a<sub>G0</sub></b>	<b>a<sub>G1</sub></b>	<b>k<sub>G0</sub></b>	<b>k<sub>G1</sub></b>	<b>k<sub>G2</sub></b>	<b>k<sub>G3</sub></b>	<b>n<sub>G0</sub></b>	<b>n<sub>G1</sub></b>	<b>n<sub>G2</sub></b>	<b>n<sub>G3</sub></b>
(1)	80.168 3	0.2354	8.8294	- 0.1876	3.3759	0.1180	0.4493	- 0.0441	-0.0164	0.065 5
(2)	80.168 3	0.2354	-	-	-	-	0.4493	- 0.0441	-0.0164	0.065 5



Table I.3. Planted stand’s density of trees initialization function (1), planted stand’s density of trees growth projection function as well as for coppices older than 3 years (2), coppice stand’s density of living stools prediction function (3), Coppice stand’s density of sprouts for stands under 3 years of age (4) and Coppice stand’s density of sprouts for stands at 3 years of age (5).

<b>Models</b>								
<p>(1) <math>N = N_{pl} e^{-am t}</math>      (2) <math>N_2 = N_1 e^{-am (t_2 - t_1)}</math></p> <p>(3) <math>N_{stools} = N_{trees \text{ at harvest}} e^{-am (t_2 - t_1)}</math>      <math>am = am_0 + am_1 rot + am_2 \frac{N_{pl}}{1000} + am_3 \frac{1}{SI}</math></p> <p>(4) <math>N_{sprouts \ t \leq 2} = b_0 N_{stools} + b_1 t</math></p> <p>(5) <math>N_{sprouts \ t=3} = N_{stools} \left( \frac{1}{1 - e^{-\left( am_2 \frac{N_{stools}}{1000} + am_3 \frac{1}{SI} \right)}}</math></p>								
model	am <sub>0</sub>	am <sub>1</sub>	am <sub>2</sub>	am <sub>3</sub>	b <sub>0</sub>	b <sub>1</sub>	b <sub>2</sub>	b <sub>3</sub>
(1)	0.0104	-0.0025	0.0023	-	-	-	-	-
(2)	0.0104	-0.0025	0.0023	-	-	-	-	-
(3)	0.0147	-0.0025	-	-	-	-	-	-
(4)	-	-	-	-	4.26831	285.96252	-	-
(5)	-	-	0.4050	13.6400	-	-	-	-

If there is any kind of thinning rule model 5 won't be needed.



Table I.4. Volume initialization function (1) and Volume projection function (2),

<b>Models</b>							
$(1) V_i = K v \ t^a \ hdom^b \ G^c \quad kv = kv_0 + kv_1 rot + \left( \frac{kv_2}{1 - \left( \frac{\cot a}{2000} \right)} \right) + kv_3 \frac{100}{SI \sqrt{N_0}}$							
$(2) V_{i2} = V_{i1} \left( \frac{t_2}{t_1} \right)^a \left( \frac{hdom_2}{hdom_1} \right)^b \left( \frac{G_2}{G_1} \right)^c$							
model	a	b	c	kv0	kv1	kv2	kv3
(1) Vu	-0.0510	0.9982	1.0151	0.3504	0.0011	0.0049	0.0908
(2) Vu	-0.0511	0.9982	1.0151	-	-	-	-
(1) Vb	-0.0548	0.7142	1.0513	0.1502	-	0.0014	0.1336
(2) Vb	-0.0548	0.7142	1.0513	-	-	-	-
(1) Vst	-0.0821	0.3440	0.9914	0.0567	-0.0002	-	0.0104
(2) Vst	-0.0821	0.3440	0.9914	-	-	-	-
Where N0 represents Npl for planted stands and N sprouts by age of 3 years for coppice stands							

Table I.5. Mercantile volume above stump without bark up to a predefined top diameter prediction function.

<b>Model</b>							
$V_{umdi} = (V_u - V_{st}) e^{a \left( \frac{di}{dgdom} \right)^b}$							
$a = a_0 + a_1 rot + a_2 \left( \frac{Npl}{1000} \right) + a_3 \left( \frac{100}{SI \sqrt{N_0}} \right) + \left( \frac{a_4}{1 - \left( \frac{\cot a}{2000} \right)} \right) \quad b = b_0 + b_1 rot$							
model	a <sub>0</sub>	a <sub>1</sub>	a <sub>2</sub>	a <sub>3</sub>	a <sub>4</sub>	b <sub>0</sub>	b <sub>1</sub>
V umdi	-1.1075	-0.3436	0.0741	1.2604	0.2660	3.1854	0.5513
Where N0 represents Npl for planted stands and N sprouts by age of 3 years for coppice stands							





Table I.6. Biomass functions.

<b>Models</b>							
$W_i = a G^b \text{hdom}^c \quad b = b_0 + b_1 \text{rot} + b_2 \left( \frac{N}{1000} \right) + b_3 \left( \frac{SI}{1000} \right) + b_4 \left( \frac{t}{1000} \right)$							
$W_a = W_w + W_b + W_l + W_{br} \quad W_r = a W_a \quad W_t = W_a + W_r$							
<b>model</b>	<b>a</b>	<b>b<sub>0</sub></b>	<b>b<sub>1</sub></b>	<b>b<sub>2</sub></b>	<b>b<sub>3</sub></b>	<b>b<sub>4</sub></b>	<b>c</b>
$W_w$	0.0967	1.0547	-0.0018	-0.0065	-0.5198	-1.2105	1.1886
$W_b$	0.03636	1.1691	-0.0083	-0.0459	3.2289	2.0880	0.6710
$W_l$	1.0440	1.0971	-	-0.0112	-1.2207	-6.2807	-0.3129
$W_{br}$	0.3972	1.0005	-	-0.0192	3.3170	-1.2747	-0.0160
$W_r$	0.2487	-	-	-	-	-	-



**Annex II – GYMMAnlin Equations**

**Table II.1.** GYMMAnlin model non-linear growth function for dominant height and basal area.

<b>Models</b>					
$Y_2 = A e^{\frac{-k}{\left(\left(\frac{-k}{\ln(Y_1/A)}\right)^{\frac{1}{n}+1}\right)^n}}$		$A_G = a_0 \text{ hdom}_1$ $k_{\text{hdom}} = k_0 + k_1 G_1 + k_2 \text{ hdom}_1$ $k_G = k_0 + k_1 \text{ hdom}_1 + k_2 \frac{N_{1(d>5)}}{1000}$			
<b>model</b>	<b>a0</b>	<b>k0</b>	<b>k1</b>	<b>k2</b>	<b>n</b>
hdom	84.2463	3.0839	-0.1142	0.1202	0.4057
G	63.9939	9.8573	0.4420	-2.2890	0.4141

**Table II.2.** GYMMAnlin model non-linear functions for total volume.

<b>Models</b>				
(1) $V = a_0 \text{ hdom}^{b_0} G^{c_0}$		(2) $V = (a_0 + a_1 \text{ coppice}) \text{ hdom}^{b_0} G^{c_0}$		
<b>Models</b>	<b>a0</b>	<b>a1</b>	<b>b0</b>	<b>c0</b>
(1) V	0.5207	0	0.9933	0.9285
(1) Vu	0.3625	0	0.9885	0.9879
(2) V_st	0.4602	0.00120	0.9796	0.9750
(2) Vu_st	0.3202	0.00231	0.9756	1.0343

**Table II.3.** GYMMAnlin model non-linear functions for merchantable volume.

<b>Models</b>		
(1) $V_{di} = V_{st_i} e^{\left(a_0 \left(\frac{d_i}{dg_i}\right)^{b_0}\right)}$		(2) $Vu_{di} = Vu_{st_i} e^{\left(a_0 \left(\frac{d_i}{dg_i}\right)^{b_0}\right)}$
<b>Models</b>	<b>a0</b>	<b>b0</b>
(1) V_di	-1.0033	3.8608
(2) Vu_di	-1.0173	3.8929

**Table II.4.** GYMMAnlin model functions for stand density.

<b>Models</b>			
(1) $N_2 = N_1 e^{a_0 (t_2 - t_1)}$		(2) $N_{2(d>5)} = a_0 + b_0 N_1 + c_0 G_2$	
<b>Models</b>	<b>a0</b>	<b>b0</b>	<b>c0</b>
(1) N	-0.00988	0	0
(2) N <sub>(d&gt;5)</sub>	-10.52037	0.85492	6.00689



**Annex III – Globulus correction equations to be used when simulation high density stands**

Table III.1. Parameter estimates and fitting statistics for the models developed to correct GLOBULUS estimates for high density plantations.

Stand variable	Module	Parameter estimates					Model performance	
		Intercept	t	S	tN	SN	Mod eff.	Maxvif
Dominant height	Projection	-0.3026	-0.0465	0.0314	-	-0.0037	4.86	1.0331
Basal Area	Initialization	0.43734	0.8034	0.1705	-0.4369	-	86.55	5.1043
	Projection	0.3685	1.5849		-0.5918	0.05270	81.39	5.5831
Stand Density	Projection	178.9250	-	-19.7864	-	3.1212	78.09	1.0166

**Annex IV - List of symbols used in the equations**

**DR** – weight average of the central values of the classes of the number of days with precipitation  $\geq 0.1$  mm found in each square of the grid (cm);

**SI** – Site Index, which is the stand's dominant height at the age of 10 years (m);

**t** – Stand age (years);

**t<sub>1</sub>** – Stand age at instant 1 (years);

**t<sub>2</sub>** – Stand age at instant 2 (years);

**t<sub>p</sub>** – Standard age, which for eucalyptus corresponds to 10 years (years);

**hdom** – Stand dominant height (m);

**hdom<sub>1</sub>** – Stand dominant height at instant 1 (m);

**hdom<sub>2</sub>** – Stand dominant height at instant t<sub>2</sub> (m);

**N** – Stand density (ha<sup>-1</sup>);

**N<sub>(d>5)</sub>** - number of trees with DBH greater than 5 cm

**N<sub>1</sub>** – Stand density at instant 1 (ha<sup>-1</sup>);

**N<sub>2</sub>** – Stand density at instant 2 (ha<sup>-1</sup>);

**Npl** – Stand density at plantation (ha<sup>-1</sup>);

**N<sub>stools</sub>** – Number of stools after the first harvest (ha<sup>-1</sup>);

**N<sub>sprouts t≤2</sub>** – Number of sprouts before sprouts selection (ha<sup>-1</sup>);

**N<sub>sprouts t=3</sub>** – Number of sprouts after sprouts selection (ha<sup>-1</sup>);

**rot** – dummy variable with 0 representing planted stands and 1 representing coppice stands;

**cota** - weight average of the central values of the classes of altitude found in each square of the grid (m);

**Rain** - weight average of the central values of the classes of total precipitation found in each square of the grid (mm);

**Frost** - weight average of the central values of the classes of nr of days with frost in a year found in each square of the grid;

**Temp** - weight average of the central values of the classes of the yearly averages of the daily average temperature found in each square of the grid (°C);

**G** – Stand basal area (m<sup>2</sup> ha<sup>-1</sup>);

**G<sub>1</sub>** – Stand basal area at instant 1 (m<sup>2</sup> ha<sup>-1</sup>);

**G<sub>2</sub>** – Stand basal area at instant t<sub>2</sub> (m<sup>2</sup> ha<sup>-1</sup>);

**V<sub>u</sub>** – Stand volume under-bark with stump (m<sup>3</sup> ha<sup>-1</sup>);

**V<sub>b</sub>** – Stand volume of bark (with stump?!) (m<sup>3</sup> ha<sup>-1</sup>);

**V<sub>st</sub>** – Stand volume of stump (m<sup>3</sup> ha<sup>-1</sup>);

**V<sub>umdi</sub>** – Stand mercantile volume without stump and bark up to a top diameter of di (m<sup>3</sup> ha<sup>-1</sup>);

**di** – top diameter with bark (cm);

**dgd** – Stand quadratic mean d.b.h of the dominant trees (cm<sup>2</sup> ha<sup>-1</sup>);

**W<sub>i</sub>** – Stand biomass per component, where i represents: w, b, l, br or r (Mg ha<sup>-1</sup>);

**W<sub>w</sub>** – Stand wood biomass (Mg ha<sup>-1</sup>);

**W<sub>b</sub>** - Stand bark biomass (Mg ha<sup>-1</sup>);

**W<sub>l</sub>** – Stand leaves biomass (Mg ha<sup>-1</sup>);

**W<sub>br</sub>** - Stand branches biomass (Mg ha<sup>-1</sup>);

**W<sub>r</sub>** - Stand roots biomass (Mg ha<sup>-1</sup>);

**W<sub>a</sub>** – Stand aboveground biomass (Mg ha<sup>-1</sup>);

**W<sub>r</sub>** - Stand belowground (roots) biomass (Mg ha<sup>-1</sup>);

**W<sub>t</sub>** - Stand total biomass (Mg ha<sup>-1</sup>);



**EFORWOOD**

Sustainability Impact Assessment  
of the Forestry - Wood Chain



### **3 RegWise: Regional simulator for Swedish forests**

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#### **Abstract:**

A new forest simulator, RegWise version 1.0, designed for long-term simulations of Swedish forest development has been developed within the research programme Heureka at SLU. RegWise is one of three applications using models in the Heureka system developed for multipurpose forestry analysis and planning. The main data source is the Swedish national forest inventory. RegWise works for all types of forests, pure and mixed-stands as well as even-aged and uneven-aged forests. All species important to wood production in Sweden are included. Basically, RegWise relies upon forecasts of the tree-layer development and output of goods and services is a result of applied management and the state of the tree layer. The time step of the forecasts is five-year periods. Assumptions on extent and intensity of different management actions are defined by the user within RegWise rules and regulation module. Results of simulations are evaluated in terms of output of goods and services expressed by a large set of indicators for each period.

**Key words:** Sweden, RegWise, forest simulator, scenarios, wood demand, indicators.



### 3.1 INTRODUCTION TO REGWISE

The forest simulator, RegWise, has been developed within the Heureka research programme (heureka.slu.se) at the Swedish University of Agriculture Sciences (SLU). The main objective of the programme was to develop multipurpose forestry analysis and planning applications. RegWise is one of three applications using common models in the Heureka system. The other applications are; PlanWise – decision support system for planning at company level and StandWise - simulating individual stand development. The development of the simulator within the Heureka programme is finalised and version 1.0 is released. This paper describes the version 1.0. All three applications are built upon a core of models that are the same for all applications such as growth, mortality, biomass and ingrowths models.

RegWise is designed for long-term forecasts (up to 100 years or more) of the development of forests for larger areas in Sweden. It is built for assessments of the future state of the forest and goods and services produced with specified assumptions on future wood demand and forest management. The model simulates the state of the forest with different management actions and conditions defined by a user. RegWise considers all type of stands, both pure and mixed stands as well even-aged as uneven aged stands.

National Forest Inventory (NFI) data (Ranneby, B. et al. 1987) is the main source of input data. The basic output of the simulator is indicators reporting the state of the forest and output of goods and services for five-year periods. Examples of indicators describing state of forest are volumes of growing stock distributed on tree species, amount of biomass and carbon in growing stock and carbon in soil. Output indicators are for example harvested volumes distributed on tree species and assortments.

### 3.2 REGWISE – APPROACH AND STRUCTURE

The basic approach adopted in RegWise for evaluating future development on a forest area is to make scenarios and evaluate the consequences of scenario assumptions in terms of outputs of goods and services expressed by a set of indicators. The assumptions of different treatments (forest management actions) is defined by the user and based on interpretation of drivers such as wood demand, economic development, forest owner behaviour and forest policy impact.

Basically, RegWise rely upon forecasts of the tree-layer as described in figure 1. Simplified, output of goods and services are a result of treatments and the state of the tree layer for each five-year period.

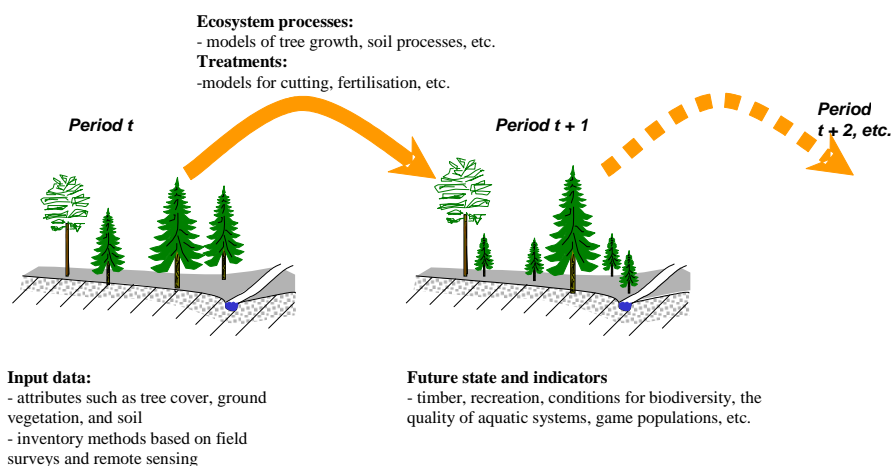


Figure 1 Outline of RegWise forecasts of the tree layer.



### Outline of a forecast

A long-term forecast with RegWise can be divided in five steps, see figure 2.

1. Select forest inventory information in the analysis area to get a description of the forest resources.
2. Choose suitable ecosystem processes models such as single tree growth models, growth models for young forests and mortality models.
3. Decide forest management and parameterise models guiding treatments by translating important drivers having an influence on the future forest development to parameter values. This in control categories, see chapter 4.4.2.
4. Assign forest areas to a control category, i.e. to a specific forest management.
5. Select which indicators to report.

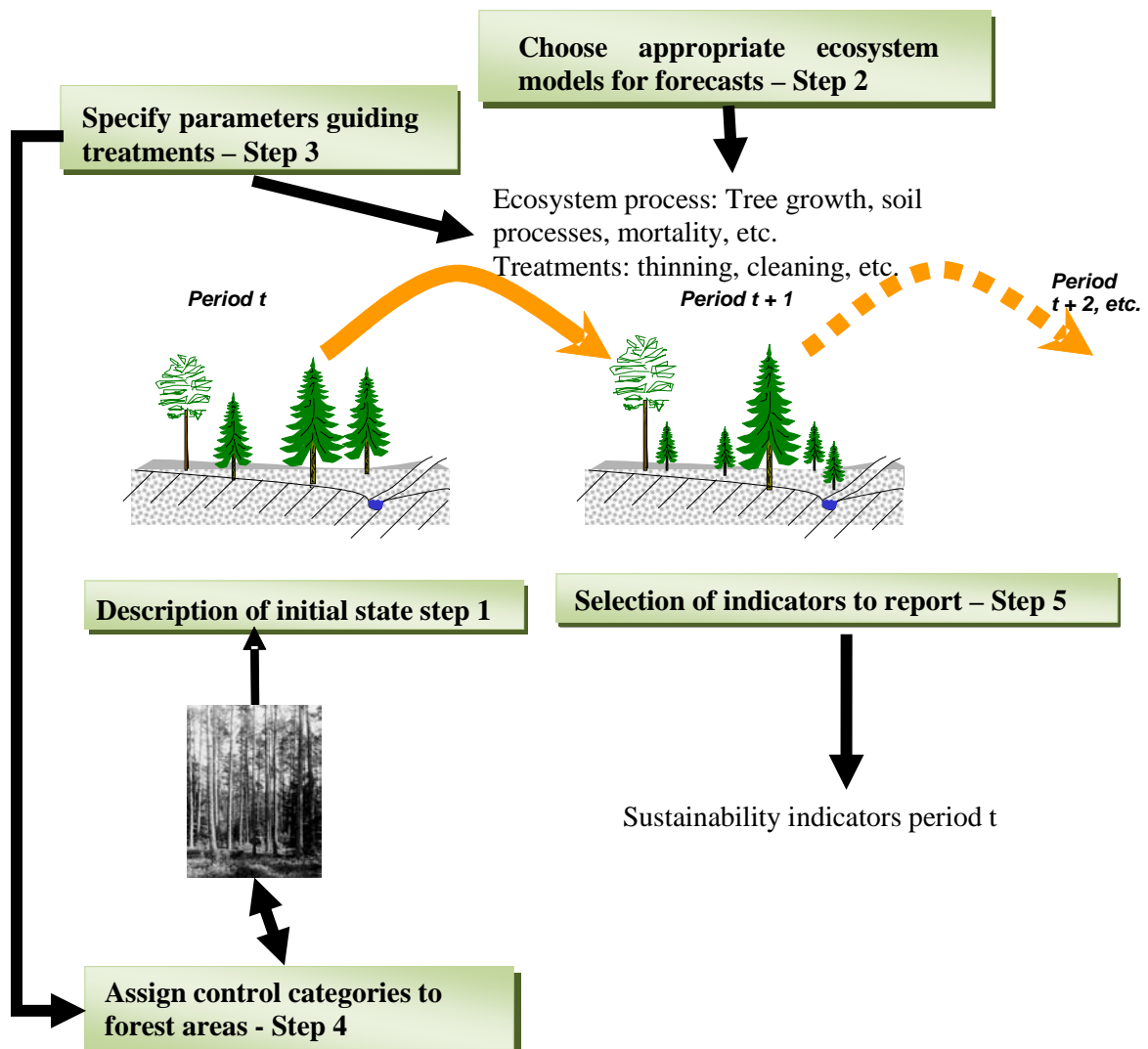


Figure 2 Outline of running RegWise.



### 3.3 INPUT DATA

#### 3.3.1 Description of initial state

To predict future forest development, a good description of the initial state on the forest area being analysed and information about other factors that may influence the evaluations are needed. In case of RegWise, the most important data is acquired from NFI sample plots, see figure 3.

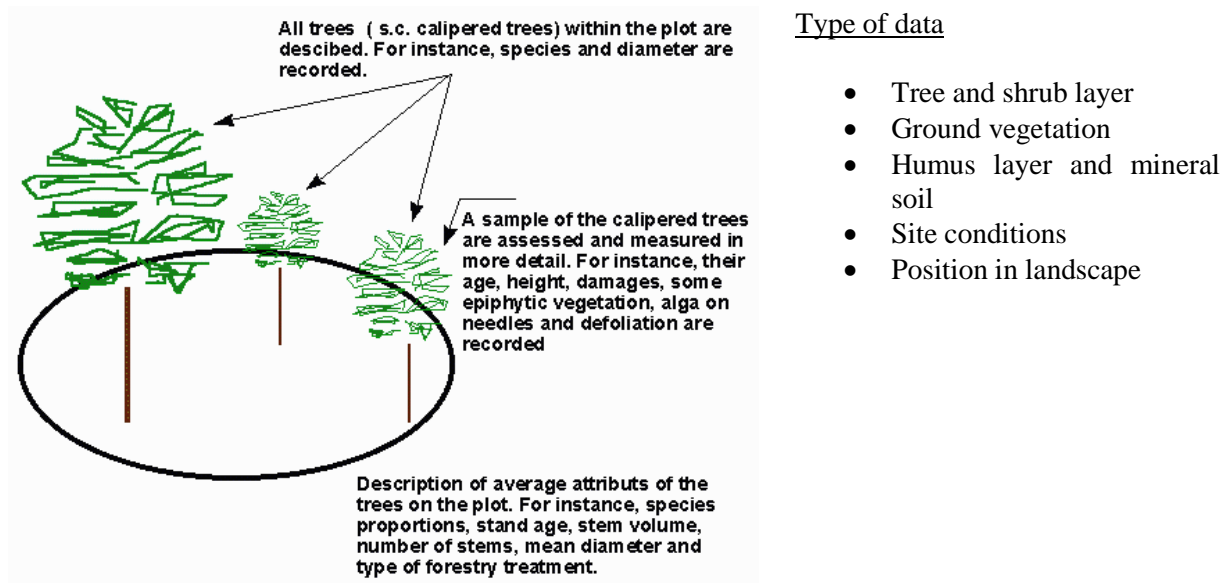


Figure 3 Description of NFI sample plots.

Input data are stored in a Heureka database (SQL Server free or enterprise version). Other external data, not originating from NFI, such as data forming restrictions on forest management on treatment unit level can be imported from other sources as digital map data.

The data describing the tree layer can be structured in levels as seen in table 1 and in figure 4.

Table 1 Data structure and levels of data

Table	Example of variables
Area	Data on analysis area.
Treatment unit	Owner, weight for scaling up, inventory year, etc.
Cell	Location of cell in landscape.
Reference unit	Forest data on sample plots such as site index, soil moisture, altitude, latitude, vegetation type, etc.
Tree	Type of tree, species, diameter and height.

To simulate young forest establishment after final felling, information from more than 4700 young forests sample plots are used. The plots contain data of state of forest (number of stems and height distribution) at 3 meters mean height associated to performed treatment after final felling.



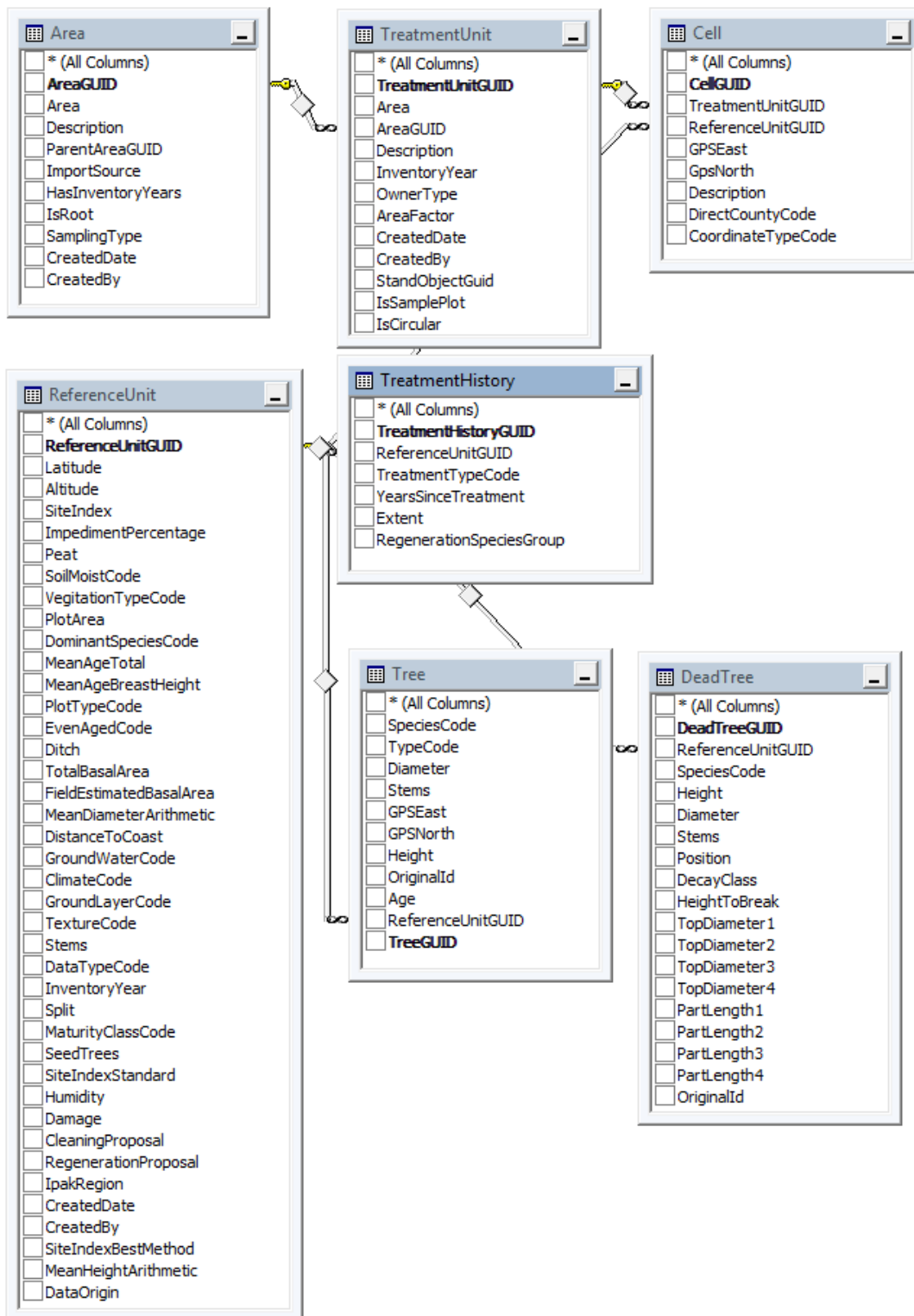


Figure 4 Example of tables in the Heureka database.



### 3.3.2 Use of data

RegWise is developed to either use individual NFI sample plots as treatment units or a number of sample plots representing treatment units to enabling spatial comprehensive (wall-to-wall) analyses on landscape level, this by using plot data assigned to treatment units by using remote sensing data. An example of this approach is the use of satellite image data combined with NFI plots (Reese, H., Nilsson, M. et al. 2003). Normally, as within EFORWOOD, the individual sample plot approach is used where single NFI sample plots makes up treatments units, see figure 5. Each treatment unit has a weight scaling up the trees and plot data to represent the analysis area. The size of the weights depends on sample plot size and the number of inventoried plots within the forest area analysed.

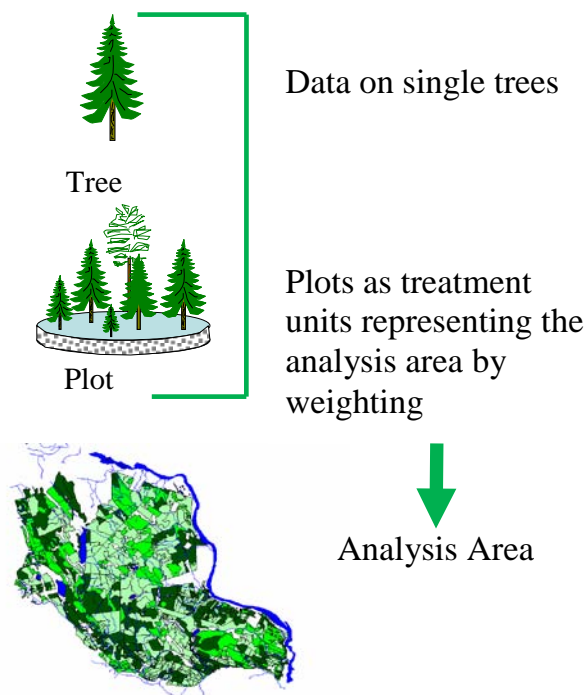


Figure 5 Data use in RegWise with the individual sample plot approach.

## 3.4 DRIVERS AND RULES AND REGULATIONS

Drivers such as population growth, oil price, government regulations, global trade, occurrence of hazards, etc. are not explicitly implemented in RegWise. The most important drivers influencing the forest development over time are wood demand and forest management. To control these drivers a user specifies a number parameter settings in control tables.

Normally, the influence of a driver can be given as a fixed or a proportion value. An example is fertilization which can be performed on a fixed area each period or on a proportion of an area suitable for fertilization. The probability of occurrence of a treatment is estimated according to priority functions parameterised by the user.

### 3.4.1 Wood demand

The total amount of volume harvested (all forms of felling) per period can be specified either by setting fixed values of volumes to be cut or relate harvest volumes to current and future growth based on a model, see equation 3.1. The distribution on clear-cut and thinning can be automatically distributed or set by the user. The treatment units are cut according priority rules (equation 3.2 and 3.3) until cuttings reaches the specified cutting level.



$$(3.1) \text{Total}_p = T_p \cdot \left[ \frac{T_{p-1}}{T_{p-2}} \right]^\alpha \cdot \left[ \frac{V_p}{V_{goal}} \right]^\beta \cdot \left[ \frac{A_{>1.0}}{R_{>1.0}} \right]^\chi \cdot \left[ \frac{A_{>0.9-1.0}}{R_{>0.9-1.0}} \right]^\delta \cdot \left[ \frac{A_{>0.7-0.9}}{R_{>0.7-0.9}} \right]^\varepsilon,$$

where

Total = total cutting volumes period p for all felling forms.

p = period

T = growth

V = Growing Stock

V<sub>goal</sub> = advisable growing stock calculated by model

A = available area in age-class<sup>1</sup>

R = desirable area in age-class

α,β,χ,δ,ε = parameters set by user

Harvest probabilities for clear-cut on a treatment unit are calculated for each treatment unit with a priority function P<sub>s</sub> and for thinning with P<sub>g</sub>.

$$(3.2) P_s = \frac{1}{P_v} \quad (\text{High number implies high priority for clear-cut})$$

where

P<sub>v</sub> is current growth divided by growing stock.

$$(3.3) P_g = \frac{G_f - G_r}{G_m - G_r} + a \cdot H + b \cdot H100 + c \cdot \text{Deciduous}$$

P<sub>g</sub> = Priority number (high number – high priority for thinning)

Deciduous = share of deciduous of growing stock

H = height of dominant trees

G<sub>f</sub> = Current basal area on treatment unit

G<sub>r</sub> = Recommend basal area

G<sub>m</sub> = Highest recommended basal area

H100 = Mean height of dominant conifer trees

G<sub>r</sub> and G<sub>m</sub> are calculated by models dependent on parameters set by the user.

### 3.4.2 Forest management

The user can associate treatment units to control categories by using the forest domain builder. A control category can be defined as a collection of rules and regulation for simulation of forest management actions (treatments) and the forest domain builder as a tool for assigning treatments units to a certain control category.

A control category includes collections of parameter groups where the user can specify which models to use and its parameter settings. Figure 6. shows all the groups (left) and an example of production models settings (right).

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<sup>1</sup> Age-class related to lowest allowable clear-cutting age according to Swedish Forestry Act. For example > 1.0 means higher than lowest allowable clear-cutting age



The assignment of treatment units to a specific forest domain is done by specifying site and tree cover criteria of optional variables available in input data. Figure 7 shows an example where criteria for selection have been used to create three forest domains. The forest domains have different parameter settings in their control category.

Control category	Control category group
<ul style="list-style-type: none"> <li>[-] Default Domain Settings                             <ul style="list-style-type: none"> <li>[-] Nature Conservation</li> </ul> </li> <li>[-] Default Control Category                             <ul style="list-style-type: none"> <li>[-] Cost</li> <li>[-] Treatment Model</li> <li>[-] Production Model</li> <li>[-] Dead wood</li> <li>[-] Performance</li> <li>[-] Recreation</li> <li>[-] Climate Model</li> <li>[-] Regional Framework</li> <li>[-] Pricelist</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>[+] <b>1. Growth and yield</b> <ul style="list-style-type: none"> <li>Growth Model Individual-Tree: Elfving</li> <li>Growth Model Whole-Stand: Elfving2009</li> <li>Growth: Compute Large Only (test): False</li> <li>Growth: Include Thinning Response: True</li> <li>Height Calibration: True</li> <li>Height Development Model: ErikssonElfving</li> <li>Height Threshold Young/Mature: 7</li> <li>Height: Initial Height Function: SoderbergWithTreeAge</li> <li>Height: Initial Height Source: UseFunction</li> <li>[+] Mortality for Retained Trees 1-5: 12; 12; 12; 12; 12; 12; 12; 12; 12; 12</li> <li>[+] Mortality for Retained Trees 6-10: 6,8; 6,8; 6,8; 6,8; 6,8; 6,8; 6,8; 6,8; 6,8; 6,8</li> <li>Mortality Fridman/Ståhl Only: False</li> <li>Mortality Model Type: Deterministic</li> <li>Volume Function: BrandellLesser</li> </ul> </li> </ul>

Figure 6. Control category groups and example of growth and yield settings within the group production model.

<ul style="list-style-type: none"> <li>[-] NatPine (100%)                             <ul style="list-style-type: none"> <li>[-] Vegetation Type = [SedgeHigh, SedgeLow, Bilberry, Lingonberry, Crowberry, Shr...</li> <li>[-] Altitude &lt; 300 m</li> <li>[-] Basal Area[Pine] &gt; 65% [Unknown, Pine, Spruce, Birch, Aspen, Oak, Beech, Decid...</li> <li>[-] Default Domain Settings</li> </ul> </li> </ul>	Control category NatPine: final felling leaving seed trees for regeneration purpose.
<ul style="list-style-type: none"> <li>[-] Intensive (100%)                             <ul style="list-style-type: none"> <li>[-] Vegetation Type = [Unknown, HerbHigh, HerbHighBilberry, HerbHighCowberry,</li> <li>[-] Site Index In [22 - 40]</li> <li>[-] Default Domain Settings</li> </ul> </li> </ul>	Intensive: fertilization on all suitable areas and harvest restudies extraction.
<ul style="list-style-type: none"> <li>[-] Other (100%)                             <ul style="list-style-type: none"> <li>[-] Default Control Category (100%)</li> <li>[-] Default Domain Settings</li> </ul> </li> </ul>	Default control category: Forest management as usual.

Figure 7 Example of Forest domains and a short description of control categories.

**3.4.3 Regeneration**

After a final felling, the treatment units are regenerated by using data from the young forest database based on assumptions of regeneration treatments specified by the user;



Method used – share of methods (plantation, seed trees, sowing or doing nothing) are set for moisture classes (dry, fresh and moist) in percentage.

Soil preparation - share of soil scarification in percentage on regenerated area dependent on method.

Species to plant – share of species in percentage if planting for moisture classes and site index classes.

Which method applied on (suitable) single treatment units is stochastically distributed depending on the shares.

#### **3.4.4 Cleaning**

Firstly, the user specifies height limits for cleaning in meters and the minimum number of stems allowed to be cleaned per hectare. Secondly, for each period the extent of cleaning is set as a fixed area or a proportion of area allowed for cleaning. Priority functions are used to direct cleaning to certain treatment units based on site index, mean height and proportion of deciduous trees. The strength of cleaning is decided by a simple model estimating number of stems after cleaning as  $a+b*\text{site index}$  in separate functions for following forest types pine, spruce or deciduous.

#### **3.4.5 Thinning**

Thinning are simulated by specifying parameters deciding thinning form (from below – directing cutting towards smaller trees or from above – directing cutting towards larger trees) and removal distributed between tree-species (within conifers and between conifers and broad-leaved). Total thinning volumes can be set by the user to a fixed volume or estimated automatically as a share of total cuttings. Priority of the single plot for thinning is calculated by function 3.3.

#### **3.4.6 Final felling**

Final felling volumes can be set to a fixed value per period or automatically estimated as a share of total cuttings, see chapter 3.4.1. The user can also decide type of final felling. Options are ordinary final felling, seed-trees felling or shelter wood system. Both seed-trees and shelter wood systems uses the thinning algorithm. Special models estimating mortality of the shelter trees are also in the system. Single-tree selection system can also be simulated as repeated thinnings with the same framework as ordinary thinnings but with other parameter settings.

#### **3.4.7 Nature conservation**

Nature conservation is specified on three different levels; treatment unit, groups of trees and on individual tree level. Treatment units can be assigned a control category with no management by using the forest domain builder. The preservation of tree groups is randomly distributed on treatment units and parts of units. The user can specify the proportion of the area that should be allocated to nature preservation. The number of trees per hectare that should be left for retention is specified by the user. The selection of retained trees is made in a prioritised order based on tree species and diameter at breast height

#### **3.4.8 Cost and revenues**

Costs for all treatments are included in the analysis. Some are specified as fixed costs per hectare such as costs for sowing, soil scarification and cleaning. Costs for harvesting and forwarding are estimated by models made by the Forestry Research Institute of Sweden.

To calculate revenues from harvested volumes, model trees representing different diameter-classes and part of the stem (root, middle or other log) are optimally marked for cross cutting against a user specified pricelist and given a value. Trees cut in the system are then assigned values based on diameter class and part of stem.

Revenues from extracted harvest residues are set to fixed revenue per ton dry weight.



### 3.4.9 Land use changes

In the current version of RegWise, there is no algorithm included to deal with land-use changes. Historically, the land-use changes in Sweden last 50 years have been small with almost constant area of forest.

## 3.5 REGWISE – ECOSYSTEM PROCESSES

The basic prediction unit is the single tree and the simulation unit is the plot. Each tree has a weight on plot level and each plot has a weight for the analysis area. **Growth models for single trees and sample plots**

The user can choose models for estimating growth and yield. In the first approach single tree models solely are used. In the second approach – which is recommended– growth level is first estimated using area (plot) based models. The growth level from these models calibrates the growth levels estimated by single-tree models. On single-tree level, the calibrated growth is assigned by the single-tree growth models. There are growth models for Scots pine, Norway spruce, Birch, Aspen, Beech, Oak and other deciduous species (Söderberg, U. 1986; Elfving, B. 2004)

### 3.5.2 Natural mortality

The natural mortality for a five year period can be modelled in two ways, with a combination of models or with on three-step approach only. The default option is to use a combination of models. One model by **Bengtsson** estimates the total volume of the mortality for a period and the models by Fridman and Ståhl (2001) distributes the volumes on single trees. The models by Fridman and Ståhl use a three-step approach to estimate mortality. It consists of (I) estimating the probability of mortality on a sample plot; (II) quantifying the mortality in terms of proportion of basal area; and (III) distributing the mortality among individual trees.

### 3.5.3 Ingrowth

The ingrowth model consists of four parts, describing: (I) Probability for occurrence of saplings (1-39 mm diameter at breast height (DBH)) on plots with  $r = 5$  m. (II) Number of saplings on stocked plots (plots with saplings of target species). (III) Probability for ingrowth of a sapling over 39 mm DBH during a 5-year period. (IV) Diameter of ingrown trees at the end of the 5-year period. The models developed were based on data from NFI permanent plots with separate functions for seven species and species groups (Wikberg, P. E. 2004).

### 3.5.4 Dead wood volumes and decomposition

Initial volumes of dead-wood distributed on decay classes originates from NFI plot data (dead-wood is defined as dead trees standing or lying more than 10 cm in diameter). Supply of dead-wood in the forecasts is derived from the mortality models. The user specifies the share of dying trees that are utilised by the forest owner and rate of decomposition of biomass and volume for the dead-wood for different tree species based on literature e.g. (Harmon, M. E., Krankina, O. N. et al. 2000) or as an expert guess.

### 3.5.5 Climate change

A process based model BIOMASS (McMurtrie, R.E. et al. 1990) was used to generate relationships between tree growth and climate change. Tree growth was simulated in response to changes in atmospheric CO<sub>2</sub> concentration, air temperature, air humidity and precipitation. Soil water condition was dealt with in the process based simulations, whereas the relationship of soil fertility to temperature change was evaluated empirically base on data from the NFI. The identified relationships were used to adjust the statistical growth and yield model. A method of linking the results from the process based





model and the statistical growth and yield model was developed. The method is based on the concept of adjusting an intrinsic tree age in the empirical growth model to target the relative changes in the growth potential found by the process based simulations, e.g. when trees are growing better they are regarded younger and more vital in growth. The adjustment of the growth potential is taking place every period of 5 years to take into account the stage of the stand development and thereby also the effects of management. The simulations of the climate change response of tree growth was based on four different climate scenarios generated by the regional climate model RCA3 at the Rossby Centre of the Swedish Meteorological and Hydrological Institute (SMHI) (Kjellström, E. et al. 2005; Kjellström, E. et al. 2009). The user of RegWise can choose between these climate scenarios to include climate change effects on growth.

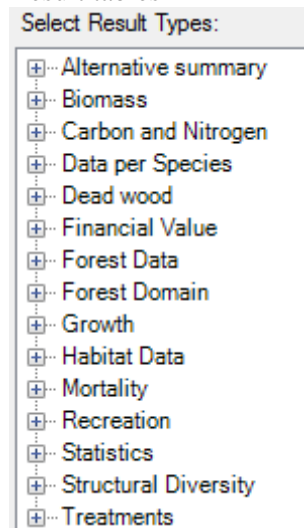
### 3.5.6 Hazards occurrence

Occurrence of hazards comprises different types of hazards such as fire, pests and diseases and storms. So far, none of these drivers have been implemented in the simulator as catastrophic (large scale) events. However, natural mortality includes some of these hazards indirectly and makes up an important part in the simulator and thereby having an effect on the tree layer development.

## 3.6 REGWISE - RESULTS

All results from a simulation are stored in a SQL server database (SQL server enterprise or express). The results for indicators are stored in tables based on type of indicator, see figure.8 and table 2. Parameter settings for the simulation are also stored in the database making it possible to rerun a more or less identical simulation. Data on forest domain areas associated to control categories is also stored in the database. All this supports a very flexible reporting of results where tables and diagrams are made based by compile indicators.

#### Result tables



#### Indicators in result table Treatments

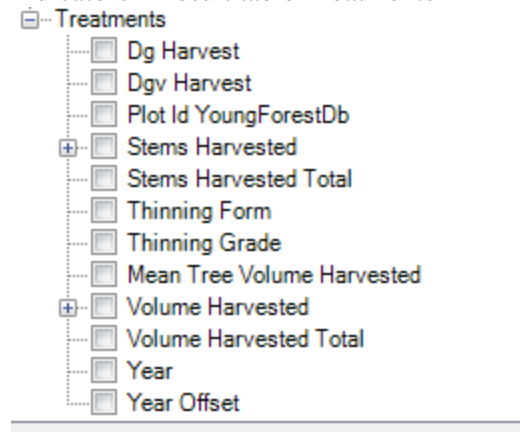


Figure 8. Result indicator tables (left) and example of treatment indicators (right).



Table 2. Description of output data stored in tables referring to treatment units

Type of output data	Example of indicators
Alternative summary	Summary of economic values as net present value, soil expectation value.
Biomass	Amount of biomass (dry weight) for parts of trees parts (stems, branches, needles, bark, roots and stumps) distributed on tree species.
Carbon and Nitrogen	Carbon and nitrogen in soil.
Data per Species	Forest indicators distributed on tree species as volumes, stems, etc.
Dead-wood	Volumes of coarse woody debris distributed on decay classes and on standing and lying dead wood.
Financial values	Costs and revenues for treatments and volumes distributed on assortments.
Forest data	Indicators such as mean age, mean diameter, mean height and volume, number of stems and basal area per ha.
Forest domain	Forest domain and control category possession.
Growth data	Net, gross and mean annual growth as total and distributed on tree species.
Mortality	Mortality as volumes and stems divided on tree species.
Recreation	Recreation index.
Statistics	Mean, standard deviation and error on treatment unit level having more than one sample plot representing treatment unit.
Structural diversity	Tree size diversity.
Treatment	Stems, volumes and basal area per ha felled. Average volume per stem, thinning form and intensity. Regeneration measures (method and area).

### 3.7 CASE STUDY

This simple case study's aim is to show the use of forest domains settings and control categories and some indicator results. The case study should be regarded as an example of the potential of the simulator.

#### 3.7.1 Assumptions

In scenario (A) all forest land are associated to one control category with same rules and regulations for all forest, i.e. with the same management specifications. In scenario (B), three forest domains have been specified;

Forest with and connected to different control categories. About 19 % of the forest area is regenerated with seed trees after final felling, about 5 % are more intensively managed with fertilization and extraction of harvest residues. The remaining area is in the same control category as all forest area in scenario A. The cutting level has been set to about 90 % of the growth in both scenarios. Regeneration methods used in control category other is by planting and seed trees on about 70 and 30 %, respectively.

The analysis area is the county of Västerbotten located in northern Sweden having a total area of productive forest on 3.4 million ha. The initial age structure is shown in figure x.



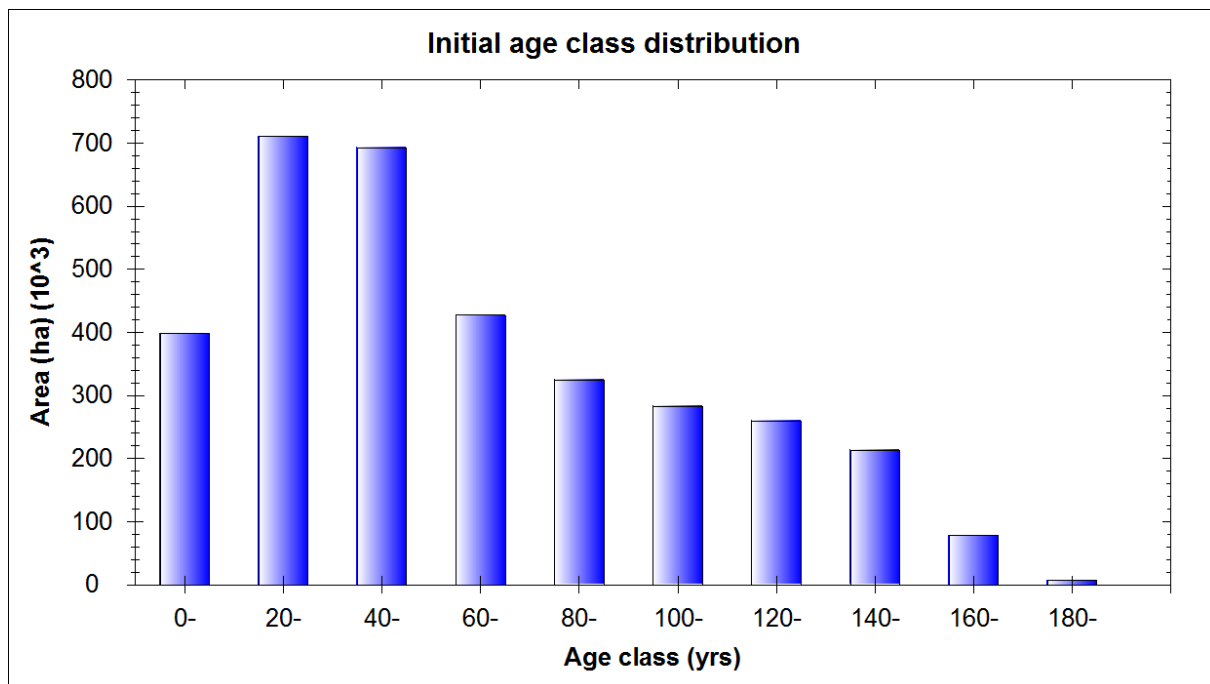


Figure x. Initial age-class distribution

### 3.7.2 Results

The results below show results for some important indicators and some comparisons between the two scenarios.

#### Forest state

Table x. Growing stock per ha and tree species in scenario A, m<sup>3</sup>

PERIOD	Tree species					Total
	Pine	Spruce	Birch	Contorta	Other	
0	42	37	12	1	1	93
1	44	35	12	2	1	93
2	46	33	12	2	1	94
3	49	31	12	2	1	96
4	51	30	12	3	1	97
5	53	29	11	3	1	98
6	54	28	11	3	2	99
7	55	29	11	4	1	99
8	54	30	10	4	2	100
9	54	31	10	4	2	100
10	52	33	10	4	1	101



Table x. Growing stock per ha and tree species in scenario B, m<sup>3</sup>

PERIOD	Tree species					Total
	Pine	Spruce	Birch	Contorta	Other	
0	42	37	12	1	1	93
1	43	36	12	2	1	93
2	45	34	12	2	1	95
3	48	32	12	2	1	97
4	51	31	12	3	1	98
5	53	30	12	3	1	99
6	55	29	11	3	1	100
7	56	29	11	4	1	101
8	57	30	10	4	1	102
9	56	31	10	4	1	103
10	56	33	10	4	1	104

**Growth**

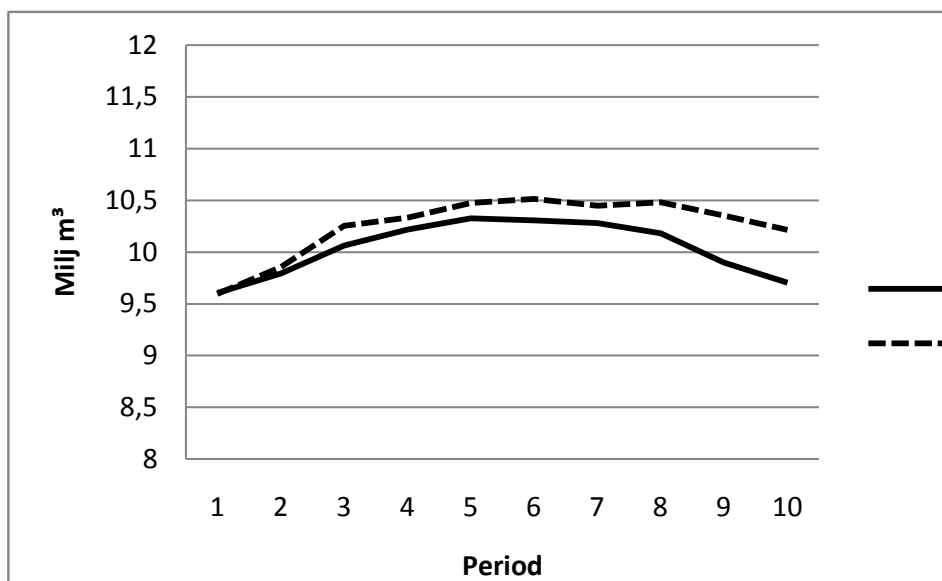
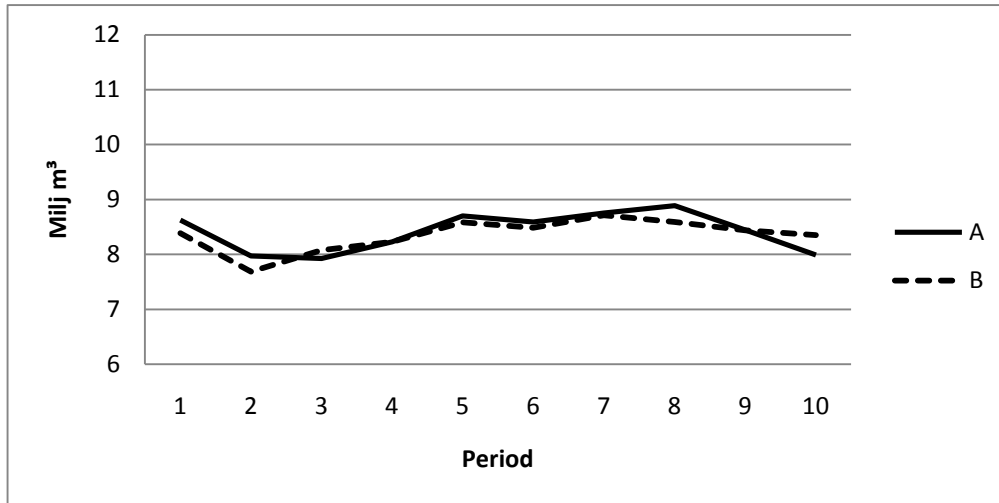


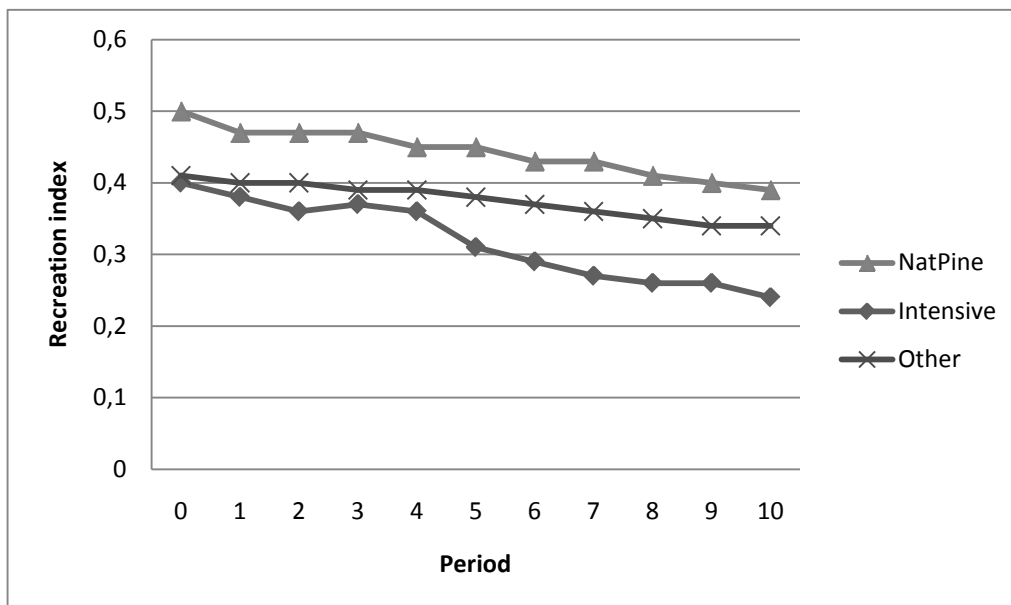
Figure x. Annual growth per period for Scenario A and B, mill m<sup>3</sup>.



### Cuttings



### Recreation index



Treatment areas – fertilization, harvest residues, regeneration, thinning, final felling

Costs and revenues

Harvest residues



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**EFORWOOD**

Sustainability Impact Assessment  
of the Forestry - Wood Chain



## **4 Sylvogene: simulator of the Maritime pine forests in Aquitaine (South West France)**

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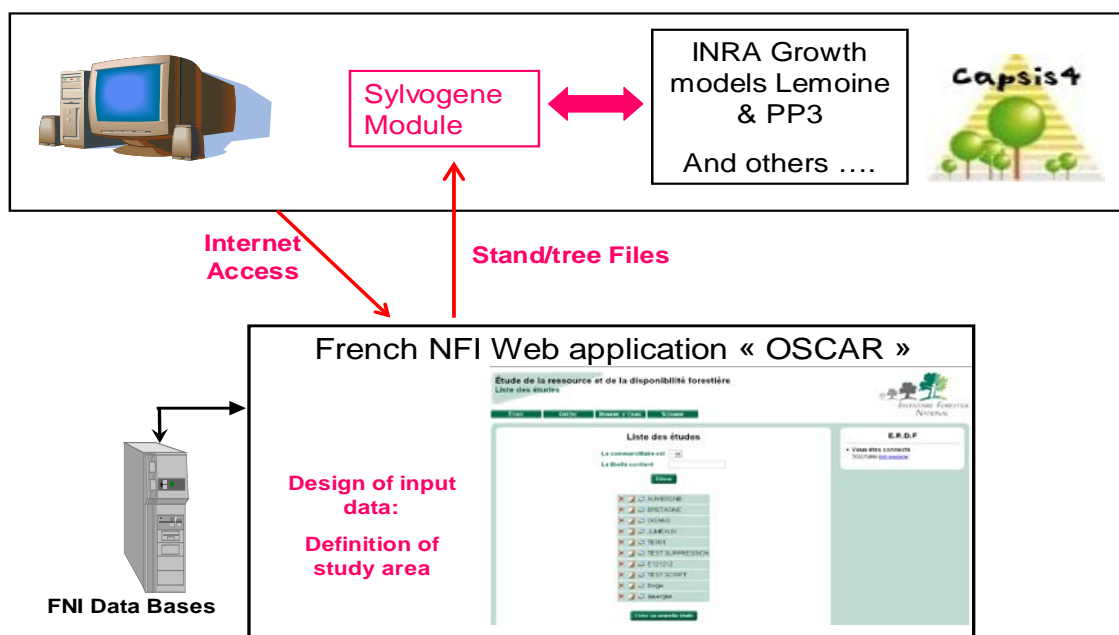
### **Abstract:**

*Sylvogene* is a regional forest simulator designed for long-term simulation using National Forest Inventory data as input. It is not spatially explicit and connected to a GIS. This simulator belongs to the *Capsis* platform. This program is like a script with user interaction at the beginning only. It runs simulations with one or several *Capsis* modules dedicated to Maritime pine growth. It interacts with three types of growth modules: distance –independent tree growth model, stand model and diameter/age classe growth model. The two first types were designed for Maritime Pine. At present, it only considers pure stands of Maritime pine of South-West France, but it was designed in order to consider other species and mixed forests depending on different modules interactions. During EFORWOOD project duration, the simulator was designed and first steps were implemented, with some improvements expected in the short term. Initial work focused mainly on NFI input data and connections with different growth models. The control variables that are needed to choose the proper growth model able to manage each NFI plot (even-aged plot, dominant species, age, stand density ...) during all the steps of simulation were selected. Then a regional harvesting module was developed to simulate clear-cut and thinning scenarios at the regional level. These specifications take into account the general characteristics of the maritime pine forest resource at regional level to carry out clear-cuts and thinning. Knowledge of the status of all plots at each time step will determine the clear cut and thinning scenario that will be applied individually before next step of implementation. Then, each plot is processed by the selected growth module.



## 4.1 INTRODUCTION

*Sylvogene* is a specific programme within *Capsis* platform without the usual structure of *Capsis* modules. This programme looks more like a script requiring inputs from the user at the start. The role of the programme is to initiate simulations with one or several modules of *Capsis* (Figure 1). The dialogue box of the interface *Capsis - Sylvogene* is opened from a command window MS-DOS in which the following command is activated:



**Figure 1:** general architecture of the simulation tool

```
C:\capsis4\bin\capsis.bat -pscript sylvogene.SylvoStarter
```

This dialogue box (Figure 2) allows request of input data files (one stand data file and one tree data file) needed for the simulation and generated from NFI data through *OSCAR* application.

Data files are text files under CSV (comma-separated values) format where each line corresponds to a table line, with cells of the same line being separated by virgules. Data files have a line with head-lines. A data file is created for NFI plots and a second one for trees. In plot data file, each line corresponds to a plot, and in tree data file, each line describes a tree.

Extracted data can then be used for running growth models for maritime pine as documented in internet forest models database D255 (INRA models – Lemoine PP1 -stand level model- or PP3 -tree level model- or other models). This extraction tool of NFI data has been applied to maritime pine forest stands of Aquitaine in the context of EFORWOOD and development of *Sylvogene*; however, genericity of the tool makes it usable in the future for any other regional context and tree species. Specifications for the extraction, are based on past department level inventories and will need to be adapted to new systematic national inventory method.



## 4.2 INPUT DATA

They are four types of data:

Factual data (year of reference for department inventories)

Geographical data (study area concerned)

Plot data

Sampled tree data

Factual and geographical data are repeated for all plots under *Oscar* application in the plot data file.

Sampled tree data are located in a second data file.

### 4.2.1 Geographical data

In the frame of *Sylvogene*, only data relevant under certain location and logical criteria could be extracted. Plots must be located in Aquitaine maritime pine forests corresponding to 4 separate geographical entities defined as « forestry regional areas »: Coastal dunes (330), Plateau of Landes (404), Marensin (401), Bazadais (334). Plots selected have to correspond to Maritime pine as a dominant species.

### 4.2.2 Plot data related to French NFI

<b>data</b>	<b>data description</b>	<b>Unit</b>
NPP	Plot identification	-
DEP	department	-
CYC	Inventory cycle	-
DATEPOINT	Date of data collection	day/m/year
ANREF	Inventory reference year	
REGD2	Forestry region	-
SFON	National Forest Structure	-
ESSPRE	Main species	-
IMPRESS	Species importance	-
CONS	Consistance	-
REGEPO	Plot Regeneration rate	1/10
REGENESS	Main species regeneration rate	1/10
CAM	Measured age class	NFI Unit
CAE	Estimated age class	NFI Unit
AGECOD	Median age class	year
AGEDOM	Main species age	year
NTIGHAP	Stem density of main species	number/ha
NTIGHAA	Stem density for other species	number/ha
HDOM	Recorded dominant height	metre
HDOMC	Calculated dominant height	metre
HM	Average height of dominant species	metre
GHAP	Basal area of main species	m <sup>2</sup> /ha
GHAA	Basal area of other species	m <sup>2</sup> /ha
GDOM	Average basal area of dominant tree	m <sup>2</sup> /ha
VP	Volume of main species	m <sup>3</sup> /ha
VA	Volume of other species	m <sup>3</sup> /ha
VE	Annual harvested volume in the last 5 years	m <sup>3</sup> /ha/yr
SX2	Extended plot area	ha



Other data concerning study and geographical domains used for the *Oscar* application need to be added to those plot data.

#### 4.2.3 Sampled tree data

This table only contains living trees of all species (main and other tree species) in selected plots; they are no dead or harvested trees or stumps.

<b>data</b>	<b>Data description</b>	<b>Unit</b>
NPP	Plot identification	-
DEP	department	-
CYC	Inventory cycle	-
A	Tree identifier	-
ESS	Tree species	-
SSU	Sub-unit	-
P	Plot tree identifier	-
NUM	Tree number	
C13	DBH	m
HTOT	Total tree height	m
G	Tree basal area	m <sup>2</sup>
V	Total tree volume	m <sup>3</sup>
AGE	Measured age	year
IR5	Radial increment over 5 years	m
L5	Height increment over 5 years	m
EC	Bark width at breast height	m
POND	Tree stem density	number/ha

### 4.3 SIMULATION STEPS

After input data selection, following steps are implemented:

- a) Checking the number of recorded data in selected NFI stand data files and in corresponding tree data files.
- b) Selection of the best suited available growth model to run the simulations (at this stage of development, only INRA Lemoine PP1 or PP3 modules can be used) according to following criteria:

#### module Lemoine

main species maritime pine : ESSPRE = "51"

high stand : SFON.= "1"

pure maritime pine: IMPESS = "1"

dominant age > 14 : AGEDOM >14

stem density per ha >= 100 : NTIGHAP >= 100

dominant height and basal area per ha > 0 : HDOM > 0 ; GHA >0



module PP3

main species maritime pine : ESSPRE = "51"

high stand : SFON.= "1"

pure maritime pine: IMPESS = "1"

stand must include trees

location must be outside forestry area « coastal dunes (330) »

dominant age > 14 : AGEDOM >14

stem density per ha >= 100 : NTIGHAP >= 100

dominant height > 0 : HDOM > 0

- c) Choice of simulation period and method; two methods can be used :

Method 1: this method is based on the simulation of the growth of each individual plot using for each module one or several thinning scenarios. This method is well suited to treat specific plots where model runs need debugging, but also to apply prospective scenarios to group of plots according to their characteristics.

Method 2: this method is based on general characteristics of the total maritime pine forest resource to determine harvesting and thinning scenarios. Each plot is treated by the growth module for one year only; the state of all the set of plots at the end of each time step of one year will determine the thinning and harvesting scenario which will be applied at the next step. In this method, thinning and harvesting scenarios are dependant of the plots selected for the study domain.

#### **4.3.1 Harvesting scenarios**

Annual clearfelling rate depends on average girth in the plot. Plots are first classified according to increasing average girth values. Within each class of 0.1 m from 0.3 to 1.9 m, plots are then classified according to decreasing girth values, the rate of clearfelling is transformed in  $n$  rounding classes then this class number is divided in  $n$  sub-groups and the first plot in each sub-class is chosen. The first class of girth is the 0.3 m class and its clearfelling rate is valid for all plots with average girth values ranging from 0 to 0.4 m excluded. The last class of girth is the 1.9 m class and its clearfelling rate is valid for all plots with average girth values above 1.90 m.

#### **4.3.2 Thinning scenarios**

After removing clearfelled plots, remaining plots are classified in a double –entry table: average girth classes (every 0.1 m from 0.3 to 1.9 m – same as above) and basal area classes (every 5 m<sup>2</sup> from 5 to 40 m<sup>2</sup>). For each combination, plots are classified by decreasing number of stems. The number  $n$  of thinned plots is calculated by rounded at the higher number; then divide that number into  $n$  subgroups, and we take the first plot of each subgroup. Thinning characteristics are always the same whatever the number of the thinning (thinning rate of 30 % and  $K_g = 0.85$ ). Those thinning characteristics are used by the growth module which has been selected. Then, all plots except clearfelled plots are grown for another yearly cycle with the growth module selected.

- d) Calculation of the number of NFI stands compatible with the selected models.
- e) State of the simulation and final outputs

At the end of the simulation, 3 types of files are recorded in the temporary files of the user, for example under Windows:



C:\Documents and Settings\nomUtilisateur\Local Settings\Temp

Each stand used for the simulation is listed in 3 separate files:

-Module\_Number.sylvogene : initial datafile including line describing the stand and eventually lines describing the trees.

-Module\_Number.sylvogene.csv : text file including simulation results for stand and trees variables after last step of evolution..

-Module\_Number.sylvogene.prj : project file of *Capsis* allowing access to simulation interactive mode of *Capsis*.

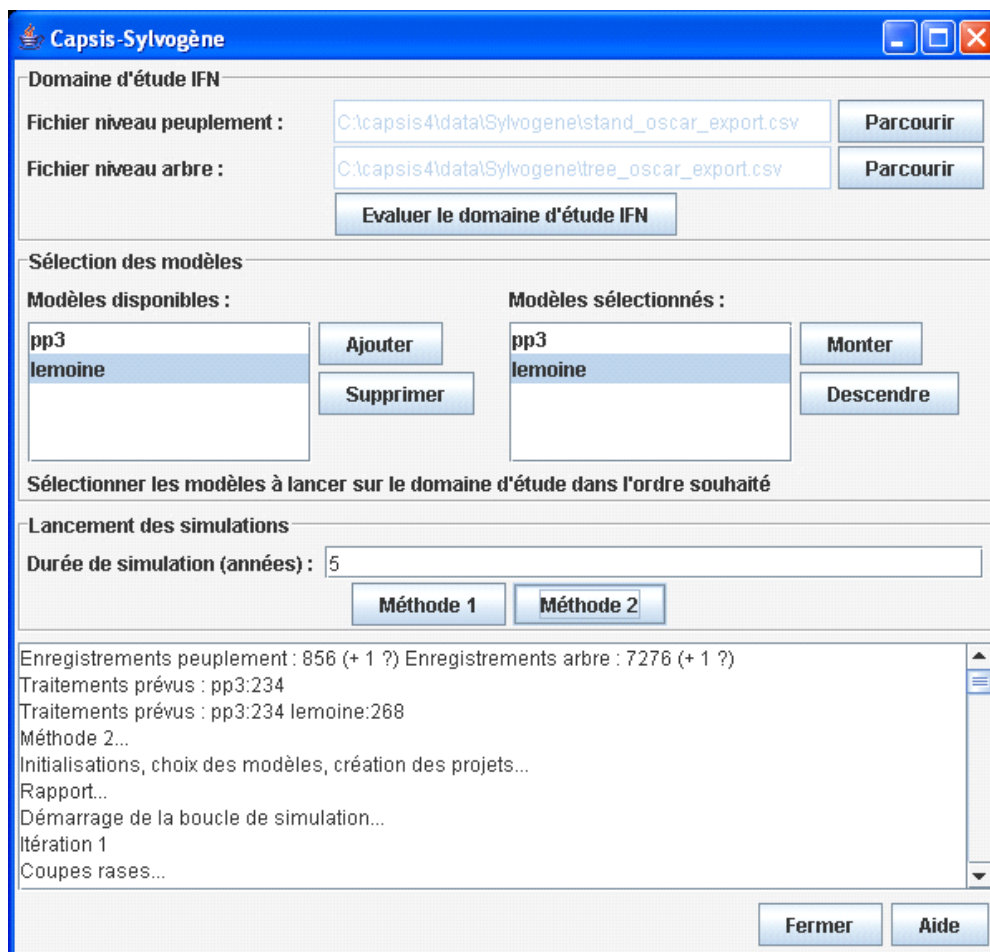
In parallel, 2 files with simulation results are recorded in temporary files under *Capsis* set-up (\*\*\*\capsis4\tmp) :

-sylvogene\_stand.csv

-sylvogene\_tree.csv

Those two files allow to concatenate results from simulations at stand or tree level. Under method 1, only final simulation results are recorded (1 stand corresponds to 1 line). Under method 2, simulation results are recorded for each year and for the whole duration of the simulation

Figure 2 : *Sylvogene* dialogue box under *Capsis* (this dialog box is also available in English)





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#### **4.4 CURRENT LIMITS AND FUTURE PERSPECTIVES**

The *Sylvogene* simulation tool is functional and can be used for analysing maritime pine forest resource in Aquitaine region; further improvements can be foreseen.

Methodologies and tools have been developed in a generic and flexible way so that this type of simulator can be further developed and used in other regional context in France. For example, the method developed for characterising harvesting and thinning scenarios can be used in other study. Also, the simulation system can run with other growth models when appropriate, and one of the advantages of *Capsis* platform is that other specific modules can be linked to the simulator to generate outputs on biomass, carbon, wood quality ....

However, there are some limitations in this initial version of the simulator concerning the treatment of young stands which are not inventoried by NFI and the adaptation to the new systematic inventory method implemented by French NFI. Those limitations will need to be addressed in the next version of the simulator, and the current architecture should be flexible enough to cope with the new inventory method.

On the basis of the current version, an update of the maritime pine forest resource after the Klaus storm from 24<sup>th</sup> January 2009 will be feasible in 2010 using damage data and harvested trees data collected by NFI after the storm on inventory plots.



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## **5 EFISCEN-Space**

### **5.1 INTRODUCTION**

Forest resource analyses have been conducted at the pan European scale with the EFISCEN V3 model successfully for a range of applications. However, these scenario projections are most reliable for managed even aged, monospecific forests which were traditionally dominant in large parts of Europe.

With European forestry shifting away from a timber production system towards more nature oriented management or short rotation biomass plantations, there is a need to adopt a more flexible approach. Furthermore, the EFISCEN V3 approach had serious shortcomings for the Mediterranean countries, where part of the data are organized by diameter class. And the EFISCEN V3 approach was often only geographically explicit down to the NUTS2 level, or even NUTS1 (country) level. This did not allow the proper use of all sorts of GIS based data. Nor did V3 provide any insight in forest structure or assortments.

As the goals of forest management are becoming more diversified and the calculation of scenario projections has grown towards extensive sustainability impact assessments integrated over a whole sector, the robust but simple approach of EFISCEN does not fulfill the current requirements anymore.

Therefore a new high spatial resolution (1 km x 1 km) forest simulator EFISCEN-Space was initiated in EFORWOOD as an improved tool to analyze the development of forest resources on a regional to European scale under scenarios of management, societal demand and environmental circumstances.

### **5.2 DESCRIPTION OF THE SIMULATOR**

The model was and is being developed to incorporate the effects of European forestry shifting away from a timber production system towards more nature oriented management or short rotation biomass plantations. It is able to deal with multiple stand types, such as even-aged monocultures, uneven-aged monocultures, mixed-species stands and coppice. For all stands, the model simulates forest dynamics in terms of forest area, species composition, stand structure, standing volume, current annual increment, as well as harvested volumes of timber by thinning and final felling at the km<sup>2</sup>.

The spatial approach allows addressing questions related to:

- The forecasting of timber yield in a spatial context and by assortments;
- The logistical and economic implications of the location of timber harvest;
- The identification of areas that will act as (future) carbon sinks, including land use changes to and from the agricultural sector;
- Spatial and forest structural aspects of nature conservation
- The effects of changing climate variables over Europe

The basis for the model is a large set of National Forest Inventory plot level data integrated in a GIS framework including earlier pan-European forest maps as well as information on soil, topography and climate.

The spatial extent covers the EU, extended with Norway, Switzerland, the Balkans, Moldavia, Belarus and Ukraine. Tree species are grouped into 20 clusters. For each cluster, 1 km x 1 km distribution maps have been modelled on the available NFI plots as well as the ICP plots (Figure 1) in combination with ancillary maps (biogeographic regions, elevation, FAO soil map, EFI forest cover map, average rainfall, average temperature, average radiation, country, XY-coordinates) (Hengeveld et al. in prep.). The result is a prediction of the coverage of each tree species for the whole of Europe at



the 1 km x 1 km scale (Figure 3). This has been translated into a series of initial stands for each species group predicted to occur in a km<sup>2</sup> by drawing randomly from a relevant subset of NFI plots. Species predicted to occur below a threshold of 1 ha are neglected. This way natural stand characteristics are preserved and both the local distribution of mixed-species and monoculture stands and the local combination of species can be maintained.

The dynamic part of the model consists of a core that simulates natural growth, mortality and regeneration at stand level. The resulting structural variables are impacted by management and disturbance modules. Growth is driven by a combination of plot characteristics (mean height and diameter, volume, density) and site information. Age is explicitly not included in the growth module to allow simulation of uneven-aged as well as even-aged forests. Competition between tree species in mixed plots is taken into account by including both tree species and total plot volume in the equations. A maximal volume is calculated from underlying GIS maps with abiotic variables. Parameters for the growth module are based on the NFI plot data with increment information.

Mortality is the “regular” mortality, i.e. caused principally by ageing, suppression, competition, by chance or “normal” weather circumstances and from normal incidence of pests and diseases. “Catastrophic” mortality is modelled in the module on disturbances (see par 4.6). (Vanclay, 1994).

Only mortality of whole trees is explicitly modelled, and is expressed as a number of trees per ha that dies with a mean height, diameter and volume. Two different kinds of “regular” mortality are distinguished:

- Density independent mortality, described as a random function (Vanclay, 1994)
- Density dependent mortality, caused by competition and suppression and based on the theory of self thinning (Reineke, 1933; Yoda et al., 1963).

Open space in the stands is filled by ingrowth of young trees. This is expressed as number of trees per ha that exceed a minimum diameter. Ingrowth depends on the “free space” in a stand, following from the theory of self-thinning. For some stands, with distinctive generations of trees, the new trees remain in a cohort of their own. For other, unevenaged, stands with a more smooth age distribution, ingrowth is part of the existing cohorts. No data of young trees are available from NFI, nor are there any data on regeneration or ingrowth rates. Thus, an analytical approach is chosen, and data are collected on a more ad hoc basis. Currently, a database with repeated (2x) surveys of forest reserves in The Netherlands is used for model development.

For decomposition of large wood and litter, as well as carbon cycling in the soil, the soil model Yasso (Liski et al., 2005) is implemented. This model has been developed for forest soils and is already in use for European applications in combination with the EFISCEN model. Initialisation will be based on the European Soil Carbon map, with a species specific profile. Modelling the soil dynamics of mixed stands will be difficult and we will probably resort to refrain from any interaction effects between the litter of different species in the same stand.

The current management module is based on stochastic harvesting with chances increasing with age and volume. This is a very simple management and will be developed further.

## **5.3 INPUT DATA**

### **5.3.1 Tree species distribution**

In order to simulate forest development at the 1 km x 1 km resolution, first the distribution of tree species over Europe should be predicted at this resolution. For the 20 species-groups that are considered, distribution maps are modelled based on the available NFI plots and the ICP plots (Figure



1) in combination with ancillary maps (biogeographic regions, elevation, FAO soil map, EFI forest cover map, average rainfall, average temperature, average radiation, country, XY-coordinates). In those areas where NFI plot data are available at a high resolution, the occurrence of species is interpolated from the locations of the plots through compositional kriging, while for those areas where NFI plot data were unavailable a multinomial logistic regression was fitted on the ICP plot data and the auxiliary maps. The regression predictions were scaled to fit the regional (NUTS-2) NFI statistics and the whole map was scaled to the European Forest map (EFI). (an extended description will appear in Hengeveld et al. in prep.). The final result is a prediction of the coverage of each tree species for the whole of Europe at the 1 km x 1 km resolution (Figure 3).

### **5.3.2 Initialisation of stand characteristics in a grid cell**

From this map, the occurrence of the species should be translated into an estimate of the stand characteristics at the scale of the km<sup>2</sup>.

To provide an estimate of the stand characteristics for each species group predicted to occur in a km<sup>2</sup>, a NFI plot containing the species is assigned to each predicted species group. These plots (including the other species reported in them) are taken as representative of the area predicted to be covered by the species. Species predicted to occur below a threshold of 1 ha are neglected. This will result in a map with for each grid cell a number of forest types completed with initial values for the core variables characterizing a stand in the dynamic forest model (Figure 2)

The subset of NFI plots from which plots are chosen, is determined first by the sample region of the NFI-plots; within NFI-sample regions for which plots are available, only those plots taken within this region are used. If the grid cell is within a region for which NFI-plots are unavailable, the subset of NFI-plots is determined by those plots that fall within the biogeographical region (Figure 4). As biogeographic region are large and are an important variable to predict species occurrence, it is not likely that any species will be found in a biogeographic region with no corresponding plots to draw data from. If this would occur, however, this species would be drawn from the whole database.

For a large part of the NFI plot dataset, all necessary variables are available. However, a substantial part of the dataset is yet incomplete. "Incomplete" sets vary from NFI regions where only species and age are available, to regions where only one basic variable is missing (for a list of basic variables see table 2). If only one or two variables are missing, and these can be estimated from the ones that are available, the stands are drawn from the regional NFI plot database, and established relations between variables (e.g., diameter - height) are used to fill the missing variables. If variance in these relations is important in the simulation, an error term may be added to create it.

If however one or very few variables are available, it is not yet clear how this information can be used. One option would be to use it along with species to narrow down the number of plots from which to draw from the total set available in the biogeographic region.

This way natural stand characteristics are preserved and both the local distribution of mixed-species and monoculture stands and the local combination of species can be maintained.

Correspondence with the NUTS-2 NFI statistics on growing stocks hopefully comes natural with the proposed approach (most likely only in the regions where the NFI-plots are available). If the discrepancy between predicted and reported statistics is too large, stands need to be either grown or reduced in age and volume to scale the prediction to the reported statistics. This scaling will involve the use of the growth model described in chapter 4.





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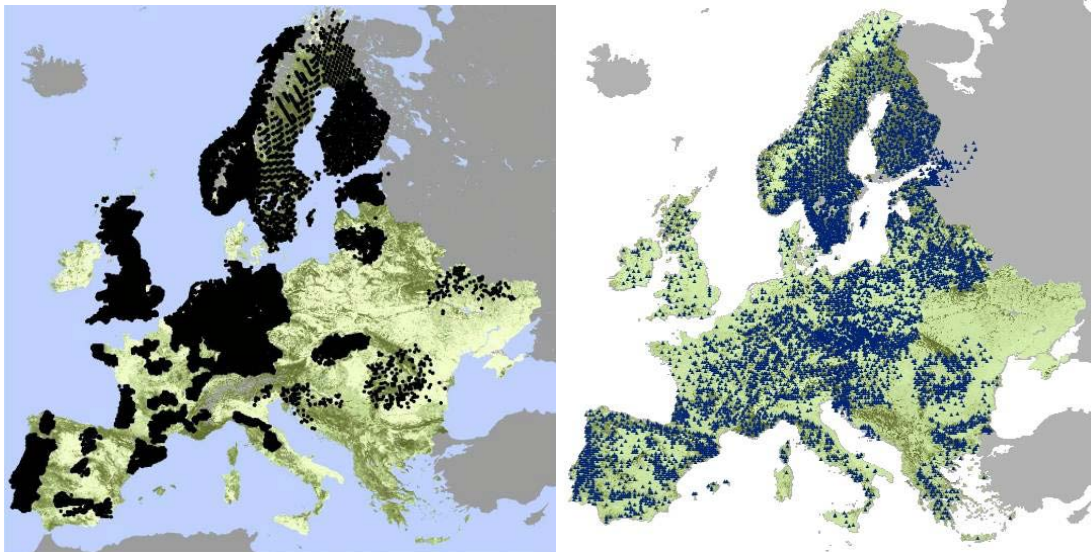


Figure 2: Location of the National Forest Inventory plots (left) and ICP forest plots (right) over Europe

**Table 1:** Tree species groups distinguished for the tree species map and the model

<b>Main tree species (groups) in Europe</b>	<b>Total Surface (kha)</b>
Abies spp.	3715
Alnus spp.	3571
Betula spp.	13377
Carpinus betulus	2100
Castanea sativa	1332
Eucalyptus spp.	1169
Fagus sylvatica	11531
Fraxinus spp.	1984
Larix spp.	1319
Other broadleaves	7232
Other conifers	730
Other Pinus spp.	7414
Other Quercus spp.	9583
Picea spp.	32863
Pinus pinaster	5596
Pinus sylvestris	48840
Populus spp.	2046
Pseudotsuga menziesii	847
Quercus robur + petraea	12343
Robinia pseudoacacia	582

**Table 2.** The variables asked for in the NFI plot data enquiry: (note that it differs per country what was received)

1. X coordinate
2. Y coordinate
3. Main tree species (scientific name)
4. Age (y)
5. Recording year (y)
6. Mean height (m)
7. Mean diameter at breast height (cm)
8. Minimum diameter at breast height (cm)
9. Maximum diameter at breast height (cm)
10. Stem number (N/ha)
11. Basal area (m<sup>2</sup>/ha)
12. Growing stock volume (m<sup>3</sup>/ha overbark)
13. Volume of dead trees (m<sup>3</sup>/ha overbark)
14. Net annual volume increment (m<sup>3</sup>/ha.y overbark)
15. Harvesting volume (fellings, overbark, m<sup>3</sup>/ha.y)



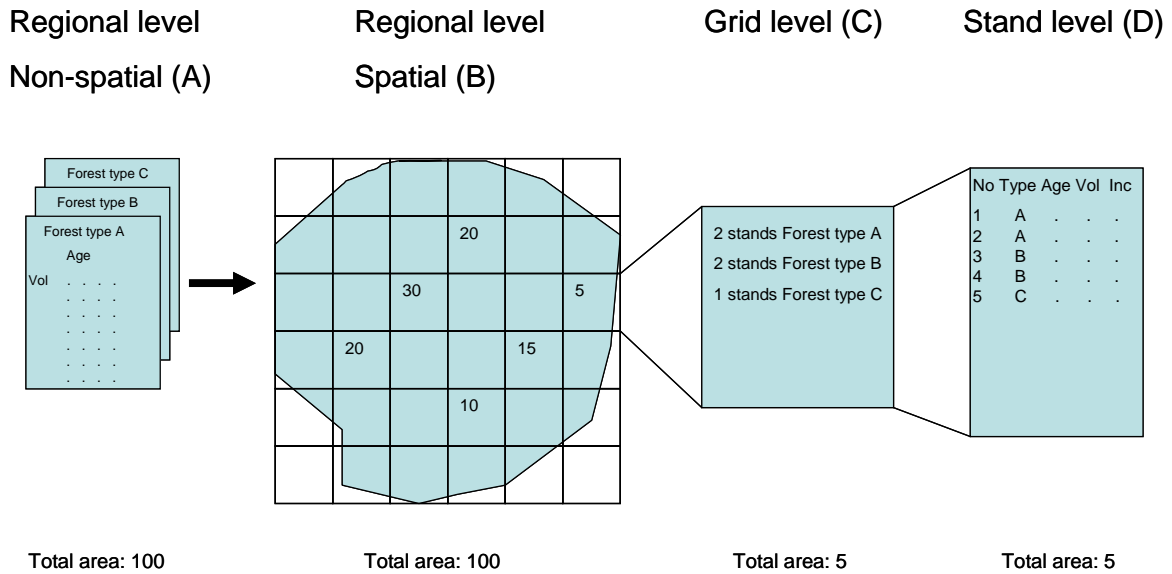


Figure 3. Schematic representation of initialization procedure of EFISCEN-SPACE. Forest inventory data are converted into matrixes of forest areas within age (including a category uneven aged) and volume classes at the regional level (A). Matrixes are subsequently converted into spatial maps (at the regional level) with the forest area indicated for each 1km x 1km grid cell (B). At the grid level, the surface for each forest type is recorded using the chance of occurrence of each species and national forest statistics (C). Note that we do not keep track of the location of the forested area within the grid cell. Finally, initial variables of each forest type are recorded, such as species composition, age structure, volume and increment (D).

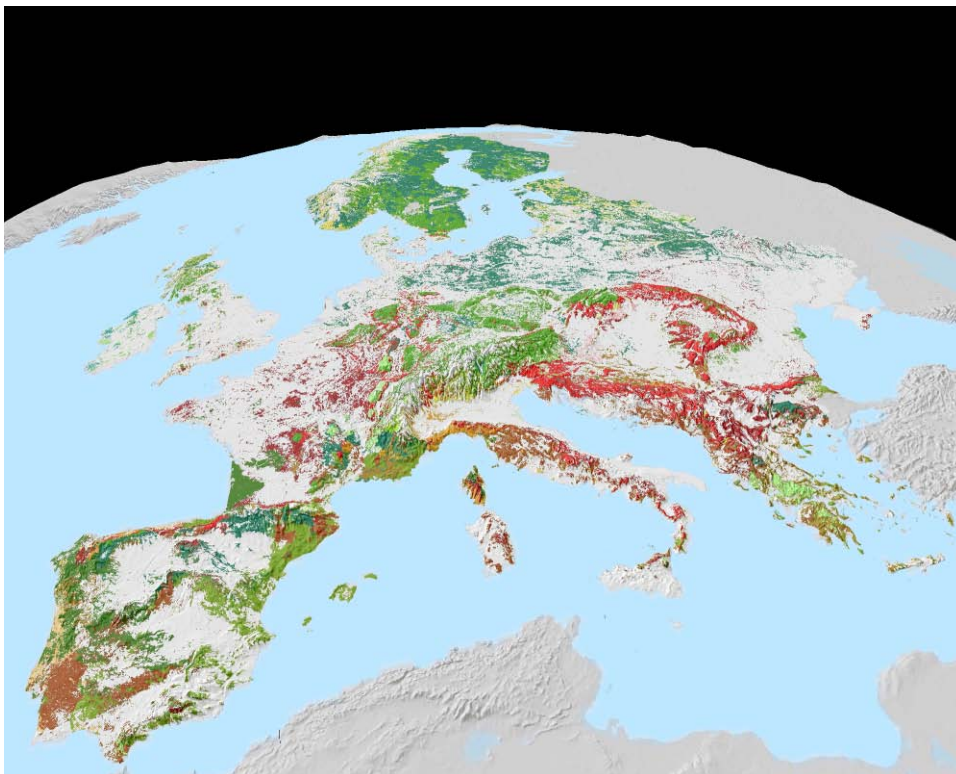


Figure 4. Tree species for Europe for 20 tree species. Each gridcell represents the dominant tree species. Only gridcells with a forest cover larger than 25% are shown.

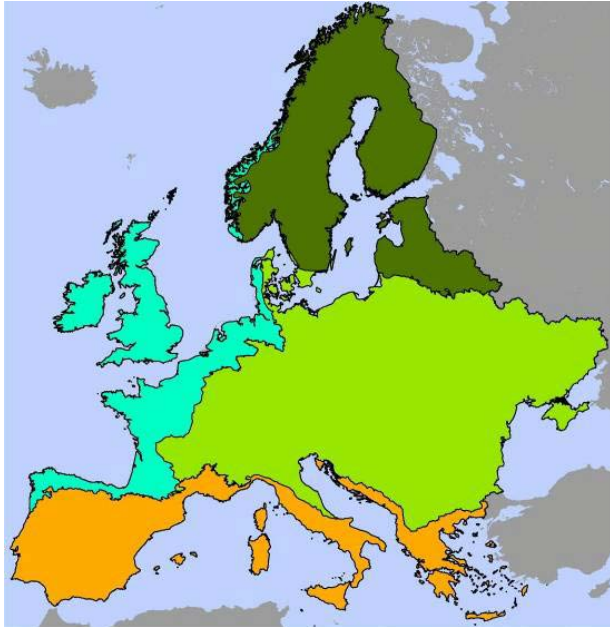


Figure 5. The biogeographical regions as used in EFISCEN Space.

## **5.4 DRIVERS AND SCENARIOS: HOW ARE THEY IMPLEMENTED**

Efiscen Space can simulate the consequences of changes in management regime or other disturbances and climate.

Scenario's that include a changing climate need to produce maps over Europe with the new climate variables. As the model is now, new values are needed for annual mean temperature, temperature seasonality, annual precipitation, variability of precipitation and precipitation in the warm season.

Scenario's that include changes in management regime need to produce new rules for application of management based on the variables that are taken into account in the model. It is also possible to simulate with prescribed management regime. In this case, a European map with management regimes need to be produced, defined in terms of the definition of management regimes as given above (). Similarly, other disturbances that result in the removal or death of part of the standing volume can be defined. In the future, it will be possible to use predefined disturbance modules (fire, windthrow) for that end.

## **5.5 SUSTAINABILITY INDICATORS: WHICH ARE CONSIDERED AND HOW ARE THEY ESTIMATED**

### **5.5.1 Above- and below ground biomass & carbon**

The calculated stemwood volumes are converted to stem biomass by using the basic wood density (dry weight per green volume). Based on the stem biomass, the model calculates the biomass of branches, coarse roots, fine roots and foliage. For this calculation the model requires biomass distribution tables, depending on diameter at breast height. These tables can be based on the results of more detailed models or on literature values, for example from literature on biomass expansion factors (BEFs).



The biomass distribution tables are defined by regions and tree species. For the conversion to carbon, the carbon content of biomass is also needed. Figure 3.4 illustrates the conversion from stemwood volume to estimates of whole tree carbon. Many of these expansion factors have been derived for the EFISCEN V3 model and can be used for EFISCEN-Space.

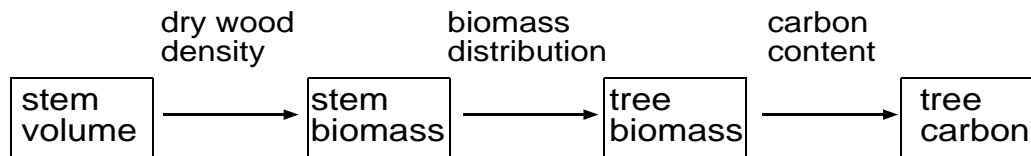


Figure 3.4: Calculation of biomass and litter

### 5.5.2 Litter production & dead wood: turnover of above- and below ground biomass

Each year, a proportion of the stems, branches, roots and leaves of the trees die, the so-called turnover. The produced branches, roots and leaves is input for the soil module. To calculate litter production, the proportion of annual litterfall of the standing biomass is needed. Also, when a thinning or final felling is carried out, all biomass of the other tree components is added to the litter production and thus litter production depends on the harvest level in the region. Litter is decomposed following the Yasso soil model (Liski et al, 2005).

For dead wood, the death of whole stems due to regular mortality (see above) and the remaining of felled stem volume in the forest is taken into account. The later is defined by the ratio between removals and fellings. Usually this is wood that is considered to be non-commercial, e.g. due to too small diameter (topwood) or presence of rot. Dead wood decomposes with a region specific turnover rate .

### 5.5.3 Regeneration

The area where regeneration occurs is known from the regeneration module. A distinction can be made between natural regeneration and planting or seeding, as well as per species. The area with regeneration can be summed at various spatial scales and is a good indicator for the sustainability of the European forest resources.

## 5.6 CASE STUDIES

The European case study was run with EFISCEN, the conceptual predecessor of Efiscen Space.



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## 6 CONCLUSIONS

This deliverable summarizes the research undertaken under EFORWOOD for the development of Regional forest simulators and of the new version of the European forest simulator EFISCEN.

Three Regional forest simulators are now available, for Portugal (sIMfLOR), Sweden (RegWise) and France-Aquitaine (Sylvogene). These simulators can be used to make analysis of the future sustainability of forests within a certain region under alternative scenarios. The input data are the National Forest Inventories. The conception of the simulators is similar but they show some differences in what concerns the drivers than can be included in the scenarios and/or the indicators that are annually predicted over time. As a set, they are important tools for the regions for which they were developed and also because they are the basis for the development of new improved versions but also for the development of Regional forest simulators for other regions.

The EFISCEN-space represents a large improvement in relation to the present version of EFISCEN, which is still the one being used for the analysis of European forests. These improvements relate not only with the resolution of the simulator and the use of growth models instead of yield tables, but also with the quality of the forest inventory data that is now available on the data base used to feed EFISCEN.

The next step will be to compare simulations by EFISCEN-space and the Regional forest simulators, so that one can assess how well a general model, developed for the whole Europe, performs when applied to a specific region within Europe.