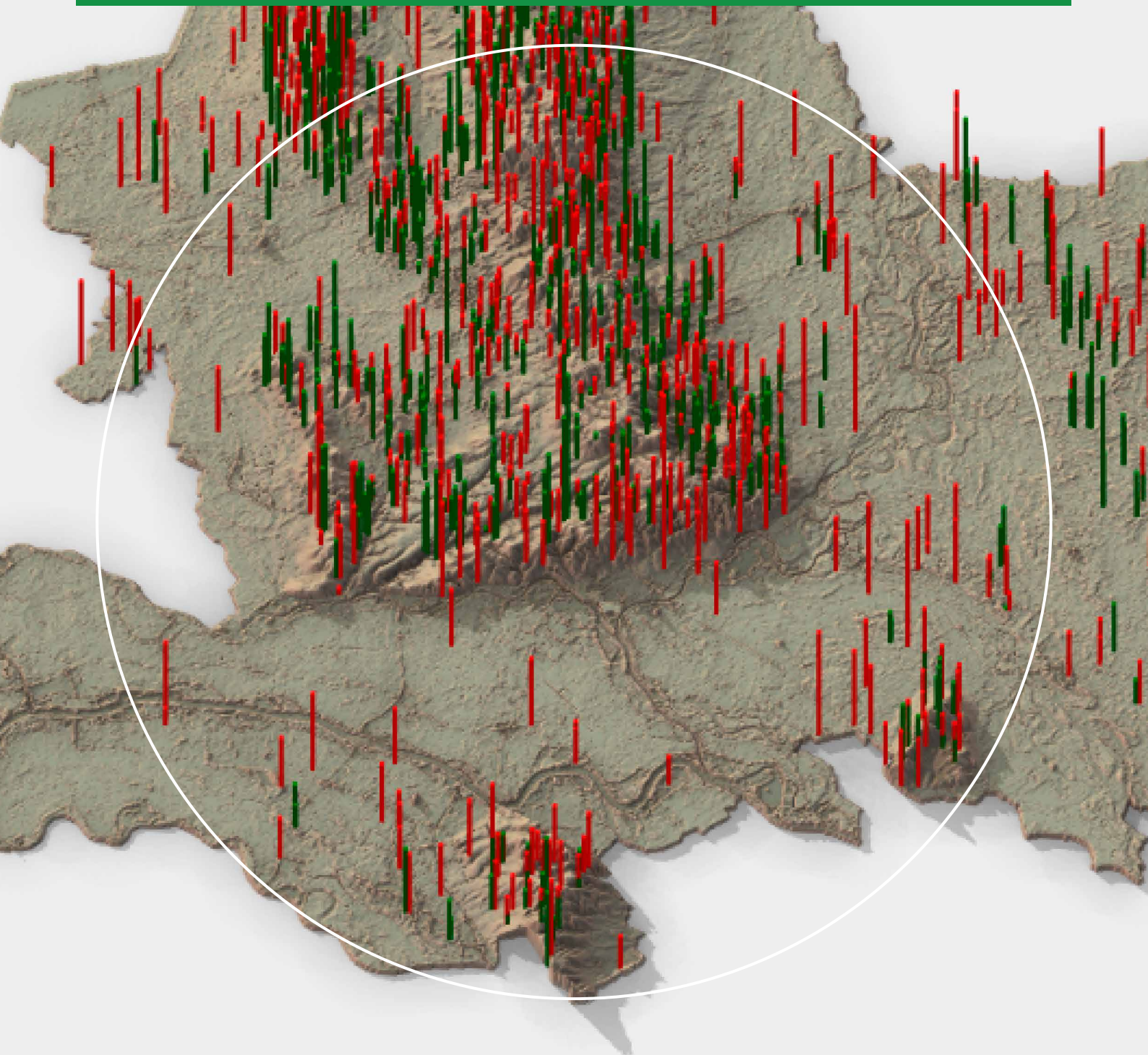# EFISCEN-Space 1.0 model documentation and manual

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EFISCEN-Space 1.0 model documentation and manual

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EFISCEN-Space is een model om projecties van bossen te maken, waarmee inzicht verkregen kan worden in de toekomstige ontwikkeling van de bossen in Europa. In vergelijking met zijn voorganger EFISCEN kan dit model overweg met meer vormen van bosbeheer, voor meer verschillende bossituaties, op een hogere ruimtelijke en temporele schaal. Het is ontworpen voor studies over duurzaam bosbeheer, mogelijkheden voor houtoogst, trade-offs tussen verschillende bosecosysteemdiensten onder alternatieve vormen van bosbeheer en koolstofbalansen. Dit rapport beschrijft de geschiedenis van ontwikkeling en gebruik van EFISCEN-Space en de huidige staat van het model. Het bevat een gebruikershandleiding, een verificatiehoofdstuk en een lijst met geplande ontwikkelingen.

EFISCEN-Space is a forest resource projection model, used to gain insight into the future development of European forests. Compared to its predecessor EFISCEN, it is able to model a wider variety of management systems and forest situations, at a higher spatial and temporal detail. It is designed to study issues such as sustainable management regimes, wood production possibilities, trade-offs between different forest ecosystem services under alternative management regimes and carbon balance issues. This report describes the history of development and use of EFISCEN-Space and the current state of the model. It contains a user guide, a verification chapter, as well as planned future developments.

Keywords: EFISCEN-Space, forest scenario model, European forests, diameter class distribution model

In 2003 Wageningen Environmental Research implemented the ISO 9001 certified quality management system.
Since 2006 Wageningen Environmental Research has been working with the ISO 14001 certified environmental care system.
By implementing the ISO 26000 guideline, Wageningen Environmental Research can manage and deliver its social responsibility.

Photo cover: Bas Lerink
Projection of growing stock volume in the province of Gelderland (R package 'Rayshader': Morgan-Wall T (2023). rayshader: Create Maps and Visualize Data in 2D and 3D. https://www.rayshader.com, https://github.com/tylermorganwall/rayshader, https://www.rayshader.com/)

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Verification

Wageningen Environmental Research (WENR) values the quality of our end products greatly. A review of the reports on scientific quality by a reviewer is a standard part of our quality policy.

Approved reviewer who stated the appraisal,

position: Senior Researcher

name: Eric Arets

date: 21 December 2022

Approved team leader responsible for the contents,

name: Nina Smits

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Summary

This manual is intended to provide a status-quo description of the EFISCEN-Space model, V1.0. Forests supply a multitude of services to society, such as the provisioning of timber and recreation possibilities, carbon sequestration, preservation of biodiversity and protection of soil and water. The demand for these services have increased over the last decades, leading to a variety of sometimes contradicting policies. Simulation models are an important tool to evaluate the possible effects of such policies on the forest resources and the future provisioning of services. The European Forest Information SCENario Model (EFISCEN) (Verkerk et al. 2016) was developed for such studies and has been in use since 1995, but the core of the model dates back to the late 1980s (Sallnäs 1990). EFISCEN is a large-scale forest matrix model that projects forest resource development on regional to European scale. The model is suitable for the projection of (mostly even-aged) aggregated, age class based, forest resource development for a period of 50 to 60 years, using aggregated data from National Forest Inventories (NFIs). The advantage of EFISCEN is that it is a rather simple and robust empirical model, with modest requirements on input data, and flexible with respect to the level of input data aggregation and data sources. However, disadvantages of EFISCEN are the 5-year time step (not allowing to distinguish annual CO_2 balances), a lack of direct climate forcing, a very coarse spatial resolution, the assumption that all forest can be modelled on an age-class basis and limited options to include management. To overcome these limitations, investigations for a new simulation model started around 2006 (Nabuurs et al. 2007, 2010). This development was facilitated by the fact that detailed National Forest Inventory (NFI) data was gradually becoming more available, plus great developments in computer science with regards to data storage and processing power.

Different concepts were tested over time in various projects alongside the build-up of knowledge and databases of both NFI data and potential predictor variables, resulting in the version of EFISCEN-Space (V1.0) as described in this report. The current shape of the model was mostly developed in the SIMWOOD project (2013-2017), demonstrating for the first time the capability of the model to run in 10 different regions in Europe, focussing on wood mobilisation potential (Kerr et al. 2017). This resulted in the publication of the increment model (Schelhaas et al. 2018a) and the analysis of harvest and management patterns as used in EFISCEN-Space (Schelhaas et al. 2018b).

The following requirements were formulated when designing the EFISCEN-Space model:
1. To be applied in similar studies as the EFISCEN model, and for similar timeframes, i.e. realistic quantitative projections of forest development up to 40-50 years and realistic qualitative projections up to 100 years.
2. To be able to simulate a wide array of management systems, including uneven-aged systems and non-managed systems.
3. To be able to deal with species mixtures, in a dynamic way.
4. To have a spatial resolution that allows easy integration of GIS data and increased possibilities of visualisation of outputs.
5. To be able to provide more detailed output on timber assortments, in terms of size and species.
6. It should be empirically-based (data-driven).
7. It should be possible to use climate-change scenarios as direct input.

From these requirements we summarise EFISCEN-Space as:
'The core of EFISCEN-Space is the geographically explicit modelling of forest development in Europe at the forest stand level, based on empirical NFI tree-wise plot data, driven by environmental datasets that have a pan-European coverage, under realistic forest management conditions. The functionality is or can be extended to cover aspects such as carbon in biomass, soil and harvested wood products, biodiversity & ecosystem services indicators and economic indicators. EFISCEN-Space is modular, such that depending on the aim of the application and resources available, modules can operate on different levels of detail, or can be excluded if not relevant. EFISCEN-Space is not intended to replace existing national models, but should be able to simulate the forest of any European country in a consistent way'.

EFISCEN-Space is under continuous development. This report describes the state of the model at July 1 2022, referred to as EFISCEN-Space 1.0. Not all the initial requirements are realised yet in the current version, and not all functionality has been fully tested yet (see also Section 5 Discussion). V1.0 features a full increment model, a full biomass model, a coupled soil carbon model and cost estimation of harvest activities. Detailed ingrowth and mortality modules are still under development, as well as a more detailed management module to allow more flexible and targeted definition of scenarios.

The focus of this report is the description of the plot/stand scale model. In future, the model will be extended to work at the landscape and national scale, which allows introduction of additional processes like spread of disturbances and modelling of supply and demand. Local forest development is modelled at the scale of a 1-ha stand with a known location, called a model stand. The state of this stand at any moment in time is expressed as the distribution of the number of trees over diameter classes, per species or species group. Diameter increment is modelled as the transition of trees to a higher diameter class. Mortality and harvesting are modelled as the removal of trees from specific diameter classes. Ingrowth is modelled as the increase in stem number in specific diameter classes (ingrowth/planting). At the level of the model stand we distinguish the ecological processes of tree growth, tree mortality, tree ingrowth and soil biomass decomposition, and the management processes tree harvesting and tree planting. The known location allows coupling of the modelled processes to exogenous location descriptors in terms of soil, weather and climate as is for example done for the increment model (Schelhaas et al 2018a). The model stands are initialised using data from forest inventories, both in terms of diameter distributions as well as the total area the plot is representing. This is most commonly done using NFIs, but can also be done using data from stand wise inventories or data from management planning databases.

The report includes a description of the concepts, formal model, implementations and associated data of the different modules of the EFISCEN-Space plot level model (Chapter 2), a brief technical description of the source code structure and an extensive operation manual/user guide including full definition of the input files (Chapter 3) and an evaluation of the performance of the model in terms of implementation testing, a partial sensitivity analysis and validation of the modelled patterns to external data sources (Chapter 4). Chapter 5 places these analyses in the context of the requirements formulated for the model and formulates directions of further model development.

Model output in terms of volume of wood or timber proved to be very sensitive to the use of different volume models. Still, simulated average growing stock at the country level proved to be quite accurate. Harvest and natural mortality are currently implemented as fixed fractions per diameter/species group, as derived from repeated tree-wise NFI observations. The challenge is to develop a new harvest routine that is more flexible, taking into account current stand conditions and current and possibly future aims, without the need of extensive parameterisation all over Europe. This also calls for a dynamic mortality model that is responsive to different types of harvesting. However, a major challenge in this respect will be to disentangle the effects of natural mortality and harvesting.

The built-in YASSO15 model allows to simulate soil carbon stocks with EFISCEN-Space for mineral soils. YASSO15 receives its input from litterfall from living trees, slash generated by harvesting activities, and biomass input as a consequence of natural mortality. A comparison at the plot level for the Netherlands and Italy shows that the average and distribution of simulated values align quite well with measured values, but that the model is unable to predict values accurately at the plot level. The simulated values for other countries match reasonably well with observations but YASSO15 generally seems to show an overestimation. The sensitivity of YASSO15 to more specific biomass models and turnover rates allows to fine-tune the simulations further to national conditions in future.

Overall we conclude that EFISCEN-Space gives an accurate simulation of the future development of forest resources in Europe at the national level, with a good spatial representation within the country. Differences between observed and simulated values at the plot level increase over time, but the overall distributions over species, diameter classes and volume classes remain satisfactory at least for simulations up to 20 years.

For the most important species the forest structure and increment are well represented, while marginal species show more deviations due to the use of common parameters for pooled species. For events within

the forest development (e.g., mortality, ingrowth, management) the current methods rely on statistics averaged over many observations. These methods fail to grasp the extremes of the impact of these events and future versions of the model should incorporate more locally attuned or process-descriptive models to allow for a finer-grained agreement with observed forest development. Furthermore, some of the components of the model need to be considered experimental, given the lack of validation on these components (e.g., management time & costs and the possibility to use annual data from climate change scenarios as input). Many of the objectives set for the model have been met, but work is especially needed on the management/harvest module, the ingrowth module and the natural mortality module. Furthermore, the model has great potential for further development for example with regard to harvested wood products, linkage to a demand model, initialisation based on remote sensing data, development of indicators of different forest ecosystem services (biodiversity, recreation, groundwater recharge), natural disturbances.

1 Introduction

1.1 About this manual

This manual is intended to provide a status-quo description of the EFISCEN-Space model, V1.0. Chapter 2 describes the concepts, formal model, implementations and associated data of the different modules of the EFISCEN-Space plot level model. Chapter 3 provides a brief technical description of the source code structure and an extensive operation manual/user guide including full definition of the input files. Chapter 4 details a number of evaluation activities that have been performed. These evaluations deal both with implementation testing, sensitivity analysis and validation of the modelled patterns to external data sources. Chapter 5 finally places these analyses in the context of the requirements formulated for the model and from this formulates directions of further model development.

1.2 Background

Since 1995, the European Forest Institute (EFI) and Wageningen Environmental Research (WENR) and its predecessors have intensively cooperated in European forest resources projection studies. Together the institutes developed the European Forest Information SCENario Model (EFISCEN). The core of the EFISCEN model was developed in the late 1980s for Sweden by Prof. Ola Sallnäs at the Swedish Agricultural University (Sallnäs 1990). The first European application of this model was carried out by the International Institute for Applied Systems Analysis (IIASA) in the early 1990s (Nilsson et al. 1992). The model was transferred to EFI in 1996 and given the name EFISCEN (version 1.0). Over time, the model has been developed further (Nabuurs et al. 2001, 2002 and Pussinen et al. 2001 (version 2.0), Schelhaas et al. 2007 (version 3.1), Verkerk et al. 2016 (version 4.1)).

EFISCEN is a large-scale forest matrix model that projects forest resource development on regional to European scale. The model is suitable for the projection of (mostly even-aged) aggregated, age class based, forest resource development for a period of 50 to 60 years. EFISCEN uses aggregated national forest inventory data (usually at NUTS2 level) as a main source of input to describe the current structure and composition of European forest resources. Based on this information, the model can project the development of forest resources, based on different scenarios. These scenarios are mainly determined by management actions, but the model can also take into account changes in forest area, as well as (indirectly) changes in growth e.g. due to climate change. EFISCEN 4 is still very much in use and up to date (https://efi.int/knowledge/models/efiscen).

The advantage of EFISCEN is that it is a rather simple and robust empirical model, with modest requirements on input data, and flexible with respect to the level of input data aggregation and data sources. However, EFISCEN also had a number of disadvantages:
- It runs at a 5 year time step, not allowing to distinguish annual CO_2 balances.
- It can only deal with changes in growth (due to climate change or deposition) indirectly, by using the output generated by other (process-based) models.
- It was developed as an even-aged forest management model, hardly able to deal with forests that are uneven-aged or mixed, and unable to simulate management approaches other than the classical thinning-clearfelling method. A broad trend in European forestry is however towards increased use of more nature-oriented types of management, such as continuous cover forestry (CCF) (Mason et al. 2021).
- The data from countries which have only a diameter recording in their national forest inventory (i.e. not age) like in Italy, Spain and parts of France, can only be used after a transformation to age.
- The aggregated inventory data at NUTS2 level made it very difficult to link the location of specific forest types to spatially explicit information sources like soils, road accessibility, nature protection zones, industry location or climate.

To overcome these limitations, WENR started to investigate possibilities for a new simulation model around 2006 (Nabuurs et al. 2007, 2010). This development was facilitated by the fact that detailed National Forest Inventory (NFI) data was gradually becoming more available, plus great developments in computer science with regards to data storage and processing power. Different concepts were tested over time in various projects alongside the build-up of knowledge and databases of both NFI data and potential predictor variables, resulting in the version of EFISCEN-Space as described in this report. The current shape of the model was mostly developed in the SIMWOOD project (2013-2017), demonstrating for the first time the capability of the model to run in 10 different regions in Europe, focussing on wood mobilisation potential (Kerr et al. 2017). This resulted in the publication of the increment model (Schelhaas et al. 2018a) and the analysis of harvest and management patterns as used in EFISCEN-Space (Schelhaas et al. 2018b). In parallel it was applied to the Netherlands in the ALTERFOR project (2016-2020), focussing on the delivery of ecosystem services under alternative management systems and climate change conditions (Nordström et al. 2019, Biber et al. 2020). Other applications to the Netherlands are a scenario study at national scale by Nabuurs et al. (2016) and for the province of Gelderland by Vural Gursel et al. (2021) and the development of the Forest Reference Level for the Netherlands (Arets and Schelhaas 2019). It was furthermore used in specific situations in the Netherlands to quantify the potential mitigation effect of Climate Smart Forestry measures as published in the Toolkit Climate Smart Forest and Nature Management (Lerink et al. 2021). The specific analysis of forests taken out of production is described in detail in Den Ouden et al. (2020). In the VERIFY project (2018-2022), EFISCEN-Space was applied successfully to 15 countries in Europe (see Section 4.11), focussing on the carbon balance of the forest at a resolution of about 14 km.

1.3   Features and application area of the model

The following requirements were formulated when designing the EFISCEN-Space model:
1. To be applied in similar studies as the EFISCEN model, and for similar timeframes, i.e. realistic quantitative projections of forest development up to 40-50 years and realistic qualitative projections up to 100 years.
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EFISCEN-Space is intended to be used for national to European scale studies on the development of forest resources and the delivery of ecosystem services under various scenarios of forest management, policy and climate change. It should thus be able to address questions like:

- What are the European wood resources, by assortment and species, in a spatial resolution of ~10 km, for up to 50 –100 years in future, as well as carbon stocks and fluxes in forest biomass and soils?
- What is the climate mitigation potential of the European forest sector at short and long term?
- What would be the effect of large-scale adaptation measures in forest management?
- How much more wood could be harvested sustainably, and where, when prices increase, or if management is intensified? Which assortments will become available in mid to long term?
- What is the effect of increased focus of forest management on nature conservation and impacts of disturbances on available wood and biomass?
- What is the effect of climate change on delivery of forest ecosystem service provisioning?

EFISCEN-Space is under continuous development. This report describes the state of the model in July 1 2022, referred to as EFISCEN-Space 1.0. Not all the initial requirements are realised yet in the current version, and not all functionality has been fully tested yet (see also Section 5 Discussion). V1.0 features a full increment model, a full biomass model, a coupled soil carbon model and cost estimation of harvest activities. Detailed ingrowth and mortality modules are still under development, as well as a more detailed management module to allow more flexible and targeted definition of scenarios.

2 Model description

2.1 Model overview

Within EFISCEN-Space, the processes that shape the forest are split over three scales (Figure 2.1):

1. The stand scale, at which the biological processes of growth, mortality, establishment and soil formation and the management activities take place.
2. The landscape level at which different plots or stands are connected and at which dispersal and disturbances spread.
3. The regional, country or continental scale that defines the economic market at which forest products are traded and the political reality within which legislation is defined.

The focus of this report is the description of the plot/stand scale model. Working at the landscape and national scale allows introduction of additional processes like spread of disturbances and modelling of supply and demand. These processes are currently not implemented, but can be developed in the future.

Local forest development is modelled at the scale of a 1-ha stand with a known location, hereafter referred to as a model stand. The state of this stand at any moment in time is expressed as the distribution of the number of trees over diameter classes, per species or species group. Diameter increment is modelled as the transition of trees to a higher diameter class. Mortality and harvesting are modelled as the removal of trees from specific diameter classes. Ingrowth is modelled as the increase in stem number in specific diameter classes (ingrowth/planting). At the plot level we distinguish the ecological processes of tree growth, tree mortality, tree ingrowth and soil biomass decomposition, and the management processes tree harvesting and tree planting. The known location allows coupling of the modelled processes to exogenous location descriptors in terms of soil, weather and climate as is for example done for the increment model (Schelhaas et al 2018a). In future, interactions with processes operating at the landscape level and/or country level can be added (Figure 2.1), but these are not part of the EFISCEN-Space 1.0.
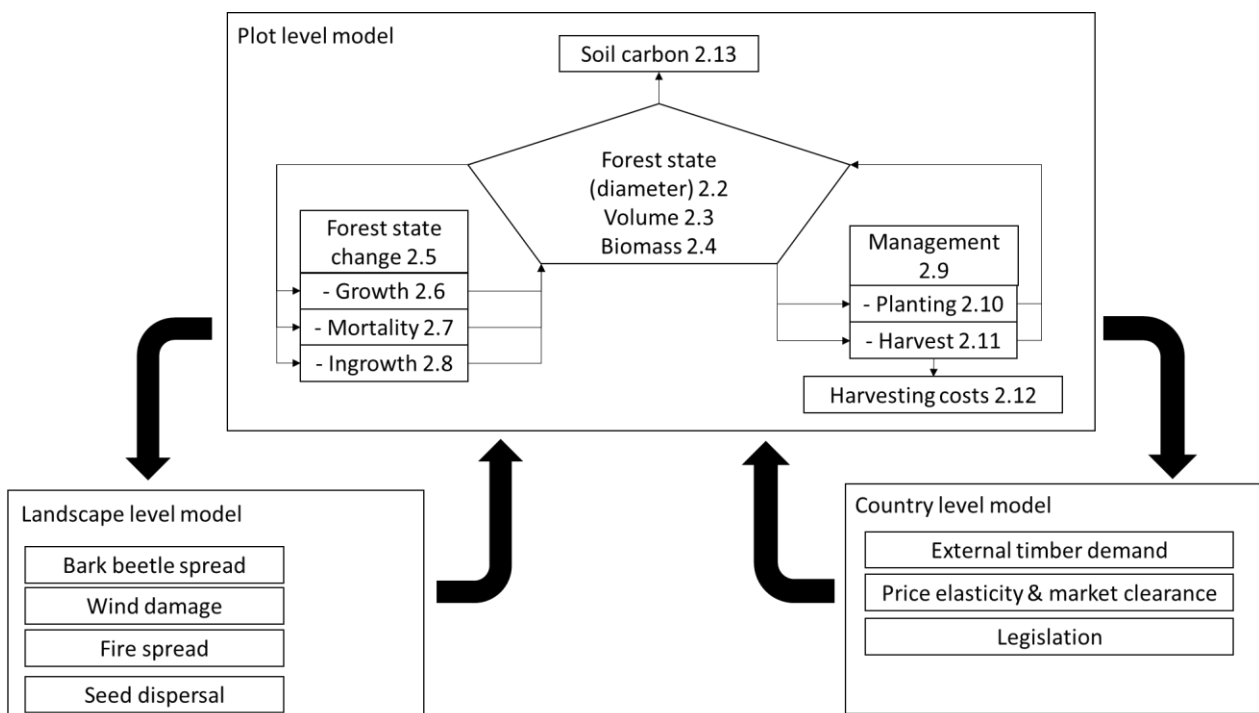
Figure 2.1   *The conceptual split of processes that impact forest development over different scales.*

2.2 Forest state

2.2.1 Concept

National forest projection models come in a large variety, representing the forest state at various levels of aggregation – from individual trees to regionally summed volume (for an overview see Barreiro et al. 2016). Each of these approaches strike a balance among the level of detail at which processes can interact with the variation within the forest with (a.o.) the availability of data, uncertainty propagation and speed of calculation. In reflection of the main specifications for EFISCEN-Space, we come to the following conceptual description of the forest unit.

The forest unit simulated in EFISCEN-Space is a forest stand of 1 ha, hereafter referred to as 'model stand'. The forest stand is assumed to be a collection of trees, defined by tree species and diameter at breast height (DBH). Trees with a height lower than breast height (1.3 m) are not represented. For simplified representation, trees are grouped into a limited number of species groups and diameter classes. Within the model stand all trees share the same environmental pressures (soil type, deposition, radiation, temperature, etc.). Within a specific diameter class of a specific species-group all trees in a model stand share the same ecological pressures (competition for light, water etc.). All trees within a certain combination of species-group and diameter class are considered to be equal with respect to diameter, basal area, volume and biomass. Tree species groups are internally homogeneous in their functional response to external stimuli and diameter status. Within the model stand, there is no spatial information on the position of trees. A model stand is assumed to represent a forest area of a specific size and to have a single management regime (see Section 2.9 Management).

2.2.2 Formalisation

The forest state of stand p is represented formally as a $N_p \times D$ matrix of N_p tree species groups within stand p and D diameterclasses. The values in this matrix represent number of trees per hectare.
For each diameterclass i, $d_{i,min}$, $d_{i,mid}$, and $d_{i,max}$ define minimum, mid and maximum diameter, such that $d_{i,min} = d_{i-1,max}$.

2.2.3 Implementation

Each model stand is represented by an instance of the class *plot*. Each *plot* contains instances of the class *plotXspecies* for the individual species treenumbers per diameterclass (initialised from the file plotNrPerHa.csv). Each plotXspecies instance refers to an instance of Species, prescribing the diameterclass-limits (defined in speciesParameters.csv) and parametersets for volume (volumeParameters.csv), biomass (BranchesParameters.csv, FoliageParameters.csv, RootsParameters.csv, WoodDensityParameters.csv), increment (speciesParameters.csv) and mortality models (mortalities.csv) for all regions. The plot (plotAttributes.csv) contains the location both in coordinates and in all regionalisations. For a full description of these classes and their implementation, we refer to Chapter 3.

2.2.4 Data

To initialise the model, data can be derived from a forest inventory, or using artificially generated stands. The first approach is used to generate projections for the area where the inventory is carried out, the second approach is usually applied to test model behaviour under specific conditions. All types of inventory data can be used for EFISCEN-Space, as long as they can be used to construct diameter distributions by tree species for a range of stands, and relate to a specific area. Statistical forest inventories consist of a certain number of inventory plots, which together are considered to represent the forest area under study. Plots are generally small, usually with a radius of 5-20 m, with densities varying from 1 per ha for monitoring for example forest districts to 100-2000 ha in National Forest Inventories (NFI). In stand-wise Forest Inventories (SFI), all stands are described in terms of species composition and area. In EFISCEN-Space, each inventory unit (NFI plot or SFI stand) is used to initialise a 1-ha model stand with the forest structure properties of that unit (see Section 4.2 for an example), and a representative area equal to the one the unit represents within the inventory. Similar to the inventories itself, the future development of the forest is modelled through the

development of the same set of inventory units. If sample-based inventories are used, the same restrictions apply as in the underlying inventories, i.e. only the total of the plots give a picture of the total development, and single plots do not say anything on the forest in the neighbourhood of these plots.

For internal consistency the diameter classes and species groups are standardised, but these can be modified by the user. EFISCEN-Space uses 40 diameter classes of 25 mm width each, starting from 0-25 mm, and distinguishes 20 species and species groups. These 20 groups (Table 2.1) are constructed so that the most important species in Europe are covered, including species with an important share in Europe as a whole (*Pinus sylvestris* (L.), *Picea abies* L. (H. Karst), *Fagus sylvatica* L., *Quercus robur* L. and *Q. petraea* (Matt.) Liebl., *Betula pendula* (Roth) and *B. pubescens* (Ehrh.)), as well as important species in a certain region of Europe, either in terms of production (like poplar plantations) or in coverage (like *Quercus ilex* (L.) and *Quercus suber* (L.) in the Mediterranean region). Remaining species are merged in three rest groups. Changes in these species groups require re-estimation of all parameters.

Table 2.1 *Species groups and their reason for inclusion: A = important for European coverage; B = important commercial species; C = important for regional coverage; D = rest group (Schelhaas et al., 2018a).*

Species (group)	reason for inclusion	Species (group)	reason for inclusion
Abies spp.	A	*Betula spp.*	A
Larix spp.	A	longlived broadleaves	D
other conifers	D	shortlived broadleaves	D
Picea abies	A	*Castanea sativa*	C
Picea sitchensis	B	*Eucalyptus spp.*	B
Pinus nigra+mugo	C	*Fagus sylvatica*	A
Other indigenous pines	C	Populus plantations	B
Pinus sylvestris	A	*Quercus ilex*	C
Pseudotsuga menziesii	B	*Quercus robur+petraea*	A
		Quercus suber	C
		Robinia pseudoacacia	B

To derive the initial plot state, each live tree recorded in an inventory plot is classified to one of the 20 species groups. Based on the DBH, it is assigned to the appropriate 25 mm diameter class. Furthermore, for each recorded tree it needs to be determine how many trees it represents on a per hectare basis. In most cases, this is simply 1/plot area. For inventories using concentric circles with different DBH thresholds, plot area depends on the DBH of the recorded tree. For inventories using an angle count method, the number per ha is usually given. Finally, all records per plot are summed up, resulting in an initial stem number distribution (N/ha) over 25 mm diameter classes for 20 species groups, for each inventory plot.

2.3 Stemwood volume

2.3.1 Concept

Stemwood volume refers to the volume of wood of a single stem or a population of stems. In a forest inventory this is usually estimated by measuring the diameter of a tree at breast height (dbh), often in combination with an assessment of the height of the tree. It includes the top of the tree and the stump (to ground level) and is generally defined by the main axis of the tree. All volumes in EFISCEN-Space are assumed to be overbark.

Since the direct measurement of volume is very difficult, especially for a standing tree, the estimation of wood volume in inventory and modelling is usually done using species- and region-specific models. Such models are based on the measured dbh and may include height as an additional variable, generally giving more accurate results. In EFISCEN-Space we assume that volume can be estimated based on diameter alone. The estimation of volume is specific for a certain region, allowing for variation in tree shape and height over large gradients in Europe, but neglecting such variation within the regions.

2.3.2 Formalisation

Individual tree volume is estimated using the mid diameter of the diameter class:

$$V_{i,s,p} = N_p F_{vol,s,p}(d_{i,mid}, \beta_{vol,s,p}, V_{min})$$ 2.1

Where $F_{vol,s,p}$ and $\beta_{vol,s,p}$ represent a regionally defined (where region is linked to model stand p), species-specific volume model and parameterset and V_{min} is the minimal volume below which a quadratic descend to the origin is assumed.

Total volume is calculated by multiplying the number of trees (present, harvested or dead) with the estimated volume of the average individual in that diameter class. Different sets of volume functions are available, usually fitted for a region or country.

To ensure positiveness, the $F_{vol,s,p}$ is forced through the origin with a quadratic function up to a minimum volume threshold, and above that threshold, a cubic relationship can be followed:

$$F_{vol,s,p,i,base}(d_{i,mid}) = \beta_{vol,s,p,0} + \beta_{vol,s,p,1}d_{i,mid} + \beta_{vol,s,p,2}d_{i,mid}^2 + \beta_{vol,s,p,3}d_{i,mid}^3$$ 2.2

$$F_{i,vol,s,p}(d_{i,mid}) = \begin{cases} F_{vol,s,p,i,base}(d_{i,mid}), & F_{vol,s,p,i,base}(d_{i,mid}) > V_{min} \\ \gamma_2 d_{i,mid}^2, & F_{vol,s,p,i,base}(d_{i,mid}) < V_{min} \end{cases}$$ 2.3

With

$$\gamma_2 = \frac{F_{vol,s,p,i,base}(d_{j,mid})}{d_{j,mid}^2}$$ 2.4

And j being the first index where $F_{vol,s,p,i,base}(d_{i,mid}) > V_{min}$.

2.3.3 Implementation

Each *plot* has an associated property *volumeRegion (defined in plots/plotattributes.csv)*. Every *volumeRegion* has a distinct set of volume models per species, defined by its functional form (linear, quadratic, cubic) and a corresponding parameter set. These are provided through expansionfactors/volumefunctions.csv.

Stemwood volume is calculated within the class *plotXspecies*. This class has functions reporting volume for standing trees (volume_per_ha), harvest (harvest_m3) and current mortality (mortality_m3).

These functions call the function species.getVolume provided the region and the tree numbers per diameter class for which the volume is calculated.

The volume functions for a species over the regions that are defined are initialized at startup using the function species.createVolumeFunction. At initialisation the quadratic leader function ($<V_{min}$) is constructed.

2.3.4 Data

Volume models are usually derived from NFI data covering a full cycle (i.e. covering the entire population it is representative for). NFI data should include for each tree the species, the measured dbh and the estimated volume using local methods. Regressions are then done by the species groups in EFISCEN-Space, applying linear, quadratic and cubic shapes. The most appropriate shape is then selected for inclusion in the model. The user should be aware that the underlying definition of volume may be different among different NFI datasets, mainly with respect to inclusion of stumps, tops and bark. Wherever possible, it is considered good practice to include stumps and tops and use overbark values for internal model consistency. However, different definitions may be used for better comparison of model results with national estimates. A full list of the volume models used can be found in the espy database. Regionalisations for volume models can be unique, i.e. different from the ones used for biomass or costs.

2.4 Biomass

2.4.1 Concept

For carbon cycle calculations, it is important to estimate the biomass of different parts of a tree.

Conform the old EFISCEN model four tree biomass compartments are considered: stem, roots, branches and foliage. The use of species- and region-specific biomass conversion and expansion models from literature is considered to allow for a sufficient estimate of the biomass.

Analogous to volume, biomass in all tree compartments is first calculated as the average biomass per compartment for one average individual tree in each diameter class, using the midpoint of the diameter class. Total biomass (per compartment) is calculated by multiplying the number of trees (present, harvested or dead) with the estimated biomass (per compartment) of the average individual in that diameter class. By assuming that biomass can be estimated based on diameter alone, variations within a region as a result of differences in site conditions and management history are neglected. The biomass module does not estimate non-tree biomass like herbs and grasses.

2.4.2 Formalisation

In line with the calculation of volume, through volume models fitted on diameter, biomass expansion models are used for estimation of biomass.

$$B_{stem,i,s,p} = N_p F_{bst}\left(V_{d_{i,mid}}, \beta_{bst,s,r_p}\right) \qquad 2.5$$

$$B_{comp,i,s,p} = N_p F_{comp}\left(d_{i,mid}, \beta_{comp,s,r_p}\right) \qquad 2.6$$

With B_{comp,i,s,r_p} the biomass of compartment *comp/stem* (kg) for diameterclass *i*, species *s*, and the plotspecific region r_p, N_p the number of trees/ha in plot *p*, F_{comp,s,r_p} the biomass expansion function for the compartment, species and region, $V_{d_{i,mid}}$ the volume (m³) of a tree in diameter class i with mid diameter $d_{i,mid}$ (cm) and β_{comp,s,r_p} the parameterset specific for this compartment, species and region. The region is determined at plotlevel and can be compartment specific.

The biomass compartment *stem* is calculated from the stem volume and the wood density to avoid discrepancies between calculations of stem biomass and volume. The biomass function for the stem compartment is defined as:

$$F_{bst}\left(V_{d_{i,mid}}, \beta_{bst,s,r_p}\right) = V_{d_{i,mid}} WD_S \qquad 2.7$$

With WD$_s$ the wood density of species *s* (oven-dry weight per fresh volume, kg/dm³) the only parameter in β.

For compartments (comp) *foliage*, *branches*, *roots*, the biomass is directly derived from the diameter and the regionally defined, species specific biomass expansion models. The biomass model for these tree compartments is derived from Forrester et al. (2017) and calculated as:

$$F_{comp}\left(d_{i,mid}, \beta_{comp,s,r_p}\right) = CF\, e^{\ln(\ln\beta_0 + \beta_1 \ln(d_{i,mid}))} \qquad 2.8$$

with CF a correction factor within β, and β$_0$ and β$_1$ parameters.

2.4.3 Implementation

For each compartment, each *plot* has an associated property *<compartment>-biomassRegion (defined in plots/plotattributes.csv)*. Every *<compartment>-biomassRegion* has a distinct set of biomass expansion models per species and compartment, defined by its functional form of F_{comp,s,r_p} and a corresponding

parameter set. These are provided through expansionfactors/<compartment>parameters.csv, where compartment is replaced with "wooddensity" for the compartment stembiomass. Because $\beta_{comp,s,r}$, $V_{d_{i,mid}}$ and $d_{i,mid}$ are static, equation 2.5 and 2.6 result in a species and region specific scalar – calculated in plotXspecies._init() - multiplied by the number of trees/ha in each diameterclass. This multiplication is performed in compartment specific @property functions within plotXspecies.

2.4.4 Data

Forrester et al. (2017) provides parameter values per compartment for most European species, as well as for the generic groups conifers and broadleaves. These generic parameter sets are available in the espy database. Alternative sources of parameters (see for example Zianis et al. 2005) should take the same functional form, or an alternative form should be implemented. For wood density usually the defaults from the IPCC Good Practice Guidance are used (Penman et al., 2003), but could alternatively be derived from other literature sources or local measurements. Regionalisations for biomass expansion models and wood density are independent from each other.

2.5 Forest state change

2.5.1 Concept

The forest state changes during the simulation due to the natural processes growth, mortality and ingrowth and through the management activities harvesting and planting. The model has a temporal resolution of a year. We make a formal distinction between the modelling of the natural processes – through a matrix model approach – and the modelling of management activities.

Based on the representation of the forest stand by diameterclasses, forest change is measured in changes in the distribution of trees over these classes. For the modelling of natural forest change we use a matrix model. Multiple matrix tree growth models are in use (Barreiro et al. 2016). The matrix model approach assumes simultaneous processes of growth, regeneration and mortality, with rates that differ depending on the position in the matrix and possibly other factors.

Management is modelled as events. This allows for management that is conditional on the state and history of the forest stand. Management results in the targeted addition or removal of stems from specified diameterclasses.

2.5.2 Formalisation

For the natural processes, a matrix model approach is used. Within the matrixmodel, tree growth and mortality is discretized to the timestep and size -or age- class size of the model.

$$n_{t+1} = m_t n_t + r_t \qquad\qquad 2.9$$

With n_t the number of trees at timestep t, m_t the growth and mortality rate matrix at timestep t and r_t the ingrowth at timestep t.

Worked out m_t is a matrix with growth and mortality rates:

$$m_t = \begin{pmatrix} a_{1,t} - m_{1,t} & 0 & \dots & 0 \\ b_{1,t} & a_{2,t} - m_{2,t} & 0 & 0 \\ 0 & \ddots & \ddots & 0 \\ 0 & 0 & b_{N-1,t} & 1 - m_{N,t} \end{pmatrix} \qquad 2.10$$

Where $n_{i,t}$ is the number of trees in diameterclass i in year t, $a_{i,t}$ is the fraction of those trees remaining in diameterclass i in year t, $b_{i,t}$ is the fraction of these trees growing to diameterclass i+1 and $m_{i,t}$ is the mortality of trees in diameterclass i in year t. A conservation rule is applied:

$$a_{i,t} + m_{i,t} + b_{i,t} = 1 \qquad\qquad 2.11$$

Trees in the final sizeclass remain there until mortality takes place ($b_{N,t} = 0$) or if they are harvested. The specific assumptions, formalization and implementation of growth, mortality and ingrowth are described separately in sections 2.6 - 2.8. Assumptions, formalization and implementation of management are described in sections 2.9 – 2.11 separately.

2.5.3   Implementation

Forest change is implemented in the class `plotXspecies`. The function `updaterates` calculates the change of the forest (`self.rate`) as the net difference between incoming and outgoing trees per diameterclass. The function `integrate` then adds the change (`self.rate`) to the trees per diameterclass (`self.number_per_ha`).

Do note, there is a rather complicated shift between rates of change and absolute change, that is caused by the interaction between growth and mortality, both as share of the trees within a diameterclass – but a different diameterclass, and the ingrowth which is an absolute number of trees.

Two checks for the mass balance are performed. First the share of trees moving to a next diameterclass is forced to the range of [0,1], since a larger share could occur if the diametergrowth is larger than the diameterclass width. A second check is performed after growth and mortality are combined to force the share of trees moving out of a diameterclass within the range [0,1].

2.6   Tree growth

2.6.1   Concept

Within EFISCEN-Space, tree growth is equated to diameter increment; Multiple diameter increment models can be established (see Schelhaas 2018a for an overview). Although the growth process is continuous, the representation of trees within EFISCEN-Space only allows for tree density within a diameter class and within a given year. Modelling the tree growth within EFISCEN-Space combines two steps:
1. Estimating the annual diameter increment of any tree dependent on the external conditions within that year.
2. Discretizing this increment to the shift in diameter class.

Factors influencing growth are
1. Tree status: diameter.
2. Within-stand ecological interactions: social position (diameter relative to diameter distribution in the stand, with diameter acting as a proxy for height) and total basal area in the stand (crowding).
3. Stand level environmental factors: Weather (short term – annual aggregate), climate (longer term– annual aggregate), soil, deposition.

2.6.2   Formalisation

Tree growth is modelled as the transition from one diameter class to the next. For simplicity, growth is limited to a single diameter class per timestep.

Assuming all trees within a diameter class to be evenly distributed over this diameter class, and the increment to be approximated as linear within the diameter class, the diameter increment is represented by the increment estimated for the mid-diameter of the class.

Following Liang 2010 we simplify

$$b_{i,t} = \frac{\Delta d_{di,mid,p,s}}{d_{i,max} - d_{i,min}}$$

2.12

Where $\Delta d_{(d_{(i,mid)},p,s)}$ is the growth for the mid diameter of the diameterclass and $d_{(i,max)} - d_{(i,min)}$ is the width of the diamterclass. Thus the fraction moving out of the diameterclass i at time t is equal to the growth of the mid diameter tree in that class, divided by the diameter class size.

The diameter increment ($\Delta d_{(i,s,l,t)}$) of species *s*, for diameter class *i*, at stand *l* and time *t* is taken as a function of the focal diameter class ($d_{(i,mid)}$), species specific parameters ($\beta_{(growth,s)}$) and stand information ($p_{(l,t)}$ and p_l).

$$\Delta d_{i,s,l,t} = F_{growth}(d_{i,mid}, p_{l,t}, p_l, \beta_{growth,s})$$

2.13

Endogenous time dependency of $p_{(l,t)}$ is caused by characteristics of the trees in the stand (e.g., basal area and relative social position). Additionally weather and climate forcing can change through time. Other stand-level characteristics (e.g. soil) are not considered to change endogenously, or exogenously and are collected in p_l.

2.6.3   Implementation

EFISCEN-Space 1.0 only contains the implementation of the functional form of the relative growth according to Schelhaas et al. (2018a).

$$\frac{dD}{dt} = \frac{b_1 D + b_2 D_{ln}(D)}{D}$$

2.14

With D diameter at breast height and b_1 and b_2 a linear combination of variables.

The variables to be used are defined in the input file `speciesparameters.csv`. Here the column `rgr` defines the function used (Schelhaas 2018 is currently the only option), further columns define optional parameters with associated position in $F_g growth$. In the current implementation these define B1 and B2 parameters for selected variables, indicated by column names S18$*P_V*. where S18$ is the default prefix for growth parameters for Schelhaas2018 curves, P is the parameter; either B1 or B2 and V refers to the variable used.

Species specific curves are expected for all species used. These species parameters are converted into a growth curve at initialisation of a species within a plot. The class `GrowthFunction` implements the growth curve by species for each plot. At initialization the variables determining growth are split into a static part (p_l), and a dynamic part ($p_{(i,t)}$)(either exogenous to the model, or endogenous).

The function `plotXspecies.updaterates` then calls the relative growth rate and calculates the change in stemnumber per hectare for this species in this plot and time.

2.6.4   Data

Schelhaas et al. (2018a) provides a set of growth functions estimated from a European wide dataset of diameter increment. Alternatively the method used by Schelhaas et al. (2018a) can be used to estimate more locally-specific growth curves as done in Arets and Schelhaas (2019).

2.7 Tree mortality

2.7.1 Concept

Trees can die due to a wide range of causes (Weiskittel et al. 2011). With tree mortality within EFISCEN-Space we mean the natural death of trees, i.e. by other causes than management activities (harvesting of trees is handled in section 2.11 Harvest). Mortality is often separated into "regular mortality" or "background mortality", caused by age, by local ecological interactions (e.g., through self-thinning) or through environmental pressures (e.g., climate change, browsing), and "irregular mortality", caused by natural disturbances and often causing massive mortality, e.g., pest outbreaks, fires, storm damage and drought (Weiskittel et al. 2011). Within the mortality module of EFISCEN-Space we focus only on the regular mortality. In line with the general concepts, we use a data-driven approach. For V1.0 we express the mortality as the fraction of trees to be removed for each species in each diameter class, regardless of the stand conditions.

2.7.2 Formalisation

Natural mortality is simulated in EFISCEN-Space as the removal of a certain number of trees of a certain species in a certain diameter class. Mortality is applied annually. Currently background mortality is applied based on diameterclass, species-specific mortality data.

$$M_{d,s,t} = N_{d,s,t} \left(1 - \left(1 - m_{s,i} \right)^k \right)$$ 2.15

Where M is the mortality in number of trees per diameterclass d, species s at time t, N is the number of stems, m the annual mortality rate (share of trees removed per year) and k is the evaluation interval (defaults to 1 year).

2.7.3 Implementation

The mortalityrate per diameterclass per species is directly imported from the file mortalities.csv and stored as attribute within the class `species`. Within `plotXspecies` the mortalityrate array is initialised within `plotXspecies.init()` and applied within `plotXspecies.updateRates()`.

2.7.4 Data

Schelhaas et al. (2018b) provides diameterclass and species specific mortality rates for European tree species, for the countries included in the study. With all the limitations these data have (see discussion in Schelhaas et al., 2018b), the estimated rates provide the best data currently available with coverage within Europe. For applications outside the countries covered in this study, rates could be used from countries with similar conditions, or mortality rates can be derived from repeated NFI data of the country under study or similar local/national sources.

2.8 Ingrowth

2.8.1 Concept

Ingrowth is defined as the trees which surpass the minimum size threshold in an inventory plot between two time steps. The ingrowth model therefore simulates the appearance of new trees, passing this size threshold, in a single aggregated process. Preceding processes such as seed production, dispersal, germination, seedling and sapling development and self-thinning are not explicitly simulated. As a result, recruitment is considered a continuous process. Recruitment only covers the naturally occurring ingrowth, while artificial ingrowth (planting or seeding) is treated in a separate section. Recruitment is defined as the number of trees per species that are added to a specific diameter class. Natural recruitment is applied every year if parameterised so. The user is free to decide in which diameterclass the new trees will appear, this can for example be aligned with the inventory threshold of the country to be simulated. The user should be aware that trees in the lowest diameter class are assumed to have reached the 1.3 m height threshold.

2.8.2 Formalisation

New trees are 'just-added' to the diameterclass as specified in the input. This is a deviation from the general concept of (Leslie) matrix population models (see 2.2 Forest state), that use a rate per class to generate the first class.

$$r_i, s, t, p = inputvalue_{i,s}$$ 2.16

2.8.3 Implementation

The file `growthandmortality/ingrowth.csv` provides the information needed to simulate ingrowth. The ingrowth (number /ha) per diameterclass per species is directly imported from the file `growthandmortality/ingrowth.csv` and stored as attribute within the class `species`. Within `plotXspecies` the ingrowthrate array is initialised within `plotXspecies.init()` and applied within `plotXspecies.updateRates()`. Within `plotXspecies.updateRates()` growth and mortality are first calculated to the forest change in numbers per hectare before the ingrowth is added.

2.8.4 Data

Data on ingrowth can be derived from repeated inventories such as NFIs or research plots. However, analysis of such data is difficult due to the high stochasticity and differences in NFI designs and thresholds. In V1.0 ingrowth should therefore be set based on expert judgement or scenario prescription.

2.9 Management

2.9.1 Concept

Forest management consists of a coherent set of activities carried out in the forest to achieve certain objectives (Duncker et al. 2012). Such activities can include harvesting, planting, soil cultivation, road construction, fertilisation, fencing, etc. Within EFISCEN-Space 1.0, only thinning-harvesting and planting are included. Contrary to the ecological processes, forest management activities are modelled as events that change the forest structure irrespective of the matrix approach.

2.9.2 Implementation

The forest management routine is initiated by the logger model. The logger (logger.py) initiates an event each time step (time + 1, repeat = 1). The event is caught by a handleEvent function that first performs an inventory of the harvesting to take place, then evaluates the need for planting and finally applies the harvest.

2.10 Planting and seeding

2.10.1 Concept

Artificial ingrowth is the active establishment of a new generation of trees, by planting or by seeding.

It is defined in EFISCEN-Space as the number of trees per species that should be added to a specific diameter class if certain conditions are met. These conditions can be specified as the ranges of total stand basal area, number of trees or volume where the artificial ingrowth process is activated. Artificial ingrowth is applied with a user-defined time-lag since the condition was satisfied. The user is free to decide in which diameterclass the new trees will appear, this can for example be aligned with the inventory threshold of the country to be simulated. The user should be aware that trees in the lowest diameter class are assumed to have reached the 1.3 m height threshold, and will be treated in the model as having an average dbh of 12.5 mm.

2.10.2 Formalisation

New trees are 'just-added' to the diameterclass as specified in the input. This is a deviation from the general concept of (Leslie) matrix population models (see 2.2 Forest state), that use a rate per class to regenerate the first class.

2.10.3 Implementation

For managed ingrowth, the logger (see 2.9) loops over all plots and species within the plots and evaluates the ingrowth conditions. Then those plots with at least one species meeting ingrowth conditions, all species will receive ingrowth (`logger.ingrowthmanagement()` in `logger.py`)

2.10.4 Data

Parameterisation of the artificial regeneration module should be done based on expert judgement, possibly assisted by densities as listed in growth and yield tables, management handbooks, etc.

2.11 Harvest

2.11.1 Concept

Harvesting removes trees from a model stand. Within the harvesting module, the 'trees to be removed' are selected, and removed from the diameterclass distribution. Harvesting is simulated in EFISCEN-Space as the removal of a certain number of trees of a certain species in a certain diameter class. Harvesting is applied by a user-defined interval. Additional constraints can be set under what conditions harvesting should be applied. These conditions can be specified as the ranges of total stand basal area, number of trees or volume where the harvesting process is activated. Harvest is defined as the fraction of trees to be removed for each species in each diameter class. Stands are harvested when the conditions are met and are thus harvested independently from each other. The total harvest in the simulation is the result of the bottom-up harvest per model stand. No mechanism exists in V1.0 to meet a required national demand. Multiple rules can be active at the same time, each being triggered by different stand conditions, and applying different fractions to be harvested.

2.11.2 Formalisation

Harvesting rules a harvesting rule is a combination of
1. species
2. harvesting condition (interval, attribute, minimum & maximum value of that attribute)
3. harvest pressure distribution % per diameterclass to be removed

Multiple rules can be defined per species.

Harvesting conditions species specific harvesting conditions are specified by the minimal harvesting interval and the condition of the stand on a single property (a window of application).

Each timestep each plot calculates the potential harvest (i.e., the cumulative harvest of all species specific harvesting rules that are applicable for the current state of the plot). Subsequently the harvest is removed from the stand.

Harvest pressure Harvest pressure is defined as the annual removal rate of stems. Harvest (H) of diamberclass d of species s at time t, is calculated as

$$H_{d,s,t} = N_{d,s,t} \left(1 - \left(1 - h_{s,i} \right)^{k} \right) \qquad 2.17$$

Where $N_{d,s,t}$ is the number of stems, h the species and diameter specific annual harvestrate and k the harvestinterval.

2.11.3 Implementation

The harvestingrules per diameterclass per species are directly imported from the file growthandmortality\mortalities.csv and stored as attribute within the class `species`. The harvesting is initiated within the `handleEvent` of `logger.py`. This function asks plots to calculate potential harvest (`plot.getPoentialHarvest()`) and then perform the harvest (`plot.performHarvest()`).

2.11.4 Data

Schelhaas et al. (2018b) provides diameterclass and speciesspecific harvest rates for European tree species, for the countries included in the study. With all the limitations these data have (see discussion in Schelhaas et al.), the estimated rates provide the best data currently available with coverage within Europe. For applications outside the countries covered in this study, rates could be used from countries with similar conditions, or harvest rates can be derived from repeated NFI data of the country under study or similar local/national sources.

2.12 Harvesting costs

2.12.1 Concept

Harvesting operations cover a chain of events from felling a tree until the delivery of the stems and/or harvesting residues at the forest roadside. This chain covers several activities, notably the felling of the tree, removal of branches (delimbing), cutting the stem into pieces to be sold in different assortments (cross-cutting), bringing the logs and/or residues out of the forest to the roadside and piling the logs/residues. For each activity several options exist, the main options per activity can be combined in different ways, and the order or combination of activities may differ. The combination of all these actions is defined here as a harvest system. Different harvest systems exist in Europe (Di Fulvio et al. 2016). Harvest systems mainly differ with respect to the degree of mechanisation. The choice for a particular system may depend on costs, terrain conditions that may limit the use of machines, owner preferences and local traditions.

In EFISCEN-Space the harvesting costs for each system can be estimated based on the time needed to carry out each activity of that system, multiplied by the labour and machine costs per hour. We assume that the time consumption for each separate activity can be estimated from the quantity of work that needs to be done, given tree sizes, number, biomass or volume of trees to be handled. Furthermore, we assume that all harvest systems can be applied everywhere, unless explicitly excluded by the user. From the available harvest systems we assume that the cheapest system is the one that is finally selected.

2.12.2 Formalisation

Harvest systems are defined as a combination of activities. The time consumption of each activity can be defined as a linear combination of elements of that activity. The time consumption of each element can be calculated as a function of a harvested quantity, in particular number of trees, size of the tree, total volume harvested and biomass removed. Functions can be polynomial, exponential, power, or a division (1 divided by a polynome) and depend on the size of the tree (dbh, basal area or volume), and the number or total volume of trees to be harvested. Each function has to be defined separately for conifers/broadleaves, as these are expected to be important in terms of time consumption. EFISCEN-Space 1.0 treats all kinds of harvests in the same way, while in reality the time consumption for the same tree to be removed during a thinning is higher than during a final felling. Time consumption is expressed in minutes.

2.12.3 Implementation

Harvest systems are defined by a combination of harvest activities in the file `management/management_activities.csv`. Allowed harvest systems per management type are defined in `management/ harvestSystemPerMgmt.csv`. Time consumption per activity is defined in `management/ cost_functions_time.csv`. The cost per activity (defined as cost per minute) is defined in

`management\cost_functions_price.csv`. The output shows the total costs for the selected (cheapest) harvest system (but not the selected system).

2.12.4 Data

Di Fulvio et al. (2016) distinguish 10 commonly used harvest systems in Europe (**Table 2.2**), which are implemented in EFISCEN-Space as well. Harvest systems 1 and 2 are highly mechanised systems: tree felling is done by a harvester, cross-cutting is done in the forest, and logs are taken out of the forest using a forwarder (1) or a farm tractor (2). Systems 3-6 rely on manual tree felling and manual cross-cutting in the forest, with logs taken out using a forwarder (3), a farm tractor (4), a skidder (5) or cable yarding (6). Systems 7-10 also rely on manual felling, but the whole tree is brought to the roadside before being processed further. Trees are brought to the roadside using a skidder (7 and 8) or cable systems (9 and 10) and processed further mechanically (7 and 9) or manually (8 and 10). All systems can optionally be combined with the extraction of forest residues.

The individual time consumption functions per activity can be implemented directly from Di Fulvio (2016), or be based on alternative sources studying time consumption of harvest activities. The espy database includes a default set time consumption parameters, based on a combination of the work by Di Fulvio et al. and additional literature sources. Costs for the different activities can be derived from economic databases that express differences between countries in terms of salaries and wages, taxes, oil prices, etc.

Table 2.2 *The 10 harvest systems included (Di Fulvio et al. 2016). If system 5 or 6 are applied, no extraction of logging residues is considered.*

| System number | Roundwood (WD) | | | | | Logging Residues (LR) | | | | |
	Harvesting method	Felling	Extraction	Landing	Wood transportation	Piling	Extraction	Piling at roadside	Chipping	Transportation
1	CTL	HA	FO	–	TR WD	HA$_{LR}$	FO$_{LR}$	–	CH	TR WC
2	CTL	HA	FT	–	TR WD	HA$_{LR}$	FT$_{LR}$	–	CH	TR WC
3	CTL	MFP	FO	–	TR WD	MFP$_{LR}$	FO$_{LR}$	–	CH	TR WC
4	CTL	MFP	FT	–	TR WD	MFP$_{LR}$	FT$_{LR}$	–	CH	TR WC
5	CTL	MFP	SKL	–	TR WD	–	–	–	–	–
6	CTL	MFP	CYL	–	TR WD	–	–	–	–	–
7	WT	MF	SKW	PCH	TR WD	–	–	PCH$_{LR}$	CH	TR WC
8	WT	MF	SKW	PCM	TR WD	–	–	PCM$_{LR}$	CH	TR WC
9	WT	MF	CYW	PCH	TR WD	–	–	PCH$_{LR}$	CH	TR WC
10	WT	MF	CYW	PCM	TR WD	–	–	PCM$_{LR}$	CH	TR WC

CTL	cut to length
WT	whole tree
HA	felling and processing with single grip harvester
HALR	piling logging residues with single grip harvester
MFP	motor-manual felling and processing with chainsaw
MFPLR	motor-manual piling logging residues
MF	motor-manual felling with chainsaw
FO	forwarding roundwood to roadside with a forwarder
FOL	forwarding logging residues with a forwarder
FT	extraction to roadside of roundwood with a farm tractor
FTLR	extraction to roadside of logging residues with a farm tractor
SKL	skidding logs with a skidder
SKW	skidding whole trees with a skidder
CYL	cable yarding roundwood logs
CYW	cable yarding whole trees
PCH	Mechanized processing at the roadside (cross-cutting and delimbing) with excavator mounted processor head
PCM	motor-manual processing at the roadside (cross-cutting and delimbing) with chainsaw
PCHLR	piling residues at the roadside with processor
PCMLR	piling residues at the roadside in motor-manual processing
CH	Chipping logging residues
TR WD	transportation of roundwood with a truck and trailer unit
TR WC	transportation of chipped logging residues with a container truck and trailer unit

2.13 Soil carbon

2.13.1 Concept

One of the major pools in the forest carbon cycle is the soil. Carbon is stored both in the litter on the ground, as well as in deeper soil layers. We assume that all carbon in the litter and the soil originally derived from litter produced by the trees. We distinguish three origins of litter: 1) litter produced by turnover of each of the tree compartments, 2) litter produced by natural mortality and 3) litter produced during harvest events. We assume litter input from turnover to be a fixed fraction per year of the biomass stocks. If a tree dies, we assume all of its associated compartments are litter inputs to the soil model. If a tree is harvested, we assume that from all compartments a user-defined fraction can be extracted and the remainder is litter input to the soil model.

The YASSO15 soil carbon model (Järvenpää 2015) is integrated into EFISCEN-Space for providing estimates of soil carbon development. YASSO15 is an improved version of original YASSO and YASSO07 models (Tuomi et al., 2008, 2009, 2011a, 2011b). It is based on four basic assumptions on litter decomposition and soil carbon cycle (Järvenpää et al 2018).
1. Litter consists of four groups of organic compounds (the so called AWEN fractions) which each have a specific decomposition rate that is independent of the litter type.
   A is hydrolysable in acid (celluloses),
   W is soluble in water (sugars),
   E is soluble in ethanol or other non-polar solvents (wax compounds),
   N is the non-soluble or non-hydrolysable remaining fractions (like lignin compounds)
2. Decomposition of any group may result in formation of carbon dioxide (CO_2), other compound groups and/or humus.
3. The decomposition rate depends on temperature and moisture.
4. Large size slows down the decomposition of woody litter.

The decomposition rate of each compartment is independent of the origin of the material. The decomposition rates depend on air temperature and precipitation that serve as proxies of soil temperature and moisture. The decomposition rates of the chemical fractions originating from woody litter depend additionally on the size of the woody litter (diameter). The AWE fractions are relatively fast decomposing carbon, whereas N has rather slowly decomposing carbon and H very slowly decomposing carbon. Inputs to the soil model as a whole consist of litter produced by the trees, mortality and harvest residues. These inputs are distributed over the AWEN pools using a fractionation approach, which depends on the bio-compartment and tree species. Initialisation of the pools can be done manually, but is usually calculated from modelled input, assuming steady-state.
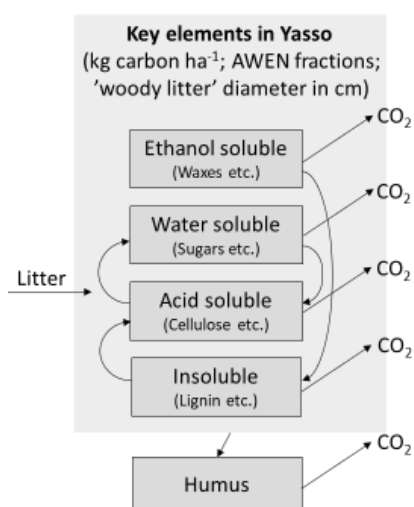
Figure 2.2 *Schematic outline of the YASSO15 model (Järvenpää et al 2018).*

We assume there is no feedback from soil carbon to the growth of the trees.

2.13.2 Formalisation

For the coupling of EFISCEN-Space to YASSO15, three types of litter input are considered: 1) turnover of living trees, 2) dead trees, and 3) harvest residues, using the following formulas:

$$CT_z = BL_z \times TO_z \times CFraction_z \qquad\qquad 2.18$$

$$CM_z = BM_z \times CFraction_z \qquad\qquad 2.19$$

$$CH_z = BH_z \times (1 - E_z) \times CFraction_z \qquad\qquad 2.20$$

with CT_z the carbon input to the soil originating from turnover for compartment z (stems, roots, branches, foliage), CM_z the input to the soil due to mortality, CH_z the input due to harvesting, BL_z biomass in living trees, BMz biomass in trees that died this timestep, BHz biomassa in trees that were harvested this timestep, TO_z turnover coefficient, Ez the fraction extracted during harvesting and $CFraction_z$ the carbon fraction. YASSO15 uses diameter-specific pools. Stems are inserted in the pools corresponding to their DBH. Roots, branches and foliage are assumed to have a fixed diameter of respectively 2, 2 and 0 cm. All parameters are species-specific. We used the annual timestep option of YASSO15, linking the required weather variables to the corresponding variables included in the input for the increment model.

2.13.3 Implementation

EFISCEN-Space provides a post-calculation of YASSO15 (Järvenpää et al 2018). This calculation reads the EFISCEN-Space outputfile `biomass.tsv` and a specific parameterfile `efiscenspace_yasso_par.xlsx` and produces an outputfile `yasso_raw_lsc.csv`.

YASSO15 calculates the carbonpool originating from deadwood and litter. The pathway of this deadwood and litter into the carbonpool is illustrated in Figure 2.2. The number in this figure refer to the datatables listed in Table 1.

1. EFISCEN-Space output is stembiomass detailed at the state[1]/dbhclass/year/species/plot level.
2. This stembiomass is converted to litterinput mass/compartment[2]/state/dbhclass/year/species/plot. Thus the data in table 'turnover' gives litterinput/turnover as mass (dryweight) per state and compartment.
3. The compartment biomass is multiplied by the carboncontent to get carbon per compartment/dbhclass/year/species/plot. The states are no longer distinguished in the subsequent calculations.
4. The carbon mass is multiplied by the AWENH-fractions per compartment. To get C/awenh/dbhclass/compartment/year /species/plot
5. The C per AWENH are aggregated at the dbhclass/compartment specific littersizeclasses. In this step both compartment and dbhclas specificity are lost and littersizeclass specificity is gained. (C/awenh/littersizeclass/year /species/plot)
6. The default parameters for YASSO15 are added
7. YASSO15 run
   a. calculate steadystate litter for intialisation (C/awenh/littersizeclass/species/plot)
   b. calculate temporal dynamics of litter stock (C/awenh/year/littersizeclass/species/plot). Within the calculation, the last 4 categories are 'looped over' taking the output of run for year i as input for the run in year i+1.
8. Generate output including a summation: C/awenh/year/species/plot

---

[1] Standing, died, harvested
[2] Foliage, branch, stem, roots

2.13.4 Data

For parameterization of YASSO15, please see the original publications. Note that currently only a limited number of species is parameterised in YASSO15.

2.14 Outputs

The basic output of the forest development module consists of the number of trees per species per diameter class, 1) as present at the end of the time step, 2) that are removed from the simulation due to mortality, 3) that are removed from the simulation due to harvesting, and 4) the number of trees that is added to the simulation due to ingrowth or planting. A more detailed description of the output files can be found in Section 3.3.2.

3 Technical program description

3.1 Overall implementation

EFISCEN-Space is implemented in Python. The minimal requirement is Python 3. We use a GIT-based versioning system, located at https://git.wur.nl/efiscenspace/efiscenspace_clean (see 3.2.1 Download and setup for further instructions how to get the model code). Inline documentation is available (but not complete yet), allowing the generation of automated documentation of the code through the use of software like Doxygen or Sphinx. Doxygen can create an online technical documentation in HTML (Figure 3.1) or an offline reference manual in RTF or PDF. Interested users can generate or download the documentation using the latest version of the code.
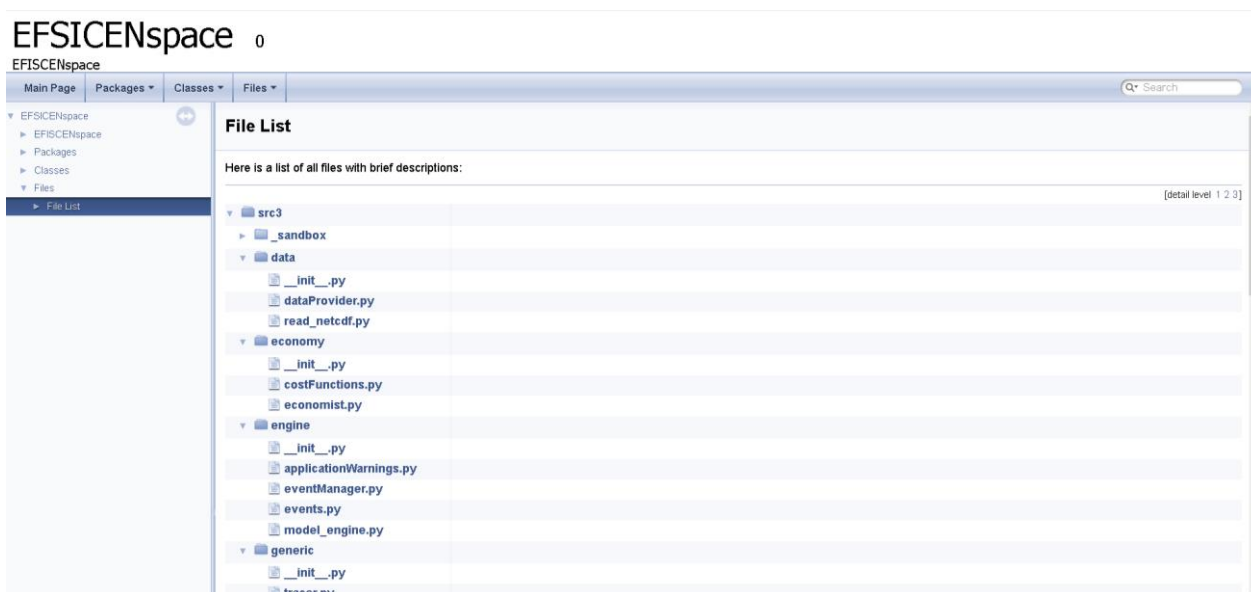
Figure 3.1 *Screenshot of the automated Doxygen documentation.*

The program runs through 5 phases of calculation in the following order (Figure 3.2).
1. Initialisation
2. Iterative loop of ecological processes and management interventions
3. Generation of output
4. Post calculation of soil carbon
5. Output aggregation

During **initialisation** all settings are fixed, the espy-model instance (ecological processes), with associated instances for stands & species within these stands and a logger-model (management interventions) are initialised and the iterative loop is scheduled. Required outputs are defined during initialisation. Optional, a spin-up period is applied to get all plots to the same initialisation year.

The scheduled **iterative loop** of ecological processes and management interventions continues for the timespan set in the settings.csv file. The model works with an annual timestep. Each year the changes due to ecological processes are calculated and applied (simultaneous within and over stands). Then the management interventions are carried out (simultaneous harvesting (within and over the stands), followed by planting).

After the loop, the required **output** files are generated. Non-selected system states are not recorded.

Based on the output files, the YASSO15 module is executed as **post-calculation** of soil carbon development.

After the post-calculations, outputs are **aggregated** to provide ease of interpretation.
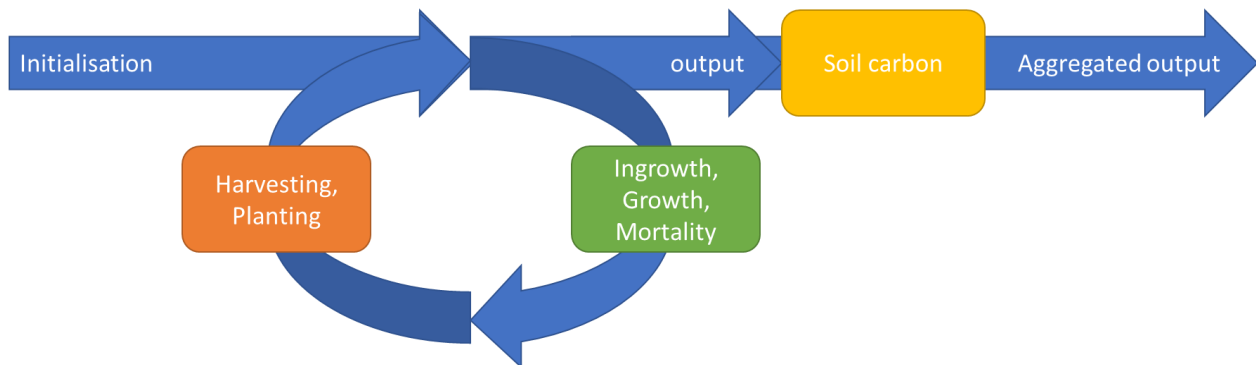
Figure 3.2 *Order of calculations in the model.*

3.1.1 File structure

The main directory (src3) contains the following subdirectories:
- data: contains data handling functionality
- economy: contains the functionality to calculate the costs of harvests
- engine: contains event-related functionality and the model engine
- generic: contains generic functionality
- IO: functionality for reading input and writing output
- model: contains the main model functionality at plot and species level. Here, the most important files, corresponding to the main classes, are:
  - espyModel.py (Figure 3.3): contains main model functionalities (model core) (Figure 3.3)
  - plot.py: contains calculations and functionality at the level of the plot (model stand) (Figure 3.4)
  - plotXspecies.py: contains calculations and functionality at the level of species per plot (Figure 3.5)
  - species: contains calculations and functionality at the level of species (Figure 3.6)
- yasso: contains the soil model

In the main directory, we have the following files/classes:
- efiscenspace.py: this is the entry point of the model, reads in data from the files as specified in the settings
- globals.py: contains the default settings
- settings.py: reads in the settings file and overrides the global settings
- runner.py: this file actually runs the core EFISCEN-Space model
- yasso.py: runs the yasso model on the output of the main model
- aggregator.py: reads in the raw output files from the main model and aggregates to 6 different levels (output sheets in Excel file).
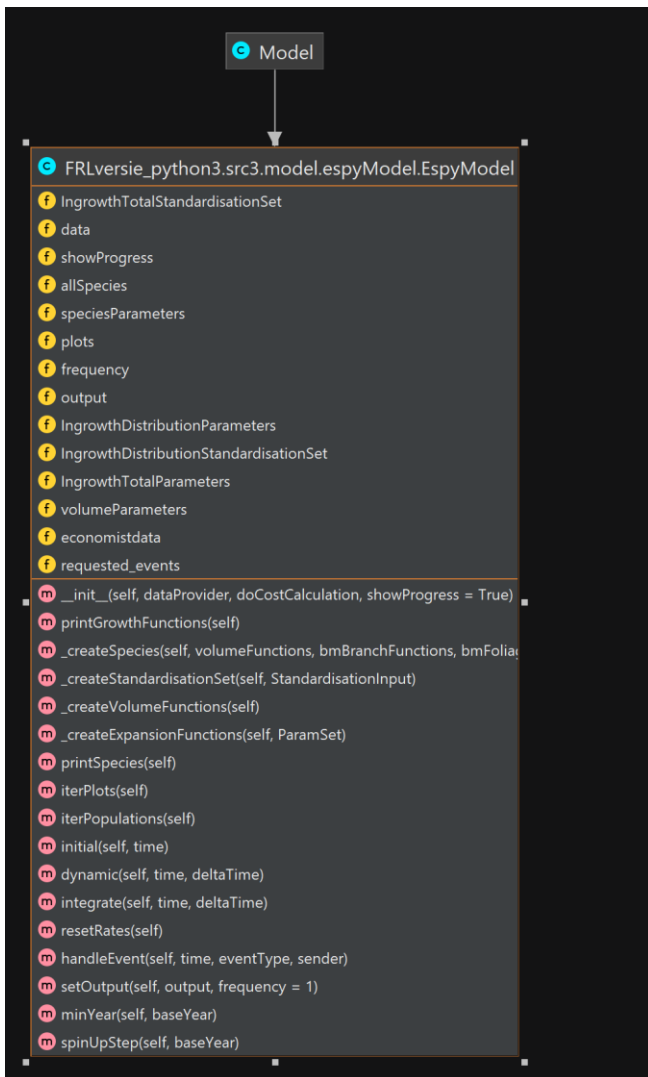
Figure 3.3 *Overview of the class espyModel.py.*

FRLversie_python3.src3.model.plot.Plot

- 🟡 potentialHarvest
- 🟡 year
- 🟡 harvestCostRegion
- 🟡 output
- 🟡 rootsBiomassRegion
- 🟡 FMA
- 🟡 stand
- 🟡 volumeRegion
- 🟡 area
- 🟡 costOfHarvesting
- 🟡 variables
- 🟡 economist
- 🟡 basalArea
- 🟡 yearOfLastHarvest
- 🟡 plotdata
- 🟡 Dq
- 🟡 stemBiomassRegion
- 🟡 removedBA
- 🟡 myEspyModel
- 🟡 foliageBiomassRegion
- 🟡 timeOfHarvesting
- 🟡 harvestingSystem
- 🟡 netcdflink
- 🟡 IngrowthThresholds
- 🟡 name
- 🟡 plotID
- 🟡 IngrowthTotalFunction
- 🟡 IngrowthDistributionFunctions
- 🟡 branchBiomassRegion
- 🔴 __init__(self, plotdata, allSpecies, netcdflink, economistdata,
- 🔴 __str__(self)
- 🔴 initial(self)
- 🔴 getBasalArea(self)
- 🔴 getNumberTrees(self)
- 🔴 getNumberSpecies(self)
- 🔴 getMajorSpecies(self)
- 🔴 getBA_Skew(self)
- 🔴 getMinMaxDBH(self)
- 🔴 getMixedForestType(self)
- 🔴 getDeadBAM2(self)
- 🔴 getNumberPerClass(self)
- 🔴 getBaPerClass(self)
- 🔴 getGini(self)
- 🔴 getDq(self)
- 🔴 yearsSinceLastHarvest(self, time)
- 🔴 updateRates(self, year)
- 🔴 integrate(self, oldTime, deltaTime)
- 🔴 resetRates(self)
- 🔴 handleEvent(self, time, eventType, sender)
- 🔴 getOutputAttribute(self, attributeNames)
- 🔴 getAttributeSum(self, attributeName)
- 🔴 getPotentialHarvest(self, time)
- 🔴 performHarvest(self, time)
- 🔴 spinUpStep(self, spinUpYear)
- 🔴 addNewSpecies(self, speciesIndex)
- 🔴 CalcNaturalIngrowth(self)
- 🔴 CalcIngrowthDistribution(self)
- 🔴 CalcTotalIngrowth(self)

Figure 3.4 *Overview of the class plot.py.*

Figure 3.5   *Overview of the class plotXspecies.py.*

Figure 3.6 *Overview of the class species.py.*

3.2 User guide for installation and setup

3.2.1 Download and setup

In this section we describe the steps to download the source code, which is needed to run the model from the source code directly (for example for debugging) or for code development. Alternatively, EFISCEN-Space can simply be run from the provided executable (see Section 3.4.3).

If you want to use EFISCEN-Space from the source code, make sure to have the necessary programs, such as PyCharm and Python on your computer. Otherwise, you can install them for free from the website www.jetbrains.com (PyCharm) and www.python.org. The programs are widely available for Windows and macOS. You do not need to install the professional version of programs. For instance, the Community version of the PyCharm is enough to get the model to work. Note that there are many available versions of the Python software. However, only version 3.6 is suitable to run the model. Furthermore, the YASSO15 model (soil carbon model) that is connected to EFISCEN-Space works only on Windows systems. Thus, if you are also interested in projection of soil carbon the only possible way to run the model is to use computer with a Windows system. After you install the required programs open PyCharm.

Depending on the aim of the user, there are two possible ways for using the model. As a code developer you need to get a copy of the model code and establish a link to the repository to up- and download model versions. However, when you are interested in using the model as a regular user it is sufficient to download the .zip file of the latest release of the model. Below you can find the procedures that will help you in downloading the model according to user type.

For code developers:
From open window *Welcome to PyCharm* select *Get from VCS* (Figure 3.7).
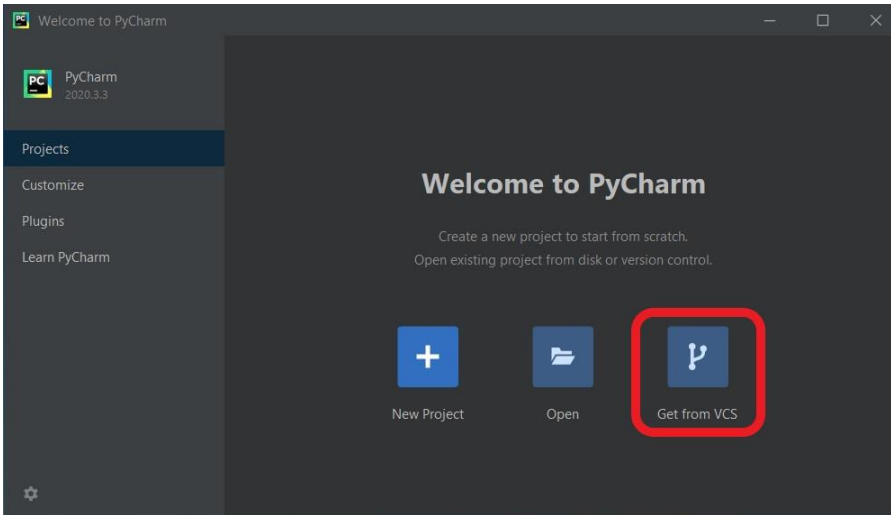
Figure 3.7   *Choose Get from VCS from Welcome to PyCharm.*

The VSC (Visual Studio Code) requires the URL resource of the EFISCEN-Space code. To get the URL address you need to contact one of the developers of the EFISCEN-Space model, since the source code of the model is not available for external users at the moment. In order to get the code, you need to sign in to https://git.wur.nl/. On the main Git website, you will find the *EFISCEN-Space Core* folder and model-related files. Click on the folder *FRLversie_python3* (includes a script of the model). To view needed URL address, click on the blue *Clone* button in the top right corner of the webpage. Two possible options of cloning the code will show up, SSH and HTTPS. Choose and copy the address under *Clone with HTTPS*. The other address SSH is used to collect the source code for unit machines, but it also requires initialization of additional keys. Paste the copied HTTPS code into the URL address in PyCharm. Before moving any further select the directory in which the files can be stored. It is recommended to create a new folder (e.g., EFISCENspace), next select this new folder and click *OK* (Figure 3.8).
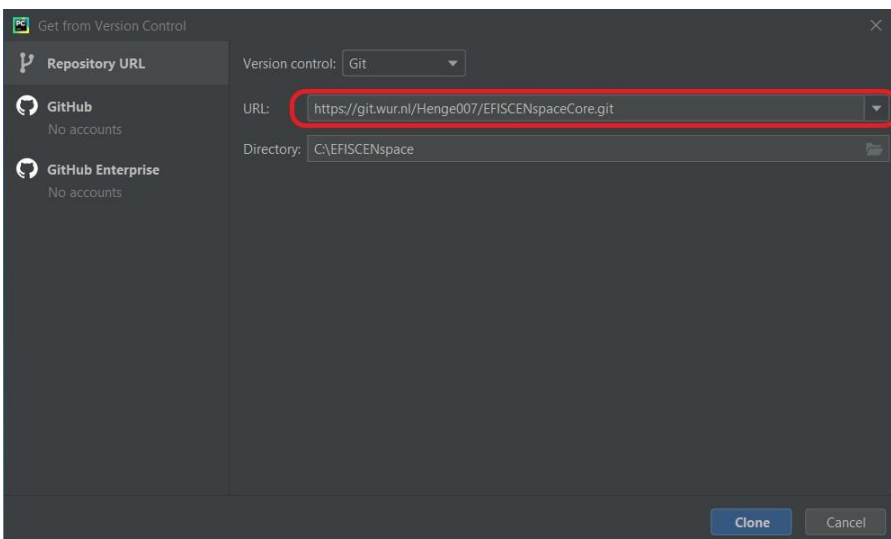
Figure 3.8   *Added URL address and selected directory.*

To install the code from the EFISCEN-Space Git Core model click on "Download and Install" located under the chosen directory. After successful installation of the Git click on *Clone* button in the bottom right corner of the window. Next, the window *Welcome to PyCharm* will show up. Select *Open* and choose the created directory folder (e.g., EFISCENspace). You will see that the folder is empty, however, it is not going to influence the further steps. Click *Open* and the main window of the EFISCEN-Space Project will show up. You can close the *Tip of the window,* it is not necessary.

For regular user (running from the downloaded source code)
First, you need to download .zip source code of the required model release, which you can find on website https://git.wur.nl/efiscenspace. In the open window click on *EFISCENspaceCore* in subgroups and projects tab. Next, from the left tab select *Project overview* and click on *Releases* (Figure 3.9). Here you will find the source code of the release version, which you need to download.
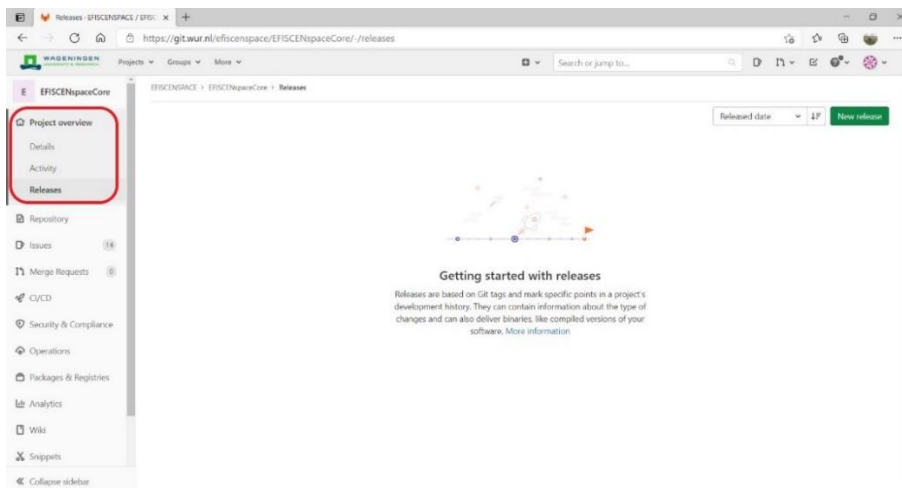
Figure 3.9   *Location of the EFISCEN-Space source code release.*

After downloading source code (zip), select a directory in which you can extract the files. It is recommended to create a new directory (e.g., EFISCENspace). Next, from open window *Welcome to PyCharm* select *Open* (Figure 3.10). From *Open File or Project* window select a previously created directory (EFISCENspace) and click *OK*. Then, the main window of the EFISCEN-Space Project will show up.
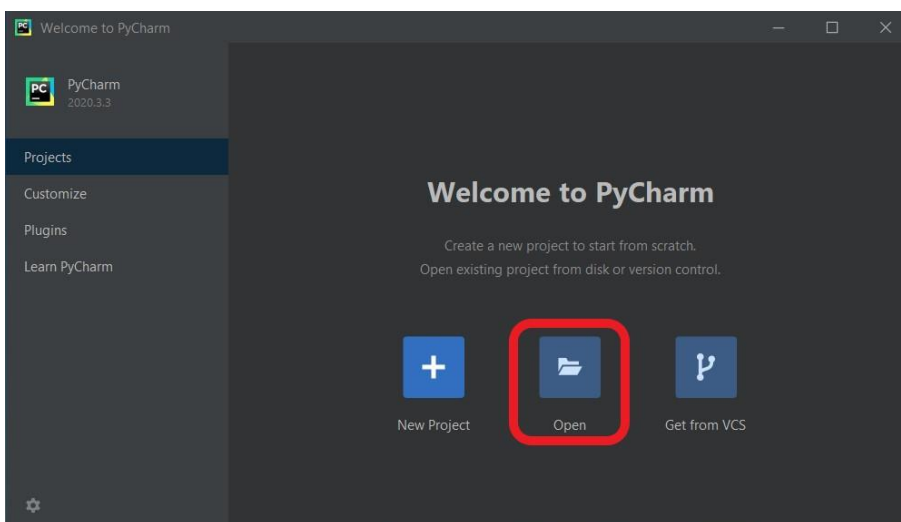
Figure 3.10 *Click on Open to select the directory with downloaded source code.*

Following steps will help you to set-up the model (applies for both types of users)

First, check the currently used version of Python, which is indicated in the bottom right corner of the viewed window (Figure 3.11). Remember that to run the model you need Python version 3.6.
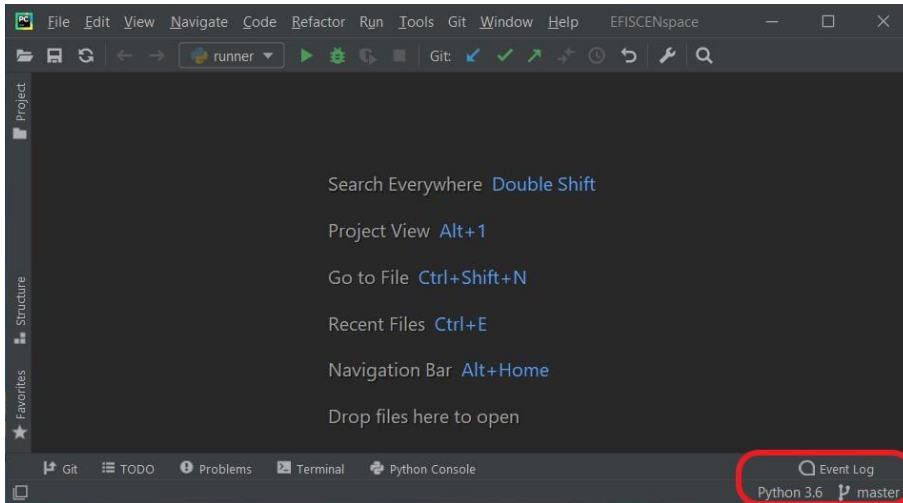
Figure 3.11 *Information about currently used Python version.*

In the case of older versions, click on the current version of Python and select *Interpreter Settings* to change it. Next, the *Preferences window* will open. To check installed and available versions of Python on the computer, expand *Python Interpreter* and click *Show All*. When you have to add a new Python Interpreter click on the *plus* (+) button in the bottom left corner. The *Add Python Interpreter* window will show up. Then, click on the *Virtualenv Environment* and select the new Python version after extending *Base Interpreter*. Before pressing OK make sure to check *Inherit global site-packages* and *Make available to all projects*. Then, the program comes back to the *Preferences* window where the installed packages are located.

Only for code developers, you have to restart the program to be able follow further steps. Thus, in the *Preferences* window where the installed packages are located, press *OK* and exit PyCharm. After restarting PyCharm paste the HTTPS code of EFISCEN-Space model to *Get from VCS* again (where to find the code was explained in For code developers). Click *OK*, then the new window *Log in to git.wur.nl* will open. Sign in using a WUR username and password (ask for external user permission). After click on *Log in* the window with initialization will open. When the initialization will indicate 100%, you will be automatically directed to the EFISCEN-Space Core.

He last step before running the model is to install needed packages. Depending on the operation system (Windows, macOS) there are two ways to install needed packages.

- For Windows, to find needed packages click on the current interpreter in the bottom right corner of the window and select *Interpreter Settings*. The window *Settings* will open.
- For macOS, to find the needed packages go to the tab *PyCharm* located at the right top of the window and select *Preferences*. Next extend the tab named *Project: EFISCENspaceCore* and select *Python Interpreter*.

First, check the Python Interpreter version on the top of the *Settings* window. It should indicate currently used Python version 3.6. Then packages that are already included in the Interpreter will be viewed below. To add other packages, click on the *plus* (+) button on the bottom left of the window. The *Available packages* window will open with all available packages. To correctly install the selected package, click on button *Install package*. After initialization of needed packages (Figure 3.12) close the *Available Packages* window and click *OK.*
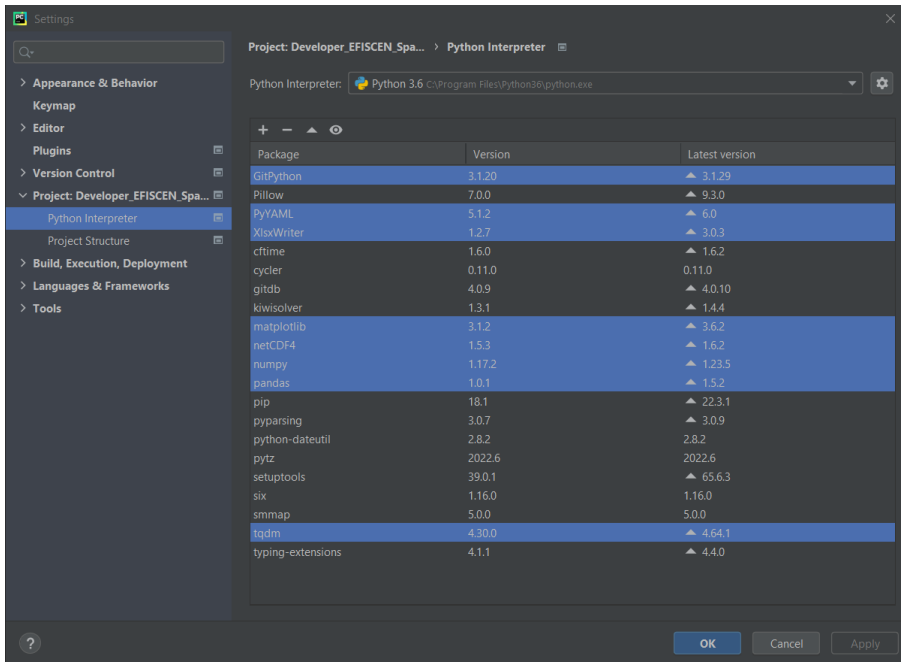
Figure 3.12 *Main packages needed for the EFISCEN-Space model and YASSO highlighted in blue. The other packages are downloaded automatically as an extension of one of the highlighted packages. Note that some of the packages use specific version.*

To start running the model you need to go to the *Project file*. The *Project file* views all files (sources) included in the model. Click on the *Project* (top left) and extend the drop bar. Next select *Project Files* it will allow you to view all sources of the model. Open folder *FRLversie_python3*, and search for folder *src3* (Figure 3.13).
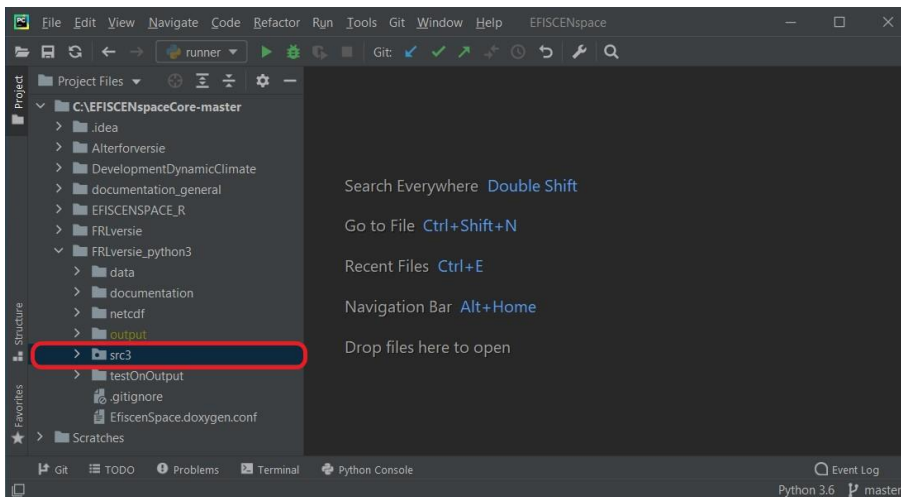
Figure 3.13 *Main source of EFISCEN-Space code is located in src3 folder.*

Finally, go back to PyCharm and click on *efiscenspace.py*, located in a *src3* folder of *FRLversie_python3* in Project Files. After the script opens, with right click on *efiscenspace.py* and choose *Modify run configuration…* option. The *Edit Run Configuration: 'efiscenspace'* window will open. Edit the *Script path* to the directory in which the model is located. More importantly, change *Parameters* to path where settings.csv of the Experiment# is located (see also Section 3.3 for a description of the folder structure). By defining the *Parameters* path the set up data will be used (Figure 3.14). In case of multiple experiments change *Parameters* path per experiment that will prevent output_Scenario# to be overwriten by new output_Scenario#.
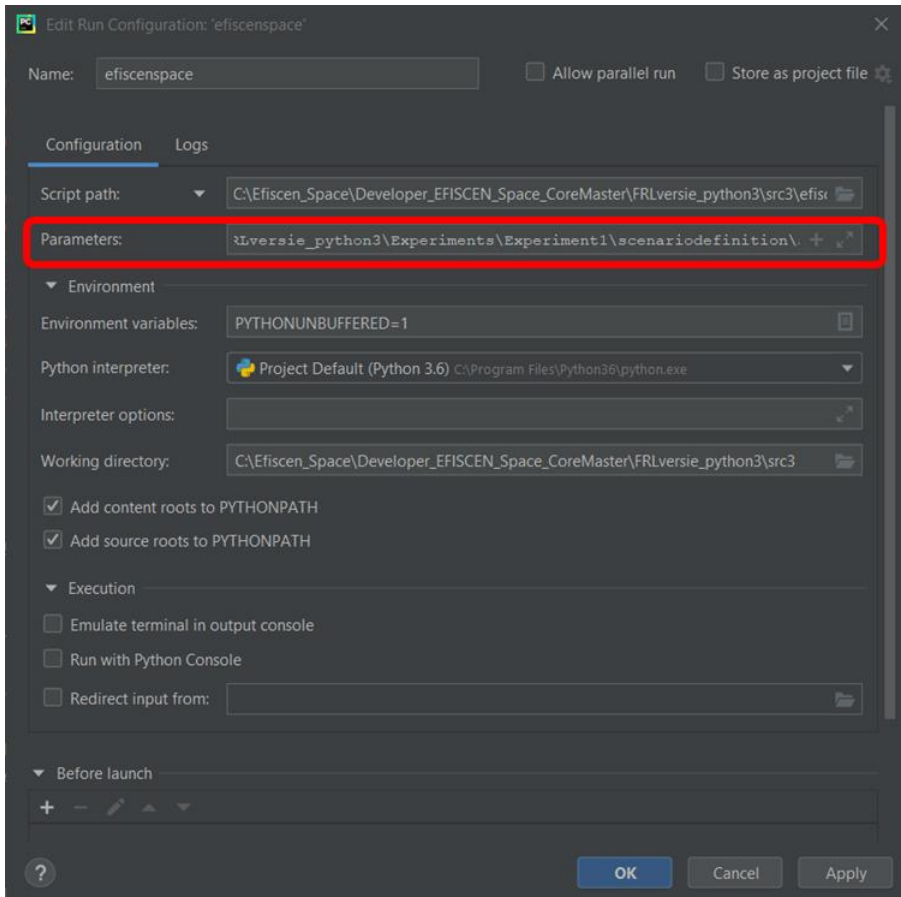
Figure 3.14 *Define Parameters path to use set up data of the experiment.*

When the correct path is set up click *OK* and press *Run* button. The model will create a log file in the *Run* tab and the output will be automatically saved in the *experiment* folder. It is possible that after running the script, the model points out errors of missing packages in the *Run* tab. The easy way to find out which packages are still needed to correctly run the model is to check the indications of the *ModuleNotFoundError*. Then follow the same steps to install packages as mentioned above and run the model again.

3.2.2   Description of Espy database

The Espy database (..\data\database\espy.mdb) contains all data needed to generate the input files to run a simulation. Next to the core tables describing the plot and species, the relationships between the tables in the database are divided in two groups; 1) initialisation, biomass and abiotic group, 2) forest management and harvest group (Figure 3.15). The information stored in the tables is described below.
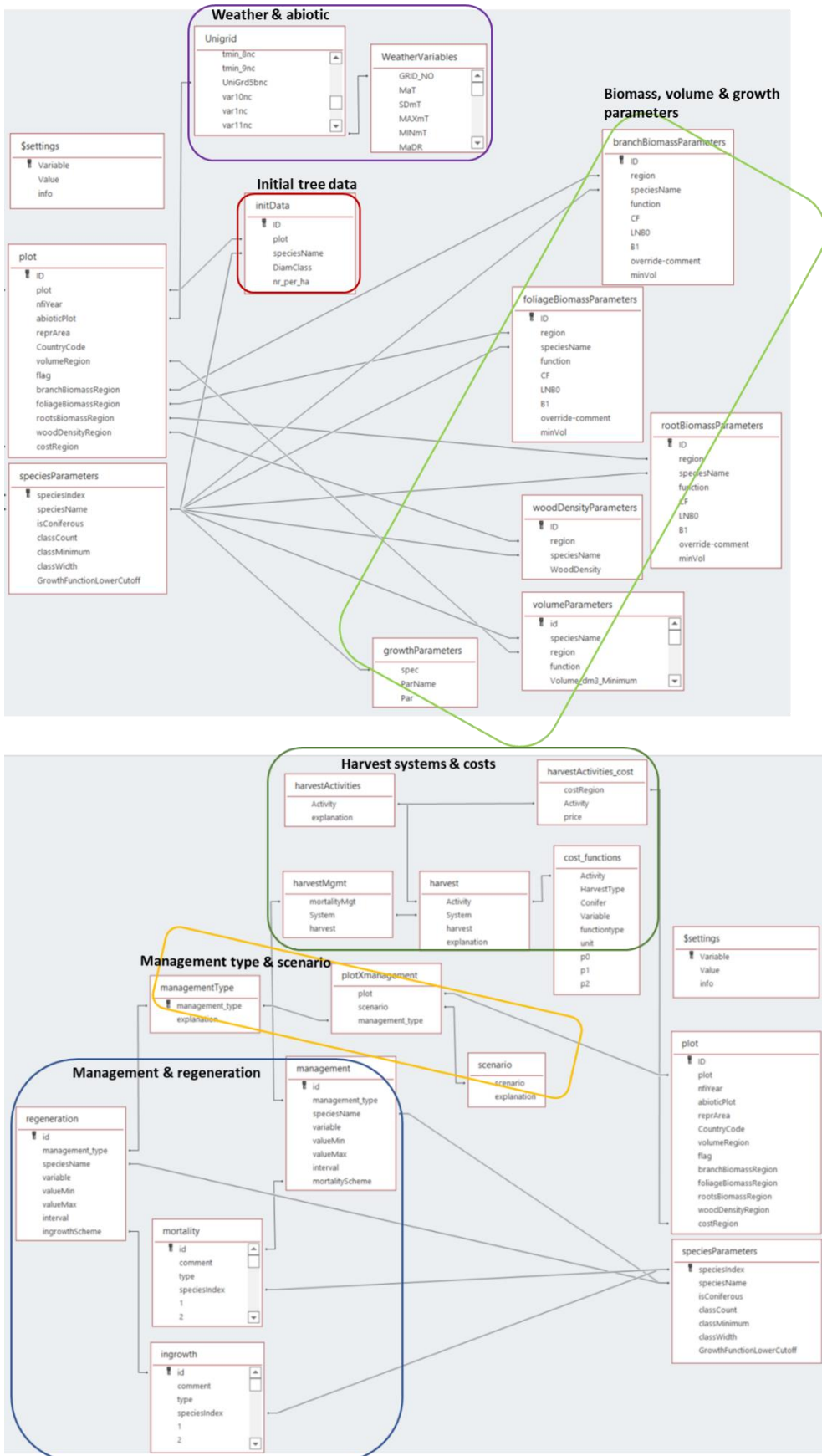
Figure 3.15 *Scheme of relationships between tables in the Espy database. Note the scheme is separated in two parts due to space restrictions. Central in both parts are the settings, plot and species descriptions. The other tables are divided into thematic groups: initial tree data; biomass, volume & growth parameters; weather & abiotic information; management & regeneration, management type & scenario; harvest systems & costs parameters.*

Table 3.1 *Description of variables that can be used in Espy database input tables. Variables are described on plot and species per plot level. Variable names are case-sensitive.*

Variable	Description
basalArea	Basal area in m2
basalAreaDBH	Basa area over specific diameter in m2
stemnumber_per_ha	Stem numbre per ha
mortality_m3	Volume of trees removed due to natural mortality in m3
harvest_m3	Volume of trees removed due to harvest & management in m3
harvest_bam2	Basal area of trees removed due to harvest & management in m2
volume_per_ha	Volume of trees per ha
BA_share	Basal area share
branchBiomass_per_ha	Amount of branch biomass per ha
foliageBiomass_per_ha	Amount of foliage biomass per ha
rootsBiomass_per_ha	Amount of roots biomass per ha
stemBiomass_per_ha	Amount of stem biomass per ha
branchBiomass_mortality	Amount of branch biomass removed due to natural mortality
foliageBiomass_mortality	Amount of foliage biomass removed due to natural mortality
rootsBiomass_mortality	Amount of roots biomass removed due to natural mortality
stemBiomass_mortality	Amount of stem biomass removed due to natural mortality
mortality_BAm2	Basal area of trees removed due to natural mortality in m2
Dq	Quadratic mean of diameter

speciesParameters: Contains the basic definition of the species and their setup like the number of species, the number of diameter classes, minimum dbh, dbh class width and growth function lower cut-off.

Table 3.2 *Description of speciesParameter input.*

Name	Type	Description
speciesIndex	Long Integer	Identifier of species
speciesName	Short Text	Name of species
isConiferous	Yes/No	Selection of coniferous species
classCount	Long Integer	Total number of diameter classes
classMinimum	Double	Minimal diameter size
classWidth	Double	Width of a diameter class (cm)
GrowthFunctionLowerCutoff	Double	Smallest diameter to be used in the growth function

plot: Contains generic plot characteristics like the plot identifier, year of measurement, the area the plot is representative for, volume region, biomass regions and cost region. Plot is the unique identifier as used in the initialisation and simulation, while *abioticPlot* refers to the *Unigrid* table which contains abiotic information. Several plots can be linked to the same *abioticPlot*, for example in the case of tracts with multiple plots but only one location for the abiotic data. The *reprArea* is defined as an area that plot is representative for. It is used to calculate statistics for the whole area in the simulation. The *reprArea* is usually the same within a country (using regular grids), but it may vary per plot (e.g., if stratified sampling is used). The *volumeRegion* refers to the appropriate set of volume functions that should be used to estimate individual tree volume from diameter at the breast height (dbh) for this plot. The *branchBiomassRegion* refers to the set of allometric equations to estimate the branch biomass that should be used for this plot. The same is valid for foliage, roots and wood density. The *costRegion* refers to the unit costs to be applied in this region. The *flag* can be used to manually select certain plots to be included in the simulation (but only applied if indicated in the *&settings* table).

Table 3.3 *Description of plot input.*

Name	Type	Descrption
ID	Long Integer	Key
plot	Short Text	Unique plot identifier
nfiYear	Long Integer	Year when measurement was taken
abioticPlot	Long Integer	Unique abiotic grid number
reprArea	Double	Area representative for one plot
CountryCode	Short Text	Code of country e.g. Netherlands NL, Poland PL
volumeRegion	Short Text	Region of applied volume functions
flag	Yes/No	Plots selected for simulation
branchBiomassRegion	Short Text	Name of volume region used to calculate a branch biomass volume
foliageBiomassRegion	Short Text	Name of volume region used to calculate a foliage biomass volume
rootsBiomassRegion	Short Text	Name of volume region used to calculate a root biomass volume
woodDensityRegion	Short Text	Name of wood density region used to calculate biomass
costRegion	Short Text	Name of cost region used to calculate harvest and harvesting actives

initData: Contains the initial data per plot. Each record refers to one diameter class of a specific species present in a specific plot. A plot can have multiple records, if it contains more than one species per diameter class, and/or has trees of the same species in multiple diameter classes. The *speciesName* field relates to the species specified in the *speciesParameters* table while the plot field relates to the plots defined in the *plot* table.

Table 3.4 *Description of initData (Initialization Data) input.*

Name	Type	Description
ID	Long Integer	Key
plot	Short Text	Unique plot identifier
speciesName	Short Text	Name of species
DiamClass	Byte	Diameter class of specific species in a plot
nr_per_ha	Double	Number of trees per hectare in a plot

Unigrid: Contains the abiotic information like soil and bioclimatic variables per plot at a 1 x 1 km grid over Europe. Cells in this grid are identified by their unique Unigrid ID (*UniGrd5bnc*), which is linked to via the *abioticPlot* field in the *plot* table. Multiple plots can link to the same Unigrid ID, if located close to each other. Weather data are available at a grid of 25 x 25 km and stored in the separate table *WeatherVariables*. The weather grid number (*25kgridnc*) in the *Unigrid* table refers to the appropriate record in the weather table. The abiotic and weather information is used to calculate the growth functions.

Table 3.5 *Description of Unigrid (bioclimatic and soil variables) input.*

Name	Type	Description
altnc	Double	Altitude
avgDepOxNnc	Double	Average deposition of oxidised nitrogen
avgDepOxSnc	Double	Average deposition of oxidised sulphur
avgDepRedNnc	Double	Average deposition of reduced nitrogen
BDRICM_02_apr_2014nc	Double	Depth to bedrock (R horizon) up to maximum 240 cm
bio_10nc	Double	Mean Temperature of Warmest Quarter
bio_1nc	Double	Annual Mean Temperature
bio_11nc	Double	Mean Temperature of Coldest Quarter
bio_12nc	Double	Annual Precipitation
bio_13nc	Double	Precipitation of Wettest Month
bio_14nc	Double	Precipitation of Driest Month
bio_15nc	Double	Precipitation Seasonality
bio_16nc	Double	Precipitation of Wettest Quarter

Name	Type	Description
bio_17nc	Double	Precipitation of Driest Quarter
bio_18nc	Double	Precipitation of Warmest Quarter
bio_19nc	Double	Precipitation of Coldest Quarter
bio_2nc	Double	Mean Diurnal Range
bio_3nc	Double	Isothermality
bio_4nc	Double	Temperature Seasonality
bio_5nc	Double	Max Temperature of Warmest Month
bio_6nc	Double	Min Temperature of Coldest Month
bio_7nc	Double	Temperature Annual Range
bio_8nc	Double	Mean Temperature of Wettest Quarter
bio_9nc	Double	Mean Temperature of Driest Quarter
BLD_sd1_M_02_apr_2014nc	Double	Bulk density in kg / cubic-meter (mean estimate) for 2.5 cm depth
BLD_sd2_M_02_apr_2014nc	Double	Bulk density in kg / cubic-meter (mean estimate) for 10 cm depth
BLD_sd3_M_02_apr_2014nc	Double	Bulk density in kg / cubic-meter (mean estimate) for 22.5 cm depth
BLD_sd4_M_02_apr_2014nc	Double	Bulk density in kg / cubic-meter (mean estimate) for 45 cm depth
BLD_sd5_M_02_apr_2014nc	Double	Bulk density in kg / cubic-meter (mean estimate) for 80 cm depth
BLD_sd6_M_02_apr_2014nc	Double	Bulk density in kg / cubic-meter (mean estimate) for 150 cm depth
CEC_sd1_M_02_apr_2014nc	Double	Cation exchange capacity in cmolc/kg (mean estimate) for 2.5 cm depth
CEC_sd2_M_02_apr_2014nc	Double	Cation exchange capacity in cmolc/kg (mean estimate) for 10 cm depth
CEC_sd3_M_02_apr_2014nc	Double	Cation exchange capacity in cmolc/kg (mean estimate) for 22.5 cm depth
CEC_sd4_M_02_apr_2014nc	Double	Cation exchange capacity in cmolc/kg (mean estimate) for 45 cm depth
CEC_sd5_M_02_apr_2014nc	Double	Cation exchange capacity in cmolc/kg (mean estimate) for 80 cm depth
CEC_sd6_M_02_apr_2014nc	Double	Cation exchange capacity in cmolc/kg (mean estimate) for 150 cm depth
CLYPPT_sd1_M_02_apr_2014nc	Double	Soil texture fraction clay in percent (mean estimate) for 2.5 cm depth
CLYPPT_sd2_M_02_apr_2014nc	Double	Soil texture fraction clay in percent (mean estimate) for 10 cm depth
CLYPPT_sd3_M_02_apr_2014nc	Double	Soil texture fraction clay in percent (mean estimate) for 22.5 cm depth
CLYPPT_sd4_M_02_apr_2014nc	Double	Soil texture fraction clay in percent (mean estimate) for 45 cm depth
CLYPPT_sd5_M_02_apr_2014nc	Double	Soil texture fraction clay in percent (mean estimate) for 80 cm depth
CLYPPT_sd6_M_02_apr_2014nc	Double	Soil texture fraction clay in percent (mean estimate) for 150 cm depth
CRFVOL_sd1_M_02_apr_2014nc	Double	Coarse fragments volumetric in percent (mean estimate) for 2.5 cm depth
CRFVOL_sd2_M_02_apr_2014nc	Double	Coarse fragments volumetric in percent (mean estimate) for 10 cm depth
CRFVOL_sd3_M_02_apr_2014nc	Double	Coarse fragments volumetric in percent (mean estimate) for 22.5 cm depth
CRFVOL_sd4_M_02_apr_2014nc	Double	Coarse fragments volumetric in percent (mean estimate) for 45 cm depth
CRFVOL_sd5_M_02_apr_2014nc	Double	Coarse fragments volumetric in percent (mean estimate) for 80 cm depth
CRFVOL_sd6_M_02_apr_2014nc	Double	Coarse fragments volumetric in percent (mean estimate) for 150 cm depth
ORCDRC_sd1_M_02_apr_2014nc	Double	Soil organic carbon content (fine earth fraction) in permilles (mean estimate) for 2.5 cm depth
ORCDRC_sd2_M_02_apr_2014nc	Double	Soil organic carbon content (fine earth fraction) in permilles (mean estimate) for 10 cm depth
ORCDRC_sd3_M_02_apr_2014nc	Double	Soil organic carbon content (fine earth fraction) in permilles (mean estimate) for 22.5 cm depth
ORCDRC_sd4_M_02_apr_2014nc	Double	Soil organic carbon content (fine earth fraction) in permilles (mean estimate) for 45 cm depth
ORCDRC_sd5_M_02_apr_2014nc	Double	Soil organic carbon content (fine earth fraction) in permilles (mean estimate) for 80 cm depth
ORCDRC_sd6_M_02_apr_2014nc	Double	Soil organic carbon content (fine earth fraction) in permilles (mean estimate) for 150 cm depth
PHIHOX_sd1_M_02_apr_2014nc	Double	Soil pH x 10 in H2O (mean estimate) for 2.5 cm depth
PHIHOX_sd2_M_02_apr_2014nc	Double	Soil pH x 10 in H2O (mean estimate) for 10 cm depth
PHIHOX_sd3_M_02_apr_2014nc	Double	Soil pH x 10 in H2O (mean estimate) for 22.5 cm depth
PHIHOX_sd4_M_02_apr_2014nc	Double	Soil pH x 10 in H2O (mean estimate) for 45 cm depth
PHIHOX_sd5_M_02_apr_2014nc	Double	Soil pH x 10 in H2O (mean estimate) for 80 cm depth
PHIHOX_sd6_M_02_apr_2014nc	Double	Soil pH x 10 in H2O (mean estimate) for 150 cm depth
prec_10nc	Double	Precipitation in October
prec_1nc	Double	Precipitation in January
prec_11nc	Double	Precipitation in November
prec_12nc	Double	Precipitation in December
prec_2nc	Double	Precipitation in February

Name	Type	Description
prec_3nc	Double	Precipitation in March
prec_4nc	Double	Precipitation in April
prec_5nc	Double	Precipitation in May
prec_6nc	Double	Precipitation in June
prec_7nc	Double	Precipitation in July
prec_8nc	Double	Precipitation in August
prec_9nc	Double	Precipitation in September
SLTPPT_sd1_M_02_apr_2014nc	Double	Soil texture fraction silt in percent (mean estimate) for 2.5 cm depth
SLTPPT_sd2_M_02_apr_2014nc	Double	Soil texture fraction silt in percent (mean estimate) for 10 cm depth
SLTPPT_sd3_M_02_apr_2014nc	Double	Soil texture fraction silt in percent (mean estimate) for 22.5 cm depth
SLTPPT_sd4_M_02_apr_2014nc	Double	Soil texture fraction silt in percent (mean estimate) for 45 cm depth
SLTPPT_sd5_M_02_apr_2014nc	Double	Soil texture fraction silt in percent (mean estimate) for 80 cm depth
SLTPPT_sd6_M_02_apr_2014nc	Double	Soil texture fraction silt in percent (mean estimate) for 150 cm depth
SNDPPT_sd1_M_02_apr_2014nc	Double	Soil texture fraction sand in percent (mean estimate) for 2.5 cm depth
SNDPPT_sd2_M_02_apr_2014nc	Double	Soil texture fraction sand in percent (mean estimate) for 10 cm depth
SNDPPT_sd3_M_02_apr_2014nc	Double	Soil texture fraction sand in percent (mean estimate) for 22.5 cm depth
SNDPPT_sd4_M_02_apr_2014nc	Double	Soil texture fraction sand in percent (mean estimate) for 45 cm depth
SNDPPT_sd5_M_02_apr_2014nc	Double	Soil texture fraction sand in percent (mean estimate) for 80 cm depth
SNDPPT_sd6_M_02_apr_2014nc	Double	Soil texture fraction sand in percent (mean estimate) for 150 cm depth
soilcompaction_evaluationnc	Double	Soil susceptibility to compaction
tmax_10nc	Double	Maximum October temperature
tmax_1nc	Double	Maximum January temperature
tmax_11nc	Double	Maximum November temperature
tmax_12nc	Double	Maximum December temperature
tmax_2nc	Double	Maximum February temperature
tmax_3nc	Double	Maximum March temperature
tmax_4nc	Double	Maximum April temperature
tmax_5nc	Double	Maximum May temperature
tmax_6nc	Double	Maximum June temperature
tmax_7nc	Double	Maxiumum July temperature
tmax_8nc	Double	Maximum August temperature
tmax_9nc	Double	Maximum September temperature
tmin_10nc	Double	Minimum October temperature
tmin_1nc	Double	Minimum January temperature
tmin_11nc	Double	Minimum November temperature
tmin_12nc	Double	Minimum December temperature
tmin_2nc	Double	Minimum February temperature
tmin_3nc	Double	Minimum March temperature
tmin_4nc	Double	Minimum April temperature
tmin_5nc	Double	Minimum May temperature
tmin_6nc	Double	Minimum June temperature
tmin_7nc	Double	Maxiumum July temperature
tmin_8nc	Double	Minimum August temperature
tmin_9nc	Double	Minimum September temperature
UniGrd5bnc	Double	Unique grid number of abiotic and bioclimatic information per 0.5x0.5km grid over Europe
var10nc	Double	Annual mean T
var1nc	Double	Mean T of warmest quarter
var11nc	Double	Mean T of coldest quarter
var12nc	Double	Growing degree-days on 0°C base
var13nc	Double	Growing degree-days on 5°C base
var14nc	Double	Mean T of the coldest month
var15nc	Double	Mean T of the warmest month
var16nc	Double	Maximum T of coldest month
var17nc	Double	Minimum T of warmest month
var18nc	Double	Number of months with mean T > 10°C
var19nc	Double	Thermicity index
var20nc	Double	Annual precipitation

Name	Type	Description
var2nc	Double	Mean diurnal range
var21nc	Double	Precipitation of the wettest month
var22nc	Double	Precipitation of the driest month
var23nc	Double	Precipitation seasonality
var24nc	Double	Precipitation of wettest quarter
var25nc	Double	Precipitation of driest quarter
var26nc	Double	Precipitation of warmest quarter
var27nc	Double	Precipitation of coldest quarter
var28nc	Double	Minimum June July August precipitation
var29nc	Double	Maximum June July August precipitation
var30nc	Double	Minimum December January February precipitation
var3nc	Double	Isothermality
var31nc	Double	Maximum December January February precipitation
var32nc	Double	Total precipitation for months with a mean monthly T is above 0°C
var33nc	Double	Annual actual evapotranspiration
var34nc	Double	Annual potential evapostranspiration
var35nc	Double	Coefficient of annual moisture availability
var36nc	Double	Aridity Index
var37nc	Double	PET seasonality
var38nc	Double	Thornthwaite 1948 humidity index
var39nc	Double	Thornthwaite 1948 aridity index
var40nc	Double	Emberger's pluviothermic quotient
var4nc	Double	T seasonality
25kgridnc	Double	Unique grid number of weather information per 25x25km grid over Europe
var41nc	Double	Annual solar radiation
var42nc	Double	Altitude + 500m

WeatherVariables: Contains the weather information like temperature, precipitation, humidity per 25 x 25 km grid over Europe. The field *GRID_NO* is linked to from the *Unigrid* table, specifying which Unigrid cell is located in which weather grid cell.

Table 3.6   *Description of weatherVariables input.*

Name	Type	Description
GRID_NO	Long Integer	Unique weather grid number
MaT	Double	Mean annual temperature
SDmT	Double	Standard deviation of monthly mean temperature
MAXmT	Double	Maximum monthly temperature
MINmT	Double	Minimum monthly temperature
MaDR	Double	Mean diurnal range
aTR	Double	Annual temperature range
ISO	Double	Isothermality
DD0	Double	Degree days above 0 degrees Celsius
DD5	Double	Degree days above 5 degrees Celsius
DD10	Double	Degree days above 10 degrees Celsius
TaP	Double	Total annual precipitation
SDmP	Double	Standard deviation of monthly precipitation
MAXmP	Double	Maximum monthly precipitation
MINmP	Double	Minimum monthly precipitation
TaPET	Double	Total annual potential evapotranspiration
SDmPET	Double	Standard deviation of monthly PET
MAXmPET	Double	Maximum monthly PET
MINmPET	Double	Minimum monthly PET
TaR	Double	Total annual radiation
SDmR	Double	Standard deviation of monthly radiation
MAXmR	Double	Maximum monthly radiation

Name	Type	Description
MINmR	Double	Minimum monthly radiation
MwaqT	Double	Mean warmest quarter temperature
McoqT	Double	Mean coldest quarter temperature
MweqT	Double	Mean wettest quarter temperature
MdrqT	Double	Mean driest quarter temperature
MwaqP	Double	Mean warmest quarter precipitation
McoqP	Double	Mean coldest quarter precipitation
MweqP	Double	Mean wettest quarter precipitation
MdrqP	Double	Mean driest quarter precipitation
MwaqR	Double	Mean warmest quarter radiation
McoqR	Double	Mean coldest quarter radiation
MweqR	Double	Mean wettest quarter radiation
MdrqR	Double	Mean driest quarter radiation
MwaqPET	Double	Mean warmest quarter PET
McoqPET	Double	Mean coldest quarter PET
MweqPET	Double	Mean wettest quarter PET
MdrqPET	Double	Mean driest quarter PET
ARi	Double	Aridity index
ThHUi	Double	Thorntwaite 1948 humidity index
ThARi	Double	Thorntwaite 1948 aridity index

branchBiomassParameters: Contains the parameter sets of the allometric models that are used to estimate branch biomass per species in different regions. It includes *region* and *speciesName* to identify specific parameter sets, as defined by the type of function and the corresponding parameters. The *override-comment* indicates whether one of the function was replaced by another one (yes), otherwise, use no. The minimum volume (*minVol*) sets a minimum acceptable volume where the function can be used. The field *region* is used in the *plot* table to identify the correct branch biomass region. The field *speciesName* relates to the species defined in the table *speciesParameters*.

Table 3.7 *Description of branchBiomassParameters input.*

Name	Type	Description
ID	Long Integer	Key
region	Short Text	Region of applied biomass functions
speciesName	Short Text	Name of species
function	Short Text	Function used to estimate biomass
CF	Double	Number of observations that lie above (or below) particular value in dataset
LNB0	Double	Logaritmic coefficient
B1	Double	Logaritmic coefficient
override-comment	Short Text	Information about use of different function than indicated in *function*
minVol	Double	Minimum volume used to estimate biomass

foliageBiomassParameters: Contains the parameter sets of the allometric models that are used to estimate foliage biomass per species in different regions. It includes *region* and *speciesName* to identify specific parameter sets, as defined by the type of function and the corresponding parameters. The *override-comment* indicates whereas one of the function was replaced by another one (yes), otherwise, use no. The minimum volume (*minVol*) sets a minimum acceptable volume where the function can be used. The field *region* is used in the *plot* table to identify the correct foliage biomass region. The field *speciesName* relates to the species defined in the table *speciesParameters*.

Table 3.8   *Description of foliageBiomassParameters input.*

Name	Type	Description
ID	Long Integer	Key number
region	Short Text	Region of applied biomass functions
speciesName	Short Text	Name of species
function	Short Text	Function used to estimate biomass
CF	Double	Number of observations that lie above (or below) particular value in dataset
LNB0	Double	Logaritmic coefficient
B1	Double	Logaritmic coefficient
override-comment	Short Text	Information about use of different function than indicated in *function*
minVol	Double	Minimum volume used to estimate biomass

rootBiomassParameters: Contains the parameter sets of the allometric models that are used to estimate root biomass per species in different regions. It includes *region* and *speciesName* to identify specific parameter sets, as defined by the type of function and the corresponding parameters. The *override-comment* indicates whereas one of the function was replaced by another one (yes), otherwise, use no. The minimum volume (*minVol*) sets a minimum acceptable volume where the function can be used. The field *region* is used in the *plot* table to identify the correct root biomass region. The field *speciesName* relates to the species defined in the table *speciesParameters*.

Table 3.9   *Description of rootBiomassParameters input.*

Name	Type	Description
ID	Long Integer	Key number
region	Short Text	Region of applied biomass functions
speciesName	Short Text	Name of species
function	Short Text	Function used to estimate biomass
CF	Double	Number of observations that lie above (or below) particular value in dataset
LNB0	Double	Logaritmic coefficient
B1	Double	Logaritmic coefficient
override-comment	Short Text	Information about use of different function than indicated in *function*
minVol	Double	Minimum volume used to estimate biomass

volumeParameters: Contains the parameter sets of the individual-tree volume models per species in different regions. It includes *region* and *speciesName* to identify specific parameter sets. Specific species in specific regions can have multiple models, e.g. if it is required to calculate both underbark and overbark volumes. This can be indicated by adding an extension to the region name (for example Ireland_underbark and Ireland_overbark). The field *region* is used in the p*lot* table to identify the correct volume region. The field *speciesName* relates to the species defined in the table *speciesParameters*. Generally, volume models are fit using a linear, quadratic and cubic model and all corresponding parameters are included in the table. The field *function* indicates which of these options should be used (linear, quadratic or cubic), to be decided by the user based on the fit on the original data. All species should have a volume model defined for a specific region. If needed, models from related species or regions can be copied to fill gaps, which can be indicated in the *comment* field. For instance, if within a certain region only few trees of *Abies* were present, and the model does not fit well, the function of *Picea* from the same region can be used instead.

Table 3.10 *Description of volumeParameters input.*

Name	Type	Description
id	Long Integer	Key
speciesName	Short Text	Name of species
region	Short Text	Region of applied volume functions
function	Short Text	Function used to estimate volume
Volume_dm3_Minimum	Double	Minimum volume per species (dm3)
Linear_Constant	Double	Parameter of linear function
Linear_b1	Double	Parameter of linear function
Quadratic_Constant	Double	Parameter of quadratic function
Quadratic_b1	Double	Parameter of quadratic function
Quadratic_b2	Double	Parameter of quadratic function
Cubic_Constant	Double	Parameter of cubic function
Cubic_b1	Double	Parameter of cubic function
Cubic_b2	Double	Parameter of cubic function
Cubic_b3	Double	Parameter of cubic function
comment	Short Text	Additional information e.g. note if volume function is over-ride by different volume region

woodDensityParameters: Contains the wood density value per species per region. The field *region* is used in the *plot* table to identify the correct *woodDensityRegion*. The field *speciesName* relates to the species defined in the table *speciesParameters*.

Table 3.11 *Description of woodDensityParameters input.*

Name	Type	Description
ID	Long Integer	Key
region	Short Text	Name of wood density region used to calculate biomass
speciesName	Short Text	Name of species
WoodDensity	Double	Value of wood density

growthParameters: Contains the parameters of the growth model per species. The shape of the growth model is hard-coded. The field *speciesName* relates to the species defined in the table *speciesParameters*. The field *ParName* includes a combination of the part of the growth model it refers to (B1 or B2) and the abiotic and weather variables as defined in the tables *Unigrid* and *WeatherVariables*.

Table 3.12 *Description of growthParameters input.*

Name	Type	Description
spec	Short Text	Name of species
ParName	Short Text	Identification of growth parameter
Par	Double	Value of growth parameter

scenario: Contains the names and descriptions of the scenarios that are defined in the database. The *scenario* links to the *plotXmanagement* table.

Table 3.13 *Description of scenario input.*

Name	Type	Description
scenario	Short Text	Name of scenario(s) e.g. unmanaged_scenario
explanation	Short Text	Explanation of scenario(s)

managementType: Contains the types of management that are defined in the database with a short explanation. Each individual *management_type* is further parameterised in the *management* and *regeneration* tables.

Table 3.14 *Description of managementType input.*

Name	Type	Description
management_type	Short Text	Name of management(s) e.g unmanaged
explanation	Short Text	Explanation of management(s)

plotXmanagement: Indicates for each *plot* what *management_type* should be applied under a specific *scenario*.

Table 3.15 *Description of plotXmanagement input.*

Name	Type	Description
plot	Short Text	Unique plot identifier
scenario	Short Text	Name of scenario(s) e.g. unmanaged_scenario
management_type	Short Text	Name of management(s) e.g. managed

management: Contains the definition of when to apply the harvesting rules a *management_type* per species. Each combination of *management_type* and *speciesName* is linked to a *mortalityScheme*. The *mortalityScheme* is retrieved from the *mortality* table, where mortality is defined by species and diameter class. Each combination will be applied with a certain *interval*, but subject to the condition that the specified *variable* (see Table 3.1) is larger than the *valueMin* and smaller than the *valueMax*.

Table 3.16 *Description of management input.*

Name	Type	Description
id	Long Integer	Key
management_type	Short Text	Name of management(s) e.g. unmanaged
speciesName	Short Text	Name of species
variable	Short Text	Attribute used for management action e.g. basal area
valueMin	Long Integer	Lower limits for used variable
valueMax	Long Integer	Higher limits for used variable
interval	Long Integer	Time over which specified management is performed
mortalityScheme	Long Integer	Identifier of used mortality

mortality: Contains the information of the fraction of trees to remove per species per diameter class in case of natural mortality and for each management type. Note that the fraction value is always specified as an annual value and will be applied taken the interval into account. The field *type* is used to distinguish between natural mortality (nat) and management (mgmt). The field *id* is linked to the field *mortalityScheme* in the *management* table.

Table 3.17 *Description of mortality input.*

Name	Type	Description
id	Long Integer	Key
comment	Short Text	Species name that corresponds with *speciesIndex*
type	Short Text	Mortality type e.g. nat (natural) or mgmt (management)
speciesIndex	Long Integer	Identifier of species
1	Double	Mortality fractions described over diameter classes
....	...	
40	Double	

regeneration: Contains the definition of when to apply the regeneration rules of a *management_type* per species. Each combination of *management_type* and *speciesName* is linked to an *ingrowthScheme*. The *ingrowthScheme* is retrieved from the *ingrowth* table, where ingrowth is defined by species and diameter class. Each combination will be applied with a certain *interval*, but subject to the condition that the specified *variable* (Table 3.1) is larger than the *valueMin* and smaller than the *valueMax*.

Table 3.18 Description of regeneration input.

Name	Type	Description
id	Long Integer	Key
management_type	Short Text	Name of management(s) e.g. unmanaged
speciesName	Short Text	Name of species
variable	Short Text	Attribute used for management action e.g. basal area
valueMin	Long Integer	Lower limits for used variable
valueMax	Long Integer	Higher limits for used variable
interval	Long Integer	Time over which specified management is performed
ingrowthScheme	Long Integer	Identifier of used ingrowt

ingrowth: Contains the information of the number of trees to add per species per diameter class in case of natural ingrowth and for each management type. Note that the value is specified as an absolute number, and will be applied regardless the interval. The field *type* is used to distinguish between natural mortality (nat) and management (mgmt). The field *id* is linked to the field *ingrowthScheme* in the *regeneration* table.

Table 3.19 Description of ingrowth input.

Name	Type	Description
id	Long Integer	Key
comment	Short Text	Species name that corresponds with *speciesIndex*
type	Short Text	Ingrowth type e.g. nat (natural) or mgmt (management - planting)
speciesIndex	Long Integer	Identifier of species
1	Double	Ingrowth fractions described over diameter classes
....	...	
40	Double	

harvest: Defines for each harvesting *System* what activities are included. A 1 in the field *harvest* indicates that this *Activity* is part of this *System*, and that the associated costs of this activity are calculated, via the link of *Activity* to the *cost_functions* table.

Table 3.20 Description of harvest input.

Name	Type	Description
Activity	Short Text	Activities included in harvest system
System	Short Text	Index of harvest type
harvest	Long Integer	Seleced harvest activity

harvestActivities: Contains the explanation of the specific harvest activity that is indicated in the *harvest* table. Each harvest activity is divided into two group: extraction of logs and extraction of residues.

Table 3.21 Description of harvestActivities input.

Name	Type	Description
Activity	Short Text	Activities included in harvest system
explanation	Short Text	Description of harvest activities

harvestActivities_cost: Contains the price of each harvest activity per cost region. The price is expressed in Euro per minute. The field *costRegion* relates to the *plot* table to identify the approprate costRegion to be used for each plot. The explanation of the specific harvest activity is in the *harvestActivities* table.

Table 3.22 *Description of harvestActivities_cost input.*

Name	Type	Description
costRegion	Short Text	Name of cost region used to calculate harvest and harvesting actives
Activity	Short Text	Activities included in harvest system
price	Double	Unit costs of harvest activity in Euro per min

cost_functions: Contains the parameters to calculate the costs of each harvest activity. The time consumption of each *Activity* can be expressed as a function of a certain *Variable* (Dbh, StemVolume, TotalHarvest, soil compaction), using a certain *functiontype* (polynomal, exponential, power and division), resulting in the time consumption expressed in a certain *unit* (min/tree, min/m³ or min). The costs are then calculated by multiplication of the total time consumed and the *price*. Each *Activity* should be defined separately for conifers and broadleaves (indicated by the *Conifer* field) and per harvest type. Please note that in EFSICEN-Space V1.0 the distinction by harvest type is not implemented yet.

Table 3.23 *Description of cost_functions input.*

Name	Type	Description
Activity	Short Text	Activities included in harvest system
HarvestType	Short Text	Cutting type such as thinning (TH) and final fell (FF)
Conifer	Yes/No	Selected harvest activities for coniferous species
Variable	Short Text	Attribute used to calculate costs of harvest activity
functiontype	Short Text	Type of function used (polynome exponential) to calculate costs of harvest activity
unit	Short Text	Units of labour
p0	Long Integer	Parameter of function used
p1	Long Integer	Parameter of function used
p2	Long Integer	Parameter of function used

harvestMgmt: Indicates which harvest systems may potentially be used in connection with what management type. For the combination of *managementType* and *harvestSystem*, a 1 in the field *include* indicates that this combination is eligible for the determination of the system with the lowest harvesting costs.

Table 3.24 *Description of harvestMgmt input.*

Name	Type	Description
mortalityMgt	Short Text	Name of management(s) e.g. unmanaged
System	Short Text	Index of harvest type
harvest	Long Integer	Seleced harvest activity

$settings: Contains the settings for the set of input files to be generated, specifying the country, plots to be included and the scenario. The field *Variable* contains the variables that need to be set to define a specific scenario. Each Variable is defined by a certain *Value* and explained in the field *info*. The variables to be set are *CountryCode*, *ManualPlotSelection* and *Scenario*. *CountryCode* relates to the *CountryCode* in the plot table, identifying the country to run. If *ManualPlotSelection* is set to *No*, all plots in that country will be included in the input set. If set to *Yes*, only the plots in that country marked as *True* in the *Flag* field of the plot list will be included. This selection can be done manually, for example to generate a small test set, or using a separate (update) query to select plots with specific attributes, for example according to owner. Two

example queries are provided, called *ResetPlotFlags* and *SelectAllPlots* that set all plots respectively to *False* or *True.* Remember that when you change the settings, you have to execute the *makeCSV_all.bat* (located in ..\data\makeCSV_all.bat) to take effect. *Scenario* links to the *scenario* table and specifies for which scenario the data should be extracted.

Table 3.25 *Description of $settings input.*

Name	Type	Description
Variable	Short Text	Includes key variables such as CountryCode, ManualPlotSelection and Scenario
Value	Short Text	Specific action settings for country, plots and scenario
info	Short Text	Explanation of variables and set values

3.2.3   Set up your own database

To set up a new database for your own project, go to …\FRLversie_python3\data\database. In the database folder you will find the Access database called espy.mdb. The espy is used as a storage place for your data which later on will serve as a way to generate the input files needed for the model. To start with inserting data to espy.mdb you need measurements of individual tree data per plot. Start with filling your data in the initData tab. The initData requires id, plot, speciesName, diameter class (DiamClass) and number of stems per ha (nr_per_ha). EFISCEN-Space uses by default the 20 species groups as listed in the speciesParameters table. You can classify the species present in your study area to these groups, or you can choose to use your own grouping. In case you want to add your own species, remember that it requires information like wood density, volume parameters and growth parameters. All plots need a unique identifier. Commonly, a plot ID as derived from NFI data is built up by 2 letters to identify the country, an integer to indicate the NFI cycle it is derived from and the plot number according to the NFI system, separated by underscores. The plot ID NL_6_27377 thus refers to plot 27377 from the Sixth Dutch NFI. To assign the correct diameter class remember that the model uses 40 classes with a width of 2.5 cm each, with 0 – 2.5 cm as the first class. Convert each measured tree to the number of trees per hectare it is representative for using the country-specific plot design.

Next, fill the plot table with generic plot characteristics such as id, plot name, year of measurement (nfiYear), representative area (reprArea), volume region, biomass region and cost region. Each plot should be represented by a single record. The information about the representative area, volume region, biomass region and cost region depend on country specific information.
- The representative area is the area that the plot represents. If the region/country where the plots are located in is 100ha and you have 10 plots, then each plot represents 10 ha. If you do not have this information available you can set the representative area to 1 ha as a default.
- The volume region is linked to the volume models which are used for volume estimation for each species. You can choose an existing volume model region, or develop a new set of volume models. The list of currently available volume models can be found in the volumeParameters table, included in the database. Published_parameters.mdb (…\FRLversie_python3\data\database).
- The biomass region is linked to branch, foliage, roots for which we use the European parameterization based on biomass parameters sets from Forrester et al. (2017). Alternatively, local biomass models may be developed and used.
- The cost region is still under development. However we wanted to have a table set up already in the database so we could built up relations with the other ones.
- The abioticPlot refers to the cell of the Unigrid the plot is located in. This can be determined using the plot coordinates. If the abiotic data is not present for this Unigrid cell, it needs to be extracted from the underlying environmental data.

After gathering all the information about plot, set up the management_type and scenarios in the plotXmanagement tab. In case when repeated inventory data are available, the management (harvest probabilities) can be calculated using the methods as described in Schelhaas et al. (2018b). Otherwise it can derived from yield tables or simply copied from another country. Remember that management type and scenario have to match with other tables, where management and scenario are used.

Following management move to *management* tab in which you need information about id, management type, species, variable, value min&max, interval and mortality scheme. The value min&max define whether the management rule is active only if the specified variable (for example basal area) is within a certain range. Use a -1 to indicate if no specific value should be used. The interval indicates the time after which the management will be applied again. MortalityScheme refers to the mortality table. In the mortality tab you need to define the fraction of trees to be harvested for each diameter class in the model for each species. The id in the mortality table corresponds to the mortalityScheme in the management table. The same steps are used for regeneration (like management) and ingrowth (mortality) tabs. Other tables included in the espy database require only small changes regarding new data like management types, scenarios, harvestMgt (for explanation of the different harvesting systems see Table 2.2), volume parameters, biomass parameters. For volume parameters and biomass parameters (branch, foliage and roots) the full set of 20 species is required, thus even if some species are not present in your data you still cannot remove them from the table. This is because the model first reads all parameters and then selects only relevant information which is included in plot data. In case when you lack data of volume parameters per species per region, you can find these information in the Published_parameters.mdb provided in the database folder. Lastly, change the $settings tab to the new country code and scenario.

Then run makeCSV_all.bat (located in …\FRLversie_python3\data) to create the .csv files, which will be used in the initialization. Created .csv files are divided across four different input folders (expansionfactors, growthandmortality, managementfiles and plots) which follows the structure of the scenariodefinition folder (Figure 3.16). The biomass, volume and wood density parameters are located in the expansionfactors folder. The ingrowth, mortality (natural & harvest) and specific species parameters are included in the growthandmortality folder. The information about types of harvest activities and their costs is in the managementfiles folder. The general plot information and number of tree per diameter class per plot are included in the plot folder.

Next, copy the .csv files that are generated to the correct folders in the scenariodefinition folder.

3.3   Input & output folder structure

The user is free to choose how to order his/her own file structure and to keep track of different scenarios and the corresponding input and output files. Here, we offer one possible template. We define an "experiment" as a fixed set of plots (usually a country or a region) that we simulate with one or more scenarios, where scenarios differ from each other by changing one more settings or input files. Each experiment is represented by a separate folder (see Experiment1 in the example Figure 3.16). Inside this folder is a folder '*scenariodefinition*' which holds the input files for EFISCEN-Space. This folder may hold alternative versions of the same type of input file to be able to run different scenarios within the experiment, while non-deviating files can be re-used between scenarios. Each scenario is defined in a corresponding settings.csv file, which lists the input files to be used for that specific scenario. It also holds the path where the output files are stored, usually directly under the Experiment folder (see the folder output_Scenario1 in Figure 3.16). The following sections describe in more detail the input and output files, structured following the subfolders in which they are located.

Figure 3.16 *Folder structure for input and outputfiles of efiscenspace.*

3.3.1   Description of input files

All input files are stored as a comma separated values file (.csv), except the Yasso parameters that are stored as an Excel file.

Settings.csv

Settings.csv is located in the scenariodefinition folder. This file is given as argument to efiscenspace.py or efiscenspace.exe and provides the direction to the input files to be used, possible switches and potentially an alternative output location. Table 3.26 provides the minimal settings that are required to run the model while Table 3.24 shows the optional settings. If no output path is specified, output will be written to the directory \Output, located under the experiment folder. If no input files are specified, the defaults as shown in Table 3.24 will be used. The layout of the table includes four columns: key, value, unit and comment. The unit and comment columns are non-functional to the script and provide information for the user. The Key column contains global parameters and switches for EFISCEN-Space, the value column the value that should be used during the simulation.

Table 3.26 *Settings.csv – required entries.*

key	value	unit	comment
StartYear	2015	yearAD	year to start the simulation
Duration	5	year	duration of simulation
runYasso	1	boolean	run the Yasso model
doCostCalculation	1	boolean	perform calculations on cost of harvesting
dynamicParamsUsed	0	boolean	use dynamic weather variables over time
doSpinUp	1	boolean	run model stands up to a common StartYear before starting the simulation
BiomassOutput	1	boolean	generate output for biomass - overridden to true if runYasso is True
NumberOutput	1	boolean	generate output with only stemnumbers
CostOutput	1	boolean	generate output for costs of harvesting

Table 3.27 *Settings.csv – optional entries.*

Key	Default value
outputPath	Output/
plotFile	plots/plotAttributes.csv
standFile	plots/plotNrperHa.csv
netcdfVariablesFilename	plots/plotattributes_dynamic.nc
mortFile	growthandmortality/mortalities.csv
ingrowthFile	growthandmortality/ingrowth.csv
speciesParameterFile	growthandmortality/speciesParameters.csv
volumeCoefFile	expansionfactors/volumeParameters.csv
bm_branchpFile	expansionfactors/BranchesParameters.csv
bm_foliagepFile	expansionfactors/FoliageParameters.csv
bm_rootspFile	expansionfactors/RootsParameters.csv
bm_wooddensitypFile	expansionfactors/WoodDensityParameters.csv
costFunctionsTimeFile	managementfiles/cost_functions_time.csv
costFunctionsPriceFile	managementfiles/cost_functions_price.csv
harvestSystemsFile	managementfiles/harvest_activities.csv
harvestSystemPerMgmtFile	managementfiles/harvestSystemPerMgmt.csv

3.3.1.1 Expansionfactors folder

Biomass...Parameters.csv (Branches, Foliage, Roots): Contains the biomass expansion models, which have been fitted for regions and species. Table includes: region, species index, used function, correction factor (CF), coefficients parameters (lnB0 and B1), override-comment and minVol. Note that the lnB0 is already log transformed in the input. The override-comment indicates whereas one of the function was replaced by another one (yes), otherwise. The minimum volume (minVol) sets a minimum acceptable volume where the model should to be used.

Table 3.28 *Description of Branches/Foliage/RootsParameters.csv.*

Name	Type	Description
region	Short Text	Region of applied biomass functions
speciesIndex	Long Integer	Identifier of species
function	Short Text	Function used to estimate biomass
CF	Double	Number of observations that lie above (or below) particular value in dataset
LNB0	Double	Logaritmic coefficient
B1	Double	Logaritmic coefficient
override-comment	Short Text	Information about use of different function than indicated in *function*
minVol	Double	Minimum volume used to estimate biomass

volumeParameters.csv: Contains the volume models that have been fitted for regions, specific species and orders of power. Table includes: region, speciesIndex, function (the one that should be applied), parameters of functions (logarithmic, quadratic, cubic) and minVol.

Table 3.29 *Description of volumeParameters.csv.*

Name	Type	Description
region	Short Text	Region of applied volume functions
speciesIndex	Long Integer	Identifier of species
function	Short Text	Function used to estimate volume
l0	Double	Parameter of linear function
l1	Double	Parameter of linear function
q0	Double	Parameter of quadratic function
q1	Double	Parameter of quadratic function
q2	Double	Parameter of quadratic function
c0	Double	Parameter of cubic function
c1	Double	Parameter of cubic function
c2	Double	Parameter of cubic function
c3	Double	Parameter of cubic function
minVol	Double	Minimum volume per species (dm3)

WoodDensityParameters.csv: Contains the wood density of specific species with regards to a region. Table includes: region, speciesIndex, WoodDensity.

Table 3.30 *Description of WoodDensityParameters.csv.*

Name	Type	Description
region	Short Text	Name of wood density region used to calculate biomass
speciesIndex	Long Integer	Name of species
WoodDensity	Double	Value of wood density

3.3.1.2 Growthandmortality folder

Ingrowth.csv: Contains the number of trees being recruited in specific diameter classes regarding type of ingrowth (e.g. natural or due to management). Table includes: regime (ingrowthMgt), used variable (basalArea, volume, stemnumber), speciesIndex, minimum value, maximum value, interval, type (natural, management) and diameter classes.

Table 3.31 *Description of ingrowth.csv.*

Name	Type	Description
regime	Short Text	Type of management (natural or due to management)
type	Short Text	Ingrowth type e.g. nat (natural) or mgmt (management - planting)
speciesIndex	Long Integer	Identifier of species
variable	Short Text	Attribute used for ingrowth action e.g. basal area
interval	Long Integer	Time over which specified management type is performed
valueMin	Long Integer	Lower limits for used variable
valueMax	Long Integer	Higher limits for used variable
1	Double	Ingrowth fractions described over diameter classes
...	...	
40	Double	

mortalities.csv: Contains the fractions of trees being removed in specific diameter classes regarding type of mortality (e.g. natural or due to management). Table includes: regime (mortalityMgt), type (natural, management), speciesIndex, used variable (basalArea, volume, stemnumber), interval, minimum value, maximum value and diameter classes.

Table 3.32 *Description of mortalities.csv.*

Name	Type	Description
regime	Short Text	Type of management (natural or due to management)
type	Short Text	Mortality type e.g. nat (natural) or mgmt (management - planting)
speciesIndex	Long Integer	Identifier of species
variable	Short Text	Attribute used for mortality action e.g. basal area
interval	Long Integer	Time over which specified management type is performed
valueMin	Long Integer	Lower limits for used variable
valueMax	Long Integer	Higher limits for used variable
1	Double	Mortality fractions described over diameter classes
...	...	
40	Double	

speciesParameters.csv: Contains the species specific information that is used. Table includes: speciesIndex, speciesName, isConiferous, classCount (number of diameter classes), d0 (minimum value), d1 (growth function lower cut-off), binWidth (width of each class), rgr (reference to parameter set used), index (species-specific) and the underlying parameters for each species.

Table 3.33 *Description of speciesParameters.csv.*

Name	Type	Description
speciesIndex	Long Integer	Identifier of species
speciesName	Short Text	Name of species
isConiferous	Yes/No	Selection of coniferous species
classCount	Long Integer	Total number of diameter classes
d0	Double	Minimum diameter of the lowest diameter class
d1	Double	Minimum diameter where the growth model should be applied
binWidth	Double	With of a diameter class (cm)
rgr	Short Text	Growth models literature reference
index	Long Integer	Key
S18$B1	Double	Parameters of species specific growth functions underlined by abiotic and weather information
S18$B1_ARi	Double	
S18$B1_aTR	Double	...
S18$B1_avgDepOxNnc	Double	...
S18$B1_avgDepOxSnc	Double	...
S18$B1_avgDepRedNnc	Double	...
S18$B1_BDRICM_02_apr_2014nc	Double	...
S18$B1_bio_7nc	Double	...
S18$B1_bio_8nc	Double	...
S18$B1_BLD_sd3_M_02_apr_2014nc	Double	...
S18$B1_CEC_sd3_M_02_apr_2014nc	Double	...
S18$B1_CLYPPT_sd3_M_02_apr_2014nc	Double	...
S18$B1_CRFVOL_sd3_M_02_apr_2014nc	Double	...
S18$B1_ISO	Double	...
S18$B1_lnPlotBasalArea	Double	...
S18$B1_MaDR	Double	...
S18$B1_MaT	Double	...
S18$B1_McoqP	Double	...
S18$B1_MdrqT	Double	...
S18$B1_MINmP	Double	...
S18$B1_MINmPET	Double	...
S18$B1_MwaqP	Double	...
S18$B1_MweqR	Double	...
S18$B1_MweqT	Double	...
S18$B1_ORCDRC_sd3_M_02_apr_2014nc	Double	...
S18$B1_PHIHOX_sd3_M_02_apr_2014nc	Double	...

Name	Type	Description
S18$B1_PlotBasalArea	Double	…
S18$B1_rDiffDq	Double	…
S18$B1_SDmP	Double	…
S18$B1_SDmPET	Double	…
S18$B1_SDmR	Double	…
S18$B1_SLTPPT_sd3_M_02_apr_2014nc	Double	…
S18$B1_soilcompaction_evaluationnc	Double	…
S18$B1_TaP	Double	…
S18$B1_TaR	Double	…
S18$B1_ThARi	Double	…
S18$B1_ThHUi	Double	…
S18$B1_var15nc	Double	…
S18$B1_var17nc	Double	…
S18$B1_var19nc	Double	…
S18$B1_var1nc	Double	…
S18$B1_var20nc	Double	…
S18$B1_var21nc	Double	…
S18$B1_var23nc	Double	…
S18$B1_var26nc	Double	…
S18$B1_var27nc	Double	…
S18$B1_var2nc	Double	…
S18$B1_var32nc	Double	…
S18$B1_var33nc	Double	…
S18$B1_var34nc	Double	…
S18$B1_var36nc	Double	…
S18$B1_var37nc	Double	…
S18$B1_var39nc	Double	…
S18$B1_var3nc	Double	…
S18$B1_var4nc	Double	…
S18$B2	Double	…
S18$B2_ARi	Double	…
S18$B2_aTR	Double	…
S18$B2_avgDepOxNnc	Double	…
S18$B2_avgDepOxSnc	Double	…
S18$B2_avgDepRedNnc	Double	…
S18$B2_BDRICM_02_apr_2014nc	Double	…
S18$B2_bio_7nc	Double	…
S18$B2_bio_8nc	Double	…
S18$B2_BLD_sd3_M_02_apr_2014nc	Double	…
S18$B2_CEC_sd3_M_02_apr_2014nc	Double	…
S18$B2_CLYPPT_sd3_M_02_apr_2014nc	Double	…
S18$B2_CRFVOL_sd3_M_02_apr_2014nc	Double	…
S18$B2_ISO	Double	…
S18$B2_lnPlotBasalArea	Double	…
S18$B2_MaDR	Double	…
S18$B2_MaT	Double	…
S18$B2_McoqP	Double	…
S18$B2_MdrqT	Double	…
S18$B2_MINmP	Double	…
S18$B2_MINmPET	Double	…
S18$B2_MwaqP	Double	…
S18$B2_MweqR	Double	…
S18$B2_MweqT	Double	…
S18$B2_ORCDRC_sd3_M_02_apr_2014nc	Double	…
S18$B2_PHIHOX_sd3_M_02_apr_2014nc	Double	…
S18$B2_PlotBasalArea	Double	…
S18$B2_rDiffDq	Double	…
S18$B2_SDmP	Double	…
S18$B2_SDmPET	Double	…

Name	Type	Description
S18$B2_SDmR	Double	...
S18$B2_SLTPPT_sd3_M_02_apr_2014nc	Double	...
S18$B2_soilcompaction_evaluationnc	Double	...
S18$B2_TaP	Double	...
S18$B2_TaR	Double	...
S18$B2_ThARi	Double	...
S18$B2_ThHUi	Double	...
S18$B2_var15nc	Double	...
S18$B2_var17nc	Double	...
S18$B2_var19nc	Double	...
S18$B2_var1nc	Double	...
S18$B2_var20nc	Double	...
S18$B2_var21nc	Double	...
S18$B2_var23nc	Double	...
S18$B2_var26nc	Double	...
S18$B2_var27nc	Double	...
S18$B2_var2nc	Double	...
S18$B2_var32nc	Double	...
S18$B2_var33nc	Double	...
S18$B2_var34nc	Double	...
S18$B2_var36nc	Double	...
S18$B2_var37nc	Double	...
S18$B2_var39nc	Double	...
S18$B2_var3nc	Double	...
S18$B2_var4nc	Double	...

3.3.1.3   Managementfiles folder

cost_functions_price.csv: Contains the costs of harvest activities per specific region in Euro per min. Table includes: region and cost of specific harvest activities (logs_... and residues_...). For full names and description of harvest activities see section 2.12 Harvesting costs.

Table 3.34 *Description of cost_functions_price.csv.*

Name	Type	Description
costRegion	Short Text	Name of cost region used to calculate harvest and harvesting actives
logs_CYL	Double	cable yarding roundwood logs
logs_CYW	Double	cable yarding whole trees
logs_FO	Double	forwarding logging residues with a forwarder
logs_FT	Double	extraction to roadside of roundwood with a farm tractor
logs_HA	Double	felling and processing with single grip harvester
logs_MF	Double	motor-manual felling with chainsaw
logs_MP	Double	motor-manual processing with chainsaw
logs_PCH	Double	Mechanized processing at the roadside (cross-cutting and delimbing) with excavator mounted processor head
logs_PCM	Double	motor-manual processing at the roadside (cross-cutting and delimbing) with chainsaw
logs_SKL	Double	skidding logs with a skidder
logs_SKW	Double	skidding whole trees with a skidder
residues_CH	Double	Chipping logging residues
residues_FO	Double	forwarding logging residues with a forwarder
residues_FT	Double	extraction to roadside of logging residues with a farm tractor
residues_HA	Double	piling logging residues with single grip harvester
residues_MP	Double	motor-manual piling logging residues
residues_PCH	Double	piling residues at the roadside with processor
residues_PCM	Double	piling residues at the roadside in motor-manual processing

cost_functions_time.csv: Contains the models to calculate time consumption per harvest activity. Table includes: harvest activity, harvest type, variable, function (polynominal, exponential) unit, coefficient parameters of function (p0, p1, p2).

Table 3.35 *Description of cost_functions_time.csv.*

Name	Type	Description
Activity	Short Text	Activities included in harvest system
HarvestType	Short Text	Cutting type such as thinning (TH) and final fell (FF)
Conifer	Yes/No	Selected harvest activities for coniferous species
Variable	Short Text	Attribute used to calculate costs of harvest activity
functiontype	Short Text	Type of function used to calculate costs of harvest activity
unit	Short Text	Units of labour
p0	Long Integer	
p1	Long Integer	
p2	Long Integer	

harvest_activities.csv: Contains the definition of which harvesting activities are used in which system. If a certain harvest activity is used by a specific system it is indicated by 1, otherwise it is 0. Full names and description of harvest activities can be found in section 2.12 Harvesting costs.

Table 3.36 *Description of harvest_activites.csv.*

Name	Type	Description
System	Short Text	Index harvest type
logs_CYL	Double	cable yarding roundwood logs
logs_CYW	Double	cable yarding whole trees
logs_FO	Double	forwarding logging residues with a forwarder
logs_FT	Double	extraction to roadside of roundwood with a farm tractor
logs_HA	Double	felling and processing with single grip harvester
logs_MF	Double	motor-manual felling with chainsaw
logs_MP	Double	motor-manual processing with chainsaw
logs_PCH	Double	Mechanized processing at the roadside (cross-cutting and delimbing) with excavator mounted processor head
logs_PCM	Double	motor-manual processing at the roadside (cross-cutting and delimbing) with chainsaw
logs_SKL	Double	skidding logs with a skidder
logs_SKW	Double	skidding whole trees with a skidder
residues_CH	Double	Chipping logging residues
residues_FO	Double	forwarding logging residues with a forwarder
residues_FT	Double	extraction to roadside of logging residues with a farm tractor
residues_HA	Double	piling logging residues with single grip harvester
residues_MP	Double	motor-manual piling logging residues
residues_PCH	Double	piling residues at the roadside with processor
residues_PCM	Double	piling residues at the roadside in motor-manual processing

harvestSystemPerMgmt.csv: Indicates which harvest system can be used in connection to which management type. If a specific system is eligible it is indicated by 1, if not then 0. Table includes: mortalityMgt (e.g., managed & unmanaged) and 10 systems.

Table 3.37 *Description of harvestSystemPerMgmt.csv.*

Name	Type	Description
mortalityMgt	Short Text	Name of management type
s1	Double	Index of harvest type
...	...	
s10	Double	

3.3.1.4   Plots folder

plotAttributes.csv: Gives the definition of each plot in terms of plotName, year of measurement, what type of management is applied, its representative area, what region parameter set to be used for volume, biomass and cost calculations, and all abiotic variables.

Table 3.38 *Description of plotAttributes.csv.*

Name	Type	Description
plotName	Short Text	Unique plot identifier
ID	Long Integer	Key
nfiYear	Long Integer	Year when measurement was taken
mortalityNat	Short Text	Natural mortality type
mortalityMgt	Short Text	Managed mortality type
reprArea	Double	Area representative for one plot
volumeRegion	Short Text	Region of applied volume functions
branchBiomassRegion	Short Text	Name of volume region used to calculate a branch biomass volume
foliageBiomassRegion	Short Text	Name of volume region used to calculate a foliage biomass volume
rootsBiomassRegion	Short Text	Name of volume region used to calculate a root biomass volume
woodDensityRegion	Short Text	Name of wood density region used to calculate biomass
costRegion	Short Text	Name of cost region used to calculate harvest and harvesting actives
BDRICM_02_apr_2014nc	Double	Depth to bedrock (R horizon) up to maximum 240 cm
BLD_sd3_M_02_apr_2014nc	Double	Bulk density in kg / cubic-meter (mean estimate) for 22.5 cm depth
CEC_sd3_M_02_apr_2014nc	Double	Cation exchange capacity in cmolc/kg (mean estimate) for 22.5 cm depth
CRFVOL_sd3_M_02_apr_2014nc	Double	Coarse fragments volumetric in percent (mean estimate) for 22.5 cm depth
CLYPPT_sd3_M_02_apr_2014nc	Double	Soil texture fraction clay in percent (mean estimate) for 22.5 cm depth
ORCDRC_sd3_M_02_apr_2014nc	Double	Soil organic carbon content (fine earth fraction) in permilles (mean estimate) for 22.5 cm depth
PHIHOX_sd3_M_02_apr_2014nc	Double	Soil pH x 10 in H2O (mean estimate) for 22.5 cm depth
SLTPPT_sd3_M_02_apr_2014nc	Double	Soil texture fraction silt in percent (mean estimate) for 22.5 cm depth
soilcompaction_evaluationnc	Double	Soil susceptibility to compaction
avgDepOxNnc	Double	Average deposition of oxidised nitrogen
avgDepOxSnc	Double	Average deposition of oxidised sulphur
avgDepRedNnc	Double	Average deposition of reduced nitrogen
bio_7nc	Double	Temperature Annual Range
bio_8nc	Double	Mean Temperature of Wettest Quarter
var1nc	Double	Annual mean T
var2nc	Double	Mean diurnal range
var3nc	Double	Isothermality
var4nc	Double	T seasonality
var15nc	Double	Mean T of the warmest month
var17nc	Double	Minimum T of warmest month
var19nc	Double	Thermicity index
var20nc	Double	Annual precipitation
var21nc	Double	Precipitation of the wettest month
var23nc	Double	Precipitation seasonality
var26nc	Double	Precipitation of warmest quarter
var27nc	Double	Precipitation of coldest quarter
var32nc	Double	Total precipitation for months with a mean monthly T is above 0°C
var33nc	Double	Annual actual evapotranspiration
var34nc	Double	Annual potential evapostranspiration
var36nc	Double	Aridity index
var37nc	Double	PET seasonality
var39nc	Double	Thornthwaite 1948 aridity index
MaT	Double	Mean annual temperature
SDmP	Double	Standard deviation of monthly precipitation
SDmR	Double	Standard deviation of monthly radiation
SDmPET	Double	Standard deviation of monthly PET
MINmPET	Double	Minimum monthly PET
MINmP	Double	Minimum monthly precipitation

Name	Type	Description
MaDR	Double	Mean diurnal range
aTR	Double	Annual temperature range
ISO	Double	Isothermality
TaP	Double	Total annual precipitation
TaR	Double	Total annual radiation
MdrqT	Double	Mean driest quarter temperature
MweqT	Double	Mean wettest quarter temperature
MwaqP	Double	Mean warmest quarter precipitation
MweqR	Double	Mean wettest quarter precipitation
McoqP	Double	Mean coldest quarter precipitation
ARi	Double	Aridity index
ThHUi	Double	Thorntwaite 1948 humidity index
ThARi	Double	Thorntwaite 1948 aridity index

plotattributes_dynamic.nc: NetCDF file containing a subset (the weather variables) of the attributes in plots/plotAttributes.csv, over time. The netCDF file has 3 main dimensions: plotID, Attribute and Time. This functionality is not tested extensively yet.

plotNrPerHa.csv: Contains the initial situation per plot. Each row contains the number of trees per ha per diameter class for the combination of a specific plot and a specific species.

Table 3.39 *Description of plotNrPerHa.csv.*

Column name	type	Units	Description	Restrictions
PlotName	String	-	Identification number of the plot	Only plotnames included in plotAttributes.csv are used in simulation.
SpeciesIndex	Positive integer	-	Species number	Should correspond to the speciesnumbers in growthandmortality/speciesparamers.csv
1	Float	##/ha	Number of trees in diameterclass	
...	Float	##/ha		value over diameter class
40	Float	##/ha		Total number should correspond to classCount in growthandmortality/speciesparamers.csv

3.3.1.5   Yasso folder

efiscen_yasso_par.xlsx: Contains parameters of turnover, carbon content, AWENH carbon pool fractions and default Yasso15 set-up split over different tabs.

Table 3.40 *Description of turnover tab.*

Column name	type	Units	Description
species	Short text	-	Species name
state	Short text	-	Type of process: harvest, living, mortality
compartment	Short text	-	Specific tree compartment: branch, foliage, roots, stem
value	Float	-	Turnover rate

Table 3.41 *Description of carbon_content tab.*

Column name	type	Units	Description
species	Short text	-	Species name
compartment	Short text	-	Specific tree compartment: branch, foliage, roots, stem
Carbon_content	Float	-	Value of carbon content

Table 3.42 *Description of awenh_fractions tab.*

Column name	type	Units	Description
species	Short text	-	Species name
compartment	Short text	-	Specific tree compartment: branch, foliage, roots, stem
A	Float	-	Acid decomposition rate
W	Float	-	Water decomposition rate
E	Float	-	Ethanol decomposition rate
N	Float	-	Soluble pools and a non-soluble pool that is further divided in to lignin-like pool decomposition rate
H	Float	-	Humus decomposition rate

Table 3.43 *Description of y15_parameters tab.*

Column name	type	Units	Description
aA	Float	a-1	Based decomposition rate for pool acid (A)
aW	Float	a-1	Based decomposition rate for pool water (W)
aE	Float	a-1	Based decomposition rate for pool ethanol (E)
aN	Float	a-1	Based decomposition rate for pool soluble pools and a non-soluble pool that is further divided in to lignin-like pool (N)
pWA	Float	-	Relative mass flow W – A
pEA	Float	-	Relative mass flow E – A
pNA	Float	-	Relative mass flow N – A
pAW	Float	-	Relative mass flow A – W
pEW	Float	-	Relative mass flow E – W
pNW	Float	-	Relative mass flow N – W
pAE	Float	-	Relative mass flow A – E
pWE	Float	-	Relative mass flow W – E
pNE	Float	-	Relative mass flow N – E
pAN	Float	-	Relative mass flow A – N
pWN	Float	-	Relative mass flow W – N
pEN	Float	-	Relative mass flow E – N
w1	Float	m-1	Leaching correction for size class 1
w2	Float	m-1	Leaching correction for size class 2
w3	Float	m-1	Leaching correction for size class 3
w4	Float	m-1	Leaching correction for size class 4
w5	Float	m-1	Leaching correction for size class 5
b1	Float	°C-1	The first-order temperature dependence of A,W,E
b2	Float	°C-2	The second-order temperature dependence of A,W,E
bN1	Float	°C-1	The first-order temperature dependence of N
bN2	Float	°C-2	The second-order temperature dependence of N
bH1	Float	°C-1	The first-order temperature dependence of H
bH2	Float	°C-2	The second-order temperature dependence of H
g	Float	m-1	Precipitation dependance of A,W,E
gN	Float	m-1	Precipitation dependance of N
gH	Float	m-1	Precipitation dependance of H
pH	Float	-	Mass flow to H
aH	Float	a-1	Decomposition rate of H
th1	Float	cm-1	The first-order woody size dependance
th2	Float	cm-2	The second-order woody size dependance
r	Float	-	Woody size dependence

Table 3.44 *Description of y15_ss_years tab.*

Column name	type	Units	Description
species	Short text	-	Species name
year_start	Long integer	-	Strat year of steady state duration
year_end	Long integer	-	End year for steady state duration

Table 3.45 *Description of y15_size tab.*

Column name	type	Units	Description
species	Short text	-	Species name
compartment	Short text	-	Specific tree compartment: branch, foliage, roots, stem
cl_1	Float	-	Assumed litter size from tree compartment in first diameter class
...	Float	...	...
cl_40	Float		Assumed litter size from tree compartment in last diameter class

3.3.2 Description of output files

The scenario output folder (…\FRLversie_python3\Scenarios\... or as specified in the settings file) contains all output files of the model. Al files are stored as tab delimited files (.tsv). Here is a short description of each file:

efiscenspace_<settingsname>_<date>_<time>.log: The log file for a scenario run is stored in the scenario base folder, because it is created before the output folder is created. This is an unstructured file containing a copy of all console output created by EFISCEN-Space.

outputRaw.tsv: Contains the detailed output of the simulation per time step, plot, species and attribute (Table 3.46). Attributes included are related to
1. the forest state: basal area (basalAreaDBH), number of trees per ha (number_per_ha) and volume_per_ha,
2. mortality: the number of trees that died during the time step (mortality) and the volume per ha that died during the time step (mortality_m3),
3. harvest: the number of harvested trees (harvest), the volume of trees that were harvested during the time step (harvest_m3).

For each attribute, the values are given per diameter class, as well as their total (sum) and their average (average over all classes). For further analysis, it is recommended to import the file into an Access database or use R scripts due to its large size.

Table 3.46 *Description of outputRaw.tsv, biomass.tsv and numbers.tsv.*

Column name	type	Unit	Description
plot	string	-	number of the plot
time	integer	yearAD	year
reprArea	float	ha	representative are of the plot in the total scenario
species	integer	-	species number
attribute	string	-	the attribute reported
average	float	depends on attribute	Average value over dbh classes
sum	float	depends on attribute	Sum value over dbh classes
cl_1	float	depends on attribute	value for dbh class 1
...	float	depends on attribute	... value over dbh classes
cl_40	float	depends on attribute	value for dbh class 40

numbers.tsv: This file is the same as outputRaw.tsv, but only contains the numbers.

biomass.tsv: Contains detailed output of the simulation for biomass per time step, plot, species and attribute. Attributes included relate to a compartment (branch, foliage, roots or stem) and either the forest state, mortality or harvest, indicated by an ending of the attribute of respectively _per_ha, mortality or harvest (Table 3.47). For each attribute, the values are given per diameter class, as well as their total (sum) and their average (average over all classes). For further analysis, it is recommended to import the file into an Access database or use R scripts due to its large size.

Table 3.47 *Attributes reported in outputRaw.tsv, numbers.tsv or biomass.tsv.*

Attribute	Unit	Description
number_per_ha	##/ha	number of living trees at end of the year
volume_per_ha	m3/ha	volume of living trees at end of the year
mortality	##/ha	number of trees died in this year
mortality_m3	m3/ha	volume of tree died
harvest	##/ha	number of trees harvested in this year
harvest_m3	m3/ha	volume of trees harvested in this year
basalAreaDBH	m2/ha	basalarea of living trees at the end of the year
branchBiomass_per_ha	kgDW/ha	biomass of branches on living trees at the end of the year
foliageBiomass_per_ha	kgDW/ha	biomass of foliage on living trees at the end of the year
rootsBiomass_per_ha	kgDW/ha	biomass of roots of living trees at the end of the year
stemBiomass_per_ha	kgDW/ha	biomass of stems of living trees at the end of the year
branchBiomass_harvest	kgDW/ha	biomass of branches on trees harvested in this year
foliageBiomass_harvest	kgDW/ha	biomass of foliage on trees harvested in this year
rootsBiomass_harvest	kgDW/ha	biomass of roots of trees harvested in this year
stemBiomass_harvest	kgDW/ha	biomass of stems of trees harvested in this year
branchBiomass_mortality	kgDW/ha	biomass of branches on trees died in this year
foliageBiomass_mortality	kgDW/ha	biomass of foliage on trees died in this year
rootsBiomass_mortality	kgDW/ha	biomass of roots of trees died in this year
stemBiomass_mortality	kgDW/ha	biomass of stems of trees died in this year

cost.tsv; Contains the cost of the harvest and harvesting actives per plot/time step (Table 3.48). The harvest relates to the number of harvested trees, whereas harvest_m3 gives the harvest amount in m³/ha. The costOfHarvesting (€/ha) is the total cost of harvest activities, while the timeOfHarvesting (hours/ha) is the time needed to complete the harvesting activity. The harvesting activities are described in the section 2.12 Harvesting costs.

Table 3.48 *Description of costs.tsv.*

Column name	type	Unit	Description
plot	string	-	number of the plot
time	integer	Year	year
reprArea	float	Ha	representative are of the plot in the total scenario
harvest	float	##/ha	number of trees harvested
harvest_m3	float	m3/ha	volume of trees harvested
costOfHarvesting	float	euro/ha	cost of harvesting in this plot
timeOfHarvesting	float	min/ha	time spend harvesting this plot
logs_HA	float	min/ha	time spend with harvester on logs
logs_MF	float	min/ha	time spend with manual felling logs
logs_MFP	float	min/ha	time spend on manual processing logs
logs_FO	float	min/ha	time spend with forwarder on logs
logs_FT	float	min/ha	time spend with farm tractor on extraction of logs
logs_SKL	float	min/ha	time spend with skidder on logs
logs_SKW	float	min/ha	time spend with skidder on whole tree
logs_CYL	float	min/ha	time spend with cable yarding logs
logs_CYW	float	min/ha	time spend with cable yarding whole tree
logs_PCH	float	min/ha	time spend with excavator mounted processor head on mechanized processing (cross-cutting and delimbing)
logs_PCM	float	min/ha	time spend with chainsaw on motor-manual processing (cross-cutting and delimbing)
residues_HA	float	min/ha	time spend with single grip harvester on piling residues
residues_MFP	float	min/ha	time spend on manual processing residues
residues_FO	float	min/ha	time spend with forwarder on residues
residues_FT	float	min/ha	time spend with farm tractor on residues
residues_PCH	float	min/ha	time spend with processor on piling residues
residues_PCM	float	min/ha	time spend with motor-manual processor on piling residues
residues_CH	float	min/ha	time spend on chipping residues

aggregatedOutput.xlsx: Aggregatedoutput aggregates the output from outputRaw.tsv. It contains six output tables (pivot tables), aggregated to different levels with attributes such as: basalArea, harvest, harvest_m3, mortality, mortality_m3, number_per_ha and volume_per_ha.

- *outputNo1* contains the totals of attributes per plot, species and time step.
- *outputNo2* contains the totals and the average of each attribute per time step per species over all stands by using the representative area of each stand (i.e. a weighted average). For instance, sum harvest_m3 contains the total volume of wood harvested in the whole region, per time step and species. Whereas, the averages express the share of each species for example in the average standing volume (species A has 25 m3/ha and species B 100 m3/ha, so total (average) volume is 125 m3/ha, this may be used to produce a plot of development of average volume over time with the components of the different species).
- *outputNo3* contains the totals over the whole simulated area per attribute per 10cm diameter class. For instance, it can be used to show the distribution of the harvest in the simulation area over diameter classes.
- *outputNo4* contains the averages per ha over whole simulated area per attribute per 10cm diameter class.
- *outputNo5* contains the totals per ha value of all attributes per plot/time step. It does not include species.
- *outputNo6* contains totals and averages of each attribute over the whole simulated area per time step. It does not include species.

Table 3.49 *Description of outputNo1.*

Colum name	Type	Unit	Description
plot	String	-	Unique plot identifier
time	Integer	year	Year when measurement was taken
species	String	-	Name of species
basalAreaDBH	Float	m2	Basal area of living trees at the end of the year
harvest	Float	##	Number of trees harvested in this year
harvest_m3	Float	m3	Volume of trees harvested in this year
mortality	Float	##	Number of trees died in this year
mortality_m3	Float	m3	Volume of tree died
number_per_ha	Float	##/ha	Number of living trees at end of the year
volume_per_ha	Float	m3/ha	Volume of living trees at end of the year

Table 3.50 *Description of outputNo2.*

Colum name	Type	Unit	Description
species	String	-	Name of species
time	Integer	year	Year when measurement was taken
avg basalAreaDBH	Float	m2	Average basal area of living trees at the end of the year
avg harvest	Float	##	Average number of trees harvested in this year
avg harvest_m3	Float	m3	Average volume of trees harvested in this year
avg mortality	Float	##	Average number of trees died in this year
avg mortality_m3	Float	m3	Average volume of tree died
avg number_per_ha	Float	##/ha	Average number of living trees at end of the year
avg volume_per_ha	Float	m3/ha	Average volume of living trees at end of the year
sum basalAreaDBH	Float	m2	Total basal area of living trees at the end of the year
sum harvest	Float	##	Total number of trees harvested in this year
sum harvest_m3	Float	m3	Total volume of trees harvested in this year
sum mortality	Float	##	Total number of trees died in this year
sum mortality_m3	Float	m3	Total volume of tree died
sum number_per_ha	Float	##/ha	Total number of living trees at end of the year
sum volume_per_ha	Float	m3/ha	Total volume of living trees at end of the year

Table 3.51 *Description of outputNo3.*

Colum name	Type	Unit	Description
species	String	-	Name of species
time	Integer	year	Year when measurement was taken
basalAreaDBH 0 - 10	Float	m2	Total basal area of living trees at the end of the year over 10cm diameter class
basalAreaDBH 90 - 100	Float	m2	Total basal area of living trees at the end of the year over 10cm diameter class
harvest 0 - 10	Float	##	Total number of trees harvested in this year over 10cm diameter class
harvest 90 - 100	Float	##	Total number of trees harvested in this year over 10cm diameter class
harvest_m3 0 - 10	Float	m3	Total volume of trees harvested in this year over 10cm diameter class
harvest_m3 90 - 100	Float	m3	Total volume of trees harvested in this year over 10cm diameter class
mortality 0 - 10	Float	##	Total number of trees died in this year over 10cm dimeter class
mortality 90 - 100	Float	##	Total number of trees died in this year over 10cm dimeter class
mortality_m3 0 - 10	Float	m3	Total volume of trees died in this year over 10cm dimeter class
mortality_m3 90 - 100	Float	m3	Total volume of trees died in this year over 10cm dimeter class
number_per_ha 0 - 10	Float	##/ha	Total number of living trees at end of the year over 10cm diameter class
number_per_ha 90 - 100	Float	##/ha	Total number of living trees at end of the year over 10cm diameter class
volume_per_ha 0 - 10	Float	m3/ha	Total volume of living trees at end of the year over 10cm diameter class
volume_per_ha 90 - 100	Float	m3/ha	Total volume of living trees at end of the year over 10cm diameter class

Table 3.52 *Description of outputNo4.*

Colum name	Type	Unit	Description
species	String	-	Name of species
time	Integer	year	Year when measurement was taken
basalAreaDBH 0 - 10	Float	m2	Average basal area of living trees at the end of the year over 10cm diameter class
basalAreaDBH 90 - 100	Float	m2	Average basal area of living trees at the end of the year over 10cm diameter class
harvest 0 - 10	Float	##	Average number of trees harvested in this year over 10cm diameter class
harvest 90 - 100	Float	##	Average number of trees harvested in this year over 10cm diameter class
harvest_m3 0 - 10	Float	m3	Average volume of trees harvested in this year over 10cm diameter class
harvest_m3 90 - 100	Float	m3	Average volume of trees harvested in this year over 10cm diameter class
mortality 0 - 10	Float	##	Average number of trees died in this year over 10cm dimeter class
mortality 90 - 100	Float	##	Average number of trees died in this year over 10cm dimeter class
mortality_m3 0 - 10	Float	m3	Average volume of trees died in this year over 10cm dimeter class
mortality_m3 90 - 100	Float	m3	Average volume of trees died in this year over 10cm dimeter class
number_per_ha 0 - 10	Float	##/ha	Average number of living trees at end of the year over 10cm diameter class
number_per_ha 90 - 100	Float	##/ha	Average number of living trees at end of the year over 10cm diameter class
volume_per_ha 0 - 10	Float	m3/ha	Average volume of living trees at end of the year over 10cm diameter class
volume_per_ha 90 - 100	Float	m3/ha	Average volume of living trees at end of the year over 10cm diameter class

Table 3.53 *Description of outputNo5.*

Colum name	Type	Unit	Description
plot	String	-	Unique plot identifier
time	Integer	year	Year when measurement was taken
basalAreaDBH	Float	m2/ha	Basal area of living trees at the end of the year
harvest	Float	##/ha	Number of trees harvested in this year
harvest_m3	Float	m3/ha	Volume of trees harvested in this year
mortality	Float	##/ha	Number of trees died in this year
mortality_m3	Float	m3/ha	Volume of tree died
number_per_ha	Float	##/ha	Number of living trees at end of the year
volume_per_ha	Float	m3/ha	Volume of living trees at end of the year

Table 3.54 *Description of outputNo6.*

Colum name	Type	Unit	Description
time	Integer	year	Year when measurement was taken
avg basalAreaDBH	Float	m2/ha	Average basal area of living trees at the end of the year
avg harvest	Float	##/ha	Average number of trees harvested in this year
avg harvest_m3	Float	m3/ha	Average volume of trees harvested in this year
avg mortality	Float	##/ha	Average number of trees died in this year
avg mortality_m3	Float	m3/ha	Average volume of tree died
avg number_per_ha	Float	##/ha	Average number of living trees at end of the year
avg volume_per_ha	Float	m3/ha	Average volume of living trees at end of the year
calcArea basalAreaDBH	Float	ha	Size of representative area for calculation of basal area
calcArea harvest	Float	ha	Size of representative area for calculation of number of trees harvested
calcArea harvest_m3	Float	ha	Size of representative area for calculation of volume of trees harvested
calcArea mortality	Float	ha	Size of representative area for calculation of number of died trees
calcArea mortality_m3	Float	ha	Size of representative area for calculation of volume of died trees
calcArea number_per_ha	Float	ha	Size of representative area for calculation of number of living trees
calcArea volume_per_ha	Float	ha	Size of representative area for calculation of volume of living trees
sum basalAreaDBH	Float	m2	Total basal area of living trees at the end of the year
sum harvest	Float	##	Total number of trees harvested in this year
sum harvest_m3	Float	m3	Total volume of trees harvested in this year
sum mortality	Float	##	Total number of trees died in this year
sum mortality_m3	Float	m3	Total volume of tree died
sum number_per_ha	Float	##/ha	Total number of living trees at end of the year
sum volume_per_ha	Float	m3/ha	Total volume of living trees at end of the year

growthf.log: Contains the growth function per plot and species. The functions are calculated from the parameters in the database and the actual value of the respective abiotic variables for the plot. The file is meant as a check of the growth function.

species.log: Contains all volume models present that can be used to convert individual tree dbh to volume. Note that it does not indicate which ones are actually used. The file is meant as a check of species volume models.

species.yml: yaml structured file echoing the species definitions (growth parameters, coniferous, diameterclass definitions).

yasso/yasso_raw_lsc.csv: Contains the full output from the yasso calculations. Within yasso, dbh-classes are converted to litter-size-classes. Full detail of calculation output is given, tracking species-specific litter inputs for different litter size-classes as they progress through the different soluble fractions (AWENH – see 2.13.1). See Table 3.55 for the definition of the table.

Table 3.55 *Description of Yasso/Yasso_Raw_lsc.csv.*

Column name	Type	Unit	Description
Plot	string	-	number of the plot
Year	integer	yearAD	year
species	string	-	species name
cmpt	string	-	Compartments are grouped (value "all")
AWENH	string	-	soluble fractionclass
sum	float	kgC/ha	total soil carbon
cl_0.0	float	kgC/ha	soil carbon in first litter mid-size class (in outputfile LSX is exchanged for the fraction values from the input)
…	float	kgC/ha	…
cl_98.75	float	kgC/ha	soil carbon in last litter mid-size class

3.4 Running the model

3.4.1 Initialization/Preparing the data

Go to the model directory and open *Experiments* in the *FRLversie_python3,* you will find there two experiment folders. The Experiment0 consists of basic set up of the input files that are initialized by the model, whether the Experiment1 can set additional parameters. For starter, use only one Experiment (e.g. Experiment*0*). The *Experiment#* folder consist of the *scenariodefinition* folder, which contains the expansion factors, growth and mortality, plots and yasso folders. Add to the folders information from created before .csv files (located in *data* folder). The best is to paste the .csv files to folders according to the given information. Note that structure of *scenariodefinition* folder is actively hard coded, thus any change in files name will cause model to stop running. After including the files, open *settings.csv* to set up model to your needs. The *settings.csv* contains the information like StartYear, Duration, runYasso, doCostCalculation, BiomassOutput. It depends on your needs which parameters you want to use for the simulation. In case when you want to use parameters indicate it by TRUE, otherwise use FALSE to not simulate parameters. Note that only for the StartYear and Duration you have to use numeric data, other parameters use boolean type data. In case you want to create new scenarios copy the *Experiment#* folder and set parameters to your needs. The set of additional parameters is listed in the *settings.py* (line #235) in the *src3* folder.

3.4.2 Running the model using PyCharm

After setting up the data, open the model in PyCharm. Then search for the *FRL_versie_python3* in the *Project Files*. The folder will include *src3*, which contains the model source. Within *scr3* folder find *efiscenspace.py,* which will allow you to execute a run of the model. Right click on the file and select *Modify run configuration…* option. The *Edit Run Configuration: 'efiscenspace'* window will open. Edit the *Script path* to the directory in which model is located. More importantly, change *Parameters* to the path where the settings file of the your scenario is located. By defining the *Parameters* path the set up data will be used. In case of multiple scenarios change the *Parameters* path per scenario that will prevent output to be overwritten by a new scenario. When the correct path is set up click *OK* and press *Run* button. The model will show the log file in the *Run* tab. Finally, the output of the simulation can be found in the *Scenario* folder.

3.4.3 Running the model using the executable

After setting up the data, unpack the executable.zip file on your local disc. Next, find the *run.bat* file which includes the reference to the settings.csv file with regard to which all inputs and outputs are created. To run the model executable, double-click on the run.bat, then the Command Prompt window will show up with the running script. The end of a run will be indicated by the line "EFISCEN-Space script ended". The Command Prompt window will close automatically after running. After the models' run, the output_Scenario1 and log can be found in the Experiment1 folder (…\efiscenSpace_exe\Experiments\Experiment1, Figure 3.17).
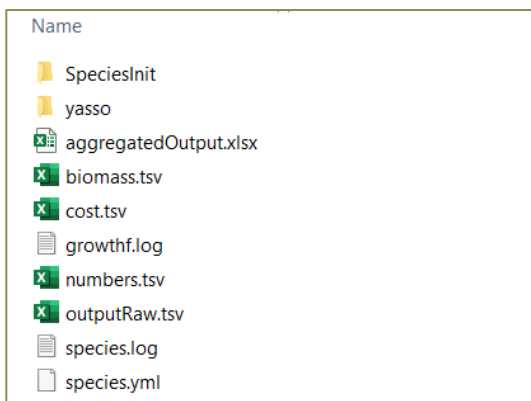
Figure 3.17 *Output_Scenario# files of EFISCEN-Space.*

You can modify the *run.bat* file using any text editor. To do so, right-click on the *run.bat* and select *Edit* from the open contextual menu. Lines starting with @rem are not executed. The file below will run Experiment1, with the scenario settings as specified in settings.csv in the scenariodefintion folder.

> **run.bat**
> *@rem*
> *@rem batchfile to ease directing efiscenspace to the desired settingsfile*
> *@rem settingsfile location dictates location of other inputfiles and location of outputfiles*
> *@rem*
> *efiscenspace.exe .\ Experiments\Experiment1\scenariodefinition\settings.csv*

It is possible to run multiple scenarios within a certain experiment, and even to run multiple experiments from the same run file. To do so, simply add more lines with the required combinations of experiments and scenarios. The file below will first run Experiment1 with settings1, then Experiment1 with settings2, then Experiment2 with settings1 and then Experiment2 with settings2.

> **run.bat**
> *@rem*
> *@rem batchfile to ease directing efiscenspace to the desired settingsfile*
> *@rem settingsfile location dictates location of other inputfiles and location of outputfiles*
> *@rem*
> *efiscenspace.exe .\ Experiments\Experiment1\scenariodefinition\settings1.csv*
> *efiscenspace.exe .\ Experiments\Experiment1\scenariodefinition\settings2.csv*
> *efiscenspace.exe .\ Experiments\Experiment2\scenariodefinition\settings1.csv*
> *efiscenspace.exe .\ Experiments\Experiment2\scenariodefinition\settings2.csv*

3.4.4   YASSO15 coupling

Before running Yasso15 you have to remember that this soil model is programmed only for Windows OS and will not work under other operating systems. Furthermore, be aware that the computation time will increase substantially, roughly 20 times that of a normal run. EFISCEN-Space will run first through all the plots in the normal way, and will then run the Yasso model on the biomass output that is generated. To include the Yasso15 model in your run, you should indicate so in the *settings.csv* file. The output of Yasso can be found in the *Experiment#\Yasso* folder.

4   Evaluation

4.1   Introduction

The aim of model verification is to give confidence in the results the model produces, and to give insight under what circumstances the model may or may not produce reliable results. This is important for the modelers (how does the model perform, has it been implemented correctly, where can it be improved), the model users (under what conditions can it be applied, for which scenarios can it be expected to give reasonable results, how accurate are the outcomes), as well as for the intended audience of the model results (is the model appropriate for this kind of study, can they trust the outcomes of a study applying this model). Bellochi et al. (2011) state "*Model evaluation includes any action in which the quality of a mathematical model is established (e.g., Metselaar, 1999; Jakeman et al., 2006).*" They cite Schaeffer (1980), who distinguished six tasks in model evaluation: (a) model examination, (b) algorithm examination, (c) data evaluation, (d) sensitivity analysis, (e) validation studies, and (f) code comparison studies. Schaeffer describes the six tasks as:

> "**Model examination** *involves questioning whether anything fundamental was omitted in the initial conceptualization of the model.* **Algorithm examination** *attempts to determine whether appropriate numerical schemes have been adopted to represent the model in the form of a computer code.* **Data evaluation** *is intended to ascertain the quality and the quantity of the data available for use with the model.* **Sensitivity analyses** *are studies directed toward identifying those parameters which are most influential in determining model predictions. The identification of these key parameters enables priorities to be established for performing experiments.* **Validation** *refers to the attempt to determine the degree to which model predictions agree with field or laboratory measurements of those same quantities.* **Code comparison** *is the process of comparing the strengths and weaknesses of various codes designed to perform similar tasks.*"

Covering all six areas in detail is a major undertaking, especially for a complex model like EFISCEN-Space that is under continuous development. This chapter therefore aims to document the current status of verification efforts rather than pretending to be complete. Efforts so far have been focused verifying the implementation of the computer code (Algorithm examination), finding appropriate parameter sets for large-scale simulations while being able to take into account local circumstances (Data evaluation and Sensitivity analysis) and comparing model results with published data and known spatial patterns (Validation). The following sections describe a number of verification experiments covering these aspects.

4.2   Initialisation check of 1 stand

In this experiment we follow the data preparation and simulation process for one particular plot, aiming to 1) clarify the individual model processes for the reader/user, 2) check the code implementation and 3) illustrate consequences of some simplifications made in the model. This example is copied and adapted from Arets and Schelhaas (2018). As basis we use the Dutch plot NL_6_27377, measured in NFI-6. This plot is a typical example of an older Scots pine forest mixed with some oak, with undergrowth of birch and Prunus serotina. It has a plot radius of 8 m (201 m^2), with 14 live trees measured above the 5 cm threshold. We ignore here any trees that were recorded as dead or harvested since the previous measurement. Table 4.1 shows the DBH and species of the live trees as assessed in the field, the individual tree volume as given by the NFI methodology, as well as computed basal area, stem biomass (based on stem volume and assuming a wood density for oak of 0.58, Scots pine 0.42, birch 0.51 (all IPCC good practice guidance defaults) and Prunus 0.61 (Annighöfer et al. 2012)) and biomass in other tree compartments using the Forrester et al. (2017) estimation procedure

(equation 2.8, using generic functions for broadleaves and conifers). Table 4.2 shows the corresponding totals at the stand level.

Table 4.1 *Characteristics of alive trees at plot NL_6_27377.*

ID	PlotID	Tree ID	Original Species	LocalName	DBH Scientific Name (mm)	Basal area (m2/tree)	Stem volume (m3/tree)	Stem biomass (kg/tree)	Foliage biomass (kg/tree)	Branch biomass (kg/tree)	Root biomass (kg/tree)
112938	27377	5	EI	Inlandse eik	220 Quercus robur	0.038	0.292	169.6	4.9	31.4	56.1
112940	27377	7	GD	Grove den	444 Pinus sylvestris	0.155	1.431	601.1	46.4	97.2	268.8
112942	27377	9	GD	Grove den	256 Pinus sylvestris	0.051	0.428	179.7	16.2	30.3	68.0
112946	27377	13	GD	Grove den	352 Pinus sylvestris	0.097	0.867	363.9	29.8	59.4	150.6
112949	27377	16	GD	Grove den	256 Pinus sylvestris	0.051	0.428	179.7	16.2	30.3	68.0
112950	27377	17	GD	Grove den	296 Pinus sylvestris	0.069	0.592	248.6	21.4	41.2	97.7
112952	27377	19	GD	Grove den	190 Pinus sylvestris	0.028	0.215	90.4	9.2	16.1	32.3
112953	27377	20	EI	Inlandse eik	90 Quercus robur	0.006	0.024	14.0	0.9	3.9	8.3
112954	27377	21	GD	Grove den	181 Pinus sylvestris	0.026	0.192	80.6	8.4	14.5	28.6
112955	27377	22	EI	Inlandse eik	325 Quercus robur	0.083	0.746	432.8	10.1	78.4	129.1
112959	27377	26	BE	Berk	159 Betula spp.	0.020	0.129	65.8	2.7	14.7	28.1
112960	27377	27	GD	Grove den	311 Pinus sylvestris	0.076	0.660	277.3	23.5	45.7	110.5
112961	27377	28	GD	Grove den	229 Pinus sylvestris	0.041	0.332	139.5	13.1	23.9	51.5
112962	27377	29	AV	Amerikaanse vogelkers	88 Prunus serotina	0.006	0.022	13.2	0.9	3.7	7.9

Table 4.2 *Stand characteristics for NL_6_27377 as computed directly on NFI data.*

Species	Stem number (N/ha)	Basal area (m2/ha)	Volume (m3/ha)	Stem biomass (ton/ha)	Foliage biomass (ton/ha)	Branch biomass (ton/ha)	Root biomass (ton/ha)	Total biomass (ton/ha)
Pinus sylvestris	448	29.6	255.9	107.5	9.2	17.8	43.6	178.0
Quercus robur	149	6.3	52.9	30.7	0.8	5.7	9.6	46.7
Betula spp.	50	1.0	6.4	3.3	0.1	0.7	1.4	5.5
Prunus serotina	50	0.3	1.1	0.7	0.0	0.2	0.4	1.3
Total	**696**	**37.2**	**316.2**	**142.1**	**10.1**	**24.4**	**55.0**	**231.6**

In the preparation procedure, each of the available species is mapped to one of the standard 20 species groups: Pinus sylvestris to 6 (Pinus sylvestris), Quercus robur to 16 (Quercus robur&petraea), Betula spp. to 10 (Betula spp.) and Prunus serotina to 20 (Short-lived broadleaves). Furthermore, each tree is mapped to the diameter class it belongs to, and the stem number per ha each tree is representing is calculated (49.7 trees/ha). Table 4.3 shows the result that is used to fill the initialisation table in the database, and Figure 4.1 the expected diameter class distribution for this plot. Table 4.4 shows the input file to the model, as generated from the database. Table 4.5 shows the initial situation as generated by the model.

Table 4.3 *Aggregated information for plot NL_6_27377 as listed in the initialisation database.*

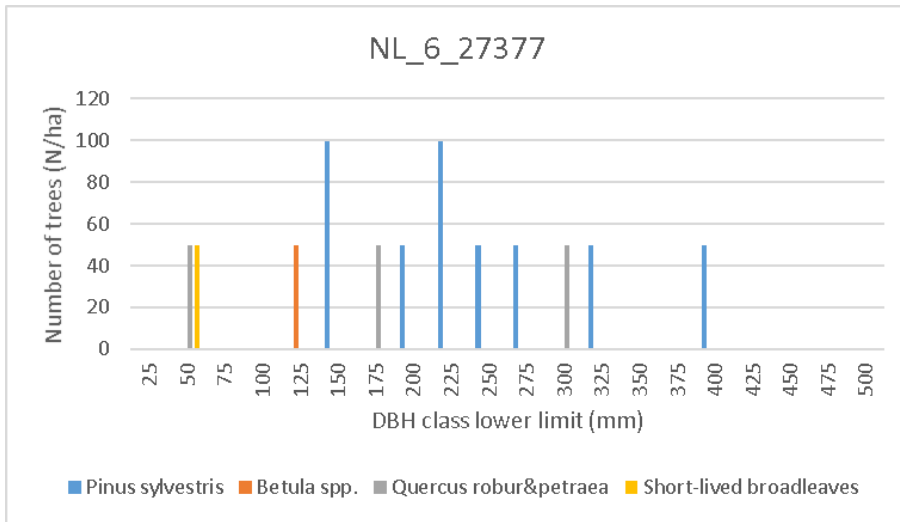| plot	SpeciesGroupCode	DiameterClassCode	StemNumber
NL_6_27377	16	4	49.7
NL_6_27377	20	4	49.7
NL_6_27377	10	7	49.7
NL_6_27377	6	8	99.5
NL_6_27377	16	9	49.7
NL_6_27377	6	10	49.7
NL_6_27377	6	11	99.5
NL_6_27377	6	12	49.7
NL_6_27377	6	13	49.7
NL_6_27377	16	14	49.7
NL_6_27377	6	15	49.7
NL_6_27377	6	18	49.7

Figure 4.1   *Expected initial diameter class distribution of plot NL_6_27377.*

Table 4.4   *Input file (plotNrPerHa.csv) as generated from the database.*

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	plotName	speciesIndex	4	7	8	9	10	11	12	13	14	15	18
2	NL_6_27377	6			99.47279		49.7364	99.47279	49.7364	49.7364		49.7364	49.7364
3	NL_6_27377	10		49.7364									
4	NL_6_27377	16	49.7364			49.7364					49.7364		
5	NL_6_27377	20	49.7364										

The basic output of plot NL_6_27377 is shown in Table 4.5. Only the first four diameter classes are visible, but the *Prunus serotina* (Tree ID = 29) and the *Quercus robur* (Tree ID = 20) can be found in the fourth diameter class column (7.5-10 cm), as well as the simulated totals. The stem number per species matches exactly with the values as derived from the NFI database directly (Table 4.2). The basal area per species shows some minor differences to those in Table 4.2. All trees in the model are assumed to have a diameter equal to the midpoint of the diameter class they are in, while in Table 4.2 their real (measured) diameter is used. The total volume per species shows somewhat larger differences, but still aligns well with the calculated volume from the NFI methodology. This is partly caused by the difference in actual versus mid-class diameter, and partly by using only one volume function in the model, while the NFI uses soil-specific functions for some species.

Table 4.5   *Basic output generated from the model for the initial situation (truncated after diameter class 4).*

	A	B	C	D	E	F	G	H	I	J	K
1	plot	time	reprArea	species	attribute	average	sum	cl_1	cl_2	cl_3	cl_4
2	NL_6_27377	2010	117.08	Pinus sylvestris	number_per_ha	11.19	447.63	0.00	0.00	0.00	0.00
3	NL_6_27377	2010	117.08	Betula spp.	number_per_ha	1.24	49.74	0.00	0.00	0.00	0.00
4	NL_6_27377	2010	117.08	Quercus robur&petraea	number_per_ha	3.73	149.21	0.00	0.00	0.00	49.74
5	NL_6_27377	2010	117.08	short-lived broadleaves	number_per_ha	1.24	49.74	0.00	0.00	0.00	49.74
6	NL_6_27377	2010	117.08	Pinus sylvestris	volume_per_ha	6.52	260.89	0.00	0.00	0.00	0.00
7	NL_6_27377	2010	117.08	Betula spp.	volume_per_ha	0.17	6.94	0.00	0.00	0.00	0.00
8	NL_6_27377	2010	117.08	Quercus robur&petraea	volume_per_ha	1.36	54.40	0.00	0.00	0.00	0.65
9	NL_6_27377	2010	117.08	short-lived broadleaves	volume_per_ha	0.02	0.84	0.00	0.00	0.00	0.84
10	NL_6_27377	2010	117.08	Pinus sylvestris	basalArea	29.99	29.99	nan	nan	nan	nan
11	NL_6_27377	2010	117.08	Betula spp.	basalArea	1.03	1.03	nan	nan	nan	nan
12	NL_6_27377	2010	117.08	Quercus robur&petraea	basalArea	6.51	6.51	nan	nan	nan	nan
13	NL_6_27377	2010	117.08	short-lived broadleaves	basalArea	0.30	0.30	nan	nan	nan	nan

Table 4.6 shows the biomass output of plot NL_6_27377. The unit of the biomass in column G is kg/ha. Simulated biomass is close to the calculated values in Table 4.2, with deviations generally in the range of

1-5% for foliage, branches and roots, for all species (Table 4.7). These differences can be explained by using the mid-class diameter in the model compared to the measured diameter in the direct calculations. Differences in stem biomass are larger, aligned with the differences as explained before for the simulation of volume, while stem biomass is calculated directly from the volume. The large deviation for *Prunus serotina* is partly caused by an underestimation of the volume (22%), and partly by the use of 0.4 in the model as default value for wood density for the group short-lived broadleaves, while in the direct calculation the species-specific value of 0.61 was used. The effect in the total simulation is negligible, with a 2% deviation in the biomass stem compartment and the total biomass of the stand.

Table 4.6   *Biomass output generated from the model for the initial situation (truncated after diameter class 4).*

	A	B	C	D	E	F	G	H	I	J	K
1	plot	time	reprArea	species	attribute	average	sum	cl_1	cl_2	cl_3	cl_4
2	NL_6_27377	2010	117.08	Pinus sylvestris	branchBiomass_per_ha	451.717	18068.68	0	0	0	0
3	NL_6_27377	2010	117.08	Betula spp.	branchBiomass_per_ha	19.19417	767.7668	0	0	0	0
4	NL_6_27377	2010	117.08	Quercus robur&petraea	branchBiomass_per_ha	146.975	5879.002	0	0	0	179.888
5	NL_6_27377	2010	117.08	short-lived broadleaves	branchBiomass_per_ha	4.4972	179.888	0	0	0	179.888
6	NL_6_27377	2010	117.08	Pinus sylvestris	foliageBiomass_per_ha	232.1278	9285.114	0	0	0	0
7	NL_6_27377	2010	117.08	Betula spp.	foliageBiomass_per_ha	3.468734	138.7494	0	0	0	0
8	NL_6_27377	2010	117.08	Quercus robur&petraea	foliageBiomass_per_ha	20.34415	813.7661	0	0	0	43.80328
9	NL_6_27377	2010	117.08	short-lived broadleaves	foliageBiomass_per_ha	1.095082	43.80328	0	0	0	43.80328
10	NL_6_27377	2010	117.08	Pinus sylvestris	rootsBiomass_per_ha	1103.61	44144.41	0	0	0	0
11	NL_6_27377	2010	117.08	Betula spp.	rootsBiomass_per_ha	36.54806	1461.922	0	0	0	0
12	NL_6_27377	2010	117.08	Quercus robur&petraea	rootsBiomass_per_ha	248.5961	9943.844	0	0	0	389.8153
13	NL_6_27377	2010	117.08	short-lived broadleaves	rootsBiomass_per_ha	9.745383	389.8153	0	0	0	389.8153
14	NL_6_27377	2010	117.08	Pinus sylvestris	stemBiomass_per_ha	2739.356	109574.2	0	0	0	0
15	NL_6_27377	2010	117.08	Betula spp.	stemBiomass_per_ha	88.4966	3539.864	0	0	0	0
16	NL_6_27377	2010	117.08	Quercus robur&petraea	stemBiomass_per_ha	788.7912	31551.65	0	0	0	375.4632
17	NL_6_27377	2010	117.08	short-lived broadleaves	stemBiomass_per_ha	8.367504	334.7002	0	0	0	334.7002

Table 4.7   *Difference between simulated and calculated biomass compartments per species.*

	Stem biomass	Foliage biomass	Branch biomass	Root biomass	Total biomass
Pinus sylvestris	2%	1%	1%	1%	2%
Quercus robur	3%	2%	4%	3%	3%
Betula spp.	8%	4%	5%	5%	7%
Prunus serotina	-49%	-1%	-2%	-1%	-26%
Total	2%	1%	2%	2%	2%

4.3   Check of increment, mortality, harvest, natural ingrowth and management ingrowth for one stand

4.3.1   Increment

The fraction of trees that moves from a specific diameter class to the next diameter class is derived from the calculated increase in diameter for a tree having the average diameter in that class. The diameter increment is based on equation 2.14 and the parameter values and abiotic values as given in Schelhaas et al. (2018a). Table 4.8 shows the parameter values for Betula, and the corresponding values of the predictor variables for plot NL_6_27377. The last rows present the calculated values for parameter b1 and b2 of equation 2.14 (indicated in the espy database and input files as respectively B1 and B2). Table 4.9 presents the calculated increment for all diameter classes with trees in stand NL_6_27377, as well as the calculated number of trees to move one diameter class up. Table 4.10 presents the expected diameter class distribution for this stand after one time step, assuming no harvest and no mortality. This fits with the simulated diameter class distribution by the model (Table 4.11). In the model we have the opportunity to adapt the increment for the lower diameter classes via the d1 parameter. With d1 parameter at 10 cm, all trees in diameter classes 1-4 will be treated as having a growth as if they were located in class 5 (10-12.5 cm). The predicted increment for Quercus robur in

class 4 will increase from 1.34 mm to 1.59 mm, which translates to the movement of 3.17 trees to class 5. For short-lived broadleaves the increment in class 4 increases from 1.67 mm to 2.04 mm, which results in 4.06 trees to move up to class 5. This agrees with the simulated distribution (Table 4.12).

Table 4.8 *Parameter and predictor values for the Betula tree in stand NL_6_27377 for the calculation of the increment at t=0. The final values of B1 and B2 are calculated as the sum of the products of the respective parameter values and the predictor values.*

Parameter name	B1	B2	Abiotic predictor values
Intercept	-0.2868	0.048725	
MaT	0.002281	-0.00031	11.3
lnPlotBasalArea	-0.01038	0.000942	3.633101
BLD	0.000108	-1.8E-05	1277
aTR	0.002753	-0.00049	16.42
PlotBasalArea	-0.00109	0.0002	37.82995
rDiffDq	0.005705	-0.00068	-0.38215
var32nc	8.94E-05	-1.5E-05	781
var39nc	0.002158	-0.00035	27
var26nc	0.000264	-4E-05	202
var23nc	-0.0007	0.000118	13
SDmR	0.000219	-2.8E-05	192.08
ARi	-0.00558	0.000771	1
SDmPET	-0.00066	8.35E-05	39.44
SLTPPT	0.000334	-5.1E-05	22
MaDR	0.001651	-0.00029	7.83
Result	**0.044533**	**-0.00644**	

Table 4.9 *Calculated increment per species and diameter class, and calculation of number of trees to move one dbh class up.*

plot	Species Group Code	species	Diameter Class Code	Mid diameter	Stem Number	Predicted increment (mm)	Share of trees to move	N trees to move
NL_6_27377	16	Qrobur	4	8.75	49.7	1.34	0.05	2.67
NL_6_27377	20	shortlived	4	8.75	49.7	1.67	0.07	3.31
NL_6_27377	10	Betula	7	16.25	49.7	1.91	0.08	3.80
NL_6_27377	6	Psylv	8	18.75	99.5	1.91	0.08	7.61
NL_6_27377	16	Qrobur	9	21.25	49.7	2.47	0.10	4.92
NL_6_27377	6	Psylv	10	23.75	49.7	2.32	0.09	4.62
NL_6_27377	6	Psylv	11	26.25	99.5	2.51	0.10	10.01
NL_6_27377	6	Psylv	12	28.75	49.7	2.70	0.11	5.37
NL_6_27377	6	Psylv	13	31.25	49.7	2.87	0.11	5.71
NL_6_27377	16	Qrobur	14	33.75	49.7	3.34	0.13	6.65
NL_6_27377	6	Psylv	15	36.25	49.7	3.18	0.13	6.33
NL_6_27377	6	Psylv	18	43.75	49.7	3.57	0.14	7.10

Table 4.10 *Predicted diameter class distribution after 1 time step, assuming no mortality or harvest.*

		Dbh class: 4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
species	time	Dbh min: 7.5	10	12.5	15	17.5	20	22.5	25	27.5	30	32.5	35	37.5	40	42.5	45
Qrobur	0	49.7					49.7					49.7					
Qrobur	1	47.1	2.7				44.8	4.9				43.1	6.6				
shortlived	0	49.7															
shortlived	1	46.4	3.3														
Betula	0				49.7												
Betula	1				45.9	3.8											
Pinus	0				99.5		49.7	99.5	49.7	49.7		49.7				49.7	
Pinus	1				91.9	7.6	45.1	94.1	54.4	49.4	5.7	43.4	6.3			42.6	7.1

Table 4.11 *Simulated diameter class distribution after 1 time step, assuming no mortality or harvest.*

	plot	time	reprArea	species	attribute	sum	cl_1	cl_2	cl_3	cl_4	cl_5	cl_6	cl_7	cl_8	cl_9	cl_10	cl_11	cl_12	cl_13	cl_14	cl_15	cl_16	cl_17	cl_18	cl_19	cl_20
2	NL_6_27377	2010	117.08	Pinus sylvestris	number_per_ha	447.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.5	0.0	49.7	99.5	49.7	49.7	0.0	49.7	0.0	0.0	49.7	0.0	0.0
3	NL_6_27377	2010	117.08	Betula spp.	number_per_ha	49.7	0.0	0.0	0.0	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	NL_6_27377	2010	117.08	Quercus robur&petraea	number_per_ha	149.2	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	0.0	0.0
5	NL_6_27377	2010	117.08	short-lived broadleaves	number_per_ha	49.7	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	NL_6_27377	2011	117.08	Pinus sylvestris	number_per_ha	447.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	91.9	7.6	45.1	94.1	54.4	49.4	5.7	43.4	6.3	0.0	42.6	7.1	0.0
7	NL_6_27377	2011	117.08	Betula spp.	number_per_ha	49.7	0.0	0.0	0.0	0.0	0.0	0.0	45.9	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	NL_6_27377	2011	117.08	Quercus robur&petraea	number_per_ha	149.2	0.0	0.0	0.0	47.1	2.7	0.0	0.0	0.0	44.8	4.9	0.0	0.0	0.0	43.1	6.6	0.0	0.0	0.0	0.0	0.0
9	NL_6_27377	2011	117.08	short-lived broadleaves	number_per_ha	49.7	0.0	0.0	0.0	46.4	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 4.12 *Simulated diameter class distribution after 1 time step, assuming no mortality or harvest, with d1 at 10 cm for all species.*

	plot	time	reprArea	species	attribute	sum	cl_1	cl_2	cl_3	cl_4	cl_5	cl_6	cl_7	cl_8	cl_9	cl_10	cl_11	cl_12	cl_13	cl_14	cl_15	cl_16	cl_17	cl_18	cl_19	cl_20
2	NL_6_27377	2010	117.08	Pinus sylvestris	number_per_ha	447.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.5	0.0	49.7	99.5	49.7	49.7	0.0	49.7	0.0	0.0	49.7	0.0	0.0
3	NL_6_27377	2010	117.08	Betula spp.	number_per_ha	49.7	0.0	0.0	0.0	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	NL_6_27377	2010	117.08	Quercus robur&petraea	number_per_ha	149.2	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	0.0	0.0
5	NL_6_27377	2010	117.08	short-lived broadleaves	number_per_ha	49.7	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	NL_6_27377	2011	117.08	Pinus sylvestris	number_per_ha	447.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	91.9	7.6	45.1	94.1	54.4	49.4	5.7	43.4	6.3	0.0	42.6	7.1	0.0
7	NL_6_27377	2011	117.08	Betula spp.	number_per_ha	49.7	0.0	0.0	0.0	0.0	0.0	0.0	45.9	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	NL_6_27377	2011	117.08	Quercus robur&petraea	number_per_ha	149.2	0.0	0.0	0.0	46.5	3.2	0.0	0.0	0.0	44.8	4.9	0.0	0.0	0.0	43.1	6.6	0.0	0.0	0.0	0.0	0.0
9	NL_6_27377	2011	117.08	short-lived broadleaves	number_per_ha	49.7	0.0	0.0	0.0	45.7	4.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

4.3.2 Natural mortality

Natural mortality is modelled as the fraction of trees that die in a certain diameter class of a certain species, expressed per year. Natural mortality is applied every time step. Table 4.13 shows fixed (i.e. constant over diameter classes) mortality patterns for the species included in stand NL_6_27377. Table 4.14 shows the simulated diameter class distribution after 1 timestep. Pinus sylvestris in diameter class 8 starts with 99.5 trees and has an assigned mortality of 20%, equal to 19.9 trees. After one year of simulation, there are 72.0 trees in class 8 and 7.6 in class 9, while in the simulation without mortality (Table 4.11) this was respectively 91.9 and 7.6. The difference is exactly 19.9 trees. Also for the other species the patterns match the expectations.

Table 4.13 *Natural mortality fractions for testing.*

regime	type	speciesInd	variable	interval	valueMin	valueMax	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
natural	nat	Pinus sylvestris	-1	-1	1		0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
natural	nat	Betula spp.	-1	-1	1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
natural	nat	Quercus robur & petr	-1	-1	1		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
natural	nat	Shortlived broadleave	-1	-1	1		0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

Table 4.14 *Simulated diameter class distribution after 1 time step, including natural mortality.*

	plot	time	reprArea	species	attribute	sum	cl_1	cl_2	cl_3	cl_4	cl_5	cl_6	cl_7	cl_8	cl_9	cl_10	cl_11	cl_12	cl_13	cl_14	cl_15	cl_16	cl_17	cl_18	cl_19	cl_20
2	NL_6_27377	2010	117.08	Pinus sylvestris	number_per_ha	447.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.5	0.0	49.7	99.5	49.7	49.7	0.0	49.7	0.0	0.0	49.7	0.0	0.0
3	NL_6_27377	2010	117.08	Betula spp.	number_per_ha	49.7	0.0	0.0	0.0	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	NL_6_27377	2010	117.08	Quercus robur&petraea	number_per_ha	149.2	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	0.0	0.0
5	NL_6_27377	2010	117.08	short-lived broadleaves	number_per_ha	49.7	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	NL_6_27377	2011	117.08	Pinus sylvestris	number_per_ha	358.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	72.0	7.6	35.2	74.2	44.4	39.4	5.7	33.5	6.3	0.0	32.7	7.1	0.0
7	NL_6_27377	2011	117.08	Betula spp.	number_per_ha	49.7	0.0	0.0	0.0	0.0	0.0	0.0	45.9	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	NL_6_27377	2011	117.08	Quercus robur&petraea	number_per_ha	134.3	0.0	0.0	0.0	42.1	2.7	0.0	0.0	0.0	39.8	4.9	0.0	0.0	0.0	38.1	6.6	0.0	0.0	0.0	0.0	0.0
9	NL_6_27377	2011	117.08	short-lived broadleaves	number_per_ha	24.9	0.0	0.0	0.0	21.6	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

4.3.3 Management

Management mortality (harvest) is modelled in a similar way as the natural mortality, defined by the fraction of trees to be harvested in each diameter class for each species, expressed per year. Management mortality is applied in intervals as defined by the user. The first time is randomly assigned to a year within the specified time interval. Table 4.15 shows fixed management regimes for Pinus sylvestris, Betula spp. and Quercus robur & petraea (20% probability in the first ten diameter classes, 100% in the higher diameter classes) and shortlived broadleaves (0% probability in all diameter classes), occurring every 5 years. The simulation results in Table 4.16 show a harvest event in 2012, visible as a reduction of the number of trees of Pinus sylvestris from 447.6 to 44.8, Betula from 49.7 to 16.3, Quercus from 149.2 to 32.1. The number of shortlived broadleaves remains at 49.7, in line with the 0% of trees to be removed annually. Also all trees in diameter class 11 and higher have been removed in 2012, in line with the 100% of trees to be removed in these classes. For the classes 1-10 a fraction of 0.2 per year is specified, which translates to a removal of

67.2% of the trees in a 5-year interval. Quercus robur has a total of 49.7 trees in class 4 to 7 in 2012. In 2013, this is reduced to 16.3 in total, so 33.4 trees have been removed (67.2%). This in line with the calculation above.

Table 4.15 *Management regimes for testing.*

regime	type	speciesName	variable	interval	valueMin	valueMax	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
test	mgmt	Pinus sylvestris	basalArea	5	0	-1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	1	1	1	1	1
test	mgmt	Betula spp.	basalArea	5	0	-1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	1	1	1	1	1
test	mgmt	Quercus robur & p	basalArea	5	0	-1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	1	1	1	1	1
test	mgmt	Shortlived broadlea	basalArea	5	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.16 *Simulated diameter class distribution for the first 5 time steps, including management mortality, without natural mortality.*

plot	time	reprArea	species	attribute	sum	cl_1	cl_2	cl_3	cl_4	cl_5	cl_6	cl_7	cl_8	cl_9	cl_10	cl_11	cl_12	cl_13	cl_14	cl_15	cl_16	cl_17	cl_18	cl_19	cl_20
NL_6_27377	2010	117.08	Pinus sylvestris	number_per_ha	447.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.5	0.0	49.7	99.5	49.7	49.7	0.0	49.7	0.0	0.0	49.7	0.0	0.0
NL_6_27377	2010	117.08	Betula spp.	number_per_ha	49.7	0.0	0.0	0.0	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NL_6_27377	2010	117.08	Quercus robur&petraea	number_per_ha	149.2	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	0.0	0.0
NL_6_27377	2010	117.08	short-lived broadleaves	number_per_ha	49.7	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NL_6_27377	2011	117.08	Pinus sylvestris	number_per_ha	447.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	91.9	7.6	45.1	94.1	54.4	49.4	5.7	43.4	6.3	0.0	42.6	7.1	0.0
NL_6_27377	2011	117.08	Betula spp.	number_per_ha	49.7	0.0	0.0	0.0	0.0	0.0	0.0	45.9	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NL_6_27377	2011	117.08	Quercus robur&petraea	number_per_ha	149.2	0.0	0.0	0.0	47.1	2.7	0.0	0.0	0.0	44.8	4.9	0.0	0.0	0.0	43.1	6.6	0.0	0.0	0.0	0.0	0.0
NL_6_27377	2011	117.08	short-lived broadleaves	number_per_ha	49.7	0.0	0.0	0.0	46.4	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NL_6_27377	2012	117.08	Pinus sylvestris	number_per_ha	447.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	85.0	13.9	41.6	88.9	57.9	49.6	10.6	38.6	11.0	0.8	36.6	12.1	1.0
NL_6_27377	2012	117.08	Betula spp.	number_per_ha	49.7	0.0	0.0	0.0	0.0	0.0	0.0	42.5	7.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NL_6_27377	2012	117.08	Quercus robur&petraea	number_per_ha	149.2	0.0	0.0	0.0	44.6	5.0	0.2	0.0	0.0	40.4	8.8	0.5	0.0	0.0	37.4	11.4	0.9	0.0	0.0	0.0	0.0
NL_6_27377	2012	117.08	short-lived broadleaves	number_per_ha	49.7	0.0	0.0	0.0	43.4	6.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NL_6_27377	2013	117.08	Pinus sylvestris	number_per_ha	44.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.8	6.2	12.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NL_6_27377	2013	117.08	Betula spp.	number_per_ha	16.3	0.0	0.0	0.0	0.0	0.0	0.0	12.9	3.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NL_6_27377	2013	117.08	Quercus robur&petraea	number_per_ha	32.1	0.0	0.0	0.0	13.8	2.3	0.2	0.0	0.0	12.0	3.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NL_6_27377	2013	117.08	short-lived broadleaves	number_per_ha	49.7	0.0	0.0	0.0	40.5	8.4	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NL_6_27377	2014	117.08	Pinus sylvestris	number_per_ha	44.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.6	10.9	11.1	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NL_6_27377	2014	117.08	Betula spp.	number_per_ha	16.3	0.0	0.0	0.0	0.0	0.0	0.0	10.4	5.0	0.9	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NL_6_27377	2014	117.08	Quercus robur&petraea	number_per_ha	32.1	0.0	0.0	0.0	11.3	4.4	0.6	0.0	0.0	8.5	6.2	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NL_6_27377	2014	117.08	short-lived broadleaves	number_per_ha	49.7	0.0	0.0	0.0	33.9	13.5	2.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NL_6_27377	2015	117.08	Pinus sylvestris	number_per_ha	44.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.0	12.8	10.9	5.2	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NL_6_27377	2015	117.08	Betula spp.	number_per_ha	16.3	0.0	0.0	0.0	0.0	0.0	0.0	8.4	5.9	1.7	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NL_6_27377	2015	117.08	Quercus robur&petraea	number_per_ha	32.1	0.0	0.0	0.0	9.2	5.5	1.4	0.2	0.0	6.0	6.8	2.7	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NL_6_27377	2015	117.08	short-lived broadleaves	number_per_ha	49.7	0.0	0.0	0.0	28.4	16.4	4.3	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

4.3.4 Natural ingrowth

Ingrowth is modelled by inserting trees in specified diameter classes, optionally connected to a threshold of a selected variable (basal area, number of trees or growing stock). Both management ingrowth (planting) and natural ingrowth can be modelled. Table 4.17 shows a possible natural ingrowth regime for Pinus sylvestris (species 6). Natural ingrowth will happen every year, with 100 trees in diameter class 1, regardless of the state of the stand since no variable is specified. Table 4.18 shows that indeed 100 Pinus sylvestris trees are inserted in the first diameter class after 1 year of simulation.

Table 4.17 *Parameters for testing natural ingrowth.*

regime	variable	speciesInd	valueMin	valueMax	interval	type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
managed	basalArea	6	-1	100	1	mgmt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
natural	basalArea	6	-1	-1	1	nat	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.18 *Simulation result with natural ingrowth after 1 year.*

plot	time	reprArea	species	attribute	sum	cl_1	cl_2	cl_3	cl_4	cl_5	cl_6	cl_7	cl_8	cl_9	cl_10	cl_11	cl_12	cl_13	cl_14	cl_15	cl_16	cl_17	cl_18	cl_19	cl_20
NL_6_27377	2010	117.08	Pinus sylvestris	number_per_ha	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.5	0.0	49.7	99.5	49.7	49.7	0.0	49.7	0.0	0.0	49.7	0.0	0.0
NL_6_27377	2010	117.08	Betula spp.	number_per_ha	0.0	0.0	0.0	0.0	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NL_6_27377	2010	117.08	Quercus robur&petraea	number_per_ha	0.0	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	0.0	0.0
NL_6_27377	2010	117.08	short-lived broadleaves	number_per_ha	0.0	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NL_6_27377	2011	117.08	Pinus sylvestris	number_per_ha	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	91.9	7.6	45.1	94.1	54.4	49.4	5.7	43.4	6.3	0.0	42.6	7.1	0.0
NL_6_27377	2011	117.08	Betula spp.	number_per_ha	0.0	0.0	0.0	0.0	0.0	0.0	0.0	45.9	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NL_6_27377	2011	117.08	Quercus robur&petraea	number_per_ha	0.0	0.0	0.0	0.0	47.1	2.7	0.0	0.0	0.0	44.8	4.9	0.0	0.0	0.0	43.1	6.6	0.0	0.0	0.0	0.0	0.0
NL_6_27377	2011	117.08	short-lived broadleaves	number_per_ha	0.0	0.0	0.0	0.0	46.4	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

To test and demonstrate the effect of the threshold, we modify the parameters as shown in Table 4.19. The maximum threshold for Pinus sylvestris is set at a basal area of 38 m² ha⁻¹ and for Betula at 40 m² ha⁻¹. Table 4.20 shows the simulated basal area of the stand, passing the threshold of 38 m² ha⁻¹ in 2016 and the

threshold of 40 m² ha⁻¹ in 2018. Table 4.21 shows that indeed no more Pinus sylvestris trees are added after 2016, and no more Betula trees are added after 2018.

Table 4.19 *Parameters for testing management ingrowth depending on basal area.*

regime	variable	speciesIndex	valueMin	valueMax	interval	type	1	2	3	4	5	6	7	8	9	10
natural	basalArea	6	-1	38	1	nat	100	0	0	0	0	0	0	0	0	0
natural	basalArea	10	-1	40	1	nat	100	0	0	0	0	0	0	0	0	0

Table 4.20 *Basal area development (m² ha⁻¹) in the simulation.*

time	basalArea
2010	37.8
2011	38.6
2012	39.4
2013	40.2
2014	41.0
2015	41.9

Table 4.21 *Simulation result (stem number per ha) using different ingrowth thresholds.*

	plot	time	reprArea	species	attribute	sum	cl_1	cl_2	cl_3	cl_4	cl_5	cl_6	cl_7	cl_8	cl_9	cl_10	cl_11	cl_12	cl_13	cl_14	cl_15	cl_16	cl_17	cl_18	cl_19	cl_20
2	NL_6_27377	2010	117.08	Pinus sylvestris	number_per_ha	447.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.5	0.0	49.7	99.5	49.7	49.7	0.0	49.7	0.0	0.0	49.7	0.0	0.0
3	NL_6_27377	2010	117.08	Betula spp.	number_per_ha	49.7	0.0	0.0	0.0	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	NL_6_27377	2010	117.08	Quercus robur&petraea	number_per_ha	149.2	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	0.0	0.0
5	NL_6_27377	2010	117.08	short-lived broadleaves	number_per_ha	49.7	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	NL_6_27377	2011	117.08	Pinus sylvestris	number_per_ha	547.6	100.0	0.0	0.0	0.0	0.0	0.0	0.0	91.9	7.6	45.1	94.1	54.4	49.4	5.7	43.4	6.3	0.0	42.6	7.1	0.0
7	NL_6_27377	2011	117.08	Betula spp.	number_per_ha	149.7	100.0	0.0	0.0	0.0	0.0	0.0	45.9	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	NL_6_27377	2011	117.08	Quercus robur&petraea	number_per_ha	149.2	0.0	0.0	0.0	47.1	2.7	0.0	0.0	0.0	44.8	4.9	0.0	0.0	0.0	43.1	6.6	0.0	0.0	0.0	0.0	0.0
9	NL_6_27377	2011	117.08	short-lived broadleaves	number_per_ha	49.7	0.0	0.0	0.0	46.4	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	NL_6_27377	2012	117.08	Pinus sylvestris	number_per_ha	547.6	99.3	0.7	0.0	0.0	0.0	0.0	0.0	84.7	14.1	41.5	88.7	58.0	49.6	10.8	38.4	11.2	0.9	36.3	12.3	1.1
11	NL_6_27377	2012	117.08	Betula spp.	number_per_ha	249.7	198.7	1.3	0.0	0.0	0.0	0.0	42.4	7.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	NL_6_27377	2012	117.08	Quercus robur&petraea	number_per_ha	149.2	0.0	0.0	0.0	44.6	5.0	0.2	0.0	0.0	40.4	8.8	0.5	0.0	0.0	37.3	11.5	0.9	0.0	0.0	0.0	0.0
13	NL_6_27377	2012	117.08	short-lived broadleaves	number_per_ha	49.7	0.0	0.0	0.0	43.4	6.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	NL_6_27377	2013	117.08	Pinus sylvestris	number_per_ha	547.6	98.6	1.4	0.0	0.0	0.0	0.0	0.0	78.2	19.4	38.8	83.5	60.7	50.1	15.4	34.7	14.7	2.3	31.0	15.9	2.8
15	NL_6_27377	2013	117.08	Betula spp.	number_per_ha	349.7	296.3	3.7	0.0	0.0	0.0	0.0	39.2	9.6	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	NL_6_27377	2013	117.08	Quercus robur&petraea	number_per_ha	149.2	0.0	0.0	0.0	42.2	7.1	0.5	0.0	0.0	36.4	11.9	1.4	0.1	0.0	32.2	14.9	2.4	0.1	0.0	0.0	0.0
17	NL_6_27377	2013	117.08	short-lived broadleaves	number_per_ha	49.7	0.0	0.0	0.0	40.5	8.4	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	NL_6_27377	2014	117.08	Pinus sylvestris	number_per_ha	547.6	97.9	2.0	0.0	0.0	0.0	0.0	0.0	72.2	23.7	36.8	78.5	62.6	50.9	19.4	32.0	17.3	4.0	26.7	18.1	4.8
19	NL_6_27377	2014	117.08	Betula spp.	number_per_ha	349.7	292.7	7.2	0.1	0.0	0.0	0.0	36.3	11.8	1.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	NL_6_27377	2014	117.08	Quercus robur&petraea	number_per_ha	149.2	0.0	0.0	0.0	40.0	8.8	0.9	0.0	0.0	32.8	14.2	2.5	0.2	0.0	27.9	17.2	4.2	0.5	0.0	0.0	0.0
21	NL_6_27377	2014	117.08	short-lived broadleaves	number_per_ha	49.7	0.0	0.0	0.0	37.9	10.4	1.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	NL_6_27377	2015	117.08	Pinus sylvestris	number_per_ha	547.6	97.3	2.6	0.0	0.0	0.0	0.0	0.0	66.8	27.2	35.3	74.0	63.7	51.8	23.0	30.2	19.1	5.8	23.2	19.3	6.9
23	NL_6_27377	2015	117.08	Betula spp.	number_per_ha	349.7	289.2	10.4	0.3	0.0	0.0	0.0	33.6	13.5	2.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	NL_6_27377	2015	117.08	Quercus robur&petraea	number_per_ha	149.2	0.0	0.0	0.0	37.9	10.4	1.4	0.1	0.0	29.6	15.9	3.7	0.5	0.0	24.1	18.5	6.0	1.0	0.1	0.0	0.0
25	NL_6_27377	2015	117.08	short-lived broadleaves	number_per_ha	49.7	0.0	0.0	0.0	35.5	12.0	2.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

4.3.5 Management ingrowth

Table 4.22 shows a possible management ingrowth regime for Pinus sylvestris (species 6). If the basal area is lower than 100 m² ha⁻¹, 100 trees will be "planted" (management ingrowth) in diameter class 1. The management ingrowth only happens after a harvest action, with the interval as specified in the input. No regeneration is visible in the years 2016-2018, but after the harvest action in 2018, 100 Pinus sylvestris trees are inserted in the first diameter class in 2019 (Table 4.23).

Table 4.22 *Parameters for testing management ingrowth.*

regime	variable	speciesInd	valueMin	valueMax	interval	type	1	2	3	4	5	6	7	8	9	10
managed	basalArea	6	-1	100	1	mgmt	100	0	0	0	0	0	0	0	0	0
natural		6	-1	100	1	nat	0	0	0	0	0	0	0	0	0	0

Table 4.23 *Simulation result (stem number per ha) with management ingrowth for Pinus sylvestris after 4 years.*

	plot	time	reprArea	species	attribute	sum	cl_1	cl_2	cl_3	cl_4	cl_5	cl_6	cl_7	cl_8	cl_9	cl_10	cl_11	cl_12	cl_13	cl_14	cl_15	cl_16	cl_17	cl_18	cl_19	cl_20
2	NL_6_27377	2010	117.08	Pinus sylvestris	number_per_ha	447.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.5	0.0	49.7	99.5	49.7	49.7	0.0	49.7	0.0	0.0	49.7	0.0	0.0
3	NL_6_27377	2010	117.08	Betula spp.	number_per_ha	49.7	0.0	0.0	0.0	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	NL_6_27377	2010	117.08	Quercus robur&petraea	number_per_ha	149.2	0.0	0.0	0.0	49.7	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	NL_6_27377	2010	117.08	short-lived broadleaves	number_per_ha	49.7	0.0	0.0	0.0	49.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	NL_6_27377	2011	117.08	Pinus sylvestris	number_per_ha	447.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	91.9	7.6	45.1	94.1	54.4	49.4	5.7	43.4	6.3	0.0	42.6	7.1	0.0
7	NL_6_27377	2011	117.08	Betula spp.	number_per_ha	49.7	0.0	0.0	0.0	0.0	0.0	0.0	45.9	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	NL_6_27377	2011	117.08	Quercus robur&petraea	number_per_ha	149.2	0.0	0.0	0.0	47.1	2.7	0.0	0.0	44.8	4.9	0.0	0.0	0.0	43.1	6.6	0.0	0.0	0.0	0.0	0.0	0.0
9	NL_6_27377	2011	117.08	short-lived broadleaves	number_per_ha	49.7	0.0	0.0	0.0	46.4	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	NL_6_27377	2012	117.08	Pinus sylvestris	number_per_ha	447.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	85.0	13.9	41.6	88.9	57.9	49.6	10.6	38.6	11.0	0.8	36.6	12.1	1.0
11	NL_6_27377	2012	117.08	Betula spp.	number_per_ha	49.7	0.0	0.0	0.0	0.0	0.0	0.0	42.5	7.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	NL_6_27377	2012	117.08	Quercus robur&petraea	number_per_ha	149.2	0.0	0.0	0.0	44.6	5.0	0.2	0.0	40.4	8.8	0.5	0.0	0.0	37.4	11.4	0.9	0.0	0.0	0.0	0.0	0.0
13	NL_6_27377	2012	117.08	short-lived broadleaves	number_per_ha	49.7	0.0	0.0	0.0	43.4	6.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	NL_6_27377	2013	117.08	Pinus sylvestris	number_per_ha	447.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	78.7	19.0	39.0	84.0	60.5	50.1	14.9	35.1	14.4	2.2	31.6	15.5	2.6
15	NL_6_27377	2013	117.08	Betula spp.	number_per_ha	49.7	0.0	0.0	0.0	0.0	0.0	0.0	39.3	9.5	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	NL_6_27377	2013	117.08	Quercus robur&petraea	number_per_ha	149.2	0.0	0.0	0.0	42.2	7.0	0.5	0.0	36.5	11.8	1.4	0.1	0.0	32.4	14.8	2.4	0.1	0.0	0.0	0.0	0.0
17	NL_6_27377	2013	117.08	short-lived broadleaves	number_per_ha	49.7	0.0	0.0	0.0	40.5	8.4	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	NL_6_27377	2014	117.08	Pinus sylvestris	number_per_ha	547.6	100.0	0.0	0.0	0.0	0.0	0.0	0.0	73.1	23.1	37.1	79.3	62.3	50.8	18.7	32.5	16.8	3.7	27.5	17.7	4.5
19	NL_6_27377	2014	117.08	Betula spp.	number_per_ha	49.7	0.0	0.0	0.0	0.0	0.0	0.0	36.5	11.7	1.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	NL_6_27377	2014	117.08	Quercus robur&petraea	number_per_ha	149.2	0.0	0.0	0.0	40.0	8.8	0.9	0.0	32.9	14.1	2.5	0.2	0.0	28.2	17.0	4.1	0.5	0.0	0.0	0.0	0.0
21	NL_6_27377	2014	117.08	short-lived broadleaves	number_per_ha	49.7	0.0	0.0	0.0	37.9	10.4	1.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	NL_6_27377	2015	117.08	Pinus sylvestris	number_per_ha	547.6	99.4	0.6	0.0	0.0	0.0	0.0	0.0	67.8	26.5	35.7	75.0	63.5	51.7	22.1	30.6	18.7	5.4	24.1	19.0	6.4
23	NL_6_27377	2015	117.08	Betula spp.	number_per_ha	49.7	0.0	0.0	0.0	0.0	0.0	0.0	33.8	13.4	2.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	NL_6_27377	2015	117.08	Quercus robur&petraea	number_per_ha	149.2	0.0	0.0	0.0	37.9	10.4	1.4	0.1	0.0	29.8	15.8	3.7	0.5	0.0	24.4	18.4	5.8	1.0	0.1	0.0	0.0
25	NL_6_27377	2015	117.08	short-lived broadleaves	number_per_ha	49.7	0.0	0.0	0.0	35.5	12.0	2.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

4.4 Initialisation check of a whole country

For this experiment we initialised all plots from the Dutch NFI-6 (3157 plots). For every plot we compared the simulated values at t=0 for stem number, basal area and volume to those given in the NFI database. One plot in the database (plot NL_6_90035) has a very low reported area and causes an extreme outlier in our comparison (Figure 4.2), while this error has been fixed during data preparation for inclusion in the model. After removing this outlier, the stem number matches exactly for all plots. This outlier is also visible in the comparison for basal area (Figure 4.3). Most other plots are close to the 1:1 line, with some exceptions that have lower simulated basal area than measured. Smaller deviations are to be expected because actual diameters are replaced by mid-class diameters. The underestimations however are caused by the fact that the model can only simulate trees with a diameter up to 100 cm, because it is limited to 40 classes of 2.5 cm. Larger trees are allocated to the last diameter class, with consequences for the simulated basal area. This situation is however rare, with 20 trees larger than 100 cm DBH out of 61881 trees used for the initialisation, affecting 17 plots. Average volume per plot is given directly in the NFI database, where the outlier is apparently already corrected (Figure 4.4). The simulated volume shows more deviations than the basal area, but follows closely the 1:1 line. The larger deviations can be attributed to using average volume functions for all tree species, while in the NFI system some species have a site-specific function. Moreover, the NFI distinguishes more individual species, while EFISCEN-Space aggregates the minor species in only a few classes.
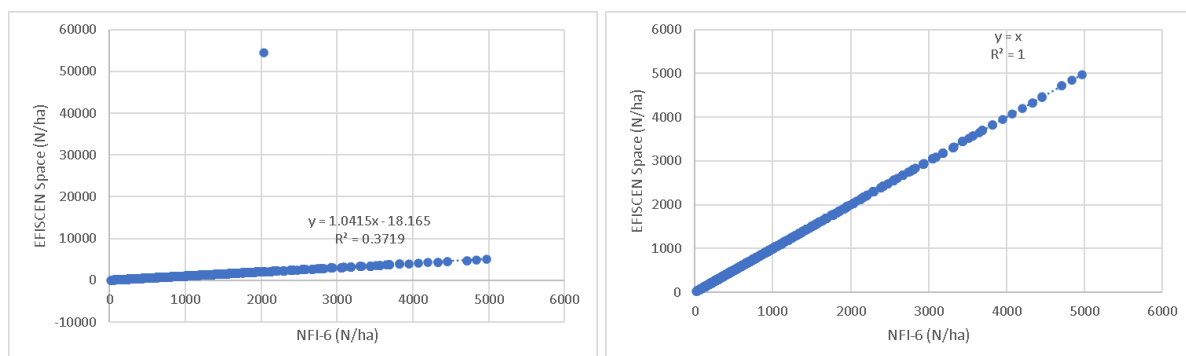

Figure 4.2 *Comparison of simulated and reported initial values of stem number per plot for the Dutch NFI-6, before (left) and after removing the outlier due to an erroneous area for plot 90035 (right).*
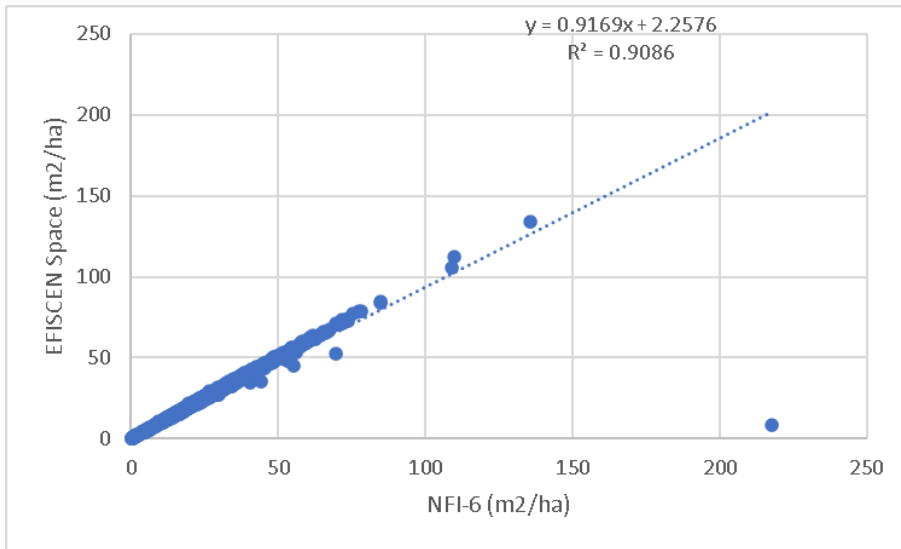
Figure 4.3 *Comparison of simulated and reported initial values of basal area per plot for the Dutch NFI-6.*
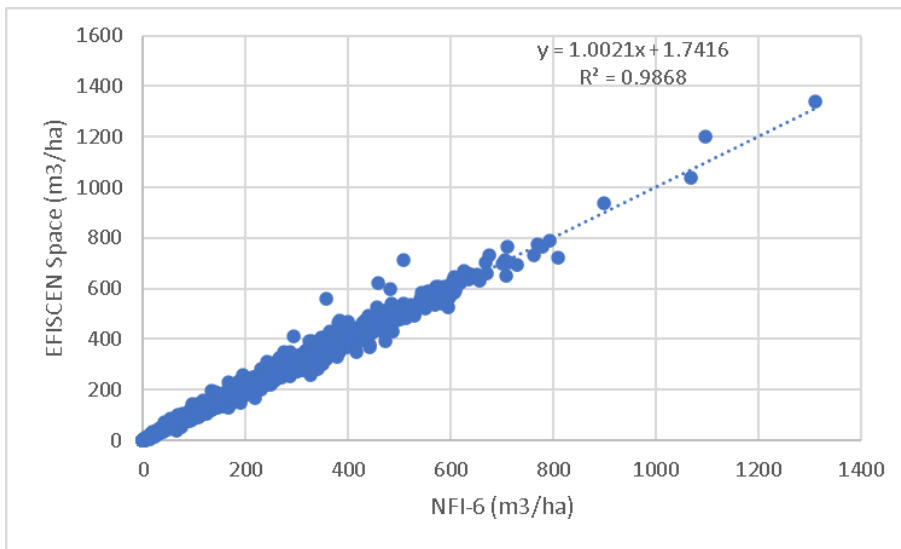

Figure 4.4 *Comparison of simulated and reported initial values of volume per plot for the Dutch NFI-6.*

We computed the stem biomass directly from the individual tree volume in the NFI database, assigning wood densities to the 20 species groups used in the NFI reporting. The simulated values are satisfactory and very comparable to the simulation of stem volume (Figure 4.5). A more detailed parameterisation of wood density for the less important species as done in the direct NFI calculation has no visible effect on the accuracy of the simulation stem biomass. Additionally we computed the biomass in foliage, branches, and roots using the generic (broadleaves/conifers) equations from Forrester et al. (2017), in the same way as done in the model. The results are generally very comparable to the simulated values (Figure 4.6, Figure 4.7 and Figure 4.8), with an underestimation for a few plots linked to the maximum tree diameter that can be simulated in the model.
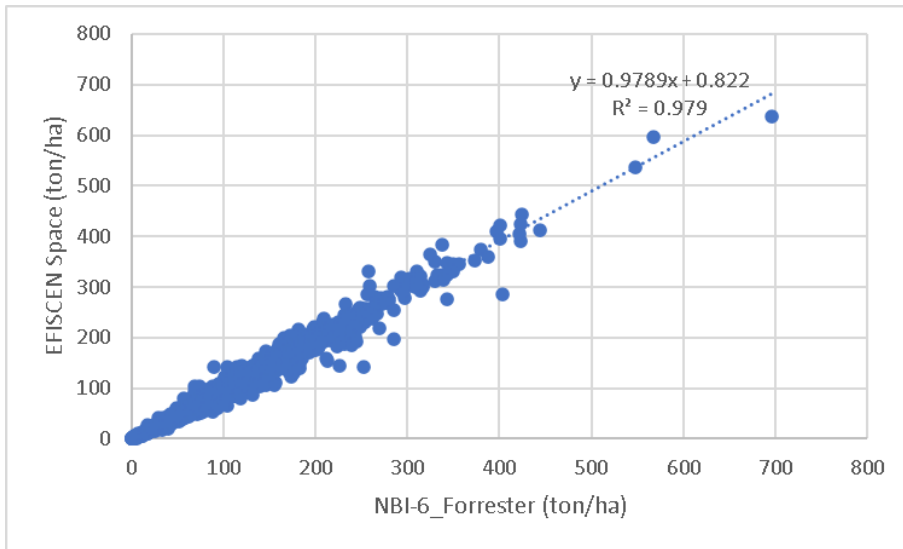
Figure 4.5 *Comparison of simulated and computed initial values of stem biomass for the Dutch NFI-6.*
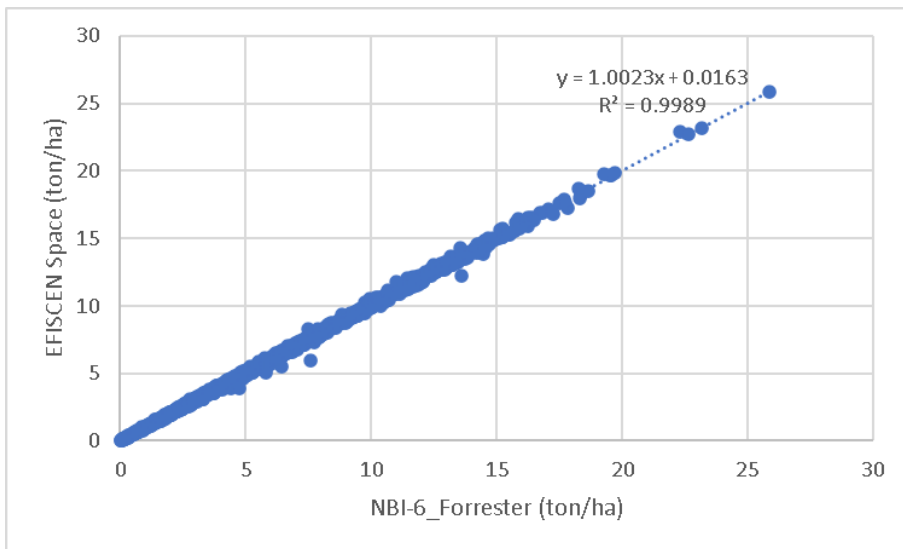
Figure 4.6 *Comparison of simulated and computed initial values of foliage biomass for the Dutch NFI-6.*
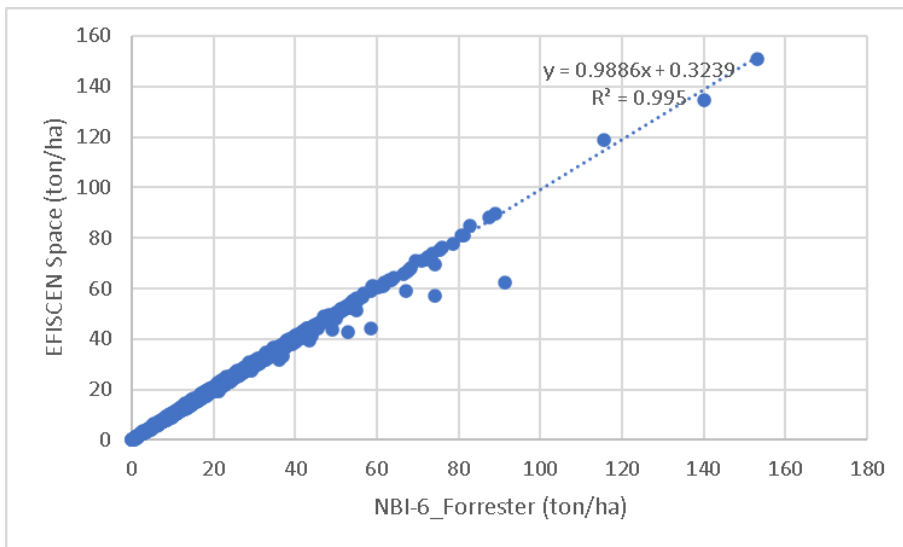
Figure 4.7 *Comparison of simulated and computed initial values of branch biomass for the Dutch NFI-6.*
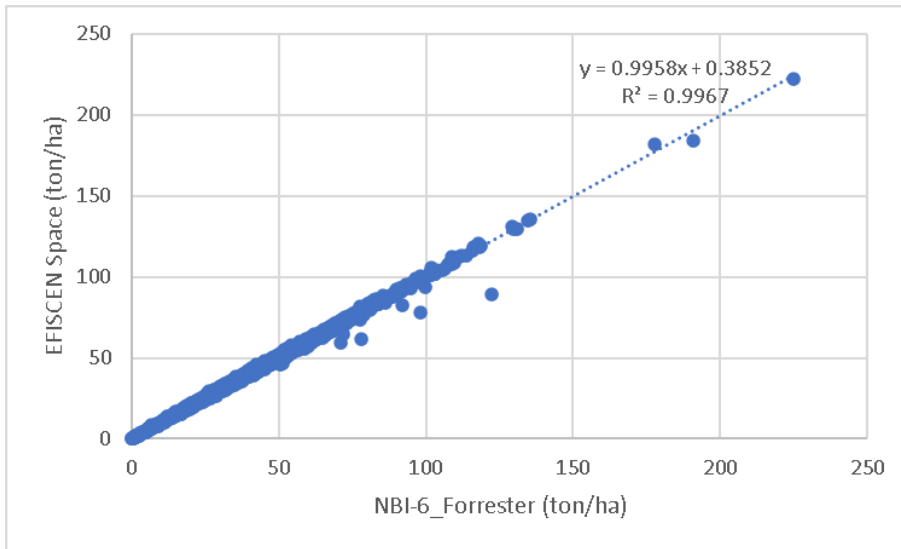
Figure 4.8 *Comparison of simulated and computed initial values of root biomass for the Dutch NFI-6.*

4.5 Evaluation of initial soil carbon

For a subset of 198 plots of the Dutch NFI-6, soil organic carbon has been measured recently (de Jong et al., in prep). For this subset we compared the measured values with simulated initial soil carbon values from the initialization experiment in Section 4.4. The average simulated soil carbon was lower by approx. 55 ton C/ha, with a larger range of simulated values as compared to the observations (Figure 4.9). Simulated soil carbon stock includes all carbon originating from litterfall, mortality and harvest residues, i.e. including deadwood and carbon in the full soil profile, while the measurements exclude deadwood and include only soil carbon to a soil depth of 100 cm. In addition to measured soil organic carbon in 100 cm depth, we also compared the carbon stock values up to 30 cm. Given shorter depth, the measured soil organic carbon was lower by 30 ton C/ha in comparison to simulated stock. Although the distributions are rather comparable in both measured depths, no correlation exists between the measured and simulated values (Figure 4.10).
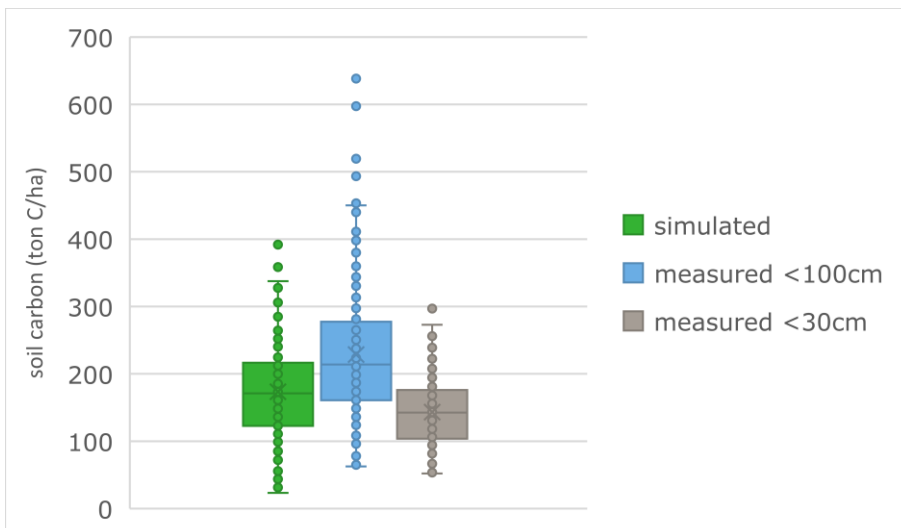
Figure 4.9 *Comparison of the distribution of measured and simulated initial soil carbon (ton C/ha) based on a subset of 198 plots from the Dutch NFI-6. The measured soil carbon stock was compared with regard to two different depths: up to 30 cm and 100 cm.*

a)

b)
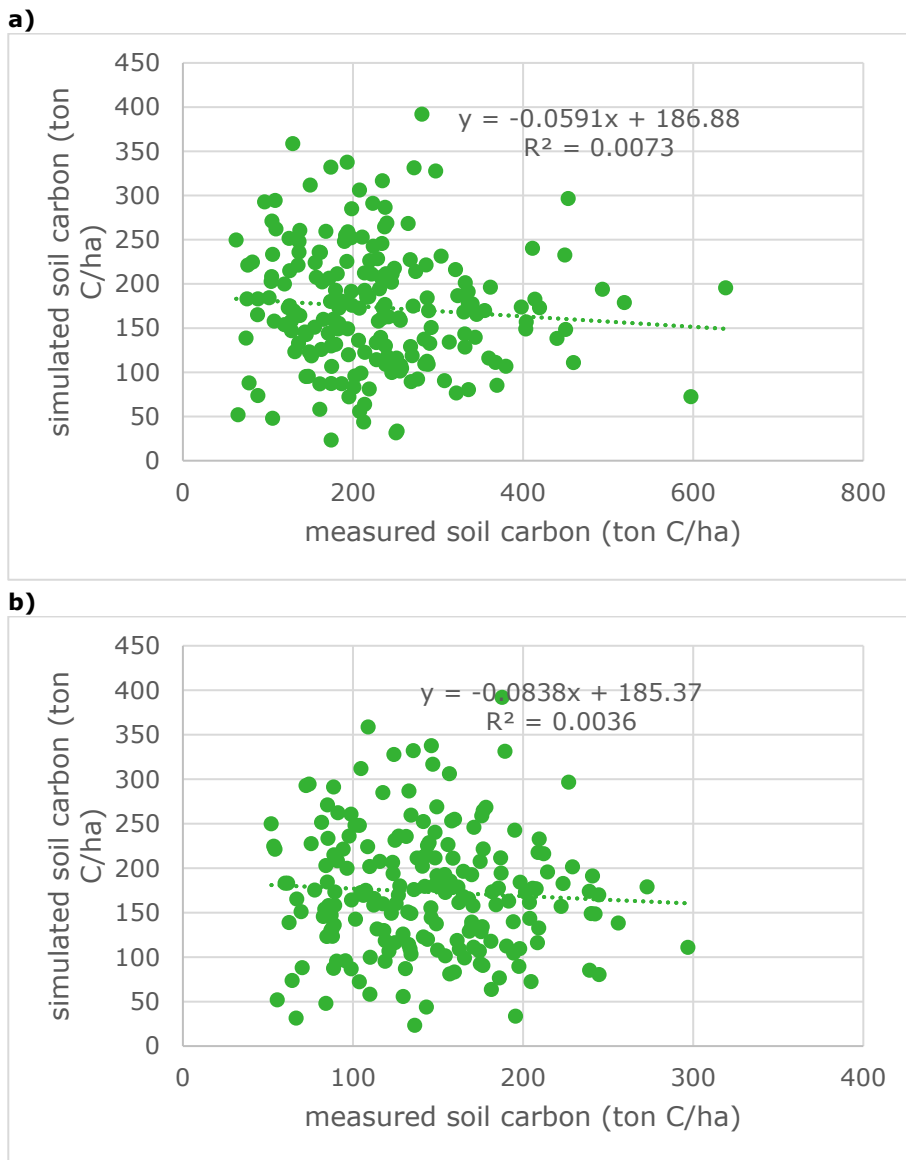
Figure 4.10 *Comparison of measured: a) up to 100 cm, b) up to 30 cm and simulated initial soil carbon (ton C/ha) per plot for the Netherlands.*

For Italy, we initialized subset of 1,352 plots from the Italian NFI-2 for which we had observations of the measured soil carbon stocks (up to 30cm) and we compared them with simulation results (Figure 4.11). The comparison showed that simulated soil carbon was higher by approx. 5 ton C/ha, and the simulated results show a larger variation in values. Moreover, there was no correlation between simulated an measured values (Figure 4.12).
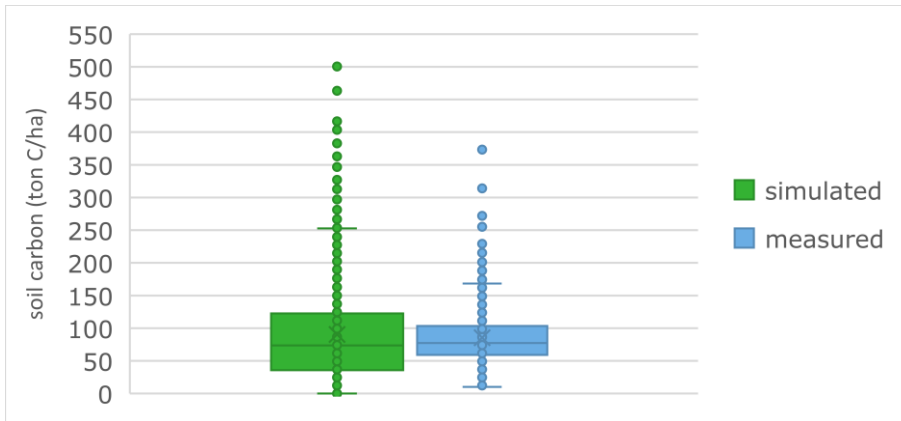
Figure 4.11 *Comparison of the initial soil carbon (ton C/ha) based on subset of 1,352 plots from the Italian NFI-2.*
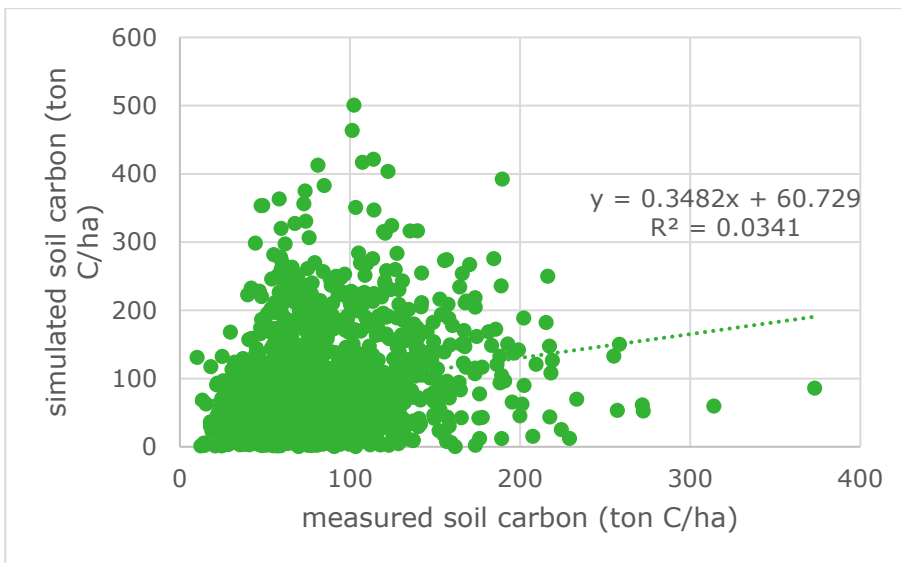
Figure 4.12 *Comparison of simulated and measured initial soil carbon (ton C/ha) per plot for Italy.*

4.6   Sensitivity to volume functions

When simulating a country, it has preference to use as much as possible information and parameter sets from the country itself. When this is not available, information and parameter sets from a neighbouring country can be used, where this country is preferably similar in terms of growing conditions and forest management. In this experiment we test the sensitivity of the model to alternative parameter sets for the volume functions. We initialised the model with data from Switzerland for 5,920 plots as measured in NFI-3 (2003-2005), and did a simulation for 5 years. In the default setting we use the parameter sets as developed on the German NFI data, which gives simulated output values quite close to those observed in SOEF 2020 for Switzerland (see also Section Application to Europe 4.11). When we apply the parameter sets as developed on the data from Southern Sweden instead, growing stock, increment and harvest are lower by around 10% (Table 4.24). When we use the Dutch parameter sets, values are lower by 16-20%, while using Spanish parameter sets, growing stock and increment are lower by 27% and harvest even by 37%. These differences can be explained by the different growing conditions in the different countries, leading to differences in observed height/diameter ratios and stem taper.

Table 4.24 *Simulated initial volume, gross annual increment and harvest for Switzerland when using different parameter sets for the volume function.*

	German volume functions	Southern Swedish volume functions	Dutch volume functions	Spanish volume functions
Initial volume (m³ ha-1)	370.6	332.9	310.7	269.3
Gross annual increment (m³ ha⁻¹ yr⁻¹)	9.4	8.4	7.5	5.9
Harvest (m³ ha⁻¹ yr⁻¹)	5.8	5.2	4.8	4.3

4.7   Sensitivity to biomass functions

In this experiment we tested the sensitivity of the model to changes in biomass parameters. To do so we replaced the generic (conifers/broadleaves) biomass parameter sets from Forrester et al. (2017) as applied in Section 4.4 for the Dutch NFI-6 by species-specific parameter sets. This was applied to the compartments branches (using the equations for living branches in Forrester), foliage and roots. In case species-specific parameters were not available, we used generic parameters as indicated in Table 4.25. The results show that using the species-specific parameters, the initial biomass was lower by 1.8 ton DM/ha in comparison to the generic parameters, while the distribution was hardly affected (Figure 4.13). At the country level the difference was 0.67 ton DM lower for the species-specific parameter set. Considering specific species, the initial biomass of Pinus sylvestris differed the most with difference of approx. 5 ton DM/ha (Table 4.26).

Table 4.25 *Biomass parameter sets applied in the sensitivity test. The second column specifies which species from Forrester et al. (2017) was applied per simulated species (first column), while the last columns indicate for which compartments this set was applied to (S). When no species-specific parameter was available, the respective default generic (G) broadleaves or conifers parameters where used.*

| EFISCEN-space species (group)	Species applied (Forrester et al.)	Branches	Foliage	Roots
Abies spp.	-	G	G	G
Larix spp.	Larix decidua	S	S	G
Picea abies	Picea abies	S	S	S
Picea sitchensis	-	G	G	G
Pseudotsuga menziesii	Pseudotsuga menziesii	S	S	S
Pinus sylvestris	Pinus sylvestris	S	S	S
Pinus nigra+mugo	Pinus nigra	G	S	S
Other indigenous Pinus	Pinus pinaster	S	S	S
Other conifers	-	G	G	G
Betula spp.	Betula pendula Or B. pubescens	S	S	S
Castanea sativa	Castanea sativa	G	S	G
Eucalyptus spp.	-	G	G	G
Fagus sylvatica	Fagus sylvatica	S	S	S
Robinia pseudoacacia	Robinia pseudoacacia	G	S	S
Populus plantations	Populus	G	S	G
Quercus robur&petraea	Quercus petraea Or Q. robur	G	S	S
Quercus ilex	Quercus ilex	G	S	S
Quercus suber	-	G	G	G
long-lived broadleaves	Fraxinus excelsior	G	S	S
short-lived broadleaves	Alnus glutinosa Or A. incana	G	S	S
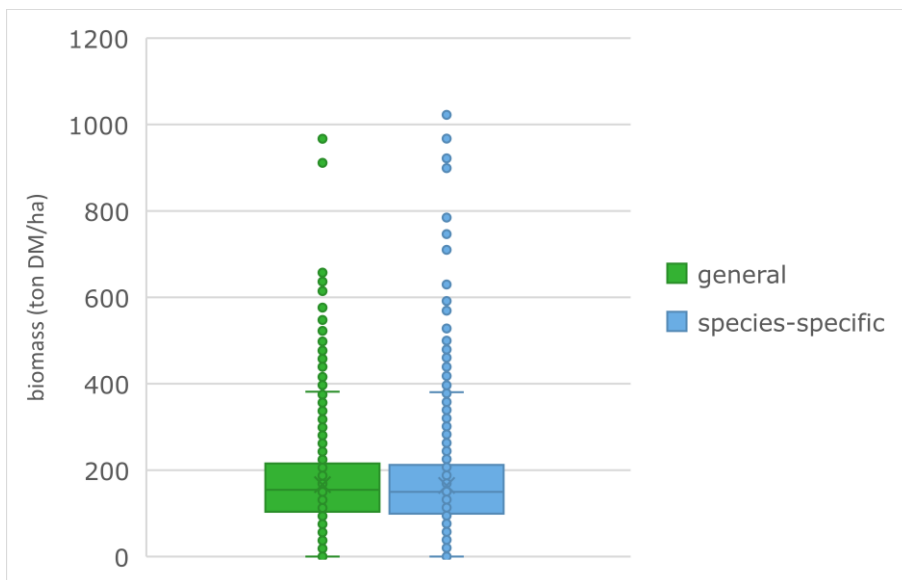
Figure 4.13 *Comparison of the initial biomass (ton DM/ha) per plot while using generic or species-specific parameters from Forrester et al. 2017.*

Table 4.26 *Overview table of the initial biomass and soil carbon per species while using general and species-specific parameters from Forrester et al. 2017.*

Species	General		Species-specific	
	Biomass (Tg DM)	**Soil carbon (Tg C)**	**Biomass (Tg DM)**	**Soil carbon (Tg C)**
Abies spp.	0.22	0.20	0.22	0.20
Betula spp.	3.95	3.94	3.80	4.26
Castanea sativa	0.28	0.24	0.28	0.23
Fagus sylvatica	4.67	3.44	5.87	3.70
Larix spp.	2.65	3.05	2.58	2.26
long-lived broadleaves	6.95	5.83	6.76	7.32
Other conifers	0.33	0.45	0.33	0.45
Other indigenous Pinus	0.17	0.06	0.17	0.08
Picea abies	2.21	2.08	2.40	2.49
Picea sitchensis	0.21	0.20	0.21	0.20
Pinus nigra+mugo	2.68	3.21	2.47	2.32
Pinus sylvestris	14.18	19.05	12.38	12.75
Populus plantations	1.53	1.35	1.54	1.48
Pseudotsuga menziesii	4.61	4.04	4.43	3.79
Quercus robur&petraea	13.72	11.41	13.78	13.15
Robinia pseudoacacia	0.34	0.26	0.31	0.19
short-lived broadleaves	3.09	3.72	3.58	4.18
Total	**61.78**	**62.53**	**61.11**	**59.05**

Since the soil carbon estimation is dependent on the amount of biomass, we also investigated the effect of generic and species-specific biomass parameter sets on the soil carbon stock. For the initial soil carbon stock, the difference between parameters sets was higher than for the biomass. When using species-specific parameters, the initial soil carbon was lower by approx. 9.4 ton C/ha in comparison to generic parameters (Figure 4.14). At the country scale the difference is 3.47 Tg C lower, with the largest difference for Pinus sylvestris, approx. 6.30 Tg C lower. In contrast to most species, Quercus robur&petraea and long-lived broadleaves had a higher initial soil carbon when using species-specific parameters (Table 4.26). We conclude that the simulated biomass per compartment per species may differ using the species-specific parameter sets, but that these differences more or less cancel out at the country scale. These differences propagate to the simulated initial soil carbon, with a somewhat larger effect due to differences among the speed of decomposition for different species and compartments.
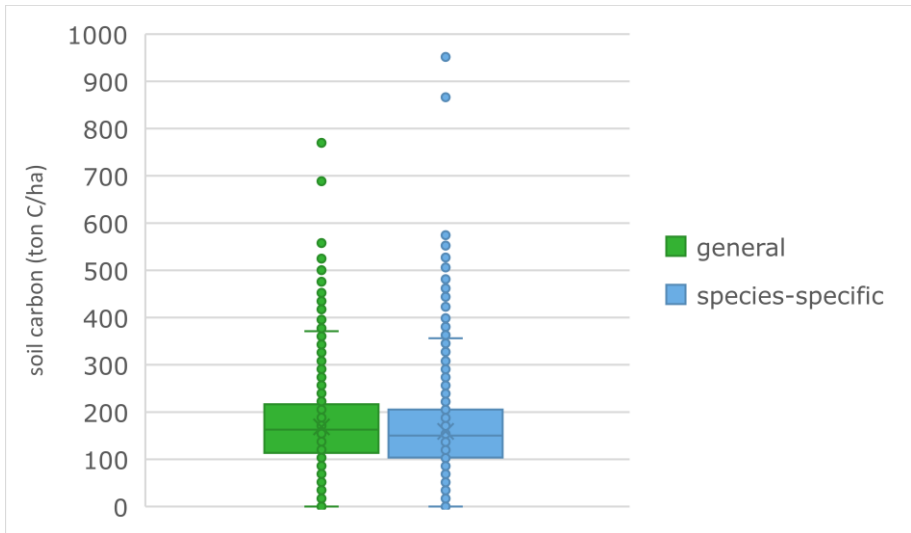
Figure 4.14 *Comparison of the initial soil carbon (ton C/ha) per plot while using general and species-specific parameters from Forrester et al. 2017.*

4.8   Sensitivity to turnover rates

In this experiment we checked the sensitivity of the soil carbon model to changes in turnover rates of the biomass compartments. We initialized the model with data from the Flanders NFI-2 (2,126 plots) in three variants, using default turnover rates and rates that were respectively 50% higher and lower compared to the default (Table 4.27). The comparison showed that the soil carbon initialized with turnover with higher rates was increased by approx. 54 C ton/ha to the default soil carbon (+31%). Whereas the turnover with lower rates was decreased by approx. 80 C ton/ha (-46%) (Figure 4.15).

Table 4.27 *Applied turnover rates in a soil carbon model in EFISCEN-Space.*

	Branch	Stem	Foliage	Roots
Default	0.02	0.01	1 (0.3*)	0.1
Higher rate	0.03	0.015	1 (0.45*)	0.15
Lower rate	0.01	0.005	0.5 (0.15*)	0.05

*Foliage turnover rate for Pseudotsuga mensiezii, Picea sitchensis, Picea abies, Abies spp.
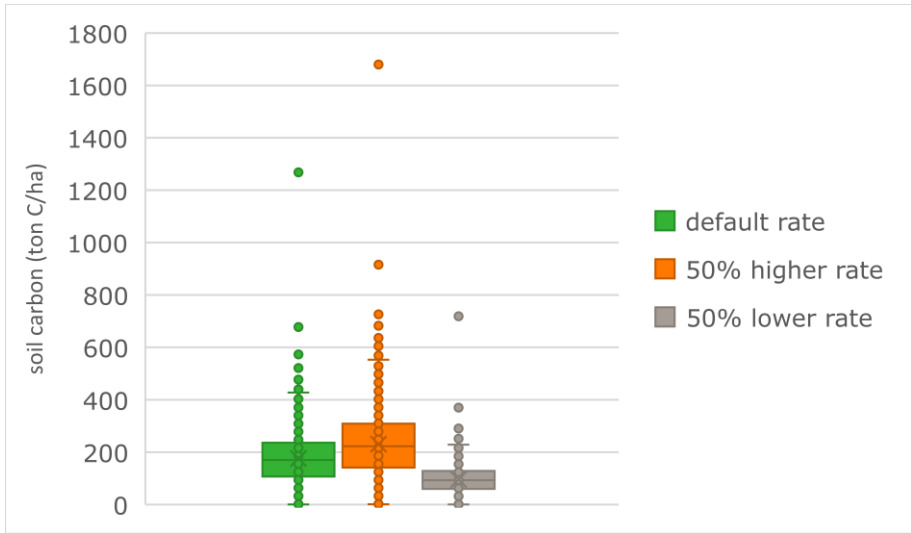
Figure 4.15 *Comparison of initial soil carbon (C ton/ha) using different turnover rates, based on 2,126 plots from Flanders.*

4.9   Country-scale validation

In this experiment we followed three inventory cycles of the Dutch National Forest Inventory (NFI-5, NFI-6, NFI-7). We initialized the model with the NFI-5 data in 2003 and simulated for a period of 20 years. Then we compared the measured NFI-6 plot volume with simulated values for year 2013 (mid-year of NFI-6) and the measured NFI-7 plot volume with simulated values for 2019 (mid-year of NFI-7). The match between observed and simulated plot values decreased over time, as indicated by a decreasing R^2 and an increasing deviation of the regression line compared to the 1:1 line (Figure 4.16, Figure 4.17). Deviations occur because increment, natural mortality, harvest and ingrowth will deviate from the actual values. A further factor is that the plot size in the Dutch NFI is variable, so the measured value for subsequent inventories may be based on a different tree population than in in the initial inventory.

The individual-tree increment functions have an R^2-adjusted of 0.1-0.57, with most of the species used here having an R^2-adjusted of 0.17-0.27 (Schelhaas et al. 2018a). No evaluation exists of the accuracy of the increment at plot level, and it is therefore unclear how much of the observed deviation can be attributed to increment. For the harvests, it is clear that there is a considerable variation among the plots used to derive the management patterns, while all plots within a group are subject to the average probabilities found in this group. One example is visible in Figure 4.16 and Figure 4.17 as measured plots having zero volume, while the simulations show a non-zero volume. These plots have been subject to a regeneration felling, while in the model only the average number of trees for that species and diameter class have been removed in the corresponding model stands. Likely there are other plots with similar characteristics where no intervention was observed, but where in the model also the average number of trees have been harvested. In these simulations, no ingrowth was assumed. One consequence of this assumption is that plots without any trees in the initial situation will not get any volume during the simulation. This is visible as plots with zero modelled volume, but with non-zero observations. It is not possible to estimate how much each of the abovementioned causes contribute to the observed differences, but it is clear that improvements can be made in the simulation of harvest patterns and adding ingrowth.
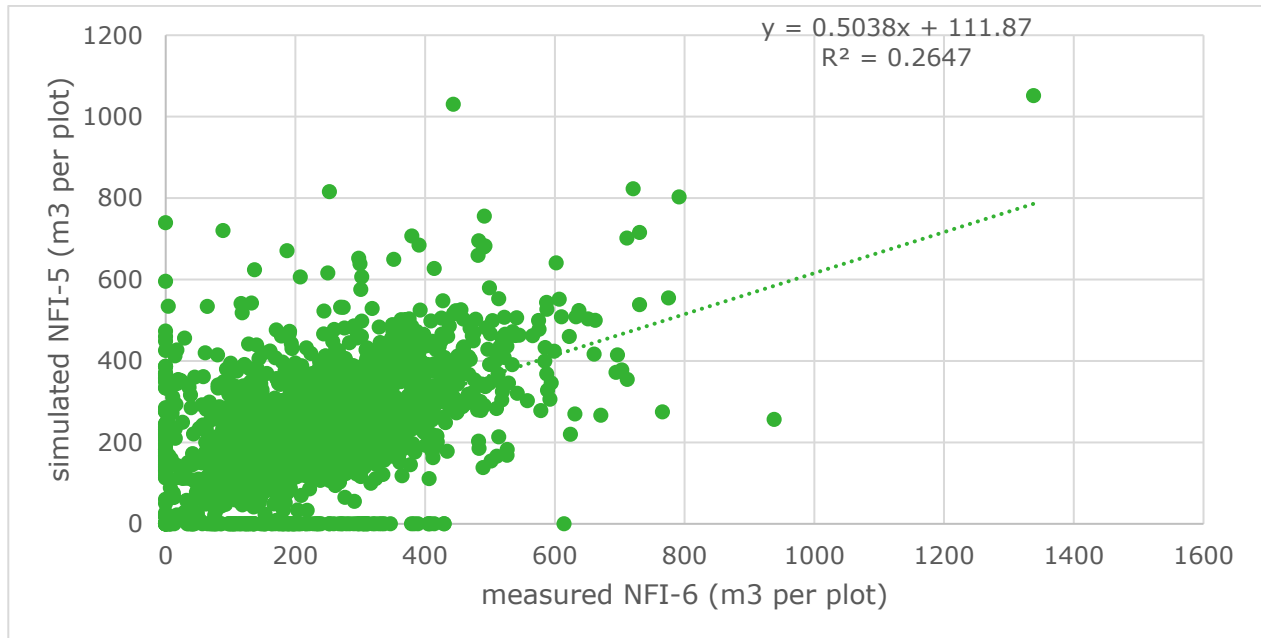
Figure 4.16 *Comparison of measured volume per plot in Dutch NFI-6 against simulated values per model stand for 2013, starting from NFI-5.*
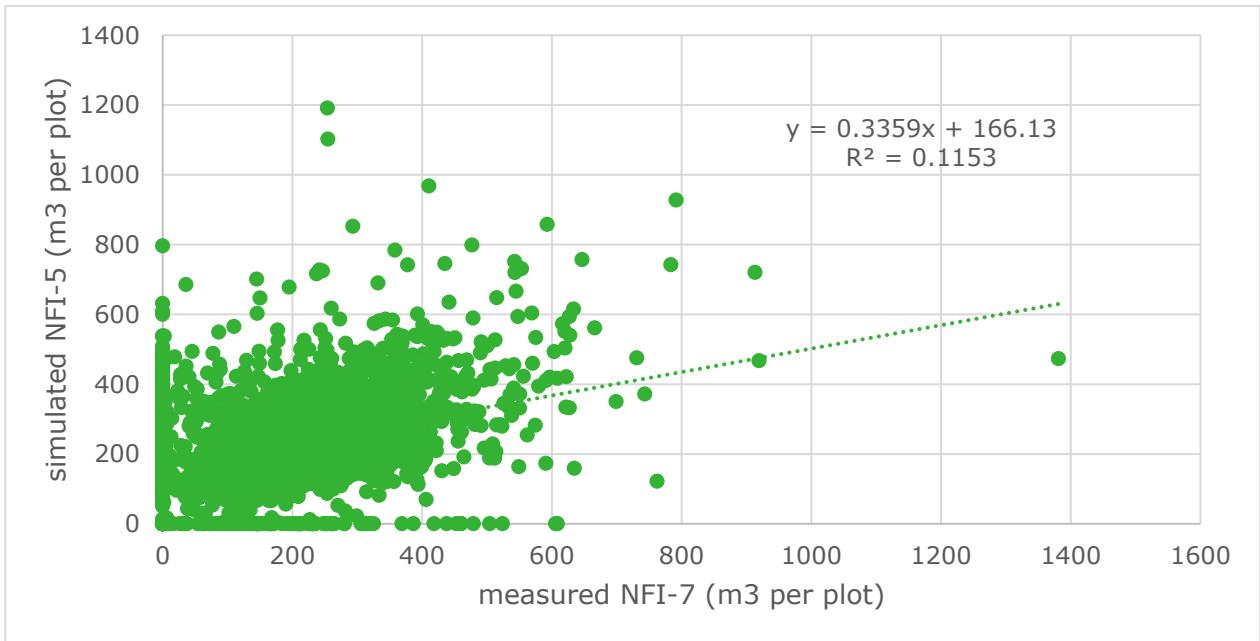
Figure 4.17 *Comparison of measured volume per plot in Dutch NFI-7 against simulated values per model stand for 2019, starting from NFI-5.*

Despite the differences for individual plots, the overall distribution of volume per ha still matched quite well between observed and simulated values, but the match again decreased over time (Figure 4.18, Figure 4.19). For both conifers and broadleaves the model tends to underestimate the volume of trees in the lower diameter classes (Figure 4.20), which is partly connected to the lack of ingrowth. The simulated volume in the diameter classes 40-60 match quite well, while the simulated values in classes over 60 cm tend to be slightly overestimated. The overall distribution of volume over species groups matches quite well with the observations, with some minor species showing somewhat larger deviations (Figure 4.21).
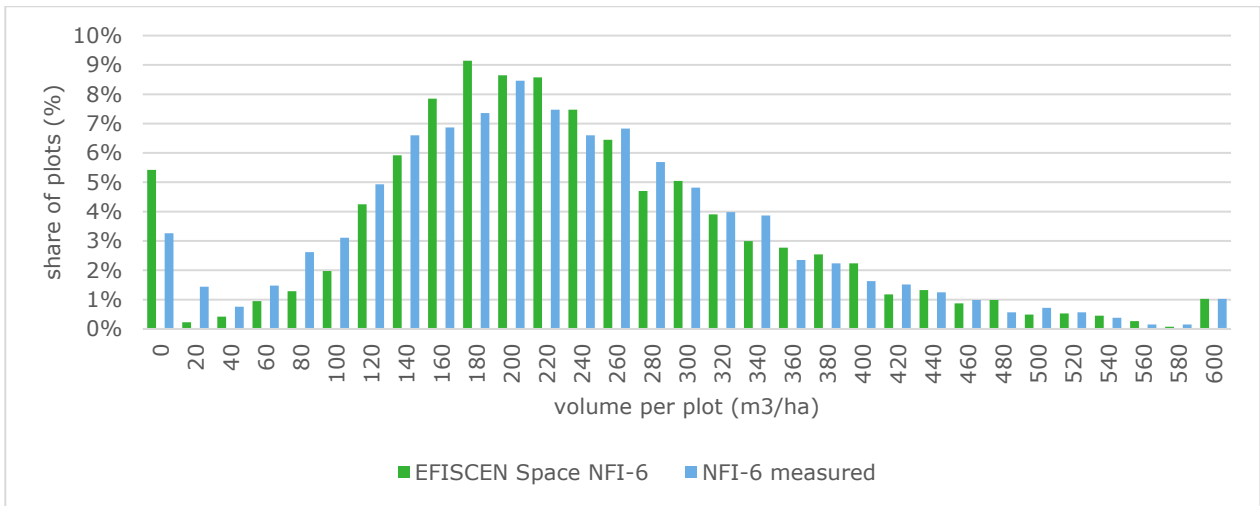
Figure 4.18 *Share of plots/model stands (%) per volume class as measured in NFI-6 and as simulated in 2013 starting from NFI-5.*
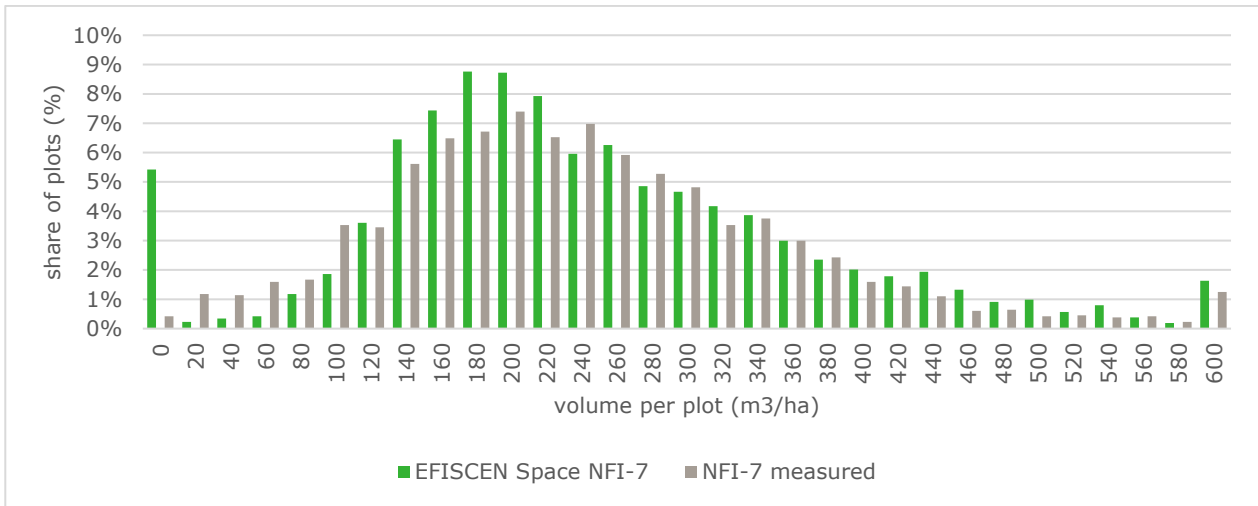
Figure 4.19 *Share of plots/model stands (%) per volume class as measured in NFI-7 and as simulated in 2019 starting from NFI-5.*
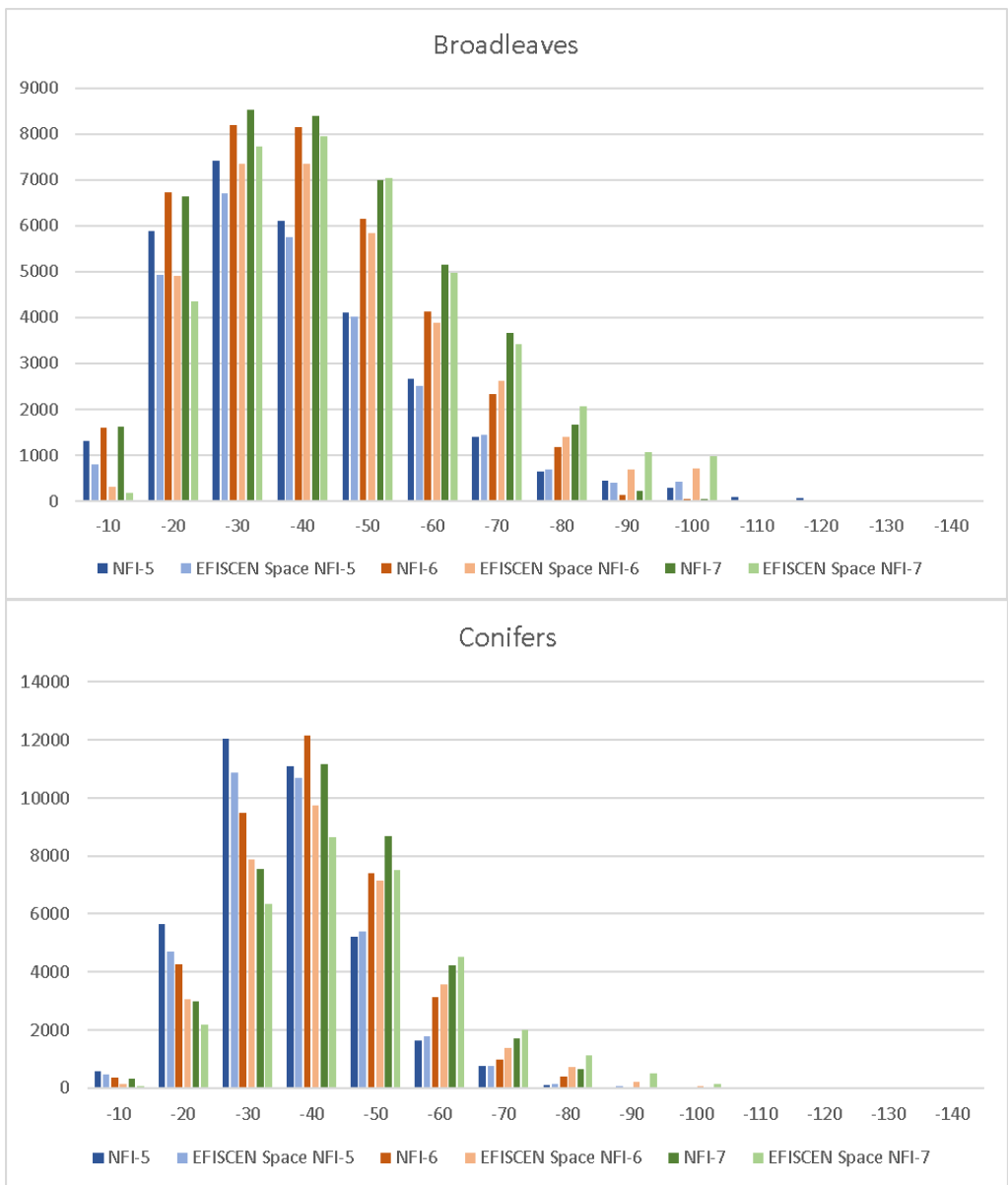
Figure 4.20 *Comparison of measured and simulated volume (1000 m3) for broadleaves and conifers per 10 cm diameter class. Simulations start from the Dutch NFI-5, using 2013 outputs for comparison with NFI-6 and 2019 outputs for comparison NFI-7.*
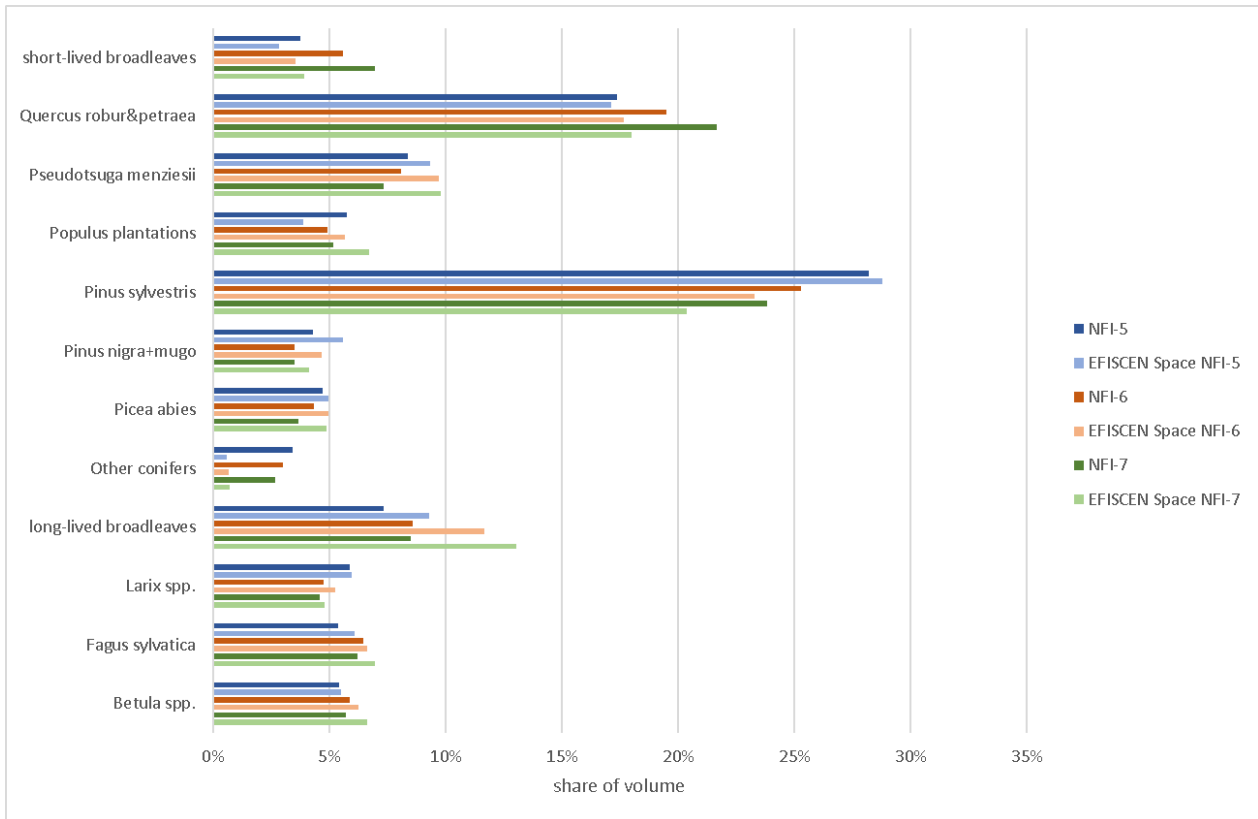
Figure 4.21 *Share of measured and simulated volume (%) per species. Simulations start from the Dutch NFI-5, using 2013 outputs for comparison with NFI-6 and 2019 outputs for comparison NFI-7.*

4.10 Verification of results for Norway

In this section we show in more detail how we apply the model to a specific country, and check and improve the simulation in cooperation with the country correspondent. As an example we take Norway, since we encountered some deviations for this country initially. The basis for the simulation is the NFI-11 as provided by NIBIO, measured in 2014-2018, containing 12,919 plots. Due to missing abiotic information, 355 plots had to be excluded from the simulation. Management and mortality patterns from Sweden were applied, as well as the volume models for Sweden. First we checked the initialisation of the growing stock. The simulated growing stock was on average 138 m^3 ha^{-1}, which is higher than the 101 m^3 ha^{-1} as reported by SOEF 2020. Still, the frequency distribution of the average growing stock per model stand (Figure 4.22) and the spatial pattern (Figure 4.23) were found to be realistic. Two potential causes were identified: 1) a generic overestimation by the volume models, and 2) the underlying sampling scheme was not taken into account in the calculation of the simulated average growing stock. After further inspection, it appeared that the Swedish volume models as used in this experiment were derived for the southern province of Småland only, which potentially gives higher volumes for trees with the same diameter than trees under more northern (boreal) conditions. A new volume data set was obtained from Sweden, covering the full range of conditions, and new volume models were derived and implemented also for Norway. Most important in this respect is the implementation of separate volume models for Norway spruce under northern and southern conditions. Furthermore we obtained the individual area weighting per plot as used in the NFI sampling scheme and included these in the simulation as the representative area per model stand. After these improvements, the simulated initial growing stock was 108 m^3 ha^{-1}, which is much closer to the reported value by SOEF 2020.
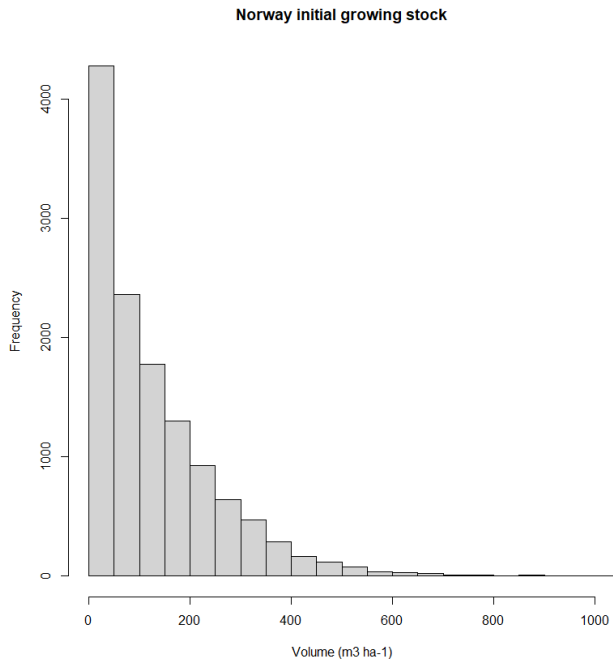
Figure 4.22 *Simulation results of the average volume per model stand (m³ ha⁻¹) after initialization, before the country-feedback process.*

Figure 4.23 *Map of simulation results of the growing stock (m³ ha⁻¹) after initialization, before the country-feedback process. The map resolution is 0.125 degrees (about 14x14 km).*

The simulated average gross increment was initially 8.1 m^3 ha^{-1} yr^{-1}, which is a large overestimation as compared to the 2.6 m^3 ha^{-1} yr^{-1} as reported in SOEF 2020. Most of the model stands were found to have a realistic value below 5 m^3 ha^{-1} yr^{-1}, but a sizable fraction of the model stands showed increments between 10 and 30 m^3 ha^{-1} yr^{-1} (Figure 4.24, left panel). From the map it is clear that the model stands where increment is overestimated are confined to two regions (Figure 4.25). Further feedback from the country correspondent indicated that the overestimation of increment seemed to be concentrated in the simulation of birch. A closer inspection of the abiotic data underlying the simulation showed that the aridity index (var39 or C-ARi) was exceptionally high in these regions. The aridity index in these regions should be zero according to the original maps, but were accidentally replaced by no-value in the preparation process. Further analysis showed that the no-value occurrences were later on actually replaced by the largest possible integer, given the number of digits reserved for this variable in the corresponding NetCDF file. Thus, in the predictor set used in the model, zeros in these regions are actually replaced by a value of 255 while the original range is 0-77. For the final simulation we replaced the values of 255 for var39 by zeros. The gross annual increment after the update was 4.0 m^3 ha^{-1} yr^{-1}, and the model stands with increments over 10 had almost disappeared (Figure 4.24, right panel).
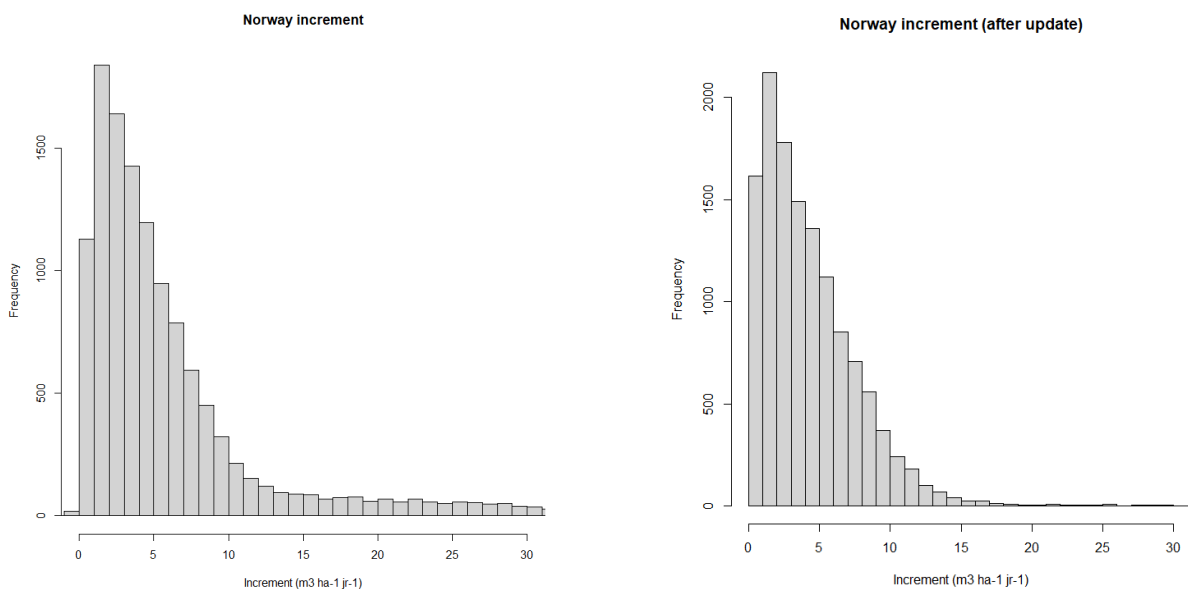
Figure 4.24 *Simulation results of the average gross increment per plot for the first 5 years of simulation (m^3 ha^{-1} yr^{-1}), before the country-feedback process (left) and after (right).*
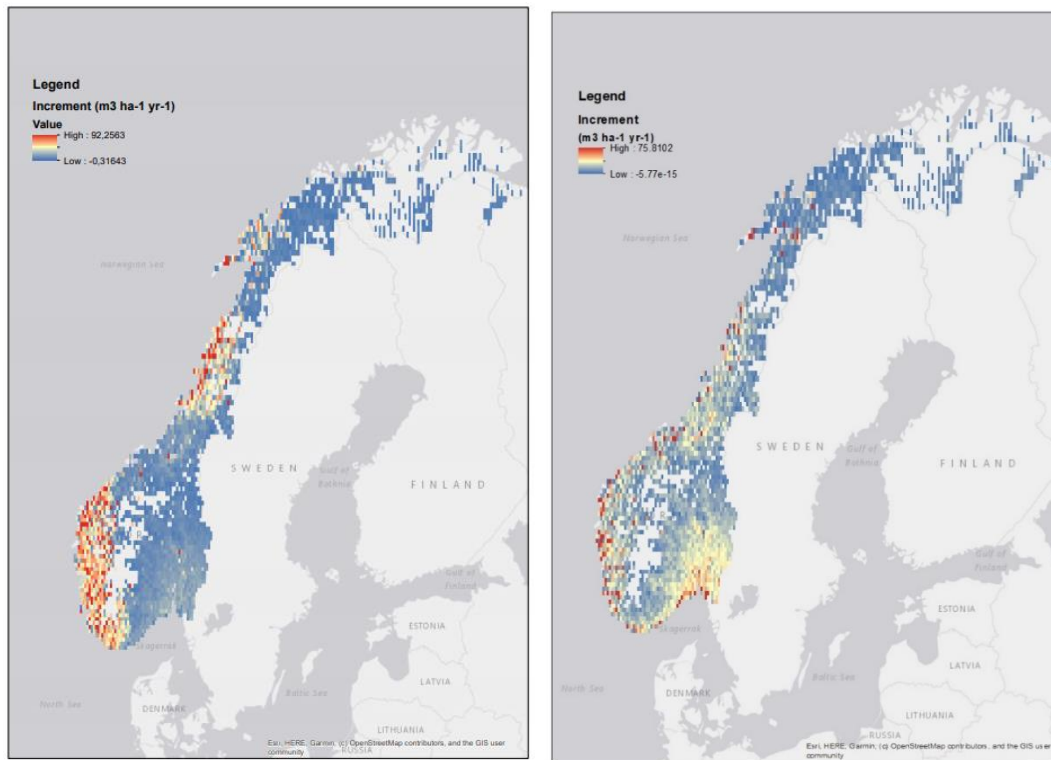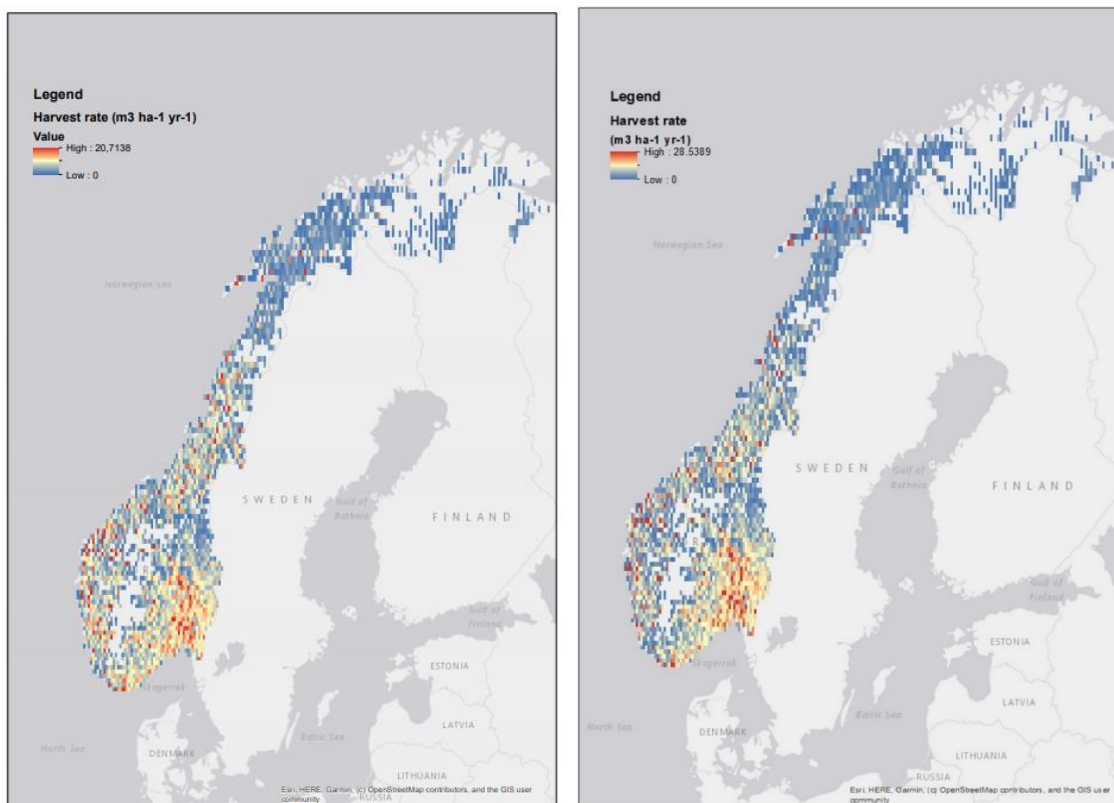
Figure 4.25 *Map of simulation results of the average gross increment for the first 5 years of simulation (m³ ha⁻¹ yr⁻¹) before (left) and after (right) the country-feedback process. The map resolution is 0.125 degrees (about 14x14 km).*

The simulated harvest was 3.3 m³ ha⁻¹ yr⁻¹, averaged over the first 5 years of simulation. Although the underlying patterns (Figure 4.26 and Figure 4.27) are plausible, this is clearly an overestimation as compared to the reported value of 1.26 m³ ha⁻¹ yr⁻¹ in SOEF 2020. This is likely influenced by the fact that the harvest patterns are derived from Southern Sweden, with a presumed higher management intensity than is applied in Norway. Furthermore, the simulated harvest was likely influenced by the same factors as mentioned in the simulation of volume, as well as by the overestimation in increment, although to a smaller extent. After updating the volume models and representative area per model stand, the average simulated harvest was 2.6 m³ ha⁻¹ yr⁻¹.
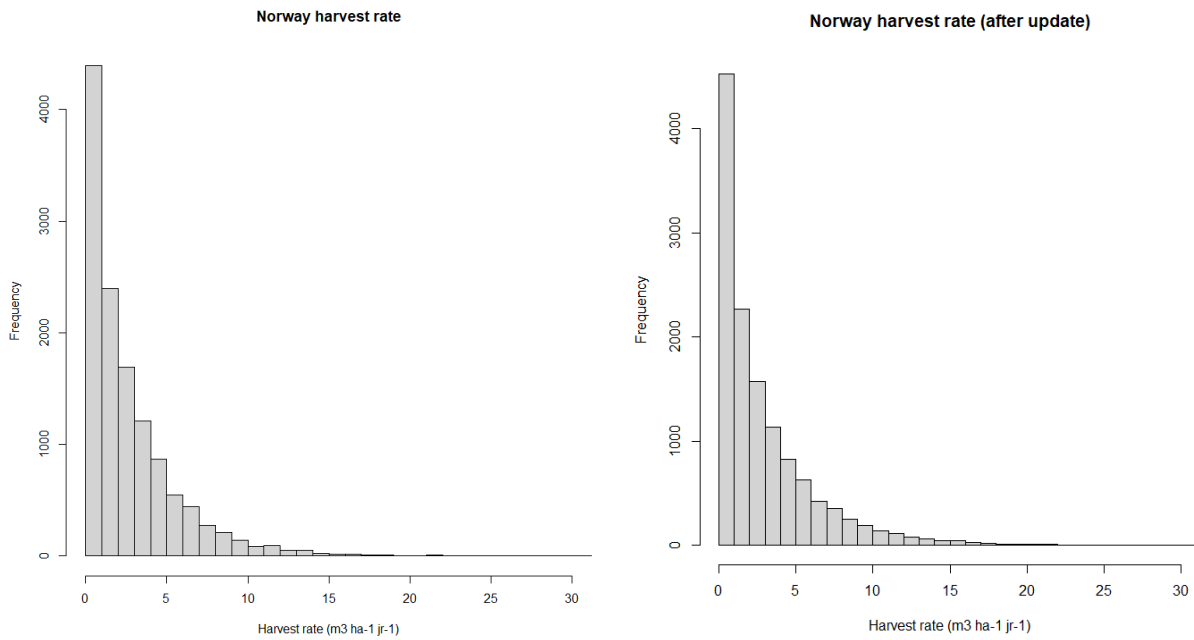
Figure 4.26 *Simulation results of the average harvest rate per plot for the first 5 years of simulation (m³ ha⁻¹ yr⁻¹) (total harvest in period/5 years) before (left) and after (right) the country-feedback process.*

Figure 4.27 *Map of simulation results of the average harvest rate for the first 5 years of simulation (m³ ha⁻¹ yr⁻¹) before (left) and after (right) the country-feedback process. The map resolution is 0.125 degrees (about 14x14 km).*

4.11 Application to Europe

This experiment provides a business as usual scenario for 15 European countries. The aim was to evaluate the large-scale performance of the model as compared to measured data and expected patterns. This experiment was part of the work in the Verify project to provide bottom-up carbon flux maps for Europe. For most countries we went through a feedback round with the national correspondent to improve the simulations, as described in Section 4.10. Metadata and country correspondents are included in Table 4.28.

Table 4.28 *Metadata of the datasets used to initialize in EFISCEN Space validation.*

Country	Dataset	Date	Number of plots	Source	Contact person
Ireland (South west)	NFI-2	2009-2012	855	Department of Agriculture, Food and the Marine	John Redmond
Norway	NFI-11	2014-2018	12832	NIBIO	Rasmus Astrup
Sweden	-	2015-2017	12052	SLU	Jonas Fridman
Poland	NFI-2	2010-2014	28398	Bureau for Forest Management and Geodesy, Poland	Andrzej Talarczyk
Germany	NFI-3	2012	54934	online	-
Netherlands	NFI-6	2012-2013	3170	online	-
Belgium - Flanders	NFI-2	2009-2016	2126	ANB	Leen Govaere
Luxembourg	NFI-2	2010	1614	Ministère de l'Environnement, du Climat et du Développement durable, Luxembourg	Thierry Palgen, George Kugener
France	NFI-5/6	2005-2012	55516	online (IGN 2018)	Antoine Colin
Spain	NFI-3	1996-2008	69689	online	-
Switzerland	NFI-3	2004-2006	5920	WSL	Esther Thürig
Italy	NFI-2	2005	7185	online	-
Czech Republic	CzechTerra-2	2014-2015	590	Institute of Forest Ecosystem Research (IFER)	Emil Cienciala
Slovak Republic	NFI-2	2015-2017	1443	National Forest Centre	Vladimír Šebeň
Romania	NFI-2	-	2892	Department of Forest Management Planning and Terrestrial Measurements, Universitatea Transilvania Brasov	Viorel Blujdea

Management and mortality patterns were taken from Schelhaas et al. (2018b), or derived from available country data (Table 4.29). For part of the countries we had no repeated NFI observations available for the estimation of management and mortality patterns, so we had to assign these from neighbouring countries. However, it is clear that countries differ in the way forests are managed, depending on their forest history, policy, soil and climate conditions, ownership etc. Nabuurs et al. (2019) produced a management intensity map that estimates management intensity based on a number of country-independent predictors like elevation, soil type, distance to cities, etc. in a Bayesian Belief Network (Figure 4.28). When we assume that harvesting patterns among countries are mainly different due to a different distribution over management classes, but harvesting patterns are similar in the same intensity classes within the same bioregion, we can use this to transport observed management patterns among countries. For Spain, Sweden and Germany all NFI plots were assigned a forest management intensity class according to the map, and management and mortality patterns were extracted for all combinations of species, countries and management intensity classes. We grouped the original six classes into three management intensity classes: low, (combining strict nature management, close-to-nature management and low-intensity management), medium (multifunctional management) and high (intensive and very intensive management). In addition, a set was derived for all observations together for application in case the management class was unknown for a model stand. For countries without nationally derived management and mortality patterns, the best (subjective) match from the available countries was taken (Table 4.29) and applied at the model stand level, depending on the intensity according to the intensity map. Volume models were applied as specified in Table 4.29, for biomass

the generic models from Forrester et al. (2017) were used, and for turnover parameters we used the defaults (Table 4.27).
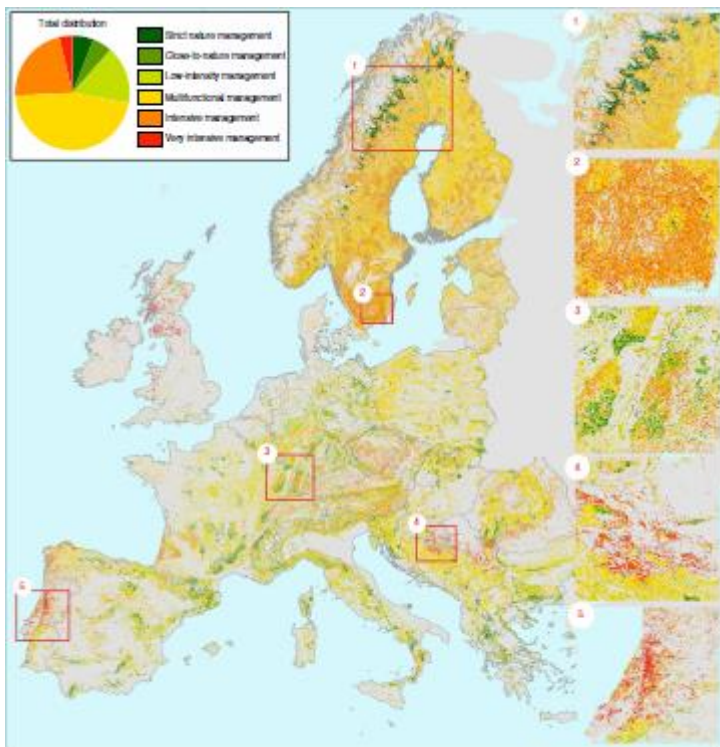

Figure 4.28 *Forest management intensity map (Nabuurs et al. 2019).*

Table 4.29 *Assumptions on management, mortality and volume models used per country.*

Country	Management & mortality dataset	Volume models
Norway	Sweden	Sweden
Sweden	Sweden (2008-2012/2013-2017)	Sweden
Netherlands	As published in Arets and Schelhaas (2019)	Netherlands
Ireland	As published in Schelhaas et al. 20181	Ireland
Belgium Flanders	Belgium Flanders (1997-1999/2009-2019)	Netherlands
Luxembourg	Germany	Germany
France	Germany	France
Germany	Germany (2000-2003/2011-2013)	Germany
Poland	Poland (2005-2010/2010-2014)	Germany
Czech Republic	Germany	Germany
Slovakia	Slovakia	Germany
Switzerland	As published in Schelhaas et al. 20181	Germany
Spain	Spain (1981-1999/1997-2008)	Spain
Italy	Spain	Spain

Simulated average growing stock and increment are very well in line with the values as reported in the State of Europe's Forests 2020 (Figure 4.29), while the simulated soil carbon stocks are in the right order of magnitude but show a considerable variation with a tendency to be overestimated. Simulated soil carbon stocks also seem high in relation to other published values. Batjes (2002) reports an average value of 158 ton C/ha for all land in Central and Eastern Europe (the region covering Poland, Czech Republic, Hungary, Bulgaria up to the Urals in the Russian Federation), while YASSO simulated values in the range of 183 ton C/ha (Slovakia) to 235 ton C/ha (Poland). However, values of Batjes exclude litter and deadwood. Grüneberg et al. (2019) reports a median of 105 ton C/ha and an average of 117 ton C/ha for forest soils in Germany, up to 90 cm depth and including the litter layer. This is much lower than the simulated value by

YASSO of 217 ton C/ha. They found a sink of 0.75 ton C ha^{-1} yr^{-1}, indicating the soils are not in equilibrium as YASSO assumes, which may be a reason for the overestimation of YASSO. Comparisons to other sources are however difficult, given that the simulated values are valid for mineral soils only, include deadwood and the full soil profile, while it can be expected that the methods and depths used in the reported values may vary per country, and include also organic soils. The latter is probably the explanation for the large deviation in Ireland, where in the south-west region 29% of forests are growing on peat and 14% on organo-mineral soils.
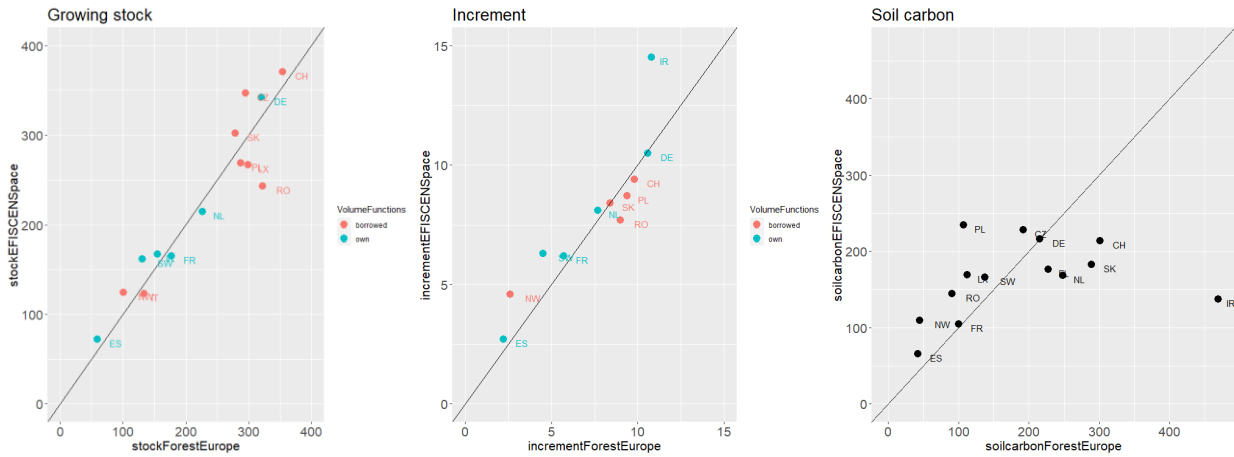
Figure 4.29 *Simulated values for growing stock, increment and soil carbon per country as compared to reported values in SOEF 2020. Blue dots show countries with volume functions derived on national data, red dots show countries where the volume function of a neighbouring country is applied. The black line is the 1:1 line.*

Patterns over Europe of growing stock (Figure 4.30), increment (Figure 4.31) and harvest (Figure 4.32**Figure 4.32**) are in line with expectations. The pattern for natural mortality shows clear differences between countries (Figure 4.33), partly in line with the differences found in Schelhaas et al. (2018b). These differences may be related to national policies regarding leaving deadwood in the forest, or to the occurrence of natural disturbances during the period of observation. For the spatial pattern of soil carbon stock (Figure 4.34) and NBP (Figure 4.35) we have no material available for comparison.
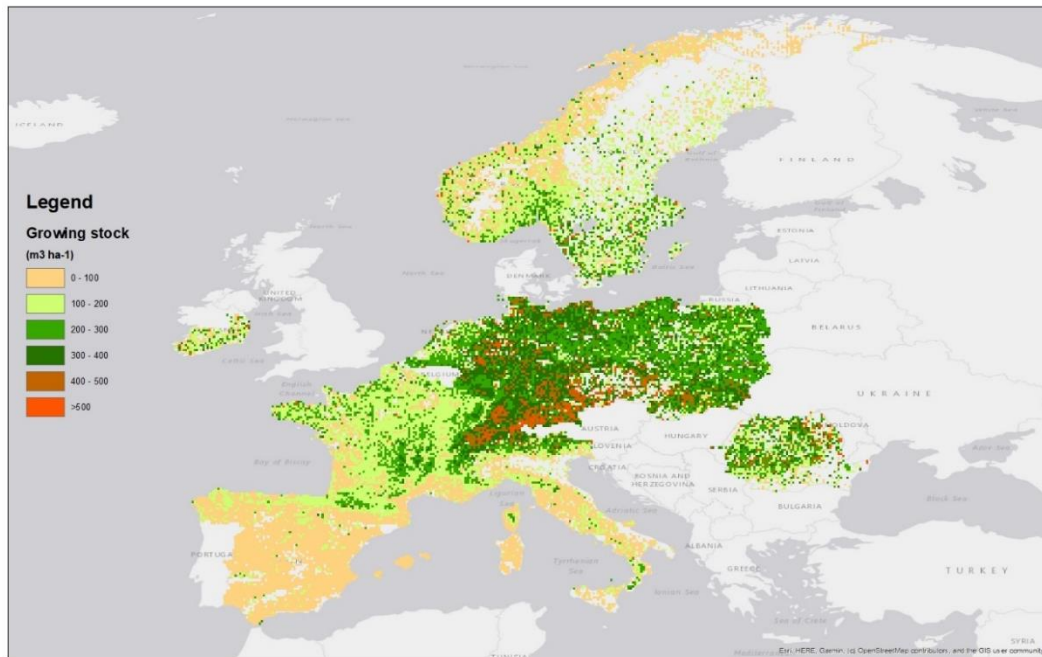
Figure 4.30 *Simulated initial growing stock pattern over Europe. The map resolution is 0.125 degrees (about 14x14 km).*
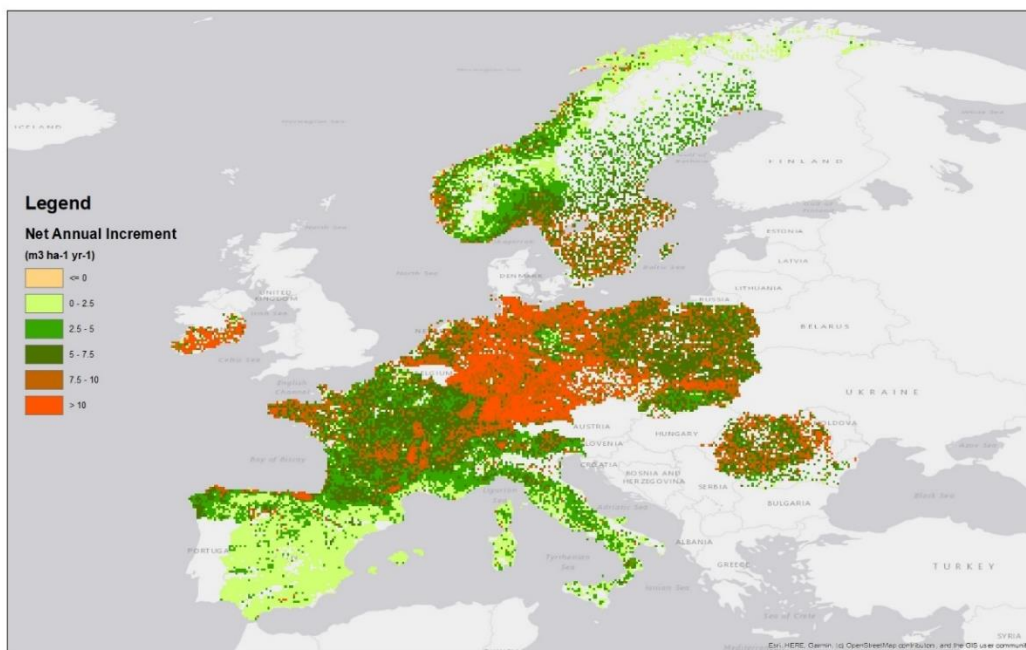
Figure 4.31 *Simulated increment pattern over Europe (average over the first 5 years of simulation). The map resolution is 0.125 degrees (about 14x14 km).*
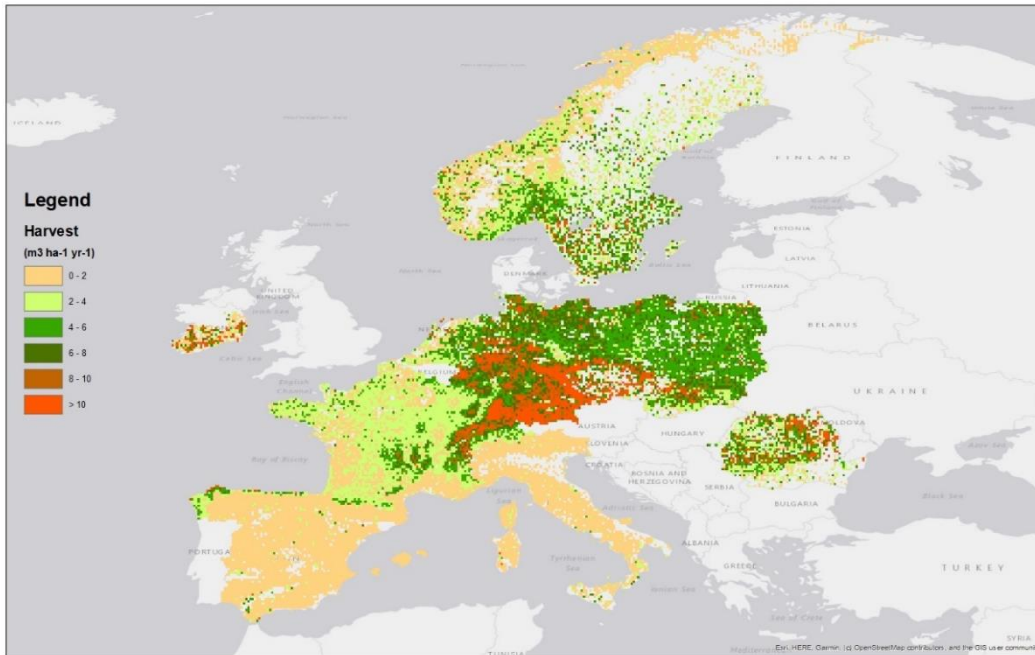
Figure 4.32 *Simulated harvest pattern over Europe (average over the first 5 years of simulation). The map resolution is 0.125 degrees (about 14x14 km).*
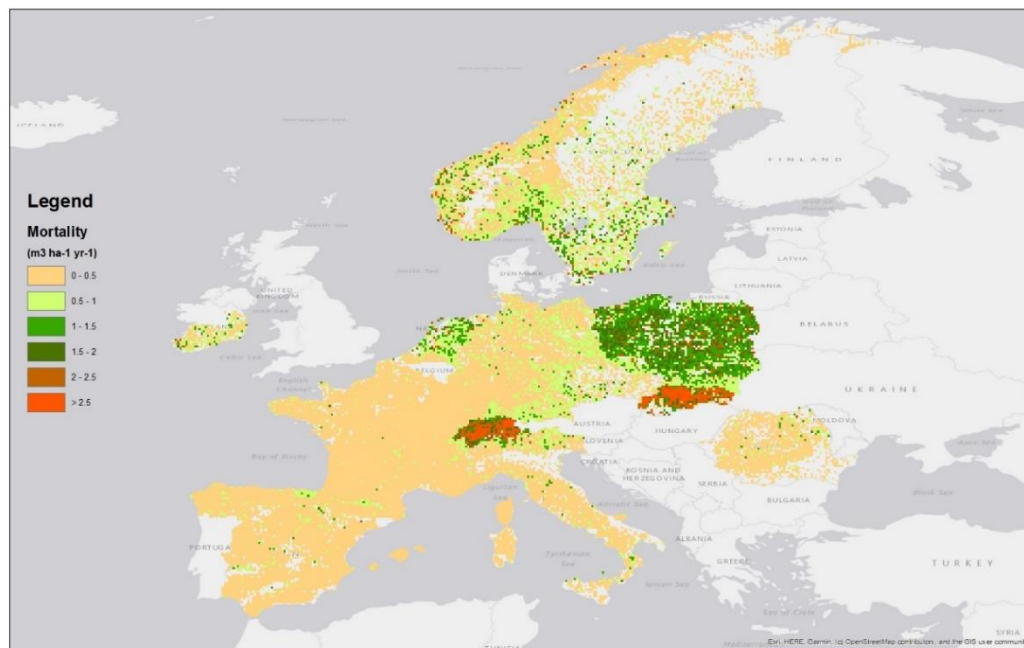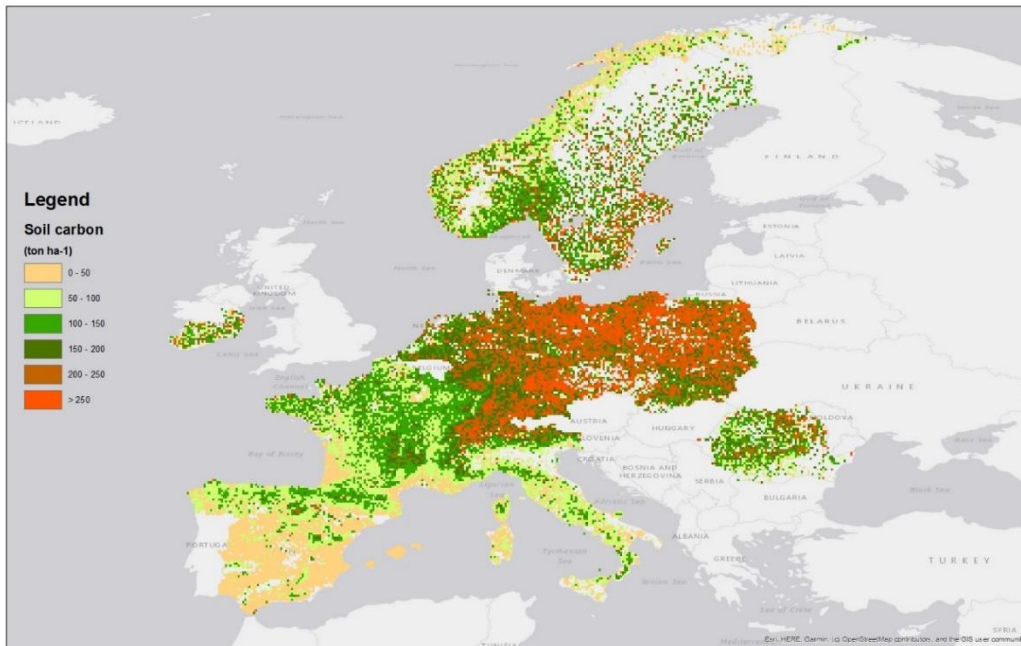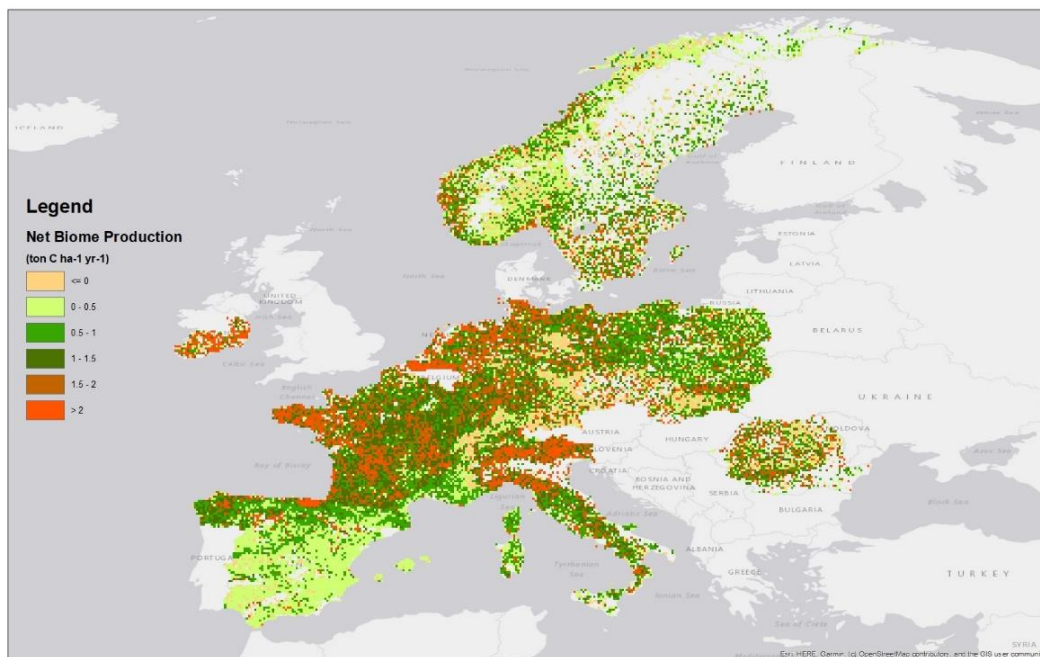

Figure 4.33 *Simulated natural mortality pattern over Europe (average over the first 5 years of simulation). The map resolution is 0.125 degrees (about 14x14 km).*

Figure 4.34 *Simulated initial soil carbon stock pattern over Europe. The map resolution is 0.125 degrees (about 14x14 km).*

Figure 4.35 *Simulated pattern of NBP over Europe (average over the first 5 years of simulation). The map resolution is 0.125 degrees (about 14x14 km).*

4.12 Comparison with remote sensing-based products

In the previous section we presented spatial patterns of some simulated output variables, as well as a comparison of simulated and reported variables at the national level. Although the spatial patterns look plausible, we lack a solid validation of the patterns at sub-national level. In this section we compare some of the components of the carbon cycle with remote sensing based products. First, we compare the simulated aboveground biomass stock for the initial year of simulation with the aboveground biomass map from the ESA-CCI (Santoro et al., 2021). The CCI map was masked to the forest area using the Hansen forest cover

product (Hansen et al. 2013), using a minimum threshold of 10% tree cover (at 30 m resolution) as definition of "forest". We only included output gridcells from the EFISCEN-Space simulations from the previous section that were based on at least 25 model stands. ESA-CCI and EFISCEN-Space agree quite well on the range of values, but the EAS-CCI map saturates at higher modelled biomass (Figure 4.36). When plotted on a map, clear patterns become visible (Figure 4.37). In regions with high stocks, such as Central Europe, EFISCEN-Space predicts higher values compared to the ESA-CCI, probably linked to the fact that the ESA-CCI product saturates at high biomass values. Spain and France show distinct patterns within the country, with lower values simulated by EFISCEN-Space in the wetter and more mountainous areas, and higher values in the drier regions as compared to ESA-CCI. These patterns seem to be related to site differences within these countries. Most of the aboveground biomass is located in the stems, and is thus dependent on the estimation procedure for the tree volume. Because we usually use one volume function per country, it will reflect the average conditions in a country, while it will overestimate the volume and biomass in poor sites and underestimate volume and biomass in rich sites.
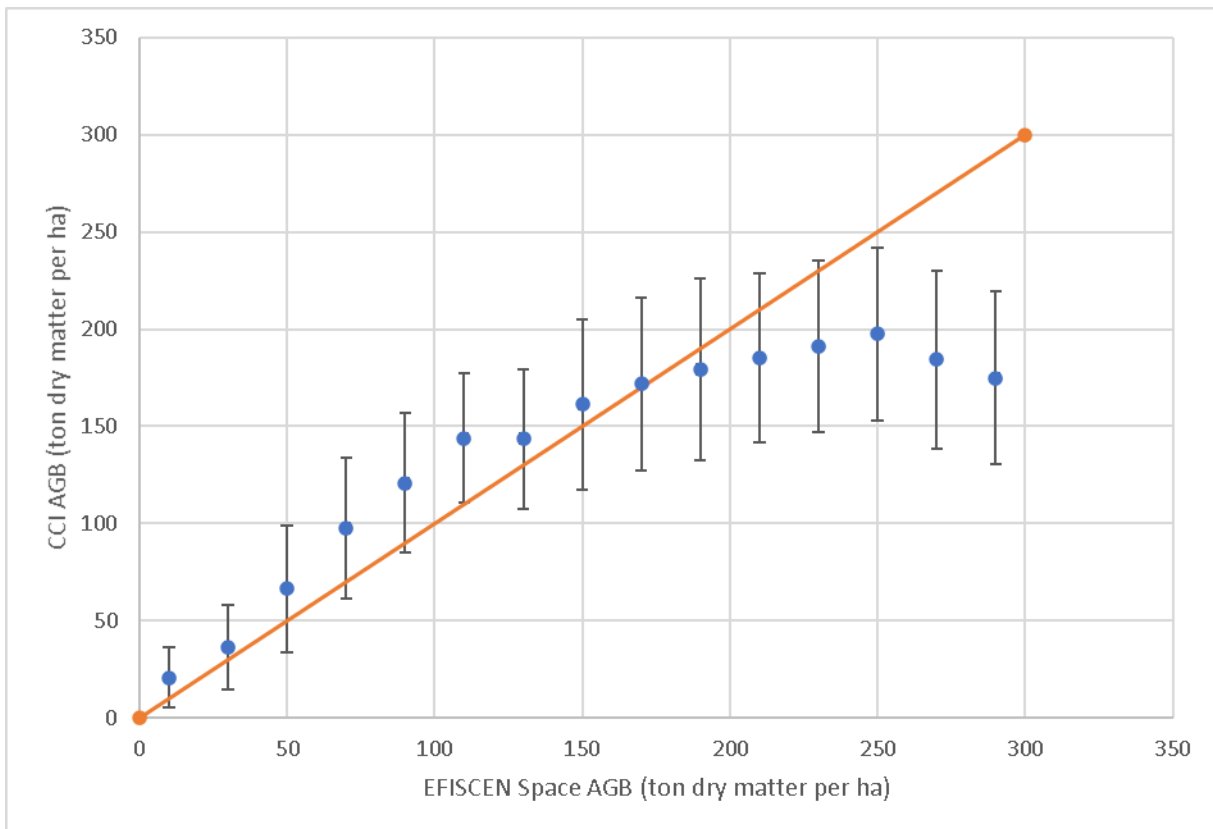

Figure 4.36 *Comparison of simulated values from EFISCEN-Space and remote-sensing based values (ESA-CCI map) for aboveground biomass, for gridcells with at least 25 EFISCEN-Space model stands. Error bars indicate one standard deviation.*
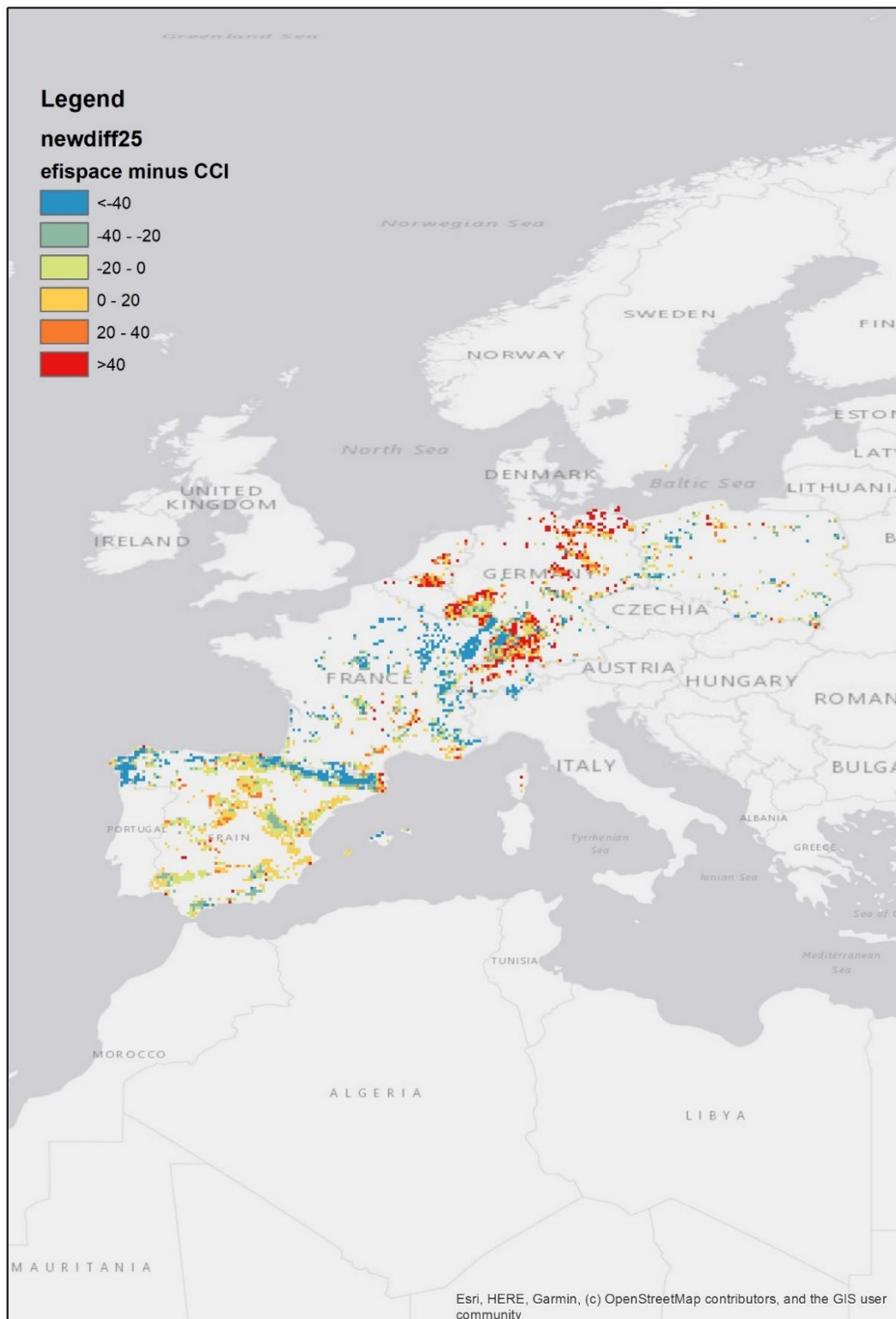
Figure 4.37 *Spatial pattern of comparison of simulated values from EFISCEN-Space and remote-sensing based values (ESA-CCI map) for aboveground biomass.*

Applying the Hansen et al. forest mask for the 2010 ESA-CCI map, we derived the AGB change for the period 2010-2018 that was compared with change values from EFISCEN-Space for the first 5 years of the simulation. The comparison did not show a good agreement between the two data sources of AGB change (Figure 4.38), which can be explained by multiple reasons driven by each data source. For instance, the initial EFISCEN-Space data do not refer exactly to the year 2010, but cover more or less the period 2000-2015, and cover a 5-year simulation from the initial data. This mostly overlaps the 2010-2018 period, but is not an exact match. EFSICEN-Space does not include clearcuts and will underestimate the biomass change in

plots subjected to this practice. On the other hand, the ESA-CCI map depicts many "small losses" (e.g. <2 Mg ha^{-1} yr^{-1}) which can be changes with very high uncertainty (Santoro and Cartus 2021). The CCI 2010 and CCI 2018 maps are also not 100% consistent in terms of the remote sensing data used, mainly on the pre-processing side of the main input as controlled by the data provider. We therefore conclude that the ESA-CCI map for aboveground biomass change based on remote sensing data is not reliable enough to compare with our simulated values.
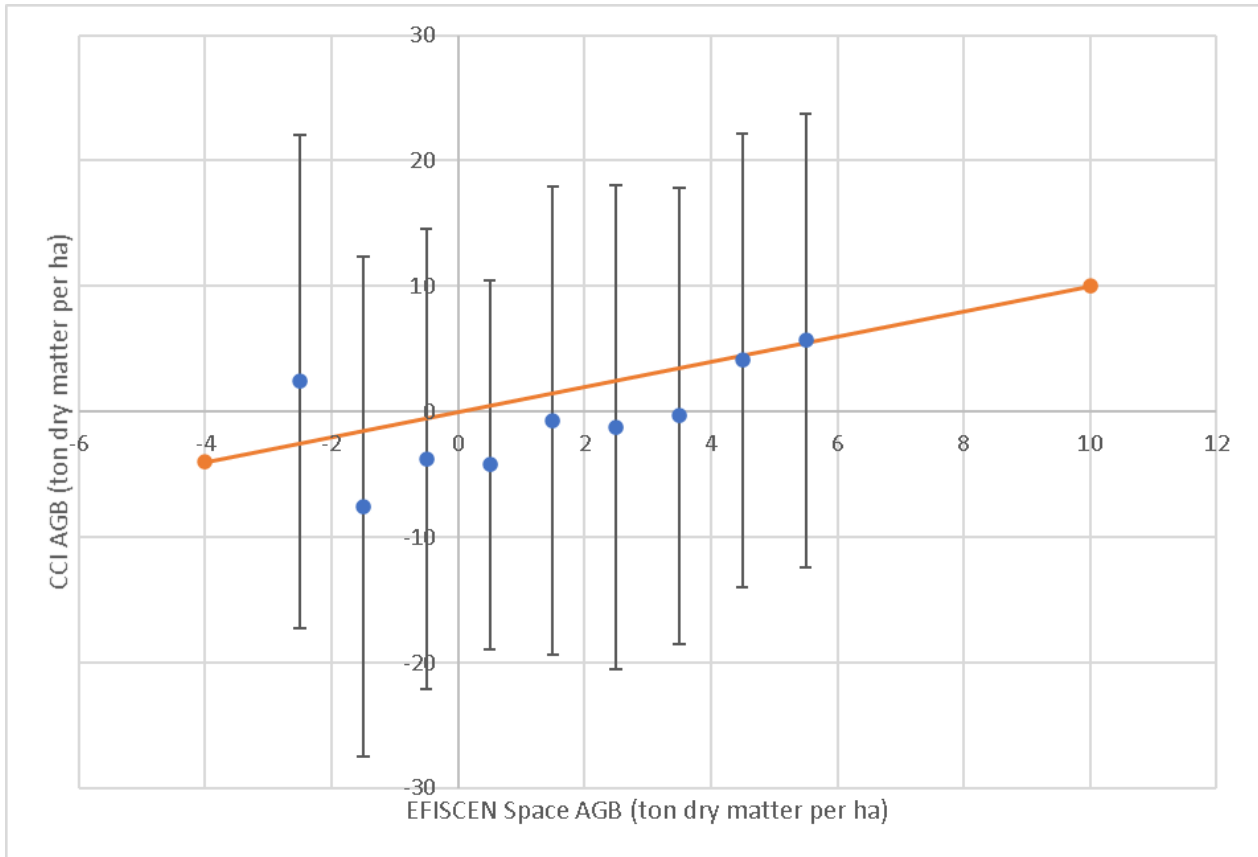
Figure 4.38 *Comparison of model-based and ESA-CCI-based change in AGB. Error bars indicate one standard deviation.*

4.13 Lessons learned

The aim of the experiments in the previous sections was to evaluate the EFISCEN-Space model, with emphasis to test if the code was implemented correctly, to evaluate how the model performs, to validate its outcomes, and to find out how sensitive the outputs are to various input parameters. We checked in detail the initialisation procedure for stem number, basal area, volume and biomass on a single plot (Section 4.2), and more generically (totals) at the country level (Section 4.4). Furthermore we checked the increment, mortality, harvest, and ingrowth processes at the single plot level by comparing the results with manual calculations (Sections 4.3). No deviations were found, and we thus conclude that these parts of the model have been coded correctly. Parts of the code that have not been scrutinised in detail are related to the calculation of litter input to the soil (from biomass turnover, harvest and mortality), the implementation of YASSO itself (via a dll), and the calculation of time consumption and costs of harvesting.

In EFISCEN-Space, the state of the forest is represented as the number of trees per 2.5 cm diameter class, distinguishing 20 tree species (groups). In the data preparation process we therefore loose the individual tree diameters, which causes small deviations in derived variables such as basal area, volume and biomass (Section 4.2 and 4.4). We found no indications that this simplification causes any bias or major problems in any of the experiments. The most important tree species in Europe are included as separate species in the

model, which allows the use of species-specific parameters. Less important species are grouped into classes like other conifers and long-lived or short-lived broadleaves. Due to this simplification, we can use only generic parameters, which may lead to large deviations compared to the use of species-specific parameters (see the case of *Prunus serotina* in Section 4.2). However, these species are expected to form at maximum 10% of the trees in any country, and the influence on the total simulation results should be modest. For greater accuracy we recommend to use country-specific parameters for volume, biomass and wood density that allow to insert differences in tree species composition within these groups between countries.

Model output in terms of volume of wood or timber proved to be very sensitive to the use of different volume models (Section 4.6). Differences in these models can be explained by the large variation in growing conditions in Europe, leading to differences in height-diameter ratios and stem taper. Even within a country such site differences are visible (Section 4.12). Furthermore, the definition of growing stock varies per country, causing deviations of up to 12.5% compared to reference definitions (Gschwantner et al. 2022). Thus we consider it good practice to calculate timber volume from the simulated diameter distributions with country specific volume models. However, simulated average growing stock at the country level proved to be quite accurate (Sections 4.4, 4.9, 4.10 and 4.11), even when the volume function from a neighbouring country had to be applied (Figure 4.29). A logical further step would be the development of site-specific volume models, which would allow easier application of the model to new regions, and would improve simulated patterns of growing stock, increment and harvest.

Harvest and natural mortality are currently implemented as fixed fractions per diameter/species group, as derived from repeated tree-wise NFI observations. This can be done either at the national scale, or by distinguishing groups with expected different harvesting patterns. The advantage of this approach is that it is expected to give a good match with reported harvests in a country, as these are usually derived from the same data source (Arets and Schelhaas 2019). However, this method fails to identify specific harvesting practices, such as regeneration fellings, since the same average harvest probability is applied, regardless of other circumstances (Section 4.9). Also, it is almost impossible with this approach to simulate new harvesting regimes that may be applied in future in response to challenges such as climate change. The challenge is therefore to develop a new harvest routine that is more flexible, taking into account current stand conditions and current and possibly future aims, without the need of extensive parameterisation all over Europe.

It is clear that there is a close relationship between harvest and natural mortality (Schelhaas et al. 2018b), which is retained in the current way of modelling harvest and natural mortality. However, it is unclear how we should interpret the simulated patterns of natural mortality (Section 4.11). The higher mortality in the Netherlands is hypothesised to be related to national subsidies that specify a minimum amount of deadwood in the forest, but the high simulated mortality in other countries (Switzerland, Slovak Republic) is difficult to explain. Sweden was hit by storm Gudrun in the period covering the repeated NFI sampling, which may influence the simulated natural mortality in both Sweden and Norway. A dynamic natural mortality model is needed to resolve these differences, similar to the current increment model. A dynamic model would also be needed for the simulation of more management options than currently available. However, a major challenge in this respect will be to disentangle the effects of natural mortality and harvesting.

The built-in YASSO15 model allows to simulate soil carbon stocks with EFISCEN-Space for mineral soils. YASSO15 receives its input from litterfall from living trees, slash generated by harvesting activities, and biomass input as a consequence of natural mortality. This allows for the generation of a simulated soil carbon map over Europe (Figure 4.34). A comparison at the plot level for the Netherlands and Italy shows that the average and distribution of simulated values align quite well with measured values (Section 4.5), but that the model is unable to predict values accurately at the plot level. The simulated values for other countries match reasonably well with observations but YASSO15 generally seems to show an overestimation (Section 4.11). YASSO is not suitable to simulate organic soils. This is a very encouraging first result, given the fact that we applied generic biomass models and default turnover parameters everywhere. The sensitivity of YASSO15 to more specific biomass models (Section 4.7) and turnover rates (Section 4.8) allows to fine-tune the simulations further to national conditions in future. More work is still needed on the initialisation of YASSO15, possibly along the lines of similar work in other countries (Ziche et al. 2019). However, it is clear that it will

be hardly possible to initialise YASSO15 in full agreement with measured values using a spin-up procedure based on current stand conditions only.

Overall we conclude that EFISCEN-Space gives an accurate simulation of the future development of forest resources in Europe at the national level, with a good spatial representation within the country. Differences between observed and simulated values at the plot level increase over time, but the overall distributions over species, diameter classes and volume classes remain satisfactory at least for simulations up to 20 years. More work is needed on the evaluation of the simulated soil carbon stocks.

For the most important species the forest structure and increment are well represented. For the marginal species that are grouped together, deviations are more noticeable. In translating the simulated distribution of tree diameters to volume of timber, biomass or soil carbon, the use of national or local expansion or conversion functions is recommended. For events within the forest development (e.g., mortality, ingrowth, management) the current methods rely on statistics averaged over many observations. These methods fail to grasp the extremes of the impact of these events and future versions of the model should incorporate more locally attuned or process-descriptive models to allow for a finer-grained agreement with observed forest development. Furthermore, some of the components of the model need to be considered experimental, given the lack of validation on these components (e.g., management time & costs and the possibility to use annual data from climate change scenarios as input).

5 Discussion

5.1 Development plan

With regard to the requirements to EFISCEN-Space as formulated in Section 1.3 we can conclude the following:

1. **Similar in use as EFISCEN:** EFISCEN-Space produces similar types of output as EFISCEN, like standing and harvested wood volumes and biomass and carbon quantities in different compartments. It has already been applied in similar studies as EFISCEN and we can thus conclude that this requirement is met. Currently the timeframe for realistic predictions is about 20 years. Further model development is still needed regarding ingrowth, natural mortality and management/harvesting for predictions as required at the scale of 50-100 years.
2. **Wide array of management systems:** Using a stand-level approach with distributions of stem numbers over diameter classes offers the possibility to introduce more sophisticated rules for harvesting, mimicking different management systems. The model is distance-independent, which limits the possibilities to some extent. Currently, such systems have not been built in yet. Another requirement for a realistic simulation of the effect of a range of management intensities is the introduction of dynamic natural mortality and ingrowth modules.
3. **Dynamic simulation of species mixtures:** EFISCEN-Space simulates a maximum of 20 species groups in one model stand, allowing differences in removal among species, and feedbacks on growth of the remaining species via the total basal area and relative diameter. The introduction of a dynamic natural mortality module is expected to further increase the dynamic interaction between species.
4. **Higher spatial resolution for integration with GIS data:** Most environmental predictors are available at a resolution of 1 km, but the real resolution of the simulation is dictated by the sampling density of the underlying inventory. Especially the studies on wood mobilisation potential proved the value of the integration with GIS information.
5. **Timber assortments**: the simulation approach using number of trees per diameter class allows full identification of assortments at time of harvest
6. **Empirically-based:** All modules are based on the analysis of extensive datasets, mostly derived from re-sampled NFI data.
7. **Climate-change data as direct input:** So far, simulations were done with weather data averaged over a certain period. EFISCEN-Space does allow inputs to vary per year, allowing a direct coupling to scenario outputs of climate models. However, this functionality has not been tested yet, and no real scenario input has been coupled. Some basic questions still have to be solved, such as how to deal with the difference in weather/climate for current conditions as compared to the current inputs, and if and how the current climate parameters should be updated over time when climate change progresses.

We conclude that many objectives are met, and there is good potential to meet all the objectives the way the model is designed. To meet all objectives, work is especially needed on the management/harvest module, the ingrowth module and the natural mortality module.

During the evaluation and application phase, several potential improvements and extensions have been identified. The following improvements are ongoing and foreseen to be finished at short term (1-2 years):
- Development of a dynamic mortality module.
- Development of a dynamic ingrowth module.
- Development of rule-based harvest routines to allow a wider variety of management options, adaptive to stand conditions and changes in management goals.
- Improved evaluation of the simulated soil carbon stocks, including the option to initialise YASSO15 with fixed quantities.
- Adding a harvested wood products module to track the carbon stored in wood products.

- Linkage of harvesting in EFISCEN-Space to locations and capacities of forest industries to allow harvesting to be more demand-driven.
- Exploring possibilities to initialise the model using remote sensing data, or a combination of remote sensing and NFI data.
- Development of a set of biodiversity indicators.

At medium term (3-4 years) the following developments are planned:
- Development of a disturbance module.
- Linkage of EFISCEN-Space to a forest products trade model.

The following improvements have been identified but are not prioritised:
- Development of volume models that are site-specific rather than averages per country. This may include the estimation of height as an intermediate step.
- Functionality to simulate coppice.
- A separate module following the quantity and probably quality (i.e. decay stage) of deadwood.
- Development of additional indicators, for example water use/groundwater recharge and recreation.
- Further evaluation of the model, including among others a sensitivity analysis, an uncertainty analysis and further plausibility checks.
- Improved visualisation tools for easier inspection of outputs, like standardised graphs and maps with variable grid cells depending on the density of inventory plots.

5.2 Final notes on the use of EFISCEN-Space

Commonly, EFISCEN-Space will be initialised using forest inventory data. The outputs of the model should thus be regarded as projections of the state of the underlying inventory plots in the future, and the results should be interpreted in the same way results of forest inventories are interpreted. This means it is not meaningful to focus on outputs of single plots/model stands, but only on averages over groups of plots of sufficient size, as being representative for the area under study. Despite ongoing harmonisation efforts, the user should keep in mind that NFIs from different countries differ in terms of design, definitions and thresholds. These differences are also present in the outputs of EFISCEN-Space, and influence comparisons of patterns over Europe and among countries.

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