



StandsSIM-MD: a Management Driven forest SIMulator

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Abstract

Aim of the study: The existing stand level forest simulators available in Portugal were not developed with the aim of including up-to-date model versions and were limited in terms of accounting for forest management. The simulators' platform, SIMfLOR was recently created to implement different growth models with a common philosophy. The objective was developing one easily-updatable, user-friendly, forest management and climate change sensitive simulator capable of projecting growth for the main tree species in Portugal.

Area of the study: Portugal.

Material and methods: The new simulator was programmed in a modular form consisting of several modules. The growth module integrates different forest growth and yield models (empirical and process-based) for the main wood production tree species in Portugal (eucalypt, stone pine and maritime pine), the management module drives the growth projections along the planning horizon according to a range of forest management approaches and climate (at present only available for eucalypt).

Main results: The main result is the StandsSIM-MD Management Driven simulator that overcomes the limitations of the existing stand level simulators. It is a step forward when compared to the models currently available in the SIMfLOR platform covering more tree species, stand structures and stand compositions. It is focused on end-users and it is based on similar concepts regarding the creation of required inputs and generated outputs.

Research highlights:

- Forest Management Driven simulations approach
- Multiple Prescriptions-Per-Stand functionality
- StandsSIM-MD can be used to support landowners decisions on stand Forest management
- StandsSIM-MD simulations at regional level can be combined with optimization routines

Keywords: Forest simulator; Forest Management Approaches; StandsSIM-MD; forest management.

Abbreviations: FMA - Forest Management Approaches; CAOF - Forest Operations Accompanying Commission; EC - European Commission; CELPA - Pulp and Paper Industries Association; SO - Silvicultural Operations; PPS - Prescription Per Stand; LUE - Light Use Efficiency; NPV - Net Present Value; LP - Linear Programming.

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Introduction

The Mediterranean region, characterized by hot and dry summers combined with complex landscape patterns, is vulnerable to climate and Land Use Changes. Therefore, threats like forest fires and overexploitation can lead to deforestation and forest degradation jeopardizing wood provision and carbon sequestration among other forest functions. After the recent discus-

sions on climate change and renewable energy sources', targets were set too high putting a strong emphasis on forest biomass (Muys *et al.*, 2013). Unlike in most Central European countries where felling levels can be considerably increased (EC, 2008), Portugal is already close to the maximum sustainable harvest level. According to the Pulp and Paper Industries Association (CELPA) wood and pulp imports have reached 29% in 2014 (CELPA, 2014). Furthermore, because wood

demand is expected to increase in the future, specifically for energy generation, questions of sustainability, competitiveness of the forest-based industries, organisation and motivation of forest owners represent the major challenges for wood mobilisation (EC, 2008). As the competition for wood increases, forest managers will have to satisfy the different wood demands under risk scenarios without compromising the other vital roles of forests or damaging the existing forest-based industries, finding at the same time sustainable forest management solutions for emerging conflicts.

Long-term analysis expressing the consequences of different courses of action in forestry may help answering these questions, forming national forest policies and taking strategic decisions regarding forest management. Across Europe, projection tools developed for strategic analyses have been used for decades. Since the first yield tables developed in the 19th century, forest models have become more complex. Nowadays the implementation of forest models in computer programs (here designated by forest simulators) is a requirement so that these models can be operationally used. Several forest simulators have been developed across Europe (e.g. RegWise in Sweden (Wikström *et al.*, 2011)), but these tools are characterized by their local application integrating specific growth models only applicable to the regions/ecosystems for which they were developed. Until recently Portuguese forest simulators were outdated and limited regarding the impact of forest management and climate. A first step towards making updated and more flexible eucalypt and cork oak simulators available was made with the creation of the SIMfLOR platform (Faias *et al.*, 2012). A more robust tool, StandsSIM-MD Management Driven simulator, was developed with the aim of covering the main Portuguese timber production species. Its current version covers eucalypt (*Eucalyptus globulus*), maritime pine (*Pinus pinaster*) and stone pine (*Pinus pinea*), but the inclusion of other species as well as of mixed-species stands is on-going. The potential users of the tool are forest owners, forest owners' associations, administration (e.g. Forest Services), policy makers and academia (lecturers/students and researchers). StandsSIM-MD's will be freely available at SIMfLOR platform. StandsSIM-MD has a modular structure linking five main Modules briefly described in the following sections. For more details on the growth models' equations, simulation mechanism encompassing simulation parameters and input data, see Rua *et al.* (2015).

Concept and structure StandsSIM-MD

StandsSIM-MD is a Management Driven forest SIMulator able to process any number of Stands. The

Input Module uses forest inventory to characterize the initial forest condition. The set of inputs depends on the type of growth model (stand, individual-tree or LUE-process-based) to be used but stand structure and stand composition are always required. The *Configuration Module* is responsible for the definition of all simulation parameters. The *Growth Module* comprises empirical individual-tree and stand growth models and a stand process-based growth model to update growth using the selected model for a given tree species according to a set of forest management prescriptions implemented by the *Management Module*. StandsSIM-MD can run under 1-PPS mode applying a specific Prescription Per Stand, which implies assigning an FMA to each stand in the input file; or under MULTI-PPS mode applying a set of defined prescriptions to each stand. The *Output Module* produces one yield table per stand and per prescription in a comma-separated file with a wide list of stand variables characterizing each stand over time under the defined prescriptions. When running under the MULTI-PPS mode it is possible to produce an additional/alternative output file structured to serve as input to a Linear Programming (LP) optimizer (Garcia-Gonzalo *et al.*, 2013), however this document only focuses on the description of the forest simulator. Tree species are simulated separately and the present version does not apply to mixed-species stands. Mixed stands can be simulated as pure stands with an area corresponding to the proportion of the basal area of the species in the stand. A new version including the simulation of mixed-species stands is under test.

Configuration Module

The control parameters shape the execution of a simulation by setting some configurations: the input and output files' hard disk locations, the tree species to be processed, the type of model to be applied (stand-level, individual-tree or LUE-process-based), the simulation mode (1-PPS or MULTI-PPS) and the number of years to simulate. The type of output files produced (yield table and/or LP) can also be defined.

Inputs Module

The input module is responsible for reading the input files and making some base calculus. Stands are characterized in terms of area, density, composition and structure (also age for even-aged stands). Dominant height, stand basal area and stand volume also have to be provided for stand level model types, whereas for

individual-tree level type models an additional input file with tree level data (e.g. species, height, breast-level height diameter, dominant code, status code) is required. The LUE-process-based model (3PG/Glob3PG) requires additional site characterizing variables (e.g. latitude, altitude, soil class, fertility rating, available soil water) as well as a climate input file (e.g. solar radiation, mean temperature, precipitation, frost days, vapour pressure deficit). Beside the inventory data, StandsSIM-MD needs the assortments defined by species and silvicultural operations' costs. More details regarding input files can be found in Faias *et al.* (2012).

Management Module

Along the simulation period stand growth is projected according to prescriptions which schedule a sequence of Forest Management Approaches (FMA). Each FMA represents the period of time corresponding to one rotation (even-aged stands) or cycle (uneven-aged stands) and defines which Silvicultural Operations (SO) will be executed, when and how often they will take place. Prescriptions define the thinning period and its periodicity. Additionally, each thinning is defined by type (high, low, selective or mechanic), criteria (Wilson factor, residual basal area, percent basal area or percent forest cover) and degree/weight (the % or weight). Along the simulation period, whenever a stand is felled, clear-felling followed by planting is assumed to take place. Plantations are carried out according to the stand density specified in the prescription (re-forestation). Afforestation can also be considered using specific prescriptions that generate a new stand (new stand-id) and define when and how many trees are planted (planting density). The SO's are user-selected out of an official list of operations, updated every 2-years, for which economic data are available (e.g. labour costs, seedling/seed and fertilizers prices, etc). The cost of each operation is used for estimating production costs and Net Present Value (NPV).

Growth and Prediction Modules

Several growth models have been implemented in StandsSIM-MD (Table 1). In the configuration module the user selects the model type (stand-level, individual-tree or LUE-process-based), which combined with information on the species and stand structure implicitly sets the growth model to be applied. For the current version of StandsSIM-MD simulation runs using the 3PG/Glob3PG model are only possible for eucalypt.

StandsSIM-MD runs on 1-year time-steps, structuring the data to be used in nested processing loops (Figure 1). The top-level loop reads the stands from the input file processing them one by one according to the indented loops. The prescriptions loop follows next either applying one or several prescriptions per stand depending on the selected mode, 1-PPS or MULTI-PPS, respectively. It is compulsory for the simulator to run properly, that prescriptions cover the whole simulation period.

As a prescription encompasses several FMA's, each corresponding to a stand rotation cycle, the third loop processes the FMA's which are applied sequentially as defined within the prescription. The lowest processing loop applies the set of SO's defined by the FMA's respect-

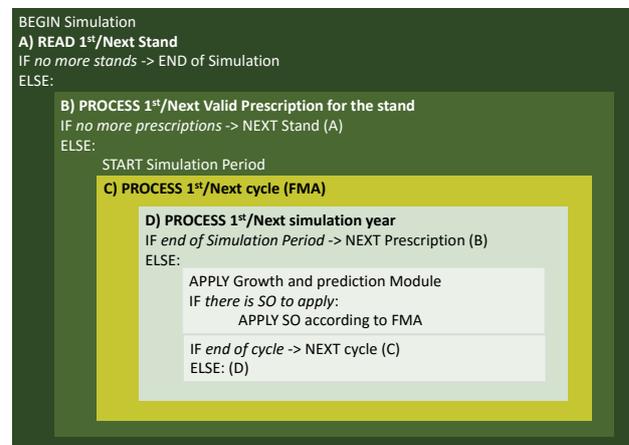


Figure 1. StandsSIM-MD functional overview algorithm.

Table 1. Growth and yield models integrated into StandsSIM-MD's *Growth and Prediction Module*

Type	Species	Stand structure	Growth and yield model		
			Name	Mixed species	Time-step
Stand-level process-based (hybrid)	Eucalypt	Even- and Uneven-aged	3PG/ Glob3PG	no	month
Stand-level empirical		Even-aged	Globulus3.0	no	1-year
Stand-level empirical		Uneven-aged	GYMMA	no	1-year
Individual-tree empirical		Even- and Uneven-aged	EucGOES	yes	1-year
Individual-tree empirical	Maritime pine	Even-aged	PINASTER	no	1-year
Individual-tree empirical		Uneven-aged	PBIRROL	no	1-year
Individual-tree empirical	Stone pine	Even-aged	PINEA	yes	1-year

For more detailed information on the models see Rua *et al.* (2015)



Figure 2. Example of the stand and prescription/FMA input files and of some output graphics built with the yield table output.

ing the stand age (or year of the cycle in uneven-aged stands) for which it was assigned. When the last year of simulation of the planning horizon is reached, StandsSIM-MD moves to the next stand. The execution is finished when the last prescription of the last stand is terminated.

Output Module

Under the 1-PPS mode StandsSIM-MD's produces a single output file, the "yield-table output", including a wide range of environmental indicators per year (e.g. total standing volume and volume by assortments, harvested and thinned volumes by assortments, carbon

stock, carbon sequestered and biomass by tree component). Figure 2 shows a prescription describing the management of a maritime pine stand harvested at age 50 and converted to eucalypt. In the example, StandsSIM-MD was run under the 1-PPS mode for a planning horizon of 60 years and the evolution of standing volume and biomass by tree components is shown.

Some economic indicators are also calculated (e.g. production costs, net present value). When running under the MULTI-PPS mode the user can choose to only produce the "LP output" containing the fields required as input by an optimizer or the "yield-table output" as well. When running using the process-based model a suit of monthly time-step 3PG/Glob3PG-

specific outputs can also be produced. All outputs are comma-separated format files that can easily be opened in Excel allowing the user to build graphics or dynamic tables to carry out the desired analysis.

Further improvements

StandsSIM-MD can be applied at stand-level or at regional-level depending on the area characterized by the stands in the input. If the National Forest Inventory plots are used the whole country can be simulated according to more or less general prescriptions. Different management alternatives can therefore be adapted to particular forest situations or to more general and comprehensive circumstances.

StandsSIM-MD is currently being improved to allow the simulation of mixed stands. This will imply the use of individual-tree models for eucalypt and some structural changes to allow species conversion to be carried out by transition prescriptions. Such improvement will allow more than one species to be simulated at the same time. Another desired improvement lies in making StandsSIM-MD spatial-explicit so that the establishment of new plantations can be more realistic. The inclusion of growth models for other tree species, such as oaks (namely cork oak) and chestnut, would broaden the application of the tool to other regions of Portugal.

Finally, the development of a graphical interface to assist users to create inputs and set up the simulation configuration in a user-friendly environment is also under-going. The new version is expected to be available in a near future.

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