Chapter 22
Portugal

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22.1 Introduction

22.1.1 Descriptive Statistics

Portuguese forest area has been increasing since 1874. The main tree species used to be cork and holm oaks (*Quercus suber* and *Quercus rotundifolia*), but it was the expansion of maritime pine (*Pinus pinaster*) that most contributed to increasing forest area. A century later, over 2.2 milllion hectares had been afforested leading to a total forest area of 2838 million hectares (DGF 1975). Maritime pine represented 48% of the forest area followed by evergreen oaks (41%) and *Eucalyptus globulus* (6%). Over time, eucalyptus plantations gained ground over maritime pine. In 2010 a backward-looking study on land uses and forest species occupation between the years of 1995 and 2010 (Fig. 22.1) documented this change. The decrease in maritime pine forest area has been accentuated after the pine wood nematode (*Bursaphelenchus xylophilus*) became established in Portugal. The application of stringent measures consisting of harvest and destruction of woody material from trees affected or showing any symptoms of decline has led to a reduction of 263 thousand hectares of maritime pine forest. Conversely, the area of Eucalyptus increased at the expense of 70 thousand hectares of harvested pine forests, 12 thousand hectares of abandoned agricultural land and 13.5 thousand hectares of shrublands and pastures (ICNF 2013).

According to preliminary results of the sixth National Forest Inventory (NFI6), Portuguese forests cover around 3.155 million hectares making up about 35% of the land surface (ICNF 2013). Eucalyptus and maritime pine, both managed for wood production, represent nearly 50% of the forest area covering 812 thousand hectares

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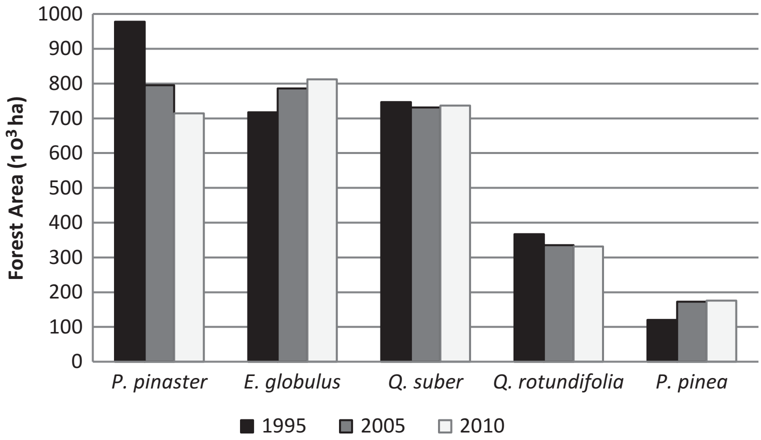


Fig. 22.1 Evolution of forest area by tree species over the period of 1995 and 2010; where P., E. and Q. stand for *Pinus*, *Eucalyptus* and *Quercus* genus, respectively

and 714 thousand hectares, respectively (ICNF 2013). About 40% of Portuguese forests are managed for non-wood forest products: 737 thousand hectares of cork oak forests managed for cork production often as an agroforestry system; 331 thousand hectares of holm oak managed as an agroforestry system; and 176 thousand hectares of stone pine (*Pinus pinea*) managed for fruit production for human consumption (ICNF 2013). The areas of cork and holm oaks are managed under severe legal harvesting restrictions and are not considered as Forest Available for Wood Supply (FAWS). In these areas, thinning is allowed to some extent, although thinned woody biomass from these forests, as well as from stone pine forests, is difficult to utilize and, when the selling price covers transportation costs, is frequently used by local communities. The species groups that make up the remaining 9% of the forest area are: other hardwoods (6%), other softwoods (2%), other oaks (2%) and chestnut (1%). In total, softwood species represent 31% of the Portuguese forest area. Maritime pine forests are mainly concentrated in the north of the country, while eucalyptus is generally found in north and central Portugal, mainly along the coast. Evergreen oaks dominate the central and southern areas. Portuguese forests are mainly managed as pure stands, although mixed stands can also be found with the most common mixtures being maritime pine and eucalyptus, cork and holm oaks and, more recently, cork oak and stone pine.

The Global Forest Resource Assessment 2010 considers Portugal among the 10 countries with greatest percentages of privately owned forests in Europe. In the mainland, 97.2% of the forests are privately owned, of which approximately 5% belong to industries.

Most forest properties are small and fragmented. Around 61% of private owners have less than 5 ha representing 26% of the forest area (Santos et al. 2013). The size of forest holdings increases from north to south. The small size of properties often makes it difficult to implement policy as well as preventive and protective measures against biotic and abiotic agents. One possible solution is organizing forest owners in associations to guarantee a minimum area for sustainable forest management (DGRF 2007). The number of forest owner associations has increased from 16 in 1977 to 177 in 2013 (ICNF 2014). Moreover, by the end of 2012, 330,000 hectares of forest were certified under FSC, and also by PEFC with some areas being certified by both systems (Santos et al. 2013).

Forest fires are the greatest threat to Portuguese forests. About 50% of fire ignitions are attributed to negligent or criminal behaviour. This factor, combined with hot and dry summers that facilitate fire spread, depopulation of the interior of the country which led to an increase in unattended shrublands and lack of forest management, the presence of fire prone species such as pine and eucalyptus, the small average holding size, and limited accessibility all contribute to a massive problem.

Since 1995, total standing stock increased from 153,600 m^3 (DGF 2001) to 172,600 m^3 (AFN 2010). In spite of the increase, a reduction in the maritime pine standing stock of 16.7 million m^3 was observed due to the pine forest area reduction, whereas a moderate increase was registered in eucalyptus standing stock (6 million m^3) mainly in pure stands. The average site index for eucalyptus is 18 m (base age 10) with an average gross mean annual increment of 12 m^3/ha per year calculated for the age of 12. As for maritime pine, the average site index (base age 50) is around 18 m, corresponding to a gross mean annual increment of 7 m^3/ha per year (Santos et al. 2013). The area of maritime pine and eucalyptus stands with a MAI higher than 22 represent 39% and 12.5% of each species forest area respectively.

22.1.2 NFI History

National Forest Inventories (NFIs) have been carried out more or less every 10 years since 1965. The Portuguese NFI involves both land cover and field data collection. Estimates of forest areas are based on photointerpretation of aerial photography and characterisation of stands with the most representative tree species in the country. However, the Portuguese NFI has not been based on permanent plots, and a different sampling design was used for each NFI until NFI5 (2005), when a 500 × 500 m systematic grid covering the whole country was established for photo-interpretation (Barreiro et al. 2010). The current NFI is based on the same grid system. Two subgrids derived from the base grid were established every 2 km and every 4 km and were used to select locations for forest and shrubland NFI field plots, respectively. The intensive sampling design was justified by the intention of implementing a system of continuous forest inventory that at the end was not implemented. NFI5 would represent the base year, for which all plots would be measured. In the course of NFI6, 8000 forest plots were remeasured. The plots were randomly selected in proportion to species abundance within the level two national subdivisions defined by the Nomenclature of Territorial Units for Statistics (NUTS II). However, an increase in sampling intensity was allowed for some species in the NUTS II subdivisions for which the number of plots led to unacceptable sampling error for those species. The scope of the current inventory (NFI6) has increased and now includes habitat identification and conservation status evaluation, soil characterisation and organic carbon evaluation, and collection of increment bores in two dominant and one average tree per plot. The Portuguese NFI provides official estimates at national level, NUTS II subdivisions, and Regions for Forest Planning (PROF) level. The last two levels do not include all statistics published at country level due to the small sample sizes for some species in some NUTS II and NUTS III subdivisions. NFI5 estimates can be accessed through the FloreStat software at the Portuguese Forest Services' website (http://www.icnf.pt/portal/florestas/ifn).

22.1.3 The Portuguese Forest Simulators

To comply with international commitments under the United Nations Framework Convention on Climate Change (UNFCCC), Portugal established a national Greenhouse Gas (GHG) inventory and regularly submits annual reports on GHG emissions and removals that require forecasting future forest development. Given the importance of the forest sector in Portugal, the Portuguese public administration has national reporting duties and therefore requires that wood availability studies be conducted.

In the beginning of 2000, stand-level forest simulators were made available separately for the three main tree species in Portugal, *Pinus pinaster*, *Eucalyptus globulus* and *Quercus suber* (FPFP 2001a, b, c). However, the programming for these simulators made updating difficult and made it impossible to include new models or updated model versions developed in the past years. It was therefore of utmost importance to support the development of European and national policies by relying on consistent national level forest information. To achieve this objective, new forest simulators were required that facilitated projecting forest development using the latest model versions while at the same time taking into account forest management, climate changes and hazards.

SIMYT, a SIMulator based on Yield Tables, was created to simulate forest resources in a region. This simulator uses as input NFI data aggregated in 1-year age classes' taking into account wood demand, hazards and Land Use Changes (LUC). This forest simulator is available for eucalyptus, maritime pine, cork and holm oaks (Coelho et al. 2012) and was used for 2009 Kyoto Reporting. Another regional forest simulator based on Markov chains was developed for eucalyptus and maritime pine forests (Rego et al. 2013). This forest simulator not only uses a high level of data aggregation (10-year and 4-year age classes for maritime pine and eucalyptus, respectively) but was developed using an NFI data series (from 1972 to 2005) to calibrate its runs, all combining to restrict flexibility in the simulations.

In Portugal, most of the industrial round-wood yield (just considering wood, furniture, pulp and paper products) originated from maritime pine and eucalyptus stands representing 77.9% of the gross economic value of forest products (Santos et al. 2013). Eucalyptus is mainly used for paper and paperboard production (45.7%), pulp (29.2%) and corrugated paperboard (10.1%), whereas maritime pine has been traditionally used for carpentry and construction (39%), sawnlogs (26%), fiberboard and particleboard (14%) (Santos et al. 2013). More recently, maritime pine wood has also been used to produce pellets that are mainly exported to Italy and the United Kingdom (Serra Ramos personal communication). Notwithstanding, over the last three decades, wood industries have been using woody biomass to produce thermal and electrical energy in Portugal. In 2005, the Portuguese Energy Strategy (PES) considered it necessary to increase the power infrastructure, and the construction of several thermoelectric plants fuelled by woody biomass was approved (Diário da República (DRE) 2005). Because the energy produced by these plants is competitively priced, there is a possibility for woody biomass to be used for bio-energy.

With the competing uses for wood, another tool was developed. SIMPLOT, a demand driven SIMulator based on NFI PLOTs, was created to overcome the disadvantages of using aggregated data. Initially developed for eucalyptus forests (Barreiro and Tomé 2011), SIMPLOT presently allows the simulation of maritime pine forests as well. SIMPLOT's projections are made separately for eucalyptus (using stand level data) and maritime pine (using stand and tree level data) and are mainly driven by wood and biomass demands. Different Forest Management Approaches (FMA), hazards (fire) and Land Use Changes (LUC) are also taken into account (Barreiro and Tomé 2012). Several forest management schedules per species can be described and assigned to each input plot. More recently, SIMPLOT was integrated into the StandsSIM forest simulator which has two alternative running options: (1) the demand driven option (StandsSIM.dd), corresponding to SIMPLOT; and (2) the management driven option (StandsSIM.md) described in Barreiro et al. (2016). Only StandsSIM.dd/SIMPLOT which was used for the last policy study carried out for the Portuguese forest sector will be described in the following sections.

22.2 Data

22.2.1 NFI Data

Field measurements are obtained for simple fixed-area circular plots of 500 m^2 for wood production forests and 2000 m^2 for cork and holm oak stands (non-wood production forests). For more details see Barreiro et al. (2010).

For each NFI plot, the diameters of all trees with diameters greater than the minimum diameter threshold are measured. Height is measured for all dominant and sample trees where dominant trees are the 100 largest trees per ha and sample trees are those whose diameters are closest to the mean diameter in each diameter class. All plot trees are classified in terms of their health condition (e.g. discoloration and defoliation), shape (e.g. broken top, diameter defect, bent and curved), status (e.g. dead, alive and stump), age and canopy position. Plot level information is also collected including accessibility, topography, hazards occurrence, natural regeneration, vertical structure by height classes and understory use (e.g. for pasture). Land use, stand composition and structure as well as evidence of recent silvicultural operations are described for the stand.

After field-data collection, and before data processing, a series of quality control procedures take place. The estimation of standing and growing stock volume and biomass is important for estimating woody biomass availability, but also for carbon evaluation, and includes several steps: (1) tree height estimation for each non-sampled tree using species-specific height-diameter models, (2) tree volume and biomass estimation for each tree on the plot using species-specific models, (3) summation of tree volume and biomass estimates for each plot scaled to a per hectare basis, and (4) aggregation of plot mean volume or biomass per hectare estimates by forest stratum and multiplication by the respective area to estimate total volume or biomass of standing stock and growing stock of each forest stratum. These variables combined with other stand level information are used as inputs for running StandsSIM.dd (e.g. Barreiro and Tomé 2011, 2012). Change estimates can also be obtained with StandsSIM.dd.

22.2.2 NFI Based Initial Forest Resources Input

Each NFI plot represents a stand with the characteristics of an NFI plot. Each stand represents an area corresponding to the total area of the species in the country divided by the number of NFI plots for that species. Most eucalyptus and maritime pine stands are managed as pure even-aged. Thus, mixed stands are simulated as pure even-aged stands by correcting the stand area based on the ratio between the species standing stock in the stand and the stands' total standing stock (Barreiro and Tomé 2011). Input requirements depend on the type of growth model used for each species. Eucalyptus stands are simulated using a stand level growth model which, apart from stand area, requires other numerical variables, namely stand age (in even-aged stands), dominant height, number of trees (stools and sprouts) and basal area. Volumes (volume under-bark with stump, volume of bark, volume of the stump) are not a compulsory input, but more accurate results are obtained if provided. In turn, maritime pine stands are simulated using a tree-level growth model and for this reason additionally require the plot area and number of trees, the measured diameter and height of the trees, as well as the status and dominance code for each tree. Additional stand level information is also required such as stand area, stand age and stand density. Non-numerical information such as stand type, composition and structure is also needed.

22.2.3 Simulation Parameters

Simulation runs depend on a series of parameters that can be modified by the user. Simulation parameters include the number of years to project, fire parameters (the minimum age for industrial use of wood after a fire and the proportion of salvage wood) and harvesting parameters (minimum age for harvesting and the harvesting probabilities by age and stand type). Additionally, StandsSIM.dd needs simulation parameters concerning short-rotation forestry (rotation length and the number of rotations) as well as parameters related to harvesting residues removal options (e.g. removal of tops, or branches, or bark or combinations of the three). Some of these parameters are obtained from published reports, such as the proportion of salvage wood. Parameters related to type of thinning, thinning intensity (the number of eucalyptus sprouts left per stool after the shoots selection, the Wilson Factor for maritime pine) and thinning periodicity need to be provided as well as assortments (number of assortments and their characteristics, namely the top diameter and log length).

22.2.4 Scenarios and Key Drivers

Scenarios can range from rather simple to quite complex depictions of the future. In StandsSIM.dd, the range of possible scenarios result from combining two or more key drivers for each species: (1) the demand of wood and biomass which has implications for the amount of felling per year, (2) the occurrence of hazards that takes into account the burnt area per forest type, (3) land use changes to and from other uses representing the afforested area per year and the deforested area per year, and (4) the application of Forest Management Approaches (FMA). The intensity of each driver is expressed by an area, volume or proportion.

The quantitative values that characterize the scenarios for each year of simulation throughout the planning horizon can result from published statistics and/or represent the expected trend of each key driver. It is important to state that the Portuguese NFI does not provide statistics on the amount of harvested woody biomass or its final use. In some cases the same statistics can be found published by different entities often presenting distinct numbers.

22.3 Methods

22.3.1 Running the Forest Simulator

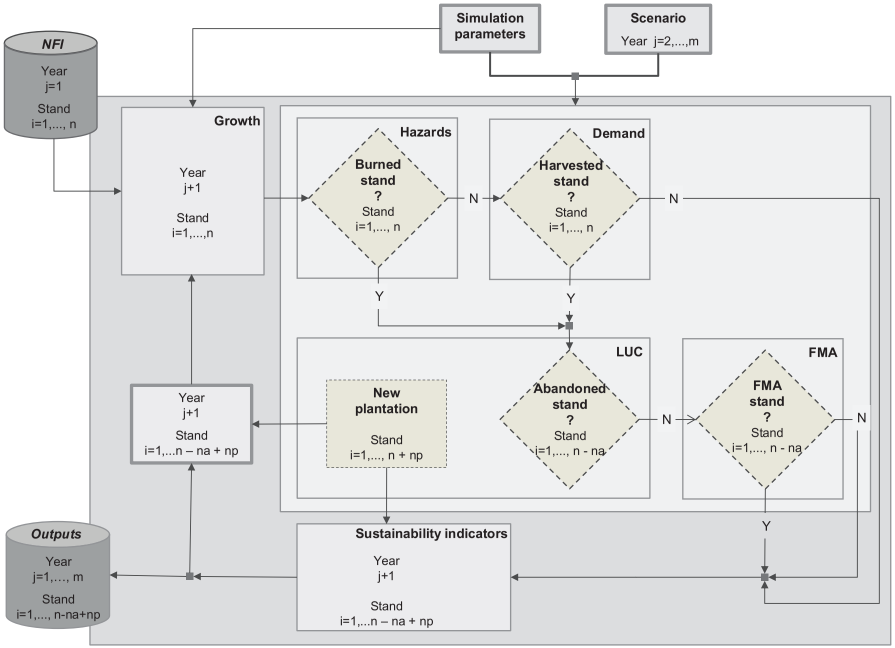
StandsSIM.dd runs for a single species at a time. It "visits" each stand every year to update growth. The growth module includes different growth models that are used according to the species and stand structure (Barreiro and Tomé 2011). The drivers (Sect. 22.2.4) are applied after forest resources have been updated. To select which stands will be burnt, harvested or abandoned, the probability of each one of these events occurring in a single stand is compared to a pseudo-random number, and the event occurs if the occurrence probability is smaller than the random number. The annual intensity of each driver per year is defined in the scenario as an area, a volume or a proportion of an area. As the drivers' modules run, burned area, harvested volume, abandoned area and new planted areas are accumulated until the values defined in the scenario for each year of simulation are met (Barreiro and Tomé 2012). When running the tool for eucalyptus, in case both wood and biomass demands have been considered, the wood volume for pulp and the woody biomass for bio-energy are calculated. Similarly, two different afforested areas are also considered: newly planted areas managed for pulp production, and newly planted areas for bio-energy. Figure 22.2 shows the structure of the simulator.

22.3.2 Growth Module

StandsSIM.dd starts by running the growth module for all the stands at year j to update forest resources to year j + 1. This module comprises different sets of forest growth models according to the species, stand structure and forest management. Eucalyptus stands are managed using stand-level growth models: GYMMA for simulating uneven-aged stands (Barreiro et al. 2004), and GLOBULUS 3.0 model (Tomé et al. 2006) or GLOBEP model (Barreiro 2011) depending on whether the even-aged stands are managed for pulp production or as short-rotations for bio-energy production, respectively. Maritime pine stands are simulated using the tree-level models PINASTER for even-aged stands (Nunes et al. 2010, 2011a, b) and PBIRROL for uneven-aged stands (Alegria and Tomé 2013). Thinning is simulated as part of the growth module. Thinned pine wood is assigned to the Wood/Pulp pool, whereas the woody biomass resulting from the shoots selection operation in eucalyptus stands is assigned to the Woody Biomass pool.

22.3.3 Hazards Module – Fire

After forest resources have been updated, a pseudo-random number is generated for each stand and compared to the stands' probability of burning. In the current version of the simulator, the probability of burning is considered equal for all stands and is set based on the proportion of the area to be burned defined in the scenario and on the total forest area (Barreiro and Tomé 2011). As the module runs, burned area per species accumulates and a user defined amount of salvage wood by tree species is considered for the Wood/Pulp pool, adding to the wood resulting from thinning, whereas the remaining wood is assigned to the Woody Biomass pool. The module stops when the burned area defined in the scenario for each species in each year of simulation is met. If the area to burn is not met after all stands were "visited", stands which were not selected in the first round will be "revisited" before moving to the next simulation year. This operation can be repeated 1000 times until the area to be burned is met.



Where *m* represents the number of years in the planning horizon; *n* represents the number of initial stands; *na* the number of abandoned stands; and *np* the number of planted stands

Fig. 22.2 Schematic overview of standsSIM.dd (SIMPLOT) simulator

22.3.4 Harvest Modules

Stands which have not burnt can be harvested. The main harvest module (WP/W) operates on eucalyptus and maritime pine stands managed for Wood/Pulp Production by generating a pseudo-random number for each stand and comparing it to each stands' probability of being harvested. The stands' harvesting probabilities are defined by the user and depend on tree species and stand structure (even-aged stands allow assigning different probabilities according to stand age). The harvested wood volume of each species is added to the respective Wood/Pulp pool, while the harvest residues are assigned to each species Woody Biomass pool. In the case of maritime pine, the Wood/Pulp pool is sub-divided into different categories representing the assortments defined by the user. After a stand is harvested, harvested wood is compared with the wood demand defined in the scenario. Harvesting continues until wood demand is met. Harvest residues contribute to the Woody Biomass pool according to the harvest residues removal option defined by the user (see Sect. 22.2.3).

In the case of the eucalyptus, if biomass demand is considered as a scenario key driver, two additional harvesting modules are used: (1) the BP/E Harvest module, which operates on stands managed for Biomass Production for bio-Energy; and (2) the WP/E Harvest module that operates on stands initially managed for Wood/pulp Production, but which are used for bio-Energy. Both these modules contribute exclusively to the Woody Biomass pool.

Whenever the biomass demand is considered, the three Harvest modules are called to operate in a specific order: (1) BP/E Harvest module, (2) WP/W Harvest module, and (3) WP/E Harvest module. In this way we guarantee that the main source of woody biomass used to meet biomass demand comes from stands specifically managed for bio-energy and is complemented with the harvest residues from Wood/Pulp production stands, which can be left on the site to minimize nutrient extraction as soon as the biomass demand is met. After the first two harvest modules have run, if wood demand is met and biomass demand is not, the third harvest module will harvest the stands managed for pulp as the last option. The BP/E Harvest module is the first to run, harvesting all bio-energy stands for which the rotation length, defined as a simulation parameter, is reached. These stands are harvested regardless of whether the Woody Biomass pool already holds sufficient biomass to meet the demand. In case biomass demand is still not met by the time the module is done, the harvest residues resulting from stands harvested to meet the wood demand (WP/E Harvest module) will be used to increment the Woody Biomass pool. However if this is still not enough, the WP/E Harvest module is used. This module harvests wood production stands according to the same age/stand type dependent probability as in the Harvest WP/W module, but the difference is that all aboveground woody biomass is assigned to the woody biomass pool.

22.3.5 Land Use Changes Modules

Two LUC modules are responsible for planting new stands and abandoning existing stands according to the new plantation areas and the deforestation defined in the scenario for each year of simulation. All stands that were harvested, due to fire or to final felling, will be visited by the deforestation module. The decision on whether to abandon a stand is based on the generation of a pseudo-random number which is compared to a probability function that depends on the value of climatic variables that characterizes the region where the stand is located. Abandoned stands are no longer simulated. Conversely, new stands are assigned a climatic region so that the site index can be estimated and stand growth can be initialized. These new stands will only be disregarded if selected to be abandoned throughout the simulation period. When both wood and energy demands are considered, two afforestation scenarios, one for wood production plantations and another for bio-energy plantations, are required.

22.3.6 Forest Management Approach and the FMA Module

Similar to the deforestation module, the FMAs module operates only for stands that have been harvested following the percentage of changes expected between different Forest Management Approaches according to the scenario. This module is expected to be of extreme interest as soon as maritime pine and eucalyptus stands will run simultaneously for studying the impacts of possible tree species conversion in certain regions.

Several FMAs can be considered for eucalyptus and even- and uneven-aged maritime pine stands. Bio-energy production FMAs can only be considered for eucalyptus. All stands classified under a given FMA are managed in the same way throughout the simulation period, except for uneven-aged stands that are converted to even-aged stands after harvest. The user can define sets of silvicultural operations under each FMA by defining when in time and how often they take place. Additionally, the cost of each silvicultural operation is known, which allows calculation of a set of economic and some social indicators. The costs of operations are based on official statistics (CAOF 2014a, b). At present, the impact of carrying out some operations such as fertilization or weed control is directly reflected in production costs, but not on volume increment.

22.3.7 Assumptions

StandsSIM.dd assumes the same burning probability for all stands, regardless of stand type, considering bark and branches biomass reductions of 40% and 25%, respectively. Burnt stands are harvested, and a user defined percentage of salvage wood is considered. Because fires usually occur from March until October and final felling can take place throughout the whole year, fire and harvesting are applied when half of the annual increment has been achieved. Eucalyptus wood production stands can only be harvested for bio-energy if wood demand has been already met. As soon as the biomass demand is met, harvesting residues are assumed to be left on the site. The areas of gaps and clumps are assumed to be maintained constant throughout the simulation period. Only stands that have been harvested can be abandoned or replanted.

22.3.8 Outputs

For each scenario run, four (.csv) output files are exported: the totals file that contains annual values for some indicators along the simulation period, the socio-economic indicators file, the areas by age classes' file, and the plot level file. The main output is given in the totals output file containing the total standing stock, felled volume and woody biomass, forest area, burnt forest area, carbon stock and carbon sequestered among other variables before and after running each drivers module. The area output contains a transition matrix with the evolution of forest area between 1-year age classes over the simulation period (Barreiro and Tomé 2011). The plot output file allows tracing the history of each stand throughout the simulation period, whereas the socio-economic indicators (production costs and wages) are saved on a separate file.

22.4 Validation and Uncertainty

Projections obtained from running regional forest simulators are often used by policy makers to assist and support their decision making processes. To increase StandsSIM.dd's credibility and gain sufficient confidence for its outputs, the simulator was run using the NFI4 (1995–1997) data and projections were compared to NFI5 (2005–2007) data. This analysis showed reliable large scale projections for standing stock and reasonable results for forest areas distribution by age classes for all stand types except uneven-aged stands which were underestimated (Barreiro 2011). StandsSIM.dd can be run stochastically to allow for some variability, although sampling and model errors have not yet been included.

22.5 Applications and Future Challenges

StandsSIM.dd is described in two scientific papers (Barreiro and Tomé 2011, 2012) and has been presented at several national and international conferences. In 2014, with the increasing trend in wood imports and the rural development policy 2014–2020 program about to be launched, StandsSIM.dd was used by the Portuguese Agency for the Competitiveness of the Forest Sector (AIFF) for a wood availability prospective study intended to assist in defining policy proposals based on a cost-benefit analysis. Apart from eucalyptus and maritime pine wood production, the study also covered cork production, although a stand level simulator (SUBER, Tomé et al. 2015) was used for projecting cork growth.

StandsSIM.dd is under constant improvement and the next steps include: (1) validating the applicability of 3PG process-based model for the whole country, (2) calibrating 3PG for maritime pine in Portugal, (3) developing a new algorithm for converting even- to uneven-aged stands, (4) improving the tool so that all NFI data, including all species and strata, can be simulated simultaneously.

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