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List of Abbreviations

AHP	Analytic hierarchy process
BAU	Business as usual
BBN	Bayesian belief network
CAOF	Portugese statistics for silvicultural operations
CDR	Cork debarking rotation
CM	Comparison matrix
CPT	Conditional probability tables
CTFC	Forest Sciences Centre of Catalonia
DBH	Diameter at breast height
DSS	Decision support system
EAA	Equivalent annual annuity
EBBN	Elicitation burden of Bayesian belief network
FDS	Forest development scenario
FM	Forest management
FMU	Forest management unit
FPU	Forest planning unit
GIS	Geographic information system
LP	Linear programing
MCDM	Multi-criteria decision making
MPT	Multi-purpose tree
NFI	National forest inventory
NIPF	Non-industrial private forest
NPV	Net present value
NWFP	Non-wood forest product
RCM	Resource capability linear program
RFP	Regional forest program
SEV	Soil expectation value
ZIF	Forest Intervention Area (Portugal)
WUE	Water Use Efficiency

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Executive summary

Decision support systems (DSSs) help decision makers such as forest owners and forestry professionals when they are making forest management decisions at stand, FMU and regional levels. Solution from DSSs is a recommendation how to manage forest and it also includes measures that describe the outcomes of certain management regime. Until now, the role of NWFPs in DSSs has been too small. Therefore, the decision makers have not had information on how forest management affects the yields of various NWFPs or how the yield of certain NWFPs could be increased. This deliverable 2.4. from Startree project alleviates these problems by reporting how the existing forest DSSs have been improved and what kind of new DSSs are available for optimizing forest management that considers both timber production and NWFPs. The report contains a reasonably large number of recent forest DSS use-situations in which NWFPs relevant for the planning regions have been integrated into planning calculations. In addition, expert knowledge based DSS that considers the region and FMU level production possibilities of NWFPs from broader perspective than only forests was introduced. In addition, the report discusses the progress and experiences gained in these use-situations through a SWOT-analysis.

The report presents optimized threatment schedules for some new (e.g. pine honey, cork production in Spain and ecosystem services) and improved solutions for several other NWFPs (e.g. berries including picking costs). At FMU-level, the examples from Finland, Portugal, Spain and Turkey showed that multi-objective forest management approach based on the development and evaluation of FMU-level alternatives is strengthening. Through alternatives, preconditions to evaluate the trade-offs between goal variables and analysis of economic consequences can be improved. A specific attention was given to visualization of the results through production possiblity frontiers and thematic maps. Interestingly, also three region level use situations to consider the production possiblities of NWFPs were given. In these, the large scale forest DSSs were developed and applied to better meet the information needs related to NWFPs and potentially existing in forest policy preparation processes. In addition, the developed expert knowledge-based multi-method DSS was advanced in at least three important dimensions. First, it is able to consider the operational environment more broadly than only from forest perspective. Second, it includes a possibility to examine both the FMU and region level capabilities of NWFPs production. Third, it is able to consider several predefined NWFPs at the same time.

The SWOT analysis revealed that progress has taken place in the DSS development. This was supported by improved availability of NWFP yield models. In addition, the properties of DSSs are advancing and characteristics that resemble real-life situations have been introduced to DSSs, despite the fact that one of the recognized weaknesesses was that simplifications are still too much taking place when NWFPs are considered in numerical calculations. In addition, models for NWFPs are still too much restricted to certain regions and management systems. However, future opportunities are opening avenues for increased utilization of NWFPs among other renewable natural resources both in forest related business and in recreational use of forest. Interests towards NWFPs among consumers is increasing and as a result, also forest owners are seeking profit increases that are based on utilization of NWFPs. These facts indicate that the work done and reported in this document has been important and that it will also continue in the future.

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1 Introduction

Authors: MK, VT

The aim in forest management planning is to find out such treatment schedule(s) for the forest stand(s) whose outcomes best correspond with the multiple forest use goals of the forest owner. Theoretically and practically, it is possible to derive a large amount of different treatment schedules with respect to timing and the degree of utilization of forest resources for each stand located within the planning area. Selecting the optimal schedules for individual stands or finding the best combination of treatment schedules for the whole planning area is not a trivial task when multiple forest use goals are considered (see e.g. Borges et al. 2014). This is why Decision Support System (DSS) development and use has been active in the field of forest management planning. Forest planning related DSSs can be defined as computer-based tools which provide support to develop the framework and solve ill-structured decision problems by integrating database management systems with analytical models and operational research techniques, graphic display, tabular reporting capabilities, and the expert knowledge of scientists, managers, and decision makers to assist in specific decision making activities (e.g. Borges et al. 2014).

Integration of one or various NWFPs in forest DSSs further increases the challenges related to properties and use of forest DSSs (see Tomé and Faias 2014), although in technical sense the yield of certain NWFP is basically only one new objective variable whose development needs to be predicted during the planning period simultaneously with several other variables that are typically dealt with in planning calculations. Due to dominance of timber production in forest planning calculations, activities related to the integration of NWFPs into DSSs have started to emerge rather recently (see Pukkala 2002). For these attempts, a model (empirical or expert knowledge based) is first needed (e.g. Ihalainen 2015, Sánchez-González et al 2015). Then, the models and supporting models need to be integrated into simulators, which can then be combined to optimization algorithm so that it can be applied to search for the solution that gives the highest value for the objective function that mimics the goals of the decision maker.

In forest management planning context, the planning situations, i.e. the DSS use-situations can be classified in different ways. Often classification is based on spatial and temporal scales, i.e. geographical coverage and time horizon (Kangas et al. 2015). Typically, in stand-level planning situations the treatment schedule of one stand for one rotation is defined (e.g. Kangas et al. 2015). In Forest Management Unit (FMU) and region level situations, the planning area is larger and it consists of several forests stands or inventory plots

which have very different forest structures. Thus, instead of one rotation, the length of the planning period is predefined and it can be e.g. 50 years and further divided into 5 or 10 year sub-periods for example.

The aim of this Deliverable is to report how the existing forest DSSs have been improved and what kind of new DSSs capable for optimizing forest management that considers and combines timber production and NWFPs have been developed or are under development. This will be done through presenting a number of recent forest DSS use-situations in which NWFPs relevant for the planning regions have been integrated into planning calculations. In addition, a new, expert knowledge based DSS that considers the region and FMU level production possibilities of NWFPs from broader perspective than only forests will be introduced. In many cases, NWFP yield models developed during the project (see Sánchez-González et al 2015) have been integrated into simulation-optimization systems which will be used in the planning calculations that serve the planning needs of the Startree case study areas.

In more detail, the deliverable aims to:

- Report the results of Startree project's sub-task 2.3.2 which aims to improve existing and create new decision support tools for improved consideration of NWFPs in forest management planning calculations.
- Report the results of sub-task 2.3.3, which has developed an expert system to identify successful combinations of NWFP and ecosystem services at regional and FMU levels.
- Discuss the experiences gained in these use-situations and analyze where the development of DSSs capable to deal with NWFPs is currently situated through a SWOT-analysis and which are the future threats and opportunities of the development.

This report is structured according to geographical scales so that different use-situations from case study regions are reported first at stand-level. This is then followed by FMU and region level use-situations. After these three geographical scales, the expert system considering more broadly the regions' and FMUs' production possibilities will be described. Finally, in discussion a synthesis through SWOT analysis is given. The results of this deliverable support in part the definition of new silvicultural guidelines (Deliverable 2.3 of Startree) which, in turn, supports the (combined) production of timber and NWFPs in different forests throughout Europe.

2 DSS development and use for stand level

2.1 Finland

Authors: JM, TP, MK

2.1.1 Berries

2.1.1.1 Use situation

Wild forest berries, including bilberry (*Vaccinium myrtillus*) and cowberry (*Vaccinium vitis-idaea*) are among the most important NWFPs in the Nordic countries (Turtiainen & Nuutinen 2012, Vaara et al. 2013). Earlier results suggest that valuing NWFPs may remarkably change the optimal stand management and increase the profitability of forestry (Palahí et al. 2009, de-Miguel et al. 2014b). Miina et al. (2010) optimized joint production of bilberries and timber, but they did not consider cowberry yields in these calculations.

The results presented here are based on the stand-level simulation-optimization system described in more detail by Miina et al. (2016). In their study, the aim was to optimize the management of stands growing on site types where the joint production of timber and bilberry (*Vaccinium myrtillus*) and/or cowberry (*V. vitis-idaea*) is feasible. The multi-product management schedules were optimized for two Scots pine (*Pinus sylvestris*) stands and a mixed stand of pine, Norway spruce (*Picea abies*) and birch (*Betula pendula*) growing on sites most suitable for bilberry and/or cowberry. A new property of the simulation-optimization system was the inclusion of berry-picking costs in calculations.

In this report, the use of the stand-level DSS was illustrated by optimizing the joint-production of timber and bilberries in a pine stand growing on *Myrtillys* type mesic heath site in North Karelia, Finland (more detailed results can be found from Miina et al. 2016). The results are applicable to the ideal situation where the forest owner can benefit from managing the stands for both timber and berry yields.

2.1.1.2 DSS description, materials and methods

2.1.1.2.1 Berry yields and picking costs

Stand development was simulated using the models of Hynynen et al. (2002) for site index, dominant height development, diameter increment, crown height, height increment and tree survival. The taper models of Laasasenaho (1982) were used to calculate assortment volumes of removed trees. In all

simulations, the temperature sum was set to 1200 degree days, the altitude to 100 m and the proportion of sea and lakes within 20 km to 0 % and 20 %, respectively. The values represent the conditions of North Karelia, Finland.

The empirical bilberry yield model of Miina et al. (2009) was used to predict the bilberry production along with stand development. The model first predicted the coverage of the berry species as a function of different parameters such as site fertility, regeneration method, stand age and stand basal area. Then, the annual berry yields were predicted as a function of species coverage and stand basal area.

The annual berry yield was predicted in a stochastic way. For each year, the bilberry yields were predicted several times by drawing the random between-year effects from its normal distribution, and the annual berry yields were computed as the mean of the outcomes. The pine stand was regarded as a good bilberry stand so that the predicted berry yields were comparable to the good bilberry yields measured by Raatikainen and Raatikainen (1983).

The berry-picking costs were calculated as follows. Assuming that two berry-pickers drive together a total distance of 20 km to pick and sell berries (Raatikainen 1978, Kangas & Markkanen 2001), the travel costs are 0.4 € km^{-1} and the total amount of 40 kg berries are picked per trip, the travel costs are 0.1 €/kg. Using the wage of 6 € per hour and assuming that berries are picked 12 kg per hour from forest stand with a good berry crop (40 kg/ha) (Miina et al. 2016), the harvesting costs are 0.5 €/kg. However, it was assumed that the cost of 0.5 €/kg holds only when the berry yield is 40 kg/ha. The harvesting cost was multiplied by 41/(yield+1), resulting in increased cost (i.e. decreased berry picking productivity) when berry yield < 40 kg/ha and decreased cost in case of higher berry yields. The total cost of berry-picking was 0.6 €/kg when the berry yield was 40 kg/ha. It was assumed that berries were collected only when the cost (travel cost + harvesting cost) was less than the selling price of berries. As a result, years of poor berry yields are not included in the incomes and reported harvested yields of berries.

2.1.1.2.2 Initial stands

A 10-year-old pine stand was used in optimization calculations. The stand represents *Myrtillys* type mesic heath site in North Karelia. The number of stems per hectare was 2000 and the mean height was 3 m. The stand was assumed to be artificially regenerated and treated with pre-commercial thinning.

2.1.1.2.3 The use of DSS software "Stand"

The berry yield models, new picking cost function and the initial stands were programmed to the stand-level forest DSS "Stand", prepared by prof. Timo Pukkala. The DSS utilizes the nonlinear programming algorithm of Hooke and Jeeves (1961) to find the optimal combination of decision variables that maximizes the value of the objective function. This algorithm has been widely employed in solving stand-level optimization problems (see e.g. Pasalodos-Tato 2010). Since Hooke & Jeeves' direct search method may converge to local optima, each optimization problem was solved 20 times with different randomly generated initial values of decision variables, and the best of these results was reported. With each direct search run, the best of 200 random combinations of the values of decision variables was used.

The objective function was to maximize the Soil Expectation Value (SEV). SEV was defined as the net present value of all future costs of and incomes from both timber and berry production. All costs and incomes of a full rotation were discounted to the beginning of the rotation. Future rotations were taken into account by assuming that the rotation will be followed by similar rotations to infinity.

The decision variables defining stand management were as follows: number of years since regeneration (first thinning) or previous thinning (other thinnings), removal percentage in each tree cohort (for each thinning), and number of years between the last thinning and final cut. The thinning percentage was the same for every sample tree of a cohort. However, since the thinning percentages of tree cohorts were different decision variables it was possible to optimize the type of thinning, in addition to thinning intensity. The number of thinnings (i.e. 1 or 2) was given to the simulation-optimization system before solving the problem.

The average unit costs of silvicultural treatments in 2013 were applied in the calculations (http://www.metla.fi/metinfo). In the beginning of the rotation, a regeneration cost of 1000 €/ha was assumed to accrue from planting, and the cost of the pre-commercial thinning was 350 €/ha. Roadside prices of timber assortments in 2013 in North Karelia were used (http://www.metla.fi/metinfo). The variable costs of cuttings were calculated using the models of Rummukainen et al. (1995).

In optimizations, the discounting rate and price of berries were varied. In stand-level calculations, these can be considered as forest owner's preferences. The interest rates of 2 % and 4 % were examined. Based on the statistics on the amounts of wild berries offered for sale in the last five years (MARSI, 2014), the average market price paid to pickers in eastern Finland was 2.4 €/kg for bilberries. In addition, zero and two-fold pricing (4.8 €/kg) were used to analyze the effect of berry prices on the optimal stand

management. Berry prices higher than the current market price paid to berry-pickers means that berries have other additional values to forest owner (recreation, health, etc.). Zero-pricing means that forest owner does not value berries from his/her own forest, and there are no incomes from berries to be included in the total SEV.

2.1.1.3 Results and discussion

Berry price and interest rate used in calculations affected markedly the optimal management of the pine stand with good bilberry prices (Table 1, Figure 1). Without valuing bilberries (0 €/kg), the rotation length was 74 years (2 %) or 69 years (4 %). With increasing bilberry price, the rotations were longer and thinnings were more intensive. As a consequence, bilberry was growing in better light conditions and bilberry yields were higher (Figure 2). Valuing bilberries increased markedly the total SEV so that a major part of the incomes came from berry picking.

Table 1. The effect of bilberry price and interest rate on the SEVs and optimal management of the pine stand with good bilberry yields.

	Interest rate 2 %			Interest rate 4 %		
	0 €/kg	2.4 €/kg	4.8 €/kg	0 €/kg	2.4 €/kg	4.8 €/kg
SEV total (€/ha)	5148	10067	16692	448	2142	4409
SEV without berries (€/ha)	5148	4734	3884	448	326	221
Additional SEV from berries (€/ha)	0	5333	12808	0	1817	4188
1. thinning at age (years)	37	39	41	38	39	39
Thinning intensity (%)	22	36	58	21	41	46
2. thinning at age (years)	49	57	72	49	54	55
Thinning intensity (%)	45	73	67	80	73	67
Rotation length (years)	74	107	139	69	91	101
Mean bilberry harvest (kg/ha/yr)	0	71.7	85.0	0	65.7	71.4

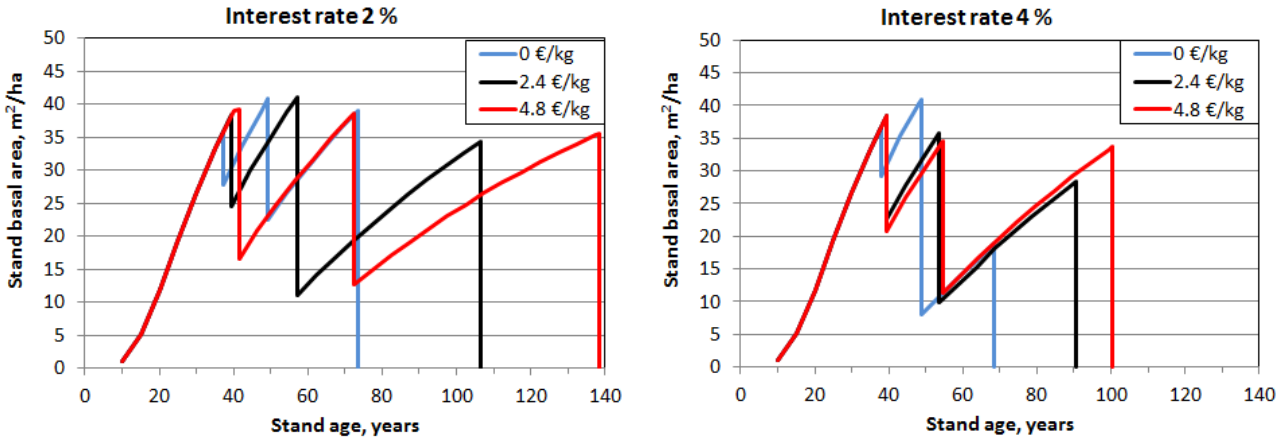


Figure 1. Effect of bilberry price and interest rate on the optimal management schedules of the pine stand with good bilberry yields.

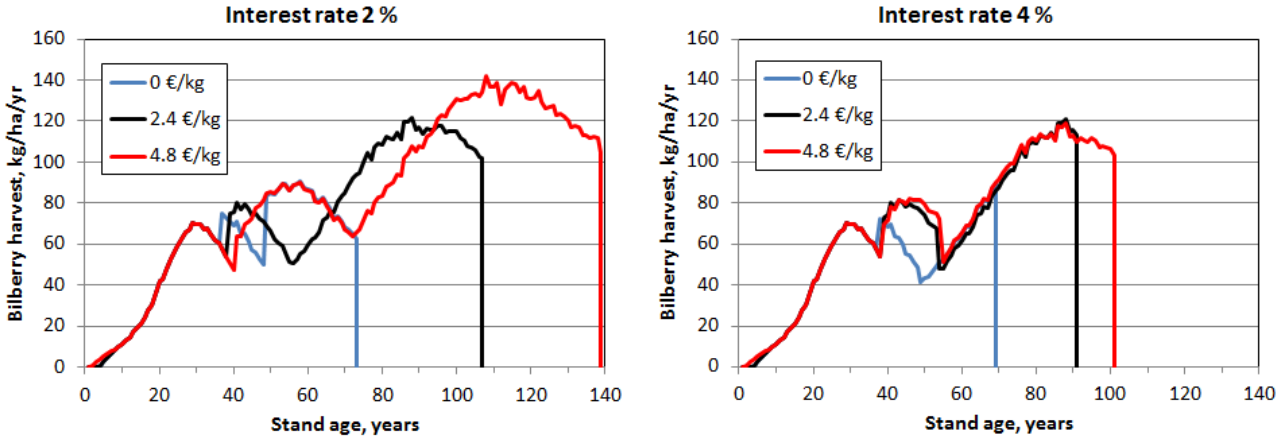


Figure 2. Predicted bilberry harvest in the optimal management schedules of the pine stand with good bilberry yields and different bilberry prices and interest rates.

2.2 Portugal

Authors cork oak: MT, JAP, JF, JHNP, SF

2.2.1 Cork – SUBER and WebCork tools

2.2.1.1 Use-situation

The SUBER model, a growth and yield model for long-term prediction of tree and cork development and growth, started to be developed in 1997 (Tomé et al., 1998, 1999, 2001). The model has been successively updated and improved over time and the last version, described in Paulo (2011), is mainly based on the sub-models presented in Sánchez-González et al. 2005, Tomé et al. (2006), Paulo and Tomé (2010), Almeida et al. (2010), Paulo et al. (2011). The most important characteristics of the SUBER model, which differentiate it from alternative models available for cork oak – CORKFITS (Ribeiro and Surový 2011) for Portuguese cork oak stands and ALCORNOQUE (Sánchez-González et al. 2015) for Spanish cork oak stands – are the following:

- it is accessible for download at the FCTOOLS website (www.isa.ulisboa.pt/cef/forchange/fctools/)
- it includes an economic module that allows the computation of net present value and equivalent annual annuity including forest management approaches selected by the user and that may include all the silvicultural operations considered in the Portuguese statistics for silvicultural operations (CAOF), usually updated every 2 years
- it simulates annual cork growth based on tree level cork growth index values, allowing the simulation of cork caliper and cork production to be carried out at tree level instead of using one average value for all the trees in the stand; cork growth index values can be obtained by a field sampling or simulated according to the county (administrative region) average distribution
- it considers tree cork quality at tree level obtained by a field sampling or simulated according to the county (administrative region) average distribution
- it allows the use of real structure of cork prices instead of average cork prices for different cork qualities; the cork caliper and quality classes can be dynamically defined by the user
- it allows for the estimation of cork weight for corks of different ages (and not only for 9 years old cork as is the case for the other alternative models)
- it allows the simulation of low thinning and of a selective thinning towards the maintenance of an approximate inverse-J shape

The model has been disseminated to several stakeholders through 2 workshops in which the participants could put their hands on the model and learn how to use it. After that, several users registered at the FCTOOLS website and several users contacted us with doubts and questions. The site has now 305 registered users (see: http://www.isa.ulisboa.pt/cef/forchange/fctools/en/whouse).

In this report we demonstrate the application of the SUBER model through one application: to study the impact of site index, cork quality and thickness distribution and cork price structure on the equivalent annual annuity (EAA), as well as to analyze the effectiveness of the extension of the cork debarking rotation (CDR) on the increase of EAA values for stands with different characteristics (more details in Paulo et al., submitted)

2.2.1.1.1 The WebCorky tool

WebCorky is a web tool, also available at the FCTOOLS website, to project cork caliber samples of a cork oak stand. The application uses equations developed by Almeida et al. (2010). The objective is to support land owners' decision on debarking based on a set of cork samples obtained when the cork is 7 to 8 years old. The cork sampling design has been studied by Almeida and Tomé (2010). WebCorky has a simple sample and multisample projection interface. The latter allows the classification of the samples evolution in time, in order to support a decision on when is the best time to debark the stand (Table 2).

Table 2. The classification uses the standard industry nomenclature (in Portuguese) for cork caliber.

Class Name	Nr Lines (1 line=2.256mm)	milimeters
Refugo	<6	<13.54
Delgadinha	≥6 and <10	≥13.54 and <22.56
Delgada	≥10 and <12	≥22.56 and <27.07
Meia Marca	≥12 and <14	≥27.07 and <31.58
Marca	≥14 and <18	≥31.58 and <40.61
Grossa	≥18 and <24	≥40.61 and <54.14
Triangulo	≥24	≥54.14

2.2.1.2 DSS description, materials and methods

2.2.1.2.1 SUBER application

Through the combination of tree data collected in three young existing stands (not debarked and for this reason without information on cork characteristics), with cork quality and cork growth index frequencies distribution, nine simulated stands were defined. Growth and cork production of each stand was simulated repeatedly, until the stand reaches 80 years of age, considering two contrasting cork price structures and Cork Debarking Rotations (CDR), ranging from 9 to 14 years, using the SUBER growth and yield model. Other variables such as cost prices, and other forest management alternatives are considered constant for all simulations. Revenues resulting from additional productions or from subsidies attributed to high natural and cultural value cork oak stands are not considered in the present analysis. A total of 324 simulations were carried out (9 stands x 2 cork price structure x 6 CDR alternatives x 3 alternative discount rate).

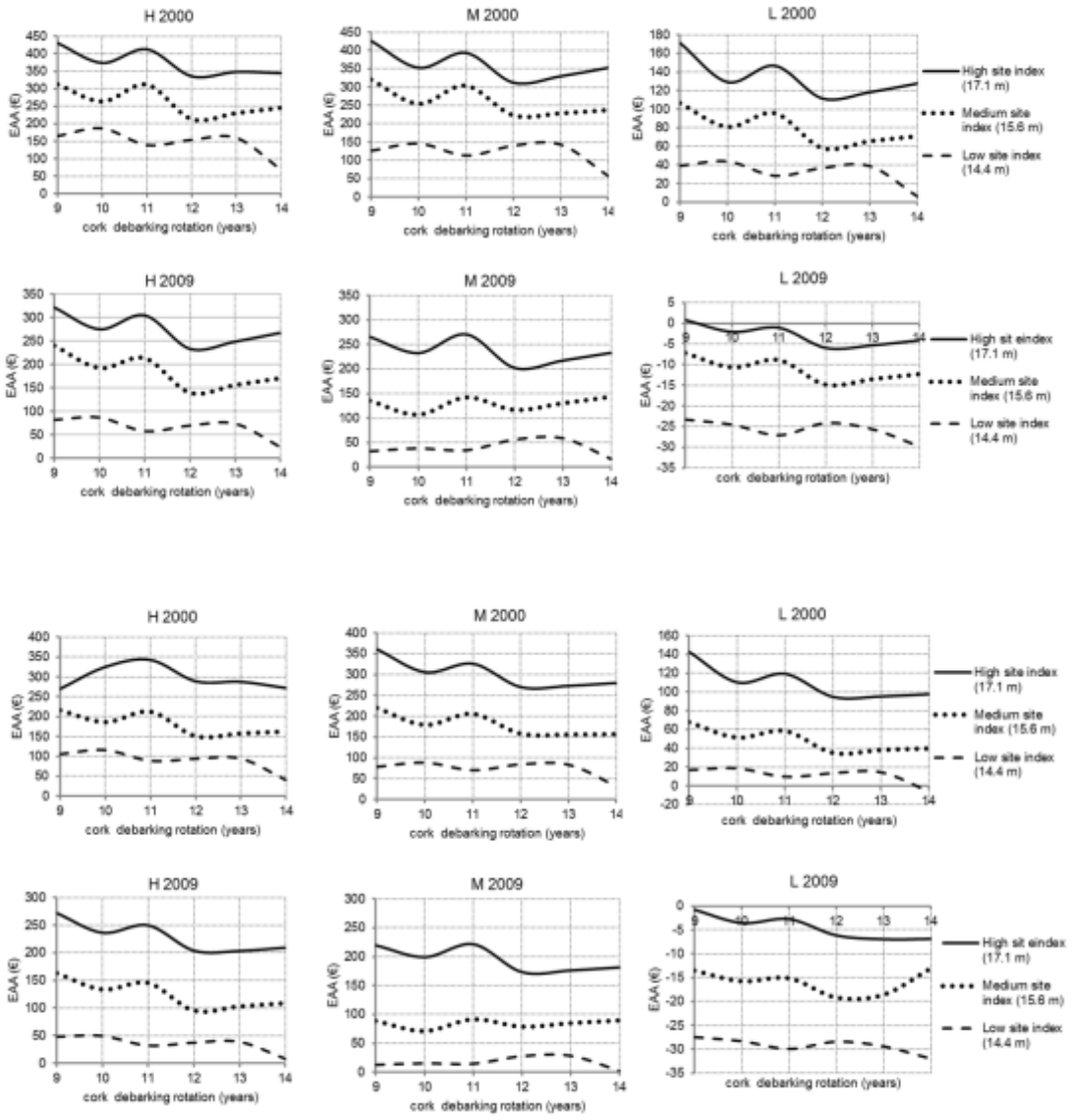
2.2.1.2.2 Webcorky application

The WebCorky application can work with samples provided by the user (cork caliber and cork quality for each cork sample, or the cork calibre for each cork sample and a distribution of cork quality). In the exercise that is used to illustrate the WebCorky tool, its result is shown for one calibre distribution combined with 3 cork quality distribution.

2.2.1.3 Results and discussion

2.2.1.3.1 Results from SUBER

Figure A presents the results from the simulations carried out considering discount rate values of 0.5%, 2% and 5%, respectively. They present the values of EAA obtained for each simulated stand and each cork price structure considered, as a function of the CDR. The analysis of the effects of different site indexes, cork quality and thickness distributions and cork price structures on the CDR that maximizes EAA are presented in the following section (Figure 3) with a discount rate of 0.5%. More details can be seen in Paulo et al. (submitted).


H 2000
M 2000
L 2000
H 2009
M 2009
L 2009
EAA (€)
cork debarking rotation (years)
High site index (17.1 m)
Medium site index (15.6 m)
Low site index (14.4 m)
High sit eindex (17.1 m)

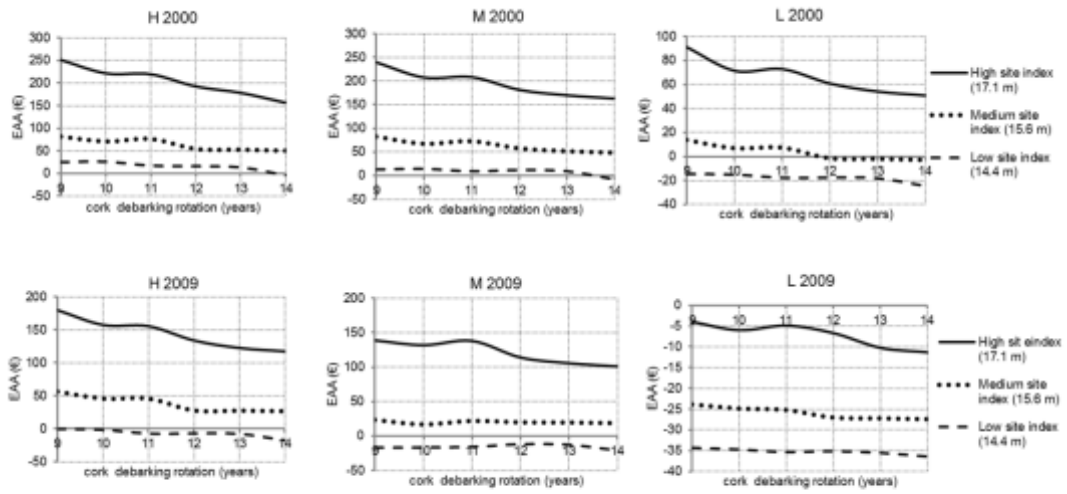


Figure 3. Equivalent annual annuity (EEA) as a function of cork debarking rotation for stands with different site index (14.4 m, 15.6 m or 17.1 m, represented by the different lines), different cork price structures (year 2000 and year 2009). The H, M and L initials identify stands with high, medium or low fraction of good quality and thick corks, respectively.

The conclusions of the study can be summarized as follows:

- The three considered variables (site index, cork quality and thickness distribution, and cork price structure) influence EAA value.
- The two most impacting variables on the CDR that allows maximizing the EAA are site index and the cork quality and cork growth index distributions. The variation of EAA due to the CDR extension was evidenced in scenarios considering 0.5% or 2% of discount rates. For these simulations similar values of EAA were obtained by postponing the debarking for CDR values of 11 years, for stands characterized by high or medium site index and high or medium cork characteristics (quality and growth index). Stands characterized by low site index or low cork characteristics presented lower, constant, and in some cases negative EAA values, despite the CDR considered in the simulations.
- For 5% discount rate the extension of the CDR period systematically originates a reduction of the EAA value, suggesting the increase of the number of cork extractions instead of the increase of cork thickness as a result of the CDR postponement.

2.2.1.3.2 *Results from Webcorky*

Figure 4 shows the results the caliber distribution and the 3 cork quality distributions used. The WebCorky tool provides, among other outputs, the graphs that will support the user in the decision of when to debark (Figure 5).

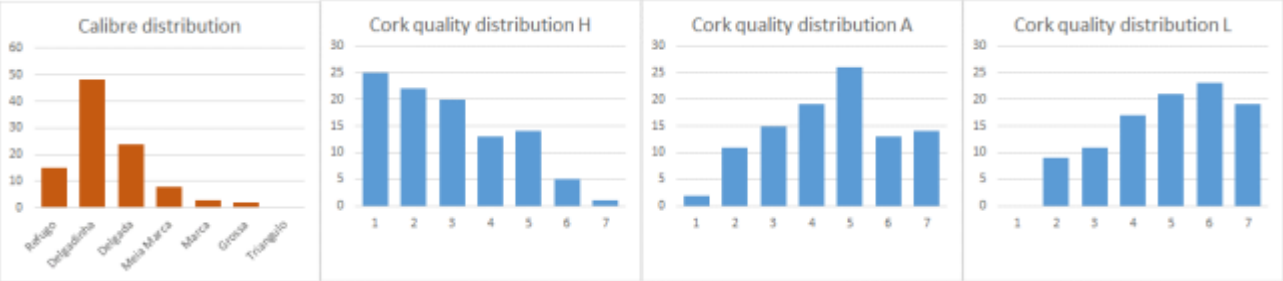
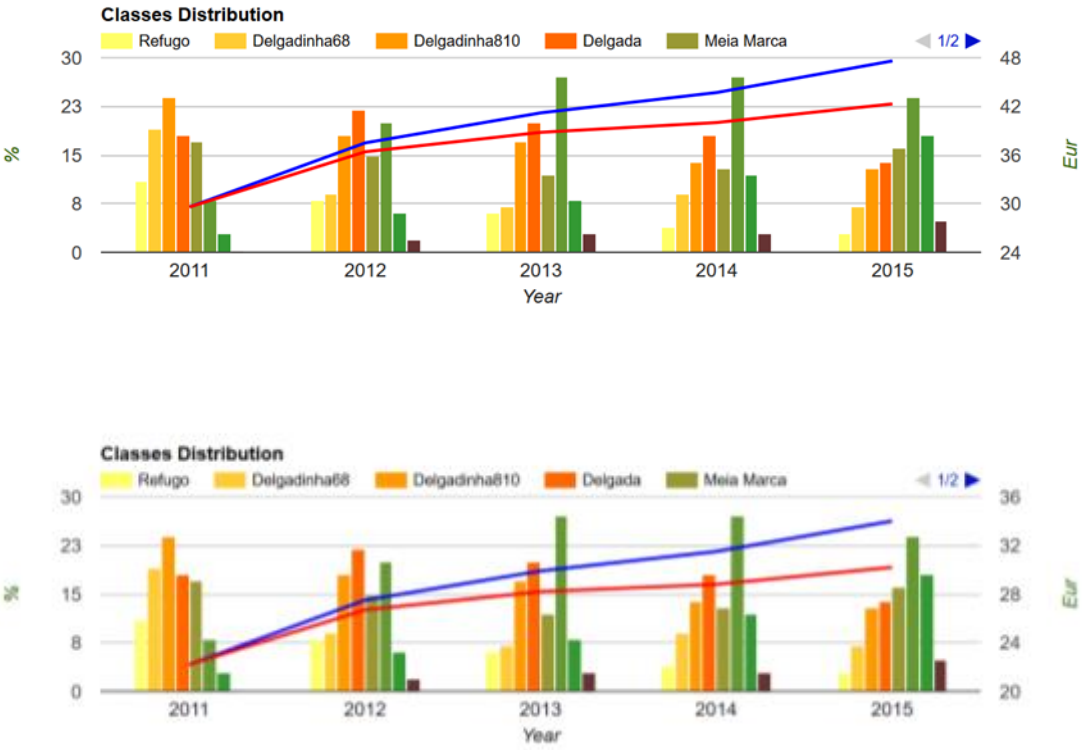


Figure 4. Calibre distribution and the 3 cork quality distributions that were used in this example of the potentialities of the WebCorky tool.



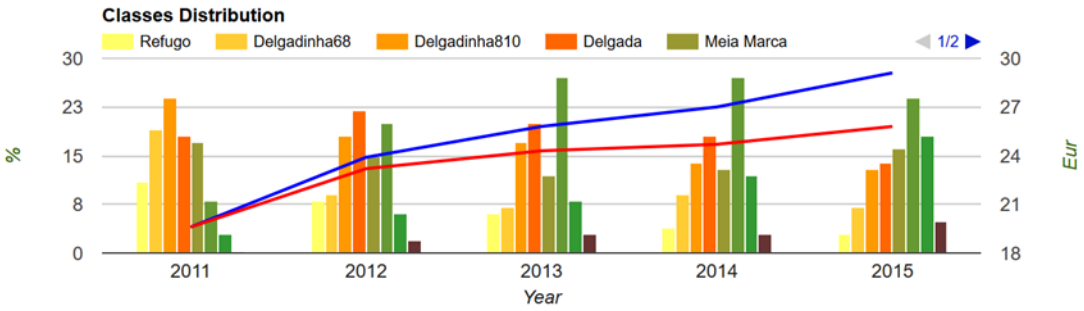


Figure 5. Simulation of the evolution of price over time for the same caliber distribution but considering different percentages of good quality cork (high on top, average on middle and low on the bottom). The blue line represents the average price and the red line the respective NPV.

2.2.2 Pine nuts – PineaManage and PINEA.pt

2.2.2.1 Use-situation

Existing stone pine stands are mostly naturally regenerated and in most cases the trees have not been object of any silvicultural treatments during their life-cycle. The growing importance of the revenues from pine nuts lead to a significant increase of stone pine area and has put some emphasis on the management of this species. With the exception of research on grafting techniques, research on silviculture and growth and yield of the species started just in the beginning of the XXI century. Therefore, the first tools are just appearing now and are starting to be used. There are two tools, which will soon be available at the FCTOOLS web site. It is easily accessible on www.isa.ulisboa.pt/cef/forchange/fctools/. The PINEAManage tool and the PINEA.pt model can be found at the standsSIM forest simulator.

2.2.2.2 DSS description, materials and methods

2.2.2.2.1 The PineaManage tool

As mentioned in D2.3 (Sheppard et al. 2016), there are very few adult plantations of *Pinus pinea* in Portugal and none of them is represented within the 100 permanent plots that are being monitored. For this reason, the PINEA.pt model (Freire, 2009) was implemented in the tool PINEA.manage with the objective to prescribe silvicultural guidelines for new Portuguese pine plantations. The PINEA.manage is an EXCEL tool that uses the PINEA.pt model for the average tree, extending it to stand information by multiplication by the number of trees/ha. The initialization of one simulation is made with a tree with 2 m of height and 0.5

cm of diameter whose age depends on the site quality. At present it assumes that, at this size, the trees are not yet competing. There is the need to study tree growth at this initial stage.

The PINEA.manage tool allows for the simulation of: different planting densities, considering the spacing between lines and between trees within the lines; and different thinning intensities. Site quality and type of trees (grafted or not) are also taken into account to prescribe a silvicultural system in a plantation. As an illustration, the tool was used to simulate a stand near Canha, the center of the main *Pinus pinea* area in Portugal with an average site quality (growth index as suggested by Freire (2009), equal to 1). A non-grafted stand was considered in this exercise, since there are few data for grafted stands, and eight initial densities 1111 (3x3), 625 (4x4), 400 (5x5), 278 (6x6), 204 (7x7), 156 (8x8), 123 (9x9) and 100 (10x10) trees per hectare. The planning horizon was 100 years.

The decision to thin the stand depends on the average distance between tree crowns. It uses the principle that at a plantation thinning should take place before crowns touch. In this exercise we considered a distance of 0.2 m between trees. Two types of systematic thinning were simulated:

1) 50% of trees in each thinning, removing 50% of the trees in each row;
2) 75% of trees in each thinning, removing half of the rows and 50 % of the trees at the remaining rows.

The NPV was computed for each alternative tested considering an interest rate of 3% for all described alternatives.

2.2.2.2.2 The PINEA.pt model implemented at standsSIM forest simulator

The PINEA.pt model was implemented within the standsSIM forest simulator, described in Barreiro et al. (2016) and integrated in the sIMfLOR interface (Faias et al. 2012). The PINEA.pt model is an individual tree model that allows the simulation of tree growth as well as pine weight (Freire, 2009). Pine weight includes climate variables as predictors, allowing for the simulation of masting. The model includes several modules: Growth – growth of tree variables, dynamic (principal variables); Prediction – static prediction of tree variables (derived variables); Computation – stand variables and SFM indicators; Silviculture – simulation of silvicultural treatments; Economical analysis – NPV, EAA, SEV. Being integrated within the standsSIM simulator and the sIMfLOR platform, it takes advantage of all the possibilities given by these tools: use of forest management approaches (even or uneven-aged) defined by the user; computation of NPV considering all the silvicultural operations that the user selects from a database that was built using the CAOF, which is the official list of prices for the silvicultural operations and updated every 2 years; possibility

to simulate different forest management approaches along the planning horizon. The possibility to simulate new stands by an uniform shelterwood system is being implemented and will be available soon. The PINEA.pt model is not yet available on the FCTOOLS because it is still under test, but also it will be available very soon. In this report it was used to simulate the growth and yield of a young plantation using a thinning regime with a 5 years cycle in which the decision to thin is taken on the basis of a residual basal area (Glim) and a threshold basal area (Glim*1.1). In a thinning year, the stand must be thinned if the measured basal area is greater than Glim*1.1 and should decreased till Glim. The initial stand density was 270 trees ha^{-1}, a dominant height of 5.5 m, a dominant diameter of 18.4 cm and a basal area of 5.89 m^2. The alternatives considered were Glim=5, 10, 15, 20, 30 m^2ha^{-1}.

The PINEA.pt model is also being included in the DSS sadFlor (Marto, 2016) so that it can be used at landscape decision support systems including optimization.

2.2.2.3 Results and discussion

2.2.2.3.1 The PineaManage tool

The number of trees per hectare, basal area and ground cover that lead to a larger NPV, considering five initial densities and two types of thinnings, are shown in Figure 6. Several conclusions can be drawn:

- At the end of the rotation the number of trees per hectare is considerably reduced regardless the initial density and type of thinning.
- Basal area per hectare and degree of cover slightly exceeds 12 m^2 ha^{-1} and 80%, respectively, at any initial density and type of thinning despite the fact that the minimum distance between the trees was used to decide about the occurrence of a thinning.
- The time between the first two thinnings is less than 10 years if 50% of the trees are thinned in a stand with the number of trees between 204 and 278 ha^{-1}. This is due to the small increment of the distance between trees after the first thinning (2.5 to 2.9 m).
- Thinnings occur in several prescriptions with low basal area and ground cover if the objective is to thin 50% of the trees. This may indicate that in certain circumstances the basal area per hectare may not be a good indicator for the realization of thinnings.
- Remaining basal area and ground cover after the last thinning are relatively small in several prescriptions which would allow forest manager to implement regeneration after the last thinning. However, the number of trees per hectare to be established should be lower than originally practiced since the existence of trees from the previous rotation must be taken into account. After

the harvest of the trees remaining from the previous rotation the number of trees per hectare may be increased in order to better use the available space. This would generate a stand with two stories.

Quadratic mean diameter and tree and stand cone evolution are represented in Figure 7. Conclusions from these results are as follows:

- Quadratic mean diameter evolution is highly influenced by thinning, namely if 75% of the trees are thinned leading to a high diameters at the end of the rotation.
- A strong difference between tree cone production can be found for the two thinning intensities. With the heavier thinning a great increase of tree cone production is predicted around 70 years especially in stands with higher initial space between trees.
- Various tree cone production peaks were observed at small ages regardless the type of thinning. This was due to the precipitation between January and May four years before cone harvest. In all cases it was higher than 650 mm, with a high impact on cone production per hectare.
- Cone production per hectare has three stages, independently of the thinning type. The first stage would last till around 40 years old. During this period the number of trees per hectare is more important for cone production per hectare than cone production per tree. This is the period in which the peaks described above took place. The second stage is between 40 and 70 years. During this period, cone production per hectare is relatively low. The third stage begins with the increase of cone production around 70 years. During this period, the cones per tree are more important for cone production than the density, especially in the case of heavy thinnings.

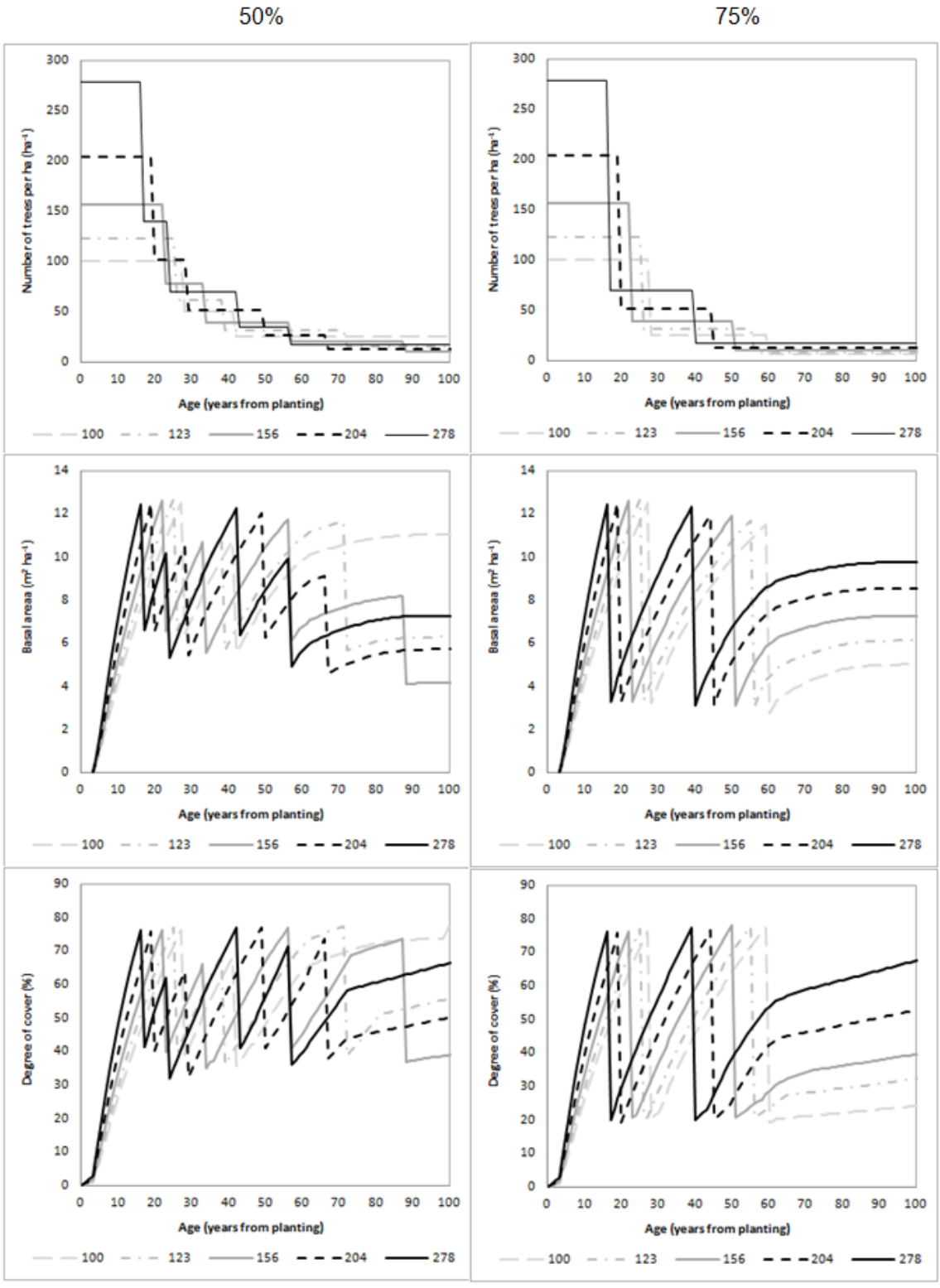


Figure 6. Stand evolution considering different initial number of trees per hectare and two thinning intensities (50 and 75% of the trees thinned).

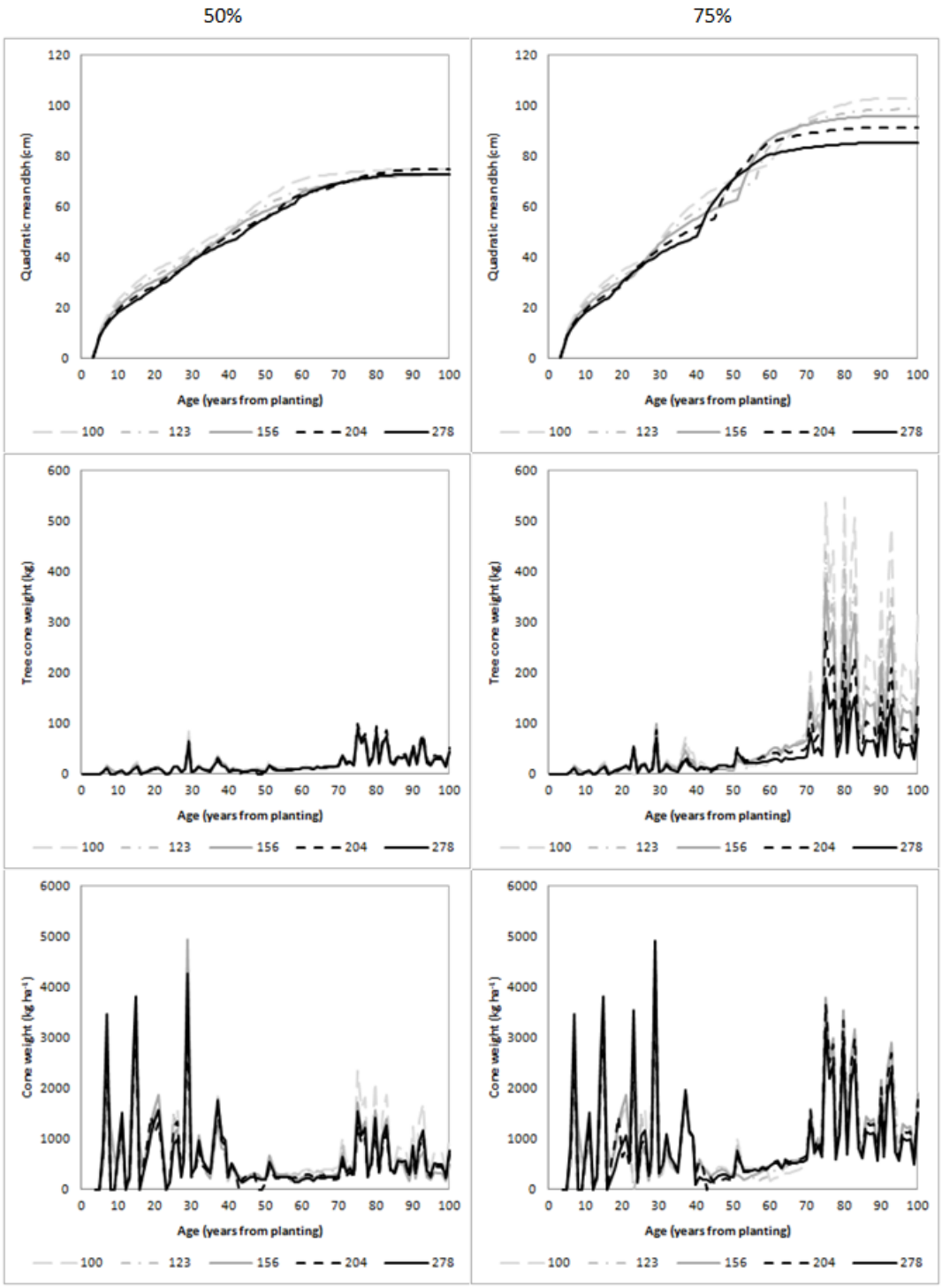


Figure 7. Quadratic mean dbh and tree and stand cone production evolution considering different initial number of trees per hectare and two thinning intensities (50 and 75% of the trees).

Tables 3 and 5 show the incomes from cones and biomass, costs from stand installation and maintenance and net present value (NPV) for the two thinning intensities (50% or 75% of the trees) when a rotation of 100 years is assumed and with initial densities listed above.

The calculations with the thinning intensity of 50% show that at least two pre-commercial thinnings before the stand reaches the age of 20 years and four later thinnings are needed for initial densities equal and above 400 ha^{-1} while for initial densities equal and below 278 ha^{-1} no pre-commercial thinning is needed. With this density, four later thinnings are needed. Taking into account the above assumptions, the highest NPV will be achieved with an initial density of 156 trees ha^{-1} (Table 3).

Table 3. Income from cones and biomass, costs and NPV for prescriptions considering a thinning intensity of 50%

Spacing		**3x3**	**4x4**	**5x5**	**6x6**	**7x7**	**8x8**	**9x9**	**10x10**
Initial density		**1111**	**625**	**400**	**278**	**204**	**156**	**123**	**100**
Income	Cones	233.32	215.06	217.59	263.43	255.63	263.36	254.71	260.28
	Biomass	0.35	0.31	0.27	0.23	0.21	0.18	0.15	0.15
	Total	233.68	215.37	217.86	263.66	255.84	263.54	254.86	260.43
Expenses	Installation	0.36	0.27	0.23	0.21	0.19	0.19	0.18	0.18
	Maintenance	4.28	3.71	3.44	3.30	3.21	3.16	3.12	3.10
	Total	4.64	3.98	3.67	3.51	3.41	3.34	3.30	3.27
NPV		229.03	211.39	214.19	260.15	252.43	**260.20**	251.56	257.16

Table 4 presents a selected prescription, considering the age when each thinning takes place, the diameter at breast height (*d*), crown diameter (*cw*), the minimum distance between crowns (*minDist*), the number of trees per ha (*N*), basal area (*G*) and percent crown cover (GC) before and after the thinning takes place.

Table 4. Description of the selected prescription considering a thinning intensity of 50% of the trees

Parameters / **Treatment**	***Age***	***d***	***cw***	***minDist*** **(m)**		***N*** **(tree ha^{-1})**		***G*** **(m^2 ha^{-1})**		***GC*** **(%)**	
				Before	After	Before	After	Before	After	Before	After
	23	32.7	7.9	8.0	11.3	156	78	12.5	6.5	76.1	39.7
Thinnings	33	42.5	10.4	11.3	16.0	78	39	10.7	5.5	66.0	34.9
	55	62.6	15.9	16.0	22.6	39	20	11.8	6.2	76.9	40.9

	75	82.6	21.8	22.6	32.0	20	10	10.5	5.4	74.9	38.5
Final cut	100	111.2	25.3			10		9.7		50.2	

When a thinning intensity of 75% is considered, at least one pre-commercial thinning before 20 years and two later thinnings are needed for initial densities equal and above 400 ha-1 while no pre-commercial thinnings and just two later thinnings are needed for initial densities equal and above 278 ha^{-1}.

Also in this case, the highest NPV will be achieved with an initial density of 156 trees ha^{-1} (Table 5).

Table 5. Income from cones and biomass, costs and NPV for prescriptions considering a intensity of thin of 50%

Spacing		**3x3**	**4x4**	**5x5**	**6x6**	**7x7**	**8x8**	**9x9**	**10x10**
Initial density		**1111**	**625**	**400**	**278**	**204**	**156**	**123**	**100**
Income	Cones	232.32	312.71	274.51	277.77	355.12	370.61	342.25	310.49
	Biomass	0.24	0.16	0.09	0.16	0.12	0.10	0.09	0.07
	Total	232.56	312.87	274.59	277.93	355.24	370.71	342.34	310.55
Expenses	Installation	0.36	0.27	0.23	0.21	0.19	0.19	0.18	0.18
	Maintenance	4.09	3.61	3.38	3.26	3.18	3.14	3.10	3.08
	Total	4.45	3.88	3.61	3.47	3.38	3.32	3.28	3.26
NPV		228.11	308.99	270.98	274.46	351.86	**367.39**	339.06	307.29

Table 6 presents a description of the selected prescription, considering the age when each thinning takes place, the diameter at breast height (*d*), crown diameter (*cw*), the mean distance between crowns (*Dist*), number of trees per ha (*N*), basal area (*G*) and percent crown cover (%) before and after the thinning takes place.

Table 6. Selected prescription when the thinning intemsity is 75% of the trees

Parameters / Treatment	***Age***	***d***	***cw***	***Dist* (m)**		***N* (ha^{-1})**		***G*** ($m^2\ ha^{-1}$)		***GC* (%)**	
				Before	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**
Thinnings	23	32.7	8.2	8	16	156	39	12.6	3.3	76.1	20.5
	50	62.5	16.1	16	32	39	10	11.7	3.1	76.7	20.4
Final cut	100	121.9	25.8	32		10		11.7		52.1	

It is important to point out that most of the data used to develop the PINEA.pt model was from naturally regenerated stands in which trees are not equally distributed in the stand being usual that existing trees

compete with their neighbors even in sparse stands. Thus, some extrapolation is being done when simulating new planted stands.

2.2.2.3.2 The PINEA.pt model implemented at standsSIM forest simulator

Figure 8 shows the simulation of the growth and yield of a young plantation using a thinning regime with a 5 years cycle in which the decision to thin is taken on the basis of a residual basal area (Glim) and a threshold basal area (Glim*1.1). In a thinning year, the stand must be thinned if the measured basal area is greater than Glim*1.1 and should decreased till Glim. The initial stand density was 270 ha^{-1}, a dominant height of 5.5 m, a dominant diameter of 18.4 cm and a basal area of 5.89 m^2. The alternatives considered were Glim=5, 10, 15, 20, 30 m^2ha^{-1}. In what concerns tree and stand growth, the results are as expected for the impact of increasing stand density. The important results are the ones on the figure on the bottom right that exhibits the prediction of cone weight over time for the different thinning alternatives tested (Figure 6). These results show that using a constant threshold basal area (Glim) as a criterion for thinning does not necessarily produce a good result. Predicted cone weight in young ages is higher in higher basal areas while this result is inverted as the stand grows. At the end of the simulation period, it is clear that the smaller the basal area, the bigger are the trees and higher is the predicted cone weight. These findings suggest the use of an optimization algorithm to find the best combination of residual basal area that optimizes cone production or the use of different criterion to decide about the need to thin, e.g. average crown distance. This is easy to implement on the field, even without the need to do a traditional forest inventory to support the decision of thinning (as is the case when the criteria is the basal area).

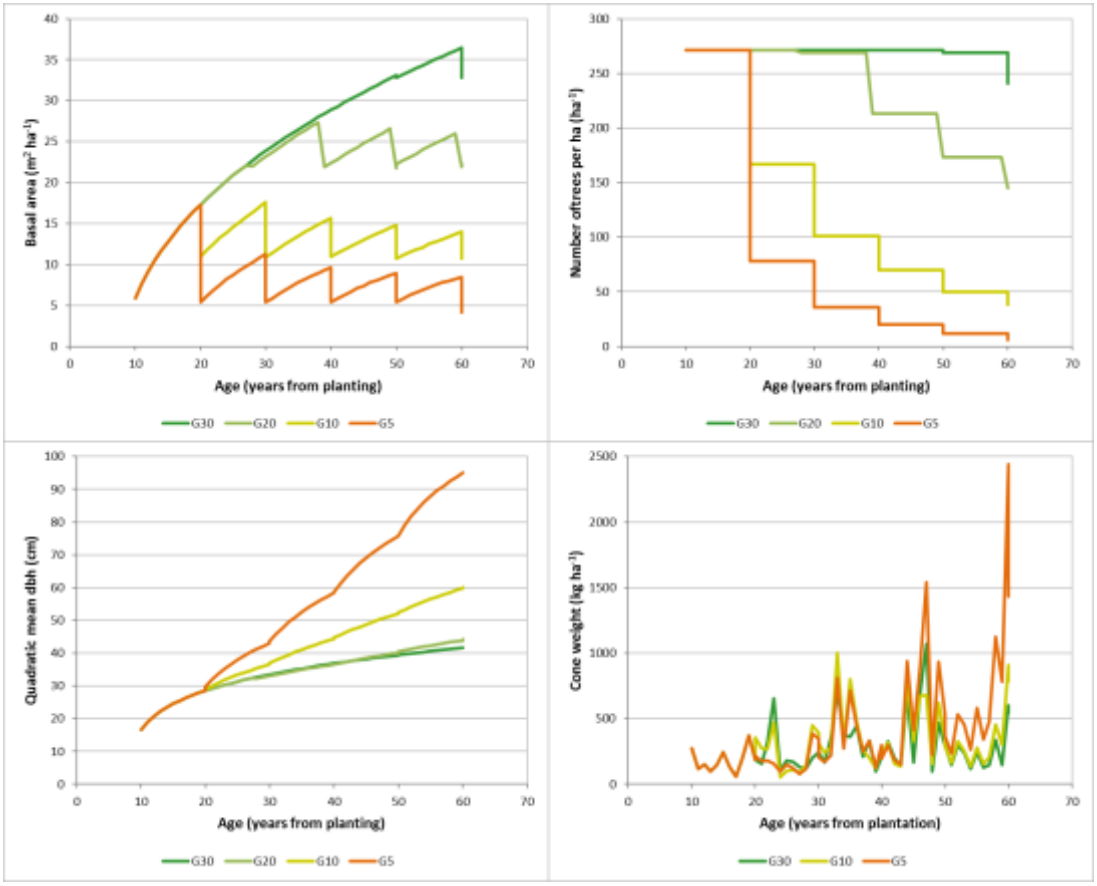


Figure 8. Stand evolution and cone production for 4 different thinning intensities defined by a threshold basal area.

The results of the simulations made so far suggested that standsSIM should simulate other thinning schemes that are not based on a thinning cycle and this improvement is taking place. Figure 9 shows the relationship between net present value and the threshold basal area when this is used as a criterion for thinning.

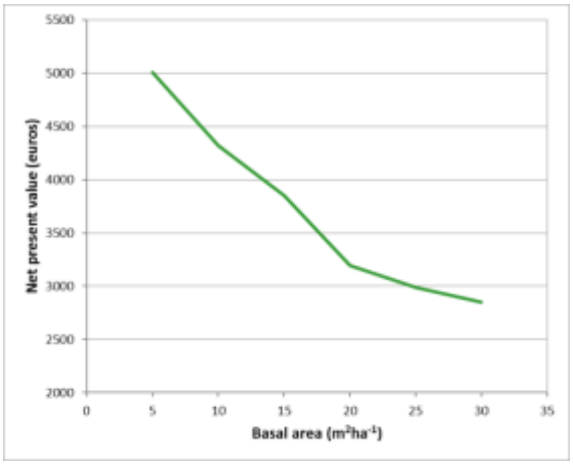


Figure 9. Net present value as a function of the different threshold basal areas.

2.3 Spain

2.3.1 Pinus pinea

Authors: MPT, TP, RC, IC, MSG

Pinus pinea and *Quercus suber* are the most important Multi-Purpose Trees (MPT) in Spain. Together with mushroom production they represent the most important sources of NWFP from the commercial point of view. In order to optimize the profitability of these products, different studies have been carried out at the stand level in Spain. In this sub-chapter, the optimization results from joint production of timber and cones in *P. pinea* stands in Spain will be presented. The materials are extracted from Pasalodos-Tato et al. (2016a).

2.3.1.1 Use-situation

Pinus pinea stands have been traditionally managed to obtain either cones or timber. Considerations regarding the joint production of both outcomes based on quantitative analyses has been ignored. The objective of the study was the optimization of the joint production of timber and cones at the stand level. This objective is especially relevant considering the masting habit that *P. pinea* presents, which covers three years. In this respect, a model has been developed that allows for the prediction of seed production in a certain year based on climatic variables of former years (Calama et al. 2011). The use of this type of predictors makes it difficult to use the model for planning purposes. Climate scenarios need to be developed to allow the model to be used for simulations. Within this context, the present study aims to develop a simulation-optimization system that finds the optimal management of *P. pinea* stands, in terms of SEV, as a function of economic parameters and characteristics of the stand, and use the system to find the optimal management of typical stands in the joint production of timber and cones.

2.3.1.2 DSS description, materials and methods

2.3.1.2.1 Scenario approach

The scenario technique (Wets 1989) was used in the simulation optimization system with the aim of integrating the stochasticity derived from climate and the cone production model (Calama et al. 2011). In this study, 500 stochastic climate scenarios were produced for the cone production of each analyzed management schedule, making it possible to calculate the expected cone yield along stand development.

To calculate the SEV, all costs and incomes were discounted to the beginning of the rotation. It was assumed that exactly similar rotations are repeated to infinity.

2.3.1.2.2 Climate scenarios

The model for predicting cone production (Calama et al. 2011) includes climatic variables as predictors. To use it, models were developed for those climatic variables that are predictors in the cone production model (see Pasalodos-Tato et al. 2016a for further details).

2.3.1.2.3 Analysed stands

Two different stone pine stands were chosen to illustrate the model. Both stands presented similar characteristics in terms of site index, but differed in stand density (Table 7).

Table 7. Summary of the characteristics of the analyzed stands.

	Stand 1	**Stand 2**
Age (years)	20	27
SI	21.2	20.6
N (trees ha-1)	715	296
dg (cm)	18.60	20.48

2.3.1.2.4 Growth and yield models

The growth and yield models employed to simulate the development of the *Pinus pinea* stands in Spain were the same as in the PINEA2 software (Pereira et al. 2015). The only difference is that PINEA2 uses the cone production model from Calama et al. (2008), which does not take into account climatic variables. Our simulator employed the cone production model of Calama et al. (2011), which allows for the prediction of cone production in a certain year based on climatic variables of former years. Moreover, an adaptation of the model for infection level caused by *Phellinus pini* by García-Güemes and Montero (1998) was developed in order to find out the proportion of rot that occurred in our simulations.

2.3.1.2.5 Economic parameters

The economic parameters needed for calculating SEV were discount rate, treatment costs and cone and timber prices. The cost parameters included regeneration and tending costs, and harvesting costs (Table 8). The timber assortments and stumpage prices were used: 30 € m^{-3} for grade I timber (top diameter (dtop) ≥ 40 cm), 18 € m^{-3} for grade II timber (40 cm > dtop ≥ 30 cm), 13 € m^{-3} for grade III timber (30 cm > dtop ≥ 20

cm) and 5 € m^{-3} for grade IV timber (dtop < 20 cm). The firewood prices were 8 € Mg^{-1} for branches thicker than 7 cm and 1.5 € Mg^{-1} for branches between 2 and 7 cm in diameter. The stumpage price of cones was 0.3 € kg^{-1}. Other prices were used when the effect of cone price was analyzed, namely 0, 0.1 and 0.5 € kg^{-1}. It was assumed that it was not profitable to collect cones unless the production was higher than 10 kg ha^{-1}. Three discount rates were used (1%, 3% and 5%) in order to cover varying economic conditions. Management of both initial stands was optimized with every combination of discount rate and cone price.

Table 8. Unit costs of silvicultural treatments in P. pinea stands.

Class		Year	Unit	Costs
Afforestation		0	€ ha^{-1}	620
Pre-commercial thinnings				
	First	10	€ ha^{-1}	336
	Second	25	€ ha^{-1}	289
Pruning				
	First	15	€ ha^{-1}	229
	Second	30	€ ha^{-1}	301
	Third	45	€ ha^{-1}	413
Commercial thinnings				
	Entry cost		€ ha^{-1}	100
	Shrub cleaning			50
	Residue treatment			10

2.3.1.2.6 Optimization methods

The optimization algorithm employed in this study was the Hooke and Jeeves' direct search method (Hooke and Jeeves 1961). This is a non-linear programming algorithm that is one of the most suitable techniques for stand-level optimization and it has been widely employed on the literature (see Hyytiäinen 2003 and Pasalodos-Tato 2010 for references). Moreover, it has also been applied in studies dealing with the joint production of timber and different NWFP (Palahí et al. 2009, Miina et al. 2010, de Miguel et al. 2014a) showing a good performance. The convergence of this method to the global optimum is not guaranteed with objective functions which are neither convex nor differentiable (Miina 1998). Because of this, optimizations were repeated 11 times, each run starting from the best of 100 random combinations of decision variables, except the first one, which started from a user-defined starting point.

2.3.1.2.7 Decision variables

The management schedule was defined by thinnings and rotation length. Thinnings were uniform thinnings and final fellings were shelterwood cuts in two stages with a time step of 10 years between them.

2.3.1.3 Results and discussion

2.3.1.3.1 Effect of cone prices on the optimal stand management

Analyzing the results obtained (Table 9) it can be concluded that management was never profitable without cone harvesting in the analyzed stands and under the analyzed economic conditions. When cone price was zero, i.e. cone production was not considered as a source of income, the SEV of the optimal management schedule was negative for both stands. In Stand 1 when discount rate was 3% and the revenues from cones were included (0.1 € kg^{-1}) forestry became profitable. In Stand 2, which is a less dense stand, positive SEV was obtained only when cone price was equal or higher than 0.3 € kg^{-1}. In both stands higher cone prices increased the optimal rotation length (Figure 10). The effect of cone prices on cone production shows that when cone price increased, the rotation length increased in both Stand 1 and 2 and the production of cones also increased.

Table 9. Effect of the cone price on the SEV and rotation length of stands 1 and 2 (r=3%).

	Cone price (€ kg^{-1})			
	0 € kg^{-1}	0.1 € kg^{-1}	0.3 € kg^{-1}	0.5 € kg^{-1}
Stand 1				
SEV (€ ha^{-1})	-1163	177	3512	6491
SEV without cones (€ ha^{-1})	-1163	-1510	-1730	-1397
Effect of cones (€ ha^{-1})	0	1686	5242	7888
Mean annual cone yield (kg ha^{-1} yr^{-1})	376.38	759.85	895.30	914.04
Mean annual cone yield (kg $tree^{-1}$ yr^{-1})	1.58	2.34	3.18	6.03
Rotation length	59	105	127	254
Stand 2				
SEV (€ ha^{-1})	-1276	-596	1127	3379
SEV without cones (€ ha^{-1})	-1276	-1281	-1855	-1899
Effect of cones (€ ha^{-1})	0	684	2982	5297
Mean annual cone yield (kg ha^{-1} yr^{-1})	358.92	396.31	545.16	634.86
Mean annual cone yield (kg $tree^{-1}$ yr^{-1})	2.45	2.55	2.88	3.04
Rotation length	91	91	132	136

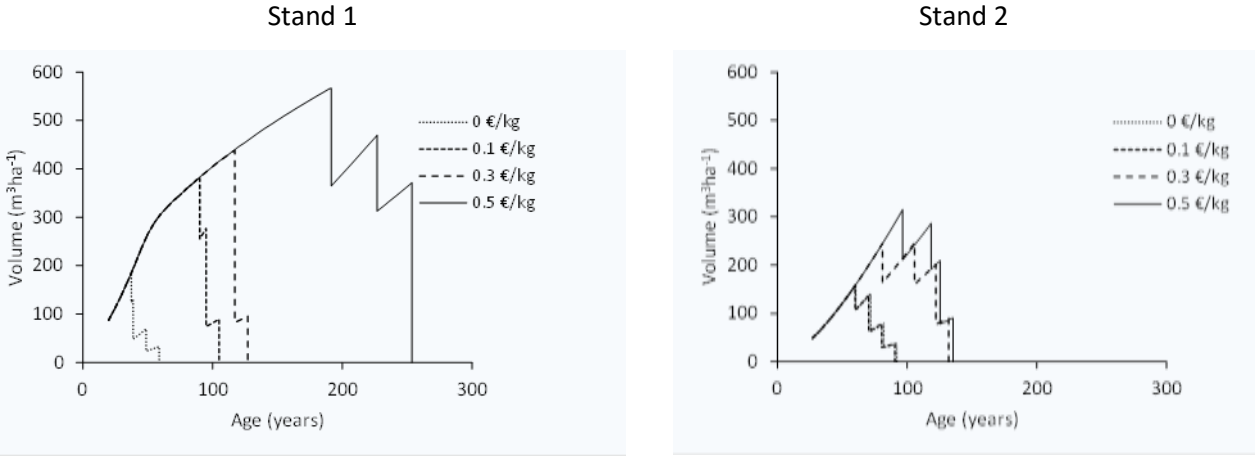


Figure 10. Stand volume as a function of age in the optimal schedules for Stands 1 and 2 with different cone prices (0, 0.1, 0.3 and 0.5 € ha^{-1}) when discount rate is 3%.

2.3.1.3.2 Effect of discount rate on optimal stand management

To depict the effect of discount rate on the optimal management schedules of *P. pinea*, two additional discount rates were tested, namely 1% and 5%. The results showed that the higher the discount rate was, the shorter was the optimal rotation length in the joint production of cones and timber (Table 10, Figure 11). The effect of discount rate on cone production was significant. When discount rate decreased, increased rotation length increased the mean annual cone production.

Table 10. Effect of different discount rate on the optimal schedule of stands 1 and 2 when cone price is 0.3€ kg-1.

		Discount rate		
		1%	3%	5%
Stand 1				
	SEV (€ ha^{-1})	22587	3512	663
	SEV without cones (€ ha^{-1})	-595	-1730	-1631
	Effect of cones (€ ha^{-1})	23181	5242	2294
	Mean annual cone yield (kg ha^{-1} yr^{-1})	940.76	895.30	779.44
	Mean annual cone yield (kg tree^{-1} yr^{-1})	4.14	3.18	2.60
	Rotation length	170	127	110
Stand 2				
	SEV (€ ha^{-1})	19794	1127	-304
	SEV without cones (€ ha^{-1})	-1372	-1855	-1319
	Effect of cones (€ ha^{-1})	21166	2982	1015
	Mean annual cone yield (kg ha^{-1} yr^{-1})	911.05	545.16	309.55
	Mean annual cone yield (kg tree^{-1} yr^{-1})	6.42	2.88	2.11
	Rotation length	354	132	91

Stand 1 Stand 2

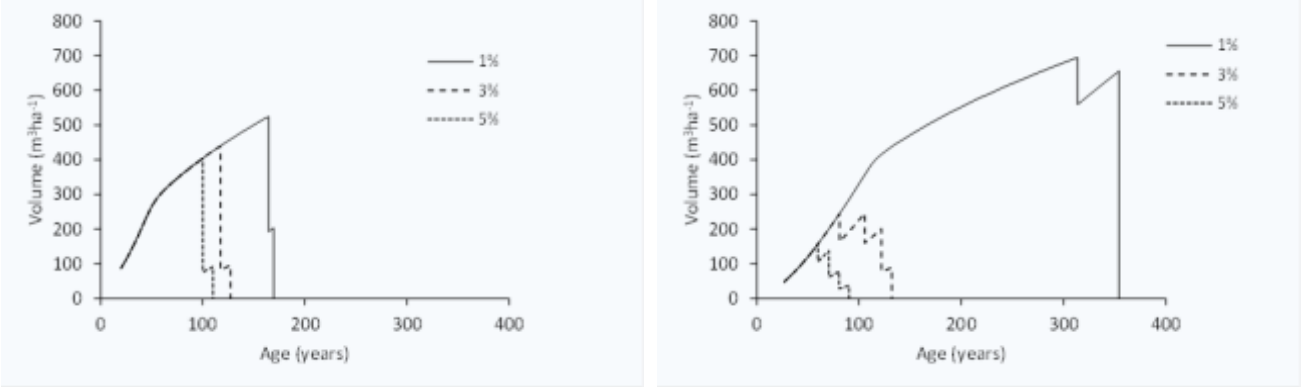


Figure 11. Optimal management schedules for stands 1 and 2 for different discount rates (1, 3 and 5%) when cone price is 0.3 € kg^{-1} as a function of the age and maximum diameter of the stand.

2.3.2 Quercus suber

Authors: MPT, TP, IC, MSG

2.3.2.1 Use-situation

Cork is the outer part of the cork oak bark and it is the main product obtained from cork oak stands. Cork oaks are debarked every 9-12 years. In Catalonia, the debarking interval can be up to 14 years. Despite the importance that cork has in the economy of those regions where it is produced, until now no economic analyses has been performed focused on the optimal management of cork oak stands with special consideration in the periods between debarkings. The present study is extracted from Pasalodos-Tato et al. (2016b). It focused on analyzing how economic conditions can influence the debarking management schedules of cork.

2.3.2.2 DSS description, materials and methods

2.3.2.2.1 Analysed stands

The study is focused in the South of Spain, in the Natural Park of "Los Alcornocales" that is one of the most important cork producing areas in Spain and can be considered representative of Spanish cork oak forests.

The area is located in the region of Andalucia where different stands are analyzed, in terms of cork thickness and site index. In the first case three stands that differ on the cork thickness will be analyzed to test the influence of cork thickness in the optimal management of *Quercus suber* stands (stands 1, 2 and 3) (Table 11).

Table 11. Summary of the characteristics of the analyzed stands.

	Stand 1	**Stand 2**	**Stand 3**	**Stand 4**
***Age* (years)**	20	20	20	20
SI	14	14	14	8
***N* (trees ha^{-1})**	625	608	618	625
d_g (cm)	16.65	15.51	16.93	6.92
***Cork thickness* (9 years) (mm)**	20.47	29.52	38.67	28.35

2.3.2.2.2 Growth and yield models

Models that describe the height and diameter growth of the dominant trees (Sánchez-González et al 2005), annual diameter increment (Sánchez-González et al. 2006) and the height-diameter relationship (Sánchez-González et al. 2007a) were employed to simulate the development cycle of the cork oak stands. For simulating the production cycle the model used was the cork growth model developed by Sánchez-González et al. (2008). For initializing the cork of the thickness before the first debarking, the model developed by Sánchez-González et al (2007b).

2.3.2.2.3 Economic parameters

Cork and firewood costs used in the study were 240 € t-1 for virgin cork and in the case of reproduction cork we differentiate the cork which is suitable to make stoppers (that cork thicker than 27 mm- quality 1) from the one that does not achieve that dimension as is used in the disintegration industry (quality 2). The price of cork used for stoppers (quality 1) is 1200 € t^{-1} and the cork for disintegration (quality 2) is assigned the same price as virgin cork (240 € t^{-1}). In order to analyze the effect of cork price in the optimal management, different prices were tested to carry out a sensitivity analysis. The demand for *Quercus suber* timber has not been reflected in the Spanish statistics and, therefore, it is assumed that all the timber from *Quercus suber* will be sell as firewood, with a price of 30 € t^{-1}. Three discounting rates were used (1%, 3% and 5%) in order to cover varying economic conditions.

2.3.2.2.4 Optimization method

The optimization algorithm employed in this study is the Hooke and Jeeves' direct search method (1961).

2.3.2.2.5 Decision variables

In the case of *Quercus suber* stands the management schedule is defined by strippings, thinnings and rotation length. The decision variables of this study were:

- For stripping: Number of years since the previous stripping (for the second one)
- For thinnings: Stand age (in the case of the first thinning) or number of years since the previous thinning (for the second one) and percentage of low thinning (% of number of trees).
- For final felling: Number of years since the last thinning.

2.3.2.3 Results and discussion

From the previously described study the following aspects related to the optimal management of *Quercus suber* stands were analysed:

-Effect of cork thickness (quality) in the optimal stand management:

Three different cork thicknesses were tested in order to analyze cork quality in the optimal management of cork oak stands. Cork thickness is used as subrogate of cork quality. The results of these analyses shows that stands with higher cork thickness present longer rotations lengths and thinnings are delayed while the number of debarking increases for the stands that present higher cork thickness (see Sheppard et al 2016).

-Effect of discounting rates on the optimal stand management

The influence of the discount rate is similar to the cork thickness influence. An increase in the discount rate leads to longer rotation lengths and a delay in thinnings. The number of debarkings increases with a decrease in discount rates, while the period between debarkings decreases (see Sheppard et al in preparation for further details).

-Effect of cork price on the optimal stand management

The effect of fluctuations in cork market prices is not as drastic as in the former cases analyzed. When cork prices of quality 1 and quality 2 decrease in 30%, rotation length decrease and thinnings occurred earlier. The number of debarkings decreases and also decrease the number of years between debarkings (see Sheppard et al. 2016).

2.3.3 *Pinus sylvestris and ecosystem services*

Authors: CG, SDM, SS,JMDA, JAB

2.3.3.1 Use-situation

Forest goods and services are gaining increasing importance throughout Europe (Forest Europe, 2011). Furthermore, multifunctional forest management in Southern Europe is crucial to improve forest sustainability and profitability in Mediterranean countries, within a framework of low profitability of timber harvesting and increasing risk of forest hazards, mainly due to forest fires. In Mediterranean countries also the climate change context much be considered. Among the most valued Mediterranean forest products, mushrooms represent the most relevant and appreciated product in several regions such as Catalonia (Northeast Spain). Mushrooms may be considered both as a forest good, because is usually sold in the markets, and a forest service, due to the increasing demand of the recreational activity related to mushroom picking.

Other important forest services that are gaining importance in the policy agenda of the South-European countries are related to water resources (see: www.planbleu.org). The increasing growing pressure on water resources, coupled with the expected decrease of the available water due to the climate change impacts in the Mediterranean basin, recommends managing forests so that the ecosystem services linked to water provision and availability are maintained.

In this context, forest managers need to tackle the challenge of combining in an optimal way multiple forest goods and services demanded by the society in a context of lack of profitability, absence of markets and global change. In this section, a new approach aiming at optimizing the management of P. sylvestris forests in Catalonia for the provision of multiple goods and ecosystem services under fire risk (extracted from Gracia et al. 2014) is introduced. In more detail the optimizing of multiple use of *P. sylvestris* forest stands is presented by considering not only timber and mushrooms (see Palahi et al. 2009 who addressed this issue), but also fire risk and the water use efficiency of the forest ecosystem.

2.3.3.2 DSS description, materials and methods

2.3.3.2.1 Modelling

For the management optimization of *Pinus sylvestris* stands for the provision of multiple goods and ecosystem services in a Mediterranean context, taking climate change projections into account, we

integrated mushroom yield and fire risk empirical models into the process-based model GOTILWA+ (Growth Of Trees Is Limited by Water). This model determines the dynamics of the forest simulating carbon and water uptake and fluxes through forests for single-tree species stands, and has been employed extensively for scientific research (Sabaté et al. 2002, Vicente-Serrano et al. 2010). GOTILWA describes the forest as a population of individuals, each of them having its particular size (diameter-DBH). The model is defined by extensive input data that include more than 90 parameters related to: climate (max. and min. temperatures, rainfall, vapor pressure deficit, wind speed, global radiation); stand characteristics (tree structure; DBH class distribution); tree physiology (photosynthetic and stomatal conductance parameters), site conditions including soil characteristics and hydrological parameters and forest management criteria (more detailed explanations of the GOTILWA+ simulator can be found in Mur et al. (2014)). Our analysis is based on a numerical study where we examine the optimal forest management of real forest stands of Scots pine located in Catalonia (Northeast of Spain), including fire risk models (González-Olabarria, non-published) and mushroom yield models (de-Miguel et al. 2014a) considering different climate scenarios and simulation conditions.

2.3.3.2.2 Climate scenarios and simulation conditions

In order to determine what is required for the optimal adaptation of forest management to CO_2 concentration trends, we considered three climate scenarios: no climate change (NoCC), and two RCP (Representative Concentration Pathways) scenarios defined by the Intergovernmental Panel on Climate Change (IPCC). The selected scenarios (RCP 2.6 and RCP 8.5), represent the most optimistic and the most pessimistic scenarios, respectively. In RCP 8.5 scenario, the CO_2 concentration is projected to reach the value of 936 ppm by the end of this century. As a consequence, the mean annual temperature can increase up to 5.6 °C with more moderate increase factor in December, January and February (4.6 °C), higher increase factors in June, July and August (6.8 °C), and an increase factor of 5.5 °C for the remaining months of the year. On the other hand, RCP 2.6 assumes that global annual GHG emissions peak between 2010-2020, with emissions declining substantially thereafter. Across all the RCP scenarios, global mean temperature is projected to rise by 0.3 to 4.8 °C by the late 21st century with a precipitation decrease up to 30 per cent by the end of the century in the most extreme scenario. In addition to these transient changes an effect of rainfall concentration and increase of the intensity of rainfall episodes is simulated. This changes result in a reduction of the number of wet days (days with precipitation), an increase of the probability of extreme rainfall events and, consequently, an increase of the standard deviation of the distribution of rainfall associated to the different rainfall episodes.

Two alternative soil depths of Scots pine stands, which affect the water capacity retention, were also considered in simulation: shallow soil (A03) with 52 cm depth and 108 mm of soil water holding capacity, and deep soil (B069) with 95 cm depth and 210 mm of soil water holding capacity.

2.3.3.2.3 Optimization technique

The multi-objective optimization method used was based on the particle swarm algorithm. The algorithm is initialized with a group of random particles (each is a combination of a set of management decisions) and then searches for the optimal one according to the objective function (Eberhart & Kennedy, 1995). Each particle updates its position according to two "best" values:

- The first one is the best solution achieved so far by a particle, which is named (**Particle best**).
- The second one is the best solution achieved so far by any particle whole set of particles, which is named (**Global best**).

After finding the above explained best values, particles update their position and velocity **(towards the best)**. The different forest management rotation lengths are randomly explored and the result on the objective function is examined. For each rotation length, thinnings (ranging from none to five) can be applied and the intensity of each thinning, measured as the basal area remaining after thinning, is also randomly explored between a minimum and a maximum thresholds defined by the user. The so-called **particle best** and **global best** values are determined for each particle and for the entire system at the end of each iteration and each particle moves according to the rules of the **particle swarm optimization algorithm** to converge to the optimal combination of decision variables which produce the optimal management (= the maximum value of the objective function).

In our case, the optimal management of each Scots pine stand was computed using SEV as the objective variable to be maximized. The SEV is defined as the net present value of infinite future net incomes. The calculations of NPV considers the incomes and production costs derived from different products. Specifically, the biomass produced, the mushroom yields or the carbon fixed over the rotation length are maximized while the water use efficiency (i.e. amount of water required to produce a cubic meter of wood) and the risk of fire are objectives to be minimized. The number of particles, the number of iterations, as well as the convergence criteria must be carefully considered in each particular application. Summarizing the above-mentioned information, the decision variables are: number of thinnings and time between thinnings, thinning intensity and rotation length considering six different scenarios (2 soils x 3 climate scenarios).

The considered management schedule includes tending at age of 15 years, with a fixed cost of 900 €/ha to leave the best 1200 trees/ha, four intermediate thinning with a final cut time and intensity to be optimized. Figure 12 summarizes the methodology followed in this study.

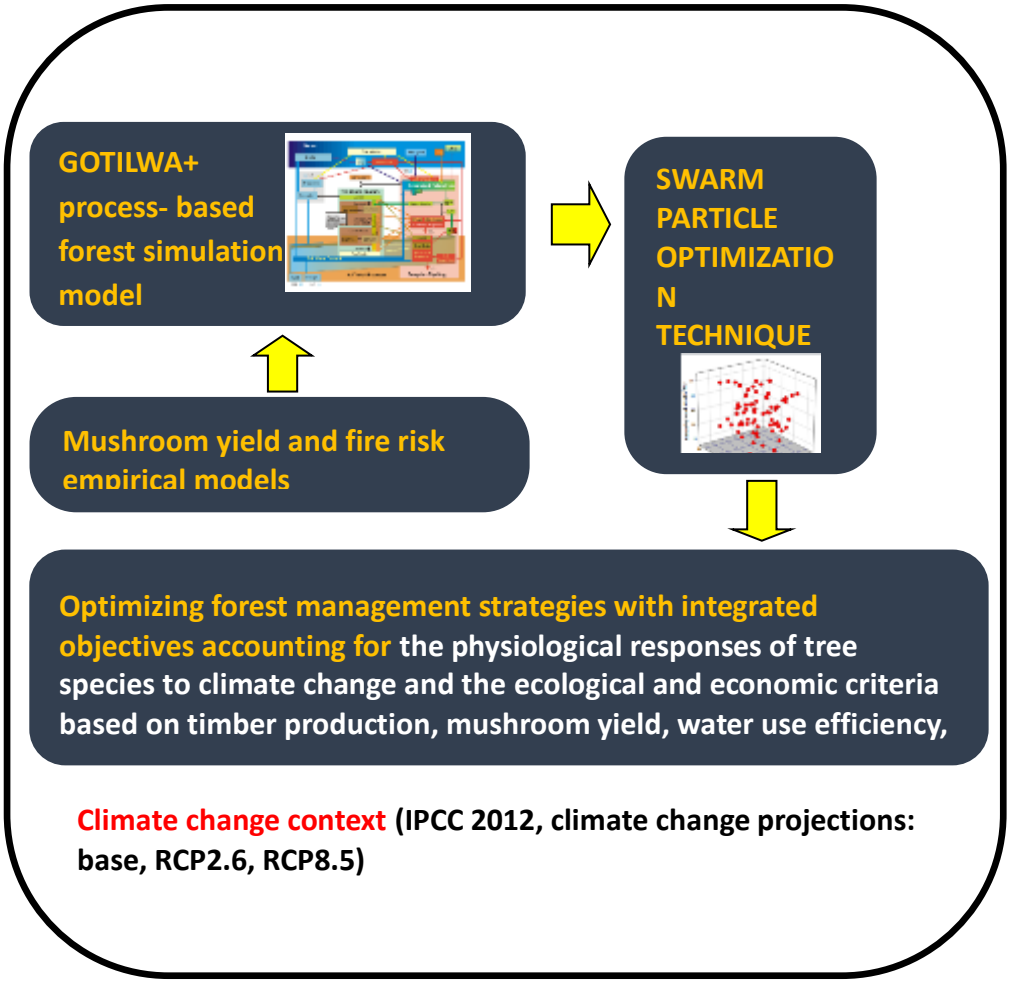


Figure 12. Flowchart of the simulation-optimization process

2.3.3.3 Results and discussion

The multifunctional management of *P. sylvestris* forests in Catalonia seems to be the most profitable. Based on the obtained results, when we considered mushroom yields in addition to timber production, the SEV increased in all scenarios. Additionally, the Water Use Efficiency (WUE, m^3 water/m^3 wood) and the wood production (m^3/ha/year) decreases and increases respectively in the presence of active forest management as compared to the non-management scenario (Table 12).

Table 12. Summary of the results regarding the different scenarios and products considered (in scenario names, the following abbreviations are used: A03= shallow soil, B069= deep soil, RCP 2.6= optimistic climate scenario (IPCC) and RCP 8.5=Pessimistic climate scenario (IPCC)).

OPTIMIZATION	Rotation Length (Years)	Starting Tree density (trees/ha)	SEV wood (€/ha)	SEV wood + Fire Risk (€/ha)	SEV wood+ Fire Risk+ Mushrooms (€/ha)	WUE (m^3 water /m^3 wood)	Wood Prod. (m^3/ha/year)
No Manag.	70	400	-187	-149	1807	1282	0.84
A03_RCP2.6 5C	70	400	1426	**689**	**2614**	528	1.83
% of SEV gain			**861**	**564**	**45**	**143**	**118**
No Manag.	65	400	-69	-61	1933	1106	0.88
A03_RCP8.5 5C	65	400	1840	**932**	**2841**	416	2.0
% of SEV gain			**2751**	**1612**	**47**	**166**	**130**
No Manag.	55	500	1736	969	3982	622	2.7
B069_RCP2.6 3C	55	500	3024	**1907**	**4407**	431	3.1
% of SEV gain			**74**	**97**	**11**	**44**	**15**
No Manag.	60	600	1028	777	3735	796	1.89
B069_RCP8.5 3C	60	600	4485	**2789**	**5621**	335	3.9
% of SEV gain			**336**	**259**	**51**	**138**	**109**

2.4 Turkey

Authors: SDM, TP, AY, JAB

2.4.1 *Pinus brutia* and pine honey

2.4.1.1 Use-situation

''Pine honey'' is a honeydew honey that represents an economically important non-wood forest product. Pine honey is produced from *Pinus brutia* forests mainly in western Turkey, but also in Greece, from where it is exported to other European countries. The honeydew from *P. brutia* forests is produced by a scale

insect, *Marchalina hellenica*, which feeds on tree sap. The insect excretes a white cotton-like fluff and exudates viscous sugary secretions (i.e., honeydew) from which honey bees produce pine honey. Due to its excellent physical and chemical properties, pine honey has a considerable economic value which contributes to the rural economies of the production areas. On the other hand, massive infestation of trees by *M. hellenica* seems to have a negative impact on forest growth and yield as well as on the provision of other ecosystem services. Determining the optimal forest management for maximizing the profitability of the joint production of pine honey and timber is a complex planning problem that can be tackled from a modelling and stand-level optimization perspective, which represented the objective of this study. The results of this sub-chapter are extracted from de-Miguel et al. (2014b).

2.4.1.2 DSS description, materials and methods

The simulation of *P. brutia* stand dynamics and management along with timber and honey production was based on even-aged forestry since this is the system traditionally applied to intensively managed *P. brutia* forests (Boydak 2004). The individual-tree forest management-oriented models published by de-Miguel et al. (2010) and a taper model published by de-Miguel et al. (2012a) were used to simulate growth and yield. Three alternative site indices accounting for good, medium and poor growing conditions for the pines were also considered in simulation-optimization. The initial stand age was 10 years for the good and medium site quality and 15 years for the poor site, the initial stand density being 1800 trees ha^{-1} in all cases. It was assumed that natural regeneration occurred after site preparation, and tending operations were assumed to occur in year 5 and year 10.

The negative effect of *M. hellenica* on tree growth in infested stands was subtracted from tree growth predictions for healthy stands using a multiplier (i.e. correction factor). For this purpose, tree diameter increment was predicted as a function of stand age for both infested and healthy trees based on Yeşil et al. (2005). In turn, the ratio between dbh increment in infested and non-infested trees was also modelled as a function of stand age, and this ratio was the multiplier accounting of the effect of tree infestation by *M. hellenica*. Thus, this correction factor was used to estimate the reduction of diameter increment and dominant height of infested trees from the growth model predictions for non-infested trees. Applying the correction factor to dominant height growth also allowed for updating site index, a predictor of diameter increment and self-thinning limit, after each simulated 10-year growth period.

It was assumed that pine honey production started in infested stands at the age of 35 years, when the infestation of trees may be relevant enough due to the existence of significant crevices and folds in the bark (Yeşil et al. 2005, Petrakis et al. 2010). In the absence of detailed scientific information about pine honey production per hectare in relation to stand development or structure, it was assumed that annual pine honey yield remains constant until final felling. Pine honey production was estimated from the average pine honey yield per hive and number of hives per hectare found in the literature. Since honey yield estimates per hectare based on previous research varied considerably, a sensitivity analysis accounting for the effect of pine honey production on optimal forest management was conducted using three alternative honey production scenarios: 30, 60 and 90 kg ha^{-1} yr^{-1}. Stumpage prices were assigned to typical timber assortments obtained from *P. brutia* (sawlog, pulpwood and firewood). The price assigned to pine honey was 7 US$ kg^{-1}. Site preparation costs were assumed to be 200 US$ ha^{-1}. Tending costs in years 5 and 10 were assumed to be 200 US$ ha^{-1} each. Pine honey production costs (i.e. material and labour costs, depreciation of hives, machinery, equipment and infrastructures, and autumn feeding of bees) were assumed to be 2 US$ kg^{-1}.

The optimization algorithm used was based on Hooke and Jeeves (1961). The objective function was the soil expectation value (SEV). It was calculated as follows using a 3% discount rate:

$$SEV = \frac{NPV}{1-\frac{1}{(1+i)^T}} = \frac{\sum_{t=0}^{T}\frac{Rw_t - Cw_t}{(1+i)^t} + \sum_{t=0}^{T}\frac{Rh_t - Ch_t}{(1+i)^t}}{1-\frac{1}{(1+i)^T}}$$

where Rw_t is revenues from all timber assortments in year t (US$ ha^{-1}), Cw_t is timber production costs in year t (US$ ha^{-1}), Rh_t is revenues from pine honey in year t (US$ ha^{-1}), Ch_t is pine honey production costs in year t (US$ ha^{-1}), i is discount rate (%), and T is rotation length (yr).

The decision variables were: (i) number of years since regeneration/planting to the first thinning, (ii) number of years since previous thinning, (iii) thinning intensity in every thinning (i.e. removed basal area in %), and (iv) number of years since the last thinning to the final cut. The best combination of the number of thinnings and the optimized decision variables was selected as the optimal schedule.

2.4.1.3 Results and discussion

The negative impact of *M. hellenica* infestation on *P. brutia* growth became more evident once stand age attained 35 to 40 years. At 50 years, the predicted dominant height of infested stands was approximately

7% lower than in healthy stands, and the mean dbh and growing stock were, respectively, 8% and 15% lower in infested stands. The predicted impact of *M. hellenica* infestation on tree mortality started to be perceptible when stands growing in medium sites reached 40 years and mean dbh of approximately 20 cm. At that stage, tree mortality was 4% higher in the presence of the scale insect as compared to healthy stands.

In good sites, SEV was the highest in healthy stands with no honey production. In infested stands growing on good sites, the contribution of pine honey to the overall SEV in the three alternative honey yield scenarios (30, 60 and 90 kg ha^{-1} yr^{-1}) ranged from 4% to 15% (Figure 13). The reduction in total SEV in good sites due to *M. hellenica* infestation ranged from 6% to 16%. In medium sites, SEV was higher in healthy stands when honey production in infested stands was 30 kg ha^{-1} yr^{-1}, the contribution of pine honey to the overall SEV being 21%, and the reduction in SEV due to the scale insect being approximately 8%. Otherwise, the optimal management for the joint production of honey and timber in stands yielding 60 or 90 kg ha^{-1} yr^{-1} of pine honey resulted in higher SEV than the SEV obtained from timber only in healthy stands. In poor sites, SEV was always higher in stands infested by *M. hellenica*. The contribution of pine honey to the total SEV ranged from 82% to 97% with increasing honey yield. Integrating pine honey production into the optimal management of *P. brutia* stands resulted in 2 to 6 times higher SEV in infested stands. The optimal stand management consisted of one thinning in good sites yielding 30 kg ha^{-1} yr^{-1} of pine honey. Otherwise, the optimal number of thinnings was two.

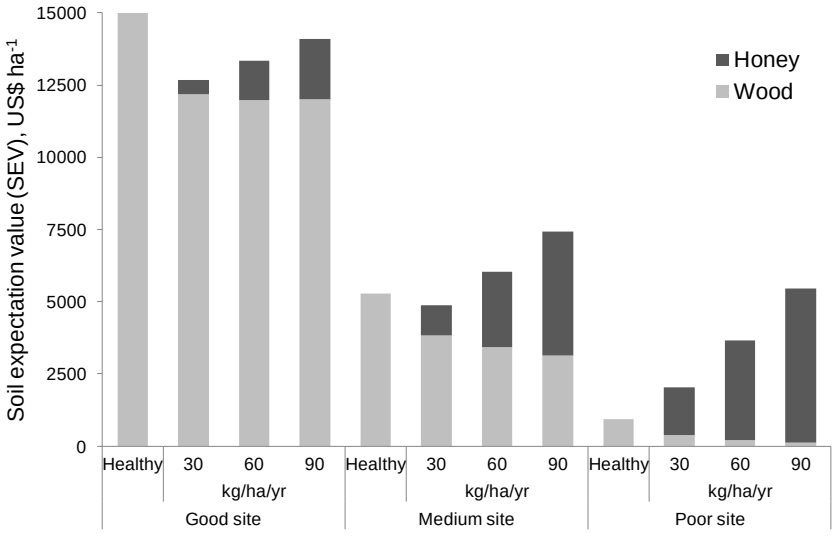


Figure 13. Soil expectation value of the joint production of pine honey and timber in pine stands infested by *M. hellenica* as compared to timber production in healthy *P. brutia* stands (source: de-Miguel et al. 2014a).

In good sites, the optimal rotation length was not very sensitive to effect of integrating pine honey yield into optimal forest management, i.e. rotation lengths were always shorter than 50 years regardless of the amount of honey produced. In medium sites, the optimal rotation length increased considerably in the alternative honey yield scenarios as compared to the 49-year optimal rotation estimated for healthy stands. In poor sites, assuming high pine honey yield (i.e. 90 kg ha^{-1} yr^{-1}) resulted in optimal rotations twice as long as in the absence of *M. hellenica*. In non-infested stands growing in medium and poor sites, rotations were also considerably longer than in healthy stands growing on good sites. Increasing optimal rotation length as a consequence of integrating pine honey production into forest management optimization of infested stands resulted in a reduction of mean annual timber production depending on pine honey yield and site quality. In poor sites, doubling pine honey yield from 30 to 60 kg ha^{-1} yr^{-1} doubled mean annual honey yield at the end of the rotation, whereas in good and medium sites, it resulted in three times higher mean pine honey yield. In the same vein, increasing honey production to 90 kg ha^{-1} yr^{-1} resulted in more than three times higher mean pine honey yield in poor sites, and four to five times higher pine honey yield in good and medium sites.

This case study highlights the great economic importance of pine honeydew honey as a non-wood forest product in the eastern Mediterranean region. On one hand, *M. hellenica* causes economic losses to those stakeholders aiming at producing timber. On the other hand, *M. hellenica*, in combination with honeybees, provides important economic benefits to the beekeeping sector and rural communities. For the society, whose aim should be the maximization of the total benefit produced by the forest, *M. hellenica* may be harmful or useful depending on the magnitude of timber yield losses as compared to the economic benefits that pine honey production represents to beekeeping. The study may be used to assist decision-making in forest management planning and policy making concerning the multifunctionality of eastern Mediterranean pine forest ecosystems since pine honey represents an opportunity to increase the value and profitability of such ecosystems. Furthermore, honey production can be much more profitable than timber production in medium and, mainly, in poor sites. Accordingly, stands growing on good sites should be managed using rather short rotations aiming at timber production, whereas, in medium and poor sites forest management should use longer rotations and take advantage of the joint production of pine honey and timber.

3 DSSs development and use at FMU level

3.1 Finland

Authors: MK, TP, JM

3.1.1 Use-situation

Non-industrial private forest (NIPF) owners represent the major ownership group in Finland and account for 60% of forests in Finland. Around 345 000 NIPF owned FMUs currently exist in Finland with average size of 30 ha. This means that inventory and management planning of the forests within these holdings are important both for forest industry and forest environment and related services.

Two major shortcomings exist in FMU level management planning. These are i) lack of multi-objective considerations that are based on creation and examination of alternatives and ii) weak position of non-timber objectives in management planning and related decision making. Until now, non-timber objectives related e.g. to recreation or provision of NWFPs are typically accounted for by setting aside individual stands or parts of stands or by "softening" the treatments of individual stands. Explicit calculations that include simultaneously production of timber and other forest products and services do not exist in practical forest planning.

This use-situation is related to use of a modern forest planning system at FMU level. The aim is more on showing the possibilities how to create alternatives and how to visualize them than on numerical results. Thus, the results can serve the development efforts of technical and reporting capabilities of forest DSSs.

3.1.2 DSS description, materials and methods

The example shows how the yield of two NWFPs can be dealt with alongside other forest use objectives in the Finnish forest planning system Monsu (Pukkala 2006). Monsu includes the yield models of bilberry (Miina et al. 2009) and cowberry (Turtiainen et al. 2013) along with several other ecosystem service models. Therefore, the use of the system for showing the interdependencies between potential goal variables in different holding-level solutions is straightforward.

The planning area was a rather large private forest holding (148.3 ha) NIPF holding in Eastern Finland. The initial growing stock of the holding was 179 m^3/ha and the site fertility varied from very fertile (Oxalis-Myrtillys type (OMT), 29.5 ha) to poor fertility (Calluna type (CT), 12.8 ha). The best berry site classes, namely MT type (Myrtillus type (48.3 ha)) and VT (Vaccinium type (VT), 52.6 ha) were the most common site types.

The creation of the alternative forest plans for the forthcoming 30-years planning period was done so that first several alternative treatment schedules for the individual stands of the forest holding were simulated. Forest management within these schedules included both even-aged and uneven-aged forest management. Then, alternative objective functions were modified. By varying these two and applying the heuristic optimization techniques of the Monsu forest planning tool, several alternative forest plans were created for the FMU as follows:

- No cuttings: no cuttings (thinnings and regeneration cuttings) will be done during the 30 year planning period.
- Even-aged: forest management allowed, thinnings from below (smaller trees removed), cutting removal target set to 8000 m^3/ 10 years, maximization of NPV with 3% interest rate
- Any-aged: (both even- and uneven-aged schedules simulated) forest management allowed, thinnings from above (i.e. bigger trees typically removed), cutting removal target set to 8000 m^3/ 10 years, maximization of NPV with 3% interest rate
- Max Bilberry: any-aged (both even- and uneven-aged schedules simulated) forest management allowed, maximization of bilberry yield
- Max Cowberry: any-aged (both even- and uneven-aged schedules simulated) forest management allowed, maximization of cowberry yield.

3.1.3 Results and discussion

The FMU level plans have different profiles in the FMU-level spider diagram (Figure 14). Note, however, that in the spider diagram the axis are in relative scale so that the minimum theoretical value of the goal variable gets value 0 and the maximum value is equal to 1 Cowberry plan shows the highest removals and cowberry yields. It simultaneously gives very high NPV due to intensive forest management. This results from the fact that highest amounts of cowberries can be picked from recently regenerated areas.

In bilberry plan, the amount of clearfellings is near minimum, but the NPV is, however, rather high. In this plan, forest management is based more on uneven-aged management principles. A combination of any-aged forest management gives the highest NPV, but rather low amounts of berries.

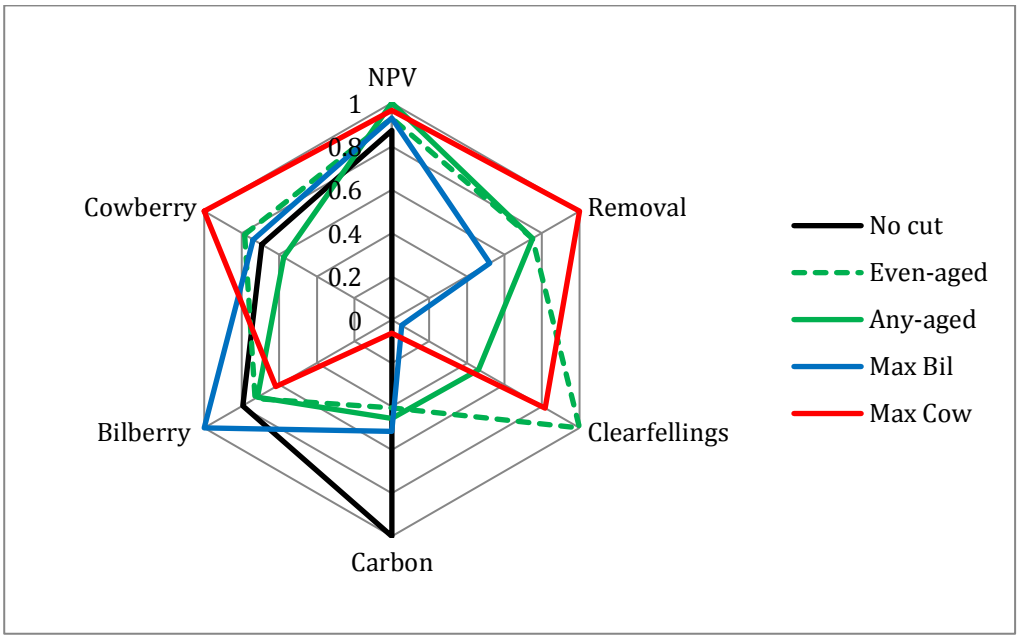


Figure 14. Illustration of profiles of the FMU-level alternative plans created with Monsu forest planning tool as spider-web diagram (3% interest rate used in calculations).

The best places to pick bilberries can be found from thematic maps created for the FMU (Figure 15). Indeed, this is a nice way to utilize quantitative information which can be obtained when the berry yield models are integrated to planning software. Interestingly, the yields in the best bilberry picking places decrease due to fact that they become too dense for bilberry.

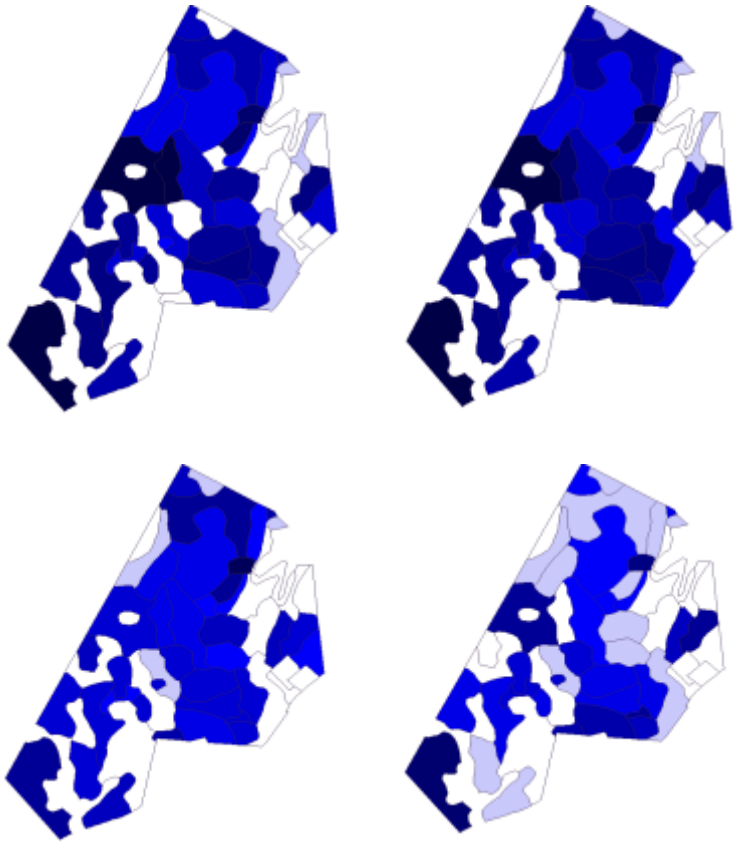


Figure 15. Thematic maps for bilberry yields for the FMU. Upper-left map shows the initial bilberry yields in 2015, upper-right map shows the bilberry yields at the end of the planning period in bilberry plan, bottom-left maps yields in no cuttings plan and the bottom-left map the bilberry yields in cowberry plan. The darker blue, the higher is the bilberry yield.

3.2 Portugal

Authors: JGB, MT

3.2.1 Use-situation

The Zona de Intervenção Florestal of Chouto Parreira (ZIF_Ch) is a forested landscape fragmented into a large number of ownerships. It is a joint management area that extends over 19,526 ha and includes 5,681 stands. It is dominated by cork-oak (*Quercus suber*) stands (63% of area). It is a privately owned area where small (<50 ha), medium (between 50 and 400 ha) and large (>400 ha) Non-Industrial Private Forest owners (NIPF) holdings extend over 6, 30 and 52% of the area, respectively. Cork and Umbrella pine cones (pine

nuts) are the most important non-wood forest products. The list of other ecosystem services provided by ZIF_Ch includes eucalypt pulpwood, carbon storage and Maritime pine saw logs.

Formal ZIF-Ch management plans – e.g. documents that the institution representing forest owners in ZIF-Ch (ACHAR) needs to report to the public administration – do not list forest prescriptions to be followed by individual forest owners to meet overall ZIF-Ch management objectives. Those documents do not report either any economic, wood or non-wood product outcome resulting from the management of ZIF-Ch. The shortcomings of these 'plans' prompted the development and test of a tool that might facilitate the negotiation of management options by forest owners and stakeholders to meet targets for the supply of ecosystem services.

3.2.2 DSS description, materials and methods

The DSS SADfLOR includes four independent and compatible components encapsulated in a graphical interface. The first component consists of a management information system. The second component consists of a model base with growth and yield models and a prescriptions generator. The third component consists of a methods base that includes the trade-off analysis functionality reported by Borges et al (2014). It currently encompasses a sub-module that provides multi-objective linear model building functionalities and a sub-module that provides an interactive decision maps building functionality to approximate the efficient frontier of a multiple criteria planning problem and to analyze trade-offs between the different criteria (Garcia-Gonzalo et al. 2015). The fourth component consists of the report writer.

The system was used to generate a total of 84,227 stand-level prescriptions over a planning horizon extending over 90 years. The SADfLOR matrix generator automated the process of developing the resource capability linear programs (RCM) from the output of its prescription writer and simulation modules. In the RCM, stand-level prescriptions correspond to linear programming Model I type decision variables (Johnson and Scheurman 1977). The RCM was further developed to include accounting variables to estimate the provision of each ecosystem service from ZIF. Finally, the RCM were edited further to identify the ecosystem services for which trade-off information is needed – cork and pine cones (non-wood products) and eucalypt pulpwood, carbon storage and maritime pine saw logs. The Pareto frontier MCDM module was afterwards used to generate the feasible set in the criteria space for the forest ecosystem management problem as well as to produce and display the information about the trade-offs between criteria, i.e. ecosystem services.

3.2.3 Results and discussion

The trade-off information provided by SADfLOR helped forest owners and stakeholders to agree on the average carbon stock level (0.98 x 10^6 Mg/year) and on the level of pine saw logs supply (0.05 x 10^6 m^3). Afterwards, they used the tool to analyze the trade-offs between the remaining three ecosystem services and select potential baskets (Figure 16). The corresponding allocation of areas to forest management programs by the Pareto frontier MCDM module helped to select the solution. The latter was characterized by an increase in the area allocated to the umbrella pine system at the expense of the area allocated to the maritime pine system.

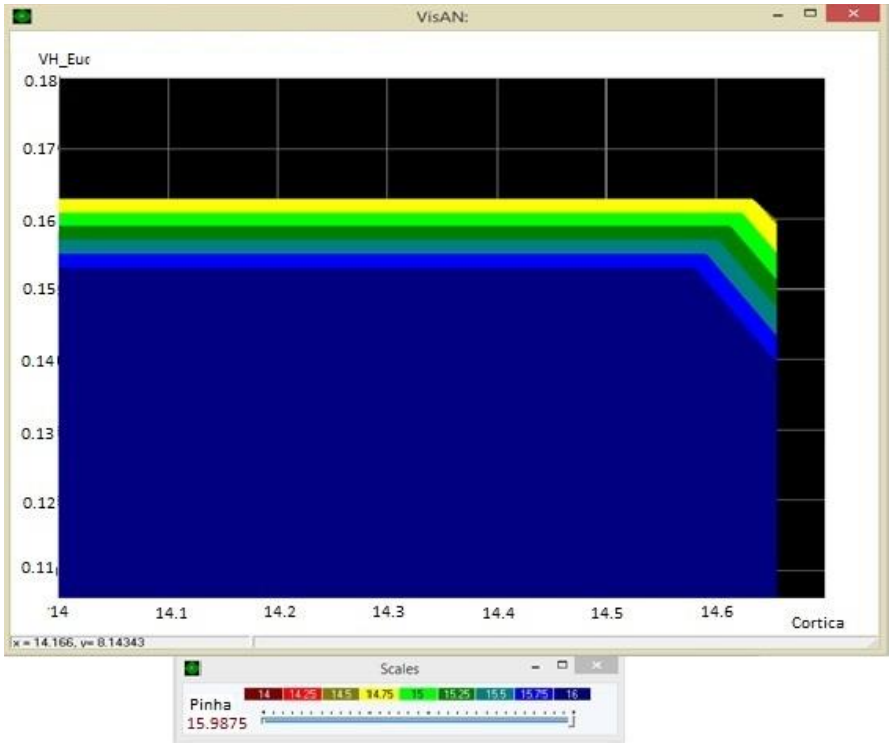


Figure 16. Cork (Cortica), Umbrella Pine Cones (PInha) and Eucalyp pulpwood (VH_Euc) trade-off information in a form of a set of decision maps (with average carbon stock fixed to 0.98 Mg/year and pine saw logs supply fixed to 0.05 x 10^6 m^3) from which stakeholders in ZIF_Ch selected a solution. Each of the 6 decision maps (displayed in different colors) corresponds to a certain level of supply of Pinha ranging from 14.75 to 16.0 x 10^4 Mg and in this way each decision map displays the trade-offs between the provisions of Cortica and VH_Euc for certain level of supply of Pinha.

3.3 Spain

Authors: SDM, JEM, JMDA, RMA, FXB, JAB

3.3.1 Use-situation

The managers of the protected forest area of Poblet (north-eastern Spain) are developing the first pilot experience in Catalonia concerning the regulation of mushroom picking. The area is partly formed by planted *Pinus pinaster* stands (i.e. four compartments named as Barranc d'en Torners, Comellàs, Era de Nogués and Serra Alta), which constitute one of the focus of interest when it comes to mushroom production in the protected area. The stands were planted in 1963 and 1967 and, therefore they are now approximately 50 years old. The public managers of the area (i.e. forest Administration) wish to manage those stands in order to enhance mushroom yield and sustain over time the provision of edible and commercial mushrooms as a public-oriented service within the protected area. The main mushroom species in the area are the following: *Lactarius deliciosus*, *L. sanguifluus*, *L. semisanguifluus*, *L.vinosus*, *Suillus luteus*, and *Tricholoma terreum*. The aim of the study was to determine the production of timber and mushrooms in *Pinus pinaster* stands under alternative management regimes and instructions (timber-oriented versus mushroom-oriented), and to assess the economic profitability of such management alternatives.

3.3.2 DSS description, materials and methods

3.3.2.1 Forest inventory

A systematic forest inventory was conducted using 60 circular plots of radius 10 meters (i.e. 314 m^2) in order to inventory at least 30 trees per plot, that is, 15 plots in each planted *Pinus pinaster* area of the protected area of Poblet (Figure 17). The number of inventory plots (*n*) was determined using the following equation:

$$n = \frac{t^2 * CV^2}{E^2 + \frac{t^2 * CV^2}{N}}$$

where *t* is Student's t value, *CV* is coefficient of variation in basal area (%), *E* is maximum error allowed in basal area (%), and *N* is the maximum number of plots assuming that all the inventory area is covered by inventory plots. The values of *CV* and *E* were 36.16% and 15%, respectively, and were estimated from a

previous inventory conducted in 2010 by the Forest Sciences Centre of Catalonia (CTFC). The Student's t value was 2.04, corresponding to a significance level of 95%.

The distance between inventory plots was computed using the following equation:

$$d = \frac{\sqrt{A}}{\sqrt{n}}$$

where *d* is distance between plot centers (km), *A* is total forest area to be inventoried (km^2) and *n* is the number of inventory plots.

Each plot center was located using GPS and, in every plot, all trees were measured for diameter at breast height using tree caliper, and three trees per plot were measured for tree height using hypsometer Vertex IV. Forest inventory was conducted in September 2014. The inventory data were processed using Lifor software (Centre de la Propietat Forestal).

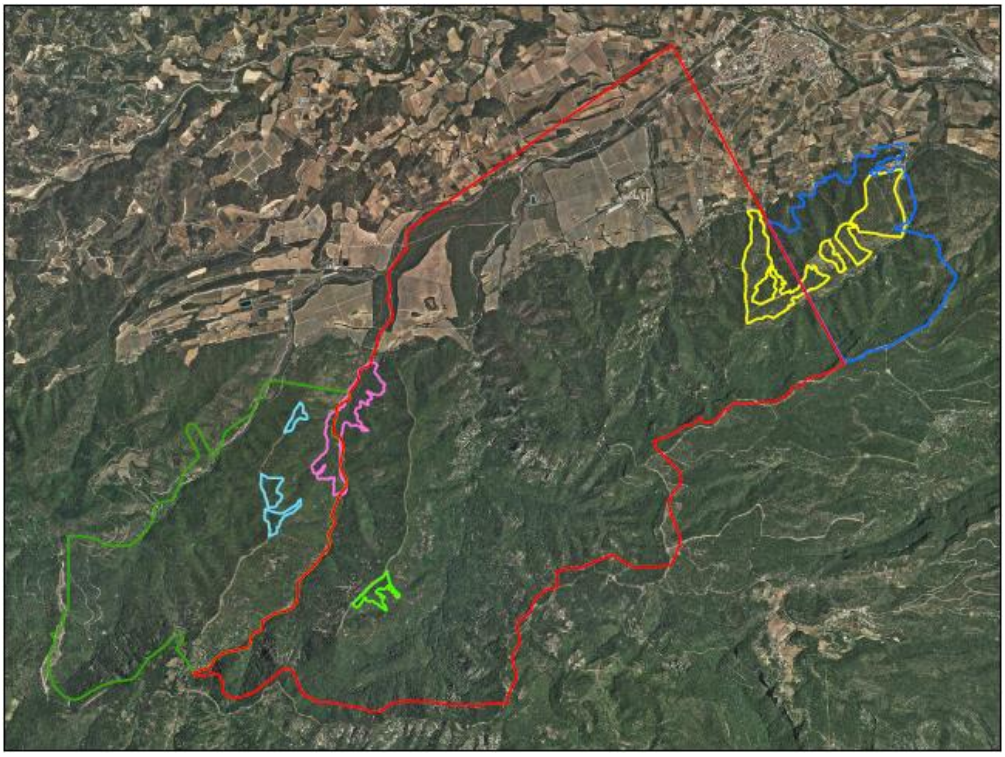


Figure 17. Location of the four Pinus pinaster reforested compartments (in yellow, pink, bright green and light blue, respectively) in the protected area of Poblet (red) and its buffer areas (green and dark blue).

Two alternative management schemes were compared in order to assess the differences between traditional timber-oriented forest management planning and mushroom-oriented management

instructions in relation to their effect on the yield of edible, commercial, mushroom species. In both management schedules, mushroom yield predictions were estimated from the mushroom forest ecosystem-specific mushroom yield models developed by de-Miguel et al. (2014a). Such equations constitute a hurdle model from which mushroom yield is estimated based on two computational stages. The first stage predicts the probability of mushroom occurrence, whereas the second stage predicts mushroom yield conditional on the probability of occurrence. The final mushroom yield estimate is computed by multiplying the estimates of both stages.

3.3.2.2 Timber-oriented management schedule

The timber-oriented management schedule was based on a yield table for *P. pinaster* published by García-Abejón and Gómez-Loranca (1989). The rotation length was set to 120 years, i.e. the maximum length considered in the yield table. Although such a stand age may result in somewhat over-mature forest stands, this enabled long-term analysis of the effect of alternative management schedules on mushroom production and profitability. Furthermore, this is also justified since the study area is a protected area also aiming at providing scenic beauty for which big trees and mature forests are an asset. The regeneration method was the shelter-wood method.

3.3.2.3 Mushroom-oriented management schedule

The mushroom-oriented management schedule was based on the same yield table, which was further adapted to meet the optimal requirements in terms of stand basal area for mushroom production in *Pinus pinaster* stands as defined by de-Miguel et al. (2014a). The optimal stand basal area that maximizes mushroom production in such stands ranges from 35 to 40 $m^2 \cdot ha^{-1}$. Therefore, the aim in the mushroom-oriented management schedule was to keep the stand basal area within its optimal range for mushroom yield. The rotation length and the regeneration method were the same as in the timber-oriented management schedule.

3.3.2.4 Economic analysis

The economic analysis of both management schedules was based on the NPV. Timber harvesting costs were retrieved from Palahí et al. (2009), where such costs are expressed as a function of diameter at breast height. Timber income was computed from the equations provided by the *Consorci Forestal de Catalunya*, where the price of timber also depends on the diameter at breast height. Mushroom harvesting costs included mushroom picking and transportation costs to Barcelona market. Mushroom income had two components, the first one being a mushroom selling price of 6 € kg^{-1}, estimated from Barcelona market

(www.mercabarna.es), and the second one being the income obtained by the picking permits delivered by the Administration of the protected area of Poblet. The economic analysis was based on a planning horizon of 20 years, since this is the official planning horizon of forest management plans approved by the public Administration.

3.3.3 Results and discussion

The resulting schedules for timber-oriented and mushroom-oriented forest management are summarized in Table 13. Thinning intensities were reasonable in terms of assuring stand stability.

Table 13. Thinnings scheduled (i.e. timing and intensity (removed basal area) in stand basal area (m^2/ha)) for the timber-oriented and mushroom-oriented management schemes.

		Compartment			
Year	**Schedule**	**Barranc d'en Torners**	**Comellàs**	**Era de Nogués**	**Serra Alta**
50	Timber-oriented	15.09	9.50	20.00	10.91
	Mushroom-oriented	15.09	-	20.00	-
60	Timber-oriented	15.28	-	18.70	-
	Mushroom-oriented	15.00	-	15.00	12.00
70	Timber-oriented	-	-	-	-
	Mushroom-oriented	-	15.00	-	-
80	Timber-oriented	-	-	-	-
	Mushroom-oriented	-	-	-	-
90	Timber-oriented	-	-	-	-
	Mushroom-oriented	10.00	-	12.00	10.00
100	Timber-oriented	-	-	-	-
	Mushroom-oriented	-	6.00	-	-
110	Timber-oriented	-	-	-	-
	Mushroom-oriented	-	-	-	-
120	Timber-oriented	-	-	-	-
	Mushroom-oriented	-	-	-	-

The mushroom-oriented management schedule was more profitable than the timber-oriented scheme (Table 14). This was mainly arising from the difference in the number of thinnings between schemes. The number of thinnings was slightly lower for the 20-year planning horizon in the mushroom-oriented management. This means that fewer interventions were needed to achieve the optimal basal area for mushroom production within that time framework. The reduction of the thinning costs was, therefore, the main reason for the higher profitability of the mushroom-oriented schedule.

Table 14. Summary of the economic analysis for both forest management schemes.

	Incomes (€)	Costs (€)	Balance (€)	NPV (€)	NPV (€·ha^{-1})
Timber-oriented	528209	460626	67583	46391	303
Mushroom-oriented	648173	487143	161030	228724	1494

Otherwise, the alternative schedules oriented toward either timber or mushroom production were quite similar. This is because the stand structure (i.e. stand basal area) that maximizes mushroom yield is very similar to the stand structure that maximizes timber production. In consequence, although the mushroom-oriented management schedule resulted in slightly higher mushroom production, the differences with the timber-oriented schedule in terms of mushroom production were minimal. This is why, at some particular time points along the development of the *Pinus pinaster* forest stands, mushroom yield could be slightly higher under the timber-oriented management, although in the long run the overall production is slightly higher in the mushroom-oriented scheme (Figure 18).

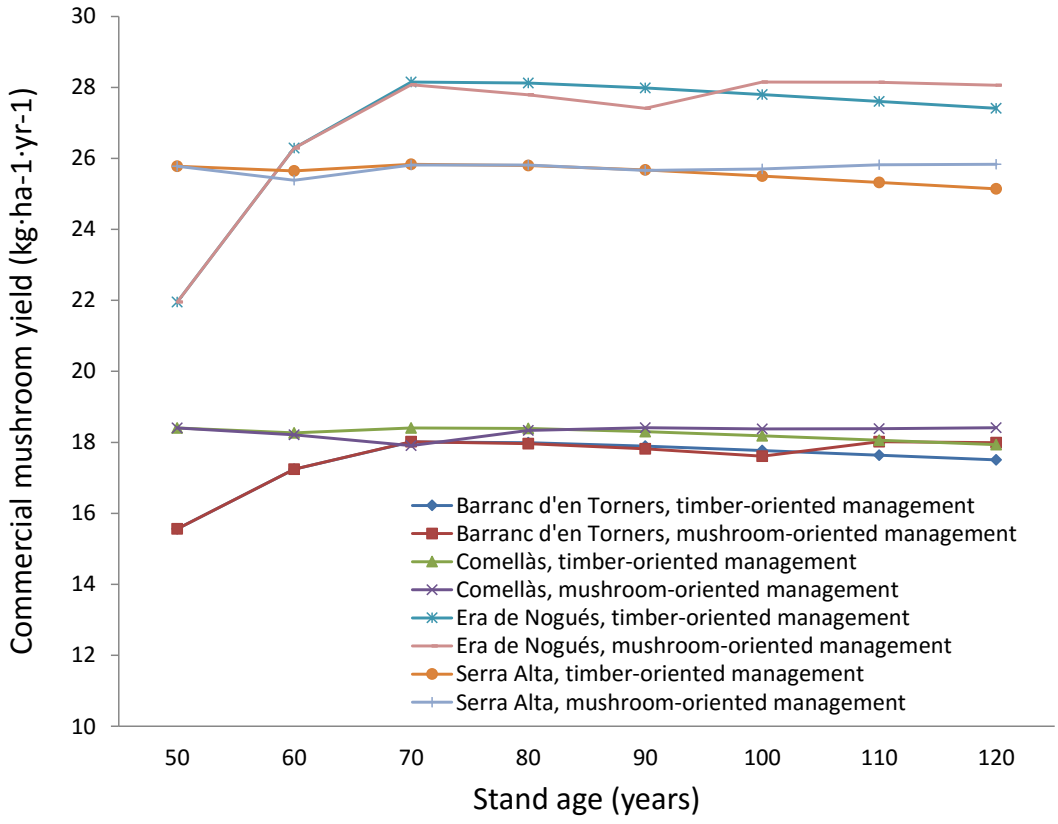


Figure 18. Production of edible commercial mushrooms along stand development in the different Pinus pinaster compartments of the protected area of Poblet for the two forest management schemes considered (timber-oriented versus mushroom-oriented).

3.4 Turkey

Authors: EB, DKM

3.4.1 Use-situation

Forest management planning aims to forecast the future forest development based on forest development and appropriate management interventions. Given a defined forest area with the inventory data, management planning basically requires ***actions*** and ***outputs*** to be defined. The actions in the form of forest management interventions are designed to understand and control the spatio-temporal dynamics of forest ecosystems under various forest management strategies towards the realization of optimal schedule with a desired flow of forest values. The values of forest ecosystem are formed by the needs of stakeholders and influenced by forest ecosystem characteristics such as tree species, age, basal area, growing stock, and development stages of stands. In this respect, the forecast of the amount and spatial distribution of forest values over time and space has been a great challenge for the sustainable management of forest ecosystems to find the best schedule under multiple objectives and constraints. Thus, forest DSSs are indispensable models to test and document the effects of some management strategies on the potential production of forest values as they are integrated into forest management plans (Başkent et al., 2008).

Over the last decades or so, forest management modeling has focused on the integration of timber production and other ecosystem values. While quite a number of DSSs are available for preparing single or multipurpose forest management plans as a leading forest management policy, there is still a need to develop forest simulation and/or optimization models that explicitly incorporate NWFPs into forest management plans. In Turkey, ETÇAP DSS is available as a prototype model for use in particularly research oriented studies to accommodate varous different forest values such as timber and water production, soil loss and carbon sequestration in forest management plans (Başkent at al. 2014). However, there are no DSSs available to accommodate NWFPs into forest management planning in practice. The aim of this article is to show how the ETÇAP DSS has been modified to accommodate mushroom production in numerical forest planning calculations. This allows examinations of the trade-offs among the combinations of timber and NWFP.

3.4.2 DSS description

Forest management planning requires a sound conceptual framework to integrate multiple forest values in a management plan. As the decision environment gets larger, making a smart decision becomes harder. Thus, a DSS tool is needed to create alternative treatments for stands and evaluate their quality with respect the values of the decision maker(s). In this study, forest inventory data from Kızılcasu FMU is used to generate several management alternatives based on different management strategies using ETÇAP optimization technique. ETCAP is a strategic level DSS that utilizes both simulation and optimization tools to find the best solution for a planning area (for detail, refer to Başkent et al., 2008, 2014). The specific scope and characteristics for the ETÇAP DSS are summarized as follows:

- It is a general purpose long-term management model that simulates the dynamic behavior of forest ecosystems with ecological and financial understandings of forest management activities.
- The smallest and basic management area for this model is a stand. There is no limit in the number of stands to be included in the simulation.
- It is a deterministic model for primarily even-aged stands.
- The dynamics of growth is driven by yield tables and forest inventory data provided by the user.
- The model provides area and volume check methods with three different flow policies such as even-flow, non-declining yield and certain level of variations between periods.
- A number of management objectives such as timber supply, water production, soil loss, mushroom production and NPV of any or all of them are currently available in the model.
- Harvesting or other interventions are only allowed in stands within the operability window of each species.
- There is no limit in the number of forest management strategies and silvicultural regimes to be prescribed.
- The model simulates long-term effects of management prescriptions on some forest ecosystem values provided by the user.
- The user can create, edit, save, and retrieve different input files needed to accomplish a simulation run and design customized reports in the form of tables, text, figures and maps.

As the starting point of the data preparation for input, the forest planning unit (FPU) under management is characterized in terms of land use category and forest stand types defined by species mix, development stages and crown closure based on both remote sensing data and field measurements. The field data gathered from systematic sampling method are compiled to calculate current characteristics of stand types

such as yield, increment, stocking and basal area. The compiled data are imported to a stand (polygon) database. The stand type map (cover type) database in association with topographical data is used to define compartments. The forest database may also be used to define FPU further into sub-management units when necessary (i.e., major species types, stratified areas, forest form and management methods). The additional data required for the model run such as planning parameters, timber prices, yield curve data, other values such as water, soil, carbon and NWFPs must also be entered into the model in a specified format before the forest development can be forecasted.

After the preparation of the database, alternative treatment schedules for each stand type in the form of silvicultural prescriptions for the future planning periods are developed to define a management strategy. Each treatment schedule is described by treatments attached to it, timber removals, and development of the growing stock characteristics. In this stage, the NWFP models included in the DSSs calculate the yields or indicator value for the NWFP in question for each treatment schedule. To develop an optimal harvest schedule for an integrated forest management plan, ETÇAP DSS accommodates various optimization techniques such as linear programming and heuristic methods. The output can be documented in the form of a forest management plan based on the national guidelines with the help of a *ETCAPclassic* module, and the results can also be connected to GIS database manually to visualize the location of management decisions on a cover type map. However, the system currently does not include any landscape visualizers to interactively visualize the output on the map for interactive analysis.

The results document the future production possibilities of different forest products and services such as timber and mushroom. By comparing different forest plans, it is possible to evaluate the trade-offs between the products and create forest management scheduling maps for the FMU with respect to the NWFPs.

ETÇAP model has been developed as a prototype model and used primarily in both graduate thesis and other studies for scientific research. However, few real case studies in Turkish forestry were also used as a trial of the model to see shortcomings and power to spread the use of it across the country. After the trial, the decision regarding the adoption of the program for practical use will be made.

3.4.2.1 Data preparation

Since the forest inventory has not been fully compiled for developing new database for Yeniköy FPU and the data collection has not finalized to develop production models for the selected NWFP so far, Kızılcasu FPU, located in Kastamonu, was selected to test and demonstrate the opportunities of joint production of

mushroom and timber. The area is located on the Northwestern of Turkey with altitudes ranging between 240 and 1435 m above sea level with an approximately average slope of 42%. Mean annual temperature is 13^0C and mean annual precipitation is 1050 mm. *Fagus oriantalis, Carpinus betulus, Abies bormülleriana, Oercus sp., Pinus silvestyris, Pinus nigra, Cestanea sativa, Fraxinus exelsius, Alnus glutinosa, Acer sp. and Platanus orientalis* are the prevailing tree species of the case study area. The planning unit is approximately 9,537 ha in size with 108 compartments and 1170 stands.

3.4.2.2 Growth and yield projection of timber production

ETÇAP DSS uses empirical models to project the development of stands over time. The models predict the growth of current stands and the regenerated stands separately. The growth of current stands is calculated based on the stand parameters collected from field inventory and the stand parameters from empirical yield tables (Keleş 2008). The regenerated stands are assumed to develop according to the empirical yield tables.

3.4.2.3 Mushroom yields

While *Lactarius*, *Morchella* and *Boletus* are widespread mushroom species in the case study area, the yield models are available only for Lactarius species (Küçüker and Başkent 2015). Among the tested Lactarius yield models, the one that best represented the relationship was selected for use. The model used to predict the mushroom yields for the appropriate stands was reported in Deliverable 2.2 (see also Kücüker, 2014). An example of the relationships between mushroom yields and stand age is given in Figure 19.

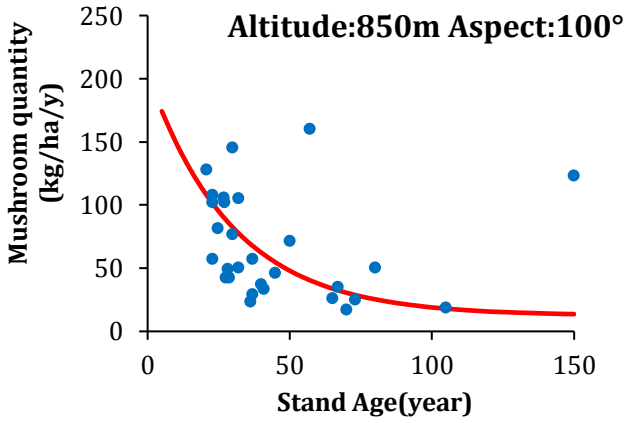


Figure 19. The estimated yield of *Lactarious spp.* plotted against the stand age.

3.4.2.4 Creation of forest management strategies

Six forest management strategies were developed to test the trade-offs particularly among timber production and mushroom yields. Maximization of amount and NPV of timber production and NPVs from mushroom production were used as objective variables in optimizations. These were supplemented with different constraints related to timber flows (Table 15).

Table 15. Forest management strategies developed and used in the test area.

Scenario	Objectives	Constraints
O1	Max NPV ^{Timber}	Even Timber Flow
O2	Max ^{Timber}	10% variation of timber flow
O3	Max ^{Timber}	No further constraints
O4	Max NPV ^{Mushroom}	Even Timber Flow
O5	Max NPV ^{Mushroom}	10% variation of timber flow
O6	Max NPV ^{Mushroom}	No further constraints

In calculations, the planning horizon was 120 years, divided into 10-year sub-periods. Regeneration is assumed to follow immediately after the harvesting of stands. Minimum cutting age for "Scots pine and Black pine" management units is 140 years, for "Fir and Beech" and "Beech and Oak" management units is 120 years and for conservation dominated areas 200 years. Maximum harvesting ages are set to be 180, 160 and 220 years, respectively. Commercial thinning actions were implemented for the stands whose ages range between 30-80, 50-90 and 40-120 years in the management units, respectively, with a removal rate of 10% to 15% of standing volume for each period. All economic calculations were conducted based on the Net Present Value (NPV) of both income and expenses provided with a 3% interest rate.

3.4.3 Results and discussion

Strategies O3 and O6 produced the highest total NPVs from timber and mushroom as these strategies did not include any timber-flow related constraints (Table 16, Figure 18). The forest management strategies with timber and timber NPV objectives (O1, O2, O3) produced higher NPVs than forest management strategies with mushroom NPV objective (O4, O5, O6). The results indicate that forest management

strategies including the maximization of mushroom NPV caused clear decrease in total income because of the protection of the forest to produce mushroom.

Table 16. Results for six forest management strategies.

Scenario	Timber (m^3)	Timber NPV (TL)	Mushroom (kg)	Mushroom NPV (TL)
O1	90.366	3.472.353	1.196.790	7.117.055
O2	2.329.037	64.215.862	8.332.531	14.142.989
O3	3.979.594	125.196.983	11.058.051	26.735.499
O4	65.111	2.281.614	1.510.115	7.728.264
O5	1.547.348	51.012.091	9.057.524	17.817.606
O6	2.810.653	96.957.681	11.764.831	29.729.071

Among all strategies, the strategy O3 contributed the highest amount and NPV of timber and mushroom. This is mainly due to the fact that the model simply maximized the timber production without any restrictions. Among all, O4 produced the lowest timber volume and the monetary income at the end of planning horizon. Such outcomes are probably caused by both the maximization of mushroom NPV and even timber flow constraint (Table 17). The results show that total timber production and its NPV decreased by 98% when mushroom NPV was maximized instead of timber NPV. Changing objective functions to the maximization of NPV of mushroom and adding an even flow constraint together forced the model to cut the same volume in each period.

The highest and the lowest mushroom yields, similar to NPV of mushroom, were generated by O6 and O1 strategies, respectively. Changing the objective from NPV of mushroom to NPV of timber with even timber flow caused a reasonable reduction by 90% and 76% in mushroom production and NPV of mushroom, respectively (Table 16). As expected, the integration of regulatory constraints into forest management plans has greatly affected both economic profit and amount of forest values such as timber and mushroom negatively (Haight et al. 1992, Hoganson and McDill 1993, Baskent and Kucuker 2010).

When all the planning strategies were compared to each other in terms of NPV, surprisingly O1 and O4 strategies drew attention with NPV of mushroom that is about two and 3,5 times more than the amount of NPV of timber, respectively (Figure 20). The main reason of such result would be issuing from the constraints. As known, incorporating volume control policies into the forest management plans generally causes limitations to timber production as well as monetary income from timber.

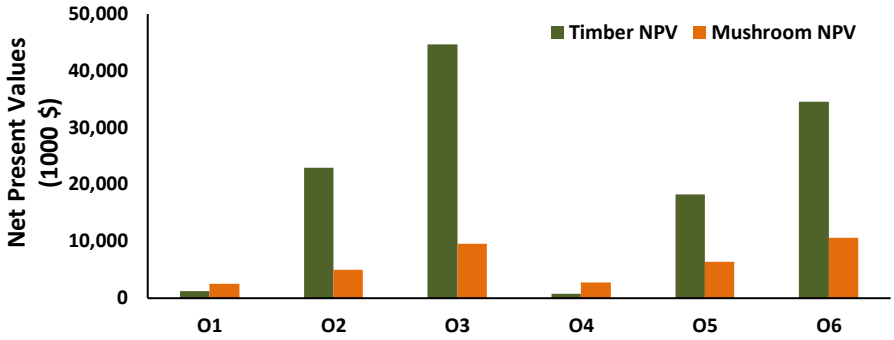
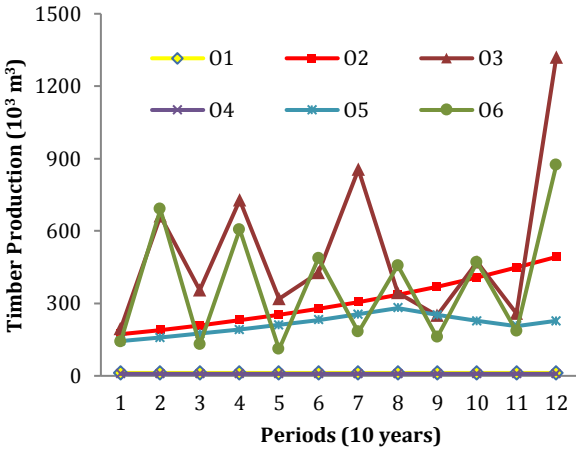


Figure 20. Total amount of NPVs of mushroom and timber from six forest management strategies.

The temporal dynamics of forest outputs can also be evaluated to better understand the trade-offs between timber and mushroom. Figures 21a and 21b show the timber and mushroom productions for each forest management strategy over 12 periods. While total timber production is rather low and regularly distributed for each period, mushroom production shows almost decreasing trend in successive periods in O1 and O4 strategies. This would be attributed primarily to the even timber flow restriction among periods. However, total timber and mushroom productions show a quite high yet unstable trend of flow over consecutive periods in O3 and O6 strategies. Such changes in the output would easily be related to the unrestricting conditions in the related management strategies. Furthermore, the dynamics of financial incomes from timber and mushroom for all strategies over time were evaluated and illustrated in Figures 22a and 22b.

a)



b)

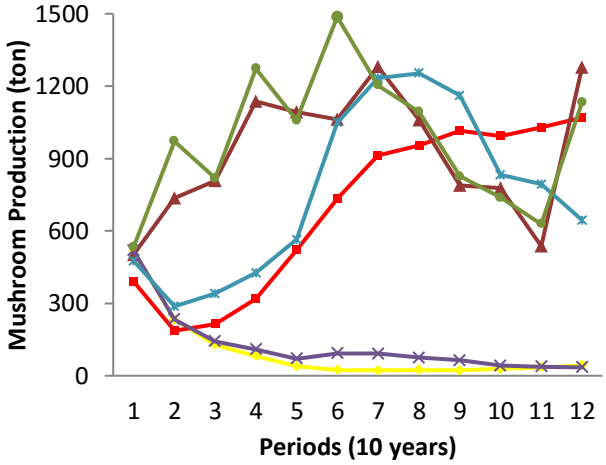


Figure 21. The amounts of timber (a) and mushroom (b) for 12 sub-periods in six forest management strategies

a) b)

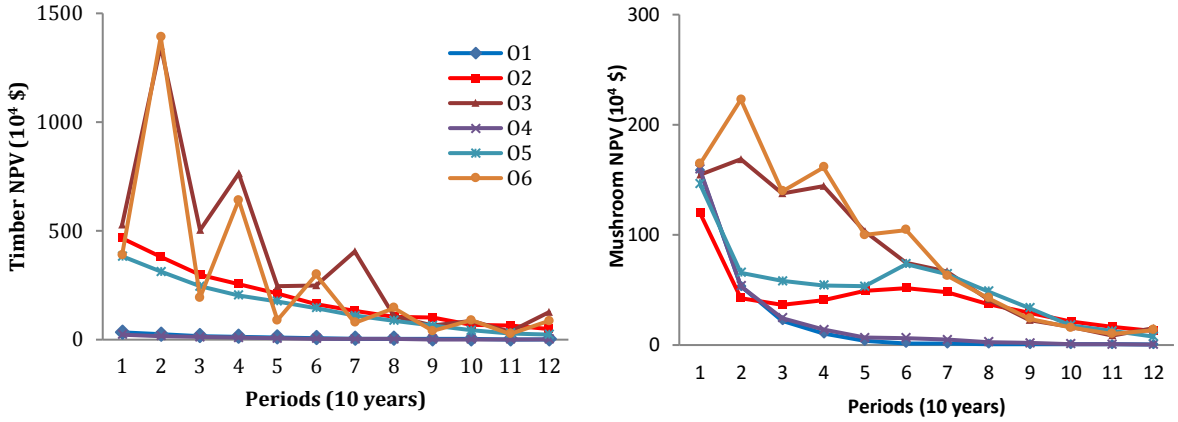


Figure 22. NPVs of timber (a) and mushroom (b) from 12 sub-periods in six forest management strategies.

3.4.3.1.1 Conclusions and challenges

Timber and NWFPs and forest related services need to be integrated well in various different forest management settings. This study presented a prototype forest management DSS "ETÇAP" modified to accommodate mushroom production and yields together with timber production using a linear programming technique. Mushroom yields were predicted from appropriate stands by using a yield model that was integrated in the ETÇAP planning system. Based on the inventory data, simulation instructions and different objective functions, ETÇAP was used in creation of six different forest management strategies that show the joint production possibilities and economic consequences of mushroom and timber production.

The results indicated that it is possible to integrate timber production and mushroom yields under the forest planning calculation tool. The results also indicate that timber and mushroom production are complementary in a sense that different forest management settings cause different economic outcomes. When timber and mushroom production are maximized separately without any constraints, highest NPV of both timber and mushroom are generated. Maximization of mushroom NPV caused substantial decrease in total NPVs because of the protection of the forest to produce mushroom. However, the effects of even-flow constraints were also remarkable and these constraints limited greatly both the production of timber and mushroom as well as their economic return. The model forecasted the results of six management strategy over long planning horizon to set up causative basis which helps to understand the forest dynamics and the interactions and trade-offs of timber and mushroom production. The trend of timber and

mushroom production over time is mostly regulated by either initial age class structure or management constraints. The study concludes that a joint production of timber and NWFPs is quite possible and understanding their interactions is paramount in designing and implementing multiple use forest management plans. However, better growth projection systems for NWFPs are needed for a comprehensive integration concept and particularly spatial control of model outputs needs to be investigated to prepare better and feasible on-the ground management plans.

4 Development and use of regional DSSs

4.1 Finland

Authors: HK, KH, JM, MK

4.1.1 Use-situation

In Finland, regional cutting scenarios have a position in forest policy. They help in setting targets for the use of forests when e.g. Regional Forest Programs (RFPs) are prepared (e.g. Tikkanen et al. 2016). However, the creation of and results from cutting scenarios focusses on timber production oriented aspects. Other forest uses and, in particular, the evaluation of the impacts of different forest management intensities on NWFPs has been missing or remained at qualitative level. The aim of this sub-chapter is to show how bilberry and cowberry yields develop in typical timber-production oriented cutting scenarios that have been recently created for North Karelia region to support the creation of RFPs.

4.1.2 DSS description, materials and methods

4.1.2.1 North-Karelian forest inventory data

The Finnish National Forest Inventory (NFI) sample plot data from 2009 to 2013 in North Karelia were used as input data. In the NFI, tree measurements were made using relascope plots. A single relascope plots (see NFI11 2016) is too small to represent a forest stand. Therefore, three to six NFI plots that fulfilled the similarity criteria for present stand characteristics and expected management and development in the future were grouped together so that they form one management unit. Consequently, the variations among individual relascope plots represent variations within management units (see Nuutinen et al. 2000). As a result, 5.699 management units were included in the calculations in this study.

In North Karelia, the total forestry land area is 1.59 million hectares of which mineral soils cover 67.5 % and peatlands 32.5 % (Korhonen et al. 2015). The total volume in 2015 was 186.5 mill. m^3 of which the volumes of pine, spruce, birch and other deciduous trees were 99.0, 50.4., 31.5 and 5.7 mill. m^3, respectively. The annual growth was 9.1 million m^3.

4.1.2.2 Planning system MELA and cutting scenarios

A planning system known as MELA and commonly used in Finland e.g. to analyze regional and national level potentials for timber production (e.g. Metinfo 2013) was modified for the purposes of this study. The acronym MELA is derived from the Finnish phrase "MEtsäLAskelma," which means "Forestry analysis tool". The MELA system consists of a simulator and an optimization package (Siitonen et al. 1996). The simulator produces a large number of alternative feasible management schedules for management units based on national forest management recommendations (Hyvän metsänhoidon suositukset 2006) and automated event simulation routines. Events include natural processes (ingrowth, growth and mortality of trees) and human actions related to cutting and other management activities. Simulation of natural processes is based on individual trees and a set of distance-independent tree-level models (e.g. Hynynen et al. 2002). The simulator includes a large number of models to predict the current state of forest and its future development. The future development of forests in alternative management schedules is deterministic.

The optimization package (Lappi 1992) based on linear programming (LP) selects the management schedules for management units. In this package, the user-specified and (region-level) objective function is optimized, subject to specified constraints. The functions and properties of MELA2009 used in this study are described in detail elsewhere (Redsven et al. 2011, see also Kärkkäinen et al. 2014 for recent description regarding the use of MELA).

Three cutting scenarios for the forthcoming five decades (from 2014 to 2064) were created. These were business as usual (BAU), maximum sustainable and even flow of timber (EVENFLOW) and maximization of NPV (MAX). In the BAU scenario, the future cutting level is set to the level of past three years (2011-2013) average level through the use of LP constraints and NPV with 4 % interest rate is used s an objective variable (see Korhonen et. al. 2015). The EVENFLOW scenario aims to even and sustainable flow of timber from forests, again using NPV with 4 % interest rate as the objective variable. Sustainability means non-decreasing net revenues and cutting removals during simulation period. In addition, the value of the growing stock in 2064 must be at least in the same level as in 2014. In MAX, the objective is to get so high net present revenues from forests as possible without any constraints using NPV with an interest rate of 5

% as an objective variable. With this formulation, large areas of less productive forest stands will be cut immediately.

4.1.2.3 Integration of berry yield models in MELA

For the purposes of this study, MELA model library was amended with the bilberry (Miina et al. 2009) and cowberry (Turtiainen et al. 2013) models in a way that enabled the system to predict the annual berry yields in simulated management schedules. The berry yield models were calibrated so that their predictions corresponded with the estimated average biological yields of bilberry and cowberry on different site classes in North Karelia (Turtiainen et al. 2005). In model calibration, firstly the stand development and management on different site classes were simulated during the whole rotation using the Motti simulator (Hynynen et al. 2002). Second, the berry yields were predicted along stand development. Third, the berry yield predictions were scaled so that the predicted average annual yields on different site classes corresponded with those presented by Turtiainen et al. (2005). In MELA, the berry yields were thus predicted by the bilberry and cowberry models that were scaled site-specifically. Because the berry yield models were based on the data collected from mineral soil sites, the berry yields were predicted only for forests located on mineral soils.

In addition to biological berry yields, harvestable yields were also calculated. This was done so that harvesting of both bilberries was assumed to take place only when the annual berry yield of the stand exceeded 10 kg/ha.

4.1.3 Results and discussion

In BAU scenario, the annual cuttings (including sawlogs, pulpwood and energywood) during the five decades remain at the level of 5.5 million m^3 in North Karelia (Figure 23). As a result, the berry yields are not affected that much. Due to increasing mean age of forests, the bilberry yields show an increasing trend and cowberry yields are slightly decreasing. At the end of the planning period, the annual total yields of both bilberry and cowberry are about 12.45 million kg.

In EVENFLOW scenario, the development of berry yields is different from that in BAU. The annual removals increase to more than 7 million m^3 in North Karelia, and the annual total bilberry yields decrease along more intensive cuttings being only 8.6 million kg in the end of the planning period. Cowberry benefits from (especially regeneration) cuttings and thus the annual total cowberry yields increase up to the level of 17 million kg already during the second decade. The development of bilberry yields in MAX scenario is similar

to that in EVENFLOW. In MAX, very intensive cuttings take place during the first and second periods, and consequently the annual total cowberry yields exceed 18 million kg during the second decade. Less (regeneration) cuttings are done during the later periods, and thus the total cowberry yields will be 16.1 million kg/year at the end of the planning period.

The development of harvestable berry yields follows logically the development of biological yields. However, the development is slightly different between the scenarios. For cowberry, the proportion of harvestable yields remains above 80% in EVENFLOW and MAX scenarios, while in BAU the proportion decreases to approximately 70%. For bilberry, the development is opposite as in scenarios with higher cutting removals (MAX, EVENFLOW), the harvestable proportion is decreasing towards the end of the planning period. In BAU, the proportion increases.

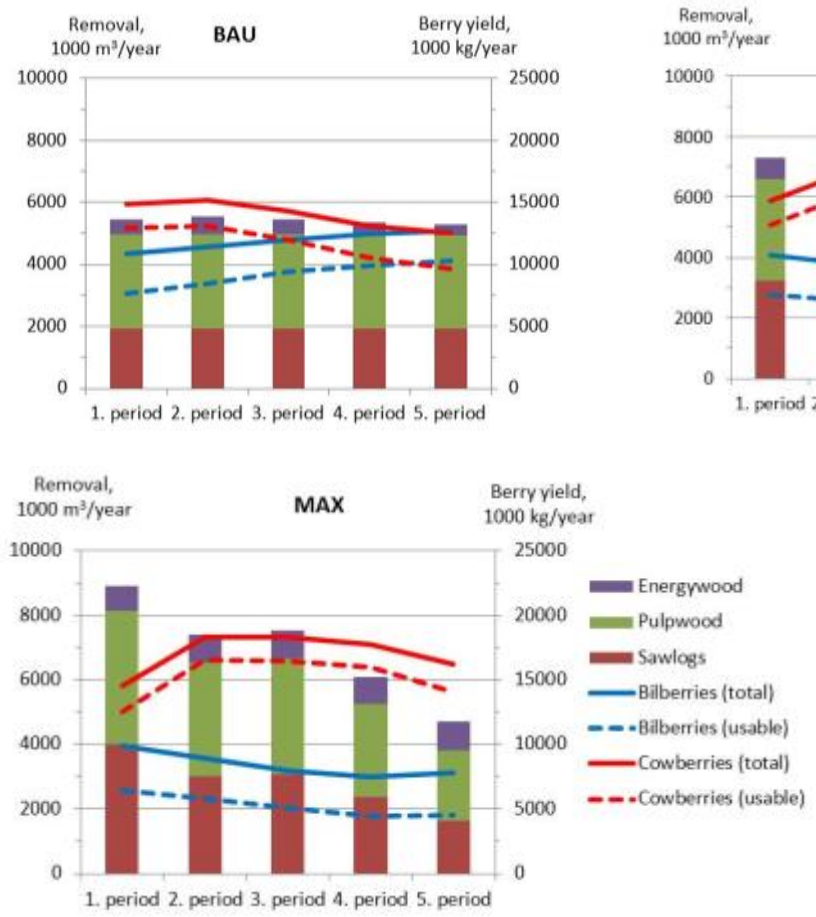


Figure 23. Removals (1000 m³/year) and biological and harvetable berry yields (1000 kg/year) in three different cutting scenarios for five 10-year periods in North Karelia. The removals have been calculated for forests on both mineral soils and peatlands, whereas the total and usable berry yields were predicted only for mineral soil forests.

In the planning calculations presented, the use of berry yield models was exogenous, i.e. the berry yields did not affect the contents of the three regional cutting scenarios which were created with the use of LP-based optimization package of MELA. The predicted berry yields correlated logically with cutting removals in different scenarios and the results show how the intensity of regional cuttings would affect berry yields in North Karelia. The preliminary result is that bilberry will suffer from more intensive cuttings but this is compensated by increasing cowberry yields. The next step is to analyze the monetary trade-offs among timber, bilberry and cowberry at the regional level.

4.2 Portugal

Authors: JAP, MT, JF

4.2.1 Use-situation

Estimation of cork and pine nuts production for a long-term planning horizon for the whole Alentejo región has never been made. A recent national strategic plan (Santos et al. 2013) with the objective to define and present forest policies for the forest sector, includes an evaluation of the respective costs and benefits. It aims to promote the increase on the availability of national raw material (wood and cork) for the Portuguese industry. This study included long-term estimation of cork production, using the SUBER model, under two scenarios: business as usual (BAU) and a Forest Development Scenario (FDS).

4.2.2 DSS description, materials and methods

4.2.2.1 Portuguese national forest inventory data

The data used as input for the simulations came from the Portuguese National Forest Inventory (NFI) from 2005. Data was collected from circular sample plot with a fixed area of 2000 m^2 that are located at a 2 km x 2 km grid. Plots were grouped in 5 strata: mature even- or uneven-aged stands (mature), young plantations (young), young plantations with some sparse big trees (young+), burned stands with all tres dead (burned), trees dispersed within stands dominated by other species (disperse). The last strata was excluded from the analyses. The regional simulator is based on the individual simulation of each plot with the SUBER model (see D2.3 and chapter 2.2 of this document) and each plot is assumed to represent an area of 400 ha. Production from all the plots is summed on a year basis in order to obtain the future cork production. A total of 1109 plots were used in the simulations, from which 1004 were in the mature, 63 in the young, 161

in the young+ and 43 in the burned strata. The regional simulator does not include optimization, it is just aiming at simulating the production under alternative scenarios.

The plot simulations used the following assumptions:

- The size of the trees from which the first debarking operation is simulated varies depending on the stand characteristics: pure or mixed stands or dispersed cork oak trees among other strata. For trees within stands the threshold dbh varied between 70cm and 100cm and the size was assigned to the trees within a stands in order to mimic the relative frequencies found in the NFI 2005 data regarding the size of virgin trees normally found within a stand. For cork oak trees dispersed among stands dominated by other species, the threshold size was randomly assigned between 70cm and 120cm. In this case the assignment was made at tree level and it followed the relative frequencies found in the NFI 2005 data for the size of isolated virgin trees.
- The maximum stripping ratios correspond to the legal maximum stripping coefficients for trees with 2 or less debarked branches (2 for virgin cork, 2.5 for second cork and 3 for mature cork). For trees with 3 or debarked branches we followed the recommendation of Natividade (1950), using a coefficient of 2.5.
- The increase of debarking height, in addition to meeting the various existing legal requirements in the management of cork oak forests, was only considered in trees with mature cork with a calibre over 24.8 mm, and when the increase resulting has a length greater than 40 cm. That is, trees with thin mature cork or when the legally allowed increase was very small the increase in debarking height was not considered.
- The frequency of stripping considered in the simulation of pure and mixed stands followed the current trend recommended to the forest owners by FilCork (Interprofessional Association for Cork) which corresponds to use 9, 10, 11, 12 or 13 years in respectively 90%, 4%, 4%, 1$%and 1% of the stands.
- The debarking rotation in the trees dispersed within stands dominated by other species was equally distributed by the rotations between 9 and 13 years.
- The operations to increase stand density were not allowed with a periodicity smaller than 10 years.

4.2.2.2 Description of the scenarios used in the simulations

4.2.2.2.1 Business as usual scenario (BAU):

The scenario assumes the continuation of the trends observed in the Portuguese forests in the last decade with regard to development of the areas of each of the three species considered (cork oak, eucalyptus and

maritime pine), percentage of burnt area, forested area, deforested area, evolution of crown cover percentage of existing cork oak stands, current mortality rates of trees in cork oak forests, frequency and intensity of regeneration in existing cork oak forests and maintenance of the type of management in the cork oak understory. It is also assumed that the evolution of the stand crown cover is equal to -1.5% for a ten year period. This value was determined by Paulo et al. (2015) when considering the evolution of the stand crown cover estimated using the data from the Portuguese NFI 1997 and the NFI 2005.

4.2.2.2.2 Forestry development scenario (FDS)

The scenario assumes that the forest policy framework, adopted for the coming years, will promote the development of the productive potential of Portuguese forests. This will result in an increase in productivity of existing forest area by promoting the improvement of management practices, knowledge and operational capacity. In addition, the currently uncultivated areas or areas with shrubs will be planted. Consequently, it is expected that this situation results in an improvement of the productivity of the existing area accumulated to the increase of the area itself. The implementation of the FDS scenario considered, for the period 2015-2021, results in an increase of 50% in the forested area in relation to the figures published for the period 2000 and 2009, under the AGRO and RURIS programs (5651 ha / year). In this scenario the density of the stands classified as forest was increased in 30% of the plots measured in the NFI 2005 in order to achieve and maintain 58% of percentage of crown cover. The stands classified as agroforestry (70% of the plots measured in NFI 2005) were simulated in the same way as in the BAU scenario.

No deforestation was considered in simulations as the legal framework does not allow the conversion of cork oak stands to other land uses, even after a fire.

4.2.3 Results and discussion

Figure 24 shows the results of the simulations for the two scenarios considered. The dotted lines represent the variability in the annual cork production, that are obtained as simulation outputs. The observed variability reflects the range of distribution of cork ages found in the NFI 2005, and of the cork rotation periods considered in the simulations. This annual pattern may be different as the decision to debark depends on several factors: structure of cork prices and weather conditions during the cork growth period. For instance, an increase in the prices of thin cork may lead to the anticipation of cork extraction, while an increase in the price of thicker corks will make landowners to postpone cork debarking by one or two years, in the expectation of increasing the percentage of thick cork. If many dry years occur during the 9 year period, some landowners may decide (on the basis of the sampling of the cork thickness) to postpone the

extraction. In order to facilitate the observation of the tendency of cork production for the Alentejo region along the simulation period. The full and dashed lines were added as 9 years moving averages of the yearly cork production. The comparison of these two lines evidences the impact of the two scenarios in the cork production for the Alentejo region. A strong impact of the measures adopted for the FDS may be expected, with an increase of cork production that would get to a maximum average of around 120 10^3 ton per year in 2080. If considering the BAU scenario, average annual cork production is expected to stabelize around 80 10^3 ton per year until 2015, and only then to slightly increase up to 90 10^3 ton per year in 2070.

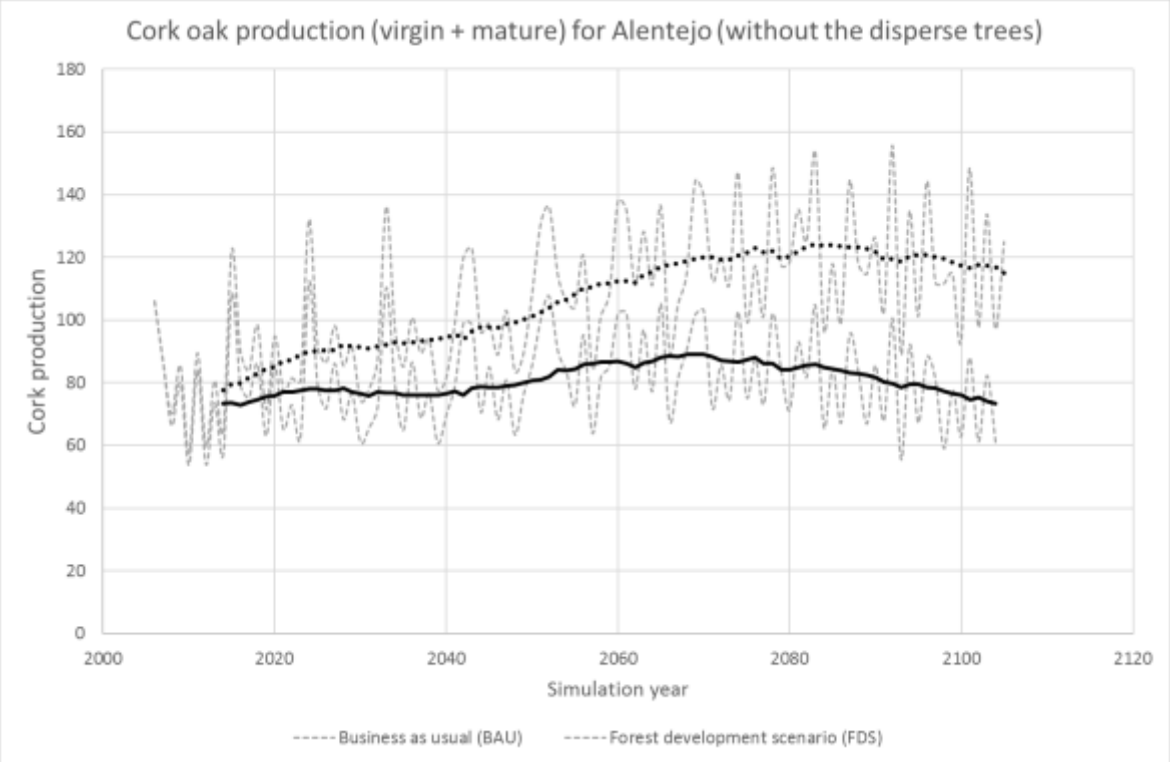


Figure 24. Simulated future cork production under the business as usual and the forest development scenario.

As illustrated in this example, the present version of the SUBER model can be used to support strategic policy measures at regional/national level.

4.3 Spain

Authors: SDM, JAB, TP, JMDA

4.3.1 Use-situation

The historical tradition of mushroom picking in Catalonian region (Northeast Spain) has put the focus on mushroom production as one of the main targets of the forest policy in the region. In spite of this, the variability of the yearly mushroom yields, mainly driven by weather conditions, but also by the forest stand structure, make it difficult to estimate mushroom dynamics accurately which, in turn, affects the process of decision-making at regional scale by policy makers. However, twenty years of continuous field research conducted by the CTFC in the region has allowed obtaining long-term data based on permanent plots. Based on such data, mushroom yield models have been developed (Bonet et al, 2008, 2010, 2012). The resulting mushroom yield models suggest a positive influence of forest management (i.e. thinning) on mushroom productivity at the stand level (Bonet et al., 2012) that contrast with the decline in forest management activity in the region. Yet, the estimated current wood harvesting in Catalonia represents only 20-30% of annual forest growth (Levers et al., 2014). In this regard, de-Miguel et al. (2014a) made one step forward studying the impact of forest management intensity at regional level using alternative scenarios based on new and improved mushroom yields models. This section summarizes the methodology and the main results of that study.

4.3.2 DSS description, materials and methods

Mushroom yield models were developed for total, edible and marketed mushroom yields in the main pine forest ecosystems of the region. The models were built using the long-term mushroom data (with minimum of 6 years of records) collected from 107 permanent plots inventoried every week during the autumn season. Additionally, the trees of the sample plots were measured for dbh and height once or twice in order to relate mushroom yield to the stand structure in a given year. The forest stand characteristics were updated for each year using individual-tree growth models for pine stands in Catalonia (see full references in de-Miguel et al. 2014a) and linear interpolation between two different measurements in some plots. Mushroom yields were predicted by means of mixed-effect models using a two-stage modelling approach: the first stage predicted the probability of mushroom occurrence using logistic regression, while the second stage predicted mushroom yield conditional on the probability of mushroom occurrence using mixed-effects linear modelling. The estimated mushroom yield was estimated by multiplying the probability of occurrence and the conditional yield estimate.

The second step was to simulate the forest dynamics at landscape-level using the information provided by the Third Spanish National Forest Inventory (NFI, DGCN, 2003). The NFI is based on systematic sampling of the forest area of the Catalonian region with a density of one plot per squared kilometre. A total of 3,272 NFI plots (representing 327,200 ha of pure and mixed pine forest stands) were selected in order to simulate stand dynamics for those forest ecosystems for which mushroom yield models were available. The forest management of the region is based on continuous cover forestry with the presence of semi-even-aged pine forest structures that should be assimilated to uneven-aged stands in terms of simulation of stand dynamics (de-Miguel et al. 2012b). Thus, existing growth models for uneven-aged Catalonian pine stands (e.g., Trasobares 2003, Trasobares et al. 2004) were used to simulate the stand dynamics of each NFI plot. Pine ecosystem-specific predictions of mushroom yield for a typical year were produced for every NFI plot using the models developed in this study.

The third step was to simulate the impact of regional forest management intensity on landscape-level mushroom yields considering four different management intensity scenarios as follows:

a) Scenario 1 or baseline: the approximate current forest management intensity in Catalonia, felling rate equal to 25 percent.
b) Scenario 2: absence of forest management, felling rate equal to zero percent.
c) Scenario 3: average forest management intensity in Europe, felling rate equal to 65 percent.
d) Scenario 4: maximum sustained yield, felling rate equal to 100 percent (annual timber harvesting equal to annual forest growth).

The time frame of each scenario was 30 years, i.e., from 2013 to 2043, subdivided into three 10-year periods. The assessment of the impact of forest management intensity on mushroom productivity focused on a group of nineteen edible mushroom species of high social and market value in Catalonia (henceforth referred to as marketed or commercially important mushrooms (see the mushroom list in de-Miguel et al. (2014a)). The simulation of forest management alternatives for the NFI plots was based on continuous cover forestry. Selective cuttings were simulated by thinning larger diameter classes more heavily than the small ones. Since stand basal area affects the timing of the thinning treatments, different management schedules were obtained by varying the stand basal area required for thinning and the intensity of thinning. One of the simulated schedules was always a no treatment alternative.

The four alternative forest management intensity scenarios were developed by formulating and solving four optimization problems by means of combinatorial optimization using simulated annealing algorithm (Dowsland 1993). The total growing stock volume at the end of the 30-year period was maximized in all

problems with the constraints that the 10-year harvest had to be 0, 1.7, 4.3 and 6.6 million m^3, corresponding to the intended forest harvesting intensities of 0, 25, 65 and 100 percent (see the full utility-theoretic formulation of the problem in de-Miguel et al. 2014a). The management objectives were the harvested volumes of the three 10-year periods and the ending growing stock volume. The sub-utility functions for the harvested volumes had an ascending-descending shape so that the target value of the harvest maximized the sub-utility.

4.3.3 Results and discussion

The updated mushroom models show that the amount of mushroom production depends significantly on stand basal area. The effect of stand basal area on mushroom yield follows an increasing-decreasing trend with an optimum dependent on the pine forest ecosystem. For the group of marketed mushroom species, this optimum ranges from 10-15 m^2 ha^{-1} in pure *P. halepensis* stands to 35-40 m^2 ha^{-1} in pure *P. pinaster* stands (Figure 25 left). A similar trend showing even greater difference between the minimum and maximum optimal stand basal areas was also observed for edible and total mushroom yield. At the landscape-level, most mushroom production is concentrated in pine forests of central and northern Catalonia, where *P. sylvestris* and *P. nigra* are the dominant pine species (Figure 25 right).

The scenario analysis showed that landscape-level mushroom productivity improves with increasing forest management intensity (Figure 26). Currently, the expected average productivity of marketed mushrooms from pine ecosystems in Catalonia is approximately 14 kg ha^{-1} yr^{-1} (4600 tonnes yr^{-1} at the regional level). If the current forest management intensity continues during the next three decades (Scenario 1 or baseline), a progressive loss in mushroom productivity can be expected as a consequence of a reduction in mushroom yield affecting 65% percent of the Catalonian pine forest area. After thirty years, the loss in productivity may be almost 0.7 kg ha^{-1} yr^{-1}. At the regional level, this would represent a decline of 220 tonnes per year (5%) in mushroom production from pine forests.

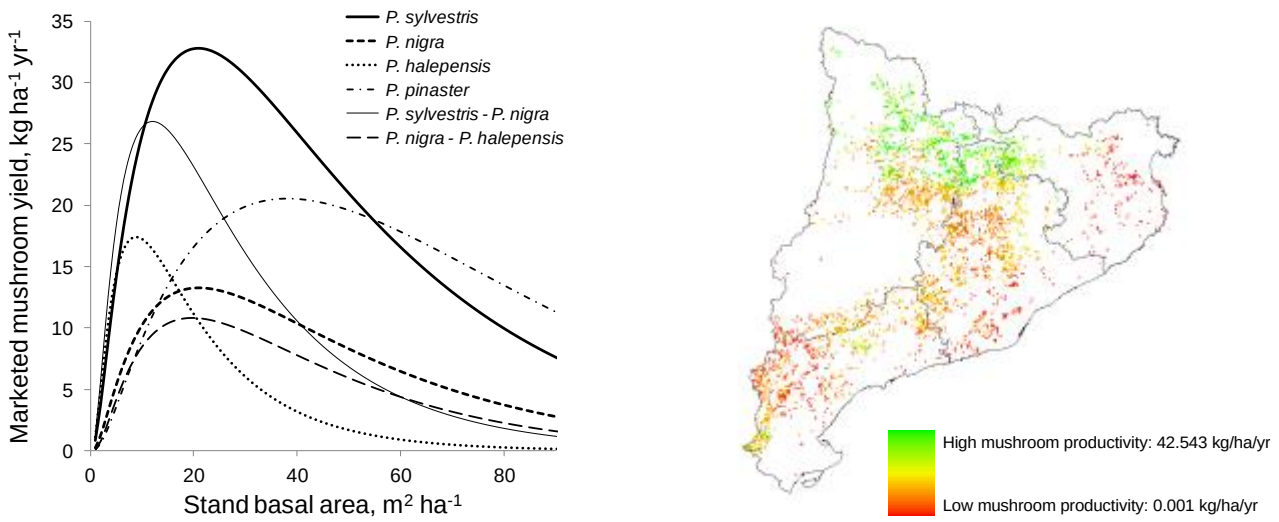


Figure 25. Influence of stand basal area (left) on the marketed mushroom yield. Predicted current mushroom productivity (year 2013) (right) in Catalonia (modified from de-Miguel et al. 2014a).

In the absence of forest management (Scenario 2), a decrease in productivity of commercially important mushrooms of approximately 0.5 kg ha^{-1} yr^{-1} every ten years (i.e., 1.5 kg ha^{-1} yr^{-1} in 30 years) could be expected. At the regional level, this means a drop in production of 163 tons per year every ten years, that is, 490 tons per year (11%) at the end of the 30-year period as compared with the current production. Such a loss in mushroom yield arises from an expected loss in mushroom productivity in 76% of the pine forest area.

The models predict that, in a landscape-level felling rate scenario of 65 percent and wood felling equal to annual forest growth (Scenario 3 and 4), the average mushroom productivity would increase by approximately 0.3 and 0.8 kg ha^{-1} yr^{-1} respectively from a rather even distribution of positive and negative changes in mushroom yield. At the regional level, this represents an increase in mushroom production of approximately 100 tons per year (2%) after thirty years in scenario 3 and an increase of 262 tons of mushroom production per year (6%) at the regional level in the scenario 4.

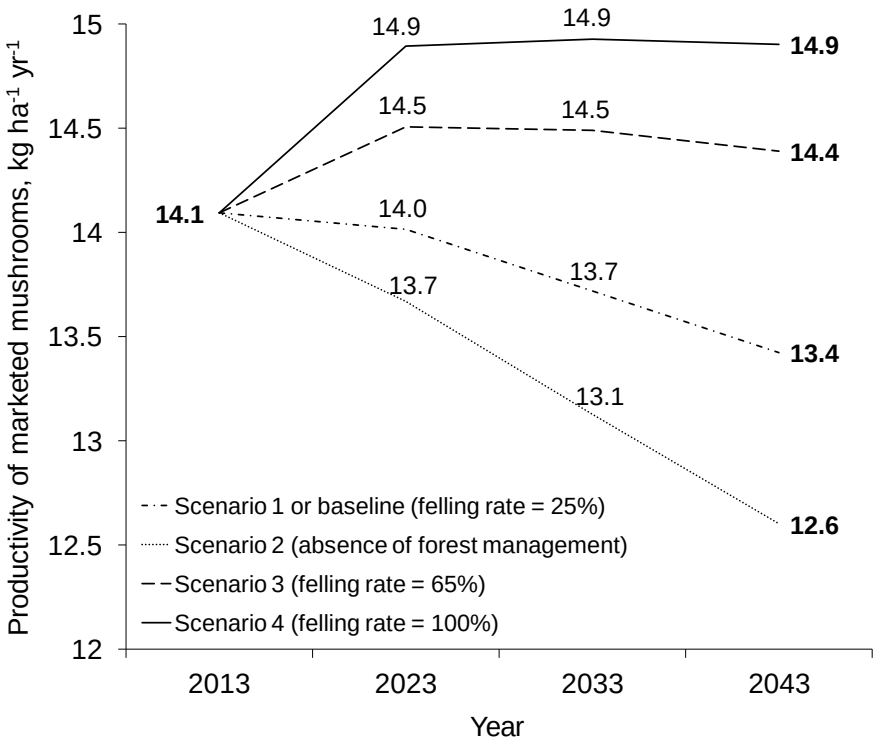


Figure 26. Evolution of the average productivity (kg ha^{-1} yr^{-1}) of valuable mushrooms in Catalonia during the next 30 years under alternative regional forest management intensity scenarios (modified from de-Miguel et al. 2014a).

5 Expert system development and use

Authors: HV, PH, BW

5.1 Rational and justification for expert model approach

Experiences in the production, management and marketing of NWFPs are growing and forest owners and users ask for new and innovative solutions beyond the production of timber. In this context Subtask 2.3.3 elaborates on the development of a knowledge-based expert model which supports forest owners in assessing the potential of NWFPs both on the region and the FMU level. As empirical data is scarce, the complex causal relationships between the sustained production of NWFPs under given natural conditions, and the organizational and market potential of forest management regimes are modelled by complementary methods. Taking into account multiple environments and a variety of management regimes Subtask 2.3.3 focused on the development of an approach that strives i) to identify the most

prominent NWFPs on a defined spatial scale and ii) to assess their potential for forest owners as regards the integration in current management regimes.

The approach comprises the use of MCDM methods, such as Analytic hierarchy process (AHP) and a Bayesian Belief Network (BBN) and strongly builds on stakeholder and expert participation. While the AHP aims to rank the most suitable NWFPs with respect to the region's operational environment, the BBN targets at the designation of a forest holding´s potential to successfully integrate one or several NWFPs in its management concept. A group of experts from different related subject areas was used in model verification and validation and contributed to the feasibility and applicability of the concept. The model was compiled iteratively including i) an initial two-day workshop of a core development group (authors of deliverable 2.4), ii) expert and stakeholder consultation (selected participants in the regional stakeholder panels of Austria, Finland, Portugal and Spain) and iii) repeated adaptation processes dedicated to the refinement of the expert model by the core development group. The application of both qualitative and quantitative methods was utilized to attain wide benefits of the proposed approach and contribute to knowledge transfer and improved problem understanding of non-expert decision makers for a sustainable co-production of wood and NWFPs.

5.2 Model components

A mix of quantitative methods is applied to assess the potential of the entire portfolio of NWFPs (Huber et al 2015). A portfolio of NWFPs comprises in this context all alternative options for the production, management and marketing of NWFPs for a given region, taking into account the ecological, economic and legislative constraints. The following flow diagram highlights the model development process to establish the current structure of the expert model (see Figure 27).

Figure 27. Flow diagram indicating the processes (rectangle), their sub-processes (split rectangle) and related decisions (diamond) with respect to the model development.

During the model development phase, a domain expert led the initial meeting with the objective to discuss the approach based on recent national and international research activities in the context of NWFPs. Criteria and indicators (C&I) were defined that could be properly modelled and were expected to meet the data needs for a single NWFP species. As a first result, a cognitive map was generated that mirrored the overall complexity of the system and provided the base for a first review and assessment of the feasibility and applicability of the concept. In a follow-up meeting the indicators were refined and their applicability for the chosen methods that build the expert model was evaluated. Following a brief description of both the AHP and the BBN structure a group of experts was contacted and invited to facilitate the further model development. Within a two-day workshop a core group of three senior researchers, a domain expert and a junior researcher evaluated the concept, and elaborated on the methods which are described in more detail in the following subchapters.

5.2.1 AHP

The Analytic Hierarchy Process (AHP) is an indicator-based MCDM method that supports collaborative decision making. Developed by Saaty (1990) it represents an approach that depends on the values and judgements of individuals and is widely used in decision making, planning and resource allocation as well as in conflict resolution. This approach allows for systematic evaluation of both qualitative and quantitative criteria or alternatives by means of pairwise comparisons and is particularly relevant to address complex decisions (Wolfslehner et al 2005). The final results provide a cardinal ranking of alternatives, including their relative priorities. In this study, the AHP is applied to generate a regionally explicit ranking of NWFPs that are available in the area under consideration. The criteria identified in the CM are arranged in a two level hierarchy with a set of NWFPs options to be evaluated under each criterion. The results of the AHP provide a reference for the assessment on the FMU level, evaluated by means of a BBN. The AHP consists of two levels of indicators, i.e. criteria and sub-criteria, which decompose an overarching goal – the decision problem under observation (Figure 28).

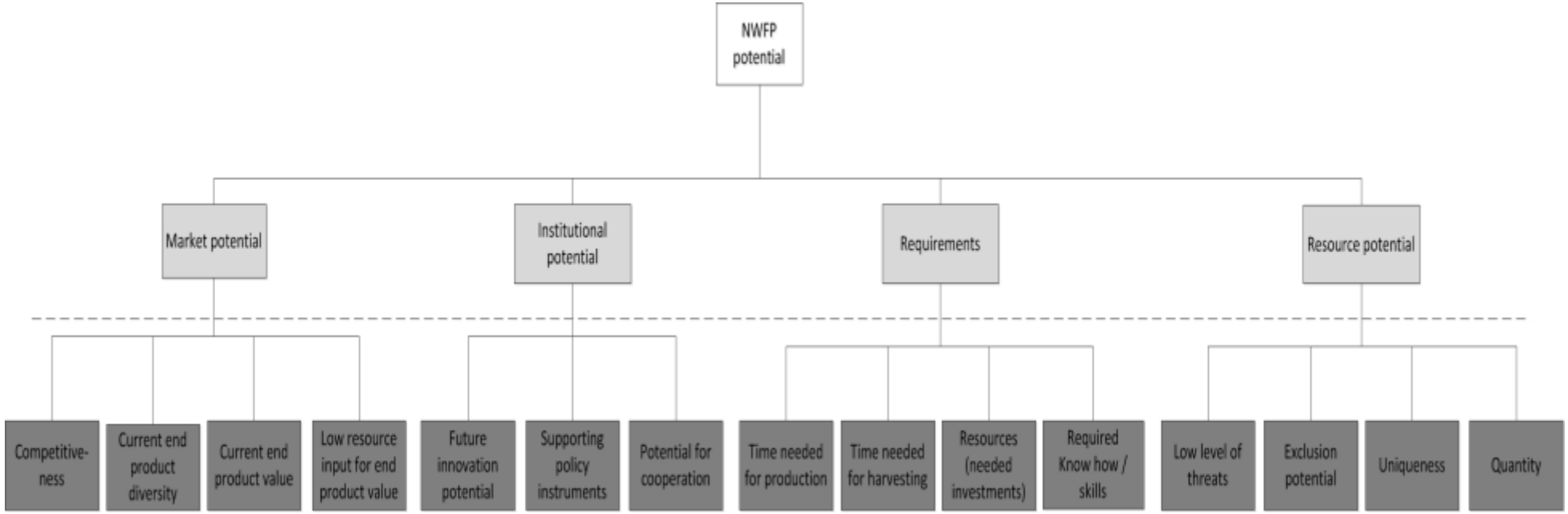


Figure 28. Overview of the AHP hierarchy including goal (white box), criteria (light-grey boxes) and sub-criteria (dark-grey boxes).

The goal is defined as to “identify the most promising NWFPs for a single FMU in the region x” (x = e.g. North Karelia, Styria and expresses the regional dimension of the analysis) and will be achieved via an assessment of four criteria. The upper level of the hierarchy is decomposed into a) market potential, b) institutional, c) requirements, and d) resource potential. Each of these criteria is specific to the region, i.e. the weight for each criterion will be derived in strong collaboration with regional experts who are actively engaged in NWFP management in their area. “Market potential” indicates the current market potential of a distinct NWFP and synthesizes existing opportunities to market them on e.g. local, regional, national, or international markets. “Institutional potential” of a single NWFP mirrors corresponding supportive or hindering structures (e.g. legislation, norms, action principles etc.). While “Requirements” highlight necessities for NWFP production and harvesting, “Resource potential” gives an estimate of the potential to successfully produce and/or harvest a single NWFP. The lower level of the hierarchy (i.e. Sub-Criteria) is used to further decompose the higher-level criteria and aims to specifically address the perceptions of a single forest owner/manager. Further details will be available in Huber et al (2016).

5.2.2 BBN

A Bayesian Belief Network (BBN) is a probabilistic graphical model that can be applied to a wide range of environmental problems (e.g. Howes et al 2010, Catford et al 2013,Landuyt et al 2014). BBN has been used as a technique to model ecological predictions and to aid resource-management decision-making (Marcot et al 2006). BBNs consist of two structural components: i) a causal network (often referred to as the directed acyclic graph), and ii) conditional probability tables (CPT) that quantify the relations in the network (Jensen 2001). In our application, the BBN is applied to unravel the potential in a FMU of integrating one or more of regionally available NWFPs in its forest management concept (Figure 29). Due to the overall complexity with respect to diverse environmental settings and management concepts the BBN is designed to be applied to clusters of NWFPs instead of individual NWFPs as follows: i) tree products (e.g. birch sap), ii) mushrooms and truffles (e.g. *Boletus edulis*), iii) understorey products (e.g. berries), and iv) animals (e.g. game meat).

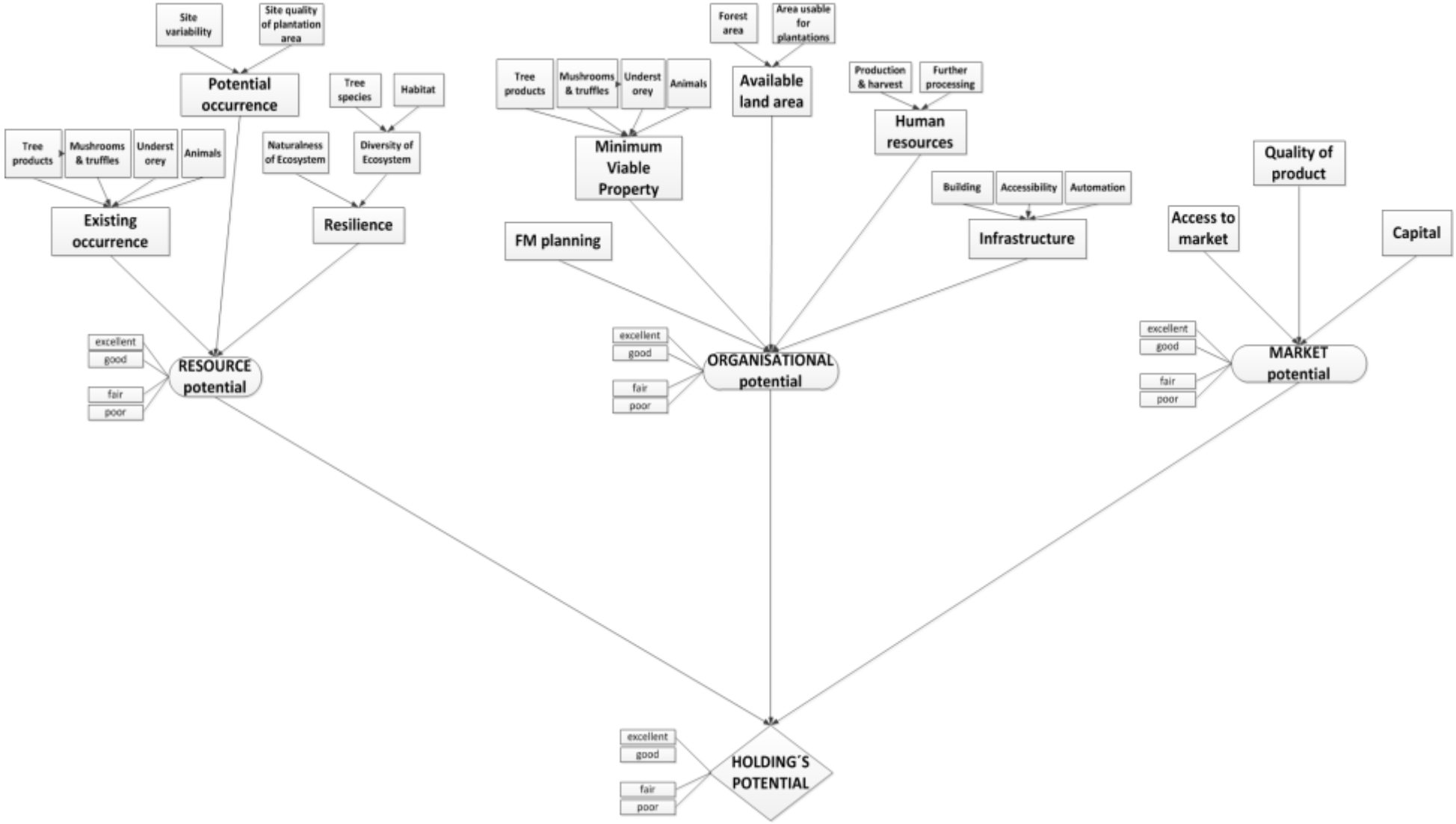

Site variability
Site quality of plantation area
Potential occurrence
Tree species
Habitat
Tree products
Mushrooms & truffles
Understorey
Animals
Naturalness of Ecosystem
Diversity of Ecosystem
Existing occurrence
Resilience
excellent
good
fair
poor
RESOURCE potential
Forest area
Area usable for plantations
Tree products
Mushrooms & truffles
Understorey
Animals
Available land area
Production & harvest
Further processing
Human resources
Minimum Viable Property
Building
Accessibility
Automation
Infrastructure
FM planning
excellent
good
fair
poor
ORGANISATIONAL potential
Quality of product
Access to market
Capital
excellent
good
fair
poor
MARKET potential
excellent
good
fair
poor
HOLDING´S POTENTIAL

Figure 29. Overall design of the BBN highlighting the relationships between network nodes.

Consisting of different nodes that are described by certain states, the causal network covers the final child node “Holding´s potential”, which is influenced by three so-called parent nodes. “Resource potential” gives indication on the potential to produce a (group of) certain NWFPs within a holding and aims to mirror a variety of ecological aspects. It is assessed via three indicators: a) Existing occurrence, b) Potential occurrence, and c) Resilience. “Organizational potential” is split into a) FM planning, b) Minimum Viable Property, c) Available land area, d) Human resources, and e) Infrastructure, and estimates the capacity of a holding to produce a (group of) certain NWFPs within its property. Finally, the “Market potential” targets at an assessment of a holding´s potential to market a (group of) certain NWFPs and is influenced by a) Access to market, b) Quality of product, and c) Capital. Wherever relevant these indicators are further refined by additional parameters (as outlined in Figure 28). The results of the BBN provide probability estimation for a selected set of NWFPs (respectively a cluster) with respect to a single FMU.

5.3 Expert elicitation process

As explained above the expert model builds on two model components, thus it has to be distinguished between expert elicitation processes relevant for the AHP and for the BBN. Both require specific routines in order to meet the distinct objectives of knowledge transfer required to populate the missing links of lacking data.

5.3.1 AHP

For the AHP, three aspects need to be covered by expert knowledge: a) regional weights for the AHP criteria, b) NWFP selection, and c) pairwise comparisons. The aim for a) is to derive at a consensual agreement on the relative importance of the main- and sub-criteria and requests for the elicitation of preference ratings in collaboration with regional NWFP experts who are actively involved in NWFP management in the study area. Two methods can be applied, but not mixed, in order to achieve the final weighting scenario, i.e. a workshop or a delphi survey. For steps b) and c) it is necessary to nominate a (group of) domain expert(s) who will elaborate on the pairwise comparisons of selected NWFPs. Once the decision on the NWFP portfolio is made, experts are asked to rank the selected NWFP species according to

each sub-criterion for the pairwise comparisons that are conducted via Expert Choice, a decision-making software for MCDM applications.

5.3.2 BBN

To assess the FMU´s potential with regard to the integration of NWPFs in its forest management concept by means of a BBN, it is essential to request for experts´ opinions on the likelihood of a given set of state combinations and their influence on the subordinate network node. Experts need to assign probability distributions across the entire network model. In order to reduce the elicitation burden for the experts the EBBN method of Wisse et al. (2008) is applied, an approach that reduces the number of probability assignments needed for an automated CPT computation. This approximation method developed by Radl et al. (2016) is used to calculate all CPTs based on a number of selected distribution scenarios. A survey amongst NWFP experts to determine the CPT values is currently under preparation.

5.4 Case study results

In the frame of the StarTree project considerable progress on the development of the expert model could be made. While the BBN is in its final development stage, ready to be populated by expert knowledge prior to an application on the FMU level, the AHP part of the model could be finalized and tested in two specified StarTree case study regions (i.e. North Karelia, Styria). Following the first results and the dissemination within the StarTree consortium the network of study regions could be expanded. In total, five case studies were developed in strong cooperation with project partners who took the lead in the AHP implementation in their region:

- Alentejo region – Portugal
- Catalonia – Spain
- Extremadura – Spain
- North Karelia – Finland
- Styria – Austria

While the case studies in Alentejo, North Karelia and Styria could build on the StarTree Regional Case Studies, inter alia taking advantage of actively involved NWFP experts, new study cases were established in the Extremadura region and in Catalonia. We used the modelling framework introduced in 5.2 to evaluate selected NWFP species across four defined NWFP categories (i.e. mushrooms & truffles, understorey

plants, tree products and animal origin) in all five regions. To derive at a consensual agreement on the relative importance of the criteria (i.e. Market potential, Institutional potential, Requirements, Resource potential) for the case study regions and to mirror potential regional divergence of NWFPs markets, stakeholder interaction was a prerequisite. Selected stakeholders from the regional stakeholder group were invited to contribute to the development of a regionally explicit weighting scenario by a stakeholder workshop and/or a delphi approach. While the former built on a Simple Multi-Attribute Rating Technique (SMART) exercise to elicit preference ratings within the meeting, the latter was prepared as two-stage electronic survey amongst the stakeholders involved and allowed for adaptation after the first round of judgements.

In total 15 single NWFP species were evaluated, clustered in the four NWFP categories, ranging from a minimum of 5 NWFPs (e.g. North Karelia) to a maximum of 8 NWFPs in Styria. The most common NWFP across all case studies was honey harvested from *Apis mellifera* (4 out of 5 study regions), followed by Boletus (*Boletus edulis*; both 4 out of 5 study regions), Bilberry (*Vaccinium myrtillus*) as well as game meat from Red deer (*Cervus elaphus*), both of them considered as relevant in two case studies. All other NWFPs were exclusively addressed within single case study settings. The final results on the performance of selected NWFPs that were derived in a series of expert meetings to conduct the pairwise comparisons for each case study, under equal weighting scenario for AHP criteria, are shown in Figure 30.

Although honey appears to be relevant in the majority of the case studies it can be denoted that the overall performance in comparison to other NWFPs differs notably among regions. While honey can be recognized as a suitable option for co-production in Styria and North Karelia, it is outranked by most other NWFPs in all other case study regions. Bilberry seems to play an important role in North Karelia, while in Styria it is only of minor relevance. Cork (*Quercus suber*) is the dominant NWFP in the Iberian case studies although there seems to be high latent potential for "Cerdo iberico" (*Sus scrofa domesticus*) in the Extremadura region and Yellow gentian (*Gentiana lutea*) in Catalonia. In Styria Christmas trees (*Abies nordmanniana*) can be assumed as an interesting opportunity for forest owners. Another, more innovative option for NWFP management is subject to the North Karelian case study where Pakuri (*Inonotus obliquus*), a parasitic fungus that is cultivated on birch, performs very well. It was ranked on second position among the evaluated set of NWFPs, only bilberry was evaluated with a higher potential.

Table 17: Overview of results in the case study regions, highlighting individual performances (i.e. global prorities) of selected NWFPs across criteria (Market potential, Institutional potential, Requirements, and Resource potential) and final rankings

Region	Category	Species	Ranking	Global priorities
Alentejo	Mushroom & Truffle	Boletus edulis	4	0,121
	Tree product	Quercus suber	1	0,263
	Tree product	Pinus pinea	2	0,177
	Tree product	Pinus spp.	5	0,102
	Understorey	Lavandula viridis	3	0,163
	Animal origin	Apis mellifera	6	0,095
	Animal origin	Oryctolagus cuniculus	7	0,080
Catalonia	Mushroom & Truffle	Lactarius deliciosus	4	0,142
		Tuber melanosporum	3	0,215
	Tree product	Quercus suber	2	0,217
	Understorey	Gentiana lutea	1	0,294
	Animal origin	Sus scrofa	5	0,132
Extremadura	Mushroom & Truffle	Boletus edulis	3	0,183
	Tree product	Quercus suber	2	0,237
	Animal origin	Sus scrofa dom.	1	0,368
		Cervus elaphus	5	0,096
		Apis mellifera	4	0,116
N-Karelia	Mushroom & Truffle	Boletus edulis	3	0,153

	Tree product	Betula pendula	4	0,131
		Inonotus obliquus	2	0,219
	Understorey	Vaccinium myrtillus	1	0,277
	Animal origin	Apis mellifera	2	0,219
Styria	Mushroom & Truffle	Boletus edulis	6	0,110
		Cantharellus cibarius	7	0,108
	Understorey	Vaccinium myrtillus	8	0,102
		Allium ursinum	5	0,113
	Tree product	Larix decidua	3	0,142
		Abies nordmanniana	1	0,162
	Animal origin	Cervus elaphus	4	0,120
		Apis mellifera	2	0,143

5.5 Discussion and Conclusion

Taking into account the huge diversity of NWFP options, different socio-economic contexts and varying ecological conditions it was a prerequisite to develop a tool that is able to cope with such a multiplicity and can thus be applied in an array of case study settings across Europe. Furthermore it was a major objective to assess the potential of NWFPs at various scales, i.e. on the regional and on the FMU level. Thus it was a crucial step to identify a combination of methods that meets these requirements. The successful implementation in five diverse case study settings of the AHP part of the expert model, that constitutes the main module for the regional assessment of NWFPs options, depicts the applicability of this method and provides a promising concept that has the potential to reach out to support forest owners in forest management planning and related decision making. As can be recognized from the case study results, the AHP could be successfully applied to a diverse range of NWFP species. Thus it can be expected that the

entire portfolio of NWFPs that is available, and for any reason relevant in a certain region, may be evaluated by this method.

The BBN approach could be developed on the basis of the AHP experiences, considering as far as possible the same criteria and NWFP categories in order to provide a logical sequence and strong link between both methods. Since the assessment on the FMU level needs to tackle additional aspects in order to come to grips with potential ecological, economic or organizational constraints that may foster or hinder the successful integration of investigated NWFPs, a set of additional parameters could be introduced in cooperation with domain experts.

The positive feedback from stakeholders as well as experts across the case study regions, who contributed with their expertise to fine-tune the expert model approach, provides a promising opportunity to continue the assessment of the NWFP potential for forest owners, at least in the case studies that could be developed within StarTree. Furthermore, the network of experts who participated in the development of the expert model proved to be a valuable platform for mutual learning and knowledge exchange particularly addressing the further development of NWPF issues in Europe. Besides knowledge transfer along the interfaces of science – practice, science – policy, science – public and vice versa, it is the main objective to continue to raise awareness on the sustainable co-production of wood and non-wood forest resources in order to diversify the product portfolio of forest holdings and thus, to positively contribute to the sustainable development of rural communities.

6 Discussion

Authors: all authors

The manifold results presented in this report show progress in the development and use of DSSs in various ways. The report was structured by following the spatial hierarchical levels that are typically applied in forest management planning. The examples and results **for stand level** are primarily targeted to be utilized by forest managers as they provide the forest managers direct recommendations on how to manage certain kinds of forest stands. The DSSs applied at stand level have been developed in mainnly for research purposes (with the exception of Portugal) (Table 18). The development and results at **FMU level** are most beneficial for forest owners of FMUs as they illustrate the outcomes of certain forest management strategies or alternatives. For example, the use-situations from Finland and Portugal, in which the results were visualized to forest owners and stakeholders, are helpful when trying to understand the multi-dimensional production possibilities of their forest holdings. At this level, the use of the DSSs at practical level is also important. **The regional level** results aim to serve particularly forest policy formulation and preparation of regional forestry programs in setting their targets and developing their actions.

At stand level, one of the first attempts to combine NWFP-originated incomes to timber harvesting incomes in stand-level optimization was the study of Palahí et al. (2009). The stand-level use-situations reported in this document follow rather similar approach and use of methods. However, new target NWFPs and characteristics were introduced in these calculations. For example, integration of non-linear berry picking costs in optimization calculations (Finland) and climate scenarios for predicting the cone yields (Spain) were new characteristics. An example of new NWFP that was included in stand-level calculations was the interesting study from Turkey regarding the pine-honey production.

Table 188. The availability of the described forest DSSs to forest managers/practitioners in different areas.

Country	Stand level	FMU level	Region level
Finland	The DSS has been developed mainly for research purposes. The results it produces have been transferred to practitioners.	The Monsu planning system is in use in various forestry schools and in some practical organizations and in this way the DSS and its approach become familiar to practice as well.	Some large forest owners (e.g. Metsähallitus managing Finnish state forests) are users of MELA systems and thus they can use the berry yield models through the system in future. The principal way to transfer results to practice is to deliver scenarios to forest managers and policy makers according to their needs.
Portugal	The stand level model is implemented in the standsSIM simulator, available in the web (*)and used by forest managers and practitioners. Some workshops for training and dissemination have been organized. The webCorky tool, to support the decision about cork extraction, is also available on the web.	The standsSIM simulator can simulate all the stands that make part of an FMU, using different forest management approaches for each one of them.	The standsSIM simulator runs according to two options, one driven by forest management and usually used at stand and FMU level and another focused on the simulation of large regions or even the country. This last is driven by several external variables such as wood and cork demand, annual area of new plantations and of deforestation and annual burned area. This option is not available on the web but was been used in a study of the future strategies for the forestry sector in Portugal.
Spain	The DSS has been developed mainly for research purposes. The results it produces have been transferred to practitioners.	The DSS used has been developed mainly for research purposes. The results it produces have been transferred to practitioners and the managers of the pilot area where the study was conducted.	The DSS used has been developed mainly for research purposes. The results and scenarios it produces have been transferred to practitioners.
Turkey	The DSS has been developed mainly for research purposes. The results it produces have been transferred to practitioners.	The ETÇAP DSS is a prototype-tool mainly developed for research purposes. However, the DSS has been tested in few case study areas (forest management units) by the state forest management department and it is under evaluation regarding its wider future use by practitioners.	

(*) http://www.isa.ulisboa.pt/cef/forchange/fctools

At FMU-level, the examples from Finland, Portugal, Spain and Turkey show that the multi-objective forest management approach based on the development and evaluation of FMU-level alternatives is strengthening. Through alternatives, the preconditions to evaluate the trade-offs between goal variables and to analyse the economic consequences are improved. In addition, the importance to visualize the

results to actual decision makers (owners) has been recognized and progress in this field has taken place. The case study results indicated that integrating NWFPs into forest DSSs is a valid approach for preparing long-term forest management in a way that acknowledges multiple forest-use objectives of owners and forest professionals. In addition, presentation of too complicated outputs from DSSs does not alleviate owners decision making process.

The development of the expert knowledge-based multi-method DSS was advanced in at least three important dimensions. First, it is able to consider the operational environment more broadly than only from forest perspective. Second, it includes a possibility to examine both the FMU and region level capabilities of NWFPs production. Third, it can examine several predefined NWFPs at the same time. These are all new and important characteristics of DSSs related to NWFPs.

In region level examples from Finland, Portugal and Spain, the large scale forest DSSs were developed and applied to better meet the information needs and other demands of forest policy and program preparation processes. Similar to the FMU level approach, also these results are based on the creation of region level scenarios. Through the scenario approach, first attempts to estimate the future production possibilities of mushrooms (Catalonia) and berries (North Karelia) in different cutting scenarios were taken. In addition, the results from Catalonia could be presented through maps, which indicates that in addition to quantities also the spatial location of different NWFPs resources is important.

To conclude the current situation regarding the preconditions for using forest DSSs in calculations that support the forest management decision making which acknowledges various NWFPs, the SWOT analysis was prepared by the authors of this report. The main authors of this report had a short common meeting where, after becoming familiar with the contents of the deliverable, the SWOT factors were identified and fine-tuned together. The strengths and weaknesses describe the current situation in the field of DSS development and use. The needs for future work are indicated through the factors included in opportunities and threats.

Strengths:

- Improved availability of NWFPs yield models, some of them enabling the considerations related to e.g. annual variation in berry yields.
- The yield dependent harvesting cost was included in calculations instead of using (more unrealistic) selling prices which ignore travelling and picking costs.
- Improved possibilities to utilize expert knowledge when empirical data are lacking.

- Some DSS are already functional in Internet, in addition generic visualization applications can be utilized to support NWFPs related decision making.
- The DSSs are flexible in the sense that they can be easily used to create alternatives also related to NWFPs and in this way they allow managers to analyse trade-offs when they are searching for the best option.

Weaknesses

- Despite numerous stochastic elements (e.g. weather), deterministic approach dominates when predicting the yields of various NWFPs (note however the Spanish stand-level example on *Pinus pinea*).
- Model and input data uncertainties are seldom reflected in calculations.
- Models and DSSs are too much restricted to certain regions and management systems.
- Still too many simplifications in calculations: e.g. the effect of NWFPs quality on stumpage prices, market conditions and harvesting costs have often been neglected.
- The scarcity of empirical data and related models still limit the DSS development too much.
- Unavailability of data to understand and model the effects of silvicultural actions on various NWFP

Future opportunities

- Bioeconomy development will shed light on the increased utilization of NWFPs, and it is becoming more important to investigate trade-offs between them and timber production in different conditions.
- Forest owners interests towards NWFP-business is starting to increase.
- Integration of (semi)cultivation aspects of NWFPs in DSSs is an emerging topic.
- Increased awareness about the potential of NWFPs in the framework of co-production.

Future threats

- Results from DSSs are not followed and traditional management continues.
- In some NWFPs with a strong position in the market (e.g. cork) the opposition of traditional managers to carry out a more adaptive and new management recommendations.
- Unsustainable utilisation of NWFPs if annual harvests or yields are overestimated by the DSSs results.
- NWFPs remain a neglected side product in intensified roundwood oriented forest resource utilization.

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