Project no. 311919

StarTree

Multipurpose trees and non-wood forest products a challenge and opportunity

Start date of project: 1 November 2012

Duration of project: 4 years

Collaborative Project

FP7-KBBE-2012-6-singlestage

D2.2. Description of the improvements in the models for NWFPs and MPTs

Due date of deliverable: **31 October 2015**

Actual submission date: **31 October 2015**

Organisation name of lead contractor for this deliverable: **INIA**

Dissemination level: **PU**

This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement No 311919

Editors

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Reference

Sánchez-González M., Pasalodos-Tato M., Cañellas I., (Editors) 2015. Description of the improvements in the models for multipurpose trees (MPT) and non-wood forest products (NWFP). D2.2 of the StarTree project FP7 Project no. 311919 KBBE.2012.1.2-06, European Commission, 69p.

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List of Abbreviations

MTP multi-purpose tree

NFI6 6th Portuguese National Forest Inventory

NWFP non-wood forest product

SFNI Spanish National Forest Inventory

Consortium partners included in task:

LUKE, CTFC, ISA, INIA, KTU, IWW, and all CSRs

This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement No 612385

EXECUTIVE SUMMARY

The objective of the present deliverable is to identify the improvements already developed or that need to be develop in order to overcome the possible weaknesses of the different MPT and NWFP models. Since the existing models have been widely described (Calama et al., 2010; Tomé and Faias, 2014), this report is focused on the improvements made to them, the ones already achieved under the StarTree project as well as the on-going research that will be concluded before the end of the project or that will be object of further research. Besides, the report is not only focused on those MPT and NWFP models that have been already developed but also on those MPT and NWFP models are been developed or will be developed in the near future within the framework of the StarTree project.

The main body of the deliverable is structured in two different chapters. The first part (chapter 2) is focused on those existing models that already present a high degree of development and that were already described in the previous report Deliverable 2.1 (Tomé and Faias, 2014). In this chapters the MPT analysed are stone pine (*Pinus pinea* L.) and cork oak (*Quercus suber* L.), and the NWFP are mushrooms and berries. All these MPT and NWFP present already models with a high degree of development. The countries in which these models have been developed are Portugal (stone pine and cork oak), Spain (stone pine, cork oak and mushrooms) and Finland (mushrooms and berries). In the case of SUBER 6.0 model (Portuguese model for the cork oak), many improvements have been proposed since the previous version of the model (SUBER 5.0), some of them already completed before the StarTree project and some others that are been developed within the StarTree project and are referred to the different modules of the model. The improvements that have been already made comprise a new function for site index estimation including soil and climate variables as predictors in the initialization module. In the tree growth and production module a model for tree total height growth in stands in the regeneration stage as well as a new model for crown width prediction have been already completed. The models that will be finalized before the end of the StarTree are related to the cork growth and production module and to the mortality module. In the former case a new annual cork growth function that includes as predictors tree, management, stand and environmental variables. For the mortality module a new mortality model using soil and climate variables is being developed. The Spanish model for cork oak, ALCORNOQUE; presents some limitations most of them related to the applicability ranges that recommend its use in those stands older than 40 years. This is the case for the model of the height growth and diameter growth of dominant trees. This shortcoming is meant to be solved with a model for younger stands. The first step to develop these models will be taken within the StarTree project with the establishment of field plots in juvenile cork oak stands. Other aims that will be

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completed within the StarTree project are the development of a methodology for predicting cork weight and the development of a diameter class model to define different stand structures for cork oak stands in Spain. In both cases plots from the SNFI are used as a database. The implementation of the ALCORNOQUE model in a simulator tool freely available (wwwx.inia.es/alcornoqueWeb) have been already completed.

In the case of the Spanish stone pine model (PINEA2), the main limitation of PINEA2 is that the model is climate insensitive. To overcome this shortcoming, a new module for tree annual basal area increment, incorporating climate parameters, is being developed. Also the effect of the damage caused by *Dyorictria mendacella* is being assessed by means of a spatiotemporal model for cone losses. Other advances that are going to be completed within the StarTree project comprise the development of a new version of stand-level simulator PINEA2, including additional modules (regeneration fellings, self-thinning, nut content & quality) and the identification of factors affecting reduction in nut yield, to be incorporated in further models. For the Portuguese model PINE_PT, the improvements that aim to be completed within the StarTree project include a module for predicting the site quality as a function of soil characteristics and climate as well as new models for tree dbh (Diameter at Breast Height) and height growth. A new module for pine cones production is also under development.

Many are the improvements achieved in the case of the berry models analysed in StarTree are corresponding to Finland. Within the project a new statistical model was estimated for cowberry using the dataset covering the whole Finland. The existing berry models were evaluated using an independent data set measured from North Karelia and the 'best' existing berry models were calibrated using the field measurements and literature. The calibrated models for bilberry and cowberry were linked to the existing stand simulators to describe the development of berry yields along the stand development. A new statistical model was estimated for bilberry using the dataset including also peatlands and covering the whole Finland. Other advances that are going to be completed within the StarTree project included the implementation of the calibrated berry yield models on the Finish forest simulator to obtain simulations at the forest management unit and regional level.

Models for the mushroom yield in Spain are been completed with the development of new empirical models that include soil characteristics as predictors. Another important improving in these models would be the inclusion of the effect of thinnings in mushroom yields. In the case of the mushroom models in Finland, the most important limitation is that the models developed are not suitable for numerical multiobjective planning since the information regarding site and stands characteristics have not been reported in mushroom inventories. In order to overcome this shortcoming, a new expert model was

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estimated for Boletus edulis in Norway spruce stands in North Karelia (Finland). Also new statistical empirical models were estimated for marketed, edible mushrooms (B. edulis, Lactarius spp. and all marketed mushrooms) in Norway spruce stands in North Karelia (Finland) using a new set of sample plots in thinned and unthinned stands.

In most of the cases, management schedules for the joint production of timber and NWFP are optimized.

The third chapter is devoted to those MPT and NWFP that, despite their importance, do not count with a yield model yet and need to be developed, not only models for new MPTs or NWFPs, but also models in different regions for the same products previously named. The development of these models is expected to begin in the framework of the StarTree project. This is the case of resin from maritime pine (*Pinus pinaster* Aiton), chesnut (*Castanea sativa* Mill.), walnut (*Juglans regia* L, *J. nigra* L., *J.x intermedia* Carr.), cherry (*Prunus avium* L.), sorbus (*Sorbus torminalis* L., *S. aucuparia* L., *S. domestica* L.), lime (*Tillia* spp.), bay leaves (*Laurus nobilis* L.) and pine honey. Since the development of a robust empirical yield model is difficult to achieve during the StarTree project, most of the tasks will be lead to the data collection that could serve as a base for future research. Other of the strategies proposed for the development of new models is the use of expert knowledge, as it is the case for mushroom yield in Portugal. In other cases were the establishment of sample plots is not an easy task, recommendations for further research were given (resin and pine honey).

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1 Introduction

Authors: MS, MP, IC

The objective of this deliverable is to provide a whole vision of the NWFP and MPT models. In this sense, the deliverable comprises two different parts. The first part is focused on those existing models that already present a high degree of development and that were already described in the previous report Deliverable 2.1 (Tomé and Faias, 2014). This is the case of models for cork, pine nuts, mushrooms and berries. The second part of the deliverable is devoted to those models that need to be developed, not only models for new MPTs or NWFPs, but also models in different regions for the same products previously named. The development of these models is expected to begin in the framework of the StarTree project.

Since the existing models have been widely described (Calama *et al.*, 2010; Tomé and Faias, 2014), this is focused on the improvements made to them, not only the already achieved under the StarTree project but also the on-going research that will be concluded before the end of the project.

The new models presented in this report refer both to NWFP of MPT that do not count with models in Europe yet, despite the proved commercial importance shown (Tomé and Faias, 2014), as it is the case of the lime tree, bay tree or chestnut , or to those species that have already an implemented model for some regions but need to develop models for different areas. This is the case of pine nuts production, that have achieved a very high degree of accuracy in the models developed for Spain while in Turkey there is no model related to that production yet. The same can be applied to berries and mushrooms in Turkey. In this sense it is important to remember the main challenges when developing NWFP and MPT models are data requirements and modelling methodologies (Calama *et al.*, 2010). In some occasions the lack of empirical measurements can be substituted by expert knowledge.

In short, the present deliverable will try to be a guide for the next steps that need to be done in NWFP and MPT yield models not only under the umbrella of the StarTree project but also as a reference in the research area for the following years in order to settle the direction towards where the future research in this area should be conducted.

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2 Existing models with an important degree of development

2.1 Models for cork

Cork oak is among the most important MPT, together with stone pine, in the Mediterranean area. Cork is obtained from the outer bark of the cork oak and usually it is collected for the first time when the trees reach a dbh above 20 cm. From this first debark, subsequent debarking takes place every nine to fourteen years. The main models for cork oak have been developed in Spain and Portugal, where cork is an important component of the forest sector.

2.1.1 Portuguese model 1: SUBER

Authors: JAP, MT, SF, PNF, PH

The SUBER model, currently available as version 5.0 (Paulo, 2011), is a distance-independent individual-tree forest growth and yield model, used in Portugal to support cork oak management decision making. The projection unit is the stand, and the maximum recommended temporal scale is 100 years, simulated at a resolution of 1 year. Projections start with the analysis of forest inventory data given as input for the model, followed by the computation of missing tree and stand variables, in order to provide a summary of current stand conditions. The remaining modules refer to tree and cork growth and production, tree mortality and the implementation of management operations, such as debarking or thinning.

Along the StarTree project different modules have been improved, using existing data complemented with data obtained by the remeasurement of existing plots and trials: (i) initialization module, (ii) tree growth and production module, (iii) cork growth and production module, and (iv) mortality module. These improvements were implemented in the SUBER stand simulator. Since this cork oak stand simulator is included in the sIMfLOR platform for the Portuguese forest simulators (Faias *et al.*, 2012), some modification in the platform had to be carried out. The new version of the SUBER model and the updated sIMfLOR platform will be uploaded to the FcTools webpage (www.isa.ulisboa.pt/cef/forchange/fctools).

The following sections describe the results obtained from these improvements, which will result in a new version (SUBER 6.0) of the model.

Initialization module

The main improvement of this module is the development of new functions for the site index estimation to be used when age is not known or not possible to determine. Within the SUBER model, site productivity is expressed by the site index concept based on the Spanish site index curves (Sánchez-González et al., 2005).

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However a large share of the cork oak stands in Portugal are adult stands of unknown age or uneven-aged stands that do not allow the use of site index curves. It is also a requirement of the model the estimation of site index (S) for the simulation of new stands in locations where cork oak was not previously present. This leads to the need of developing a model for estimating site index, which does not depend on stand age. A first version of this module was developed for version 4.0 of the SUBER model using a preliminary data set that included 30 observations (Tomé, 2004). A new model was now developed using an extended data set and an alternative data analysis methodology.

Site productivity, assessed through site index in 100 plots established in 42 even-aged cork oak stands of known age, was modelled using partial least squares (PLS) regression (e.g. Abdi, 2010) as a function of soil and climatic variables. Two alternative models were developed: (a) a full model, considering all available explanatory variables, and (b) a reduced model, considering only variables that can be obtained without digging a soil pit. The developed models indicate the importance of water availability and soil water holding capacity for site index value estimation. Site index was related to climate, namely evaporation and frost, and soil characteristics such as lithology, soil texture, soil depth, thickness of the A horizon and soil classification.

The full and reduced models were both included in the SUBER model (initialization module) and the sIMfLOR platform forms (Faias *et al.*, 2012) were updated in order to allow the selection of the climate and soil variables required by the models. When caring out a simulation, the selection of one of the two models is made by the user depending on the available soil information concerning the stand to simulate. If soil classification (FAO classification and lithology), textural class, soil depth and thickness of the A horizon were locally accessed, the full model may be used. If not, soil data must be obtained through digital cartography from the environmental atlas available at the Portuguese Agency for the Environment website (http://sniamb.apambiente.pt/webatlas/), and the reduced model is considered by the SUBER model during the simulation. Regardless of the model selected, climatological variables (mean monthly evaporation and mean number of days with frost per month) are obtained from the 83 meteorological stations network of the Portuguese Meteorological Service. The variables considered are computed from average monthly data over a 30-year period, which is available within the FCTOOLS site: http://www.isa.ulisboa.pt/cef/forchange/fctools/pt/ferramentas/normaisclimatologicas6090. The present work resulted in a publication already available (Paulo *et al.*, 2015a), where additional details can be obtained.

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Tree growth and production module

- *Model for tree total height growth in the regeneration stage*

The SUBER model considers four stages for the tree life: regeneration, juvenile, adult or dead (Paulo, 2011; Tomé *et al.*, 2015). The transition between the regeneration to the juvenile stages is based on the definition of the moment when tree dbh can be accurately measured and, consequently, modelled and simulated by the growth model. Due to the typical development of cork oak trees, which many times is characterized by a shrubby form in its first years of growth, even when the tree reaches 1.3 meters of total height it is frequent that diameter at breast height is not measured. For this reason the SUBER model defines the transition between the regeneration and juvenile stages as the moment when the tree reaches a total height of 3 m. This threshold was confirmed by the analysis of data collected in existing permanent plots in young stands (Braga, 2015).

The growth and yield module of the SUBER model considers height distribution at a certain age and tree growth in total height. The model included in the current version was developed with a restricted data set, collected in 3 different locations/stands (Tomé, 2004). For this reason a new model for total height growth in the regeneration stage was developed, now using a data set including 1129 pairs of total height measurements collected in 24 permanent plots located in 12 even-aged cork oak stands of known age. For the development of the new model two alternative methods were compared: potential growth multiplied by a modifier function and the difference equation method (Burkhart and Tomé, 2012), the first one being selected for the final model fitting.

The final model includes a distance independent competition index defined as the ratio between the subject tree total height and the stand dominant height. The inclusion of this variable reveals that the position of a tree in the stand influences its growth even in these early stages of development. The number of trees per hectare was tested in the model parameters but not included in the final formulation.

Details on this work can be obtained in Braga (2015).

- *Model for crown diameter estimation for trees in the juvenile and adult stages*

In the SUBER model, trees in the juvenile or adult stages are characterized by several tree variables, one being the tree crown diameter. This variable is used for the computation of stand crown cover, an important stand variable for the assessment of forest productivity and sustainability. In the SUBER model stand crown cover is also used for the definition of thinning limits in the Forest Management Alternatives (FMA) module. Due to the increase of time measurement and associated costs implied by crown diameter measurements, this variable is not frequently measured in forest inventories and therefore is not available

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in the input data set to be used by the SUBER model. This has led to the development of generalized crown diameter models that are used both in the initialization and growth and yield modules.

The SUBER 5.0 model version included two different equations for crown diameter estimation: one for the juvenile stage (Paulo and Tomé, 2009), using tree and stand variables based on diameter at breast height measured over cork as regressors, and one for the adult stage (Tomé, 2004), using tree and stand variables based on diameter at breast height measured under cork. In some particular cases these two functions provided estimated values that presented incompatibility issues. This has led to the decision of using one single function, which can be used in both tree life stages, and consequently to the development of a new model.

The data used in the development of the new model consist of 12768 observations, measured on 320 permanent plots spread over the area of distribution of cork oak in Portugal. The methodology used in the model formulation included as regressors variables based on tree diameter at breast height under cork. For juvenile trees, usually measured over cork, diameter at breast height under cork is estimated with the model proposed by Paulo and Tomé (2014). Due to the nested structure of the data a mixed model approach (e.g. Pinheiro and Bates, 2000) was considered in addition to the nonlinear least squares method.

When looking at the variables present in the models formulation, a distance independent competition index was included: the ratio between tree diameter an quadratic mean diameter of the stand. This index demonstrates the importance of the measure of the hierarchical position of the tree within the stand to predict crown dimensions (Burkhart and Tomé, 2012). More details on this work can be obtained in Paulo et al. (2015b).

- *Model for diameter at breast height growth for trees in the juvenile and adult stages*

In the version 5.0 of the SUBER model, diameter at breast height growth is estimated for trees in the juvenile or adult stages using an age-independent difference equation model for cork oak dominant trees (Tomé *et al.*, 2006). The method used for the estimation of diameter at breast height growth for non dominant trees is described in Tomé (2004). This method does not include explanatory variables regarding stand characteristics, debarking intensity or tree intraspecific competition.

A new model for the estimation of tree diameter growth is being developed, based on a data set of measurements already available for the project, and on additional data collected in existing permanent plots spread along the distribution area of cork oak in Portugal. The final data set will include around 3500 pairs of diameter measurements, made with an interval between measurements of 9 to 14 years. The variation in the length of the measurement interval results from the fact that available permanent plots are

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measured in debarking years, that varies between stands. This work is included in an undergoing PhD thesis, and will result in a working publication.

Cork growth and production module

The main improvement of this module is the development of a model for annual cork growth estimation. The current version of the SUBER model uses the Almeida et al. (2010) system of equations to predict the evolution of individual tree mature cork caliper over time. The system of equations estimates cork thickness growth using the difference equations method, but the parameters that are included do not dependent on management, stand or environmental variables. A new model for the estimation of cork annual growth is being developed, based on a first data set of measurements already available, and on the measurement of additional data. The final data set will include close to 9000 measurements of annual cork growth, corresponding to growth years from 1988 to 2014. The sampled trees are located in a set of permanent plots spread along the distribution area of cork oak in Portugal. The data set characteristics allow to test the significance of tree (diameter as a proxy of tree age, total height), management (debarking coefficient, vertical debarking height, number of debarked main branches), stand (number of trees per hectare, basal area) and environmental variables (precipitation and temperature) in the model parameters. This will contribute not only for the improvement of the cork growth sub-model, but will also provide information on the impact of those variables on cork growth and therefore relevant information for silvicultural4 recommendations. This work has already resulted in a first publication presently submitted (Paulo *et al.*, submitted), and a second one is being prepared (Paulo and Tomé working paper).

A preliminary analysis based on a model to predict cork thickness at t years of age (ct) (Eq.1), as the sum of cork thickness at t-1 years of age (ct1) and the annual cork growth of year t (ict) modelled with a hyperbolic function (Eq.2). This model included both total annual precipitation (Prec) and diameter at breast height (du) as independent variables, but the parameter associated to vertical debarking height was not significant. The number of main debarked branches (nbru) was included in the model and associated to a significant negative coefficient. The model presented a mean sum of squares of 0.92 and a value of adjusted R^2 of 0.9873.

$$ct = ct1 + ict \quad (1)$$

$$ct = ct1 + \frac{-0.00002\,Prec^2 + 0.05617\,Prec - 0.00711du^2 + 0.973627\,du - 1.32289\,nbru}{11.91309 + age} + \quad (2)$$

$$0.423734\ AR(1) + 0.147354AR(2)$$

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Due to the nested structure of the data (trees inside plots) and to the correlation between observations, additional methods of statistical analysis will be considered for the final version of the model.

Mortality module

The simulation of tree mortality in the current version of the SUBER model is made separately for mortality after planting (regeneration stage) and subsequent mortality. The first is estimated with a constant mortality rate of 2% until the age of 10 years and of 1% afterwards until the trees attain the juvenile stage while the second is simulated with a Richard's function, which estimates an individual tree mortality probability as a function of site index and tree age. This model does not account for mortality increases due to: insects and pathogens; climate conditions and therefore climate change scenarios; other causes (machinery damage, debarking damage, animal damage, etc.). The improved mortality model includes the differentiation of two mortality functions: (i) Definition of a specific mortality function for the regeneration stage trees (mortality after tree plantation) considering different mortality rates depending on site characteristics; (ii) Definition of an alternative method for the estimation of the mortality probability of juvenile and adult stage trees.

Regarding the definition of a specific mortality function for the trees in the regeneration stage, the methodology consisted in modeling the annual proportion of dead trees in young plantations of cork oak, using a set of permanent plots established in different regions of Portugal. Three logistic regression models that allow the prediction of the annual proportion of dead trees (%) as a function of soil and/or climate variables were fitted, their difference lying in the need of opening a soil profile and the capacity to determine the presence of a waterproof layer. The resulting parameters showed a reduction of dead tree proportion in stands with a higher site index, higher soil depth and in the presence of medium soil textures. The increase of the proportion of dead trees with the increase of medium annual temperature and in the presence of a waterproof layer was also demonstrated. The details are presented by Castel-Branco (2014) where more details can be obtained.

Although more data is available resulting from the measurement of existing permanent plots in the research group, the data set is still insufficient for the development of a new model that improves the estimation of tree mortality probability for adult trees. This will require additional long term data series, and information from specific research that is presently not available.

Forest managers dealing with cork oak stands are characterized by a deep knowledge of their management areas. After inquiring several forest managers, some of them included in the Alentejo Regional Stakeholder Group, decision was made regarding the inclusion of a new alternative for tree mortality rates input in the

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SUBER model. In the new version, users will be able to choose to run the model considering the existing Richard's function, or alternatively, to insert mortality rates that will be used by the model. This mortality rates, expressed in number of dead trees per hectare and for a period of 9 years, may refer to the all stand value, or may be recorded as a value per diameter class.

2.1.1.1 Summary of achievements during the StarTree project

Already achieved under the StarTree project:

- A new function for site index estimation when age is not known
- A model for tree total height growth in stands in the regeneration stage
- A new model for crown width prediction

On-going research that will be concluded before the end of StarTree:

- A new cork growth model
- A new mortality model

2.1.2 Portuguese model 2: SUBER-3PG

The SUBER model, as an empirical growth and yield model, is not appropriate to simulate the impact of climate change scenarios. Due to the present relevance of climate change, there is on-going research to calibrate the 3PG model for cork oak stands and to hybridize it to the SUBER model in order to obtain a model with an output as detailed as the one provided by the SUBER model and that is sensitive to climate change.

The 3PG model calibration is being made using several data, namely biomass data from destructive sampling, data from a flux tower, litterfall data, jointly with a set of yield tables built with the SUBER model. Data from the permanent plots available at the ForChange research group will also be used, namely for validation purposes.

2.1.2.1 Summary of achievements during the StarTree project

On going research that will be concluded before the end of StarTree:

- Calibration of the 3PG model for cork oak and hybridization of the calibrated model with the SUBER model

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2.1.3 Spanish model: ALCORNOQUE

Authors: MS, MP, IC

In order to predict the development of cork oak stands at any point in time, different models have been developed, and successfully applied, for the management of cork oak stands in Spain (Montero, 1987; Sánchez-González *et al.*, 2005; 2006; 2007b; 2007c; 2008). The model developed by Sánchez González (2007a) has been devoted to high density stands of *Quercus suber* in both Andalusia and Catalonia, without considering open woodlands (dehesas). It includes modules for the growth of cork oaks (Sánchez-González *et al.*, 2005; 2006; 2007c) as well as modules that predict the yield of cork (Sánchez-González *et al.*, 2007b; 2008). Regarding the modules that describe the growth of cork oaks, they can be considered a tree level model and include distance independent competition indices, stochastic formulation and the possibility of tree and stand level calibration for new locations (Sánchez-González *et al.*, 2007a). The different sub models included are (i) height growth of dominant trees; (ii) diameter growth of dominant trees; (iii) annual diameter increment, (iv) height-diameter equation and (v) crown diameter. The modules describing cork yield includes also different sub models for instance a (i) cork growth and (ii) cork thickness. The model developed by Montero (1987) only takes into account the cork weight as a function of circumference at the breast height (over and under bark, there are variations for both options) and the debarking height. There are variants of this model for six different regions in Spain. Considering that, in order to predict and plan cork oak stands for cork production, different models are important, namely cork weight, cork growth and cork thickness the combination of the models developed by Sánchez González (2005; 2006; 2007b; 2007d; 2008) and Montero (1987) mean a powerful tool for the management of cork oak stands in Spain, being the cork quality model still a challenge that need to be overcome in the region.

Despite the good performance of the above described models still some shortcomings need to be solved. Some of these issues can be easily amended within the framework of the present project. Some others would require further research and data gathering; however the first steps to improve them could be stated in the present deliverable.

The model that predicts the height growth of dominant trees (Sánchez-González *et al.*, 2005) allows the prediction of the height of the tree at any point in time based on an initial value for height and age. This model allows defining site quality in cork oak stands. The most important shortcoming of this module is that it cannot be applied to those stands younger than 40 years, meaning that it is a model devoted to mature stands. The same happens with the model for the diameter growth of dominant trees that loses reliability when applied to stands younger than 40 years. Therefore, a model for younger stands needs to

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be developed. In this respect, between the years 1990 and 2000 more than 100.000 hectares have been reforested with *Quercus suber* in different Spanish regions (namely Extremadura, Castilla La Mancha and Andalucía), providing useful data for the development of growth and yield models for stands younger than 40 years. In the context of the StarTree project a network of forest plots would be established in order to gather data for developing a growth model for juvenile cork oak stands (before the first debarking).

In addition, it is also important to note that the inclusion of the information about the stand density has been included in the model for predicting the diameter growth of dominant trees by means of the height diameter ratio, which is not the best proxy for considering the competition among the trees within a stand, however this is not an easy-to-solve issue in the context of the StarTree project.

Another issue that would be interesting to address is the variety in stand structures that the cork oak present, namely even-aged stand, uneven-aged stand or two-aged stand, although most of the times they do not even present a well-defined stand structure (Calzado Carretero and Torres Alvarez, 2013). Therefore, among the challenges that could be overcome within the StarTree project the development of a diameter class model that would allow the definition of different stand structures for cork oak stands in Spain should be considered. For doing so, data from the Spanish National Forest Inventory (SNFI) would serve as an excellent data set.

It also necessary to update the existing cork weight modelling in order to improve them by taking into account the main points that should be considered when developing new models (Vázquez and Pereira, 2008; Paulo and Tomé, 2010). In our future model the main points would be to use oven-dried cork weight as dependent variable to avoid the variation in the weight because of the water content variability and to apply a suitable approach that deals with the heteroscedasticity, the multicollinearity and the spatial autocorrelation of the cork weight data. In addition, this new model would estimate cork weight for different cork ages.

Recently the ALCORNOQUE model has been implemented in a simulator called alcornoqueWeb which is freely available at wwwx.inia.es/alcornoqueWeb. This is simulator is a useful tool that will support managers on their job. This first version has a very simple functionality but within the StarTree framework will be upgraded to the second version.

2.1.3.1 Summary of achievements during the StarTree project

Already achieved under the StarTree project:

- Implementation of the ALCORNOQUE model in a simulator tool freely available at wwwx.inia.es/alcornoqueWeb

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On-going research that will be concluded before the end of StarTree:

- Establishment of field plots for developing a growth model for juvenile cork oak stands (before the first debarking).
- Optimal management schedules for the production of cork
- Development of a methodology for predicting cork weight with data from the Spanish National Forest Inventories (SNFI)
- Development of a diameter class model to define different stand structures for cork oak stands in Spain using data from the SNFI.

2.2 Models for pine nuts (Stone pine)

Pinus pinea (stone pine) is one of the most characteristic species of the Iberian Peninsula. The most important outputs from *P. pinea* stands are timber and the seeds that are very appreciated for human consumption. One difficulty in managing stone pine stands for cone production is the long masting and fruiting process, covering three years, with consequent large temporal variation and high probability of failure in cone production.

Ungrafted stone pines start to produce cones under the age of 10, the average production of pine cone increasing up to 50 years and remaining regular up to 90 years old, decreasing afterwards. The cone collection in an ungrafted stone pine do not usually stop because of its age but because the trunk height, when cones are harvested manually, or the trunk diameter when they are harvested with a machine. In the first case men generally refuse to climb when the branches are too high and in the second case most of the cones remain in the tree even if the tree is strongly shaken resulting in most cases in a severe damage to the trunk.

Grafting is a new operation in stone pine, taking place in Portugal for about 25 years, so it is still unclear if the longevity of the pine cone production is reduced. The grafting is carried out usually at three or four years old, depending on the thickness of the rootstock. The grafted pine trees begin to produce pine cones two years after grafting. Observation of real stands showed that at eight years of age it is possible to harvest more than 40 cones in grafted pines with reduced competition and no water deficit and that in 16 years old grafted pines with some dryness issues the production attained 200 cones.

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2.2.1 Spanish model: PINEA2

Authors: RC, SM

The current version of the integrated model PINEA2 (see Calama *et al.*, 2007 for more details) allows to describe and predict the growth of a single pure, even-aged stand of *Pinus pinea*, as well as its main productions (timber, pine nuts, CO2 fixation), in response to different management schedules. Model PINEA2 is a tree-level model, thus stand level predictions are carried out by aggregating tree level predictions. The model PINEA2 is a modular system, composed by (i) site quality module; (ii) auxiliary module;(iii) state module, incorporating size allometries (diameter-height functions, crown dimensions functions); stem curve functions permitting end-size classification of timber products; probability for stem rot affection by *Phellinus pini*); model for tree cone production (Calama *et al.*, 2008b), predicting individual tree cone production for a 5-year period as a function of stocking density, single tree diameter, tree social status and an ecological stratification of the territory (mainly depending on soil water holding capacity); (iv), transition module, incorporating a diameter increment function allowing to project diameter of the trees in 5-year steps, as a function of a distance independent competition index, stand stocking, stand maturity and site index (Calama and Montero, 2005), and self-thinning rules developed by Montero and Candela . The original model PINEA2 was implemented into a stand-level simulator (Madrigal *et al.*, 2009), freely available at https://sites.google.com/site/regeneracionnatural/pinea2. Model PINEA2 meant an advance over previously stand-level model PINEA (García-Güemes, 1999).

Further development of model PINEA2 attempted to cover some of the limitations detected in the model. The original model was developed for pure even-aged stands. New versions were constructed to be applied on uneven-aged stands (Calama *et al.*, 2008a) and afforestations (Calama *et al.*, 2009). Given the large interannual variability in cone production, model for average cone production does not mimic the reality adequately. Thus, was constructed a spatio-temporal model for predicting annual cone production (Calama *et al.*, 2011) using as predictors climate traits (rainfall during different instants of flowering and fruiting process) as well as stand maturity, stand stocking, tree diameter and competition indices. Moreover, while model PINEA2 predict cone production, end users are interested in pine nut production, thus models for predicting pine nut yield and pine nut quality attributes as a function of average cone weight (Morales, 2009) were developed. Natural regeneration of the stands can be now simulated by means of the integral model including seed production, dispersal, predation, germination and seedling survival (Manso *et al.*, 2014). Biomass equations by Ruiz-Peinado et al. (2011) were also incorporated.

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Despite the wide development of model PINEA2, several shortcomings are still detected, and some of them are in phase of development. The main limitation of PINEA2 is that, except for the module of cone production, the model is climate insensitive, simulating growth at 5-year steps, not permitting to carry out simulations under different climate scenarios. To tackle with this a new module for tree annual basal area increment, incorporating climate parameters, is under development (see Calama *et al.*, 2014 for a preliminary version). Although incorporating a natural regeneration module, current model PINEA2 does not allow to predict initial stages of development of the stand (from sapling to pole), though specific experiments focusing on growth response to shelterwood fellings, sapling development, tending and precommercial thinnings are required.

Model PINEA2 is also a pure empirical model, lacking mechanistic or phisyiological based processes which broad the range of applicability to new ecological conditions. While some modelling effort has been focused of physiological processes for seedlings and saplings (Calama *et al.*, 2013; Pardos *et al.*, 2014b), there still exists a wide gap in modelling physiological processes for adult trees. To surpass this limitation, attempts to couple model PINEA2 with process-based models as PICUS or 3PG are now in progress (Pardos *et al.*, 2014a). A sound physiological basis will allow surpassing other of the main limitations of the model, as is its dependence on site index equations, which consider constant values of potential productivity. Other topic to be improved under this physiological approach is tree die-back and mortality. While model PINEA2 successfully predicts self-thinning mortality, processes of decay and mortality of older trees are not adequately mimicked by the model.

Concerning pine nut production, model PINEA2 fails to predict annual damage by different pests, as *Dyorictria mendacella* or *Pissodes validirostris*, which can significantly reduce annual cone crops. Currently, a specific model for the former is under construction. Other topic of interest not yet covered by the model are the reductions in pine nut yield recently observed throughout all the Mediterranean basin (Mutke *et al.*, 2014), and mainly attributed to the invasive pest *Leptoglossus occidentalis.*

Upscaling of model PINEA2 is one of the main challenges for the future. In a first step, while model PINEA2 relies on the assumption of pure stands, forests generally show a mixed, heterogeneous, structure, which can be assessed in the model. Apart from this, forest-level simulators, which allow carrying out simulations beyond the spatial limitation of the stand are highly demanded. Finally, while model PINEA2 is largely developed for Northern Plateau and Central Range, applicability in other regions, as Andalusia and Catalonia is much more limited. Calibration of cone production functions for these two regions are now under development.

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2.2.1.1 Summary of achievements during the StarTree project

Already achieved under the StarTree project:

- A function for annual basal area increment based on climatic predictors
- Optimal management schedules for the joint production of cone and timber

On-going research that will be concluded before the end of StarTree:

- Spatiotemporal model for cone losses associated with damage by *Dyorictria mendacella*
- A new version of stand-level simulator PINEA2, including additional modules (regeneration fellings, self-thinning, nut content & quality)
- Identification of factors affecting reduction in nut yield, to be incorporated in further models

2.2.2 Portuguese model: PINEA-PT

Authors: JF, LF, MT

The existing model for *Pinus pinea* growth and yield was developed in 2009 (Freire, 2009). It is a distance-independent individual tree model that includes the following modules that project a stone pine stand over time: (i) site quality; (ii) tree growth; (iii) pine cones production. The PINEA_PT model applies to even and uneven-aged, pure and mixed stands. However, it does not include a module for the initialization of new plantations.

The module that estimates site quality is based on a growth index that relates the observed dbh growth (estimated from increment cores) with the estimated (average) dbh growth (Trasobares and Pukkala, 2004; Trasobares *et al.*, 2004). The module for tree growth includes an equation to project individual tree dbh growth and equations to predict tree height, crown diameter and crown length. The production of pine cones is made in two stages that include a model to predict the probability that a tree has already started to produce and another one that, if the tree is under production, predicts the amount of pine cones.

Along the StarTree project several modules are being improved, using existing collected data complemented with data obtained by the re-measurement of existing plots and trials: (i) initialization module, (ii) tree growth and production module, (iii) cone production module.

The initialization module will include a function to predict site quality as a function of soil characteristics and climate, the simulation of tree height distribution at the age of 3 years, a tree height growth model and a model to predict individual tree dbh when the tree, after an annual growth period, attains a height greater than 3 m.

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Concerning the tree growth and production module the tree dbh growth model, that is part of the present version of the PINEA_PT model, was developed with dbh annual growth obtained from increment cores, the objective is to develop a new model with the dbh growth data that are available at present within the ISA research group. The same is true for tree height, nowadays there is sufficinent data to build a tree height growth model.

A new cone production model is being developed, in collaboration with the INIA team, using the present data base that includes more years of pine cones data than the one used to develop the model included in the first version of the PINEA_PT model.

2.2.2.1 Summary of achievements during the StarTree project

On-going research that will be concluded before the end of StarTree:

- A module for initialization of new plantations of stone pine
- New models for tree dbh and height growth
- A new module for pine cones production

2.3 Models for berries

Authors: JM, MK, KS

Wild berries are among the most important NWFPs in northern Europe (e.g. Kangas, 2001; Turtiainen and Nuutinen, 2012; Vaara *et al.*, 2013). The public and private forest landowners, both industrial and non-industrial, place a high value on the multiple-use aspects of forests, and thus objectives other than wood production have got increasing weight in forestry decision-making. Production functions suitable for planning calculations are needed when integrating e.g. wild berries in numerical multi-objective forest planning.

Some production functions have been formulated for wild berries in Finland on the basis of expert estimates (Ihalainen and Pukkala, 2001; Ihalainen *et al.*, 2002; Ihalainen *et al.*, 2005). The first empirical berry yield models developed were based only on regional yield data (e.g. Ihalainen *et al.*, 2003), but recently also the datasets covering the whole of Finland have been used to estimate bilberry (Miina *et al.*, 2009) and cowberry yields (Turtiainen *et al.*, 2013).

The existing berry yield models (incl. data collection and modelling methods) have been described and their usability for forest planning calculations has been assessed in the doctoral dissertation by Turtiainen (2015). In addition, the existing berry yield models have been evaluated by comparing model predictions with an independent data set measured from North Karelia, Finland (Kilpeläinen *et al.*, 2015).

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The most recent models have been prepared for the mean percentage coverage of the berry species (Model 1) and the mean number of berries in the stand (Model 2) using the datasets covering the whole Finland (Miina *et al.*, 2009; Turtiainen *et al.*, 2013). The models are prepared using generalized linear mixed models (GLMMs). The coverage of species is treated as a proportion, and Model 1 is expressed by the logit-link function with a binomial response (McCullagh and Nelder, 1989). The model for counts (Model 2) is expressed by the log-link function with a Poisson response (McCullagh and Nelder, 1989).

The multilevel hierarchy of the data sets, and subsequently correlated observations, is taken into account by including random effects at different levels in the variance component models, and by allowing the intercept to vary randomly across the levels (e.g. Searle *et al.*, 1992; Snijders, 1999; Goldstein, 2003). As suggested by Browne et al. (2005), overdispersion in the GLMMs is taken into account by adding a random term as being at the bottom level ("pseudo" level). The GLMMs are estimated with the pseudo quasi-likelihood (PQL) method using the glmmPQL function of the R software (R Core Team 2, 2014). Because the glmmPQL function does not allow the random cross-effects, the effects of the years are included using dummy variables in fixed predictors. Random terms at different hierarchical levels are assumed to be uncorrelated.

In simulations, the models for the coverage (Model 1) and yield (Model 2) are used together. First, the coverage of the species is predicted as a function of e.g. site fertility, regeneration method, stand age and stand basal area (Fig. 2.1, the development of stands was simulated using the Motti simulator) , and then the annual berry yield is predicted as a function of the species coverage and stand characteristics (Fig. 2.2, the development of stands was simulated using the Motti simulator). Finally, the number of berries is converted into the berry yield (kg/ha/yr) by multiplying it by the mean fresh weight of one berry.

In stochastic simulations, the annual berry yield is predicted, for example, several hundred times by drawing the random between-year effects from its statistical distribution (normal distribution), and the annual yield is computed as the mean of all outcomes. The lower and upper bounds of the 95% confidence interval for the annual yield are calculated using the 0.025 and 0.975 quantiles of the simulated outcomes. Alternatively, the 95% confidence interval is calculated using the 0.025 and 0.975 quantiles of the statistical distribution of the year effects (Fig.2.2).

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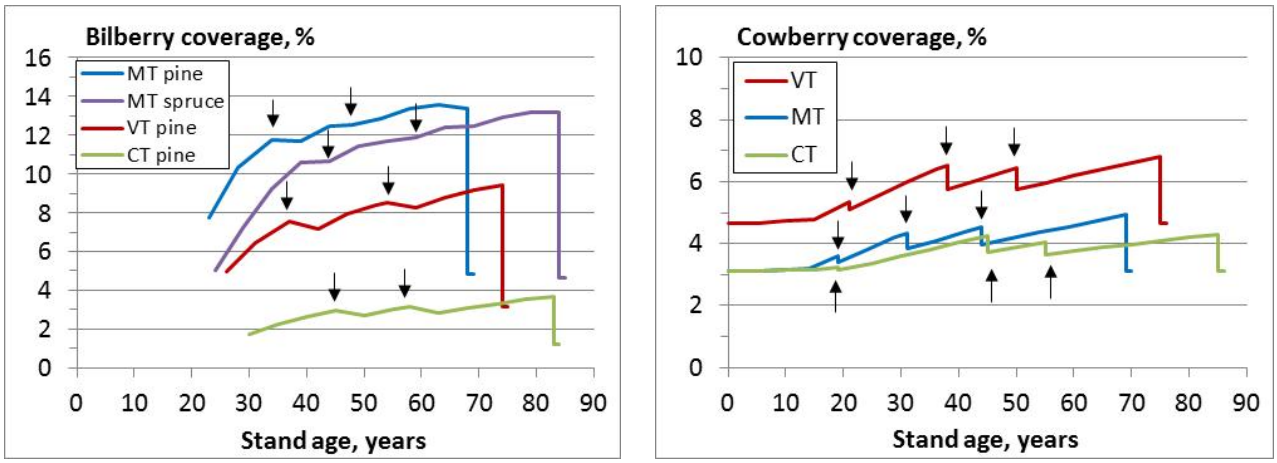

Figure 2.1. Predicted coverages of bilberry (Miina *et al.*, 2009) in pine and spruce stands and cowberry (Turtiainen *et al.*, 2013) in pine stands of different site fertilities (arrows indicate thinnings) VT: Vaccinium type; MT: Mirtyllus type; CT: Cowberry type

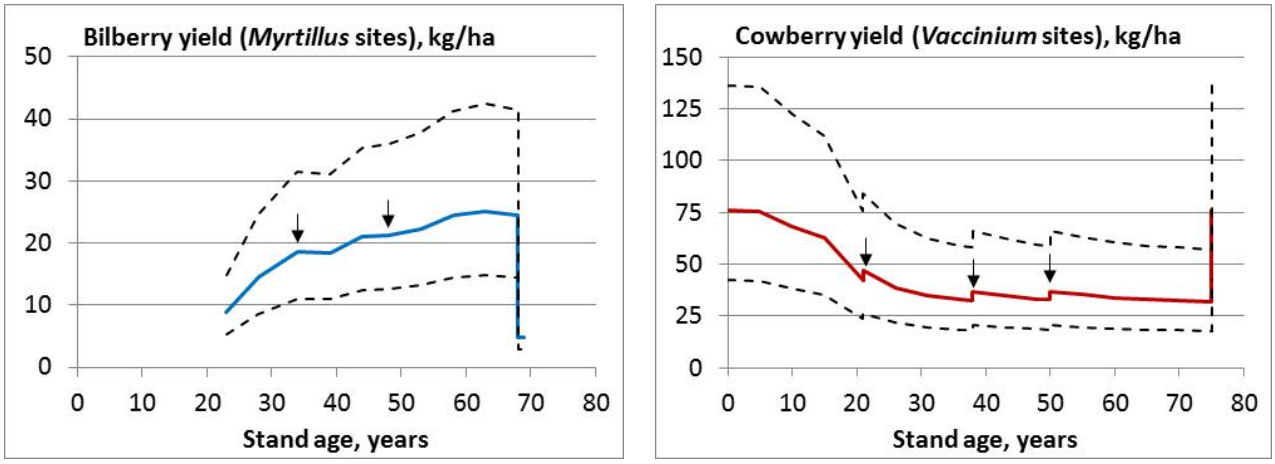

Figure 2.2 Predicted average annual yields of bilberry (Miina *et al.*, 2009) and cowberry (Turtiainen *et al.*, 2013) and their 95% confidence intervals in pine stands of different site fertilities (arrows indicate thinnings)

According to Turtiainen (2015), the existing models produce predictions that were quite similar to each other despite of very different data collection methods and modelling techniques. Modelling expertise was found to be a reasonable way to create production functions for both bilberry and cowberry. It would be feasible to utilize expertise in modelling the yield of other non-wood forest products, too. In particular, the method based on visual assessments conducted in the field was found to be a promising one.

Bilberry yield predictions computed using different models were consistent and correlated positively and statistically significantly with each other (Kilpeläinen *et al.*, 2015; Turtiainen *et al.*, 2015). Most of the correlations of predictions of different cowberry yield models were positive and statistically significant, but there were a few insignificant, even negative correlations among the predictions (Turtiainen, 2015). The

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reason for weak or even negative correlation was that some models produced good cowberry crops at the beginning of the stand rotation (openings and young seedling stands), while some models produced the best crops at the end of the rotation (mature stands).

Berry yield predictions computed using different models correlated positively with the berry yield data measured from North Karelia (Kilpeläinen *et al.*, 2015) (Fig. 2.3). In general, bilberry yield predictions were more precise than cowberry yield predictions. Due to a very different nature of the datasets used in modelling, bias involved in predictions was expected. For example, some berry models were based on the datasets collected from stands known to be potential berry forests (e.g. Turtiainen *et al.*, 2013).

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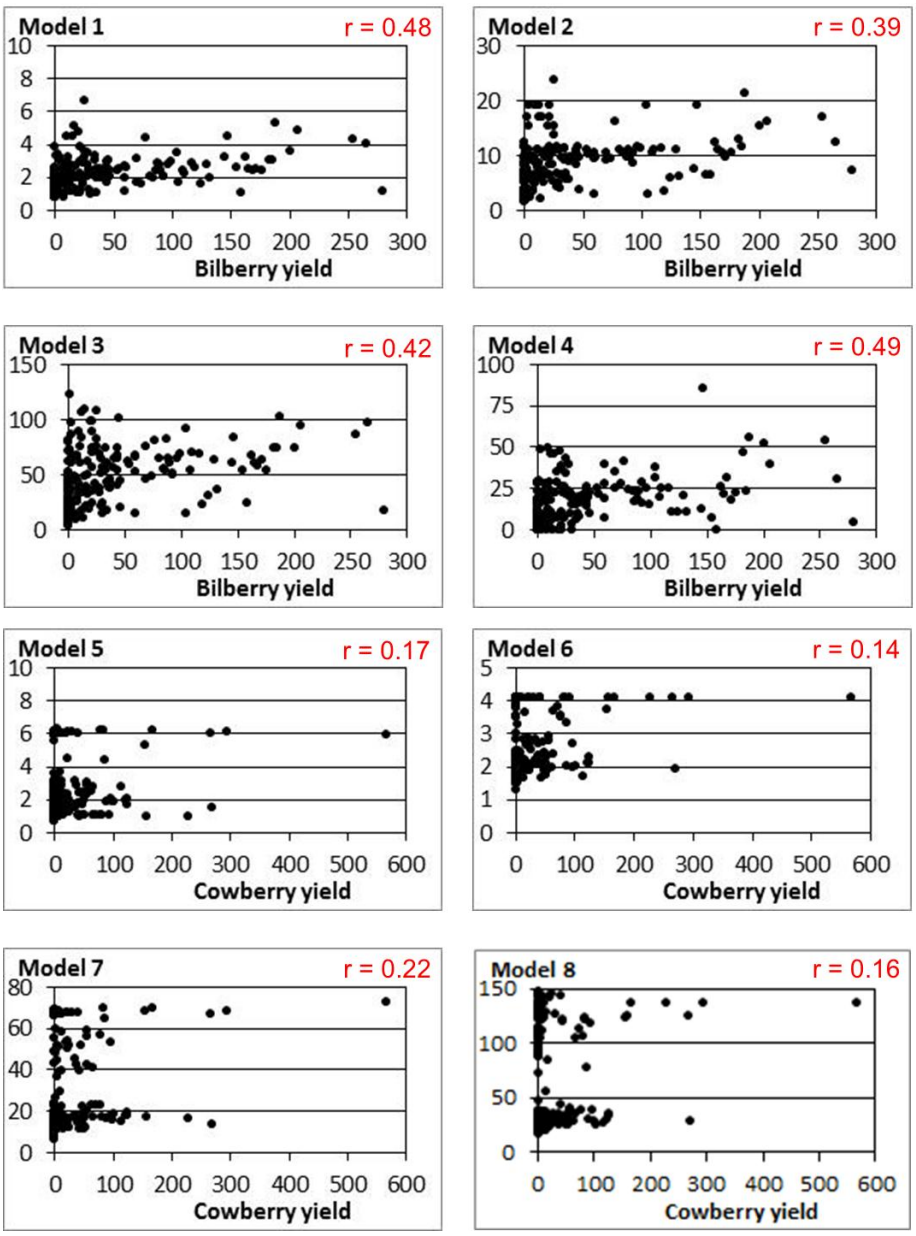

Figure 2.3 Scatterplots and Pearson correlations showing the relation between measured and predicted berry yields for the sample plots (N = 230) in North Karelia (Kilpeläinen *et al.*, 2015).

Yields are in kg/ha/yr, except Models 1 and 5 give the priority in terms of berry yield. Models: 1 & 5 - Ihalainen et al. (2002); 2 & 6 - Ihalainen et al. (2003); 3 & 7 - Ihalainen et al. (2005); 4 - Miina et al. (2009); 8 - Turtiainen et al. (2013)

The above evaluations indicated that the dependence of cowberry crops on stand characteristics should be further explored. Especially, the positive effect of final felling on cowberry production may be overestimated, since it can take few years before cowberry will recover from cutting. The performance of

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different bilberry models was quite similar, but the effect of thinning on bilberry yields needs to be further explored.

A large unexplained variation is very typical for empirical berry yield models. For example, the annual (between-year) variation in berry yields has not been included in most of the models. Besides the human consumption, wild berry plants are important for many forest species as they provide both food and shelter. Thus, models considering also the coverage of berry plants would enable to incorporate game management considerations into calculations of forest planning.

Most existing models consider only mineral soils, and for example the predictions of bilberry yields on peatlands cannot be produced. In addition, most models are regional and may not produce unbiased predictions at national level. Though the existing models produce logical berry yield predictions, calibration of the models is needed to estimate the national and/or regional supply of berries.

Besides accurate predictions in kg/ha/year, the usability of existing models was further explored in predicting the relative goodness of different stands for bilberry or cowberry picking. Figure 2.4 shows how well the predictions of the bilberry yield models are able to locate the best bilberry plots in an independent data set measured in North Karelia. The sample plots are in descending order by the yields measured or predicted by Models 1–4. In calculations, a sample plot represents the area of one hectare. In the future, the aim is to prepare thematic maps for the most productive berry habitats pursued by berry pickers.

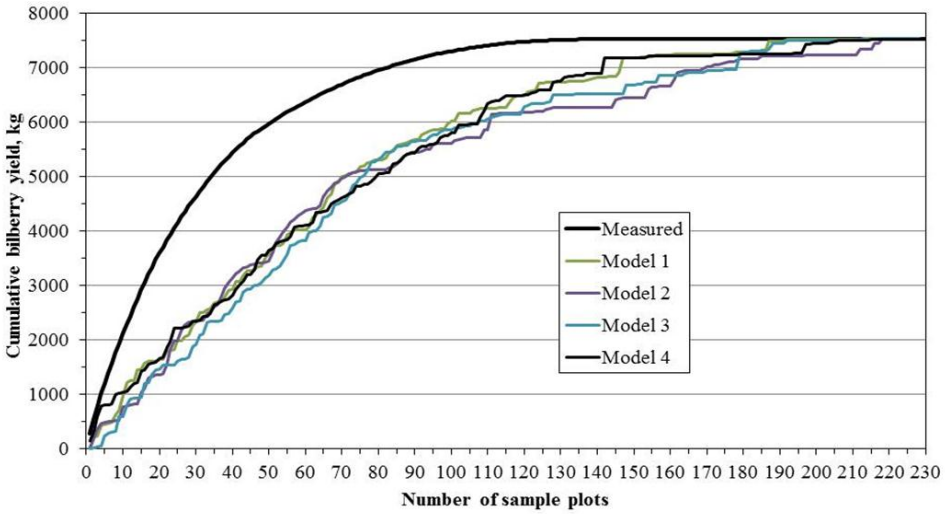

Figure 2.4 Cumulative bilberry yield measured from the sample plots (N = 230) in North Karelia (Kilpeläinen *et al.*, 2015). Models: 1 - Ihalainen *et al.* (2002); 2 - Ihalainen *et al.* (2003); 3 - Ihalainen *et al.* (2005); 4 - Miina *et al.* (2009).

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2.3.1.1 *Already achieved under the StarTree project:*

- The new statistical model was estimated for cowberry using the dataset covering the whole Finland (Turtiainen *et al.*, 2013).
- The existing berry models (incl. the new cowberry model) were evaluated using an independent data set measured from North Karelia (Kilpeläinen *et al.*, 2015).
- The 'best' existing berry models were calibrated using the field measurements and literature.
- The new statistical model was estimated for bilberry using the dataset including also peatlands and covering the whole Finland (Turtiainen, 2015).
- The calibrated models for bilberry and cowberry were integrated into decision support systems (e.g. MONSU and MELA). For example, optimizing the joint production of timber and berries at stand level can be used to create and revise silvicultural guidelines for forestry practise. Both stochastic and deterministic simulations can be conducted using the models.

2.4 Models for mushrooms

2.4.1 Mushroom models in Spain

Authors: JAB, SdM

In Spain there is a deep-rooted tradition of mushroom picking and trade. Hundreds of tonnes of edible forest mushrooms are sold annually in local markets, and contribute to a significant economic activity of several million euros. In the current context of low profitability of timber-oriented forestry arising from the high harvesting costs compared to the income from wood products, the economic benefit from mushroom harvesting can be clearly higher than the economic profit obtained from timber production (Alexander *et al.*, 2002; Palahi *et al.*, 2009). Furthermore, mushroom picking for self-consumption gives additional value to wild mushrooms as a recreational and environmental service (Martínez de Aragón *et al.*, 2011).

Spain has led much of the research conducted so far on mushroom yield modelling covering a number of forest ecosystems. The first mushroom yield models were developed by Bonet et al. (2008) with the aim of predicting i) the total production of mushrooms as well as the yield of edible and marketed fungi, and ii) mushroom species richness in *Pinus sylvestris* forests in north-eastern Spain. The results showed that productions were greatest when stand basal area was approximately 20 m^2 ha^{-1}. Increasing elevation and northern aspect increased mushroom production. Increasing slope decreased mushroom yield. The annual variation in mushroom production correlated positively with autumn rainfall. Mushroom species richness and total mushroom production were also positively correlated. Bonet et al. (2010) improved the aforesaid

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mushroom yield and species richness models for *P. sylvestris* and expanded the modelling work also to *Pinus nigra* and *Pinus halepensis* stands, also in north-eastern Spain. Stand basal area remained as the main significant stand attribute. The optimal stand basal area that maximized mushroom yield ranged from 15 to 20 m^2 ha^{-1} depending on the pine ecosystem. Terrain slope and aspect coupled with altitude above sea level and autumn rainfall also determined significantly mushroom yield and species richness. Martínez-Peña et al. (2012) developed mushroom yield models for ectomycorrhizal mushrooms in *P. sylvestris* stands in north-central Spain, with special focus on target mushroom species of high market value such as *Boletus edulis* and *Lactarius* group *deliciosus*. Autumn precipitation and temperature were significant predictors in all the fitted models. In addition, the total yield of ectomycorrhizal fungi was significantly affected by dominant height and stand age. The production of *L.* group *deliciosus* was influenced by dominant height and stand basal area. The yield of *B. edulis* was also significantly influenced by stand basal area. More recently, de-Miguel et al. (de-Miguel *et al.*, 2014a) published new mushroom models for pure and mixed stands of most pine forest ecosystems in north-eastern Spain, namely pure stands of *P. sylvestris*, *P. nigra*, *P. halepensis* and *P. pinaster* as well as mixed stands of *P. sylvestris-P. nigra*, and *P. nigra-P. halepensis*. These models enable the prediction of both the probability of mushroom occurrence and mushroom yield. Both the occurrence of sporocarp emergence and the amount of mushroom production depended significantly on stand basal area. As in previous research, the effect of stand basal area on mushroom yield followed an increasing-decreasing trend with an optimum dependent on the pine forest ecosystem. For the group of marketed mushroom species, this optimum ranged from 10 to 15 m^2 ha^{-1} in pure *P. halepensis* stands to 35–40 m^2 ha^{-1} in pure *P. pinaster* stands. The probability of mushroom occurrence was higher with increasing northness, whereas sporocarp emergence was less probable in south-facing slopes. Altitude also had a significant positive effect on mushroom yield.

Beyond mushroom production in wooded lands, mushroom yield models were recently published also for fire-prone *Cistus ladanifer* scrublands in central Iberian Peninsula (Hernández-Rodríguez *et al.*, 2015) (Hernández-Rodrígueza, 2015 #1094). In addition to providing models for annual production and species diversity of mycorrhizal and saprotrophic fungi, this study also devoted special attention to *B. edulis* production due to its high economic importance in these scrublands, which are often seen as unproductive lands. Predictors accounting for vegetation management (i.e. either clear-cutting or total burning treatments), time after treatment, shrub structure and meteorological variables were considered in modelling. The mean minimum temperature in autumn was the most significant climatic variable affecting mushroom yield. Furthermore, the mean height of the scrub vegetation was also a highly significant

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predictor of mushroom production and diversity. According to the models, *B. edulis* yield is expected to start 5 years after treatment and the peak of production is reached after 14 years. Mushroom production was higher after clearcutting than after total burning, whereas fungal diversity was higher after burning.

Some of the above-mentioned models published from 2008 to present have been fitted using mixed-effects modelling approaches accounting for between-plot and/or between-year and/or between-ecosystem variation in mushroom yield, whereas some other models have been fitted using fixed-effects regression analysis.

On the other hand, previous research conducted in a thinning experiment established in *Pinus pinaster* stands in north-eastern Spain aimed at modelling the immediate effect of thinning on *L.* group *deliciosus* production. This study reported that moderate thinning intensity, coupled with favorable autumn precipitation, immediately enhanced mushroom productivity (Bonet *et al.*, 2012).

Despite the modelling efforts reported in previous research, models based on new and improved data can bring deeper insight into the influence of forest stand structure and management on mushroom yield (Pilz and Molina, 2002). In this regard, although it seems clear from previous research that soil properties may play a key role in determining fungal dynamics (Courty *et al.*, 2010; Martínez-Peña *et al.*, 2012), the models published so far do not account directly for the effect of soil characteristics on mushroom yield. Including such information in the prediction of mushroom productivity may increase the accuracy and biological consistence of the models. Therefore, new mushroom yield models will be developed based on data obtained from the weekly monitoring of mushroom production from 82 permanent sample plots in stands representing pure and mixed pine-dominated forest ecosystems found in north-eastern Spain. The number of sample plots in pure *Pinus sylvestris*, *Pinus nigra*, *Pinus halepensis* and *P. pinaster* stands will be 19, 14, 8 and 30, respectively. The number of plots in mixed *P. sylvestris-P. nigra* and *P. nigra-P. halepensis* stands will be 7 and 4, respectively. In order to assess the influence of soil characteristics on mushroom production, detailed information on physical and chemical soil properties will be included in the analyses. The soil variables that will be tested as potential predictors in the new mushroom models will be the following: CaCO3 (% sms), electrical conductivity (dS/m), calcium (mg/kg sms), cation exchange capacity (meq+/100g sms), active lime (% sms), large elements (D>2mm) (%), large silt (0.02 < D < 0.05 mm) (%), small silt (0.002 < D < 0.02 mm) (%), clay (D < 0.002 mm) (%), sand (0.05 < D < 2 mm) (%), USDA textural classification, moisture (%), potassium (mg/kg sms), magnesium (mg/kg sms), organic matter (% sms), sodium (mg/kg sms), nitrogen (% sms), phosphorus (mg/kg sms), C/N ratio and pH. In addition to soil characteristics, variables accounting for stand structure and site characteristics will be also tested as

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potential predictors of mushroom yield in order to improve model performance (Table 2.1). Mixed-effects models, which can account for the spatial and temporal correlation among observations, and can deal with unbalanced data (Pinheiro and Bates, 2000), may be used to predict annual mushroom yield.

Table 2.1. Summary of the data to be used to model mushroom yield in pine forest ecosystems

Forest type	Temporal data series	Range	Mushroom yield, kg ha^{-1} yr^{-1}		
			Marketed	Edible	Total
P. sylvestris	1995-2001 2007-present	Min.	0.0	0.0	0.0
		Mean	26.3	62.3	91.3
		Max.	260.5	563.0	743.5
P. nigra	1997-2001 2007- present	Min.	0.0	0.0	0.0
		Mean	12.6	42.2	55.2
		Max.	144.2	332.3	365.2
P. halepensis	1997-2001 2007- present	Min.	0.0	0.0	0.0
		Mean	14.8	45.6	53.9
		Max.	137.4	403.7	420.6
P. pinaster	2008- present	Min.	0.0	0.0	0.0
		Mean	44.5	74.7	83.5
		Max.	441.7	448.9	449.8
P. sylvestris – P. nigra	2007- present	Min.	0.0	0.0	0.0
		Mean	30.2	79.8	101.6
		Max.	196.1	410.6	472.1
P. nigra – P. halepensis	2007- present	Min.	0.0	0.0	0.0
		Mean	4.4	31.0	36.1
		Max.	41.4	377.8	405.0

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Moreover, in the absence of conclusive information concerning the mid-term impact of thinning on mushroom productivity, further research is required to fill the existing gap in knowledge concerning the thinning effects on mushroom yield. In this regard, the mid-term impact of thinning intensity on mushroom yield (i.e., 5 to 6 years after thinning) will be modelled within the framework of the thinning experiment established in *P. pinaster* stands in north-eastern Spain.

2.4.1.1 Summary of achievements during the StarTree project

On-going research that will be concluded before the end of StarTree:

- New empirical models including soil characteristics as predictors of mushroom yield will be improved
- Impact of thinning intensity on mushroom yield will be analysed.
- Forest management schedules for the joint production of timber and mushrooms in pine forest stands will be optimized using the new empirical mushroom models and thinning effect models.

2.4.2 Mushroom models in Finland

Authors: JM, MK, KS, VT

There have been no empirical mushroom yield models suitable for numerical multi-objective forest planning in Finland. Despite the fact that several datasets on mushroom yields have been collected in Finland (e.g. Ohenoja and Koistinen, 1984; Hintikka, 1988; Ohenoja, 1988, 1993; Salo, 1993; Väre *et al.*, 1996; Ohenoja, 2005), the mushroom yields observed have not been modelled as a function of site and stand characteristics. Moreover the existing mushroom datasets may not be possible to utilize in modelling, because stand and site characteristics needed as predictors may not have been measured.

In order to collect mushroom data for both expert and empirical modelling, the fruiting bodies of commercial mushroom species were inventoried in planted Norway spruce (*Picea abies*) stands in eastern Finland (Miina *et al.*, 2013). A total of 56 sample plots was established and inventoried during the harvest seasons 2010–2015. The characteristics of sample plots cover the wide range of stand ages and both unthinned and thinned stands were included. From the marketed mushroom species, the special interest is given to the yields of *Boletus edulis* and *Lactarius* spp.

Firstly, the lack of empirical modelling data on *B. edulis* yields was overcome with expert modelling so that experienced mushroom pickers or researchers rated different stands according to *B. edulis* production

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(Tahvanainen, 2014). The model was based on 25 experts' pairwise evaluations of photographs of 25 spruce stands. Experts were selected among active mushroom pickers and scientific researchers. However, the independent variables used in the model were not statistically significant. The experts were also asked to assess the stand characteristics, which are favourable for *B. edulis*. They estimated that the highest yields are in advanced thinning stands. The experts' opinions concerning the characteristics of a good *B. edulis* forest varied greatly, but cuttings were considered to decrease the yields. A shortcoming was that the annual variation in mushroom yields could not be incorporated in this kind of expert modelling. Thus, the time series of empirical annual mushroom yields are needed.

Secondly, empirical models were prepared for the annual yield of fruiting bodies (kg/ha/year) by mushroom species (*Boletus edulis*) and/or species groups (*Lactarius* spp., all marketed mushrooms) using the inventory data from planted spruce stands in eastern Finland (Tahvanainen *et al.*, 2015). In analyses, the number of fruiting bodies was converted into the mushroom yield (kg/ha/year) by multiplying it by the mean fresh weight of one fruiting body. The models were prepared using non-linear mixed modelling (NLMM) approach to account for the longitudinal data structure. Mushroom data inventoried from 56 sample plots during the years 2010–2014, as well as stand and annual climatic variables on the plots were used in modelling. Annual observations for the same plot were correlated, which was accounted for by random plot effects. Due to annual climatic conditions, observations for the same year were cross-correlated, which was accounted for by the fixed year effects. To explore the annual variation in mushroom yields, climatic factors (e.g. monthly precipitation and mean temperature) were used as predictors.

Several plots were located in stands approaching the first commercial thinning, because the special aim was to study the effects of thinning on mushroom production in young thinning stands. The stands are actively managed, and consequently many plots were thinned before the plot establishment or during the study period, but also unthinned plots were included in the modelling data.

According to the fitted models, the highest yields of *B. edulis* were obtained in younger stands with the age of about 25–30 years. The highest yields of *Lactarius* spp. and all marketed mushrooms were obtained slightly later at the age of 30–35 years. The maximum mushroom production thus coincided with the peak of stand volume increment in planted spruce stands in Finland. For *B. edulis*, stand basal area close to 25 m^2 ha^{-1} was most preferable, whereas slightly higher stand density (about 30 m^2 ha^{-1}) was preferred by *Lactarius* spp.

The mushroom yields were promoted by a warm pre-season (in July) and wet conditions during the fruiting season (in August). The relative low numbers of years and thinned plots did not enable to detect the

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possible joint-effects of climatic and stand variables and thinning operations. A longer period for monitoring mushroom yields on thinned plots, or preferably on designed thinning experiments, will be needed to study the effect of thinning on mushroom yields.

The performance of the estimated models can be illustrated by simulating the development of the mushroom yields along with the development of a spruce stand with a high mushroom productivity (Fig. 2.5). Mushroom yields increased along with stand age until a certain point after which the yields started to decline. The declining in *B. edulis* yields happened after the stand age exceeded 25–30 years. Two thinnings done according to the silvicultural recommendations seemed to improve slightly the *B. edulis* yields.

The yields of *Lactarius* spp. did not react positively on thinnings but rather declined after the stand exceeded the age of 30–35 years (Fig. 2.5). Thus, unthinned stand seemed to produce better yields in a case of *Lactarius* spp. The peak at all marketed mushroom yields was at the age of about 35 years and yields of all marketed mushrooms declined considerably after the thinning.

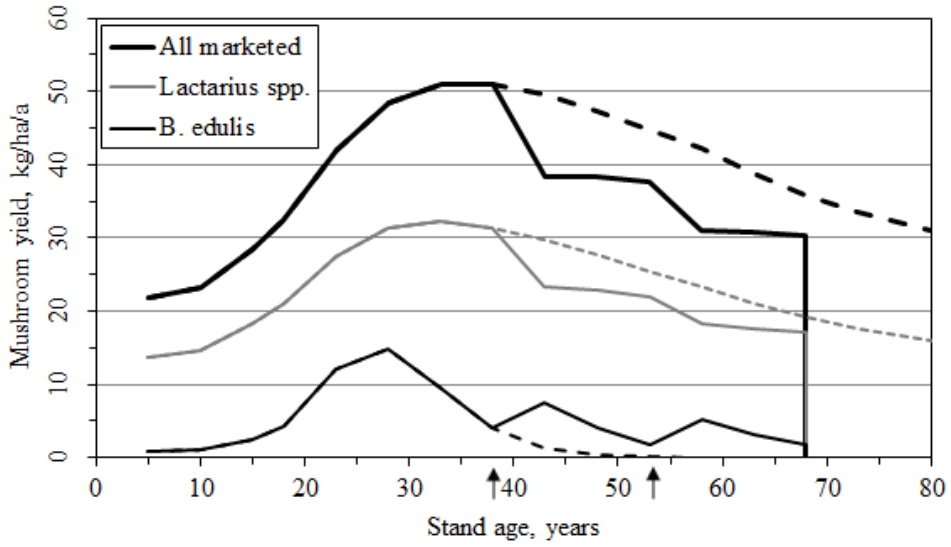

Figure 2.5 Predicted development of the yields of *Boletus edulis*, *Lactarius* spp. and all marketed mushrooms in a planted spruce stand in eastern Finland (Tahvanainen *et al.*, 2015).

The stand is regarded as a good mushroom stand. The stand development was simulated using the Motti simulator, and thinnings (arrows) and final cutting were simulated according to the silvicultural recommendations. Unthinned regimes are shown by dashed lines

In a good mushroom stand, the contribution of mushrooms to the total net present income (with 3 % interest rate) during the whole rotation was 25 % (Fig. 2.6). The total mushroom yields, as well as incomes from mushrooms obtained during the rotation were the highest when thinnings were delayed by five years

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from silvicultural recommendations applied in Finland. However, the advanced thinnings (i.e. five years earlier than recommended) seemed to be the best for *B. edulis* and also the economic result of timber production benefited from the advanced thinnings.

Interpreting the effect of thinning on mushroom yields should be regarded as preliminary. Using the inventory data, the effects of thinning and stand density were not able to be separated from each other. Thus, in simulations, the effect of thinning on mushroom production was described through the change in stand basal area. For *Boletus edulis*, the optimal stand density was about 25 m^2 ha^{-1}, which was obtained and exceeded before the first commercial thinning. Thus, the highest yields of *B. edulis* were obtained also before the first thinning. In thinnings, the stand basal area was decreased, and consequently, the *B. edulis* yields increased temporarily until the stand density of 25 m^2ha^{-1} was achieved again. For *Lactarius* spp. and all marketed mushrooms, the optimal stand density was higher than that for *B. edulis*. Thus, pre-thinning stand densities were more suitable than post-thinning ones, and consequently, thinnings decreased the yields of mushrooms other than *B. edulis*.

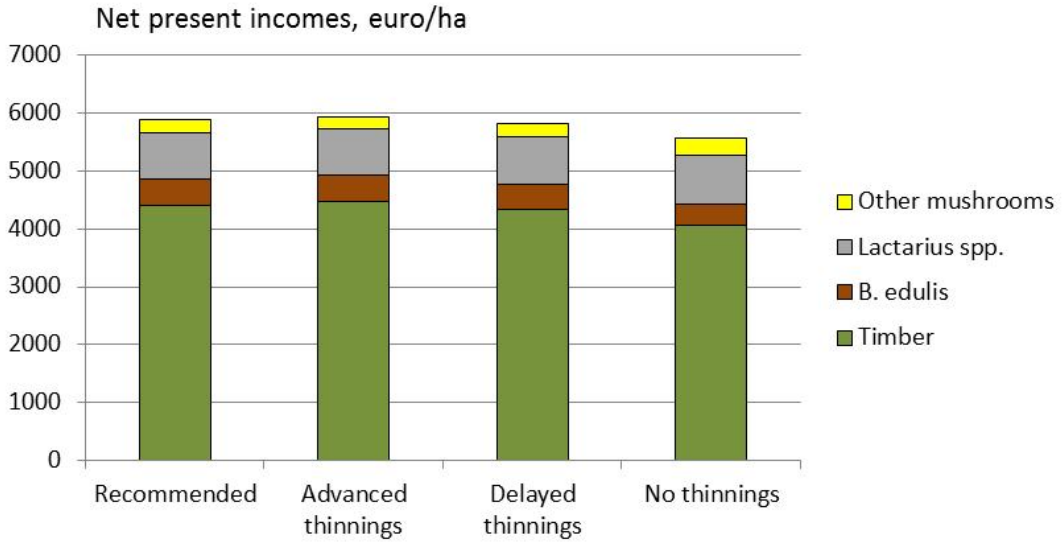

Figure 2.6 Net present incomes (euro/ha at 3% interest rate) from timber and mushrooms obtained from a good mushroom stand when following different thinning regimes with the same rotation length (Tahvanainen *et al.*, 2015).

The stand was regarded as a good mushroom stand so that the 90th percentile of the distributions of the random plot effects were added to the predictions of the mushroom yield models.

Despite their preliminary nature, the models enable predictions of mushroom yields along with the development of spruce stands and thus support multiple-use planning and management of forests.

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2.4.2.1 Summary of achievements during the StarTree project

Already achieved under the StarTree project:

- The new expert model was estimated for *Boletus edulis* in Norway spruce stands in North Karelia, Finland (Tahvanainen, 2014).
- The new statistical empirical models were estimated for marketed, edible mushrooms (*B. edulis*, *Lactarius* spp. and all marketed mushrooms) in Norway spruce stands in eastern Finland (Tahvanainen *et al.*, 2015).

On-going research that will be concluded before the end of StarTree:

- The empirical yield model for *Boletus edulis* will be integrated into a stand simulator for describing the development of *B. edulis* yields along with stand development, and optimizing the joint production of timber and *B. edulis* in a planted spruce stand.

3 New models to be developed

3.1 Models for the same products in different regions

3.1.1 Models for mushrooms in Portugal

Authors: MT, MM, AC, LF, PS, JSU, RO

There are no empirical mushroom yield models in Portugal. As a first step towards the development of an empirical mushroom yield, we looked for available data sets. To our knowledge the only data sets that include mushrooms production are the ones monitored by Celeste Santos-Silva's research group from Universidade de Évora (Santos-Silva *et al.*, 2011). Those data are restricted to two specific sites, therefore not appropriate to develop a model for general use in forest planning. Nonetheless, we established a protocol of collaboration with the University of Évora with the objective of guaranteeing the maintenance of the existing plots and also for the collaboration of the two research teams.

Following the methodology used in Finland for B. edulis, the lack of empirical modelling data on mushroom yields can be overcome with expert modelling so that experienced mushroom pickers or researchers rate different stands according to mushroom production. A shortcoming is that the annual variation in mushroom yields cannot be incorporated in this kind of expert modelling but we thought that it is a good starting point.

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An analysis of existing literature on the application of expert models for wild berries in Finland (Ihalainen and Pukkala, 2001; Ihalainen *et al.*, 2002; Ihalainen *et al.*, 2005) lead to the selection of the methodology to be used to develop a first model of mushroom production in Portugal. The development of the model will be based on a sub-sample of the plots measured during the 6th National Forest Inventory (NFI6) that is taking place in Portugal. Each forest inventory plot is photographed using a series of rules that were analysed by the research team (ISA and Universidade de Évora) and considered appropriate to evaluate the adequacy of each site for mushrooms yield evaluation. The following mushrooms were selected to be part of the modelling exercise: *Amanita ponderosa, Boletus edulis* group, *Cantharellus cibarius, Terfezia* spp. The verification stage of the field measurements from the NFI6 is still taking place. The plots used to develop the expert-based mushroom yield model were selected from a set of plots already checked distributed among 6 strata defined by the species and composition of the stand: pure cork oak, mixed dominated by cork oak, pure holm oak, mixed dominated by holm oak, pure stone pine, mixed dominated by stone pine. The initial data set that is being selected by the Portuguese NFI is planned to consist of 75 plots from each strata (a total of 450 plots). The following method was defined for the selection of the plots that will be used for the model development: the 450 plots will be classified according to 3 classes of basal area X 3 classes of number of trees per ha and 4 plots were selected from each of the 9 combinations so obtained, resulting in a final data set of a number close to 216 plots. The number 216 will be attained if there will be at least 4 plots in each one of the 9 combinations of basal area X number of trees per ha what may not happen. The photographs of each plot, jointly with a brief description of the plot (location, basal area, number of trees per ha, crown cover, use of understory, amount of shrubs, etc.) will be organized in a digital booklet that will be sent to the experts together with the explanation of the work that is being developed and what we are expecting from them. The objective is that each expert will classify each plot in a 0-10 scale (0, very poor; 10, excellent) for the production of each one of the 4 mushrooms selected for the study. It will also be asked to give an estimation of the absolute mushroom production (kg ha^{-1}) which corresponds, in their opinion, to the maximum value of the scale (10). This will made it possible to develop model in terms of kg ha^{-1} (Ihalainen *et al.*, 2005).

3.1.1.1 Summary of achievements during the StarTree project

On-going research that will be concluded before the end of StarTree:

- The first model for the prediction of mushrooms yield in cork oak, holm-oak and stone pine stands (pure or mixed) in Portugal

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3.2 Database development for future models

3.2.1 Resin

Authors: SM

Resin tapping had been a traditional forest use with importance in the rural economy of Southern Europe during XIX and XX century. Maritime pine, *Pinus pinaster* Ait., had been the most relevant specie, and nowadays it is the only one tapped for resin in the western Mediterranean countries, where it is one of the main forest trees and comprises the most extensive conifer woodlands in Spain, Portugal and southern France. Resin flow is induced by mechanical wounding and chemical stimulants applied, often acid. Induced mean annual yield is about 2-4 kg resin per tree (Alía and Martín, 2003; Mutke *et al.*, 2013). Until 1980, resin obtained by tapping pines had been a regionally very important non wood forest product. In Spain, the maximum resin production had reached 55,000 t in the 1960s, but then decreased and nearly disappeared after Spain's integration in the European Common Market in 1986. During two decades Spanish resin output had been less than 5,000 t yr^{-1}, until a strong price increase for natural resins since 2010 allowed for a current comeback of resin tapping in Spain, surpassing (Picardo and Pinillos, 2013).

Due to this long-lasting abandonment of resin tapping as economic activity in Europe, there had been nearly no papers published about resin yield and its modelling, though maritime pine has been one of the best-studied forest species in Spain and Portugal, and numerous growth models are available (Nanos *et al.*, 2001; Tadesse *et al.*, 2001; Bogino; Bravo-Oviedo *et al.*, 2010; Genova *et al.*, 2014). Since 2006, a recent research line on resin tapping has been developed at the Regional Forest Technological Centre CESEFOR in Spain, centring on tapping methods, its mechanisation and ergonomics (Pinillos *et al.*, 2009). In this project, several ten thousand multi-annual single-tree resin yield data were obtained that have allowed analysing weather and tree covariate effects: Induced resin flow is strongly related to climatology, especially to high temperatures and moderate drought. Additionally, strong differences among individual trees exist and are stable among years: mean individual resin yield was less than 3 kg yr^{-1}, but the most productive trees yielded more than 6 kg yr^{-1}, especially larger and more vigorous trees produced more resin. Also lower stand densities/basal areas per hectare increased resin production per tree, though not always per hectare (Roig *et al.*, 2010; Rodríguez-García *et al.*, 2014).

Thus covariates such as tree diameter, percentage of living crown, or stand density might be used as link-functions to predict resin yield from individual tree growth models for management decision support systems and silvicultural guidelines. Nevertheless, the sound data required would imply building a stable

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sampling network in collaboration with professional resin tappers, the need to standardise their tapping technics, fortnightly individual tree resin collection and measurement throughout the whole summer semester, replicating all possibly influencing factors at tree and stand level, as well as the climate factors in time (pluri-annual studies). Considering the existing differences at landscape and regional scale also an extensive geographic sampling scheme would be required (Nanos *et al.*, 2001). That major middle-term research effort would be possible only in collaboration with forest administration or the private sector, e.g. at management unit scale.

Nevertheless, its setup is hampered by serious uncertainties, concerning both the resin and rosin world market prices and the high unemployment rates that press on labour costs and makes profitable the tapping, and especially the high risk to arrive of the pine wilt nematode (*Bursaphelenchus xylophilus*), one of the most dangerous threats to European coniferous forests, especially for the susceptible maritime pine that is killed massively by these quarantine organisms.

3.2.2 Chestnut

Authors: JS, EB, MP

Commercially produced chestnut fruits derived from *Castanea sativa* (sweet chestnut) are most commonly grown within orchard style production systems where growth and production of fruits can be optimised, this often includes a control of the size and shape of the tree to facilitate harvest, but moreover, the size, quantity and quality of the fruits produced. It should be noted that commercial chestnut production often utilises grafted cultivars that also employ other chestnut species such as *C. mollissima* (Chinese chestnut) and *C. dentata* (American chestnut). A number of models considering *C. sativa* can be found in the literature. Among these models some of them describe the height growth (Álvarez-Álvarez *et al.*, 2010; Hein *et al.*, 2013) in forest stands and height growth in coppice stands (Manetti *et al.*, 2001) and the crown width as a function of dbh (Savill, 1991; Hein *et al.*, 2013). Moreover, the ability to resprout post coppicing has been described by Giudici & Zingg (2005). Serdar and Demirsoy (2006) modelled the leaf area as a function of leave length and width. Total above ground biomass, stem biomass (including bark), bark biomass, main stem (underbark) biomass, flowers and leaves, and branches are also available (Patrício *et al.*, 2004; Montero *et al.*, 2015).

In Spain, where chestnut is a very important NWFP, various literature containing silvicultural schedules for the management of *C. sativa* stands has been published (e.g. Álvarez-Álvarez *et al.*, 2010; Montero *et al.*, 2015). These schedules consider different management objectives, namely high quality timber production,

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small-dimension timber products and chestnuts. In principal, the joint production of different outputs has not been considered yet. However, most of the times these management schedules are not based on growth and yield models but on expert knowledge and traditional management. This does not mean that the management schedules are wrong but they need to be tested based on data field and statistical analysis in order to allow their application to different forest regions.

By applying the above models to forests stands, much can be deduced about the size and form of the tree, little however, is known about the fruiting capacity of *C. sativa* growing under similar conditions. Work in Spain where data was collected from a number of Spanish regions has compiled a number of models for *C. sativa.* These are placed within a silvicultural handbook including models for tree density, tree size and a fruit yield model (Montero *et al.*, 2015). Fruit yield is suggested to be a function of the tree size employing as a predictor the diameter at breast height (dbh). Although the model for the fruit production is very simple and based on data from grey literature and technical reports of different Spanish regions, it could be a first step for assessing this interesting topic in different European regions.

The requirement of permanent sample plots is upmost for the study of chestnut yield, this allows for the collection of multi-year data which can be correlated with tree parameters and applied silvicultural treatments. The construction of yield models for *C. sativa* would enable forest managers to reliably predict potential harvest of chestnuts whether for commercial sale, for seed harvest or as a means of providing recreational benefit to forest stands.

3.2.3 Walnut

Authors: JS

Juglans regia (English/ European/ Persian walnut) is commonly grown as a source of high value timber for veneer or furniture construction or as a source of walnuts within a farmed landscape. A number of models have been published to aid assessment of certain tree parameters: Adhikari et al. (1995) published a number of allometric models for the determination of the biomass production of *J. regia* in Bhutan. Adhikari et al. (1995) also published predictive models for the calculation of branch, twig, foliage, stump root, lateral root and fine root portions. As leaf area has been suggested to be an important variable for nut size and nut filling potential, Keramatlou et al. (2015) propose a model that predicted leaf area as a function of leaflet length and leaflet width

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Yield models for the fruiting capacity of *J. regia* are not frequent within the literature, Ojaghloo et al. (2014) proposed a model for the prediction of nut yield as a function of trunk cross sectional area (TCSA) and lateral bearing percentage (LTB, is defined as the average number of one year old lateral buds at the time of blooming). Two yield models for the production of nuts by *J. nigra* in the USA as a function of dbh were reported (Ares and Brauer, 2004; Brauer *et al.*, 2006) and may go some distance to frame the production potential of European *J regia*.

3.2.4 Cherry

Authors: JS

The commercial production of cherry fruits derived from *Prunus avium* is confined almost exclusively to orchard production here tree parameters are closely controlled for the single goal of cherry production. Large differences in site treatment and silvicultural management are evident in comparison with timber production. To date many models have been published within the scientific literature regarding cherries produced within cherry orchards, these include models that describe fruit characteristics such as fruit size, shape, fruit quality, hardness and sweetness both at harvest (Beyer *et al.*, 2002; Muskovics *et al.*, 2006; Shahbazi and Rahmati, 2013) and post-harvest regarding storage-ability (Bernalte *et al.*, 2003). Models are available that provide yield predictions based on climatic and other external variables such as prediction of flowering time as a factor of the North Atlantic Oscillation (Gormsen *et al.*, 2005), the relationship between frost events and bud damage (Miranda *et al.*, 2005) and those that highlight extrogenous factors such as the importance of pollination by bees (Holzschuh *et al.*, 2012). With greater applicability towards forest trees, the modelling of tree parameters is also reported. This includes the determination of leaf area (Demirsoy and Demirsoy, 2003; Cittadini and Peri, 2006; Demirsoy and Lang, 2010) important as a function of photosynthetic capacity. Modelling has also been applied to both orchard and forest trees in respect to management operations carried out to pursue respective production goals. Either to optimise tree form (Láng, 2003; Hein, 2009) or direct management to increase crop load (Ayala and Andrade, 2009), models can also be applied for the determination of crown width (Pryor, 1988), important for planning thinning operations.

3.2.4.1 Modelling biomass production

The application of allometric modelling can be utilised in order to relate an easily obtainable measurement such as stem diameter to a parameter that is more difficult to obtain. Allometic equations for total above ground woody biomass between different compartments of *P. avium* in a forest stand, namely, stem,

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branch and bark fractions have been published by Morhart et al. (in review) within the framework of the Startree project. Predictor variables include dbh (diameter at breast height/ 1.3m above the ground), BD_{origin} (Branch diameter at origin from the stem) and $d_{overbark}$ (overbark diameter). The ordinary least-squares regression method was carried out utilising the log transformed data providing the model as given in Eq. 3. Retransformation to arithmetic form was carried out using the regression coefficients deduced from the general linear function (Eq. 4), since the use of natural log transformed data shows a tendency to slightly under-predict the dependent variable a correction factor (β) was applied (Eq. 5). Regression coefficients can be seen in Table 3.1.

$$Ln(B) = Ln(a) + b\ Ln(X) \quad (3)$$

$$B = \exp[\{a + \beta\} + b\ Ln(X)] \quad (4)$$

$$\beta = 0.5\ S_e^2 \quad (5)$$

Table 3.1. Regression coefficients of biomass models, their standard error (Se) and statistical significance (Morhart et al., in review)

Output	Model	Independent Predictor	a	b	r^2_{adj}	F	df	S_e	*p*
Whole Tree Biomass	1	dbh	0.109	2.450	0.991	4219.2	1,37	0.138	<0.001
Stem Biomass	2	dbh	0.108	2.290	0.988	3208.4	1,37	0.148	<0.001
Branch Biomass	3	dbh	0.010	2.969	0.969	1177.4	1,37	0.317	<0.001
Individual Branch Biomass	4	BD_{origin}	0.029	2.868	0.959	8556.5	1,368	0.470	<0.001
Total bark biomass	5	dbh	0.039	2.258	0.991	2083.5	1,18	0.137	<0.001
Stem bark biomass	6	dbh	0.042	1.906	0.992	2462.7	1,18	0.106	<0.001
Branch bark biomass	7	dbh	0.005	2.822	0.958	431.7	1,18	0.377	<0.001
Individual branch bark biomass	8	BD_{origin}	0.010	2.669	0.975	2672.8	1,67	0.304	<0.001
Bark thickness by diameter class	9	$D_{overbark}$	1.456	0.536	0.810	735.7	1,172	0.230	<0.001

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3.2.4.2 Modelling Cherry Yield

There is a distinct absence of cherry yield models within the current published literature for the fruiting capacity of *P. avium in* forest stands (Tomé and Faias, 2014). It is hypothesised that yield will be a factor of a number of predictor variables, namely: dbh/ stem diameter, height/ length, crown size (area/ volume), tree age, climate, soils and other external variables.

The addition of yield models for *P. avium* will improve the predictive capacity of producing cherries within the forest allowing for optimised management and thus facilitating forest managers greater economic forecast and an ability to plan for the future.

A pilot study was conducted on a research site situated in southern Germany (N 48.07021 E 7.58991; 182m a.s.l.). The site was established on abandoned agricultural land in 1997. *P. avium* of a local provenance (Lilliental) were planted in a mixture with other broadleaved species with spacing of 1.5m within the rows and 7.5/15.0m. The area has a climate dominated by warm summers and mild winters. Mean annual precipitation sum is 705 mm; mean annual air temperature is 10.1°C. In mid-June 2014 a number of unpruned *P. avium* were identified (n=7), consisting of both co-dominant and suppressed individuals. A degree of natural regeneration was evident forming an understory between rows. Tree parameters such as dbh and crown projection area were recorded and the tree was felled (at a slow speed by leaving a large felling hinge) onto a tarpaulin. Stem length was measured to the tip and the height of the lowest live branch was also recorded for the calculation of crown volume. It was intended to utilise a randomised branch sampling methodology for the sampling of cherries and attribute cherry biomass to individual branch parameters. However, a fewer amount of cherries were observed on the majority of trees, therefore although time consuming, it was decided to count total cherry biomass. Cherries were removed in a methodical way including those that had fallen onto the tarpaulin during felling. The cherries were weighed and a total sum per tree was recorded.

A wide range of variability was observed between sampled trees. Total tree yields ranges between 0.09 and 4.1kg as can be seen in Table 3.2. It was hypothesised that larger trees, both in terms of stem diameter and crown volume will present greater fruit yields. Within the sampled trees this is not evident no relationship could be found (Figures 3.1.a and 3.1.b).

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Table 3.2. Data derived from empirically measured forest trees of *Prunus avium*

Tree	dbh (cm)	Tree Height (m)	Crown Volume (m^3)	Cherry Yield (g)
1	7.8	7.6	23.2	195.9
2	9.9	8.2	48.4	280.4
3	11.7	11.0	44.6	4083.9
4	13.4	10.5	55.5	89.6
5	13.7	11.1	60.5	449.2
6	14.3	12.3	40.5	410.2
7	12.3	11.7	46.8	1235.6

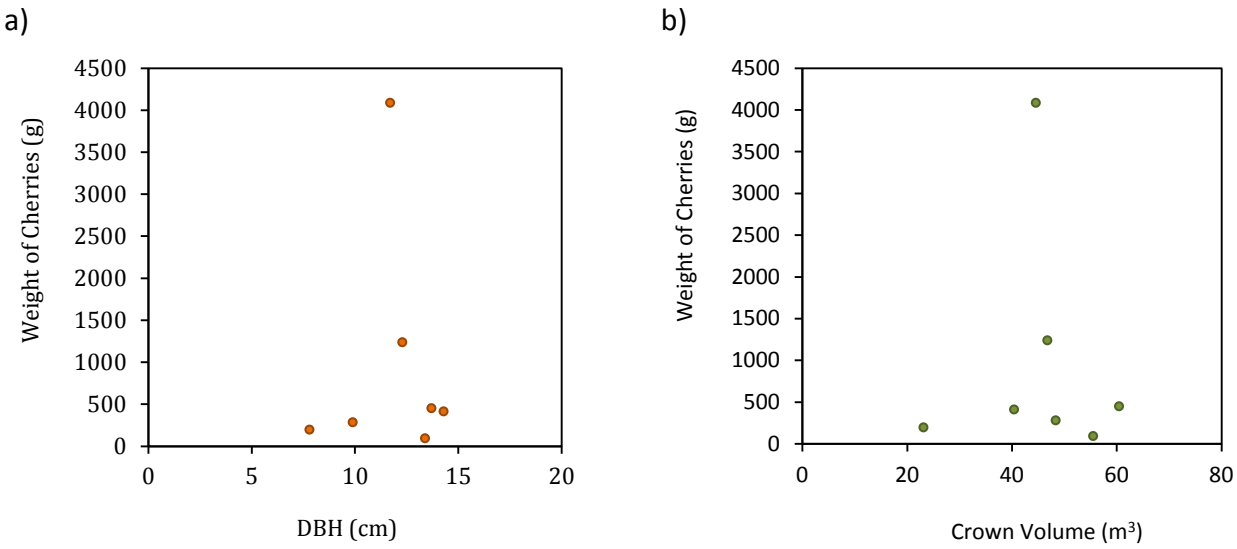

Figure 3.1. Cherry yield as a function of dbh (a) and crown volume (b)

Trees were 20 years old at the time of sampling in what has rhetorically been described as a good year for stone fruit. Sampled trees were taken from co-dominant and sub dominant social classes as part of a pre commercial thinning operation. Heterogeneous yields may be attributed to the immature nature of the stand which has not yet fully reached full cropping potential this may be coupled with differences in tree social class, where co-dominant trees may be seen to produce greater yields than suppressed individuals. Due to the reported preliminary results this empirical study was curtailed to re-evaluate the methodology and hypothesis.

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In order to assess cherry production potential within established systems in order to frame the production potential of forest trees, a meta-analysis of published data was carried out as briefly described by Sheppard & Spiecker (2015). This analysis reviewed cherry yield data reviewed 385 data points across 16 publications (see Appendix A). In the absence of cherry yield data from forest stands the derived yield values were sourced exclusively from commercial cherry production (i.e. orchard stands). A large discrepancy of management treatments was seen between orchard and forest production systems but also within orchard management regimes. This was focused on pruning, tree density, fertilisation and weed treatment operations (see Appendix A), for our purposes this was largely ignored. Modelling was carried out using standard multiple linear regression methods.

Regression output can be seen in Table 4 and Figure 8 the model follows the form given in Eq. 6.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots \beta_p X_p \quad (6)$$

Table 3.3. Regression parameters for meta-analysis yield model

	β	SE	t	*p*	$F_{2,382}$	r	r^2_{adj}
Cherry Yield (kg/tree)					133.2	0.64	0.41
Intercept	-6.714	1.363	-4.925	<0.001			
Stem Diamter	1.594	0.136	11.741	<0.001			
Tree Age	0.568	0.197	2.879	0.004			

The predominant and most significant predictor variable was stem diameter. In many cases a value for trunk cross sectional area (TCSA) was reported and thus converted to a diameter measurement (cm) upon analysis, however, in many cases it is not known at what height on the stem this measurement was taken, this difference was disregarded. Tree age (in years) was also a significant predictor of cherry yield with fruiting suggested to commence at an age of approximately four years, a value consistent with grafted stock. Most papers did not include data detailing the height or crown size of the studies trees (a summary can be seen in Appendix A). Furthermore, differences with reference to stand density were also evident but not significant when considering cherry yield.

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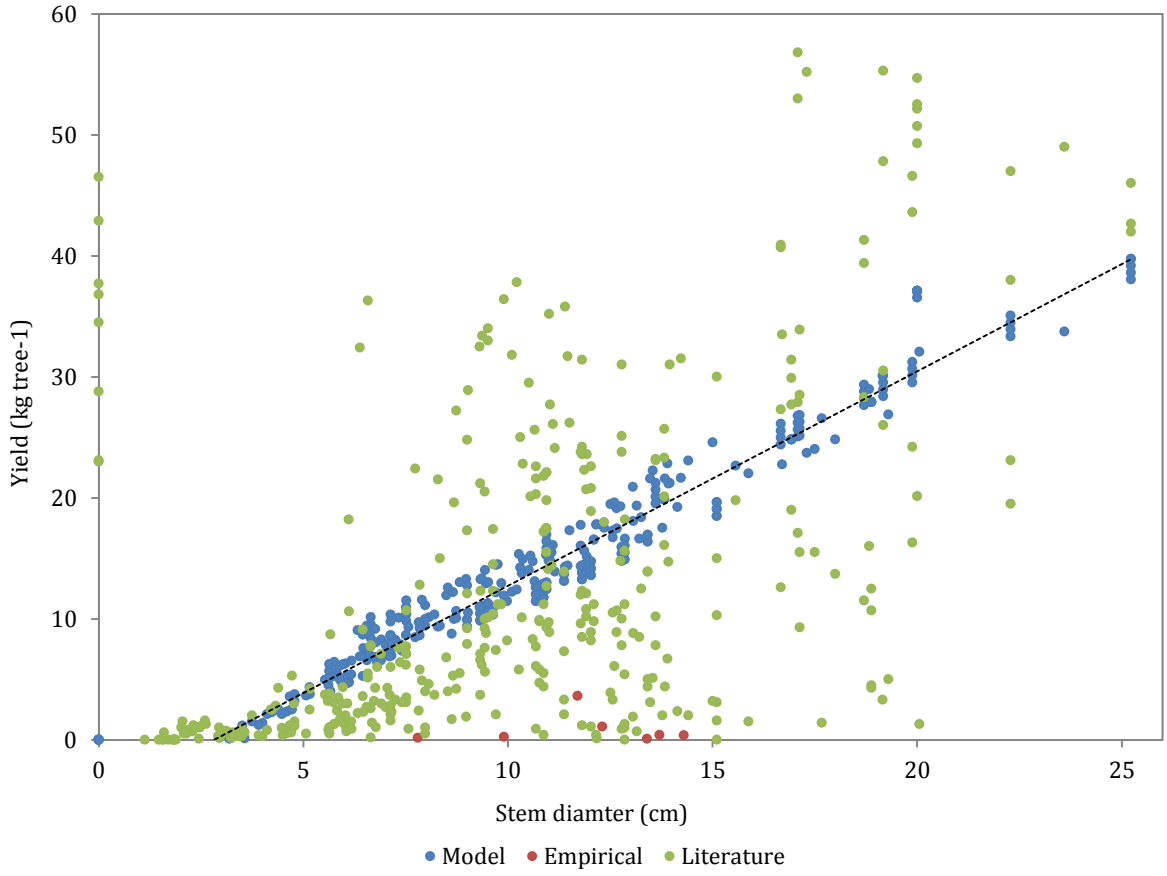

Figure 3.2 Meta-analysis model for *P. avium* fruit yield

A wide spread of points can be observed, meanwhile, the model presents a relatively poor value for the coefficient of determination (R^2_{adj}), thus suggesting that the model reflects only approximately 40% of the values derived from the literature. The low predictive capacity of the model can be attributed to the wide variation of management operations, particularly due to disparate pruning techniques (Lang, 2001) coupled with differences in productivity and precocity due to cultivar and rootstock combinations (Whiting *et al.*, 2005).

The seven empirically sampled trees as described in Table 4 can also be seen in Figure 8, here cherry yield vs. stem diameter and tree age values lie within the range of values from the literature, but are substantially lower than those suggested by the model. As these trees are not grafted, this may be attributed to the age of the trees (≈20 years) where full fruiting had not yet commenced. This is more likely to be due to the fact that these trees are not optimised for cherry production, but instead for timber production (Springmann *et al.*, 2011), even though the chosen individuals were unpruned and at relatively

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low densities, therefore, likely to produce more cherries. Nevertheless, no trend in yields vs. tree size/age could be seen within this small sample.

3.2.4.3 Recommendations for future work

The modelling of cherry yield in forest stand requires greater predictive capacity and improved applicability to forest stands. This must be carried out through the collection of empirical data within a wide range of scenarios.

The collection of multi-year data can account for annual climatic differences, bi-(or tri-) annual bearing of fruit and precocity issues in young trees. For this reason a need for permanent trial plots across Europe is necessary. Furthermore, the collection of data under a range of silvicultural management treatments remains an important focus. Such data will create a robust view on the management of forest stands when considering the co-production of fruit alongside a timber goal. There is an apparent need to sample cherries from mature trees which are at peak production. The sample design employed within section 2, suggests that *P. avium* at an age of 20 years do not produce neither a consistent nor large quantity of cherries within a forest stand.

The utilisation of a randomised branch sampling methodology represents a less destructive method of data collection. Such data can be used to calculate crop load per branch thus providing the potential to relate the pruning of branches to the loss in cherry productivity. Nevertheless, difficulties remain when considering accessing branches and accurately enumerating yield. Whole tree estimates of cherry yield proved a broad scope for creating allometric relationships between tree parameters and yield.

As a conclusion the use of models derived from the meta-analysis goes some way to frame the production potential of younger *P. avium*. However, it can be suggested that there is low potential for cherry production within forested systems. Other systems should be explored where individual trees can be managed for such disparate goals.

3.2.5 Sorbus

Authors: JS

Sorbus fruits can be derived from a number of species, The Startree deliverable 2.1 (Tomé and Faias, 2014) discussed *Sorbus aucuparia*, *S. domestica* and *S. torminalis.* Sorbus species are generally found within a mixture of other broadleaved species, never as pure stands. To date only one growth model could be found

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within the literature, this concerned the calculation of stem volume of *S. aucuparia* in Norway as a function of diameter at breast height (dbh) and tree height (H) (Braastad 1996).

Growth and yield models for both *Juglans* and *Sorbus* species are lacking within the current literature. The establishment of permanent plots where multi-year data can be collected for the assessment of tree growth and fruit yield is highly recommended. The construction of such models will allow forest managers to reliably calculate potential production returns from these species.

3.2.6 Lime

Authors: EB, DMK

The Lime tree (or Linden tree) flowers are used as herbal tea, as fragrance in perfumes and soaps, essential oils, extracts, botanical facial masks and creams, sun care and body lotions and shampoo, bath and shower gels, and has also been utilized within greater health and well-being syrups and nerve system tranquillizers (Tomé and Faias, 2014). Estimating the productivity of lime tree flowers is a quite new endeavor in the literature. Although some researches succeeded, they focus on the development of some allometric relationships related to wood growth (Semenzato *et al.*, 2011) as well as the biomass components of lime trees such as stem, branch, stump, coarse root and total foliage (Wang, 2006) and to the ecology and silviculture of three different lime tree species (Radoglou *et al.*, 2008). Until now, none of the researches has been focused on the production of lime tree flowers. Within this topic, the first step is to obtain the database for the development of models to estimate lime tree flowers with bract and inflorescence.

First of all, inventory systems with two different sampling methods were developed for the establishment of database and estimation of productivity. The first level of inventory is related to the regular forest inventory towards the preparation of forest management plans and the other focuses on the estimation of productivity of flowers. The regular forest inventory is modified to include necessary parameters such as age, height and site conditions and uses systematic sampling method to create forest cover type maps and standing volume per area in a database. The sample plots were distributed over the area with 300m by 300m intervals and data were measured in summer 2015. The size of the plots is circular and varies according to the crown closures (<40% →800m^2, 41%-70% →600m^2 and > 70% →400m^2, in accordance with forest inventory guidelines in Turkey). For each plot, all trees with dbh over 8 cm were measured and tree species were recorded. Additionally, tree age, total tree height, bark thicknesses and the radial growth for the last 10-years were recorded for 3-5 trees representing the stand for each plot. Dominant height in a stand was estimated based on a principle of 100 dominant trees per ha.

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The second level of inventory relates to the productivity of lime tree flowers. In this stage, nearly 30 sample plots were taken from the case study area based on stratified sampling method. Total 7 stratas were determined from lime tree stands. 6 of stratas were selected from two age classes and three site classes (good site, medium site and poor site) in lime stands with crown closure and the other strata was selected from degraded areas. Nearly 3-5 sample plots from each strata and 2-3 sampling trees within each plot were taken. All the fruit bearing branches of sample trees were cut down by rural person who expert in climbing tree.

The data collection time should be selected carefully based on the fruiting period of the tree and the study area. In the case study area, the data were collected from 10th of June to 25th of June. First of all, the inflorescences were cut off from the branches with a suitable scissors on the ground and then all bractes on the branches were collected by hand for each sample tree. All inflorescences and braches collected were separately weighted in fresh with a sensitive manual scale in the sample plots. To calculate fresh to dry rate of inflorescences and bractes, some samples were put in marked boxes and taken into labs for only a sample tree in the each plots. After drying of the samples, fresh and dry weights of sample inflorescences and bractes were recorded on inventory sheets. Furthermore, some site parameters such as slope, aspect, elevation were taken with a GPS for each sample plot and recorded into the database.

To predict the changes of biometric parameter in time, age is used as the independent variable. However, stem diameter is available in forest inventories and in any case easier to measure. For this reason, after finding a good fit for age against dbh, the latter is used as the independent variable (Semenzato *et al.*, 2011). The selection of an appropriate growth model will be decided based on the prediction ability of several equations. Some logarithmic and nonlinear equations proposed by (Peper *et al.*, 2001; Peper and McPherson, 2003) will be used in deciding the appropriate equations. Nonlinear exponential model will also be tested for the prediction of leaf area and the amount of flower production from dbh as suggested by Peper et al. (2001) and Peper and McPherson (2003).

3.2.7 Bay leaves

Authors: EB, DMK

Despite the importance of bay leaves in the Mediterranean region, so far there is not a sound model that would allow the prediction of their production. In order to develop a model, it is necessary to create a complete database. However, developing a model for the prediction of bay leaves is not straightforward. First, it requires taking the forest coverage into account. As the bay leaves grow both as understory

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vegetation shrub competing with other species and pure stands, modeling should take both conditions into account. Second, site factors are important in developing yield models. Third, socio-economic issues would also affect the level of shoots in bay leaves. Lastly, the production method along with the interval of coppicing should be taken into consideration in developing models. Based on those complex issues, there has been no sound and functional models developed so far though there is a simple model developed by Güler (2006).

For this case, 80 sample cohorts were selected. Although simple random sampling is used for sampling design, different site conditions and cohort sizes were targeted to better represent the variety stand conditions. The picture of each cohort is taken as well. For the per area productivity, the fresh weight (kg) of the cohorts is measured only for the three year-shoots (shoots + leaves). Within each sample, the total bay shoots are cut and weighed for fresh weight. In the meantime, the percent crown coverage and abundance of bay leaves are also measured based on Braun-Blanquet method to calibrate the per area productivity (Avcıoğlu, 1996). Alternatively, for the measurement of coverage density as well as productivity, the number of cohorts/ha, distances (cm) to all neighbourhood cohorts, number of individuals in a cohort, collar diameters (mm) and ages of individuals in a cohort, crown length (cm), height and width (cm) of cohort and the site factors are also measured (Güler, 2006 see the data collection Table 3.4). The statistical relationships between the fresh weight of leaves and all other parameters are sought for model development.

The number of cohorts per ha is determined based on:

$$N = \frac{10000}{\pi {r_3}^2} \times k_3 \qquad (7)$$

Where N is the number of individuals per ha, r_3 is the nearest distance among the nearest three trees/cohorts, k_3 is a coefficient (in a simple statistics k_3=0.5).

An index was developed for estimating the top surface area of the crown (Güler and Baş, 2005). A regression analysis will be carried out to develop a model to predict the amount (kg) fresh weight laurel leaves with respect to crown index.

Bay laurel grows both freely in mix stands generally in degraded areas or in understory vegetation. Thus, model development requires sample plots to be distributed according to these two types of growing environments. In bay leaves area located understory, sampling design will be done based on density class of bay leaves determined by Non-Wood Forest Products and Services Department in 2013. From this point

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of view, min 10 max 45 sample plots will be taken randomly from each bay leaves area with different densities. Also, selected sample plots are aimed to represent widest range of different stands and topographic characteristics such as aspect, slope, and elevations. Each sample plot will be a 400-800m^2 size based on crown closure. In each plot, the number of cohorts/ha, the number of stem in a cohort, distances (cm) to all neighbourhood cohorts, collar diameters (mm) and ages of individuals in a cohort, crown length (cm), height and width (cm) of cohort and the site factors will be measured. Since bay leaves are generally managed under copping, they grow in cohorts. Thus, a sample plot would include a number of cohorts inside. To determine productivity of bay leaves, all shoots except one or two vigorous shoots in two cohorts representing each sample plot will be cut by saw machine or hedge shears. All cut shoots will be measured by a digital hand scale. In order to see the time or seasonal effects, next year, other two cohorts within each sample plot will be cut and measured similarly.

Table 3.4. Data base design for modeling bay leaves (modified from Güler and Baş, 2005)

Cohort No	Distances to adjacent Cohort (cm)	Width of Cohort crown (cm)	Depth of Cohort crown (cm)	Height of Cohort crown (cm)	Stems in a cohort (number)	Diameter of stems (mm)	Age of the dominant individuals (year)	Site condition	Fresh weight of shoots (w/leaves) in a cohort (kg)
1									
2									
…									

In degraded bay leaves areas, max 20 sample cohorts will be selected randomly based on different aspect and elevation

In addition, classic forest inventory will be also performed to estimate stand parameters in each sample plot.

3.2.8 Pine honey

Authors: SdM

‘‘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 and Greece. The honeydew

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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 perspective. However, due to the lack of models concerning such a complex system, previous research has been based on some assumptions and sensitivity analyses regarding the interactions between *P. brutia*, *M. hellenica* and honeybees (de-Miguel *et al.*, 2014b). Further modelling-oriented research on this topic should focus on improving our knowledge on the interaction between the scale insect and forest stand dynamics (i.e., its impact on tree growth and mortality). Such models should aim at predicting: (i) which trees are infested by the scale insect, (ii) what proportion of trees may be infested in pine stands affected by the scale insect, (iii) to what extent the amount of honeydew produced is related to tree vigour, site quality, and the infestation status (iv) whether the infestation pattern and bee attendance may be influenced by stand structure and through forest management. Further insight into the efficiency of honeybees in processing different amounts of available honeydew to produce pine honey would also contribute to improving pine honey yield prediction. Finally, it seems that considerable fluctuations in honeydew and honey production arise from the sensitivity of *M. hellenica* to changes in meteorological conditions (Gounari, 2006). Therefore, improved knowledge on its weather sensitivity could also contribute to improving honeydew yield predictions under different climatic scenarios. For instance, the dynamic model of honeydew droplet production by *Ultracoelostoma* spp. feeding on *Nothofagus* tree species developed by James et al. (James *et al.*, 2007), and the prediction of honeydew flow from *Physokermes hemicryphus* feeding on spruce conducted by Pechhacker (1988), could inspire further modelling-oriented research on pine honey.

4 Discussion

Authors: MS, MP, JS, IC

In the framework of the StarTree project the existing growth and yield models for the selected NWFP and MPT have been analyzed in order to identify the needs for improvement and the gaps. The main conclusion made by Calama et al. (2010) in their reviewe of the existing models for the main NWFP in Europe was that

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there were very few models for non-timber products in Europe, due to the lack of systematically collected data, together with some challenges which make it difficult to develop predictive models. The previous report Deliverable 2.1 (Tomé and Faias, 2014) concluded that it was expected that the StarTree project will represent a big advance in the modeling of NWFP. From the model improvements described on this report joined with the new models that are going to be developed as a consequence of the empirical data collection that will began within the StarTree framework, it can be stated that this expectation has been fulfilled.

Most of the improvements that are already achieved under the StarTree project or that are going to be concluded before the end of the project are using statistical techniques, in particular empirical models; although in some cases also process-based models will be incorporated. This is the case of the SUBER model that is going to be hybridized to the 3PG model after calibrating it for Portuguese cork oak stands. Among the empirical models, the general trend is to include climatic variables and/or soil conditions in the models reaching such a high level of accuracy that allows for the prediction of yields even for those species which exhibit masting, or in those whose dynamics are still barely known (for instance mushrooms). In the case of MPT, the improvements are related to the knowledge in the tree growth dynamics at the regeneration and juvenile stage. In NWFP the most common applied statistical procedures consist in modelling the fruit production by means of a two stage model. This is the case of berries and mushroom, and a similar technique has been used for stone pine nuts production in Spain.

Besides statistical models the prediction of the growth and yield of NWFT and MPTs can be made by processing expert opinions. In this sense a new expert model was estimated for *Boletus edulis* in Finland and in Spain it is going to be developed and expert model for optimizing the multifunctionality of cork oak stands. In Portugal, since there is a lack of appropriate data sets for developing an empirical mushroom yield model the first model for the prediction of mushrooms yield in cork oak, holm oak and stone pine stands will be an expert model.

Many of the improvements will represent a big advance in the quality of forest management when NWFP are part of the management objectives. In Finland, the forest management schedules for the joint production for timber and berries and for timber and mushrooms will be optimized at stand level. In Spain, the optimization of the management schedules will be done for the joint production of cone and timber in *Pinus pinea* stands, for the production of cork in *Quercus suber* stands and for the joint production of mushrooms and timber in pine stands. In this sense, the new forest simulator AlcornoqueWeb from the

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ALCORNOQUE models that has been developed, or those simulators that have been improved, as the one from the SUBER model and the PINEA2 model or the MONSU and MELA simulators, will help forest managers on their tasks at different management levels.

The only model in a different region for one of those NWFP that already have existing models in other regions is the expert model that is going to be developed in Portugal for mushrooms. There are other NWFP models available that could be adapted for new regions. This is the case of stone pine and mushrooms in Turkey or cork oak in Italy and France.

Table 4.1 Difficulties in modelling yield for direct NWFP (nuts and berries)

Cause of variation in empirical yield	Detail	Possible solution
Between year climatic variation	Variability in rainfall and temperature between years	Collection of multi-year data from the same trees, correlate climatic variables with yield data.
Alternate bearing for fruit	Natural bi- or tri- annual bearing	Collection of multi-year data from the same trees
Ripeness	Genetic and environmental differences	Sampling to be spread across whole fruiting season
Herbivory	Varied pressure due to external influences	Net trees used for empirical study, quantification of natural loss
Fruit loss due to damages	Climatic and pest events including: frost, wind, heavy rain, drought, fungal infections, insect infestation	Collection of multi-year data from the same trees, note damage events as potential outliers.
Age of tree	Tree too young to have reached full fruiting potential. Or tree is too old and has passed peak production.	Collection of multi-year data from the same trees. Assess age of tree(s) within sampling design, if possible utilise a range of tree ages.
Silviculture/ management/ natural disturbance	Application of a silvicultural treatment or natural disturbance that positively or negatively affects fruit production	Effect of thinning and pruning on individual or neighbouring trees within sampling design.
Genetic differences	e.g. fruit size, due to genetic differences or the used of grafted cultivars	Assess choice of tree within sampling design, if possible utilise a range of trees
Sampling methodology	Fruit not equally distributed within canopy, methodology poorly represents level of fruiting.	Whole tree sampling or utilise a robust sampling methodology

The development of growth and yield models for some of the NWFP and MPT that do not count with models in Europe yet is going to begin within the framework of the StarTree project. The first step will be

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the collection of suitable data for the construction of reliable predictive models. In Turkey this task is being accomplished for modeling lime tree flowers and bay leaves. For resin, chestnut, walnut, cherry and sorbus, a need for permanent sample plots has been highlighted, hence, multiyear data can be collected for the assessment of tree growth and NWFP yield. However it must be taken into account that the collection of data for NWFP models must overcome a number of difficulties in order to ensure that a fair representation of yield is given as a model input (Table 4.1)

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This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement No 612385

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Appendix 1: Meta-analysis summary (Cherry yield data reviewed 385 data points across 16 publications)

n	Stem Diameter	Height	Crown Volume	Cultivar(s)	Rootstock(s)	Management	Tree age range	Trees ha^{-1}	Country	Reference
5	y	n	y	g	6, 8, 16 (also 16 as interstem)	Central leader	5	889	Poland	(Bielicki and Rozpara, 2010)
60	y	n	y	h, k	8, 9, 10, 11, 12, 13, 15, 18, 26, 29, 30, 32	Spindle	1-2	1333	Czech Republic	(Blažková and Hlušičková, 2004)
49	y	n	n	o	2, 5, 16, 22, 27, 28, 29	Minimal	8-25	500	Spain	(Cantín *et al.*, 2010)
78	Y	n	n	c	3, 7, 10, 16, 17, 18, 19, 20, 23,	Central Leader / Open Vase	2-3	785	USA	(Facteau *et al.*, 1996)
16	y	n	n	j	1	Unknown	7-10	331-546	USA	(Hanson, 1991)
4	y	y	Crown area	n	23	Control (assumed unpruned)	3-6	553	Canada	(Kappel *et al.*, 1997)
60	y	n	n	h	7, 9, 10, 11, 12, 13, 14, 15, 16, 26, 30, 32	Spindle	5-10	667	Lithuania	(Lanauskas *et al.*, 2012)
8	y	y	Crown area	a, b, d, g, h, k, o, p	25	Central leader	5	370	Bulgaria	(Lichev *et al.*, 2004)
30	y	n	n	h	16	Irrigation, fertilisation and spur thinning	5-7	555	Canada	(Neilsen *et al.*, 2007)
9	y	n	n	m	29	Spanish Bush/ Spindle	5-7	1754-3759	Croatia	(Radunic *et al.*, 2013)
3	y	n	n	e	16, 17, 24	Unknown	4	Unknown	USA	(Robinson *et al.*, 2005)
23	y	n	y	f	8, 15, 16, 31	Pyramid with crown reduction	8-13	893	Latvia	(Rubauskis *et al.*, 2013)
5	y	y	Crown area	m	4, 16, 22, 23, 29	Unknown	6	331-606	Portugal	(Santos *et al.*, 2006)

This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement No 311919

7	y	n	n	q	1	Differing ground cover crops	20-21	278	USA	(Sirrine *et al.*, 2008)
12	y	n	n	c	16, 17, 23	Central Leader/ Bush/ Y Trellis, Palmette	8	864	USA	(Whiting *et al.*, 2005)
16	y	n	Crown width	i	6, 8, 21, 23, 26	Differing Soils	3-5	Unknown	Poland	(Wociór, 2008)
385							**1-25**	**278-3759**		

Rootstock/ Cultivar Notation

1- Unknown, 2- Adara, 3- Brooks 60, 4- Cab 11E, 5- CAP 6P, 6- Colt, 7- Damil, 8- F12/1, 9- Gi148/8, 10- Gi154/7, 11- Gi195/20, 12- Gi209/1, 13- Gi497/8, 14- Gi523/02, 15- Gisela 4, 16- Gisela 5, 17- Gisela 6, 18- Gisela 7, 19- Gisela 8, 20- Gisela 12, 21- Mahaleb, 22- MaxMa 14, 23- Mazzard, 24- MxM.2, 25- P1, 26- P-HLA, 27- SL405, 28- SL64, 29- Tabel (Edabriz), 30- Weiroot 53, 31- Weiroot 154, 32-Weiroot 158.

a- 13-S27-17, b- Bigarreau Burlat, c- Bing, d- Celeste, e- Hedelfingen, f- Iputj/Krupnoplodnay, g- Kordia, h- Lapins, i- Łutówka, j- Montmorency, K- Regina, l- Start Hardy Giant, m- Summit, n-Sweetheart, o- Van, p- Vanspur, q- Unknown

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