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List of abbreviations

cgi	Cork Growth Index	NPV	Net Present Value
DBH	Diameter at Breast Height	NTFP	Non-Timber Forest Product (*Syn. NWFP*)
dg	Quadratic Mean DBH	NWFP	Non-Wood Forest Product
d_t	Target diameter	OMT	*Oxalis-Myrtillus* Type
DOW	Description of Works	PFQ	Professional Forester's Questionnaire
DSS	Decision Support System	q_1	reproduction cork - quality 1
EMM	Extramatrical Mycelia	q_2	virgin cork - quality 2
MPT	Multi-Purpose Tree	SEV	Soil Expectation Value
MT	*Myrtillus* Type	VT	*Vaccinium* Type

Executive summary

The production of non-wood forest products (NWFP) can be positively affected by silvicultural practice; a revision of current silvicultural practice can influence increased yields of both direct and indirect NWFP. This document aims to provide an overview of selected management systems employed for the production of NWFP in Europe. Furthermore, it makes suggestions towards how NWFP-yields can be increased by means of revised silvicultural guidelines. 13 selected NWFP distributed throughout Europe, have been described and suggestions for improved management systems have been made. In the preceding StarTree report concerning the silvicultural state of the art, Tomé and Faias (2014) suggested that forest production is largely focused on wood, while NWFP is often a minority product or coincidental good, produced in an informal manner. This is despite that the harvest of most NWFP within Europe has a long tradition and is commonly part of regional culture. But often those who are responsible for the silvicultural management of forest stands are removed from those benefiting from the occurrence of NWFP, thus, presenting one dimension of the proposed silvicultural dilemma.

For some NWFP (for example mushrooms, cork (*Quercus suber*), cowberries (*Vaccinium vitis-idaea*) and bilberries (*Vaccinium myrtillus*) empirical studies have been conducted where NWFP yields have been measured under varied silvicultural conditions. Production cost and market prices have been factored within models aiming to estimate the ideal silvicultural system for the optimised production of both, wood and NWFP. For other NWFP (for example wild cherry (*Prunus avium*), lime (*Tilia spp.*) and sweet chestnut (*Castanea sativa*) recommendations are made based on expert knowledge, and are thus, conjecturally based. The modification of one or more treatments within an existing prescription may allow for greater quantities or a more sustainable harvest of NWFP over time, while enabling the co-production of non-wood with wood. Some common silvicultural activities are suitable to promote the production of various NWFP such as the choice of provenance and genetics, choice of spacing/stand establishment, thinning regime and pruning activities. Those measures should therefore always be considered when establishing

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a NWFP-focused system. For instant it could be shown, that ceps (*Boletus edulis*) grow best in forest stands with a defined basal area; or that combined formative and high pruning can promote the production of cherry and high value timber concurrently.

The production of NWFP often involves a compromise (i.e. additional workload and/or a decrease in wood production). However, may also present additional benefits for the land holder, while risk diversification and an increase in biodiversity can be achieved. In conclusion, the compromise between wood and non-wood goals must be evaluated on an individual basis. The co-production of contrasting products is possible in many situations, but the land manager must appraise likely outcomes based on temporal and spatial constraints, site conditions (i.e. European location, climate and site productivity), market fluctuation, labour cost, individual species requirements and management capacities.

Many recommendations within this document are conceptual, and thus, must yet be tested empirically. Other recommendations are the result of modelling and/or have been tested in the field. The economical, ecological and cultural situation within the European counties differs greatly. Therefore, the direct transfer of experiences between study regions must be carefully considered. Further research should test the applicability of these recommendations within other situations.

It is common knowledge that forests produce much more than wood. Nevertheless, in the past the silvicultural focus in most European countries has shifted strongly towards a single wood production goal, whereby the stand production potential is often not maximised. This document makes one step towards the promotion and recovery of NWFP; a product group with a large potential for the sustainable production of a variety of goods and the support of rural development.

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1 Introduction

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1.1 Silvicultural definition and aims of management

The term non-wood forest products (NWFP) encompasses all tangible goods of biological origin with the exception of wood products that are derived from forests (Mantau et al. 2007), the term non-timber forest products (NTFP) is often used as a synonym although some definitions make further distinctions between wood and timber. Importantly forest services and benefits are excluded from the definition. NWFP can be subdivided into two groups dependent on derivative origin: a **direct NWFP** describes a product that is directly derived from a particular species i.e. cherries or walnuts, whereas an **indirect NWFP** describes species that coexist with trees when provided with certain site conditions that the overstory bestow. Such species representing sought NWFP are often not part of a predetermined forestry production goal but coincidentally co-exist due to particular site conditions, possibly induced or influenced by a pre-existing silvicultural regime.

The practice of silviculture has previously been defined as: "*...the various treatments that may be applied to forest stands to maintain and enhance their utility for any purpose...*" (Smith and Hawley 1986). Nyland (2002) expands this definition suggesting that "*These include benefits derived either directly or indirectly from the trees themselves, other plants, water, wildlife and minerals found in forested areas",* a definition that clearly encompasses the production of NWFP. Furthermore, Montero et al. (1998) suggests that the application of silviculture amounts to more than forest management, rather efficient planning of forest management practices to ensure continuous and sustainable production. A set of silvicultural procedures covering the tending, harvesting and re-establishment of a forest stand is referred to as a **silvicultural system**.

1.2 Current situation

A comprehensive literature review was carried out by Tomé and Faias (2014) assessing the silvicultural state of the art of common NWFP in Europe. Therefore, information concerning 14 different NWFP, commonly harvested within the European Union has been gathered. Supporting this forestry practitioners shared their NWFP experiences by responding to the StarTree 'professional forester's questionnaire'.

It was suggested that forest production is largely focused on wood and timber, while NWFP is often a minority product or coincidental good, produced in an informal manner.

Thinning was carried out by the majority of responders, exclusively for the production of timber. Hence, the effects of thinning on NWFP was not mentioned whereby further investigation is needed to ascertain how thinning affects NWFP production. As reported in the survey, the main reasons for pruning is high quality timber production (41 %) followed be forest fire protection (14 %). Only in 5 % of the cases pruning was carried out of for NWFP reasons. The vast majority on NWFP are harvested by manual methods and several NWFP require of skill for their correct identification and developmental stage (e.g. mushrooms, berries, cork). Dogs are largly employed in the hunt for truffles. Whereas, motor manual and fully mechanised methods are largely reserved for the production of timber products. The deliberate retention of NWFP producing tree species during the course of normal thinning operations is adopted by almost half of the respondents.

Grafting was suggested as a useful tool to the practitioner, as the technique obtains trees with better fruiting characteristics.

Only 26 out of 225 questioned practitioners reported that they had changed their silvicultural practice in the last ten years in order to promote NWFP production. The low innovation potential in this sector may in some cases result from a decrease in demand for a particular product, the low return on sales or the small scale and informal nature of the markets. Additionally it seems that many forest managers are lacking the specific knowledge how to tend multi-purpose trees in order to increase the yield of NWFPs and simultaneously achieve high quality timber.

Pine cone production is one of the exceptions where the management has been changed towards improved NWFP production. A clear intensification is the result of increased market prices for pine cone and decreased labour cost due to high unemployment rates. In cork oak plantations better soil management is employed and younger stands are irrigated in order to increase survival rates. In addition the cork harvesting regime has evolved, now favouring longer debarking intervals and reduced total height of debarking in order to increase the amount of usable cork (i.e. thickness) for bottle stoppers (Tomé and Faias 2014)

The harvest of most NWFPs in Europe has a long tradition and is part of regional culture. Under today's financial climate the production of many NWFP is, under present management systems, harvesting techniques and market prices, not profitable. Therefore, recreational collection is often dominant.

1.3 The silvicultural dilemma

Changes from the status quo

Silvicultural operations can be placed on a continuum of management intensity between extensive and intensive operations (Duncker et al. 2012). Natural systems with minimal intervention maybe more suited for the production of a range of products, intensively managed plantations often may be managed for one goal only (often wood), thus leaving little room for the culture of other products. The scope ranges from passive systems such as unmanaged forest or nature reserves over medium systems with a combined objective forestry such as agroforestry towards intensive managed systems for example short-rotation crops (Table 1.1).

Two questions arise when considering the production of NWFP in this way. *i)* How can the employment of silvicultural treatments increase the production of NWFP? *ii)* What can be changed within the silvicultural prescription to facilitate the increased production of NWFP?

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Table 1.1: Intensity of silvicultural systems illustrated with an example forest type

Intensity of management	Passive	Low	Medium	High	Intensive
Management Strategy	Unmanaged forest / Nature reserve	Close-to-nature forestry	Combined objective forestry	Intensive even-aged forestry	Short-rotation forestry
Land Use	(Natural forests)	(Semi-natural forests)	(Semi-natural forests, Agroforestry)	(Plantations)	(Short-rotation coppice)

The quantity of NWFP produced from an individual tree or stand can be influenced by the silvicultural treatments that are applied (Figure 1.1). Both positive (more NWFP) and negative (less NWFP) effects are possible, a balance must be sought encompassing site specific and economical goals and occasionally a trade-off must be made between a timber orientated goal and an additional NWFP.

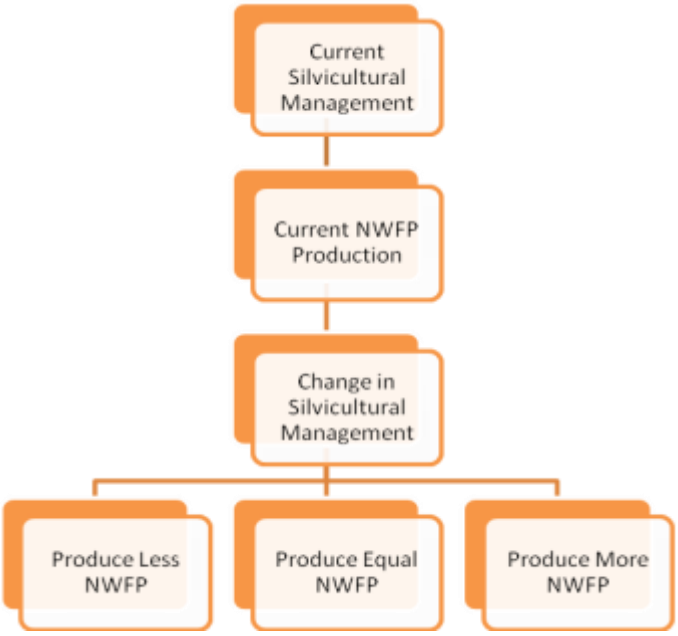

Figure 1.1: Schematic showing the impact of change in silvicultural prescription on the production of NWFP

Changes to the silvicultural regime can have differing effects to both direct (NWFP that is directly harvested from a tree, i.e. nuts, berries or bark) and indirect NWFP (symbiotic or parasitic association with tree, i.e. mushrooms or requirement the conditions that the tree's presence makes, i.e. understory plants).

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In some cases timber orientated silvicultural management can have a positive effect on NWFP products. For example, tree harvest and mushroom production can be complementary or even synergistic activities, since thinning affects moisture and sunlight conditions at the forest floor in a way that promotes mushroom growth. Current silvicultural practice for the production of selected NWFP species in Europe has been comprehensively reviewed (Tomé and Faias 2014), discussing both timber and NWFP production.

'Where there is a will. There is a way'

Overlying potential compromise for the production of increased NWFP is the simple issue that in many cases 'those that invest do not reap the benefits', i.e. changes in silvicultural regime must be followed by a clear benefit for those undertaking the forest management. It is common that an everyman's right to harvest applies to a particular product (e.g. mushrooms in Germany), however forest management and silviculture is strictly under the control of private and state forest managers often for a timber orientated goal. Convincing such parties that the silviculture of a stand could or should be changed for a NWFP benefit may be difficult. Small scale private forest owners may be more open to changes to the way they manage their trees. The need for a NWFP outlet (i.e. a marketable product or ingredient for an added value product that can be produced in-house thus providing economical returns unhindered by property rights and other legal frameworks) may ensure that changes to established silviculture could occur. Such changes are often worthwhile since the combination of timber and NWFP production allows for greater product diversity and income generation, an aspect especially important for small scale land owners and managers.

A number of changes to established silvicultural treatments are possible in order to promote NWFP production, and in some cases can provide a reduction in the trade-off between NWFP and timber production. The following examples can be considered:

Changes within establishment technique: During the establishment of stands which have a NWFP co-production goal, it is important to choose the right species (including native and non-native species) and provenances suitable to the local growth conditions, furthermore, land managers have the opportunity make a sympathetic choice towards species that will foster indirect NWFP in the area. Grafting can promote a faster growth earlier fruit production. By inoculating the planting stock the growth of mushrooms and truffles can be promoted given suitable overstory conditions. Finally planting operations themselves can be less intensive and disruptive to established stocks (Table 1.1) for example relying more on natural regeneration only with sporadic planting for defined production goals.

Changes in stand composition and stand structure: NWFP can be promoted by the employment of innovative planting design that facilitates a co-production system for example agroforestry systems, mixed species stands and close to nature forestry approaches all may increase the biodiversity and at the same time the product yield. Very often the promotion of valuable multi-purpose trees is done on the forest road side as this allows a continuous observation of the yield, support easy harvesting and might even sustain other ecosystem services (e.g. attractive landscape for eco-tourism). This will then have an impact of the forest edge structure and the way of how the structure is maintained over a longer time period. A shift in intensity

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(Table 1.1) from a more intensive single objective stand to a more flexible close(er) to nature approach may increase the opportunity for the production of NWFP.

Changes in tending regime by the selection criteria of future crop trees: Crop tree selection for wood production may favour unforked trees with straight stems, uniform crowns and with defect free stems. A holistic view would include a variety of trees in view of the desired crop, those trees that would be removed due to poor form or defects may provide the correct conditions for a NWFP benefit, and therefore should be retained shifting from a single production goal orientated perspective to a stand based productivity perspective.

Changes in pruning regime for increased tree product yield: Pruning will affect direct and indirect NWFP in contrasting ways: pruning allows for the cultivation of a branch free bole, a requirement of valuable timber where knots should be confined to a knotty core with a predefined diameter. Pruning treatments will reduce the available branch scaffold for the production of direct NWFP such as fruits and berries. Likewise, the pruning of tree boles will restrict growth and potentially force the tree to invest energy into new branch growth to increase photosynthetic potential rather than investing in reproductive material. The pruning of tree boles to create a clear branch-free stem will also push the production of fruit higher in the tree, thus making the harvest more difficult. A reduction of shade may be brought about by pruning treatments either positively or negatively affecting forest floor flora (also indirect NWFP), similarly pruned branches may litter the forest floor changing the specific conditions required for a certain species such as humidity, light and nutrient availability.

Changes thinning regime and procedures (intensity, stand age, frequency, uniformality): There are multiple thinning methodologies, dependent on the desired silvicultural goal, thinning from above or below, and the application of treatments at different times within a rotation. The direct removal of trees will reduce the production potential of direct NWFP, however, thinning provides the opportunity to the remaining trees to grow larger and potentially produce greater volumes of NWFP. Thinning will dramatically change the characteristics of the forest floor, greater amounts of sunlight will increase temperatures and decrease humidity either favouring or alienating existing understory plant species. With greater gaps between trees an increased level of competition maybe seem which can affect understory plant communities, shifting the focus from on plant community to another succession group.

Change in deadwood regime or scale of biomass/assortment removal: By retaining an element of deadwood in the stand, desirable habitat can be formed that would otherwise be non-existent, this can include both fallen and standing deadwood. Besides NWFP benefits, such deadwood can promote a multitude of fauna. Meanwhile, as mentioned above, the presence of deadwood may also change the micro-dynamics of the forest floor changing humidity and light levels and increasing nutrient availability.

Change in final cutting and regeneration regime: A shift from a large disturbance (i.e. clearcutting, where permitted) to a harvesting operation that is more sympathetic to the stand with undoubtedly have less effect on existing NWFP, with the exception of cases where high light levels are required by a NWFP species or

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within stands that are not suitable for the established forest system. A less intensive cultivation of trees will provide a less invasive harvesting methodology.

Regeneration can in part utilise more natural methods of tree establishment both natural regeneration and allowing regrowth from coppiced stools will return the stand to a more natural state. Planting can be utilised to ensure that timber goals are also provided for. Of course at this time future NWFP and timber co-production goals can be considered and planned for in the next rotation.

Changes in forest infrastructure: Many forests in Europe can be characterised by an extensive forest road network, this facilitates the harvest and extraction of timber. The use and expansion of the road network can present both positive and negative impacts on the presence and cultivation of NWFP which in part links with the issue of property rights. An extensive forest road network makes NWFP accessible to all, assisting both formal and informal collection.

1.4 Rationale: the need for silvicultural guidelines for the management of NWFP

It is intended that this project output serves as a basis for further research into modification to current silvicultural prescriptions for the increased production and increased profitability of NWFP in Europe. The modification of one or more treatments within an existing prescription may allow for greater quantities or a more sustainable harvest of NWFP over time, while enabling co-production of non-wood with wood. Practitioners, academics and policy makers alike have a vested interest in “on the ground management techniques” paving the way for new technology and application of existing knowledge. It is intended that the presented revised silvicultural guidelines should be applicable to as many case study regions as possible. Furthermore, the optimal output from the project would be guidelines that extend beyond defined regions, thus providing a resource for many forest managers on a European scale.

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2 Silvicultural prescription for increased production of NWFP

2.1 General methodology

Tasks within StarTree's working package 2 have been designed to create linkage and support one another. Figure 2.1 outlines the linkage and employed approach employed within the project. Output as defined in the project's DOW, namely, D2.2 (Sánchez-González et al. 2015) and D2.4 (Kurttila and Tahvanainen 2016) which provide support for the silvicultural decisions defined in this report.

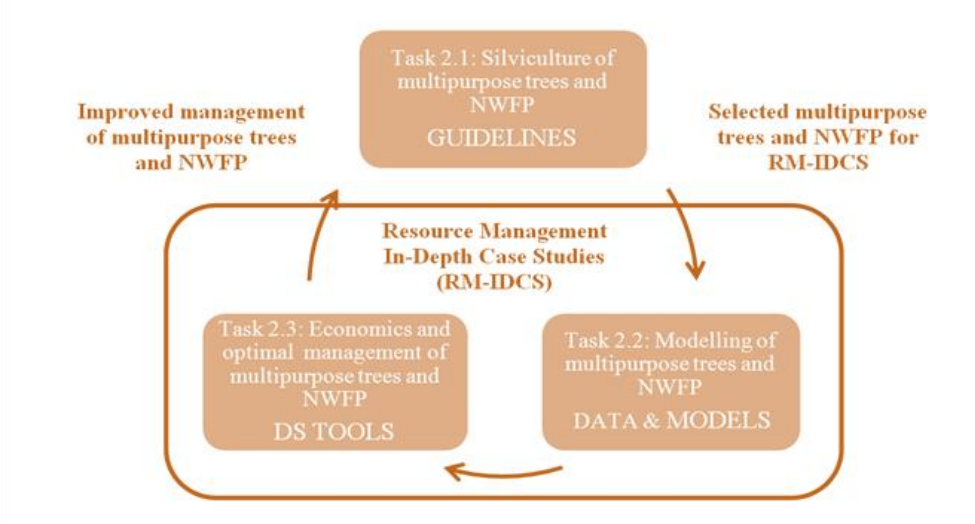

Figure 2.1: Work flow and linkages within WP2

StarTree has scrutinised a small number of species spread throughout Europe. Their significance assessed in specified case study regions (Wong and Prokofieva 2014) most specifically within the Professional Forester's Questionnaire (PFQ) where forestry professionals were asked to define the relevance of NWFP within their respective regions. However, it must be noted that this was not an exercise to assess the presence of a species within a particular case study region, nor the scale of any economic benefit that the culture and harvest of such a product brings, but rather a perceived product presence in each given region. Summarised output of the PFQ can be seen in Table 2.1.

Here the undefined group "Mushrooms" is suggested to feature in the majority of case study regions (however, given the variety of mushrooms available within Europe this is unsurprising) with direct tree products such as cherries, sweet chestnuts and walnuts featuring in responses from many central European countries. Meanwhile, core Mediterranean NWFP such as cork and pine nuts are reported by both Spain and Portugal.

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Table 2.1: Relevance of selected species to StarTree's 14 case study regions as defined by PFQ (Tomé and Faias 2014)

	Cork	Resin	Birch Sap	Cherry	Chestnut	Walnut	Sorbus	Lime	Bay leaves	Pine Nuts	Bilberry	Cowberry	Mushrooms	*B. edulis*
Alentejo	●	●								●			●	
Bursa					●			●	●				●	
Catalonia	●	●			●					●			●	
Eastern Scotland			●	●	●	●	●						●	●
Latvia			●								●		●	●
North Karelia			●								●	●	●	●
Osrednjeslovenska				●	●	●	●	●					●	●
Styria				●	●	●	●						●	●
Suceava				●	●	●	●						●	●
Sumadija and Western Serbia								●					●	●
Trentino Alto Adige					●								●	●
Valladolid	●	●								●			●	
Waldmärker			●	●	●	●	●				●		●	●
West Wales and The Valley			●	●	●	●	●	●					●	●
	Resin, bark & sap			Tree fruits berries & leaves							Understory plants		Mushrooms	

Comprehensive literature studies were conducted by project partners considering the current silvicultural state of the art of selected MTP and NWFP (Tomé and Faias 2014). In-depth case studies were conducted in order to define new or improve existing yield models (Sánchez-González et al. 2015) and DSS (Kurttila and Tahvanainen 2016), in conjunction with extensive long-term institutional knowledge.

It was evident from the output of the PFQ that there was a need for the clarification of species resource (i.e. the species from which the NWFP is derived). In many cases a generic term was used by respondents such as "mushrooms". Such terminology is too broad for a targeted silvicultural approach, clarification is needed. Nevertheless, such groups of species are commonplace, mushrooms can be considered and an important NWFP suggested to be relevant in all 14 case study regions (refer to Table 2.1), this is closely followed by the defined *B. edulis* which is suggested to be of relevance in all but the Spanish and Portuguese case study regions. The silvicultural guidelines for promoting bilberry (*Vaccinium myrtillus*) and cowberry (*Vaccinium vitis-idaea*) yields in Finland are based on the results obtained by using the stand-level simulation-optimization system described in more details of Miina et al. (2016). Also D2.4 (Kurttila and Tahvanainen 2016) provides a description of the stand-level decision support system (DSS) applied. The berry yield models included in the DSS were prepared, evaluated and/or calibrated during the StarTree project. The DSS was

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used to optimise the management of stands in the joint production of timber and berries. It is recommended that the revised silvicultural guidance in respect to NWFP yield offered herein is subjected to experimental quantification.

2.2 Resin, bark and sap

2.2.1 Cork (*Quercus suber* L.)

Authors: MPT, TP, IC, MSG, MT, JAP, JHNP, SPF

Cork is obtained from the cork oak tree (*Quercus suber* L.) as a renewable and sustainable product obtainable over the entire life of the tree. The distribution of the cork oak is confined to the centre and western part of the Mediterranean basin, including Portugal, Spain, France, Italy, Morocco, Algeria and Tunisia. Within Mediterranean ecosystems, cork oak plays a key ecological and socio-economic role. In cork oak forest ecosystems, cork production constitutes a basic source of income. However, these ecosystems are also efficiently exploited for other uses which include acorn production, cattle grazing, production of firewood, hunting or for biological and landscape diversity. In economic terms, the manufacture of natural cork stoppers to be used in the bottling of wines constitutes the most important use. It is the suitability of the raw cork material for this production that establishes its commercial value and is a key factor in determining the end use of the raw cork as well as the cost-effectiveness of processing (Cumbre et al. 2000; Pereira 2007).

In Spain and Portugal, cork oak stands are mainly managed as agroforestry systems, where all the products (namely cork, acorns, firewood and pasture) are obtained together, usually cork constituting the most important NWFP. However other options are possible and other landowners may aim at the co-production of cork and cattle, or recreation. The following guidelines are updates of the detailed state of the art in specific silviculture and models included already in the previous StarTree Deliverable D2.1. (Tomé and Faias 2014). The discussion about silvicultural guidelines that follows is presented separately for Spain and Portugal as there are some differences between the stands in both countries and also on the silvicultural guidelines rand tools used in the two countries.

Silviculture guidelines for cork oak stands in Spain

New plantations in Spain present cork production as the main objective. For this reason, the following silvicultural prescriptions refer to cork production. The main silvicultural treatments at each stand developmental phases are outlined in Table 2.2.

In this case the base for updating the management guidelines for cork oaks stands is the stand-level optimisation of these stands from the economic point of view. The main aim of this optimisation was to analyse how different factors can influence the optimal management of cork oak stands. Among the factors considered we found economic (discounting rates, cork prices) and stand-related factors (cork thickness). As a result new recommendations for the optimal management of these stands were delivered.

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Table 2.2: Main silvicultural treatments for cork production at each stand development stage

Phase	Silvicultural treatments
Regeneration	Plantation in densities that ranges from 625 trees/ha to 300 trees/ha
	Bushes clearing
Juvenile	Formative pruning
	Thinning
Cork production	Cork extraction
	Thinning depending on stand density and market conditions
	Regeneration fellings following shelterwood system

Optimising the management of cork oak stands for cork production:

One of the most important issues when dealing with the management of cork oak stands in Spain, is the establishment of the optimal management schedule of these stands with special attention towards the rotation period between debarking operations. This problem is usually solved by expert knowledge and few attempts have been made to assesss it in a quantitative manner based on projections from growth and yield simulations (Paulo 2011, Paulo and Tomé, submitted). Most of the time debarking operations are set in fixed cycles all over the rotation length of the stands. Debarking is performed at regular intervals, varying between 9 and 14 years depending on the region. However, there is evidence that shows that cork yield is not constant during the entire production cycle and varies between debarking operations, either due to tree aging (Natividade 1950) or to aging combined with the precipitation during the cork growth period (Paulo et al. 2016). The most productive period during the tree life occurs in the middle of the production cycle (Natividade 1950).

With the aim of reviewing the silvicultural guidelines for high density cork oak stands in Spain and analyse the optimal debarking schedule, an optimisation-simulation system has been developed to explore the optimal debarking periods in different stands.

The growth and yield models employed to simulate the development of the analysed stands were those developed by Sánchez-González et al. (2005; 2007a; 2007b; 2008). The *Hooke and Jeeves* direct search algorithm (1961) was utilised within this investigation, as frequently employed in studies similar to this one. The objective function employed was the soil expectation value (SEV). A more detailed description of the system is given in Pasalodos-Tato et al. (2016).

Different stands were analysed in order to determine the trends that would define the optimal silvicultural guidelines. Three different stands of the same age, similar site index and stand density but differing in terms of cork thickness (20, 30 and 40 mm at 9 years) were tested (Table 2.3). Different cork prices (0.84/0.17, 1.2/0.24, 1.56/0.31 € kg^{-1} of reproduction cork -quality 1 (q_1) - and virgin cork –quality 2 (q_2)- respectively) and discount rates (1 %, 3 %, 5 %) were also applied in order to analyse the effect of the economic variables.

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Table 2.3: Summary of the characteristics of the analysed stands.

	Stand 1	Stand 2	Stand 3
Age (years)	20	20	20
SI	14	14	14
N (trees/ha)	625	608	618
d_g (cm)	16.65	15.51	16.93
Cork thickness (9 years) (mm)	20.47	29.52	38.67

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

Three different cork thicknesses were tested in order to analyse cork quality in the optimal management of cork oak stands. Cork thickness is used as proxy for cork quality. The results of these analysis shows that stands with longer rotations lengths and with delayed thinnings present greater cork thicknesses (Table 2.4 and Figure 2.2). In relation to debarking operations, the number of times debarking can be carried out increases for the stands that present higher cork thickness (Table 2.4 and Figure 2.3). At the same time these stands tend to present shorter periods between debarking procedures (Figure 2.2).

Table 2.4: Effect of different cork thickness on the optimal schedule of stands 1 and 2 when discount rate is 3% and cork prices of quality 1 and 2 are 1.20 and 0.24, respectively.

	Cork thickness		
	20 mm	**30 mm**	**40 mm**
SEV (€/ha)	-19	-21	360
SEV without cork (€/ha)	-599	-648	-1641
Effect of cork revenue on *SEV* (€/ha)	580	627	2001
Cork weight q_1 (t/ha)	0.31	1.21	17.12
Cork weight q_2 (t/ha)	7.14	11.08	29.11
Mean annual cork yield (t/ha/yr)	0.11	0.13	0.39
Number of debarkings	4	5	10
Rotation length	66	94	117

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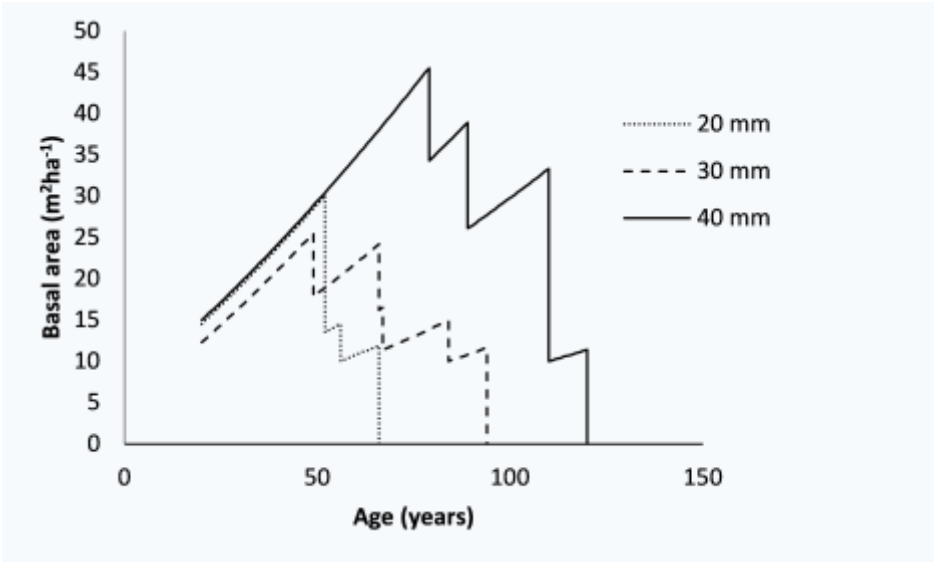

Figure 2.2: Optimal management schedules of the development cycle for stands with cork thickness 20, 30 and 40 mm respectively when discounting rate is 3% and cork prices of q1 and q2 are 1.2 and 0.24 €/kg, respectively.

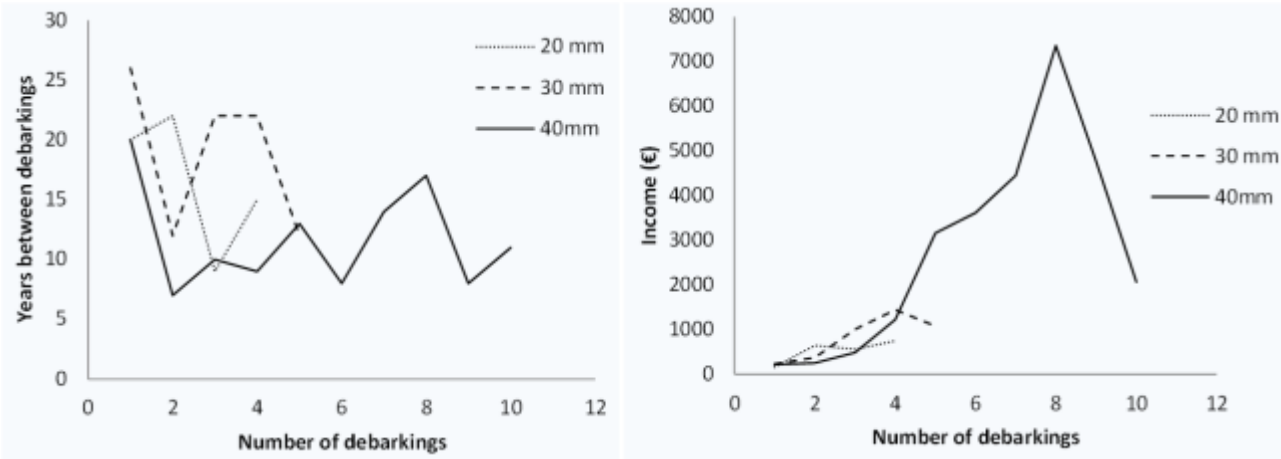

Figure 2.3: Optimal management schedule of the cork production cycle. The figure in the left shows the optimal number of debarkings and the number of years between them and the figure on the right shows the incomes obtained on each optimal schedule.

Effect of discounting rates on the optimal stand management:

In the case of discount rate, its influence is similar to the cork thickness. An increase in the discount rate leads to longer rotation lengths and a delay in thinning treatments (Figure 2.4). Also the number of debarkings increases with a decrease in discount rate, while the period between debarking decreases (Figure 2.5). It is worth noting that the effect of discount rate is highly relevant in terms of profitability. A regular discount

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rate of 3 % provides incomes of 360 €/ha while economic scenarios with discount rates of 5 % make the management of cork oak stands a non-profitable activity. On the contrary, with low discount rates such as 1 %, the profitability increases considerably, up to 26,559 €/ha giving an idea of the high influence of this factor (Table 2.5). It is also very interesting to note that under these schedules, the amount of cork of grade q_1 is higher than the amount of q_2.

Table 2.5: Effect of different discount rate on the optimal schedule of stands when cork thickness is 40 mm and cork prices of quality 1 and 2 are 1.20 and 0.24, respectively.

	Discount rate		
	1 %	**3 %**	**5 %**
SEV (€/ha)	26,559	360	-533
SEV without cork (€/ha)	-2,127	-1,641	-785
Effect of cork revenue on *SEV* (€/ha)	28,686	2,001	251
Cork weight q_1 (t/ha)	50.38	17.12	0.40
Cork weight q_2 (t/ha)	47.55	29.11	6.41
Mean annual cork yield (t/ha/yr)	0.63	0.39	0.11
Number of debarkings	11	10	4
Rotation length	156	117	64

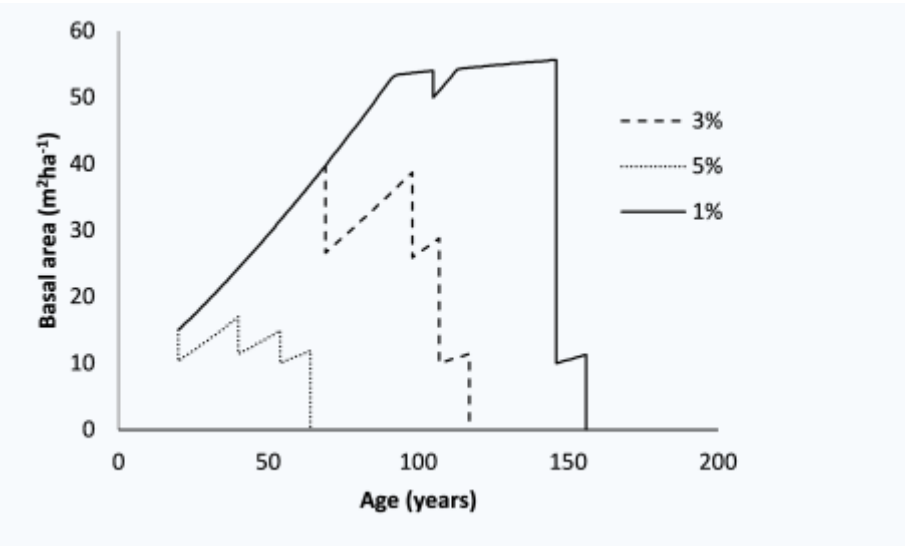

Figure 2.4: Optimal management schedules of the development cycle for stand 3 (cork thickness 40 mm) for different discount rates (1, 3 and 5 %) when cork prices of q1 and q2 are 1.2 and 0.24 €/kg, respectively.

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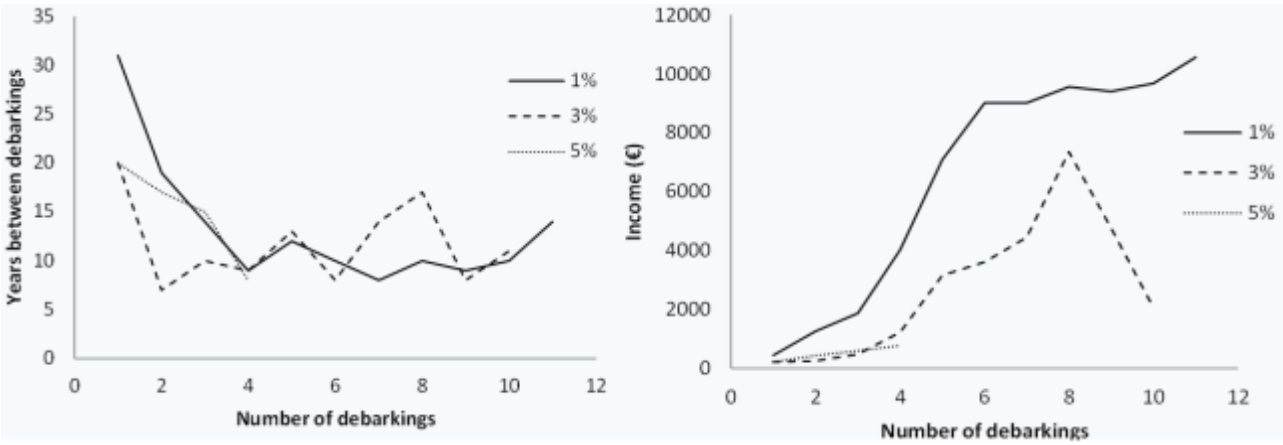

Figure 2.5: Optimal management schedule of the cork production cycle. The figure in the left shows the optimal number of debarkings and the number of years between them and the figure on the right shows the incomes obtained on each optimal schedule.

Effect of cork price on the optimal stand management:

The effect of fluctuations in cork market prices is not as drastic as in the former cases analysed. When cork prices of q_1 and q_2 decrease by 30 %, rotation length decreased and thinnings are recommended to be carried out earlier (Table 2.6). At the same time the number of debarkings decreased as well as the number of years between debarking operations (Figure 2.6 and Figure 2.7).

Table 2.6: Effect of different cork prices on the optimal schedule of cork oak stands when cork thickness is 40 mm and discount rate 3 %.

	Cork prices (€ kg^{-1})		
	0.84/0.17	**1.2/0.24**	**1.56/0.31**
SEV (€/ha)	285	360	1304
SEV without cork (€/ha)	-877	-1641	-1437
Effect of cork revenue on *SEV* (€/ha)	1162	2001	2741
Cork weight q_1 (t/ha)	9.62	17.12	20.92
Cork weight q_2 (t/ha)	20.40	29.11	33.22
Mean annual cork yield (t/ha/yr)	0.29	0.39	0.43
Number of debarkings	8	10	9
Rotation length	103	117	127

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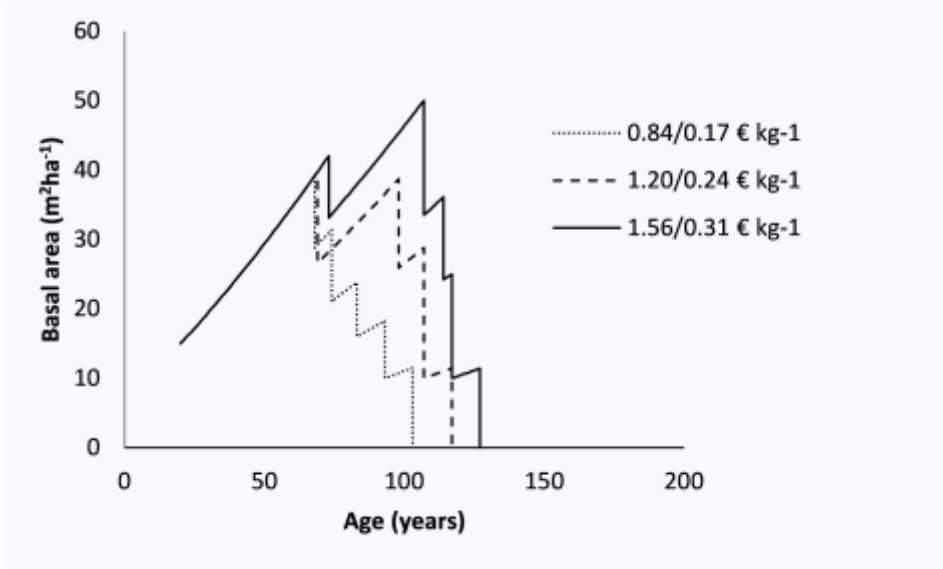

Figure 2.6: Optimal management schedules of the development cycle for stand 3 (cork thickness 40 mm) for different cork prices of q1 and q2 when discount rate is 3 %.

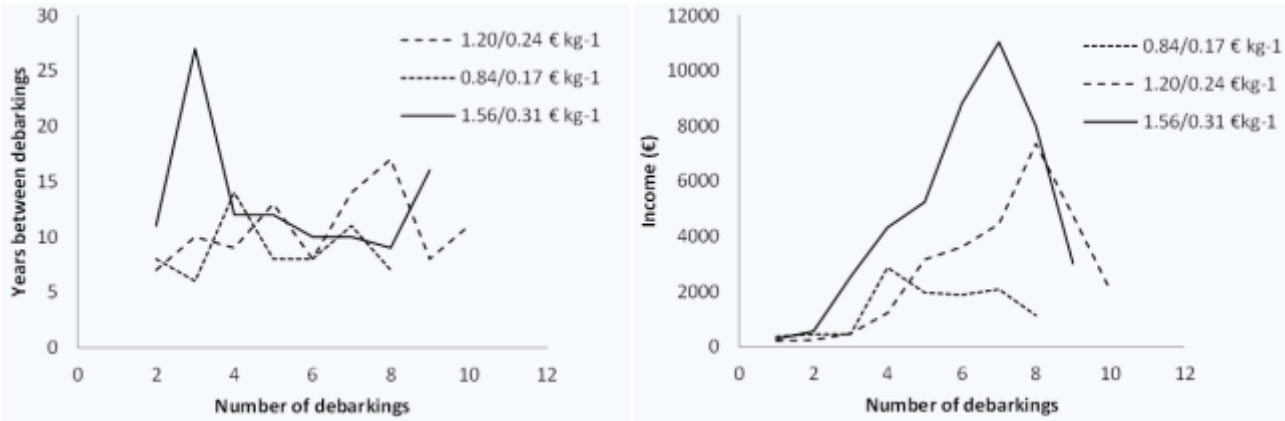

Figure 2.7: Optimal management schedule of the production cycle. The figure in the left shows the optimal number of debarkings and the number of years between them and the figure on the right shows the incomes obtained on each optimal schedule.

In short, when managing cork oak stands with an economic objective, the establishment of the number of debarking operations carried out and periods between them is not a straightforward task. It depends on many factors that need to be taken into account in order to obtain the optimal profitability of these stands. The management schedules provided by optimisation exercises are guidelines that would help the forest manager in the decision making process. These guidelines provide information regarding in which direction the management should be oriented depending on market conditions and/or cork qualities.

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Silviculture guidelines for cork oak stands in Portugal

Table 2.7 lists the silvicultural operations that take place in a new plantation. The same silvicultural operations are applied in existing even-aged stands. Uneven-aged stands must be managed using the same silvicultural operations as stands in the mature stage but with a different type of thinning (light thinning is applied in even-aged stands while trees of different sizes are thinned in uneven-aged stands if the objective is to maintain the uneven-aged structure). Note that in practice thinnings just takes place in young stands in order to avoid inter-tree competition. Adult stands are usually sparse (last national forest inventory (NFI) indicates crown an average percent cover of 26.5 %, with just 0.5 % of the stands above 58 % (Paulo et al. 2016) and the occurence of mortality is high which makes the thinning operations usually not used in Portuguese cork oak stands.

Table 2.7: Main silvicultural treatments for cork production at each stand development stage

Phase	Silvicultural treatments	Decisions
Regeneration	Site selection	Where to plant / use another species
	Tree plantation	Number of trees/ha
	Control of spontaneous vegetation	Periodicity and method
	Formation pruning	When to take place
Juvenile	Formation pruning	When to take place
	First cork extraction	When to take place and debarking intensity
	Control of spontaneous vegetation	Periodicity and method
	Thinning	When? How intense?
Mature	Periodic cork extraction	When to take place and debarking intensity
	Sanitary thinning	If needed
	Control of spontaneous vegetation	Periodicity and method
	Thinning	When? Type? How intense?
Regeneration of the following stand	Selection of the silvicultural system	Shelterwood systems
	Periodic cork extraction	When to take place and debarking intensity
	Sanitary thinning	If needed
	Control of spontaneous vegetation	Periodicity and method
	Thinning	When? Type? How intense?

Forest management of cork oak stands in Portugal is quite dynamic and an adaptive approach must be used, namely in what concerns the decision for cork extraction. In practice the decision of the forest manager concerning the debarking is mainly influenced by two aspects: structure of cork prices and weather

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conditions during the cork growth period. An increase in the prices of thin corks may led to the promotion of cork extraction, while an increase in the price of thicker corks will encorage landowners to postpone cork debarking for one or two years, in the expectation of increasing the percentage of thick cork. For instance, in the years between 2000 and 2010, cork price structure experienced considerable fluctuations, generally showing a significant decrease in the value for most of the cork assortments. This was more evident in cork classified as poor and medium quality classes (APCOR 2014). In recent years the prices have been more stable, but it is noticed that an increasing number of forest managers have been extending their cork rotation debarking in an attempt to increase the value of cork, and therefore, increase the resulting income (APFC, ACHAR ANSUB, personal communication). Climate may also influence cork thickness, with drought decreasing the cork growth and therefore increasing the period between cork extractions. These unique features of the cork market and influence of climate on cork growth reinforce the need of accomplishing cork sampling previously to the cork extraction, between 7-8 years after the previous debarking in order to increase knowledge on the cork product characteristics. This practice allows the assessment of present cork characteristics and prediction of the expected price for different cork rotation periods, and provides input data for decision support tools that allow the simulation of future stand development and associated revenues (cork, cattle, recreation, game, etc).

Taking this need for an adapted forest management, the proposed silvicultural guidelines for new plantations in Portugal are based on the use of user-friendly support tools (developed/improved under StarTree, most of them already available at http://www.isa.ulisboa.pt/cef/forchange/fctools/pt/inicio, or expected to be so until the end of the project: 2016) to help the landowner/forest manager in the most important decisions listed on Table 2.7:

1. Support tool to study the adequacy of a pre-selected site (WebCorkS)
2. Support tool for the prediction of mortality rates in the regeneration stage as a support to the definition of the number of trees at planting (WebCorkm)
3. Use the SUBER model at planting to make long-term simulations of the stand under alternative management options so that the landowner/forest manager may decide on the silvicultural system and management details he/she is going to adopt and have an idea of the expected revenue
4. To carry out a cork sampling around 7-8 years after the previous debarking and use a tool to predict cork price for different cork rotations (WebCorky)
5. Repeat steps 3 and 4 after each debarking in order to adjust/modify the silvicultural system and/or the management details previously adopted

The tools refered in 1 and 2 and the SUBER model were already described in D2.2 (Sanchez-Gonzalez et al. 2015).

The use of these tools prior to the establishment of a new cork oak plantation, will contribute to:

- The avoidance the establishment of continuous plantation areas that include parcels of land characterised by soil conditions where cork oak tree mortality is expected to be significant and where growth and production will be compromised. These areas may be instead planted using adequate

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tree species and consequently favouring stand and landscape biodiversity as well as other ecosystem services.

- Estimation of stand mortality rates for the regeneration stage using the model proposed by Castel-Branco et al. (2015): This will contribute to the definition of adequate tree densities within a plantation, in relation to the expected final tree density that may vary according to management purposes, i.e. exclusive cork production or agroforest/silvopastoral management. It is also expected this will contribute to a reduction of costs associated with beating up and thinning silvicultural operations that are currently carried out in the years that the first cork extraction is anticipated. The SUBER model can be used to support the user in decisions such as provided in D2.4 (Kurttila and Tahvanainen 2016).
- The best time to start the debarking: it is usually recommended to initiate debarking procedures when the quadratic mean diameter at breast height (dg) is equal to 22.3 cm which means that all trees greater than the average tree can be debarked. The SUBER model allows the user to user to test different ages around the age when dg = 22.3 cm and find the one that, for a pre-fixed forest management approach and a certain planning horizon, maximises net present value (NPV).
- If there is an advantage of having an uneven-aged structure for cork debarking: In this case the stand is debarked at intervals shorter than the normal cork rotation period and the cork rotation is fixed at tree level. One common option among the landowners is to make the first debarking when the dg is close to 22.3 cm and come back for the debarking of the remaining trees some 3-6 years later, in which case the stands will have corks with two ages.
- To find the cork debarking rotation that maximizes NPV for a certain stand and planning horizon considering the same cork rotation age for all the debarkings. The combination of different cork debarking rotations is not considered, since the model predictions for cork growth spanning an individuals tree life is not good enough to justify such optimisation and also because, as previously explained, the landowner/forest manager's decision depends on many factors which are made close to the debarking year.
- To analyse the impact of different debarking intensities on cork production, assuming that debarking intensity has no impact on tree and cork growth. Debarking intensity is usually evaluated by the value of the debarking coefficient: ratio of debarking height and perimeter at breast height over cork. For the application of the Portuguese legislation (see below) debarking height is measured along the stem plus the average length of the debarked branches, but it can also consider the accumulated length of debarked branches or be measured in the vertical.
- Comparing alternative silvicultural systems and or management details that relate to tree and cork growth, such as cork rotation debarking, thinning and re-stocking. In the case of thinning the current tree diameter at breast height (DBH) growth model does not consider inter-tree competition but there is on-going research to develope a new model that, if needed, will include this factor. Most of the existing stands in Portugal are sparse and on-going research (Faias et al. In prep.) Shows that most of them do not have signs of competition. Even though, we will check the possibility to include

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competition indices in the new DBH growth model. At present users are advised not to test alternatives with high stand densities because of this limitation of the SUBER model.

- Study different transition methods for the new stands: clearcut system (not possible to use in practice due to legislation, but possible to simulate) uniform shelterwood systems and irregular shelterwood systems (other shelterwood systems, such as group shelterwood systems, can be considered, but at a landscape level, not at stand level).

The SUBER model does not yet include the effect of some silvicultural operations on tree and cork growth and yield, but some reserach has been undertaken within the StarTree project (sometimes in collaboration with other projects) to improve the knowledge about these relationships. The most important results are shown below:

- **Impact of spontaneous vegetation control on tree and cork growth:** it is a common practice to carry out this operation in order to reduce tree-shrub competition as well as fire risk. However, the possible impact of this operation towards tree and cork growth has to date not been researched. Current research (Faias et al. In prep.). Comparing DBH and annual cork growth of trees growing with different understory vegetation (no shrub control, shrub control and legume cultivation, shrub control and fertilizer application) shows that diferent responses are found not only between trees but also between blocks/stands. A significant response of annual cork growth is found in one or two years after shrub control (whether followed or not by legume cultivation), except in the years were climate conditions did not favour legume establishment, namely due to low precipitation. The analysis made at stand level for cork thickness distribution, resulting from the debarking operation after 9 years of cork growth demonstrated the existence of significant differences between plots management with different understory vegetation alterantives. Even so, it is important to notice that when expressed in terms of cork price, no significant differences result in terms of the resulting revenues. These results are in line with those presented by Caldeira et al. (2015) who associates the absence of spontaneous vegetation control management operations coupled with severe drought events, with tree death. The present version of the SUBER model assumes that the periodicity of the control of spontaneous vegetation will be enough so that serious shrub encroachment will not occur.
- **Impact of different debarking coefficients on tree and cork growth:** it is assumed by forest managers and the scientific community that the level of tree stress induced to cork oak trees by the periodic harvest of cork increases proportionally to debarking intensity. National legislation defines the maximum values of debarking coefficients for different stages of tree development: 2.0, 2.5, 3.0 for the first, second and following cork debarking operations respectively. Research on this topic focused two approaches:
    1. Experimental trials installed in stands debarked for the first time (Paulo and Tomé, under review for re-submission)
    2. Modelling approaches using large data sets collected in adult stands along the distribution area of the species in Portugal (Paulo et al. 2016).

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All research is being conducted at tree level, and assuming that tree response is highly variable between trees, between stands, and according to edaphoclimatic conditions. Results of the two experimental trials, located in distinct regions characterised by a low and a high productivity class, showed a slight but significant effect of debarking intensity. At the first cork extraction the cork thickness on the site charactersed by a low productivity class, revealing that higher debarking coefficients resulted in thinner cork thickness distribution values but the effect of debarking intensity at the first cork extraction was not significant in the high productivity site (Figure 2.8). It is therefore suggested that debarking coefficients should be defined not only according to legal constrains, but should be adapted considering site edaphoclimatic characteristics (Paulo and Tomé, under review for re-submission).

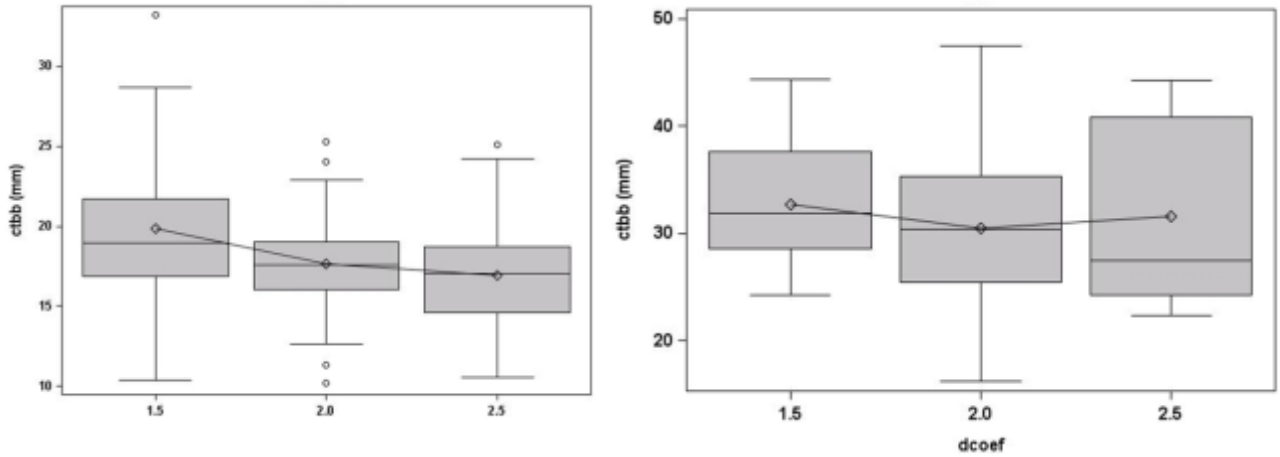

Figure 2.8: Differences in cork thickness before boiling (ctbb in mm) obtained from trees where different debarking coefficients were applied: 1.5, 2.0 (maximum value allowed by national legislation) and 2.5. The trial is located in a low (left) and a high (right) productivity site. (Source: Paulo and Tomé, under revision for re-submission).

This study shows that the assumption of no impact of debarking intensity on cork growth used in the SUBER model need to be corrected for low productivity sites. Regarding adult trees, the results presented in Paulo et al. (2016) are not so clear and evidence the importance of long term monitoring plots and trials for the assessment of the impact of debarking intensity in tree and cork growth and production. The authors formulated the hypothesis that high debarking intensity would have a negative impact on cork growth but found the opposite result (although not very clear, Figure 2.9). A detailed analysis of the data suggests that these results are influenced by managers, i.e. trees with thicker cork may have been debarked to higher heights, while others that produce thinner cork are subjected to lesser debarking intensity (as it is often found that cork thickness decreases along the stem). Suggested silvicultural guidelines again recommend that debarking coefficients should be defined not only according to legal constrains, and instead adapted to site edaphoclimatic and tree conditions. For instance, it should be important to adapt debarking coefficients according to tree age

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(using tree diameter as a proxy for age), vigour, presence of wounds and/or to the number of debarked branches.

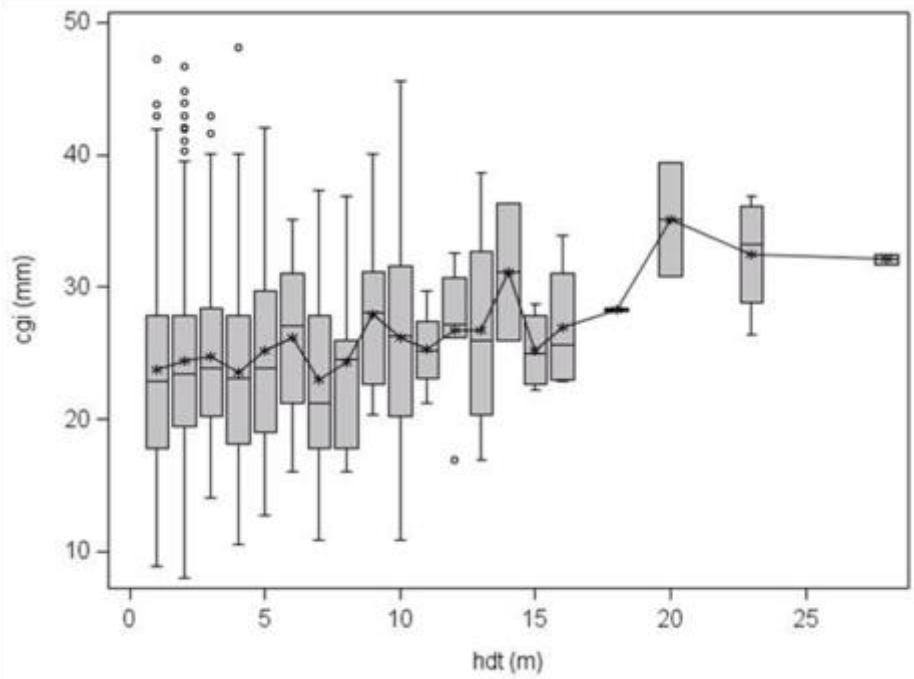

Figure 2.9: Relationship between cork growth index (cgi – thickness of eight complete cork growth rings) and total debarking height (hdtot) tree variables. Variable hdtot is grouped in 1m range classes. 'o' – outlier value; '*' – mean value; horizontal line on each box-plot – median value. (Source: Paulo et al. 2016).

- **Evolution of cork growth along successive rotations:** Paulo et al. (2016) studied and modelled the relationship between cork growth index (accumulated thickness of the first 8 complete years of cork growth) of two consecutive cork extractions for the same tree. When analysing the evolution of cork growth in two consecutive cork growth periods, a linear relation between the two cork growth index (cgi) values was evident (Figure 2.10), underling the individual tree effect on cork growth. The amount of precipitation occurring along the cork growth period and the number of main branches debarked also influences the final value of the cgi. As expected larger amounts of precipitation during the cork growth period have a positive effect in the resulting cgi values, and higher number of main branches debarked have a negative effect. Although the variability of debarking intensity was large among the data set, no relation between this management option and cgi was observed by any of the considered models. When analysing which variables are related to cgi, increasing tree size (assessed by DBH under cork and total height) is associated to higher values of cgi. For the presented data set, stand density does not limit the values of cgi. These results should not be taken linearly,

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since higher values of number of trees/hectare and precipitation values characterising the stands may impact and lead to different results as suggested by previous research. The present conclusions are restricted to trees under 114.6 cm DBH under cork, stands under 203 tree/ha and under 1000 mm of average annual precipitation. This study points out for the need of additional research based on long term permanent plot records and cork samplings to clarify the long term impact of debarking intensity, tree competition, as well as the effect of other possible explanatory variables not included in the present research.

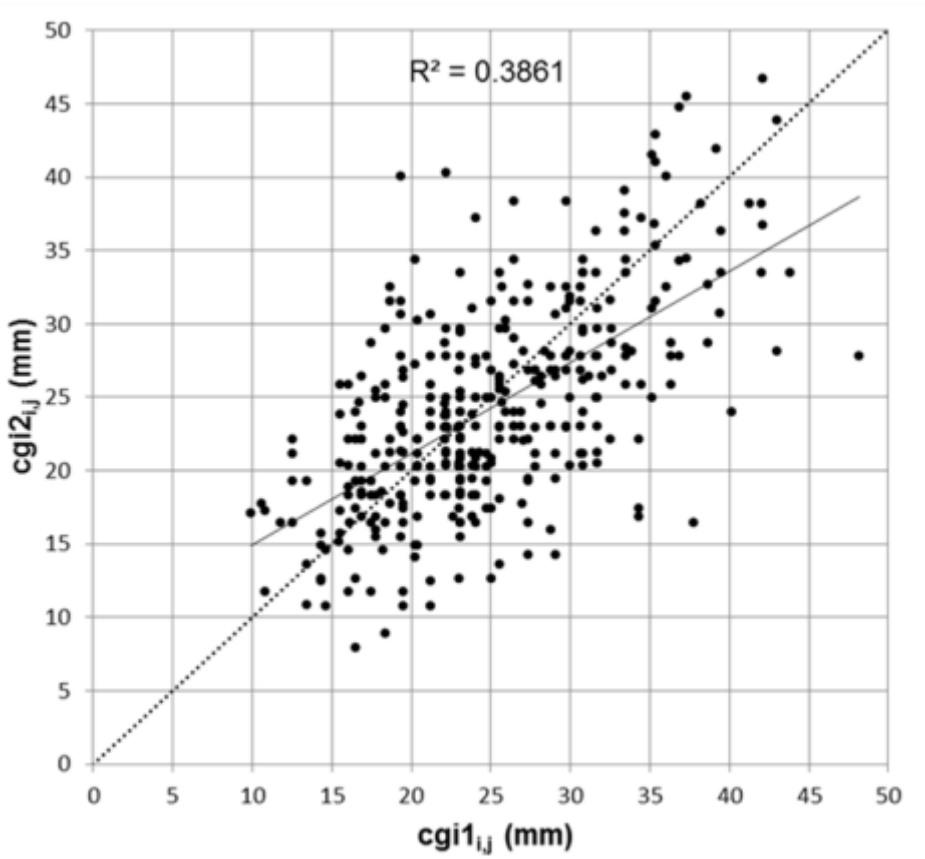

Figure 2.10: Plot of tree level cork growth index from two consecutive cork extractions, respectively cgi1ij and cgi2ij (n=370 trees). Source: Paulo et al. (2016)

There are some silvicultural operations that are not taken into account by the SUBER model, and that are identified as research gaps of current state of the art for the management of montado systems:

- Impact of formation pruning in tree and cork growth and yield: formative pruning is an usual practice undertaken in order to obtain trees with a better shaped and longer stem and, to our knowledge, its effect on tree or cork growth has never been studied.

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- Impact of pruning along the life: when the grazing by pigs was one of the most important revenues in cork and holm oak (*Q. Ilex*) stands, pruning was a very common practice undertaken with the purpose to increase fruit production. Studies performed in Spain show that pruning does not have an impact on cork yield and growth (Canellas and Montero 2002) but that pruning may have some impact on acorn yield, depending on the production of the year being above or below the average (Canellas et al 2007).
- Impact of the application of fertilizers: it is an operation that is being considered by some landowners, however, there are no research results that may support its inclusion in the SUBER model.

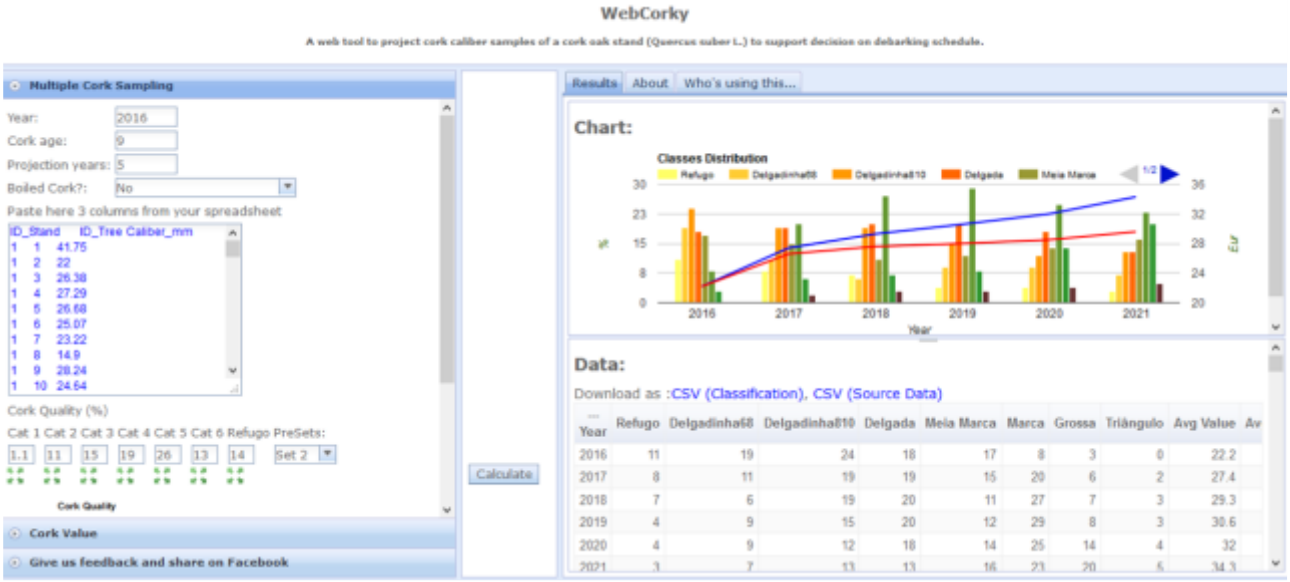

Figure 2.11: WebCorky tool. The presented output is based on the Almeida et al. (2010) cork growth model.

The tool to support the decision about cork rotation period (WebCorky; Figure 2.11) is an important support for the landowner/forest manager to take decisions on the opportunity of debarking. As previously mentioned, annual cork growth and cork caliper are known to be related to climate, namely precipitation and temperature (Caritat et al. 1996, 2000; Tomé and Faias 2014). As cork price is partially defined by cork thickness (sum of cork annual growth between two debarking operations), climate conditions should be taken into consideration when defining the most suitable cork debarking rotation period for a given tree or stand. Even if the 9 years interval is still the most frequently applied between two consecutive debarkings (here referred to as cork debarking rotation), a tendency towards increasing this period to ten or more years has been observed in Portugal. This is many times justified due to extreme dry weather conditions that occured along the cork growth period or during the ninth year of growth within any given rotation, and/or

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due to the low price of cork (APFC, personal communication; Centro de Estudos Florestais - CEF/ISA - database). Recent modelling tools now allow this expert judgement to be supported by scientific knowledge. Therefore, an important silvicultural guideline is the importance of including as a recurrent management operation the accomplishing of forest and cork inventories, at tree level, using appropriate sampling strategies (Almeida and Tomé 2010), especially seventh or eighth after the last cork debarking operation. The data collected in this operation (cork calliper and cork quality at tree level collected in forest inventory plots) should then be used to simulate cork thickness evolution for cork debarking rotations over 9 years (e.g. 10 to 12 years according to stand growth conditions and management objectives), taking into account climate and cork price scenarios. These simulations can be accomplished with the SUBER model but also using the WebCorky tool.

The outputs of these tools include the evolution, for increasing cork debarking rotations, of the percentage of cork to be extracted that reaches the minimum value associated to a given cork price, and consequently the final income evaluated as equivalent annual annuity of net present value (Figure 2.11). The present version of the tool will be updated in order to include a model that expresses climate effect on cork growth (Tomé and Faias In prep.).

2.2.2 Maritime pine resin (*Pinus pinaster* Ait.)

Authors*:* SM

The most relevant pine species in Europe tapped for resin historically has been maritime pine, *Pinus pinaster* Ait., followed by *P. nigra* in central-eastern Europe (c.f. chapter 2.2.3) or *P. halepensis* and *P. brutia* in Greece and Turkey (Açar et al. 2013). Maritime pine produces resin of high quality for a wide range of industrial products. Resin was considered to be the most versatile material in the pre-industrial world (Langenheim 2003) and is still the raw material for a wide range of industrial products and one of the most important NWFP. Since the 19th century, resin tapping had been a traditional forest use with great importance for rural economy in Europe and Northern America (Hernandez 2006; Calama et al. 2010; Hall et al. 2013).

In western Mediterranean countries, maritime pine is one of the main forest trees and comprises the most extensive conifer woodlands in Spain, Portugal and southern France. Most pinewoods are pure, though mixed stands are also common, with *Pinus sylvestris, P. nigra, P. pinea* or *P. halepensis*, as well as with *Quercus ilex, Q. suber, Q. faginea* or *Q. pyrenaica*, or even *Eucalyptus globulus* or *Castanea sativa* (Casado and Herrera 1996; Louro et al. 2000; Correia and Oliveira 2003; Serrada et al. 2008). Management practices for maritime pine vary widely, depending on priorities for different products such as wood, resin, or hunting. Maritime pine forests are often associated with erosion-prone coastal or inland arenosols. Priority uses and functions of Mediterranean pine forests are, hence, mainly soil protection, water regulation and conservation as natural habitat. Some *P. pinaster* forests, however, present a compatible yield of goods such as timber, fuel biomass and resin. Presence of maritime pinewoods defines several European Natural Habitat types, such as the 'Wooded dunes with *Pinus pinea* and/or *Pinus pinaster'* (Nature2000 code 2270), 'Wooded dunes of the Atlantic, Continental and Boreal region' (2180) or 'Mediterranean pine forests with endemic

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Mesogean pines' (9540), that require special protection being included in the Annex I of the "Habitat" Directive (Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora, EC 2013). In large part, natural pine forests have remained only at sites without aptitude for agriculture or other uses (poor or no soils, excessive slopes, etc.) and thanks to their inclusion in networks of protected areas under legally binding norms, such as the Natura 2000 network or the Spanish "Catalogues of Forests of Public Interest". Therefore, most natural and semi-natural Mediterranean maritime pine forests are managed obligatory under a multipurpose approach and with consideration of primordial protection and conservation issues implied (soil, water, wildlife, landscape, fire prevention, etc.). Even many even-aged pine plantations derived from mid-20th century afforestation are today often aimed to be transformed by selective cuttings and enrichment plantations, or to evolve spontaneously, into mixed and structurally more complex forest types, given their preferred protective purposes.

Figure 2.12: Aerial view of pure maritime pine age-class forest, shaped by management for resin tapping as main forest productive activity since 19th century (Coca, Tierra de Pinares [Pinewood County], Spain).

For obtaining natural rosin (processed and solidified resin), resin flow from pine stems can be induced after local bark stripping, mechanically by cutting grooves in the underlying wood or chemically by applying stimulants, often acid. The resin is collected in pots fixed beneath on the stem. In temperate zones, tapping activity is clearly seasonal, for example in the Mediterranean region it starts in March-June and finishes in October-November, with resin flow peaking during the summer, when high temperature increases resin fluidity (Rodriguez-García et al. 2015). Induced mean annual yield is about 2-4 kg resin per tree (Alía and Martín 2003). For allowing a profitable exploitation by a resin tapper, even-aged pure maritime pine stands are required for optimising workflow, because each tree must be revisited every 1-2 weeks during the season for renewing the wound, collecting the full pots, etc., allowing for a batch of up to 5,000 pine trees to be attended by the same worker. Pines need to reach a minimum stem diameter before starting resin extraction

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(e.g. 30 cm DBH), hence stands generally come into production at half the rotation age. Since the late 19th century, these requirements for even-aged stands had implied a huge effort in forest planning and management for achieving those regular, pure stands. They emulate the classic age-class forest management system based on the Prussian "Normalwald" paradigm, shaping several thousand square kilometres of continuous chessboard-like pine forests in Southwestern Europe, nowadays regionally valued as emblematic forest landscapes where villages are mere clearings embedded in the forest matrix (Figure 2.12). On the other hand, the ability of the species to grow in very poor, eroded, bare soils, and under prolonged drought, has been one of the reasons for its wide use in afforestation programs throughout countries with Mediterranean climate, for soil protection or ecosystem restoration, and, if compatible, for wood and/or resin production (Alía et al. 1996; Serrada et al. 2008; Mutke et al. 2013).

Until 1980, resin obtained from pines had been a regionally very important NWFP as a raw material for the chemical industry. In Spain, the maximum resin production had reached 55,000 tonnes in the 1960s, but then decreased and nearly disappeared after Spain's integration in the European Common Market in 1986. During two decades, annual Spanish resin output had been less than 5,000 tonnes. A similar trend, (although with a 10-20 year lag), can be observed in Portugal, where the production reached 108,000 tonnes in 1986, but reduced very drastically thereafter, 63,000 tonnes in 1990, approximately 30,000 tonnes/yr in 1995-97 and only 5,000 tonnes after 2004. The world production of resin-derivate products reached its maximum in 2007, when the rosin production exceeded a million tonnes and the turpentine production 170 thousand tonnes. But since 2009, China's export as world's main natural resin exporter dropped from 0.4 million tonnes in 2006 to less than 0.25 million tonnes/year, owing to its need to supply the own growing chemical industry. This shortage has forced a strong price increase for natural rosin, from a minimum of 0.75 €/kg in 1991 to more than 2 €/kg in 2011. Also the development of new tools and extraction methods, combined with breeding programs, are of importance for this NWFP. These conjuncture has allowed for current resurgence of the European resin subsector, surpassing in 2015 already 14 million € as primary value for raw resin only in Spain, 6 million € in Portugal (CESE 1998; Pinillos et al. 2009; de Diego and Sanz 2013; Picardo and Pinillos 2013; SORENA, 2016).

Nevertheless, investment in European resin value chain development is hampered by serious uncertainties, concerning both the resin and rosin world market prices and the currently high unemployment rates that has pressed on labour costs and made resin tapping profitable. But there is especially one high biotic risk associated with the spreading of the pine wilt nematode (*Bursaphelenchus xylophilus*), one of the most dangerous threats for European coniferous forests, not the least for the susceptible maritime pine that is killed in Portugal already massively by these quarantine organisms (Nunes da Silva, 2015; Zas et al., 2015).

Summary of key points and knowledge gaps:

Due to the lasting abandonment of resin tapping as relevant economic activity in Europe since 1980s, that fall together with the only recent strong development of modern forestry research in southern Europe during the last twenty years, there have been few innovations in related silviculture practices, nor many papers

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about resin yield and its modelling either, though maritime pine itself has been one of the best-studied forest species in Spain and Portugal (Tomé and Faias 2014) and numerous studies and growth models are available that might allow a linking of resin yield by tree size (DBH or crown dimensions) and other covariates as modular model complement. Since 2006, a new 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 that project, several ten thousands of pluri-annual single-tree resin yield data were obtained that have allowed analysing weather and tree covariate effects: Induced resin flow is strongly related to climate, especially to high temperatures in summer and moderate drought. Additionally, strong differences among individual trees exist and are stable among years: mean annual individual resin yield was less than 3 kg, but the most productive trees yielded more than 6 kg each year; larger, more vigorous trees especially produced more resin. Also lower stand densities/basal areas per hectare increased resin production per tree, though not per hectare (Roig et al. 2010; Rodríguez-García et al. 2014, 2015). The potential for genetic improvement might be high because the resin yield of the individual tree is under strong genetic control, and progenies test for high resin producers are advanced (Alía et al. 2013). But environmental risks and priorities possibly will limit its applicability because a genetically narrow-based, production-centred silviculture might involve excessive uncertainties in a scenario of ongoing climate changes towards a warmer and drier Mediterranean area.

Silvicultural practices in maritime pine:

In this context, the present silvicultural guidelines are only updates for the ecology and state of the art in specific silviculture and models included already in the previous StarTree Deliverable D2.1. (Tomé and Faias 2014) and D2.2. (Sánchez-González et al. 2015).

Natural regenerated stands can present over 2,000 trees/ha. Plantations range from 1,100-1,700 trees/ha in the pure stands managed by the Forestry Service (often forest restoration) to 800-1,300 trees/ha in pure stands managed by private owners for productive aims (Louro et al. 2000; Serrada et al. 2008). In Portugal, most stands derived originally from plantations containing genetic materials from Leiria national forest. In Spain, there are numerous natural forests grouped in 20 provenance regions (Alía et al. 1996), which are very different regarding soil requirements, climate adaption, growth, stem form and performance in plantations (Alía et al. 1991, 1997). The appropriate provenance should be selected to ensure adaptation to the site (Serrada et al. 2008).

Clearing of fire-prone shrubs (especially cistus, heaths or brooms), if present, is usually necessary to avoid propagation of forest fires. It also allows easy walking through the forest to get the resin. Therefore resin exploitation that implies clearing by the workers within their work schedule can be seen as tool for active forest fire prevention (Serrada et al. 2008). This view of the resin as a contribution to the defence against forest fires was the basis of a European project - SUSTFOREST - participated by France, Portugal and Spain, which aimed to facilitate multifunctionality, conservation and rural employment in the territory of southern Europe by extracting resin (http://www.sust-forest.eu).

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Formative pruning is almost never necessary, because the worse trees will be removed in the first thinning treatment. A non-commercial thinning before the age of 10-15 years reduces stocking density to 800-1,200 trees/ha (Louro et al. 2000). Traditional thinnings aimed at reducing stocking density to 150-250 trees/ha (in Spain) or 300-500 trees/ha (in Portugal) at 30-40 years to attain the necessary DBH to start resin extraction (Baudín 1963), resulting in two or three heavy thinning treatments before this age. This minimum diameter is regulated by specific legislation that considers two types of resin extraction: "to death" - trees are tapped heavily during 4 years immediately preceding felling – or "alive" meaning that the tree is tapped during several decades in a sustainable, lower intensity no damaging the tree strongly. In Portugal, the minimum DBH is 19 cm (60 cm in circumference) and 25.5 cm (80 cm in circumference) to resin extraction "to death" and "alive", respectively (Oliveira et al. 2000). In Spain this minimum DBH is about 30 cm for tapping "alive", depending on the number of consecutive tapping faces that shall be opened on the tree, normally four or five, each of which will last for during five consecutive years of resin production (Mutke et al. 2013).

Table 2.8: Management regime for combined timber and resin production

High site quality			**Low site quality**		
Age	Trees/ha	Operation	Age	Trees/ha	Operation
0-20	1000	Pre-commercial thinning if N > 1000 Low pruning to 2 m when trees are 6 m tall (500 trees/ha)	0-25	1000	Pre-commercial thinning if N > 1000 Low pruning to 2 m when trees are 6 m tall (500 trees/ha)
20	500	Thinning from below High pruning to 4 m when trees are 12 m tall (300 trees/ha)	25-30	500	Thinning from below High pruning to 4 m when trees are 12 m tall (300 trees/ha)
25	250	Thinning from below	35-40	250	Thinning from below
30	200	Thinning from below Start production sub cycle	45-50	200	Thinning from below Start production sub cycle
80-100		Regeneration cut	100-120		Regeneration cut

Before resin tapping fell in disuse thirty years ago, pruning usually started when trees had a DBH of 10 cm. Trees were then successively pruned to a height of 4 m when reaching the age for starting tapping (Baudín 1963; Oliveira et al. 2000). Nowadays, trees are only pruned up to 1.5-2 m after the first thinning (at 15-20 years, i.e. tree height = 7.5-8 m) and a high pruning treatment (4-5.5 m) is applied only to the 150-200 trees/ha (Spain) or 300-500 trees/ha (Portugal) remaining after the last thinning that are being tapped (when trees are 30-40 years old, i.e., tree height = 17-18 m) (Louro et al. 2000; Serrada et al. 2008).

The rotation ages are usually between 40 and 45 years in Portugal and 80 and 120 years in Spain (Louro et al. 2000; Serrada et al. 2008), (

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Table 2.8). Maritime pine stands exploited for timber or resin are almost always even-aged, to facilitate and optimise resin tapping and harvest operations. Three sub cycles are established through the life of the stand: Regeneration sub cycle (the necessary time to obtain regeneration); Development sub cycle (the necessary time to get the minimum dimensions to start resin extraction); Production sub cycle (time period in which resin is extracted). Average production of resin is about 2-3 kg/tree/yr (usually from 1 to 5, with very few trees excceding 10 kg/yr) (Palma 2007; Serrada et al. 2008; Mutke et. al. 2013).

2.2.3 Black pine resin (*Pinus nigra* J.F. Arnold)

Authors: HV, MMM

Ecology:

The black pine (*Pinus nigra* J.F. Arnold) is a coniferous evergreen tree. It needs full sun to grow well but is undemanding regarding local soil conditions. The black pine has an expansive, robust taproot system and survives annual precipitation under 600 mm and summer droughts. It also can handle temperatures down to -30°C and is resistant against anthropogenic emissions (Schwarz 1934). Sexual maturity is reached between 15-40 years. It blooms, depending on the site, from April to the beginning of June. The mature seed cones are 5 to 10 cm long and they ripen in autumn of the following year. The wind-dispersed seeds are distributed when the cones open from December to April. When *P. nigra* matures, it usually has an umbrella-shaped crown. The black pine trees in Austria can reach an age of up to 800 years (Kohlross 2006).

Distribution:

The black pine occurs across southern Mediterranean Europe from Spain to the eastern Mediterranean on the Anatolian peninsula of Turkey. Small populations can be found in the high mountains of the Maghreb in North Africa. The subspecies *P. nigra* var. *austriaca* has his northernmost natural distribution in eastern Austria. On poor, dry dolomit-lime sites at the eastern border of the Alps it naturally forms open pine forests (Frank 1991). In Austria black pine forests can be found covering 22,000 hectares as pure stand and the species occurs in mixture stands on 80,000 hectares. Most of the stands are artificial planted since the 18th century (Kohlross 2006).

Utilisation (timber):

Although timber characteristics of *P. nigra* are comparable with *P. silvestris*, the timber value of black pine is much lower. This may be a result of the high concentration of resin, whereby surface processing of the wood is more difficult. Therefore, black pine is not well-received by carpenters and craftsmen (Schnabl 2001). However, an important and interesting usage of the timber is as wooden floor in theatres, since black pine planks do not squeak. In former centuries, resinous splints from pines were used as kindling and torches. However, based on expert opinion the utilisation of the timber of trees tapped with modern instruments is

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not only still possible but even allows an easier processing in sawmills because of the reduced concentration of resin.

Utilisation (resin):

P. nigra has the highest resin content of all European conifers. Resin is a mixture of organic compounds such as resin alcohols, resin acids and essential oils. More than 200 constituents could be detected (Kohlross 2006). Resin was first used as bonding agent for arrows and spears. The old Greeks and Romans used pine resin as natural remedy against gynecological disorders, cough and asthma, pain in the limbs or open wounds.

The extraction of resin, so called pine-tapping, has a long tradition in Austria. Pine-tapping requires the wounding of the stem surface, to artificially increase the resin flow (Schnabl 2001). First reports of pine-tapping in Austria were recorded in the 12th century. Resin patches and ointments were used as universal remedy. The economic importance of resin rose at the beginning of the 18th century, when large areas were reforested with black pine, also to stabilise aeolian sand soils. During the peaks of the production in the late 19th and early 20th century up to 5,000 tonnes of resin were harvested in Austria each year, which made resin production more important than the utilisation of black pine wood (Frank 1991). In the 1960s resin lost its importance due to a number of factors, including forest fires, the absence of workers, the overageing of stands, but primarily because of the invention of artificial petroleum products and cheap import of products originating from resin derived from foreign countries.

Today, resin production of *P. nigra* is almost entirely managed by the Pecherhof Hernstein in Lower Austria. The resin company is the last of its kind in Austria and employs eight resin workers. Pecherhof Hernstein is the only natural resin production facility in Europe without chemical stimulants (Bojar et al. 2007). Around 10,000 trees are used for resin extraction. Each pine can yield 2.5-4 kg raw resin per year. Around 40 tonnes of pine balm, the mixture of resin, palm fat and beeswax, are produced each year (Schnabl 2001).

By distillation of the raw resin, colophony and turpentine oil are obtained. The Pecherhof uses resin for balms and creams. Colophony is used in many places, e.g. in the paper industry, in adhesives, in medicine products, detergents, in electrical and plastics engineering, in cosmetics, as rosin for violins, in varnishes, colours and paintings, as incense material and in vine production (Retsina). Turpentine oil is mostly used as binder and dilution in colours and varnishes, as leather care product and for pharmaceutical compounds.

Silvicultural guidelines for promoting resin production of *Pinus nigra*:

Kohlross (2006) argues that an absent shrub layer is important for the accessibility of resin-tapped pine stands. He points out that straight grown trees facilitate the treatment and enable climbing per ladder. Schnabl (2001) indicates that the logging of resin-tapped pines should be done before the operating life

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exceeds 12 years, because until then influences by resin production have only a small effect on the quality, and hence the value of its roundwood. Apart from this, silvicultural guidelines are scarce in the literature. This might be a result of the in general little importance of resin-tapping. Most advices that were found in (popular) scientific papers only include tips on the correct and best protecting treatments of resin trees. Some of them are:

- Resin-tapping should not be started earlier than on trees with a DBH of 30-40 cm (90 to 130 years). Only on poor sites the work shall start with a smaller DBH (Schnabl 2001)
- The trees should be given a rest for at least for one week (ideally three weeks) after each tapping
- The use of the modern "Hobelverfahren", where a plane is used, which results in a smooth and even surface is recommended. This leads to less contamination with splinters/dirt and a higher yield of resin (Kohlross 2006).

Bojar et al. (2007) pointed out the fact, that resin-tapping in Austria is economically worthwhile. When tapping a tree over 30 years the rental yield of ten trees can be acquired. Yet the need for resin is low and the work is heavy, whereas only few forest owners choose this alternative.

Often misgivings are voiced regarding the negative influence of resin deprivation on the health of trees. Nguyen (1992) found out, that in general trees continue to grow normally, when resin-tapping has stopped. Negative effects were identified with trees that were already infected by root rot or honey agaric fungus (*Armillaria sp.*). Also resin-tapping might result in lower resin production and higher needles loss, when pollutant contamination is high. The protective effect against insect infestation can diminish in the course of resin-tapping operations.

According to the elaboration of Schnabl (2001), vitality of resin-tapped pines is not different from unused trees. It is assumed that tapped pines have evolved adaption strategies by increasing xylem flux, to compensate the reduced sapwood area.

A reduction in timber quality is possible when pines fill the sapless tree core with resin as protection against insect infestation. This leads to a disadvantage regarding the further processing in timber industries, as the timber is not usable for carpenters and too heavy to be used as lumber. Indeed, when applying the nowadays common "Hobelverfahren" technique, there was not found a substantial penetration of resin in the direction of the inner trunk even after many years (Schnabl 2001). Moreover, modern lumber mills seem to have no problems with resin-filled stems, while in older establishments saws agglutinated which led to a higher risk in handling.

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2.3 Tree fruits, berries and leaves

2.3.1 Wild cherry (*Prunus avium* L.)

Author: JS, LM, HS

Description:

The wild cherry (*Prunus avium* L.) is a fast growing tree with can reach 20-30 metres in height. It has a straight stem and prominent blossom in April and May (FVA Baden-Württemberg 2011). The fruits of wild cherries are known for being smaller with less flesh than their cultivated counterparts, the stone of wild cherry constitutes a large proportion of total fruit volume and weight.

Ecotype:

Wild cherry displays a preference for warm and sunny sites (Spiecker and Spiecker 1988; Joyce et al. 1998), the species is noted as having a relatively high water demand, mean annual rainfall approximately 700 mm and above with an mean summer precipitation of above 120 mm (Coello et al. 2013). Best growth can be observed on sites with deep podsolised soils overlaying calcareous parent material, thus allowing for sufficient root development (Pryor 1988; Savill 1991; Spiecker 1994; Joyce et al. 1998). Pretzsch et al. (2010) suggested that the growth of wild cherry is the most site dependent species among common forest tree species.

Specific/generalised location and climatic adaptability:

Wild cherry can be considered widespread throughout Europe and beyond, extending north into Scandinavia (to 61°N), south into northern Africa and west into Asia and Siberia (Pryor 1988; Savill 1991; Ducci and Santi 1997; Joyce et al. 1998). However, it is difficult to ascertain the natural range of the species due to widespread and long term cultivation (Joyce et al. 1998). Since altitude and thus mean annual air temperature affects the potential rate of growth of *P. avium*, the species range can be found from sea level in northern latitudes, to 1,700 m in southern locations (Pryor 1988; Coello et al. 2013; Ducci et al. 2013). Pure stands are rarely found, rather as a scattered component of mixed woodland or occurring in clumps (Ducci and Santi 1997; Thies et al. 2009; Ducci et al. 2013) and may be present as lone trees within fields, at field edges, utilised within streuobst-like systems (agrosilvopasture) or within planted high intensity orchards. *P. avium* is intolerant of frequent drought stress (Hemery et al. 2010; Savill 1991). On the contrary soils must be moist but not waterlogged or stagnant (Evans 1984; Pryor 1988; Savill 1991; Joyce et al. 1998; Hemery et al. 2010; Ducci et al. 2013). Changing climatic regimes may alter site conditions shifting once ideal sites to marginal ones.

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Forest, species and habitat conservation:

According to current research, no apparent conservation values were associated with wild cherry. No reported habitat conservation requirements are apparent.

Current long-term forest development goal:

Veneer production represents the main use of wild cherry timber; demand for this usage is only second to that of walnut timber (Ducci et al. 2013). Therefore, production goals for such a product stipulate a branch free log lengths of 5 m or more, but this has been reported to range between 4 and 15 m (Thies et al. 2009; Hein and Spiecker 2009) with a mean mid underbark diameters greater than 40 cm and with a knotty core of less than 10 cm in diameter (Joyce et al. 1998).

Current silvicultural management system:

Pure wild cherry stands are commonly established by active planting activities. Appropriate plants should be two years old nursery trees (1+1) at a height of 120 - 150 cm (Spellmann et al. 2004). Trees should be planted in rows with a density of 2000 – 3000 plants/ha. If trainer trees (*Tilia cordata, Carpinus betulus, Quercus robur, Acer campestre, Fagus sylvatica*) are used, this number can be decreased to 1000 - 1500 plants/ha (Spellmann et al. 2004; Pretzsch et al. 2010). Furthermore, the number of plants can also be decreased when the genetic quality is controlled and artificial pruning is applied (Springmann et al. 2011).

Formative pruning of potential crop trees should be applied at a height of 2-6 m in order to remove steep branches and forks. Before the second pruning (6 m height) 100 - 150 potential crop tree candidates/ha are selected at an average distance of 8 - 10 m. Later crop trees should be selected, pruned and released in a distance depending of the target diameter (d_t). The distance between crop trees should be d_t x 25. In order to obtain a high quality product, artificial pruning is of upmost necessity and is frequently advocated (Otter 1954; Balandier and Dupraz 1999; Oosterbaan et al. 2009; Springmann et al. 2011; Nahm et al. 2016). As soon as the targeted crown base is reached trees are continuously released so that no branch will die (Spiecker and Spiecker 1988).

The main intention of pruning and thinning for wild cherry is to maintain and develop a clear bole as well as a healthy and vital crown to ensure good diameter growth. As cherry trees are susceptible to root rot when they get older, the target diameter should be reached at an age of 60 to 80 years (Spiecker 1994).

Revised silvicultural prescription:

General Thoughts

The production of high quality timber for veneer production and the commercial co-production of cherries at the same time are impractical since the trade-offs between the two production systems are large. But if

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the main focus stays on wood production and some additional silvicultural guidelines are followed, the coincidental co-production of cherries can create an advantage to the land holder, especially when the landholder has a direct usage for the fruit (e.g. schnapps, culinary usage). The production of cherries should not impinge too greatly on the highly profitable goal of producing high quality timber for veneer. But when low grade timber is being produced an element of compromise can be considered. The land holder should have some means of harvesting equipment and transport for the harvested NWFP. Many of the suggestions made herein are theoretical, experimental quantification must follow.

Establishment

As the growth of wild cherry is highly site dependent special focus should be spend to include the species within suitable sites (Pretzsch et al. 2010). When included in mixed broadleaved woodlands, the trees should be planted in clumps rather than as solitary trees. Attention should also be spent to selected relevant provenance and strong genetics for cherry production. The inclusion of wild cherry within widely spaced agroforestry systems where access is good and 'stands' are visited frequently can also be considered (Morhart et al. 2014), silvicultural treatments can be adapted for the production of fruit as a secondary goal to producing timber. Within widely spaced agroforestry systems the technique of grafts may also be applied for the increased production of desirable cherries early after establishment. The grafting scions of known cultivars atop an established rootstock (preferable a non-dwarfing variety such as "Mazzard") can achieve this goal. This method has been previously employed with both walnut and sweet chestnut in Europe (Mary et al. 1998; Conedera and Krebs 2010). Grafting can be conducted when the stem of the planted rootstocks presents a height greater than 2 m, this may be reached three to four years after planting with 1+1 stock. When grafting high focus should be taken to minimise the damage to the tree, while the use of a strong graft should be made, this provides a high contact graft union. This is practiced in order to reducing the healing time while increasing the rate of successful grafts. Healing time is of special importance, since wounds (especially slow occluding wounds) cause a high risk of fungal infections, which can decrease the timber value enormously.

Fruit producing trees should be located on forest perimeters and on roadways to maximise the available light to the crowns additionally access should be provide access for annual cropping. The location of trees on level ground facilitates the use of tree shakers and similar equipment, similarly the ground should be level and free of obstacles to ensure that the shaken fruit can be caught and collected. High levels of light are important for the increased production of cherries within forest systems; however, it must be ensured that stems are shaded to reduce the risk of sun damage (high temperature injury or winter sunscald). This can be by either self-shading or by shade cast by neighbours/trainer trees to reduce the risk of sun damage (Sheppard et al. 2016a). The blossom of wild cherry is also known to be sensitive to late frost events (Joyce et al. 1998), establishment of wild cherry for fruit production should focus on areas where late frost risk is minimal.

Tending and Thinning

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A larger crown implies greater fruiting potential, which means that less pruning will lead to more cherry fruit; undoubtedly this presents a compromise towards the target of a maximised branch free bole for valuable wood production. Nevertheless, a larger crown may result in greater diameter growth. We suggest that a maximum branch free log length of 3 m may be sufficient when cherry production should be a major aim. Nevertheless, silvicultural best practice should be applied at all times, the application of pruning is an intentional wounding of the tree; each wound presents a potential entry point for wood decay. Correct pruning practice should be applied for rapid wound occlusion, i.e. prune branches when they are less than 2.5 cm in diameter, keep branch stubs to a minimum (without cutting the branch collar) and aim to optimise radial increment of the tree by thinning and other silvicultural treatments (Sheppard et al. 2016b).

A co-production goal is often impractical within mixed stands (see above); however, we make suggestions towards how an additional NWFP goal can be achieved without detracting from the existing main (wood) production system. We propose a combination of high quality trees for timber with lower quality (2nd class) but vigorous trees for cherry production with a difference in the silvicultural approach applied to each as described below. Such an approach can be applied in both pure (see Figure 2.13) or mixed stands with similar outcomes. Thinning should remove weaker neighbours to allow full crown development of those trees designated for the production of cherry fruits. Total tree height of such 2nd class trees should be limited by the removal of apically dominant shoots to create an open and spreading crown to facilitate annual cropping. This dual system (good quality trees for wood production and medium quality trees for fruit production, plus lower quality wood at the end of the rotation) leads to less compromise required from individual crop trees that show superior stem form and diameter growth. Thus, meaning there is no detraction from the long term goal of producing timber. An example of the suggested management system is displayed in Figure 2.13 where cherry trees are planted in line with a distance of 15 m between rows (Figure 2.13a). At a height of 10 to 15 m potential crop trees are selected and pruned. Pruning activities are carried out three to four times; until the branch free bole length reaches ⅓ of the final tree height. Meanwhile, 2nd class trees are formative pruned in order to create an open and spreading crown and to prevent height growth, aiming to promote fruit production. Less vital trees are thinned to gain better light excess for the remaining trees (Figure 2.13b). It is important to ensure an unhindered crown development of the crop trees, and therefore, the amount of fruit trees is reduced constantly during the second half of the rotation period (Figure 2.13c).

Harvesting and Regeneration

After the final harvest of crop trees, the regeneration of the stand can be left for natural regeneration (it is assumed that cherry stones remain in the seed bank and the presence of root suckers will remain). Likewise, if some seed trees are left on site using a seed tree silvicultural approach following cohorts of cherry can be established. At anytime wild cherry can be promoted by active planting.

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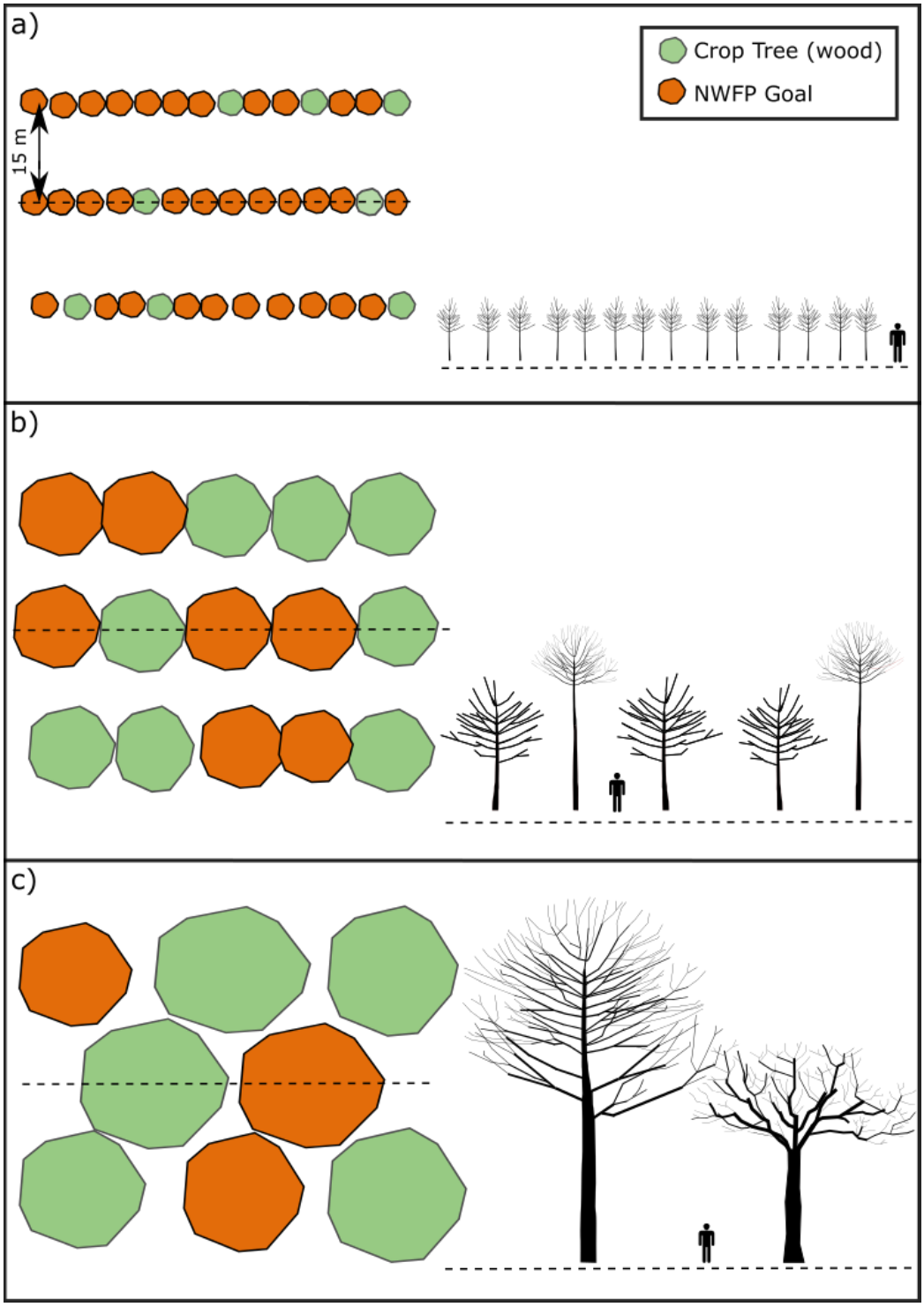

Figure 2.13: Schematic of three development stages of a pure cherry stand, managed under revised silvicultural guidelines (note the same approach can be carried utilising mixed species stands). The left side shows crown development form, a topview, while the right side shows height and structure of the trees from the side (transect depicting the dotted line from the topview).

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2.3.2 Sweet chestnut (*Castanea sativa* Mill.)

Authors: JS, LM

Description:

The chestnut tree (*Castanea sativa* MILL.) is considered part of European culture; timber and nut production within silvo-pastoral and silvo-arable production systems started with the Greeks and the Romans who expanded chestnut cultivation to the whole of central and southern Europe. Historically the species was present in the Mediterranean region in low numbers only. The light dependent nature of chestnut will have certainly profited from human exploitation timber management. Chestnut was actively introduced and cultivated in regions where it was not present naturally (Conedera and Krebs 2010). Historically there have been two main purposes in cultivating chestnut; nut production in orchards and fuel wood in coppice systems. Most current Chestnut forests originate from one of the two types. Abandoned coppice will often convert into high forest. Dual-purpose chestnut varieties for both fruit and timber production can be found in some southern European regions (Conedera and Krebs 2010).

Ecotype:

Chestnut demands a fair to high annual rainfall sum (Evans 1984; Gallardo-Lancho 2001) with summer precipitation greater than 130 mm and with no more than 200 mm of annual precipitation deficit (Álvarez-Álvarez et al. 2010; Fioravanti et al. 2010). The ideal climate for the successful culture of chestnut are those areas that experience a temperate humid climate with mild winters (Haltofová and Jankovsky 2003; Urbisz and Urbisz 2007). Sites which are susceptible to late ground frost should be avoided (Oosterbaan 1998; Urbisz and Urbisz 2007). Likewise, the annual number of days without risk of frost (temperature > 2 °C) is an important factor, this should total no less than 3-4 months (Álvarez-Álvarez et al. 2010). Mean annual temperature is quoted as a limiting factor to growth (Gallardo-Lancho 2001), moreover, as temperature is a factor of elevation, growth has been reported to decrease with increasing altitude (Álvarez-Álvarez et al. 2010). Nevertheless, varied estimations of maximal elevation have been reported (ca. 500 m to 1200 m) (Bottema 2000; Urbisz and Urbisz 2007). Maximal elevation of occurrence is also dependent on aspect (Conedera et al. 2001), degree of exposure (Everard and Christie 1995) and latitude.

Specific/generalised location and climatic adaptability:

Chestnut is native of north Africa, southwest Asia and southern Europe. The centre of domestication is considered to lie in modern western Turkey (Everard and Christie 1995; Reams et al. 2000) but can be found throughout Europe due to human influence (Urbisz and Urbisz 2007; Conedera and Krebs 2010). It has been speculated that the occurrence of chestnut in Scotland is possibly the most northerly incidence of the species (Braden and Russell, 2001).

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Chestnut displays poor growth on sites with a high water table and soils with poor drainage, including areas that are waterlogged for only short periods of time (Everard and Christie 1995; Oosterbaan 1998). Conversely, a low soil moisture storage capacity in dry climates is an important growth-limiting factor (Gallardo-Lancho 2001). The extreme summer drought in 2003 highlighted the potential susceptibility of chestnut trees to climate change: especially in the driest Mediterranean areas, these conditions may represent the limits of the species' potential ecological range (Conedera and Krebs 2010). It is reported that during the last 15 years the regeneration potential of chestnut in northern area such as in middle Germany and along the Baltic Sea in Poland, has increased strongly. It has been suggested that this may be due to higher temperatures in spring and autumn as well the absence of late frost (Hetzel 2009 2012; Urbisz and Urbisz 2007). Indications suggest that the natural distribution of chestnut in Europe is shifting towards the north.

It has been reported that chestnut occurs more often in association with oaks (*Quercus* spp.) than with beech (*Fagus sylvatica*) (Bottema 2000), this may be attributed to relatively high light demands made by chestnut, management of the species from above should reflect this requirement. However, chestnut can also tolerate some degree of shading illustrated by its occurrence with *Fagus orientalis* (Oriental beech) in Turkey.

Forest, species and habitat conservation:

According to current research, no apparent conservation values were associated with wild cherry. No reported habitat conservation requirements are apparent.

Current long-term forest development goal:

Three main management practices concerning the cultivation of chestnut, driven by distinct production goals can be found in Europe, namely: high forest, coppice and orchards (Pereira Lorenzo et al. 2010). High forest production is mainly concerned with the production of high value timber for veneer and furniture, coppice for firewood, charcoal, wood chips, pole and other small wood products while orchards are utilised for the production of sweet chestnuts. 79 % of the area ascribed to chestnut forest or mixed forest with chestnut is devoted to timber production (1.75 million ha) divided between coppice systems (1.48 million ha) and high forests (0.29 million ha). The area devoted to nut production is declining and amounts to 0.43 million hectares (19.3 % of the total area for chestnut growing; Conedera and Krebs 2010).

Current silvicultural management system:

Differing silvicultural approaches are necessary in terms of regeneration/plantation establishment, tending and thinning operations and according to the culture of chestnut within a forest stand, a coppice crop or in an orchard. A comprehensive state of the art is given by Pereira Lorenzo and Ramos-Cabrer (2004) and additionally by Tomé and Faias (2014) as part of the StarTree deliverable 2.1.

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In order to produce nuts, dependent on the site condition and the plant material, a spacing of 8 x 8 m to 9 x 9 m (Pereira Lorenzo et al. 2010) and 10 x 10 m to 12 x 12 m (Castro 2009; Martins et al. 2010) between trees is recommended. A higher tree density may lead to the need for intense pruning to increase accessibility of sunlight within the crowns (Pereira Lorenzo et al. 2010). It should be noted, that in relatively open stands, fruits are produced after 20-30 years, whereby in dense stands the fruit production starts at an age of 40-60 years (Bottema 2000), and therefore, requires a degree of thinning at a later stage (Pereira Lorenzo et al. 2010). Nut production should be located in areas suited to the culture of chestnut particularly with a low water deficit and low slope, providing technical advantages for harvest methodology (Álvarez-Álvarez et al. 2010). A wide range of varieties have been bred for nut production in southern Europe (Everard and Christie 1995). A choice of cultivars should be made according the market demand. For fresh consumption, nuts should mature early, be of good size, taste and facilitate easy peeling. For the processing industry peelability, a low percentage of double nuts and suitability for cooking are paramount (Martins et al. 2010). Chestnut cultivars have been traditionally propagated utilising three of four year old rootstocks often of interspecific origin. Bark or flute grafts are utilised in-situ during early spring often using selected marron type cultivars that produce desirable nut qualities, such methodology continues to be common practice in the establishment of orchards (Pereira Lorenzo et al. 2010). There are various budding and grafting techniques that can be applied for earlier precocity of the crop (Pereira Lorenzo et al. 2010). Plantations can be established with grafted plants or by planting the rootstocks first and grafting the plants after 3-4 years (Pereira Lorenzo et al. 2010). Grafting always aims to increase the productivity and health of the tree and is essential to establish a productive chestnut orchard.

Formative pruning in chestnut orchards is carried out to shape the crown into a form that is conducive to chestnut production, creating strong, spreading, equally spaced branches for the production of nuts. Maintenance pruning is carried out to increase fructification, maintain such a structure, to correct faults and to remove diseased and damaged limbs that may jeopardise the health of the tree (Castro 2009; Martins et al. 2010; Pereira Lorenzo et al. 2010). In order to facilitate a machine based harvesting technique, the ground must remain clear from high vegetation. Depending on the humidity of the site, different methods are applied such as grass for pasture or mowing, ploughing and use of herbicides (Pereira Lorenzo et al. 2010).

Timber production includes thinning to favour trees displaying high radial increment, a substantial height growth (placing individuals within dominant or co-dominant cohorts), plus displaying good form. High pruning of the selected crop trees is generally performed to ensure a branch free bole length satisfying high quality timber requisites (Everard and Christie 1995).

Given the differencs in production system relating to the desired final production goal, it is assument that the co-production of timber and chestnuts is highly impractical in many situations. Within established timber systems the collection of nuts can be assumed to be coincidental rather than commercially viable

Revised silvicultural prescription:

The sweet chestnut tree is known for its multi-functionality and its wide range of products (Abrudan et al. 2010). The co-production of timber and non-timber is not commonplace but a combination of systems is possible and has been noted in some Mediterranean countries. Co-production within the forest is possible;

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this can be optimised if provenances that are site specific with genetics predisposing large nuts are planted. If current silvicultural practice is applied to timber crop trees a coincidental yield of nuts will be harvestable from the forest floor. For a more targeted commercial production of nuts with an additional timber product goal a modification of an orchard system may be considered. If nuts are of particular importance a wider spacing is important, as light availability is crucial. Bottema (2000) suggests that in relatively open stands, chestnuts are produced after 20-30 years, whereby in dense stands precocity is much later and chestnut production can start at an age of 40-60 years.

Startree proposes an innovative single tree management system where grafted trees can be established within a agroforestry system or similar as an example of the idea. The proposed management may allow for a combine goal using choice cultivars while resulting in a high quality timber product. Note that such an example may also be applied to widely spaced mixed stands; however, nut production may be adversely affected if canopy cover is too dense. We propose that chestnut can be established within a wide spacing with a goal of producing a minimum branch free bole length of 2 m. Similar systems have previously been reported to manage to produce a log length of between 1.6 to 1.8 m (Herzog 1998). Due to a wide spacing additional livestock farming can also be carried out. Such an agroforesty system facilitates the production of chestnuts, high value timber and livestock simultaneously (sometimes referred to as 'Streuobst'; Nahm 2016). According to Castro (2009) and Martins (2010) a square spacing of 10 m or 12 m (70 to 100 trees/ha) is suggested at the time of establishment, thus reflecting the widely spaced nature of the system, however, densities of as low as 20 trees/ha can also be established. In order to promote nut production with large high quality nuts early after establishment (as opposed to waiting until individual trees mature and reach fruiting age) grafting of selected cultivars is advocated. The grafting scions of known cultivars atop an established rootstock (preferable a non-dwarfing variety) can achieve this goal. This method has been previously employed with chestnut in Spain (Conedera and Krebs 2010) and in walnut co-production systems (Mary et al. 1998). Grafting is conducted when the stem of the planted rootstocks has a height greater than 2 m, Hein et al. (2013a, 2013b) suggests this will be reached three to four years after planting. When grafting high focus should be taken to minimise the damage to the tree, while the use of a strong graft should be made, this provides a high contact graft union. This is practiced in order to reducing the healing time while increasing the rate of successful grafts. Healing time is of special importance, since wounds (especially slow occluding wounds) cause a high risk of fungal infections, which can decrease the timber value enormously.

To increase the production of nuts a strong well spaced scaffold of branches must be created. The utilisation of formative pruning treatment will allow the shaping of the crown with such an aim of creating strong, well spaced branches that will provide sufficient area to support nut production and permitting high levels of light to penetrate the crown. Apically dominant shoots can be pruned to promote forking, the arising branches can be further pruned to afford the desired crown form, Pereira-Lorenzo et al. (2010) suggest that the promotion of 4 to 6 vertical branches atop a 2 to 3 m stem is desirable. Figure 2.14 demonstrates individual tree form under the proposed system.

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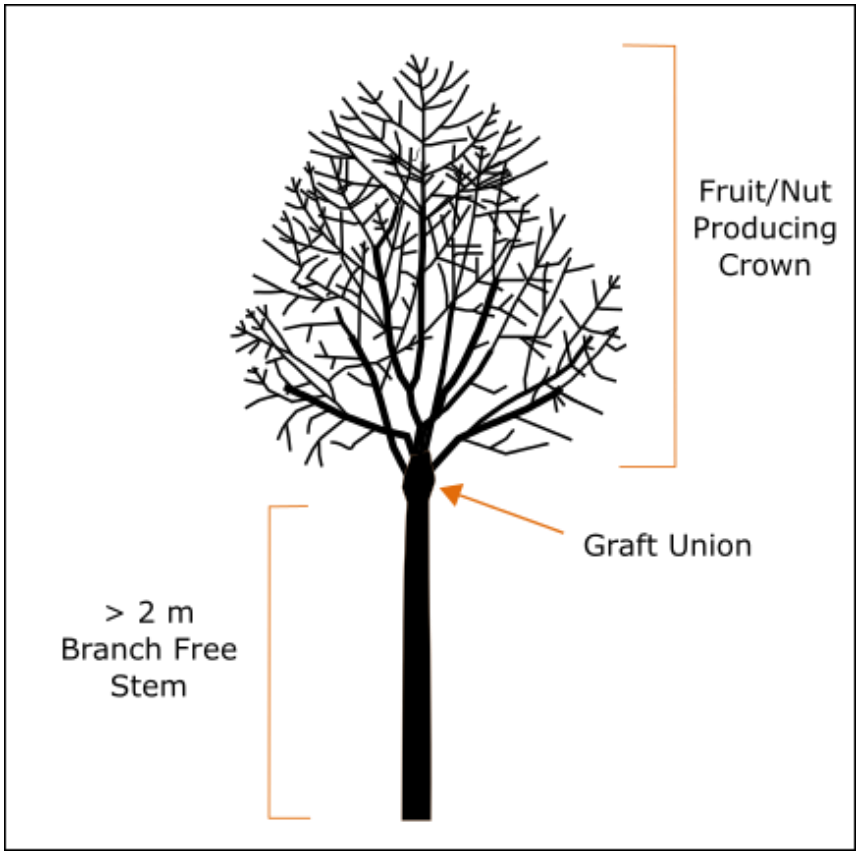

Figure 2.14: Single tree schematic of a grafted sweet chestnut tree with a branch free stem length of more than 2 m; an open and spreading crown for nut production and the overgrowen graft union.

If grazing is to be implemented under trees when established in an agroforestry system fencing must be utilised in order to protect trees from animal damage (Morhart et al. 2015). Furthermore, trees must be fenced individually to ensure that browsing of the crown, damage to the stem and trampling of the roots do not occur (Nahm 2016). Each tree guard should be constructed as a reasonable distance to the stem (approximately 1/4 of the final projected crown diameter). It is suggested that under normal growing conditions within a rotation period of 50 to 60 years, stem diameters of 50 to 60 cm can be reached (Hein et al. 2013a, 2013b) within a Streuobst system we suggest that diameters over 40 cm at the time of harvest are considered acceptable.

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2.3.3 Checker tree (*Sorbus torminalis* L.)

Authors: HV, MM

Ecology:

The checker tree (*Sorbus torminalis* L.) is a medium-sized deciduous tree growing to a height of up to 25 m. The tree is classified as durable pioneer by spreading seeds, after disturbances and also by root suckers and coppice growth from the stump (Mayer and Klumpp 2013). The optimal yearly mean temperature range for the species is between 10 °C and 17 °C, with a minimum of 7.5 °C (Kölling and Müller-Kroehling 2011). Yearly precipitation sum must exceed 600 mm with an optimum of approximately 800 to 1500 mm. *S. torminalis* reaches sexual maturity at an age of 15-20 years and can, on average, reach a maximum age of 100 years. Flowering takes place from May to June (Pietzarka et al. 2008), in eastern Austria, where most individuals can be found, the beginning of flowering is already in the first half of May. The flowers are hermaphrodite, produced in corymbs and are pollinated by insects, primarily hymenoptera and bugs. Fruits are 10-15 mm in diameter and mature in mid to late autumn.

Distribution:

The main distribution area of *S. torminalis* is Central and Southern Europe. Small populations can be found in southwest Asia and in North Africa. One of the northernmost populations stocks on the Danish island Møn (Mayer and Klumpp 2013). The checker tree grows on warm locations, south-exposed slopes and is a half-light demanding tree species. Most individuals are found in oak-beech and hornbeam communities. *S. torminalis* is less competitive towards European beech (*Fagus sylvatica*) on sites that are nutritious and have good water availability.

Utilisation (timber):

The rotation period for stands dominated by the checker tree is between 100 to 120 years, which allows the production of DBH measurements ranging from 40 to 50 cm. In general, the tree displays good natural pruning and tends not to produce water sprouts (Schrötter 2001). Timber of *S. torminalis* is valuable with prices around 450-750 € per cubic metre and shows a heating value comparable to European beech (Mayer and Klumpp 2013). Cabinet makers and turners appreciate the reddish-white wood and its stability. Timber is primarily used for veneers and saw wood for furniture production and musical instruments.

Utilisation (fruits):

The ruby fruits that grow in umbels do not need frost to be enjoyable, in contrast to the fruits of blackthorn for example. The fruits are manually picked with the aid of ladders. The work, which in Austria is done in groups of 2-4 persons, is exhausting and dangerous. The collected fruits are rubbed from the umbels, a time-consuming activity, and thereafter further processed. A fertile tree in single stand can carry 250-300 kg of

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fruit, in particular cases up to 500 kg. The fruits are primarily used for spirit production, but also for jam, fruit spreads, liqueur, pralines and chutney, in breads, sausages and cakes. They can also be dried or refrigerated. The blossoms of checker trees are used for syrup production (Mayer and Klumpp 2013).

In eastern Austria the Leader-Project "Elsbeere Wienerwald" was designed to promote *S. torminalis* for fruit utilisation, marketing and events with local enterprises and restaurants.

Revised silvicultural prescription:

It is very rare that natural regeneration by seeds of *S. torminalis* is successful. Very often the vegetative propagation by sprouting from roots is the major source for the next generation. Another good possibility is grafting. The duration until the first fruit production drops down to 10-12 years, instead of more than 20 years when grown by seeds. With the selection of graft trees the possibility to gain suitable trees for fruit production is increased. *S. torminalis* in Austria is seldom bred by generative reproduction but over e.g. root budding, bud graft or chip-budding (Mayer and Klumpp 2013).

Checker trees should not be planted in pure stands as the species is vulnerable towards fungal and bacterial infections. The best design for establishment within forest cultivation are to plant in groups or clusters, mainly because individual *S. torminalis* are not very competitive in the thicket phase (Hochbichler 2008). It is also possible to choose a single tree orientated cultivation in meadows with scattered fruit trees. Here, stems can reach a DBH of 50-60 cm within 50 to 80 years. A canopy coverage of 50 % should be targeted to allow sufficient grassland yields.

In young mixed stands much support must be provided to *S. torminalis* regarding the weak intraspecific competition. Additional measures against browsing are needed. Dense stands are required to support the natural pruning and reach a branchless stem of a length between 4-5 m. In widely spaced single tree orientated cultivations, shaping the crown by thinning as well as artificial pruning in the young and thicket phase are necessary, beginning with a tree height of 2-3 m, since natural pruning only occurs under shade conditions (Mayer and Klumpp 2013). While the diameter growth of *S. torminalis* can cumulate with 60 years the height growth can cumulate with 30 years. Therefore, it is important to favour selected crop trees continuously as the crowns need sufficient growing space. In case that the competition from neighbouring trees is too large, the angles of the branches will be very steep as they are growing towards the light (Studhalter et al. 2001). This reduces the tree quality. In young growth phase it is important to remove individuals with negative characteristics (forked trees, poor quality trees) and conduct some individual tending of the crown. In the thicket phase it is important to support the natural pruning of the trees and perform no additional tending measures (only in case that the tree number is too high). In case that the natural pruning is not working sufficiently, artificial pruning can be made in 2-3 entries, considering around 60-80 crop trees with an average distance of 10 – 14m. The total height of the artificial pruning should be less than 6 m at this stage and the crown length of the selected trees should be more than 40% (Hochbichler, 2008). At the later stage a selective thinning will be performed to favour the crop tress and 2-4 competitors should be removed with each thinning entry. The following measures should target to the development of

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the individual crowns in order to increase the diameter growth and reduce the likelihood of dead branches in the lower part of the crown (Studhalter et al. 2001). This will lead to improved timber quality and support the production of fruits as well.

Regarding potential damaging factors, *S torminalis* is robust against winter and spring frosts. It has a good stability against windthrow, at least those individuals grown from seeds, but is sensitive towards herbicides such as glyphosate. Checker trees are possible carriers of fire blight, which is a notifiable disease. However this disease is not relevant on *S. torminalis* until now. As most promising seems to be the recommendation to concentrate on mixed forest stands (mainly oak or pine trees), which can reduce the vulnerability against the fire blight. Leaf scab (by the sac fungus *Venturia inaequalis*) is the most important leaf disease, which mostly evolves under wet conditions and leads to the loss of leaves. The checker tree is vulnerable to Verticillium-wilt. Also the pathogens of wood rot can be a problem, such as *Armillaria spp.*, *Pholiota squarrosa*, *Ganoderma spp.*, or *Inonotus spp.* on old trees (Schröder et al. 2011). Deciduous mistletoes might affect checker trees but can be removed by pruning, and can also provide an indirect NWFP benefit.

S. torminalis is only endangered by insects to a minor degree. The greatest hazard for this species comes from mammals. Browsing from game species might be observed including rabbits, meanwhile, water voles and short tail mice can threaten the root growth (Mayer and Klumpp 2013).

2.3.4 Lime tree (*Tilia spp.*)

Authors: EZB, DK

Description:

The linden or lime tree is a member of the *Tiliaceae* family among approximately thirty species of trees, native throughout most of the temperate Northern Hemisphere, in Asia, Europe and eastern North America. It is a tree of 20-30 meters in height with dense branches and wide crest (Radoglou et. al. 2008). The size of the leaves is 5-10 cm in length. Flowers blossom in June and July and are harvested together with leaves and let to dry in the shade.

Ecotype:

T. platyphyllos grows in the lowlands and foothills of mountain regions as an auxiliary tree in mixtures with other broadleaved tree species up to an elevation of 1,800 m in the Alps in central and south Europe. *T. platyphyllos* and *T. cordata* are found in Italy on warm and wet sites with an abundance of nutrients. *T. tomentosa* grows up to 1000 m in elevation in Romania. In Bulgaria *T. tomentosa* grows in the north-eastern part and is found in the flat hills and foothill of the Mizian zone, covering a 17,273 ha area. In Greece, *T. cordata*, *T. platyphyllos* and *T. tometosa* are found in the vegetation zones of deciduous broadleaves in mixture with beech, oak, ash, and maples; pure stands are very rare up to 1200 m elevation. The linden generally grows in northern part of Turkey, for instance, particularly in the regions of Marmara, Western

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Black Sea, Central Taurus Mountains and Northern Anatolia. Generally, the species exists in both boreal and temperate zones.

Specific/generalised location:

The distribution of *T. cordata* is strongly correlated with the temperature of northern Europe with an annual isotherm of + 2 °C and July isotherm of + 17 °C (Boratyńska and Dolatowski 1991). Its distribution is suboceanic to subcontinental and it is most abundant from north-east France through central Germany and Poland to central Russia and north Ukraine. It is common in the Swiss plain and the lowland parts of Austria, Czech Republic and western Hungary, occurs sparsely in the Alps valleys. The majority of the southernmost localities are at altitudes above 200 m and on north-facing slopes or cliffs (Barna 1996). It is almost certainly summer drought which determines the southern limit of *T. cordata* in the Mediterranean region.

Forest type:

The linden tree grows mostly in mixed forests with other deciduous trees such as beech *(Fagus sp.),* oak *(Quercus sp.*), maple *(Acer sp.)*, hornbeam *(Carpinus sp.)*, as well as coniferous species such as Norway spruce *(Picea abies)*, Scots pine *(Pinus sylvestris),* yew *(Taxus sp.)* and silver fir *(Abies alba)* as co-dominant tree species as a result of its vitality and adaptation to the changing environment. Pure stands can be found in the eastern part of Europe (i.e. lime or lime-oak forests in Russia).

Ecology:

Linden requires light and humid areas growing on rich soils, mesotrophic or mesoeutrophic, fresh or moderately moist, with mull or moder humus. Such soils have neutral or alkaline pH soil reaction. Lime prefers sites with higher calcium content (Jaworski 1995). *T. cordata* grows naturally on a wide range of soil types from podzols through brown podzolic soils, brown earths and brown calcareous earths to rendzinas (Radoglou et. al. 2008). It can be found on soils with a wide range of textures: from soils with a high proportion of clay and silt to those containing mainly sand or a high proportion of pebbles, as well as on screes and block screes. Various taxon of *Tilia* require different ecological and climatic conditions. For example, *T. platyphyllos* grows well on the region where the average temperature is above -3 to -8 °C, and *T. cordata* from -7 to -16 °C (Korotaev 1994) with an upper limit of 44 °C. The species is susceptible specifically to stagnant water (Lyr 1993). Almost all lime species, especially *T. platyphyllos*, are resistant to drought, dry winds and low temperatures. The Lime species may well be used as commercial purpose as well as protective planting (Biryukov 1991).

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Ecological situation/climatic adaptability:

Lime trees can mainly be found as co-dominant tree species in mixed stands either with softwood or hardwood species as a result of its vitality and adaptation to the changing environment. The adaptation to the environment and/or various climatic condition may well be due to its "waiting and persisting strategy". The species can play a positive role in forest development on relatively poor sites as the leaves decompose rapidly (Hommel and DeWaal 2003). Pure stands can rarely be found in the Eastern Europe. There are not specific studies to pinpoint its true adaptation to changing climate condition. However, the species is quite tolerant and can be mixed with various broadleaved species and deciduous species across Europe. As such, this wider co-existence with many other species suggest an inclination towards an adaptation to a changing climate.

Forest conservation:

According to current research, no apparent conservation values were associated with lime trees. However, lime trees within mixed broadleaved high forests are suggested to be protected. Their inclusion in mixtures is favoured by silvicultural treatments because of their soil-improving abilities, better site utilisation and landscape aesthetics.

Long-term forest development goal:

Lime trees are used as supporting or trainer trees in high-value oak stands and used in urban areas such parks, streets, and roads as allée trees. Mixed stands with linden trees having vertical structure are favoured for the maintenance of structural diversity. Veneer (rotation 80-100 years) and sawlog (50-80 years) are two primary timber products as production goals. As a major NWFP production goal: linden flowers are used in products such as herbal tea, and 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. The trees are also frequently used as ornamental trees by urban forestry in streets and parks. Quality of lime tree is obtained in well stocked mixed stands.

Species and habitat conservation:

No reported habitat conservation is apparent.

Establishment:

The tree has specific biological and ecological properties such as regeneration by stump/root suckers, almost annual fructification, and maintenance of soil fertility by the rapid decomposition of litter foliage, shade tolerance. Seed production as well as flowering of trees begins at about 25-30 years, but trees originating

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from suckers bloom 10-15 years earlier. The tree bears rich seeds generally at 2-3 years intervals. There is a double dormancy germination prevention problem coming from hard shells and endosperm that needs special treatments before production. To overcome the obstacle, the seeds are treated with 95 % pure sulphuric acid (H_2SO_4), are put short in hot water or are scarified with mechanical tools. The auto-vegetative production, particularly cuttings from the roots, is a successful production system. Grafting and layering are successfully used to reproduce the lime tree.

Tending:

The first cleaning/re-spacing is performed at a stand age of 10-12 years focusing on the upper storey to eliminate non-desirable species and defective trees (forked trees or other undesirable defects) and repeated in 4-6 years of interval. After tending, canopy closure is assured at 80 %.

Thinning:

Thinning starts at 20-25 years for spacing of future crop trees. Rotation of thinning increases from 5-6 years in pole stage to 8-10 years in high-forest stage. Thinning ceases at 55-60 years with the exception of silver lime stands targeted for the production of veneer logs. In such case, the last thinning is applied at 60-70 years. The early growth culmination as well as the quality development of lime stands requires the application of **selective thinning** in younger stands and moderate thinning in older stands. For example, *T. cordata* reaches 35-40 m in height on good sites and develops branch-free stems in fully-stocked stands. Stem quality is best in very dense stands, where the percentage of forking is reduced (Rossi 1993).

Maintenance:

Lime trees are maintained in mixed stands for stand durability and natural structure of the forest during regeneration because of their soil-improving abilities, better site utilisation and landscape aesthetics.

Harvesting and regeneration:

The biological rotation age varies between 150 and 200 years, while the technical rotation ages vary to the objectives (50-60 for sawlogs, 80-100 for veneer logs). Due mainly to germination prevention, there is no specific system for natural regeneration of Tilia. However, lime regenerates naturally under the stand canopy during the shelterwood cuttings on rich sites. Generally, vegetative reproduction is very important for populations growing on the border of its natural range. Lime trees sprout strongly after cut and show no decline in sprouting vigour with age (Pigott 1991). This ability is a part of a life strategy that allows the possibility of outnumbering other species. Thus producing sprouts prolongs the life of lime trees, even after damage to old stumps (Radoglou et al. 2008). Although lime seedlings and saplings are able to survive under dense shade, their growth in the third and fourth years needs more light for a successful regeneration.

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Revised silvicultural prescription:

Pruning has not been an appropriate method for better flower production. Fill planting under the shadow is recommended for the low crown coverage stands. Coppice like cutting systems including sprouting, layering and pollarding should be favoured as practical silvicultural prescription. As for NWFP, no apparent silvicultural prescriptions were found to be used for the specific management of lime tree flowers. However, coppice like management and intensive thinning to give more space for more branches and thus flowers are encouraged. Rehabilitation or revitalisation and plantation need to be applied to lime stands in different regions of Turkey. The revised silvicultural practices about Lime tree need to favour larger crown generation in a stand. The larger the crown the more productive the trees are for leave and flowers' production of lime trees. Therefore, density management of lime trees would be very effective in managing the stand for NWFP. Additionally, early thinning to provide more spacing for lime trees is quite critical. Thus, any silvicultural practices that promote larger space and wider crown formation instead of greater height with small crowns are to be prioritised as alternative or revised silvicultural practices for Lime trees when NWFPs are the target.

2.3.5 Bay leaves (*Laurus nobilis* L.)

Authors: EZB, DK

Description:

Bay laurel (*Laurus nobilis*) is an evergreen shrub or small tree, indigenous to the Mediterranean basin and the near east. It is a 5-10 m tall evergreen tree or a large shrub with a high sprouting ability. Leaves are 5-10 cm long and 2-4 cm wide with an elliptical shape. Its leaves and oils from both the leaves and fruits are the main NWFP that have frequently been used in the medical, cosmetic and canning industries.

Ecotype and specific/generalised location:

Native to the Mediterranean region, the laurel tree grows on the coastal parts of the Aegean, Mediterranean and Black Sea regions and the Laureate zone wherever the Mediterranean climate is felt. It has been reported that *L. nobilis* occurs in association with the maquis vegetation growing in typical Mediterranean climate, pure or under Calabrian pine (*Pinus brutia)*, this may be attributed to relatively high light demands. The tree does not tolerate cold regions.

Forest type:

The tree mixes in group with oak (*Quercus sp.)*, olive (*Olea sp.),* juniper (*Juniperus sp.),* sandalwood *(Arbutus sp.),* thyme *(Thymus sp.),* plane tree (*Platanus sp.)* and other hardwoods.

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Forest history/forest condition:

Most of the last remaining laurel forests around the Mediterranean are believed to have disappeared approximately ten thousand years ago, although some remnants still persist in the mountains of southern and western Turkey, northern Syria, southern Spain, north-central Portugal, northern Morocco, the Canary Islands and in Madeira.

Ecology:

Laurel trees prefer humid areas up to 1200 m in elevation (Anonymous 2005). While the laurel tree does not have any specific soil requirement, it grows mainly on clay, sandy clay, clay sand, sandy clay loam, loamy clay or loam in alkaline soil (pH between 6.7 – 8.0) with an annual precipitation sum of between 600 mm and 2000 mm. The species generally grows on shadowed aspects and prefers limestone or calcareous soils. One of the most important parameters required for growth is a relatively high water table. The species requires water and humid air on the site with an average annual air temperature of approximately 14 to 15 ^{o}C. Thus, it commonly prefers stream banks or humid riparian areas, warm in summer and cool in winter. However, it also grows in southern aspects that are exposed to maritime environments. In brief, water as well as humidity is more or less the limiting factor affecting its growth and thus the boundaries of spatial distribution of the tree.

Ecological situation/climatic adaptability:

There are some insects found to be pests in Laurel. Some of them are; *Trioza alacris*, *Aonidia lauri*, *Archips rosanus* and *Cacoecimorpha pronubana* causing leaves to curl, reshape and ultimately slows the growth of the whole plant. However, the most common pest is the aphid causing frequent distortion to the leaves. Although there seems to be some pests causing damages to the shrub, they do not pose serious impact on the development of Laurel. Thus, mechanical treatments instead of chemical treatment are suggested to be implemented wherever necessary in association with the use of biological counterparts of these insects as they naturally appear.

Forest conservation:

According to current research, no apparent conservation values were associated with Bay laurel.

Long-term forest development goal:

The main management goal of the tree is the production of NWFP (particularly leaves and oils) and to provide mixture in stands. Wood production is not a primary management goal.

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Silvicultural development of the initial stocks:

The laurel tree can be produced either naturally from seed or by coppicing from the stumps and roots based on vegetative propagation. *L. nobilis* boasts a high capacity for re-sprouting; hence a coppice style management is prevalent in most areas. However, there is a germination prevention mechanism that requires special treatment prior to sowing. The seeds are generally removed from the shells and put out for layering. For vegetative propagation, the shoots are carefully cut at 15-20 cm in length in late July and September. Leaf production is known to be highest from the seedlings planted at 2x1 m intervals. A study indicated that seedlings planted at a closer spacing of 1.5x0.66 m intervals provide far better results (Chakhaidze and Vadachkoriya 1989).

Species and habitat conservation:

No reported habitat conservation is apparent.

Establishment:

Laurel tree is generally cultivated for leaf production. The tree can be regenerated with a plantation, pollarding and cutting (coppice) management regime. The best plantation interval is suggested to be 1.5x 0.66 m or 2.0x1.0 m with nearly 10.000 seedlings/ha, usually planted in autumn. One year before taking shoots for the coppicing/cutting, the selected trees are cut at the root collar level to let the stump and roots re-sprout. The shoots are cut at 15-20 cm in length and 0.8-105 mm in diameter from the newly sprout from stump or roots for shoot production. In water, it takes about 12-14 months before the cutting/shoots begin to sprout, thus additional nutrient is applied to the leaves. The shoots were first humidified and dipped into the soils. In fact, best rooting environment for Laurel is the sandy soil and other soil treated usually with perlite-peat. The shoots were then planted on the ground with humid soil for best growth of the species.

Tending, Thinning and Maintenance:

There are no specific reported silvicultural prescriptions designed and applied to bay leaf stands other than harvesting/coppicing.

Harvesting and Regeneration:

While there is no specific cutting system, the natural system for economical production is to cut the branches together with the trunk at 10 cm above the root collar every other year for a period between July to September. The 2-3 year old shoots with leaves are cut for NWFP and all are taken from the site to the nearest stocking place - only the stumps remain on site, which are left to re-sprout. For the production of oil

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and seasoning, pruning from the tip of the branches is advised. Winter production is preferred wherever there are no drying problems. The best leaf harvesting method is found to be the combination of coppice and shoot cutting or pollarding at 2 year intervals (Polat at al. 2009). Commercial bay leaf production starts five years after stand initiation (within plantations).

Revised silvicultural prescription:

Bay leaf production combined with other products as a mixed system (such as agroforestry) instead of allocating the land for only bay culture is suggested to be an alternative silvicultural system. Harvesting leaves with coppicing and pollarding or in combination is suggested silvicultural prescriptions for the renewal of Bay laurel. In fact, producing bay leaves in combination with other species as agro-forestry practices may be an example for innovation. It could further be studied to look for a widespread application in different environments or sites before calling the ideas as an innovative process. Yet, the success of reproduction and treatment for best results depends highly on the availability of watering systems particularly in the stand initiation stage. Although the reproduction of laurel is relatively new, plantations with 1x2 m interval provide best results of leaf production in case studies conducted in Turkey. The best renewal or cutting location is found to be 8-10 cm above root collar in 2-3- year-rotations. Furthermore, pruning the tip of braches each year was found to help improve seasoning and oil production of laurel.

The revised silvicultural practices would best involve the reproduction of laurel in cohorts in three-years-of rotation. Each cohort is to be subjected to various types of sprouting such as from the roots, stumps and stems of laurel. Most of the individuals in a cohort are cut right above root collar in coppice, however nearly 3-5 individuals are left to grow in a cohort. The left over trees are allowed to grow and let the stems to shoot by providing through pollarding almost 2/3 of crowns of standing individuals. Thus, sprouting is allowed to happen in roots stumps and stems to allow better renewal of laurel. Such semi-conceptual approach could well be treated as a revised silvicultural practices in laurel stands for both leaf and seed production.

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2.3.6 Mediterranean pine nuts (*Pinus pinea* L.)

Silvicultural guidelines for managing *P. pinea* stands in Spain for cone production

Authors: RC, SM

Mediterranean stone pine (*Pinus pinea* L.) renders the most expensive edible nut collected in European forests, the genuine Mediterranean pine nuts extracted from its cones. For this purpose, cones are collected manually (climbing the trees) or by mechanised methods (by tree-shakers) during the winter, before they open in spring and release their seeds. Main cone production is still wild-collected from semi-natural or multipurpose forests throughout the Mediterranean countries, though an important effort is made for developing an innovative approach of orchard plantations, often using grafted clones. Stone pine is plainly on that edge of the *silvicultural dilemma*, quoted in section 1.3, of the present StarTree Deliverable D2.3, between wild collection from semi-natural forest and domestication for agroforestry systems or as an agronomic crop (Mutke et al. 2012).

Main producing countries are Portugal, Spain, Italy, Turkey, and Lebanon, with some production also from Tunisia, Morocco and Syria. Especially in Portugal, stone pine has enlarged its forest and plantation area from 40,000 to 175,000 hectares within forty years. In Spain, the stone pine forests have been expanded since 1900 from 180,000 to 490,000 ha. All in all, stone pine covers more than 800,000 ha, being present in most Mediterranean countries. For the most part, planted forests dominate, though also old natural or semi-natural forests are relevant, pure or mixed with *Pinus pinaster*, *Pinus halepensis, Quercus ilex, Quercus suber*, among other species. Out of its natural distribution area, it has not been planted extensively as a forest tree, though it has been introduced locally in California, Chile, South Africa, Australia or New Zealand.

Cones have been collected by man since antiquity. Since early 20th century, forest management planning has integrated cone production as one of the main objectives of silviculture applied to pine forests in Spain and Portugal. Additionally, the low-quality and slow-growing, formerly locally used stone-pine wood has been widely substituted by alternative timbers from abroad, and even by other raw materials. Hence, timber has been relegated to be a secondary product in Mediterranean stone pine forests, evolving the applied silviculture in the last decades towards open stands with lower crown competition, favouring higher cone yields at tree and stand level.

The following guidelines are updates of the detailed state of the art in specific silviculture and models included already in the StarTree Deliverable D2.1. (Tomé and Faias 2014). Since the 1980's', large effort has been made concerning the modelling of stone pine growth and cone production in Spain, Portugal and Italy and on developing management support tools for *P. pinea* aiming at the multifunctional forest management, such as site index curves, yield tables for adaptive silviculture based on Reineke's Stand Density Index, and different growth and yield models such as the stand simulator PINEA, as outlines within the StarTree Deliverable D2.2. (Sánchez-González et al. 2015).

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Traditional silvicultural practices in Mediterranean stone pine:

Traditionally, the management of stone pine forests has combined multiple objectives: cone production for edible pine nuts, timber, firewood, as well as ecosystem services such as recreational use, landscaping, biodiversity conservation, groundwater and soil protection, the latter especially against wind erosion in dunes. The value of Mediterranean pine forests with *P. pinea* is recognised as EU Habitats Directive Annex I Habitat types 9540 and 2280, the latter being a priority habitat type.

Plantation or natural regeneration of existing stands oriented for timber production or multipurpose forestry usually starts with a density between 600 and 1,700 trees/ha. Traditional management of even-aged stands of stone pine in the Valladolid has focused on promoting individual cone production, in order to increase the yield of manual – traditional – harvesting of cones. To do this, management of stocking density has aimed to attain a final density over 80 trees/ha (Montero et al. 2008). To achieve this objective, a first pre-commercial thinning is recommended at 12-15 years in order to reducing stand density to less than 600 trees/ha. A second thinning is applied at 20 years, and then every 15-20 years, until the age of 60-70, given that older trees show a reduced response to release. At each intervention 40 % of stems are eliminated, especially trees with undesirable stem and crown form, as well as unhealthy, less vigorous and damaged trees. Final densities after last thinning are below 100 trees/ha (Montero et al. 2008).

Simultaneously with the first pre-commercial thinning, a first pruning is applied to clean the bole up to 2/3 of tree total height. Pruning is repeated every 15-20 years, up to a maximum height of 6-8 m. Stem pruning is not recommended in stands older than 50 years or with a DBH exceeding 30 cm, given their low diameter growth and capacity to close the wounds; this treatment is, hence, mainly a tending practice in young stands. Traditionally, a second type of formative pruning directed at the inner crown, known as *"olivación"* due to its similarity to crown formation in olive trees, this treatment was applied at thetime of the second and third thinning treatmentsof the stand. This type of pruning eliminated dead and less vigorous branches in the inner part of the crown for ease of tree climbing and efficiency of manual cone collection, beside its original objective to provide fuel wood without felling trees, nowadays is obsolete. Moreover, in analogy to pruning of dicot fruit tree, a hypothetic increment in cone induction/production by pruning has traditionally been supposed by forest dwellers, though it has never been quantified or even confirmed by experiment. Traditional silviculture has been widely described by Correia et al. (1999); Cañadas, (2000); Calama et al. (2003); Montero et al. (2004) and Montero et al. (2008).

Proposed rotation length was 80-100 years, or even shorter, in order to prevent heartwood affection by red ring rot, *Phellinus pini* (García Güemes and Montero, 1998), as well as based on the traditional assumption of maximum cone production at this age and its decay after. A traditional method for regeneration was a shelterwood method consisting of two intensive fellings carried out in a 10 years period (preparatory felling and seeding felling), and cutting the few stems still standing ten years later (final felling). Common observed failure in natural regeneration due to harsh climate conditions resulted in artificial sowing in order to regenerate the stands (Sanchez Cozar 1963a,1963b; Castellani 1989; García-Güemes 1999).

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Up to this point, these references are the classical multipurpose silvicultural scheme for stone pine producing timber, or combined timber and cones. Nevertheless, in real life silvicultural treatments, especially thinnings, have been often delayed or even neglected in the management (or rather lack of management) in many even-aged, dense pure stone pine forests derived from protective or restorative afforestation realised during 20th century, as well as more recently planted as farmland set-aside forestation under CAP since 1993. Also in small private forests, the applied silviculture (if any) doesn't follow always such a schedule. As a matter of fact, the first and most urgent challenge for improving cone production, as well as the forests' health and resilience, consists of applying sustainable forest management in those artificial plantations that have not had natural dynamics for evolving into self-regulatory forest ecosystems, nor current adequate stand structure.

On the other hand, at present forest management in *P. pinea* focuses increasingly on pine cone production as primary forest product, due to revenues exceeding those obtained for timber and other forest goods or services. New plantations for nut production usually start with a spacing density of 6x5, 6x6, 8x6 m, *i.e.* 200 to 300 trees/ha (Correia et al. 1999; Costa et al. 2008). As in other fruit and nut tree crops, grafting offers important advantages. The primer advantage of grafting is that it allows the propagation of selected superior genotypes. Since the early 1990s, several grafted clonal trials have been established in Spain and Portugal within the framework of regional and national research programs for the characterisation of the crop and the tested genotypes. As second advantage, grafting mature scions also skips the rapid growth juvenile stage, getting hence lower tree crowns and reducing the initial delay in production from 20 to less than 8-10 years until the first yield (Carneiro et al. 2007; Mutke et al. 2012). In grafted plantations, recommended density of 8x8 m (150 trees/ha) on the installation allows for tractor passage for tilling and mechanical harvest by tree shakers (Correia et al. 1999; Mutke et al. 2012). But these open grown plantations, grafted or not, have been raised only in the last decade, and optimised management schemes are still under development.

Revised silvicultural guidelines for promoting cone and pine nut production in Valladolid, Spain:

In this section revised silvicultural prescriptions for promoting cone and pine nut production in stone pine forests in Valladolid province (Spain) are presented. This intensive change of paradigm in the management of the stands is derived from a multisource analysis:

- Expert based knowledge from forest managers and forest owners.
- Long term series at forest scale of cone production and forest evolution, derived from the forest inventories, management planning and annual harvesting statistics.
- Long-term experimental trials, maintained since the mid 1960s and amplified in the 1990s. This network of trials includes permanent plots focusing on timber yield and cone production, natural regeneration trials, thinning trials and genetic tests.
- Simulations based on models predicting growth and annual cone production (Calama et al. 2007; Freire 2009; Calama et al 2011), as well as on optimization routines (Pereira et al. 2015; Pasalodos et al. 2016).

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Scientific basis for the change:

Assessment on these new practices is based on the recently developed knowledge on the ecology and management of the species, which can be based on:

- Large dependence of spatial variability in cone production on site, stand and tree attributes: larger cone production is attained on larger co-dominant trees, with well-developed crowns, growing in open stands (Calama et al. 2008).
- Early and intensive reduction of competition results in enhanced growth, large crown development and accelerated cone production (Gordo et al. 2012).
- Climate control (mainly rainfall deficit) has been found as the main factor controlling regulating masting habit (Mutke et al. 2005, Calama et al. 2011).
- Pruning in initial stages results in severe stress to young saplings (Cañellas et al. 2008), not being effective as a method for controlling fire propagation (Gordo et al. 2009). Crown pruning in adult trees is a quite expensive practice, not resulting in a clear increment in cone production. Widely applied in the past, crown pruning also resulted from the requirement of fuelwood in the locally subsistent rural society, this meant that pruning costs were covered by the firewood obtained. When in the second half of the 20th century, labour costs rose and fossil energy sources became available, traditional pruning practices first persisted even after becoming costly, but nowadays experiences have showed no negative effect when they are abandoned, and they have fallen largely in disuse due to excessive costs and security risks (Montero et al. 1999; Gordo et al. 2009).
- The rotation period can be extended to at least 150 years, with no observed decrease in cone and nut production if no forest health problem exists (Yagüe 1995; Montero et al. 2008). Given current low prices of timber, economical losses due to timber rot are minimised in comparison of expected benefits due to enlarged cone production; hence schedules based on optimised models recommend rotation lengths of up to 140-150 years (Pasalodos et al. 2016).
- Cone production per hectare in mature stands is not influenced by stand density, within a range of stand density between 100–250 trees/ha, varying only the individual cone production. Harvesting of cones under current prices is profitable with individual production over 2-3 kg/tree (manual collection), or 1 kg/tree (mechanised collection).
- Low dense stands (with less than 100 trees/ha) aiming to promote individual cone production results in very large gaps where no seed for arrives hampering natural regeneration (Manso et al. 2012). Densities for attaining natural regeneration should exceed 150 mature trees/ha (Manso et al. 2014), far from the current low densities found in some current stands.

Revised silvicultural schedule

Rotation length:

Rotation length can extend up to 120-140 years in the best sites, in absence of phytosanitarian problems.

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Tending practices:

In those natural or artificial young stands densely overcrowded, a heavy pre-commercial thinning should be applied. This intervention should be applied when the trees are over 2-3 m height, which depending on the site quality could be attained at 8-15 years old. Thinning should be a semi-systematic one, aiming to attain a final density of 500 trees/ha. Trees to be eliminated should be selected among those with worst shape, less vigorous crowns, attempting to obtain a regular spatial distribution of trees.

Main aim of this practice is to prevent early processes of decay, stagnation and dieback in very dense stands, resulting in reduced growth rates and delayed initial cone production (Cañellas et al. 2008; Gordo et al. 2009). This heavy early pre-commercial thinning results in gaps wide enough as to favour individual crown development, but still interrupting fuel continuity.

Unlike in former silvicultural practices, an initial pruning at this phase aiming to interrupt fuel continuity should be delayed. This initial pruning should be carried out 10 years after the pre-commercial thinning, simultaneous to the first selective thinning, when average height of the trees will reach 5-6 m.

Thinning regimes:

Thinning regime in even-aged *P. pinea* forests should aim to promote growth and crown expansion of about 150 trees/ha with the largest potential as cone producers (best shape, dominant, healthy crowns). The objective is to attain final density before the mid-rotation, thus stocking reduction should be carried out in two more thinnings:

- First selective thinning: to be carried out when average height of the trees is 5-6 m (20-25 years old). In this operation stand density should be reduced up to 250 trees/ha, selected among those with great potential, and aiming to have an uniform spatial distribution with a mean spacing between trees of 5-6 m, which permits the entrance of mechanical vibrators for cone collection.
- Second selective thinning: to be carried out when average height of the trees is 10-11 m (45-50 years old). Stand density should be reduced up to 150 trees/ha, selected as the most promising cone producers. This density, which would be the final density of the stand, is considered as a compromise density between promoting individual cone production and avoiding the formation of large gaps.

Pruning regime:

Simultaneous with the first selective thinning, pruning of remaining trees must be carried out. Trees are pruned up to a height of 2-3 m, in order to prevent fuel continuity and clean the stem to permit mechanized cone harvesting (by using vibrators). Further pruning, always elapsed a minimum interval of ten years, can be applied to obtain a clean stem up to a height of 4 m, never reaching more than half of the total tree height.

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A third pruning, that can be carried out by the time of the second thinning, is only recommended in stand with very high site quality, and can reach up to 2/3 of the total height of the tree.

Traditional crown pruning, focusing on the elimination of dead branches located in the inner part of the crown, is avoided. Nowadays in Europe, pruning that would imply tree climbing has been abandoned, due to excessive labour costs and especially due to health and security risks. Moreover, in any zone accessible for tractors, cones are harvested now mechanically with tree shakers. Only in regions with risks of heavy snowfalls, such as the higher belt of Mount Lebanon, the issue of crown cleaning may still be relevant.

Maintenance:

The period with a sound cone production extends up from the application of the second selective thinning (around 50 years-old) to the beginning of the regeneration felling's (over 100 – 120 years-old). During all this period cones will be collected annually, and the only interventions to be applied should be:

- Sanitary felling's on damaged, unhealthy or dead trees.
- Tending of competitive individuals of other species or understory (e.g., *Cistus* shrubs) and/or nonviable advanced regeneration of *P. pinea.*

Cone harvesting:

Cones will be annually harvested, during the period extending from mid-November to the end of March. Harvesting of cones should be carried out using mechanical vibrators, except for:

- Days with sub-zero air temperatures.
- Areas where natural regeneration is under promotion or already established.
- Areas with excessive slope.
- Areas with special protection.

Natural regeneration:

Renewal of the stands should be attained by natural regeneration or under planting. The proposed silvicultural system is a uniform shelterwood system, to be carried out in three fellings as detailed below:

- Seedling cutting: in this intervention stand density should be reduced to 90 trees/ha, with a basal area of 12-13 m^2/ha. The objective of this intervention is to attain the establishment of a wide number of viable seedlings under the area of projection of the crown. Trees to be maintained should be selected among those with larger crowns, best shape and greatest cone production. Gaps with a diameter over 12 m should be avoided.
- Shelterwood cutting: once a viable regeneration of seedlings is established under the crowns (which can happen between 5-10 years after the seedling cutting) a secondary cutting should be applied.

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This cutting aim to free these seedlings after this initial phase, attempting to promote their individual growth. Within this intervention we should leave 30-40 mature trees/ha.

- Final cutting: to be carried out 5 years after the previous cutting treatment. All the remaining trees should be removed, except 5-10 trees/ha which should be reserved as cone producers, such trees also fulfil the objective of promoting biodiversity, animal habitat and deadwood provision.

Silvicultural guidelines for managing *P. pinea* stands in a southeastern Portuguese region for cone production

Authors: JF, MT, CSS, MRT

In Portugal the management objective of stone pine stands is almost always the optimization of cone production per hectare, with the wood from thinnings being considered as an additional revenue, therefore this is the one that will be considered. Most of the adult stands are naturally regenerated but since around 1970 plantation has emerged throughout the distribution area of the species with an increasing tendency (the area increased 46 % from 1995 to 2010, being now 176 thousand hectar. For this reason, two silvicultural systems were considered, one for existing naturally regenerated stands and another for new plantations. The following silvicultural treatments were taken into account:

- Initial density in new plantations
- Selection of genetic material
- Decision about grafting/not grafting
- Thinnings
- Pruning
- Cone harvesting methods
- Regeneration method in existing stands (including new plantations when they get old) and time/age to start regeneration treatments.

Irrigation and fertilization are also being considered in recent years by Portuguese forest managers but, since there are very few data about the influence of these treatments on cone production, they were not considered here. Another important treatment is the grafting that is becoming more and more frequent in the establishment of new plantations.

Table 2.9. Portuguese traditional silvicultural systems for cone production

Operation	Correia & Oliveira (2002)	Louro et al. (2002)	Costa et al. (2008)
Initial density	625 ha	500 to 600 ha	208 to 400 ha

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Beating up	Between one and three years after installation if applicable (plantations)		
Pruning	Remove branches without female flowers (no prescription)	Removing 1/3 of branches: - Between 8 and 12 years - Between 20 and 25 years Removing branches that don't produce female flowers: - Between 35 and 40 years - Between 50 and 60 years	Removing 1/3 of branches: - Between 5 and 6 years - Between 10 and 12 years - Between 20 and 25 years
Thinnings	10 years till 500 ha 15 years till 300 ha 31 years till 100 ha	Between 15 and 20 years old 440 ha Between 20 and 25 years old 352 ha Between 25 and 30 years old 281 ha Between 35 and 40 years old 225 ha	Between 5 and 6 years old Between 20 and 25 years old (no information about densities after thinning)
Final density	100 ha	225 ha	Between 100 and 120 ha
Final cut	80 years old	Between 80 and 100 years old	No information

Traditional silviculture practices in Portugal:

Traditional silvicultural systems for Portuguese stone pine managed for cone production have been described by three authors (Table 2.9). The traditional guidelines focus decisions relative to initial density in plantations (including beating-up), pruning and thinning and age for the final cut. They do not describe the regeneration method in existing stands (including new plantations when they get old) and time/age to start regeneration treatments.

Updated silvicultural guidelines for promoting cone and pine nut production in the southeast region of Portugal:

As previously mentioned, the silviculture guidelines described below focus stone pine management for cone production, considering guidelines for the existing stands and for the new plantations separately. They took into account data collected into 100 permanent plots, considering a diverse range of development stages, stand structure and stand density as well simulations undertaken with a decision support tool based on the PINEA.pt model (described in Freire 2009) that was built with data from the permanent plots.

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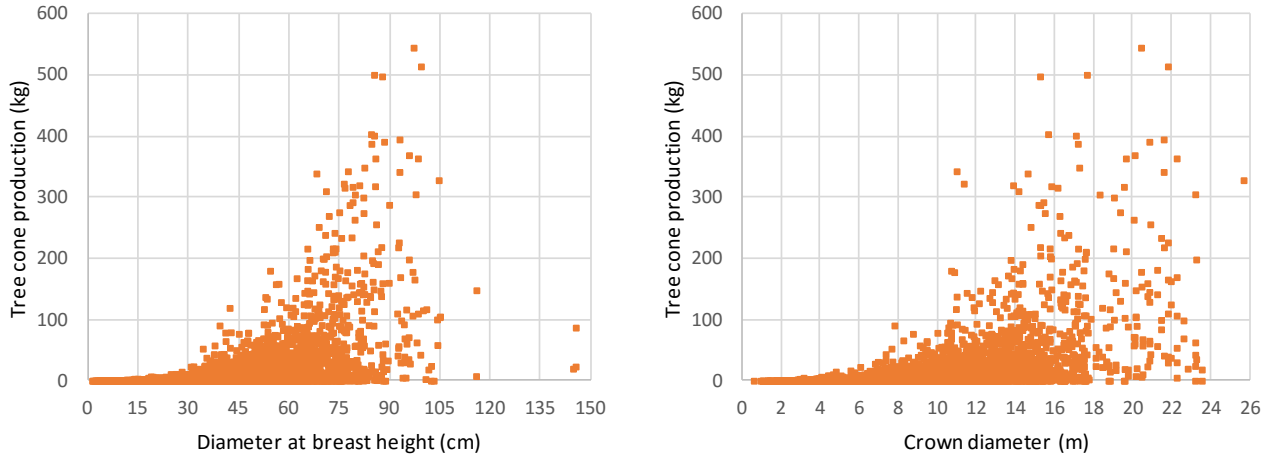

Figure 2.15: Cone production per tree in relation to DBH and crown diameter.

Naturally regenerated existing stands

Thinning:

The higher cone productions occurs in trees with large DBH and crown diameter, being frequent to find out trees in very sparse mature stands trees, with DBH between 75 and 100 cm and crown diameter between 18 and 24 m, producing more than 400 kg of cones, going to more than 6 tons of cones/ha in good crop years (Figure 2.15). The cone heterogeneity shown in Figure 2.15 is due to the masting habit. Larger trees show greater heterogeneity into cone production. Nevertheless, till now, in each year plots with very big sparse trees are always the ones with higher cone production per hectare despite the average production for the year. In order to obtain trees with these crown diameter sizes the stands must have a stand density between 15 and 30 trees/ha. Figure 2.15 also shows a number of overmature trees, with a DBH greater than 1 m, growing with little or without competition but with small cone production. This information suggests that rotation length in even-aged Portuguese *P. pinea* stands for cone production should be around 90-100 years and that the maximum diameter in selection forest should be around 1 m.

Cone production per hectare increases with basal area until a threshold is attained from which cone production start to decrease probably due to competition (Figure 2.16). The threshold is between 14 and 18 m^2/ha independently of the stand structure. Thus, thinning should take place before this threshold is reached.

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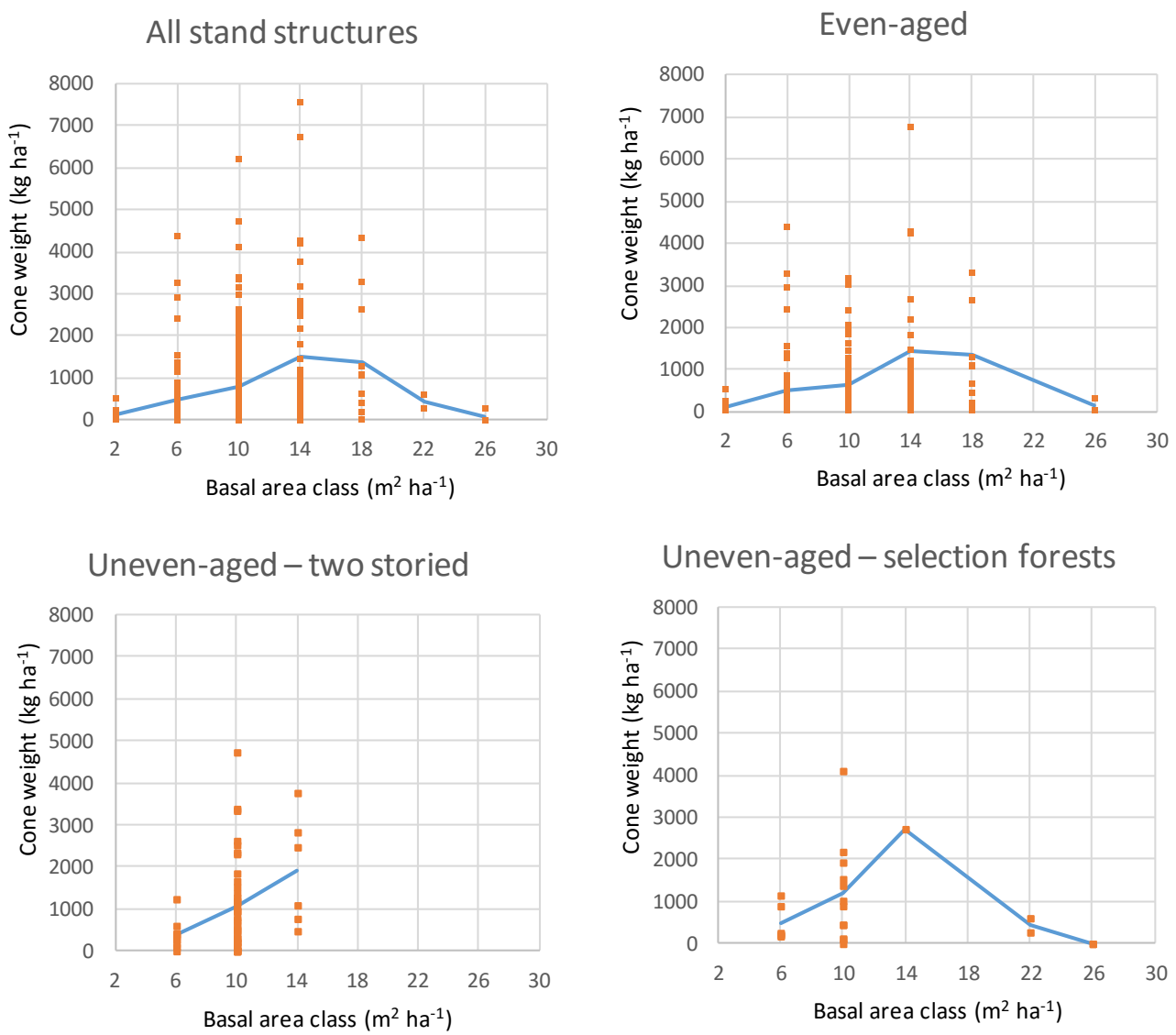

Figure 2.16: Impact of basal area on cone production for the different stand structures analyzed. The blue line represents the average production (all plots in all sampled years).

Besides cone production, cone quality is a parameter that has an increasing importance. Cone quality can be evaluated by mean cone weight due to the relationship between kernel production and cone dimension. Big cones origin more kernel with bigger dimensions. Medium weight of a cone decreases with basal area but the decrease is larger for basal areas greater than 14 m^2/ha (Figure 2.17). This result is not so clear for the plots classified as uneven-aged-selection forest.

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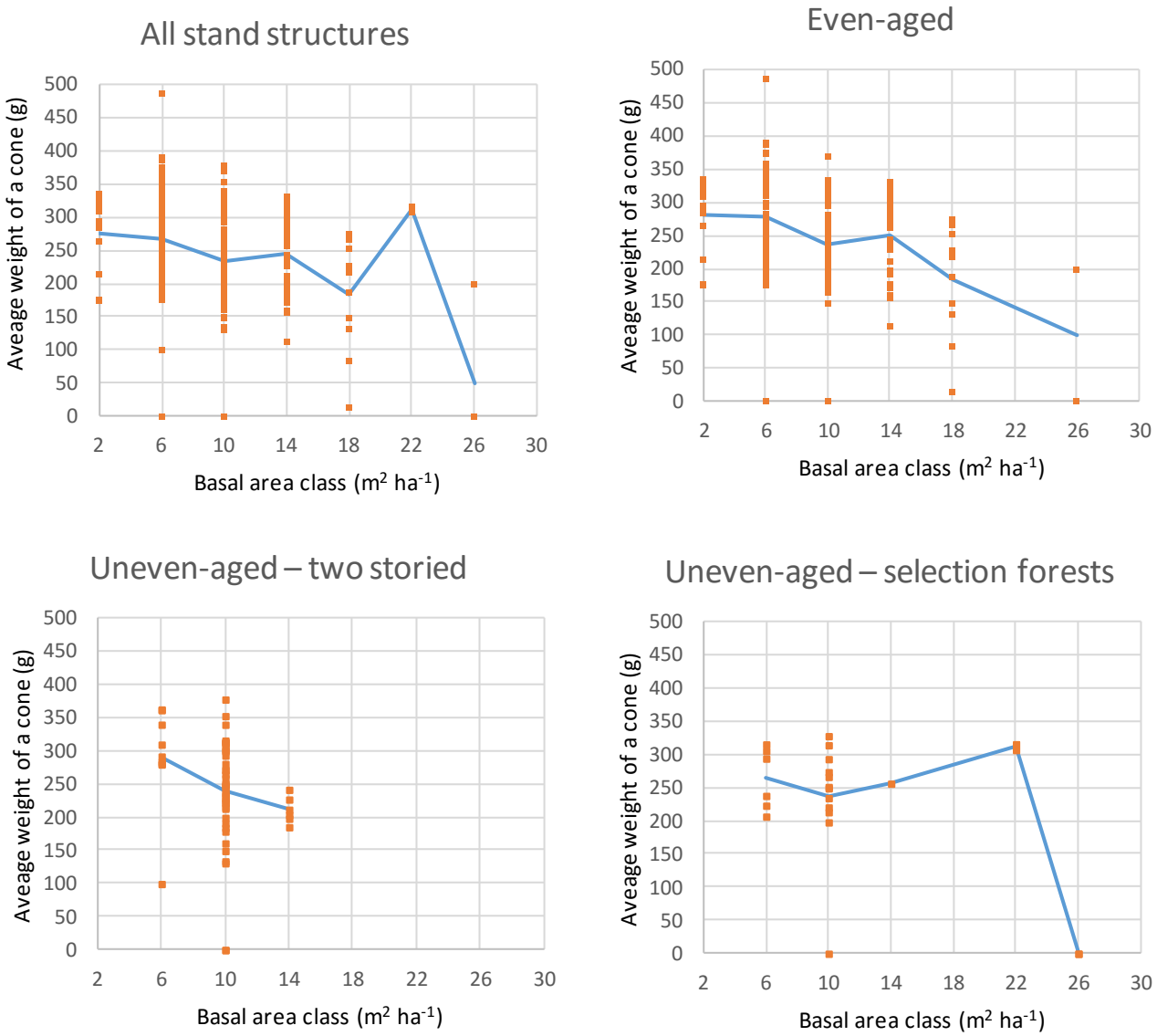

Figure 2.17: Impact of basal area on cone quality (using average cone weight as a proxy for cone quality) for the different stand structures analysed.

The relationship between cone production per hectare and stand density was also analysed. It was found that the higher cone productions occurs in very sparse stands with a stand density between 15 and 30 trees/ha despite the stand structure (Figure 2.18).

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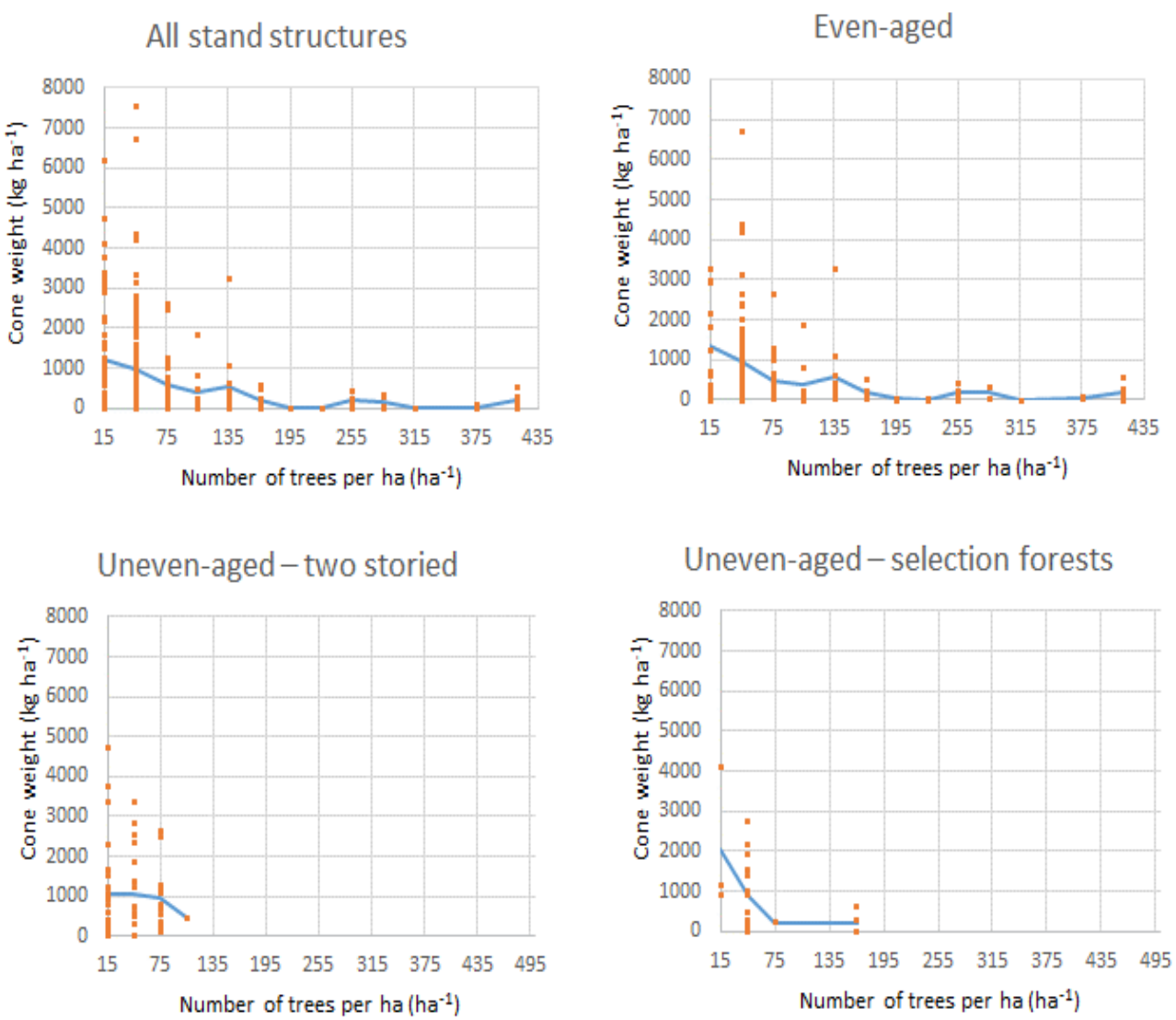

Figure 2.18: Relationship between cone production and number of trees/ha for the different stand structures considered.

Cone yield and stand structure are very heterogeneous into the permanent plots, therefore the plots with higher production in each of 4 quadratic mean DBH (dg) classes were analyzed. It can be concluded that in even-aged stands average basal area is around 12 m^2/ha for plots with a *dg* higher than 30 cm. Thus, an easy way to manage *P. pinea* stands in Portugal for cone production could be to maintain basal area into an interval 8 to 14 m^2/ha (Table 2.10). Whenever the above limit would be reached thinning would take place in order to achieve the bellow limit. This is a way to deal with the problem that in good sites trees grow more than in power ones.

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Stand density is other element that has to been taken into consideration. In average data from the permanent plots show that the number of trees needed to get higher cone productions per hectare in Portugal is much less than the referred in the traditional guidelines. For the higher *dg* classes in average it is possible to achieve more cone production in even-aged stands than in uneven-aged ones. Cone production decreases even more if a stand structure near selection forest is considered. Another conclusion is that, in average, it is possible to attain more cone production per hectare in Portugal than in Spain. The number of thinnings to be held in a stand will depend upon initial density and site quality.

Table 2.10: Analysis of plots with the highest cone production in Portugal per dg classes.

Stand Structure	dg	Cone yield (kg/ha)			G_{Pm} (m^2/ha)			N_{Pm} (ha)		
		Min	Avg	Max	Min	Avg	Max	Min	Avg	Max
Even-aged	[0, 30]	1.4	302.9	553.8	3.8	**7.2**	12.1	60	**220**	509
	[30, 50]	319.2	1631.1	3335.9	6.1	**12.9**	24.7	39	**96**	215
	[50, 70]	7.1	2593.0	6349.0	5.6	**11.0**	18.4	18	**44**	88
	[70, 90]	3261.5	4819.7	7550.8	7.2	**12.5**	15.3	18	**28**	32
Uneven-aged two storied	[30, 50]	463.9	1560.8	3161.0	10.0	**13.4**	26.9	60	**102**	297
	[50, 70]	175.5	1365.0	3344.1	6.5	**8.8**	11.5	21	**31**	56
	[70, 90]	35.8	1501.8	4731.8	2.5	**8.1**	10.9	6	**18**	28
Uneven-aged selection forests	[30, 50]	329.1	880.9	1706.5	12.5	**16.3**	20.7	127	**133**	151
	[50, 70]	109.0	842.1	1538.0	8.8	**10.5**	11.6	35	**42**	50

More details about the analysis of the permanent plots in Portuguese stone pine stands towards the development of new silvicultural guidelines can be seen in Freire et al. (in prep. a).

Pruning:

Land owners in Portugal usually prune the remaining trees after a thinning justifying this practice with the increase of cone production after the operation. However, no research results are available on the influence of pruning over cone production and land-owners income. In order to understand if pruning is a treatment to be held in a stand for cone production it will be needed to establish trials to study the influence of pruning taking into account costs/benefits. This study should last for several years because the influence of thinning over cone production could last for several years.

Until then for Portuguese stone pine stands, silvicultural guidelines must consider the pruning methodology that is being held in Portugal in stands for cone production:

- First pruning usually occurs when trees are 10 to 12 years hold, being pruned to a height of 2.0 m.

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- Whenever a thinning takes place the remaining trees are pruned in average 1.8 m per pruning removing both dead and green branches.
- The higher base crown height by pruning in permanent plots is 10.7 m, therefore 11.0 m should be assumed as the maximum pruning height.

Regeneration method:

The existing naturally regenerated stands regeneration depends mainly on the stand structure but also on the forest manager objective. If the stand structure is even-aged or a two-storied structure and the objective is to maintain this type of structure, a uniform shelterwood system seems to be the most appropriate. However even-aged stands may be converted to a more or less uneven-aged structure by using a single tree selection system, although numerous preparatory cuttings are needed to prepare the transformation. If the stand structure is already uneven-aged and structure is to be maintained, a single tree selection system will do the job. This implies the definition of a cutting cycle, an expected diameter distribution and a maximum diameter. The traditional J-shaped diameter distributions were traditionally recommended, but Smith (1993) suggests that foresters should focus on maintaining a continuous stock of larger trees, without excessive concern about perfectly balancing age classes. In Portugal there is no experience on the regeneration of existing stands by such complex silvicultural systems, therefore our advice for forest managers is to follow the rules presented for Valladolid above.

Cone collection technique:

In Portugal cones are harvested from 1st December till 15th April the following year. There are two ways of collecting cones: manual and/or mechanical harvest. The selection of the technique to be considered to collect cones – manual versus mechanical – has to take into account the dimension of the trees, namely DBH, total and base crown heights, number of cones per tree and the time when the operation is performed.

Manual cones harvesting was the traditional method to collect cones in Portugal. It is performed with the aid of a steel ladder and hooked sticks. Mechanical harvesting may be performed tractor mounted tree shakers. If the stand is dense and composed with relatively small diameter tall trees with few cones per tree, harvesting cones mechanically may be an option if the harvest takes place until mid February. The mechanical collection of cones has some advantages: it is a secure method that can be applied to a large number of trees in a short period of time allowing a reduction of cone theft. The weather conditions are not a limitative issue to catch cones from the trees. But it also has some disadvantages: if the collection is performed later then mid February as it increases the probability of loss of the cones that would mature in the following year; such cone loss with this kind of harvest can reach up to 30 %; the vibration intensity applied to each tree must be modulated and be just enough to drop the mature cones. This requires the appropriate training and the skill of harvesting machines operator to adapt vibration to each situation; often the vibration process causes wounds on the trunk of trees with considerable dimensions, presenting an open door for pathogens. Meanwhile, the DBH can restrict the efficiency of the utilisation of this method. To understand the efficiency

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of this kind of harvest to collect cones this method was used in two plots for three harvest campaigns: after the trees had been shaken a man climbed the trees in order to collect the remaining cones. Figure 2.19 shows the percentage of number and weight of cones that were harvested considering a mechanical process and the cones which have remained in the pines which were removed by manual harvest. It can be seen that for trees with a DBH larger than 48 cm and 57 cm, respectively, more than 30 % and 50 % of the cones (number and weight) remained in most of the analysed trees after mechanised harvest.

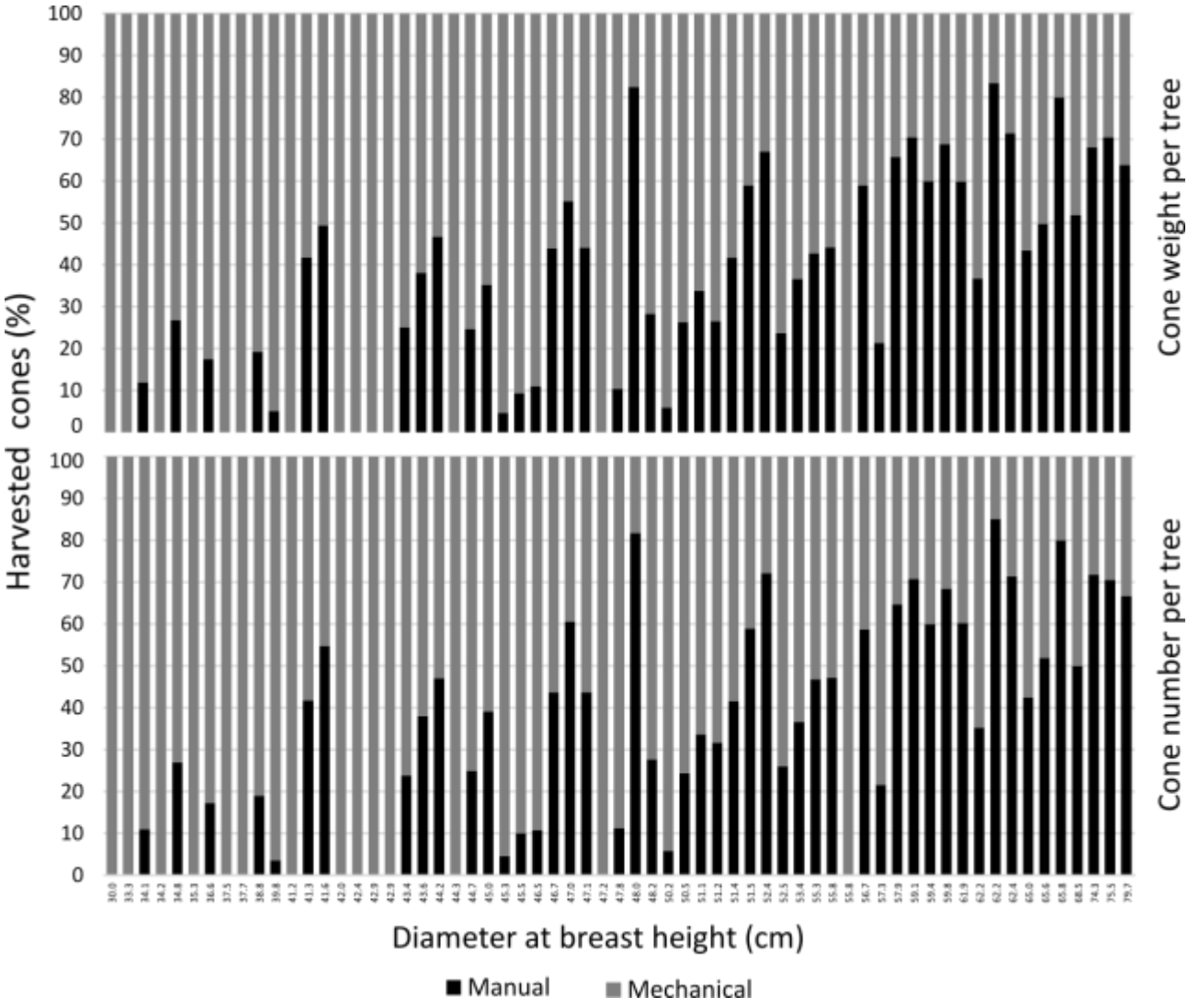

Figure 2.19: Percentage of cones collected by mechanical and manual methods

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New plantations:

In Portugal there are very few adult plantations of *P. pinea* and none of those few are represented within the 100 permanent plots that are being monitored. For this reason, the PINEA.pt model (Freire 2009) implemented in the tool PINEA.manage has been used to prescribe silvicultural guidelines for Portuguese pine plantations. The PINEA.manage tool is an EXCEL tool that uses the PINEA.pt model for the average tree, extending it to stand information by multiplication by the number of trees/ha. The tool is described in the StarTree Deliverable D2.4 (Kurttila and Tahvanainen 2016). In the meanwhile the PINEA.pt model is being implemented in the SadFlor DSS (Marto et al. 2016).

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

At a plantation thinning should take place before crowns touch; at this exercise we have considered a distance of 0.2 m between trees. In order to simplify the exercise, we just considered an average site quality and two types of systematic thinnings:

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

The NPV was computed for each alternative tested considering an interest rate of 3 % for all described alternatives, being selected the one with higher value of NPV.

This exercise with the thinning intensity of 50 % shows that at least two pre-commercial thinning before 20 years old and four more thinnings are needed for initial densities equal and above 400 trees/ha while for initial densities equal and below 278 tree/ha no pre-commercial thinning is needed, with the interventions reduced to four thinnings. Taking into account the listed above assumptions the alternative with higher NPV considered an initial density of 156 trees/ha (Table 2.11).

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Table 2.11: NPV for prescriptions considering a thinning intensity of 50 %.

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

Table 2.12 presents a description of the selected prescription, considering the age when each thinning takes place, the *DBH*, crown diameter (*cw*), the minimum distance between crowns (*minDist*), the number of trees/ha (*N*), basal area (*G*) and percent crown cover (%) before and after the thinning takes place.

Table 2.12: Description of the selected prescription considering a thinning intensity of 50 % of the trees

Parameters / Treatment	*Age*	*DBH*	*cw*	*minDist* (m)		*N* (tree/ha)		*G* (m^2/ha)		*GC* (%)	
				Before	After	Before	After	Before	After	Before	After
Thinnings	23	32.7	7.9	8.0	11.3	156	78	12.5	6.5	76.1	39.7
	33	42.5	10.4	11.3	16.0	78	39	10.7	5.5	66.0	34.9
	55	62.6	15.9	16.0	22.6	39	20	11.8	6.2	76.9	40.9
	75	82.6	21.8	22.6	32.0	20	10	10.5	5.4	74.9	38.5
Final cut	100	111.2	25.3			10		9.7		50.2	

When a thinning intensity of 75 % is considered, at least a pre-commercial thinning before 20 years old and two more thinnings are needed for initial densities equal and above 400 trees ha while no pre-commercial thinning and just two thinnings are needed for initial densities equal and above 278 trees ha. Taking into account the above listed assumptions the alternative with higher *NPV* considered an initial density of 156 trees/ha (Table 2.13).

Table 2.14 presents a description of the selected prescription, considering the age when each thinning takes place, the DBH, crown diameter (*cw*), the mean distance between crowns (*Dist*), number of trees/ha (*N*), basal area (*G*) and percent crown cover (%) before and after the thinning takes place

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Table 2.13: NPV for prescriptions considering a intensity of thin of 50 %.

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

Table 2.14: Selected prescription when the thinning intemsity is 75 % of the trees.

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

More details about the PINEA.manage tool can be seen in D2.4 (Kurttila and Tahvanainen 2016) and in Freire et al. (in prep. b). It is important to point out that most of the data used to develop the PINEA.pt model was from naturally regenerated stands in which trees are not equally distributed in the stand being usual that existing trees compete with their neighbors even in sparse stands. Thus, some extrapolation is being done when simulating new planted stands. The guidelines for pruning presented for existing stands are also recommended for the new plantations. The same is true for the regeneration method and the cone collection techniques.

Main differences between traditional silvicultural systems and revised guidance

There are two main differences between the updated and traditional silvicultural systems:

1) The initial density. The density at planting proposed in the prescribed silvicultural system is much smaller than the one used in the traditional silviculture, reducing or even eliminating the need of pre-commercial thinnings that are costly to land owners.
2) Considering that trees growth and cone production after 25, 30 or 40 years is highly influenced by inter-tree competition, being necessary to adjust competition among trees in order to maintain and/or increase cone production per hectare. Thus, it is essential to thin more often taking into

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account tree crown growth, site quality and initial density, reaching a final density substantially lower than the prescribed in traditional Portuguese forestry systems.

2.4 Understory plants/berries

Authors: JM, MK, TP

Optimising the management of stands in the joint production of timber and understory berries:

Silvicultural guidelines are prepared for Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* L.) Karst.) and silver birch (*Betula pendula* Roth) stands, as well as a mixed stand of pine, spruce and birch. In Finland, pine, spruce, birch and mixed stands are growing on *Myrtillus* type (MT) mesic heath most suitable for bilberry and pine stands on *Vaccinium* type (VT) mesic heath most suitable for cowberry and sometimes also for bilberry.

The market prices paid to berry pickers (MARSI 2014) and berry-picking costs were used in calculations. The effect of berry prices (zero and double-prices) on the optimal stand management was also analysed. Therefore, the following results are the most applicable to situations where the forest owner directly or indirectly benefits from managing the stands for both timber and berry yields.

The management was optimised assuming that all initial stands having the age of 10 years were good for bilberry and/or cowberry. Stand development was simulated using the models of Hynynen et al. (2002). The empirical berry yield models for bilberry (Miina et al. 2009) and cowberry (Turtiainen et al. 2013) were used to predict the berry production during the development of the initial stands. The models first predicted the coverage of the berry species as a function of e.g. site fertility, regeneration method, stand age and stand basal area. Then, the annual berry yields were predicted as a function of e.g. dominant tree species, species coverage and stand basal area. In a mixed stand, the bilberry yield was calculated as the weighted average of the tree species-specific predictions. Due to the lack of models, the bilberry yield for birch was calculated using the model for Scots pine-dominated stands. Cowberry yields were predicted only in a pure pine stand. The annual berry yields were predicted first in a stochastic way, and then calculated as the mean of the 200 outcomes.

The yield models were calibrated using the berry yields measured in North Karelia, Finland (Kilpeläinen et al. 2016) and the results on berry yields reviewed and reported by Turtiainen et al. (2005). To correct over predictions in berry yields immediately after regeneration cutting, the additional 'ad hoc' reductions were assumed for berry yields in the beginning of rotation. The reduction affected mostly cowberry yield predictions.

Despite seemingly optimal site and stand characteristics for berry crops, not all forest stands are able to supply good berry yields in Finland (e.g. Raatikainen 1978; Raatikainen and Raatikainen 1983; Raatikainen et al. 1984). Therefore, it is more profitable to modify the stand management for promoting berry yields in stands which are good berry stands (Miina et al. 2016). The stand was assigned as a good berry stand by

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setting the random plot effects into berry yield models. The values of the random plot effects were such that the yield predictions for good berry stands were comparable to the good yields measured by Raatikainen and Raatikainen (1983) for bilberry and by Raatikainen (1978) for cowberry.

In optimisations, the objective function was the soil expectation value (SEV) with 3 % discounting rate. SEV was defined as the net present value of all future costs of and incomes from both timber and berry production. The average unit costs of silvicultural treatments and the mean roadside prices were applied in the calculations (http://www.metla.fi/metinfo). The fixed entry cost of a cutting was taken as 100 €/ha, and the variable costs of cuttings were calculated using the models of Rummukainen et al. (1995).

The berry-picking costs included travel cost per collected kilogram (0.1 €/kg) and yield-dependent harvesting cost (0.5 €/kg). However, the harvesting cost was increased (due to decreased berry picking productivity) when berry yield was less than 40 kg/ha and decreased in case of higher berry yields. It was assumed that berries were collected only when the berry-picking costs were less than the selling price. As a result, poor berry crops were not included in the incomes and harvested berry yields.

The nonlinear programming algorithm from Hooke and Jeeves (1961) was used to find the optimal combination of decision variables: number of years since regeneration (first thinning) or first thinning (second thinning), removal percentage separately for each tree cohort (for both thinning treatments), and number of years between the last thinning and final cut. The number of thinnings (i.e. 1 or 2) was given to the simulation-optimisation system before solving the problem.

2.4.1 Bilberry (*Vaccinium myrtillus*)

Optimal management of stands producing timber and bilberries:

Without valuing bilberries, the optimal management schedules of the pine and birch stands on *Myrtillus* (MT) site consisted of one thinning and a final felling at the age of 52 years in the pine stand and 38 years in the birch stand (Figure 2.20). The spruce and mixed stands were thinned twice and clear-felling was done at the age of 55 years in the spruce stand and 62 years in the mixed stand (Figure 2.20). The mixed stand was converted into almost a pure spruce stand towards the end of rotation (Figure 2.21).

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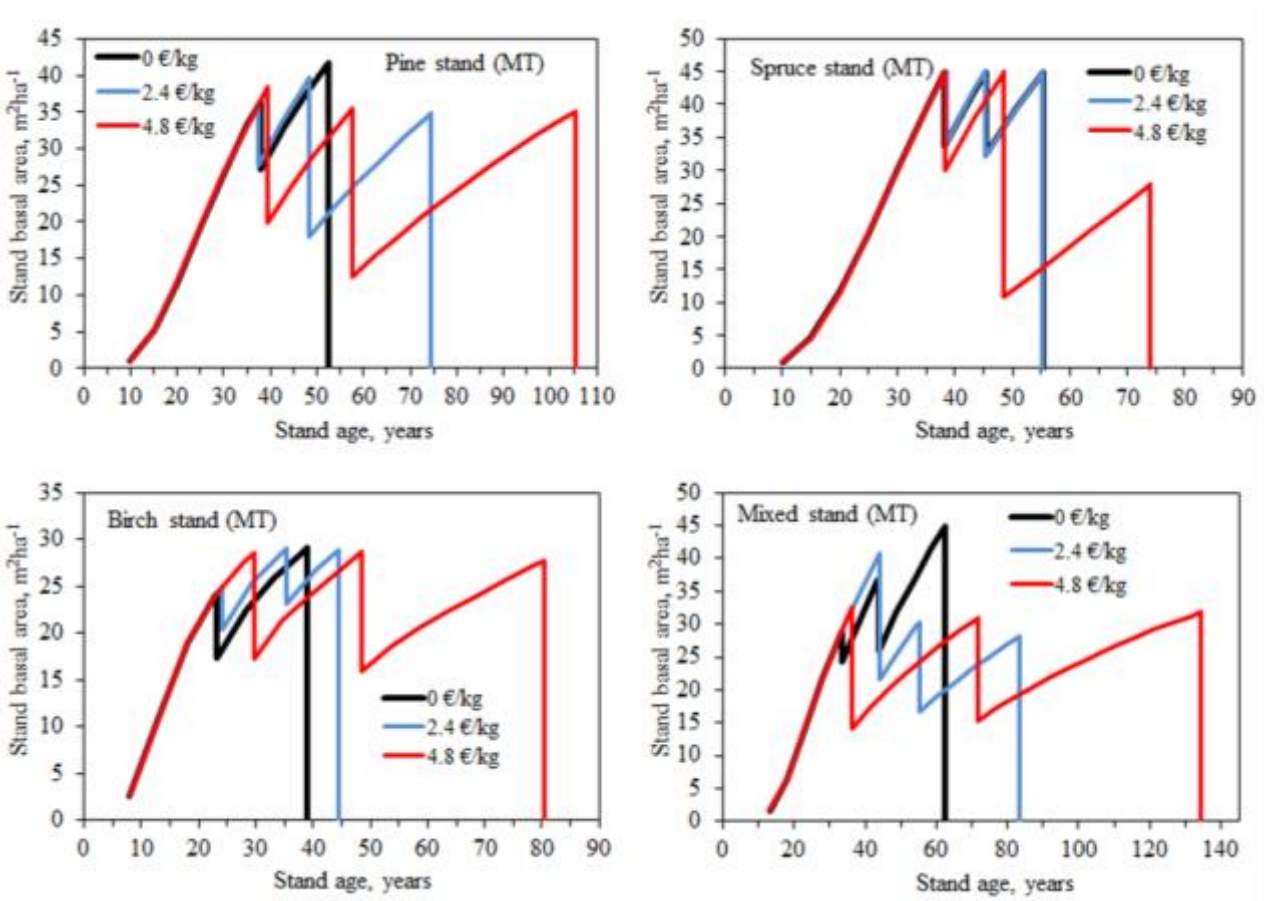

Figure 2.20: Effect of bilberry price on the optimal management schedules of the pine, spruce, birch and mixed stands on *Myrtillus* site (MT) type with good bilberry yield.

With the current market bilberry price (2.4 €/kg), the optimal management of the stands on *Myrtillus* (MT) site was clearly changed, except in the spruce stand (Figure 2.20). In the pine, birch and mixed stands, longer rotation, and more frequent and heavier thinnings were applied to reduce canopy shading to a level that is favourable for bilberry crops (Figure 2.23 and Figure 2.24). In the spruce stand, more frequent and much heavier thinning treatments may be needed to promote bilberry yields. The optimal stand management was changed and berry harvests increased most significantly in the mixed stand (Figure 2.20, Figure 2.23 and Figure 2.24). The mixed stand was converted into a pine-birch mixture, instead of a spruce-dominated stand (Figure 2.21). With doubled bilberry prices (4.8 €/kg) it was more profitable to apply still longer rotation lengths and higher thinning intensities, also in the spruce stand (Figure 2.20). With the current bilberry price (2.4 €/kg), the SEV with berries was more than twice as high as the SEV without berries, except in the spruce stand (Figure 2.22 and Figure 2.23).

With a doubled bilberry price (4.8 €/kg), bilberries contributed manifold to the SEV of the joint production of timber and bilberry and the profitability of management of the pine, birch and mixed stands was almost

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doubled. In the spruce stand, bilberry benefit did not exceed timber benefit even if bilberry price was doubled.

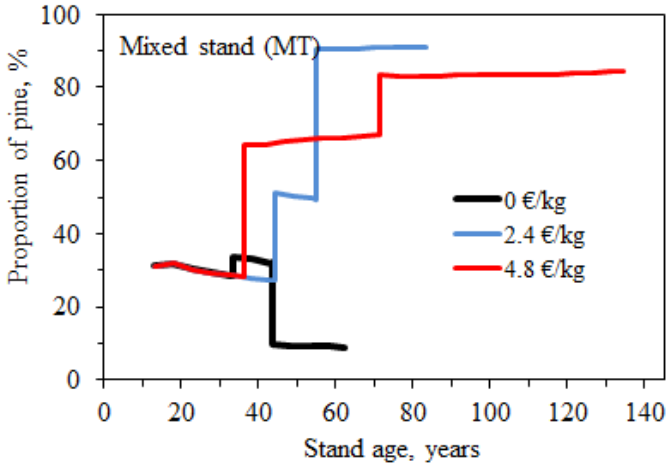

Figure 2.21: Proportion of pine of the total stand basal area in the optimal management schedule of the mixed stand on *Myrtillus* site (MT) type with good bilberry yield and different bilberry prices.

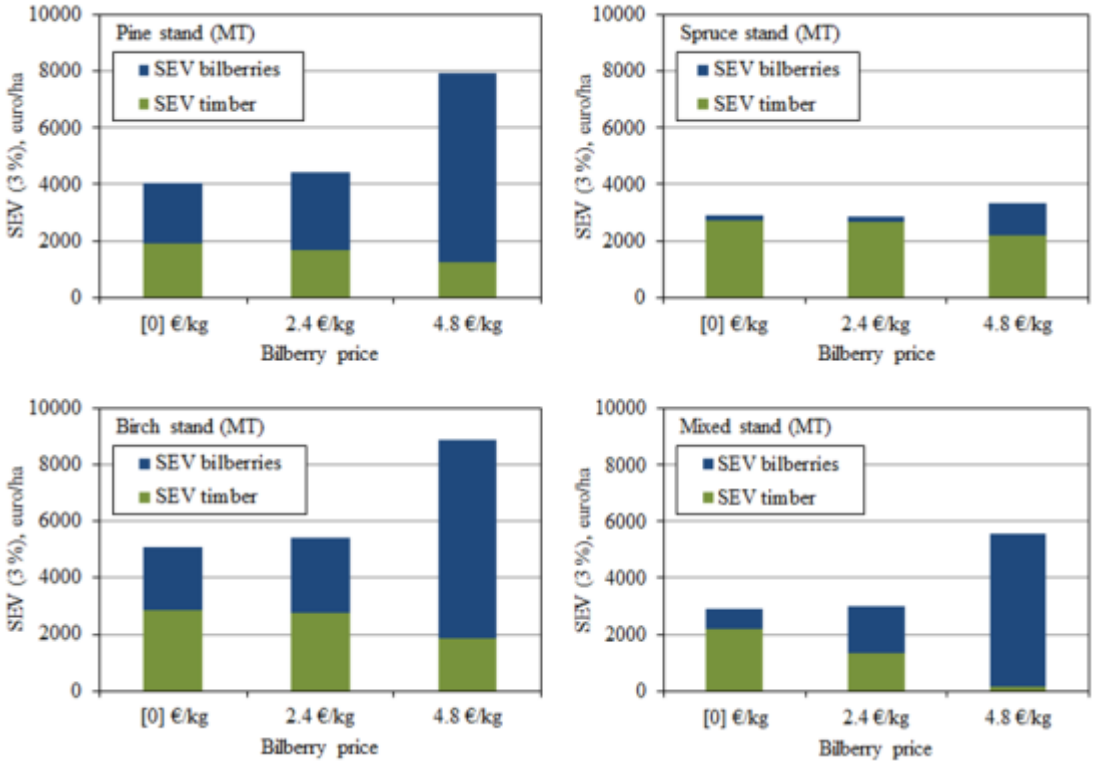

Figure 2.22: Effect of bilberry price on the soil expectation value (3 %) without bilberry incomes (SEV timber) and the additional SEV from bilberries (SEV bilberries). The management schedules were optimized for the stands on *Myrtillus* site (MT) type with good bilberry yield. [Note: In the optimal zero-pricing schedules, bilberry harvests and the additional SEV from bilberry were recalculated assumeing bilberry price 2.4 €/kg.]

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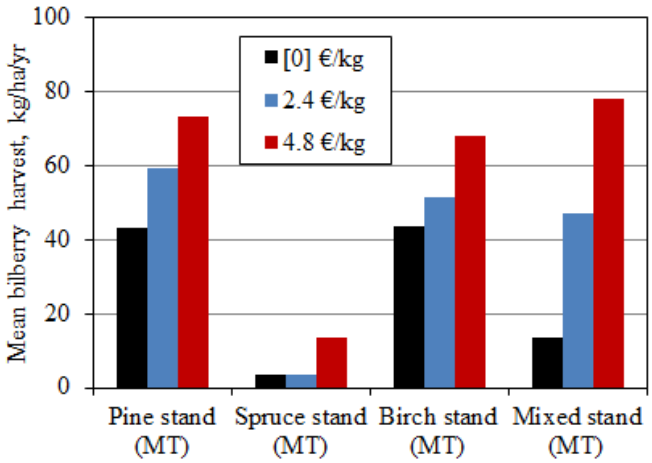

Figure 2.23: Effect of bilberry price on the mean annual bilberry harvest during the rotation of the stands on *Myrtillus* site (MT) type with good bilberry yield. [Note: In the optimal zero-pricing schedules, bilberry harvests were recalculated assuming bilberry price 2.4 €/kg.].

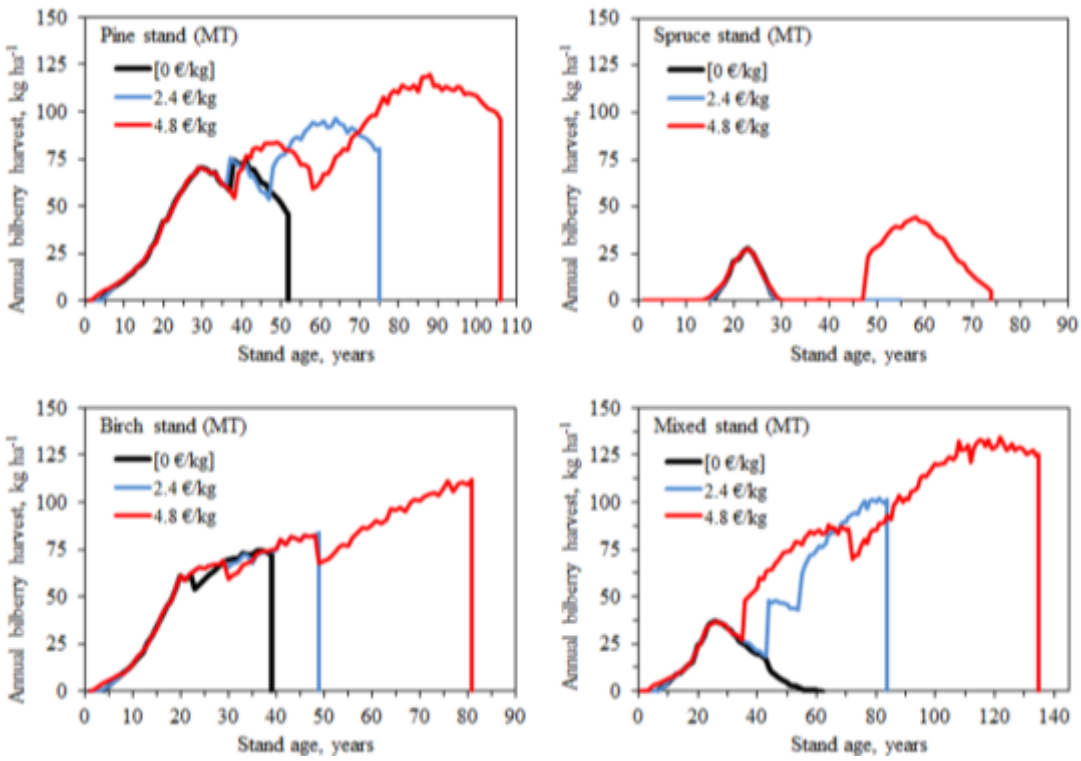

Figure 2.24: Predicted bilberry harvests in the optimal management schedules of the stands on *Myrtillus* site (MT) type with good bilberry yield and different bilberry prices. [Note: Bilberry harvests in the optimal zero-pricing schedules were recalculated assuming bilberry price 2.4 €/kg.].

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Silvicultural recommendations for promoting bilberry production on *Myrtillus* site in Finland:

Pine stands: Even-aged forest management which promotes bilberry yields is the most profitable in pine stands where the bilberry yields are known to be or can be assumed to become high (Miina et al. 2016). With the current market bilberry price and berry-picking costs, more frequent and heavier thinning and 20 years longer rotation are recommended when compared to the optimal management schedules without considering income from bilberry. In sparse, mature pine stands, applying a longer rotation results in a higher mean annual bilberry harvest during the rotation due to the fact that the highest bilberry harvests are obtained in the end of the rotation.

Birch stands: Modifying the management of birch stands (i.e. more frequent and heavier thinning and longer rotation) may be as profitable as in pine stands (Miina et al. 2010). However, empirical knowledge on bilberry yields in birch stands is missing. Also results on the optimal management for maximising the profitability of joint production of timber and bilberries should be taken with caution. In simulations conducted so far, bilberry yields for birch have been calculated using the yield model for Scots pine-dominated stands.

Spruce stands: It is not profitable to thin spruce stands more frequently and heavily, and to increase rotation length in order to benefit from bilberry production (Miina et al. 2010). According to the simulation studies, in the uneven-aged management of spruce stands, the stand basal area would be constantly at a level that enabled good bilberry yields and thus the potential bilberry yields would be higher than under the current even-aged management system (Pukkala et al. 2011).

Mixed stands: Instead of aiming at the spruce-dominated stand, mostly spruces are removed during thinning operations so that the stand will be converted into a mixture of mainly pines and some birches, which are favourable for bilberry (Miina et al. 2010, 2016). Heavier thinning and 20 years longer rotation are recommended.

2.4.2 Cowberry (*Vaccinium vitis-idaea*)

Optimal management of stands producing timber and cowberries:

Without valuing cowberries, the optimal management schedule of the pine stand on *Vaccinium* (VT) site included in one thinning and a final felling at the age of 51 years (Figure 2.25). When only cowberries were harvested, the optimal management of the pine stand was practically not changed with increasing cowberry price. It was not profitable to change the optimal management of pine, though the proportion of cowberry incomes of the total SEV was as high as 60 % with the market cowberry price 1.8 €/kg and 80 % with double-pricing 3.6 €/kg (Figure 2.26).

When both cowberries and bilberries were harvested from the pine stand on *Vaccinium* (VT) site, applying the market berry prices (cowberry 1.8 €/kg and bilberry 2.4 €/kg) berry picking increased the thinning intensity and rotation length only slightly (Figure 2.25). However, berry incomes contributed over 70 % of the total SEV (Figure 2.27).

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On the contrary, with two-fold berry prices the optimal stand management was markedly changed (Figure 2.25). A second heavy thinning was done and the rotation length was more than doubled. These changes in stand management decreased the SEV of timber production by 40 % (Figure 2.27), but at the same time, canopy shading was reduced to a level that was favourable for berry crops also in the end of rotation (Figure 2.28). Consequently, during the whole rotation the mean annual cowberry and bilberry harvests increased respectively by 20 % and 50 % (Figure 2.26).

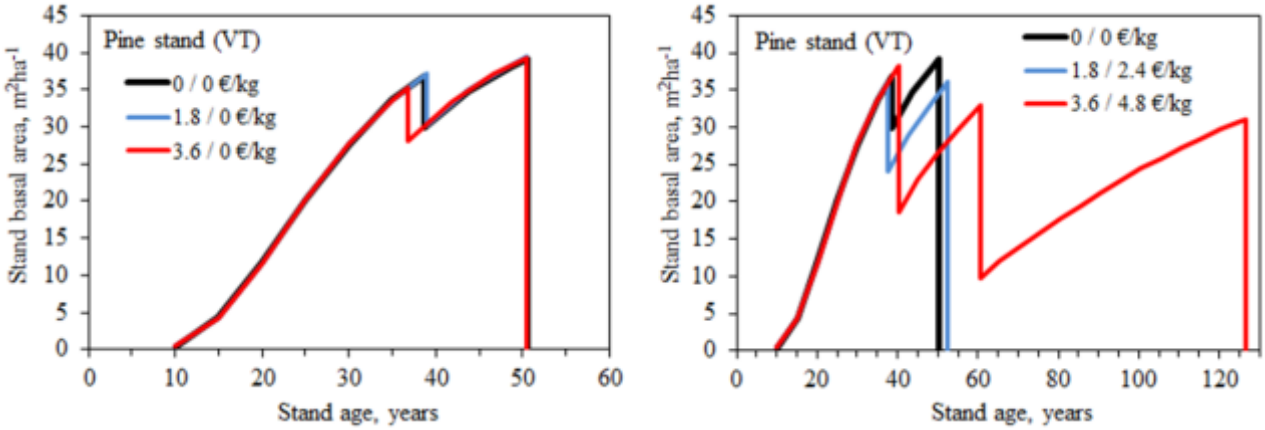

Figure 2.25: Effect of berry prices (cowberry/bilberry) on the optimal management schedules of the pine stand on *Vaccinium* site (VT) type with good berry yields when bilberries are not harvested i.e. bilberry price is 0 €/kg (left) or are harvested together with cowberries (right).

Silvicultural recommendations for promoting cowberry production on *Vaccinium* site in Finland:

Treeless open habitats are most suitable for cowberry, and therefore few years after regeneration cuttings (clear-cutting or seed-tree cutting) the cowberry yields would increase in pine stands on *Vaccinium* sites.

In practice, valuing cowberries (and bilberries) with the current market price does not affect the optimal management of pine growing on *Vaccinium* sites (Miina et al. 2016). This is due to the fact that according to the cowberry yield model applied, the highest cowberry yields in the pine stand were obtained in the beginning of the rotation and stand management does not markedly affect the cowberry yields later during the rotation. In young pine stands, thinning would promote cowberry yields but early thinning is not profitable.

However, if the aim was to increase cowberry (and possibly also bilberry) yields also in the end of rotation, heavier thinning treatments would reduce canopy shading to a level that is more favourable for cowberry (Miina et al. 2016). Because sparse mature pine stands are also suitable for cowberry, longer rotation lengths could be applied to maintain simultaneously the cowberry production and forest cover.

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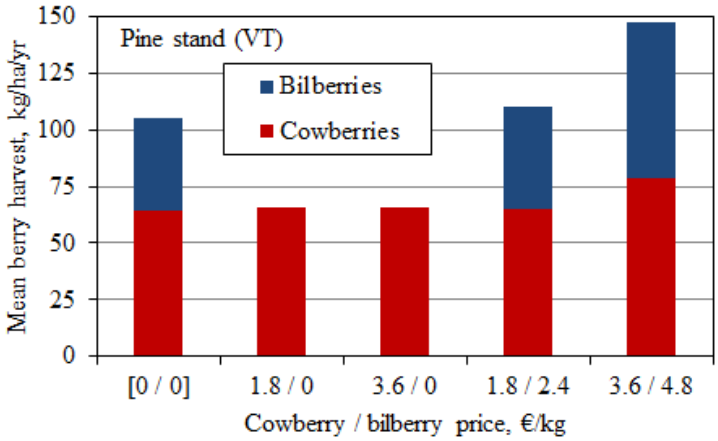

Figure 2.26: Effect of berry prices (cowberry/bilberry) on the mean annual bilberry harvest during the rotation of the pine stand on *Vaccinium* site (VT) type with good berry yields. [Note: In the optimal zero-pricing schedules, berry harvests were recalculated assuming cowberry price 1.8 €/kg and bilberry price 2.4 €/kg.]

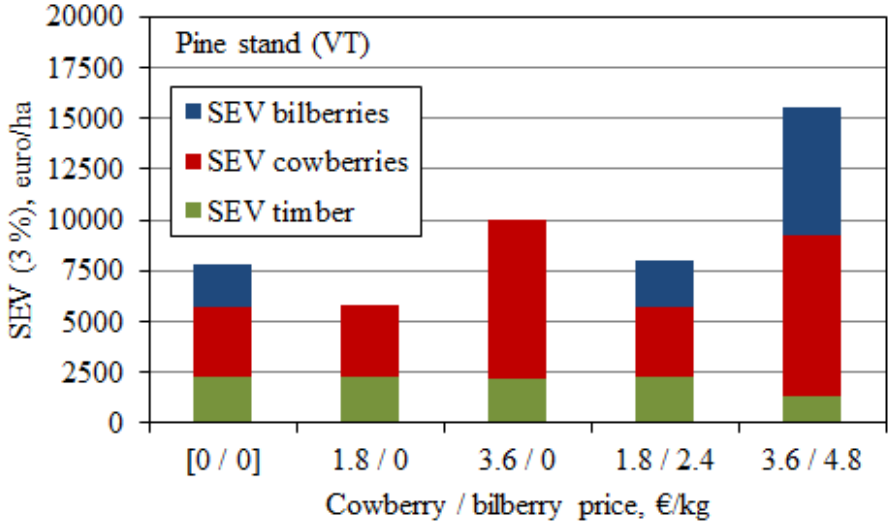

Figure 2.27: Effect of cowberry and bilberry prices on the soil expectation value (3 %) without berry incomes (SEV timber) and the additional SEV from cowberries (SEV cowberries) and bilberries (SEV bilberries). The management schedules were optimized for the pine stand on *Vaccinium* site (VT) type with good berry yields. [Note: In the optimal zero-pricing schedules, berry harvests and the additional SEV from berries were recalculated assuming cowberry price 1.8 €/kg and bilberry price 2.4 €/kg.]

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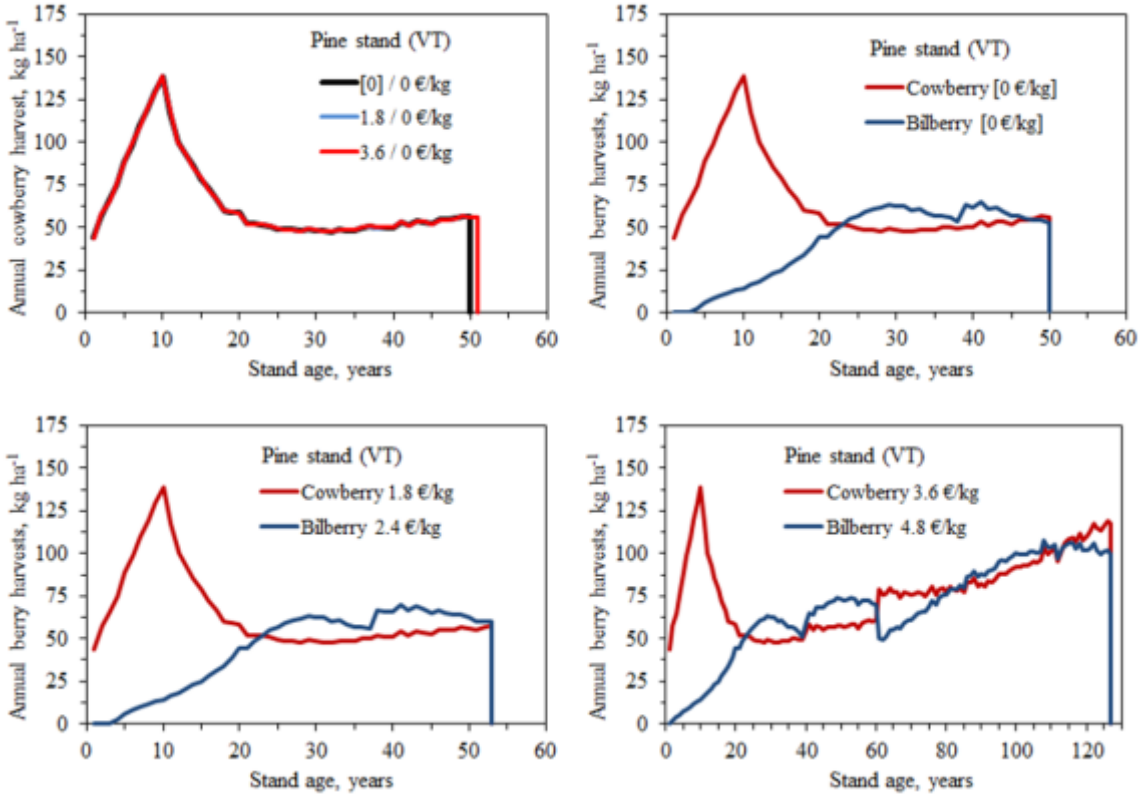

Figure 2.28: Predicted berry harvests in the optimal management schedules of the pine stand on *Vaccinium* site (VT) type with good berry yields and different berry prices. Upper left: bilberries are not harvested (bilberry price 0 €/kg); lower left and right: bilberries and cowberries are harvested. [Note: Berry harvests in the optimal zero-pricing schedules were recalculated assuming cowberry price 1.8 €/kg and bilberry price 2.4 €/kg.]

2.5 Mushrooms

Authors: JAB, SdM, RA, FXB, JMA

Annual mushroom production varies considerably in response to different factors. Weather may explain as much as 60 to 80 % of the variation in mycorrhizal fungal sporocarp production (Dahlberg 1991), namely rainfall and temperature constituting key drivers for mushroom fruiting conditions (Martínez de Aragón et al. 2007). In addition to weather variables, other factors have been identified as influential for mushroom emergence. Martínez-Peña et al. (2012) grouped the variables in three main groups: weather conditions, local site characteristics (elevation, aspect, soil, etc…) and forest stand characteristics (tree species, density, stand age…).

In Spain, the availability of long-term mushroom databases and the use of modelling techniques allowed identifying the influential factors affecting the mushroom yields and diversity. The first mushroom yields models were developed by Bonet et al. (2008) in even-aged *Pinus sylvestris* forests in north-eastern Spain.

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The models predict higher mushroom yields when, coupled with appropriate weather conditions, the basal area was around 20 m^2/ha. Posteriorly, Bonet et al. (2010) published new models expanding the analysis to *P. nigra*and *Pinus halepensis* ecosystems. Stand basal area remained the most significant stand attribute, so that maximum productions of total, edible and marketed mushrooms were found when basal area was around 15-20 m^2/ha (Figure 2.29).

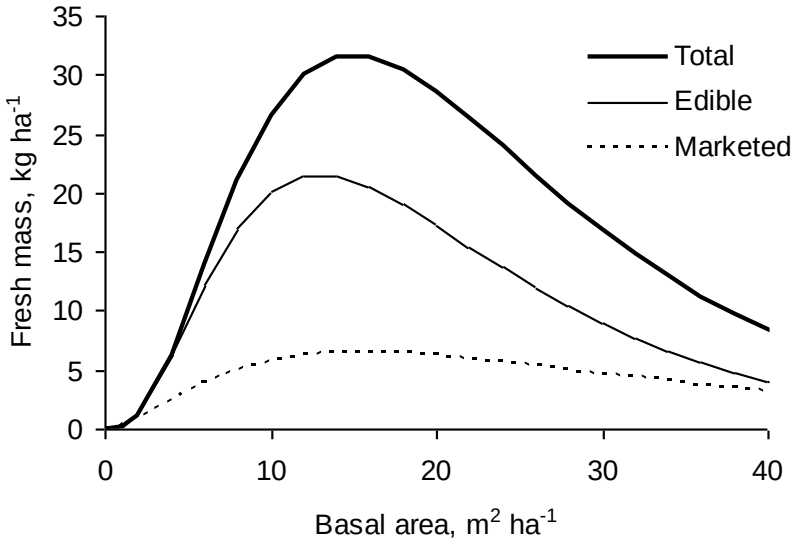

Figure 2.29: Mushroom production as a function of stand basal area in *P. nigra* and *P. halepensis* stands (Bonet et al. 2010).

In 2014, de-Miguel et al. (2014) updated the previous models established by Bonet et al. (2008 and 2010) by incorporating more data series and enlarging the pine forest ecosystems to be modelled. The target ecosystems for such study were pure stands of *P. sylvestris*, *P. nigra*, *P. halepensis* and *P. pinaster* and mixed stands of *P. sylvestris-P. nigra* and *P. nigra-P. halepensis*. The obtained models continued to show the relevance of the stand basal area on mushroom yields with different predicted mushroom yields depending on the pine forest ecosystems (Figure 2.30).

However, the observed pattern of occurrence of mushrooms in a certain forest ecosystem for total, edible and/or marketed productions may not be the same for individual target species. Similar to plant species, fungal species have adapted their own ecological strategies to survive in the very diverse soil ecosystems. Thus, the literature reflects very contradictory effects of silvicultural treatments on the individual species (see for example: Kardell and Eriksson 1987; Ohenoja 1988; Shubin 1988; Kropp and Abee 1996; Kranabetter and Kroeger 2001; Egli et al. 2010). Additionally, most of the studies are very local or regional, and consequently between-region differences in terms of site characteristics, weather and forest structure

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prevent adopting general recommendations, and further in-depth analysis focusing on individual fungal species is recommended.

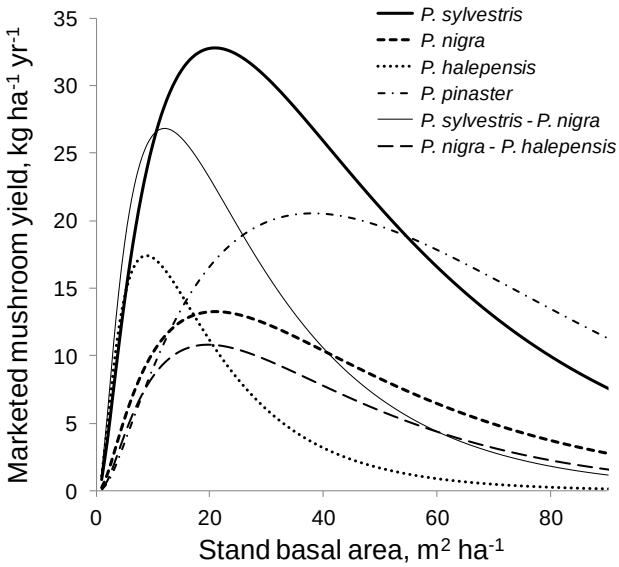

Figure 2.30: Effect of stand basal area on the yield of commercially important mushrooms.

2.5.1 Cep (*Boletus edulis*)

Silvicultural recommendations for promoting *B. edulis* yields in Spain:

Authors: JAB, SdM, RA, FXB, JMA

Among the large number of edible mushrooms (Boa 2004) only few species are marketed, and among them, only *Cantharellus cibarius* and *B. edulis* are officially authorised for trading in a large number of European countries (Peintner 2014). The boletes or ceps are probably the most traded mushroom species worldwide, being also an important complementary economic activity at local and regional scales (Salerni and Perini 2004; Cai et al. 2011; Martínez de Aragón et al. 2011). *B. edulis* is commonly associated with mature forest stands (Martín-Pinto et al. 2006) growing as a simbiont with different host species in different ecosystems, including pine forest, oak forests, beech forest, birch forests, chestnut forest and scrublands.

Similar to other mushroom species, climatic factors drive the fructification of boletes. In this sense, Savoie and Largeteau (2011) reported the personnel communication of Leprince and Guinberteau in France who noted the need of having both, temperature cold shock of more than 5 °C and rainfall representing at least 40 % increase in soil moisture. With such conditions, sporocarps could be picked from 6 to 25 days after the rain event, depending on the soil temperature. In Spain, Hernández-Rodríguez et al. (2015) reported the significance of the mean minimum temperatures of September and October for the presence of *B. edulis* in

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Cistus ladanifer ecosystems. Similarly, Martínez-Peña et al. (2012) also noted the positive influence of autumn precipitation and temperature in *Pinus sylvestris* ecosystems in North-Central Spain. The latter study, based on fifteen years of continuous mushroom records in eighteen different plots, developed the first model for the species, showing that stand basal area also affects significantly mushroom yield of *B. edulis*. The model was as follows:

$$Boletus = \exp(-14.706 + 0.007\, P_{autumn} + 0.129\, T_{autumn} + 5.049 \ln(G) - 0.121\, G)$$

where *Boletus* is the annual yield of *B. edulis* (kg/ha/yr), P_{autumn} is the sum of the total precipitation in August, September and October, T_{autumn} is the sum of the mean temperature in September, October and November, and *G* is the stand basal area)

Based on the model, the optimal stand basal area for *B. edulis* production was 40-45 m^2/ha (Figure 2.31).

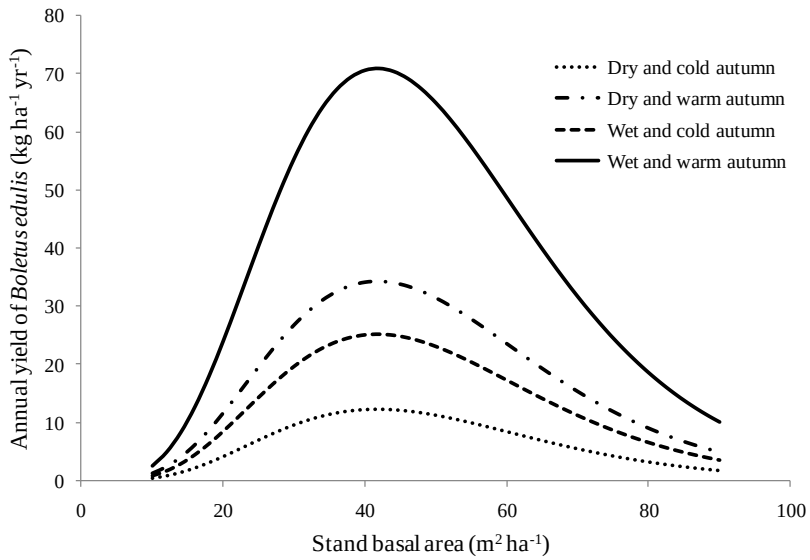

Figure 2.31: Relationship between annual yield of *B. edulis* and stand basal area in *Pinus sylvestris* stands (Martínez-Peña et al. 2012).

The influence of forest stand conditions was also confirmed in other countries as Italy. In Tuscany, Salerni and Perini (2004) carried out a thinning experiment on 54 sites, of which one third were subjected to medium thinning, one third to heavy thinning and one third remained as a control. The biweekly survey of the *B. edulis* fructification during two consecutive years showed a greatest number of fruitbodies in stations with medium thinning, with very poor productions in the plots subjected to heavy thinning. The authors concluded that this species does not need a dense canopy in mixed forests (i.e., *Abies alba*, with a minor presence of *Picea*

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abies, *P. nigra*and *Acer monspessulanum* in that study), but an open and sunny habitat for maximiszing their yields.

The influence of clearing and the burning of the vegetation on *B. edulis* production and mushroom functional diversity were also studied by Hernández-Rodríguez et al. (2015) in *Cistus ladanifer* ecosystems in Western Spain. *Cistus* scrublands are sources of highly appreciated mushroom species such as boletes, which normally appear when a disturbance occurs, namely clearing or a forest fire. The authors modelled *B. edulis* yield in plots subjected either to total clearing or total burning treatments. They observed that the production of *B. edulis* sporcarps is expected to start at about 5 years after treatment, whereas the maximum production, which can achieve more than 50 kg/ha/yr is reached at 14 years (Figure 2.32a). *B. edulis* production starts when the mean height of the scrubland reaches one meter, and reaches its maximum at a mean height of 1.5 metres. The highest production was associated with a canopy cover of 80 % (Figure 2.32b), which is reached already at early ages (before 10 years) and maintained during the rest of the life cycle of *C. ladanifer*, which also matches with the observation of Salerni and Perini (2004) in a very different ecosystem.

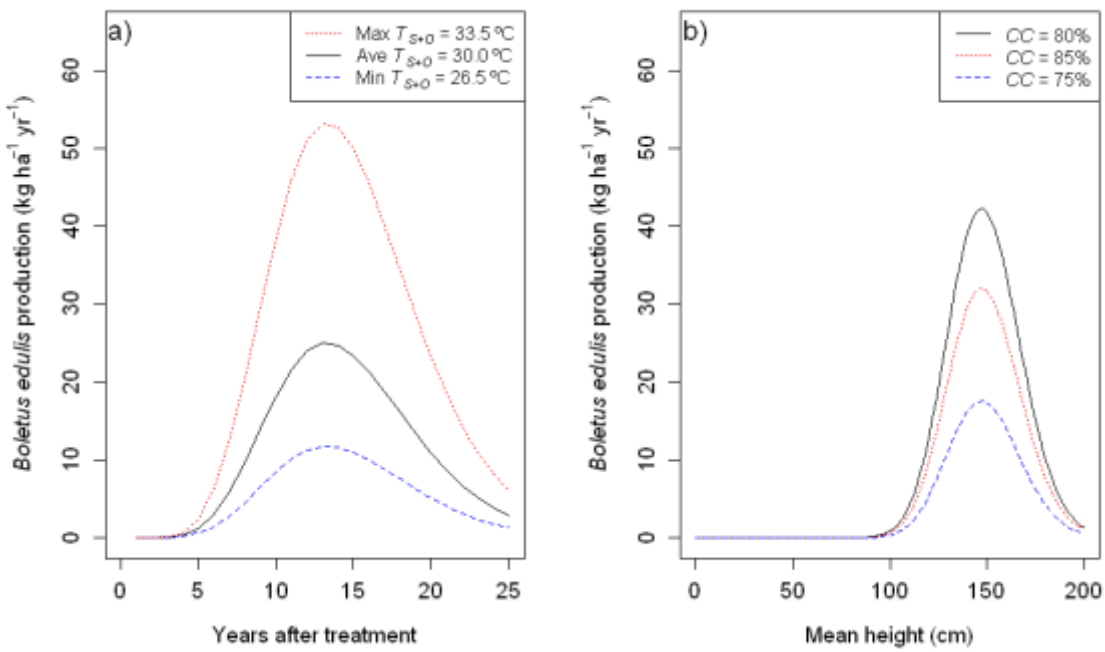

Figure 2.32: Effect of climate, time after treatment and vegetation characteristics on *B. edulis* production. T S+O: sum of the mean temperature of September and October; Max: maximum value of a given predictor observed during sampling period; Ave: average value of a given predictor observed during the sampling period; Min: minimum value of a given predictor observed during the sampling period; CC: canopy cover. Increasing minimum temperature of September and October produces a high increase in *B. edulis* production (Hernández-Rodríguez et al. 2015).

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Stand management for producing timber and *B. edulis* in spruce stands in Finland:

Authors: JM, MK, VT, KS

Mushroom yields in a Norway spruce (*Picea abies*) stand were predicted using the mushroom yield models by Tahvanainen et al. (2016). The stand was regarded as a good mushroom stand so that the 90th percentiles of the distributions of the random plot effects of the models were added to the yield predictions. Stand development and management were simulated using the Motti simulator (Hynynen et al. 2002). The initial stand was planted at the density of 1,800 trees/ha on *Oxalis-Myrtillus* (OMT) type in eastern Finland. In the simulations, stand management followed the silvicultural recommendations applied in privately owned forests in Finland (Metsätalouden kehittämiskeskus Tapio 2006). The stand was thinned at the age of 38 and 53 years and clear-cut at the age of 68 years. In other thinning regimes, the same rotation age was used but the timing of thinning treatments was either advanced or delayed by five years from recommendations. Also, an un-thinned regime was simulated.

For each thinning regime, the net present value (NPV) of incomes from timber and mushroom production was calculated using 3 % interest rate. The average stumpage prices of spruce pulpwood and saw timber in Finland were used in calculations (http://www.metla.fi/metinfo). Based on the statistics on the NWFPs offered for sale (MARSI 2014), the following prices paid to mushroom pickers were used: 3.4 €/kg for *Boletus* spp., 1.5 €/kg for *Lactarius* spp. and 1.2 €/kg for other marketed mushrooms. Incomes from selling timber and mushroom were discounted to the beginning of the rotation; the costs of forest regeneration and tending, mushroom picking, etc. were not included in calculations.

B. edulis yields increased along with stand age until a certain point, after which the yields started to decline (Figure 2.33). *B. edulis* yields declined when the stand age exceeded 30 years. Thinning improved *B. edulis* yields only slightly. According to the simulation results, advanced thinning (i.e. five years earlier than recommended) was the best for *B. edulis* yield and also the economic result of timber production benefitted from application of advanced thinning (Figure 2.34). However, the stands with advanced thinning generated the lowest total yield of all marketed mushrooms.

The total value of all marketed mushrooms was the highest in un-thinned stands (Figure 2.34). When the timber values were also considered, the stand with advanced thinning treatments generated the highest total NPVs. In the spruce stand with advanced thinning and good mushroom yield, the contribution of mushrooms to the total NPV during the entire rotation was as high as 25 %.

A topic of future study is to find out forest management practices which would optimise the joint production of timber and mushrooms in spruce forests in Finland. Forest owners, who prefer only mushrooms or both mushrooms and timber production, need to know how they should best manage their spruce stands.

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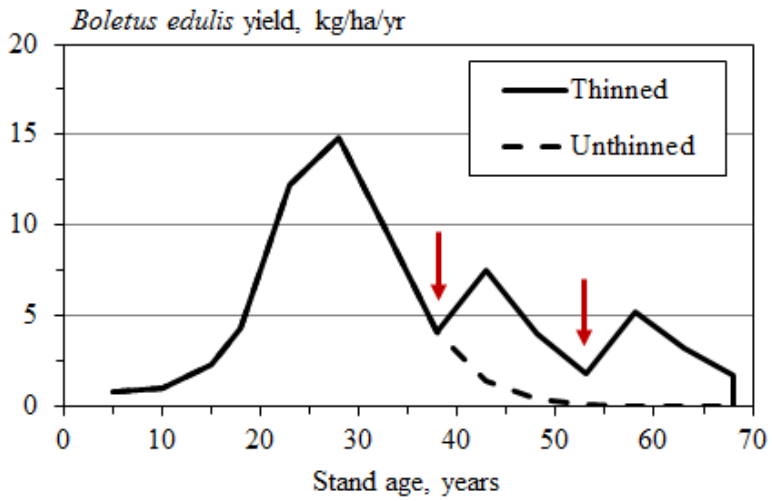

Figure 2.33: Predicted *B. edulis* yields in a planted spruce stand with good mushroom yield in eastern Finland. Thinning treatments (arrows) and final cutting operations were simulated according to the silvicultural recommendations. Unthinned regimes are shown by dashed lines.

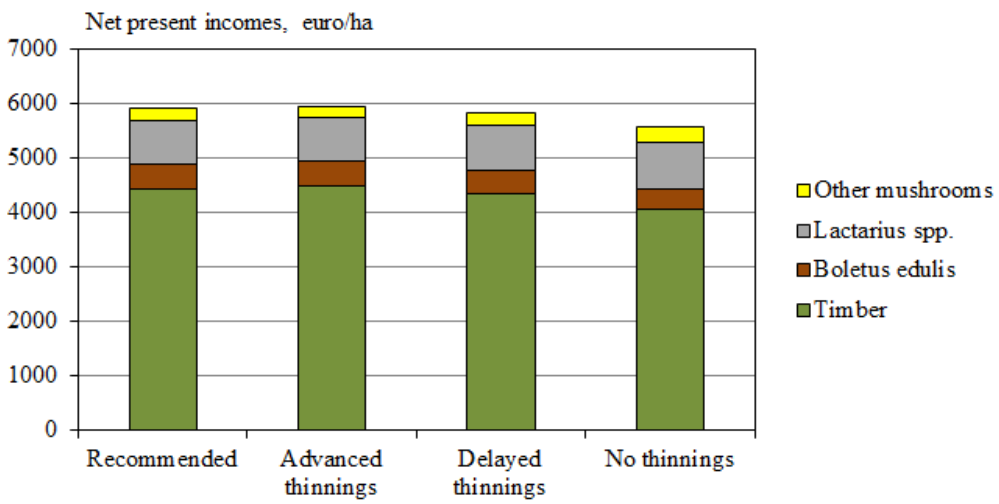

Figure 2.34: Net present values (at 3 % interest rate) of incomes from timber and mushrooms (B. edulis, Lactarius spp. and other marketed mushrooms) obtained from a planted spruce stand with good mushroom yield. Stand management was simulated according to silvicultural recommendations. In other thinning regimes, the same rotation age was used but the timing of two thinnings was either advanced or delayed by five years from recommendations. Also, the unthinned regime was simulated.

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Silvicultural recommendations for *B. edulis* production:

B. edulis as a mycorrhizal fungus suffers from regeneration cuttings of spruce stands. *B. edulis* yields increases along with stand age and development so that the highest yields are obtained just before the first commercial thinning (at the age of 25–30 years and the stand density of 25 m^2/ha) (Tahvanainen et al. 2016). The peak in the yields of *Lactarius* spp. and other marketed mushrooms is slightly later. According to the preliminary results, the yields of *B. edulis* increases after the first thinning and also after the second thinning but to a lesser extent. Thinning opens up the canopy and rainfalls are more likely to wet the forest floor, which may promote mushroom yields after thinning.

2.5.2 Saffron milk cap (*Lactarius delicious* Fr.)

Authors: JAB, SdM, RA, FXB, JMA

Silvicultural recommendations for promoting *Lactarius* yields in Spain:

Lactarius deliciosus Fr. (saffron milk cap) is probably the most abundantly marketed species in Spain (Voces et al. 2011), also having very well-established markets in Europe, Asia and North Africa (Boa 2004). The sporocarps of this species are usually sold together with other species including *L. sanguifluus*, *L. semisanguifluus, L. salmonicolor* and *L. vinosus*. Hence, in this paper we will refer to *Lactarius* group *deliciosus*.

L. deliciosus is considered a generalist species usually found across a wide range of conditions in conifer forests, fruiting from late fall to mid-winter. *L. deliciosus* has been described by Fernandez-Toirán et al. (2006) as an early coloniser of plantations (early-stage fungi), and found in greatest abundance in young stands. In this sense, Martínez Peña (2009) observed two peaks of production in Scots pine (*P. sylvestris*) forests of different age classes, the first peak occurring at the age of 16-30 years and the second one at the age of 70 years. However, Bonet et al. (2004) noted that saffron milk caps are found in all age classes and on all aspects of *Pinus sylvestris* plantations in Northeast Spain. Those apparent contradiction was explained by such authors arguing that open forest conditions with relatively low basal areas typical to the early phase of natural forest succession (before canopy closure) were favourable for saffron milk caps production. These authors hypothesised that canopy closure was an important factor influencing their findings and proposed the use of silvicultural treatments to decrease the density of older stands in order to enhance *L. deliciosus* production, assuming that forest stand structure is more relevant to saffron milk cap productions than stand age.

Bonet et al. (2008), who developed the first empirical mushroom yield models for *Pinus sylvestris* pure stands of Central Pyrenees by including forest stand and topographical variables as potential predictors, specifically raised this question. The authors observed that stand basal area, associated with some topographical variables (i.e. slope and aspect) influenced the yield of marketed *Lactarius* mushrooms. Posteriorly, Martínez-Peña et al. (2012) also developed mushroom yield models for *Lactarius* group *deliciosus* in *P. sylvestris* stands

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in north-central Spain, and found that saffron milk caps yield is influenced by weather (autumn precipitation and temperature) as well as by forest stand variables (dominant height and stand basal area), as follows:

$$Lactarius = \exp(-3.309 + 0.008\, P_{autumn} + 0.106\, T_{autumn} + 0.653 \ln(Hdom) - 0.018\, G)$$

where *Lactarius* is annual yield of *L.* group *deliciosus* (kg/ha/yr), P_{autumn} is the sum of the total precipitation in August, September and October, T_{autumn} is the sum of the mean temperature in September, October and November, *Hdom* is stand dominant height and *G* is stand basal area.

The average annual yield of *Lactarius* predicted by the model is around 9 kg/ha/yr with a maximum estimated yield of 200 kg/ha/yr in exceptional years. The optimal dominant height for *Lactarius* production seems to be 13-14 meters (Figure 2.35). In an average *P. sylvestris* stand from the study area (site index = 23 meters), such dominant height is reached when the stand is about 45 years old, although *Lactarius* mushrooms were present across the whole range of stand age classes in *P. sylvestris* forests.

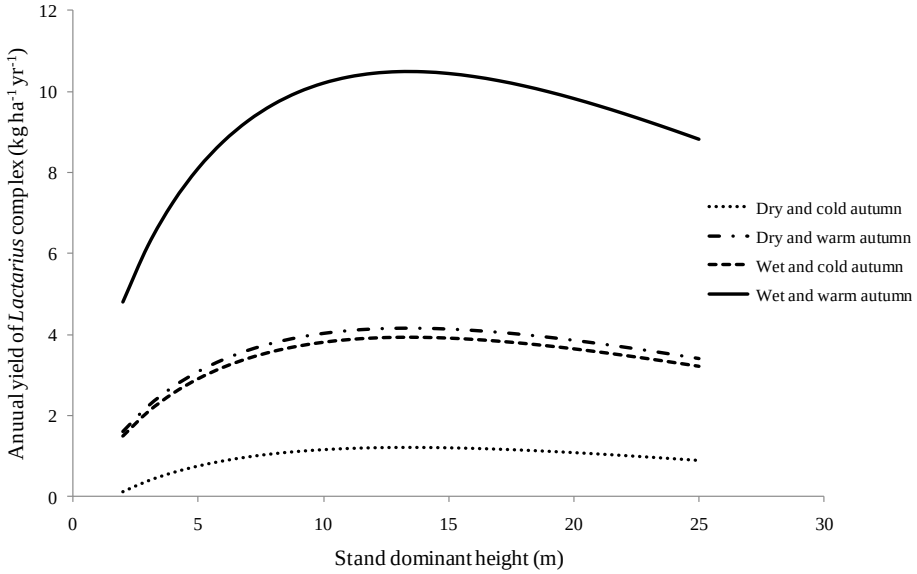

Figure 2.35: Relationship between the annual yield of L. group *deliciosus* and stand dominant height (Martínez-Peña et al. 2012)

The empirical models for *L.* group *delicious* developed by Bonet et al. (2008) and Martínez-Peña et al. (2012) further supported the importance of stand basal area as the most relevant predictor, in terms of the silviculture and forest management for *Lactarius* yields, since site characteristics (i.e., aspect or slope) and weather conditions cannot be modified by forest managers. This finding was definitively confirmed by Bonet

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et al. (2012) who carried out an experiment initially based on 15 plots established in 2008. That first set of plots was expanded in 2009 by establishing 15 additional paired plots, which were thinned with varying thinning intensity in stand basal area ranging from 0 to 77 %. The production of *L.* group *deliciosus* has been surveyed every week during the Autumn Period from 2008 to date.

The thinning treatments positively affected *Lactarius* yields during the first two years after the forest thinning, but with an upper limit of around 35 m^2/ha of removed basal area, beyond which the model predicts a decrease of fungal yields, as compared with unthinned plots (Bonet et al. 2012) (Figure 2.36).

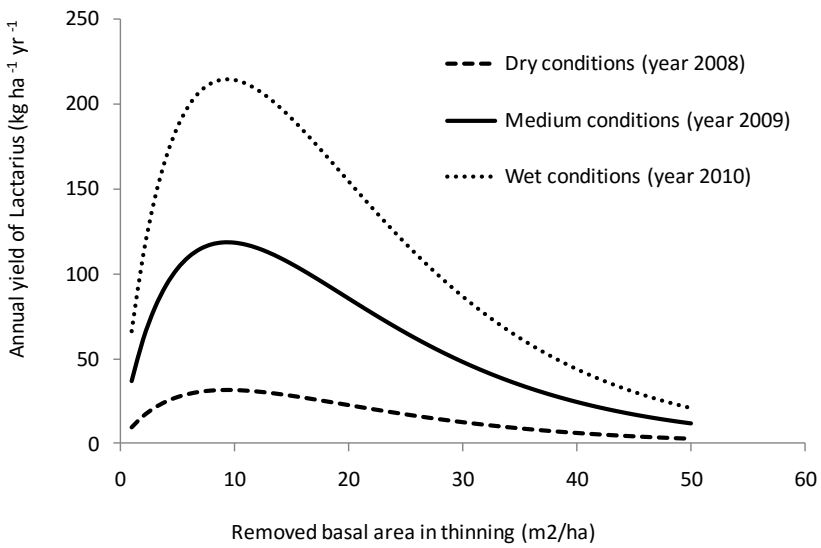

Figure 2.36: Relationship between the annual yield of *Lactarius group deliciosus* and removed basal area in thinning in the years of study (Bonet et al. 2012).

The model shows that light thinning (i.e., around 10 m^2/ha of basal area removal) favours saffron milk cap yields, concluding that *Lactarius* group *deliciosus* prefers growing in relatively open forest conditions and when stand age is close to the period of highest tree growth. This also suggests that *L.* group *deliciosus* has a high adaptive ability to different stand structures beyond the particular habitat preferences of the individual species included in the group deliciosus (*Lactarius deliciosus*, *L. vinosus* and *L. sanguifluus*).

Preliminary results based on the continuous inventory of mushrooms during the years 2011-2015 suggest that the thinning effect on the production of *Lactarius* group *deliciosus* has only an immediate effect that may fade away two or three years after thinning (Figure 2.37).

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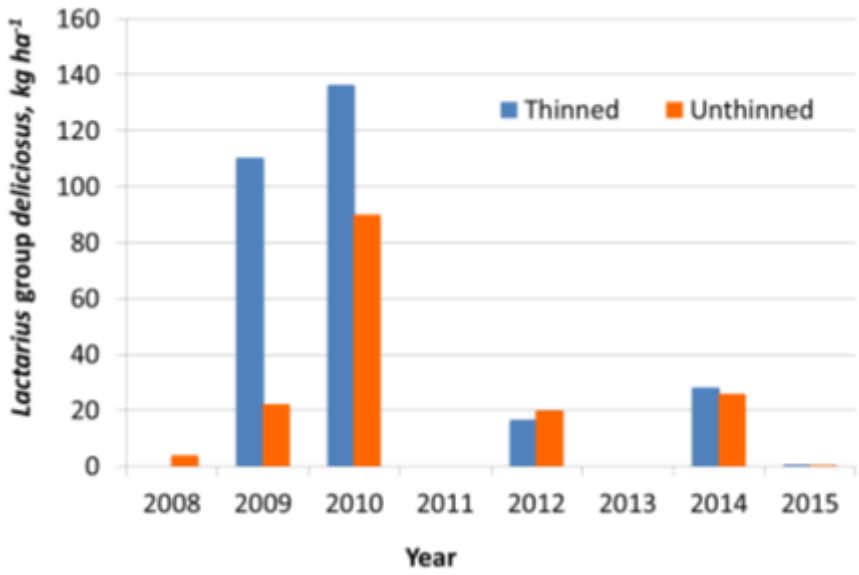

Figure 2.37: Effect of thinning on *Lactarius group deliciosus* yield in the period 2008-2015 (Unpublished data).

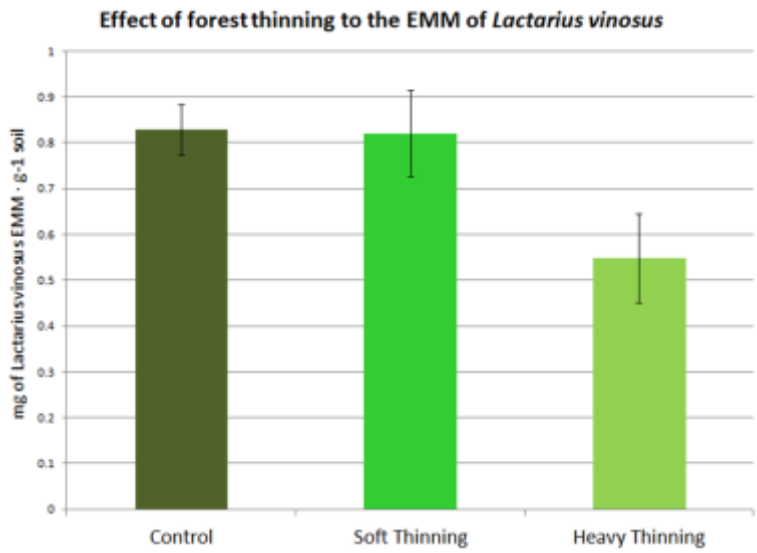

Figure 2.38: Effect of forest thinning on the quantity of extramatrical mycelia of *Lactarius vinosus* present in the soil. Control are unthinned plots, soft thinning (less than 35 % thinning intensity in stand basal area) and heavy thinning (more than 35 % of removed basal area). The samples were taken during March, April and May 2015 (Unpublished data).

However, the very poor weather conditions during the last years, which halted the emergence of almost all mushroom species prevents drawing definitive conclusions on the effect of thinning operations on saffron milk caps yields. In order to shed more light to this open question, alternative techniques, complementary to mushroom inventories, could be used. A good example could be the quantification of the extramatrical

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mycelium (EMM)using Real-Time PCR (qPCR). This molecular technique has already been employed to study the persistence of different ectomycorrhizal species in soils (Parladé et al. 2007) and the same approach was used to quantify *Lactarius vinosus* in forests soils. Eight soil samples per plot were randomly taken during the months of March, April and May of 2015 in all the thinned and unthinned plots. Soil samples were then homogenised and pooled in-situ to obtain a composite sample, allowing to quantify the presence of *Lactarius vinosus* in the soil (Castaño 2016). The results shows a decrease of the quantity of *Lactarius vinosus* extramatrical mycelia in the plots subjected to heavy thinning (those plots in which the removed basal area was higher than 35 %, in comparison with the unthinned plots or light thinning plots (i.e., plots in which the removed basal area was less than 35 %) (Figure 2.38).

Table 2.15: Spearman correlations calculated between earlywood (EW) and latewood widths (LW) and mean annual mycorrhizal fungi yield (MFY) in different pine forest stands of Catalonia. Partial correlations were also calculated between LW and MFY controlling for climatic (cumulative precipitation from August to September) or growth effects (EW). Pine species abbreviations correspond to PS = *Pinus sylvestris*; PN = *Pinus nigra*; PH = *Pinus halepensis*; PP = *Pinus pinaster*. Significance levels: *0.05<P≤0.1; **0.05<P≤0.01; ***0.01<P≤0.001 (Primicia et al. 2016)

Site	Pine species	Plot	No. years of data	EW vs. MFY	LW vs. MFY	Partial correlations	
						LW vs. MFY controlled for precipitation	LW vs. MFY controlled for EW
Solsonès	PS	29	13	0.44	0.37	0.33	0.09
		30	13	-0.55*	-0.07	-0.12	0.34
		31	13	0.13	0.07	-0.16	0.01
		32	13	-0.23	-0.30	-0.37	-0.21
		33	13	-0.24	0.15	0.06	0.31
	PN	8	13	-0.59*	0.21	0.14	0.52*
		9	13	0.58*	0.47	0.48	0.31
		11	13	-0.05	0.48	0.51	0.53*
		17	13	-0.59*	0.04	0.02	0.58*
	PH	36	13	-0.49	-0.41	-0.47	-0.25
		40	13	-0.11	0.19	0.19	0.32
		41	13	-0.35	0.09	0.04	0.34
		42	13	-0.25	0.40	0.43	0.63**
Prades	PS	343	7	-0.07	0.04	-0.59	0.13
		344	7	0.11	0.43	-0.39	0.74*
	PP	301	6	0.33	0.64	0.07	0.69
		302	7	-0.36	0.71	0.61	0.85***
		311	7	0.18	0.75*	0.85**	0.76**
		314	7	-0.11	0.82*	0.79***	0.85***

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These results seem to confirm the preferences of *Lactarius* group *deliciosus* for medium density forest stands in which the maximum mushroom productivity should coincide with the peak of annual basal area increment in these pine forests. This coincidence sounds ecologically reasonable since the saffron milk caps are ectomycorrhizal fungi that grow in symbiosis with forest trees. Thus, it is hypothesised that the maximum tree growth of the tree matches with the maximum mushroom productivity due to the derived carbohydrates of the tree to the fungal communities. However, the analysis of such relationships in Catalonian pine forest stands shows no clear temporal synchronization between mean annual mushroom yields and seasonal wood formation except in some pine stands growing on more xeric sites (Primicia et al. 2016; Table 2.15).

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3 Discussion

Authors: JS, LM

3.1 Overview of silvicultural treatment aiming to promote NWFP production

Revised silvicultural guidelines have been a key output from the StarTree project. Such guidelines have been suggested for a number of NWFP and can serve as a basis for further research into the modification of current silvicultural prescriptions for the increased production and increased profitability of specified NWFP by means of co-production within Europe.

The findings collected in this document are as diverse as the products themselves. Some production systems combine the production of NWFPs and timber already in a developed way and an improvement of the system is not required, such as can be seen in the case of resin production. While other systems are still strongly driven by a timber orientated point of view and the potential for a combined and optimised production system encompassing both timber and non-timber is considered as being major opportunity (e.g. for understory berries and mushrooms). But there are also systems where timber or NWFP are produced as a single goal, a combination of both is not always advocated (for example bay leaf production in Turkey). Many recommendations within this document are conceptual and thus must yet be tested empirically. Other recommendations are the result of modelling and/or have been tested in the field. Further research should test the applicability of these recommendations in other areas.

Chapter 2.4 demonstrates how variations in market price for bilberries and cowberries in Finland affect the optimal stand management when both berry and timber yields are assessed with an aim to maximise the combined output. The models have been applied for different stand types such as pure pine, birch and spruce stands as well as for mixed stands. For bilberries it could be demonstrated that under current market bilberry price the optimal stand management would be clearly changed, except for within spruce stands. As the bilberry production increases with reduced canopy shading, more frequent and heavier thinning treatments would be applied. An expansion of the rotation period would results in a higher mean annual bilberry harvest, due to the fact that the highest bilberry harvests are obtained in the end of the rotation period. Cowberries are growing the best in open treeless habitats. Therefore, the highest cowberry yield can be expected a few years after a regeneration cutting. The models have shown that even under higher market prices the economic return from the culture of cowberry would not affect the established silvicultural system, if only cowberries are collected. When both studied berry species are harvested from a pine stand, thinning intensity and rotation length are increased slightly under current market conditions (cowberry 1.8 €/kg and bilberry 2.4 €/kg). Hence, a doubling of the market prices would change the optimal stand management markedly, causing a second thinning operation and expanding the rotation length from 50 years to more than 120 years.

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A multitude of studies have highlighted the strong influence of stand basal area on mushroom production (chapter 2.5). Within *P. sylvestris, P. nigra* and *P. halepensis* stands in Spain, the highest productions of total, edible and marketed mushrooms can be expected when the basal area ranges from 15 to 40 m^2/ha, regardless if the stands are pure or species are mixed between each other and mainly depending of the weather conditions of the fores stand. The highest mushroom yields (> 30 kg/ha/yr) can be found in pure *P. sylvestris* stands. Another study, focusing on *B. edulis* yields only, describes a stand basal area of 40-45 m^2/ha as the optimal density for maximising the yield of *B. edulis* within *P. sylvestris* ecosystems in a Mediterranean continental area. It follows that, regular and effective thinning operations are necessary in order to keep the basal area on an optimised level where mushroom production is at its maximum. Tahvanainen *et al.* (2016) analysed *B. edulis* yields in spruce stands in Finland. Since these mushroom species suffer from regeneration cutting in spruce stands, the yields are increasing with stand age and reaching their peak 25–30 years after the event, when basal area is around 25 m^2/ha. From that point on the mushroom yields are decreasing continuously but thinning has been shown to be able to reverse this trend for a short period of time. The yield of *L. deliciosus* mushrooms is also depending strongly on the stand basal area and weather conditions since access to light plus wet and warm weather conditions in autumn is more important for their growth than the stand age, slope or aspect (chapter 2.5.2). The optimal dominant tree height for *Lactarius* production seems to be 13-14 m. It could be demonstrated that thinning treatments, with a minimum soil disturbance could have a positive effect on *Lactarius* yields during at least the first two years after the event, whereby light thinning (i.e., around 10 m^2/ha of basal area removal) favours saffron milk cap the most.

In chapter 2.2.1 the influence of bark thickness (quality), discounting rate and marked price on the optimal management of cork oak stands is demonstrated. The thickest barks are produced in stands where first thinning is delayed (~80 years) and with long rotation periods (~150 years). This coupled with low discount rates (1 %), suggests that long rotation periods are the most profitable, whereas, under high discount rates (5 %) short rotation periods are more recommended. The marked prices for cork do have similar effects on the rotation period. A price decrease of 30 % leads to a rotation length decrease with thinning treatments applied earlier. A consistent silvicultural guideline for the economically most attractive production of cork oak cannot be given. This is, as described above, due to the fact that discount rate and marked prices have a strong influence on the optimal rotation length and debarking interval. Therefore a shift from a fixed management system towards more flexible, marked condition orientated and optimised management system is recommended.

The main purpose of *Laurus nobilis* cultivation is the production of bay leaves. The leaves are commonly produced in coppice management regime and firewood is utilised only in minor amounts (chapter 2.3.5). The combination of bay leaves with agricultural products at the same site (i.e. agroforestry) is recommended to enrich the diversity. The production of timber from bay leaf trees is not operational. Therefore, a change within production system is not recommended.

Finally, as illustrated in chapter 2.3.1 the production of high quality timber and the commercial co-production of cherries can be viewed as impractical, since the trade-offs and compromises required between the two production systems are large. For this reason it has been recommended that the production focus remains

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on high value timber, meaning that the management of future crop trees should remain the same as recommended for a timber only orientated management system. while co-dominant and other substandard individuals are chosen early in the rotation for cherry production, and thus, follow an alternative silvicultural prescription. This requires a shift from the classical single tree goal orientated perspective to a more holistic stand based productivity outlook. Here, cherry production is improved and access to the tree crown is facilitated by means of formative pruning, the removal of competitors and removal of the apically dominant shoots to ensure a spreading crown with a strong scaffold of branches. This co-production of cherries creates a benefit for the land holder, especially when the landholder has a direct usage for the fruit.

As seen, this document gives a broad overview of different NWFP all over Europe, the silvicultural treatments represented in this document present a multitude of approaches. The economical, ecological and cultural situation within the European counties differs greatly. Therefore, the direct transfer of experiences from one case study region to another can be considered limited. For example in Spain the collection of mushrooms is profitable and can thereby create a commercial substituted to timber production. Whereby in Germany, where mushrooms are mainly collected for recreation and personal usage (and prohibited to trade) the economic benefit is absent and therefore cannot compete against established timber production goals. Likewise, many NWFP-systems are time intensive. The cost-effectiveness of a system is therefore strongly dependent on the labour cost of the particular country. Nevertheless, some common silvicultural activities are suitable to promote the production of various different NWFP regardless of species or location.

Particularly applying to direct NWFP, the choice of provenance and genetics must be considered crucial, such choice within the planning stages allows for the best pairing between site and climatic conditions with other important factors such as stem form which is dominantly controlled by genetic factors. Furthermore, the requirements of a MPT with a NWFP co-production goal are more diverse than for an individual tree with a single timber orientated goal. Genetic can also be used for selecting lineages with large or persistent fruit production or a resistance to disease and/or pests.

Thinning can be considered as the silvicultural treatment with the highest influence on the production of NWFP, regardless whether it is a direct or indirect NWFP. By influencing the amount of light penetrating the tree crowns and the forest floor, thinning has a large influence on the growth of stem and crown diameter, branch free bole length, branch size, humidity and temperature of the air and soil within the forest, and therefore, also the understory plant community. One example for the influence of the basal area on the productivity of indirect NWFP is mushroom production in Spain. Both presented case studies indicate, that a moderate and regular reduction of stand basal area induces a moderate increase of sunlight on the forest floor, which consequently leads to a significant increase in the annual yield of *B. edulis* and *Lactarius delicious* mushrooms. Considering direct NWFP such as cherries, pine nuts or chestnuts, thinning treatments can have a positive effect on the yield, despite that the number of trees/ha being reduced. This can be attributed to the fact that light penetration of the crowns is increased.

Similar to thinning operations, the application formative pruning increases the amount of sunlight available within the crown. The aim of formative pruning for fruit production should be to encourage a strong scaffold of branches and an open branch structure. It is recommended to carry out formative pruning while the trees

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are small and the work can be performed from the ground instead of climbing the tree, whereby the risk of injury and the labour costs are reduced. Pruning should be targeted and carried out following best practice methodology.

3.2 Potential effects of revised silvicultural treatments on wood production

The increase of NWFP production by revised silvicultural treatment can have an effect on timber production at the single tree level. In order to address the potential influence of revised silvicultural treatments on timber production, the corresponding experts within the StarTree project were asked to rate the influence of the revised silvicultural guidelines on the production of a timber orientated goal. Table 3.1 displays the results according to the expert's assessment. Here, wooden products have been group into four product classes (high value timber, sawlogs, pulp and biomass) representing main usages of wood in order to provide a more distinguished picture. It must be noted that the results are subjective and may differ in practice between location and individual product goal. Results showed that the polled experts see either no or negative influences on wood production caused by revised silvicultural treatments for direct NWFP such as fruits and leaves. For berries the revised system leads to a decrease in pulp and biomass production but to an increase in sawlogs and high value timber. Whereas, an increase mushroom production predominantly leads to a decrease in all wood product classes possible due to decrease basal areas within productive stands.

3.3 The silvicultural dilemma: *a lasting relationship is all about compromise*

As illustrated in the introduction (chapter 1.3), the silvicultural dilemma is a multidimensional issue that cannot be ignored. The production of NWFP is often directly competing with an established and economically sound timber industry. Also in many cases those that invest in revised silvicultural treatments for the production of NWFP may not directly benefit from the resulting increase in NWFP (i.e. everyman's right). Therefore, the dilemma must be approached on a country by country or region by region basis to find the optimal solution that negates the specific regulatory constraints to for an improved bio-economy. The suggested prescriptions may not reduce the effect of the silvicultural dilemma, but may go some length to find a compromise within the defined production goals. Implementation must be decided at the stand level and sometimes even at the tree level for small land holders who have a direct use. One example to mitigate the silvicultural dilemma is the spreading of timber and NWFP production on different tree individuals within one stand, for example as described for wild cherry (future crop trees utilised for high value timber and secondary grade trees for cherry production).

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Table 3.1: Effect of changes on a single tree level concerning established silvicultural practice to produce increased NWFP yields. The effect of each NWFP on the different wood product classes (high value timber, sawlogs, pulp and biomass) are displayed separately.

	Species derivative	High Value Timber	Sawlogs	Pulp	Biomass (e.g. fuelwood, wood chips)
Resin, bark and sap					
Cork	*Quercus suber*	n/a	n/a	n/a	o or +
Maritime Pine Resin	*Pinus pinaster*	n/a	-	n/a	+
Black Pine Resin	*Pinus nigra*	+	-	o	-
Tree fruits, berries and leaves					
Wild Cherry	*Prunus avium*	-	-	n/a	n/a
Sweet Chestnut	*Castanea sativa*	-	-	n/a	n/a
Checker tree	*Sorbus spp.*	-	-	n/a	n/a
Lime tree	*Tilia spp.*	-	-	o	o
Bay Leave	*Laurus nobilis*	n/a	n/a	n/a	o
Pine nuts	*Pine spp.*	n/a	+	n/a	+ or -
Pine nuts	*Pine spp.*	n/a	-	n/a	+
Understory plants and berries					
Bilberry	*Pinus sylvestris*	+	+	-	-
Bilberry	*Picea abies*	n/a	n/a	n/a	n/a
Bilberry	*Betula spp.*	+	+	-	o
Cowberry	*Pinus sylvestris*	+	+	-	-
Mushrooms					
Cep	*Picea abies*	?	+	-	-
Cep	*Pinus sylvestris*	-	-	-	-
Saffron milk cap	*Pinus pinaster/P. sylvestris*	-	-	-	-

Legend:

+	Positive change (more wood)
o	No change (same wood)
-	Negative change (less wood)
n/a	Not applicable
?	Not known

The utilisation of such a theoretical approach may go some distance to reduce the dilemma. However, as wild cherries are smaller with less flesh than their cultivated counterparts and mechanised picking within a

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high forest is not possible, the proposed silvicultural system is confined to suitable sites and must be tailored on an individual basis to achieve an acceptable level of profitability. For some other tree species (e.g. fruits of the checker tree) the utilisation of the fruits for producing high priced beverages (Schnaps) might be a good option for increasing the profitability.

Some systems feature a higher proportion of wood while others are more NWFP orientated, the proposed revised silvicultural systems may affect the yield of timber derived from a stand. Based on expert knowledge Table 3.2 provides an overview of the proportion of timber vs. non-timber under both current and revised silvicultural guidelines per NWFP. The reader should note that proportions of timber vs. non-timber are conjectural without units for illustration purpose only.

Wood and NWFP are of course not the only goods produced in a forest. For many pine forests in Spain and Portugal it is assumed, that these two product groups sum up to only 25 % of the total use, while the main objectives for such forest stands are soil and watershed protection, nature conservation and recreation. This situation is also common elsewhere in Europe also where forest stands have multiple purposes aside from a product orientated goal.

For sweet chestnut an ordinary orchard system (current system) was theoretically compared with an orchard system optimised for timber production (revised system). It was assumed, that timber production could be increased. Nevertheless, the actual proportion between timber and NWFP is highly dependent on the applied production system (coppice, high forest or orchard). Meanwhile, proportions for bilberry are based on maximising soil expectation value (SEV) with 3 % discounting rate in a Scots pine stand without (the proportion of SEV from timber is 84 % under current silviculture) or with considering incomes from bilberry picking (the proportion of SEV from timber is assumed to be 82 % under a revised system). Proportions for cowberry are based on maximising soil expectation value with 3 % discounting rate in a Scots pine stand without (here under current management the proportion of SEV from timber is 59 %) or with considering incomes from cowberry picking (the proportion of SEV from timber is 58 % with an applied revised system) (see Miina et al. 2016). Under current market conditions berry picking has only a marginal influence on timber production. In some cases, such a cork, revised silvicultural guideleines do not change the proportion of wood and non-wood. Here, the main focus remains on cork production with a drive to increase volume (thickness) and quality, wood production is a by-product aimed at the firewood market at the end of the cork rotation, hence there is no compromise shown within Table 3.2.

Agroforestry systems often provide greater opportunities for co-production than forest systems. By design a combination of goals are incorporated into the system. The proposed system for producing chestnuts within an agrosilvopastural system similar to the Streuobst system in Germany allows for the production of chestnuts, high value timber and livestock. The system requires a reduction of the branch free bole length compared to a high forest thus constituting the compromise. Compared to a pure nut orchard the system requires a grafting of a desirable nut cultivar higher on the stem, the practitioner must ensure a high rate of success in the graft union to not detract from the quality of the wood product. Such a system is likely to be implemented in regions with a great demand for high value chestnut timber and chestnut.

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Concerning lime, an increase in flower production is archived by intensive thinning. This leads to a greater number of stronger branches; the consequence of this is that the timber quality is reduced. Herein, the dilemma is not solved by the revised system and the production of flowers will only be enhanced in situations where it is more profitable than high value timber production, a satisfactory compromise must be reached.

In other examples modern processing technology has overcome disadvantages presented by a co-production system. It was reported that using the "Hobelverfahren" technique of producing black pine resin stems were seen to accumulate only negligible amounts of resin within the heartwood. Meanwhile, modern sawmill technology no longer has problems sawing logs with a high resin content. But despite high labour costs and low resin prices, limited conflicts between production goals are seen.

In order to increase the production on bilberry and cowberry within Finnish forest systems, there is a requirement to reduce the basal area of the stand in the form of earlier and more intense thinning operations in comparison with traditional silvicultural systems. This leads to positive effect on high value timber and saw logs. Yet the increased maintenance/harvesting cost of the timber equals the benefits received by the increased berry yield, under current market condition (2.4 €/kg bilberries; 1.8 €/kg cowberries). The silvicultural compromise can be considered acceptable if the market price for both berries rises. Likewise, the production of both *B. edulis* and *L. deliciosus* are strongly dependent on stand basal area. Therefore thinning operations must be carefully balanced between providing the optimal conditions for mushroom growth coupled with the most suitable tree density for continued timber production of the desired quantity and quality.

In conclusion, the compromise between wood and non-wood goals must be evaluated on an individual basis. The co-production of contrasting products is possible in many situations, but the land manager must appraise likely outcomes based on temporal and spatial constraints, site conditions (i.e. European location, climate and site productivity), market fluctuation, labour cost, individual species requirements and management capacities.

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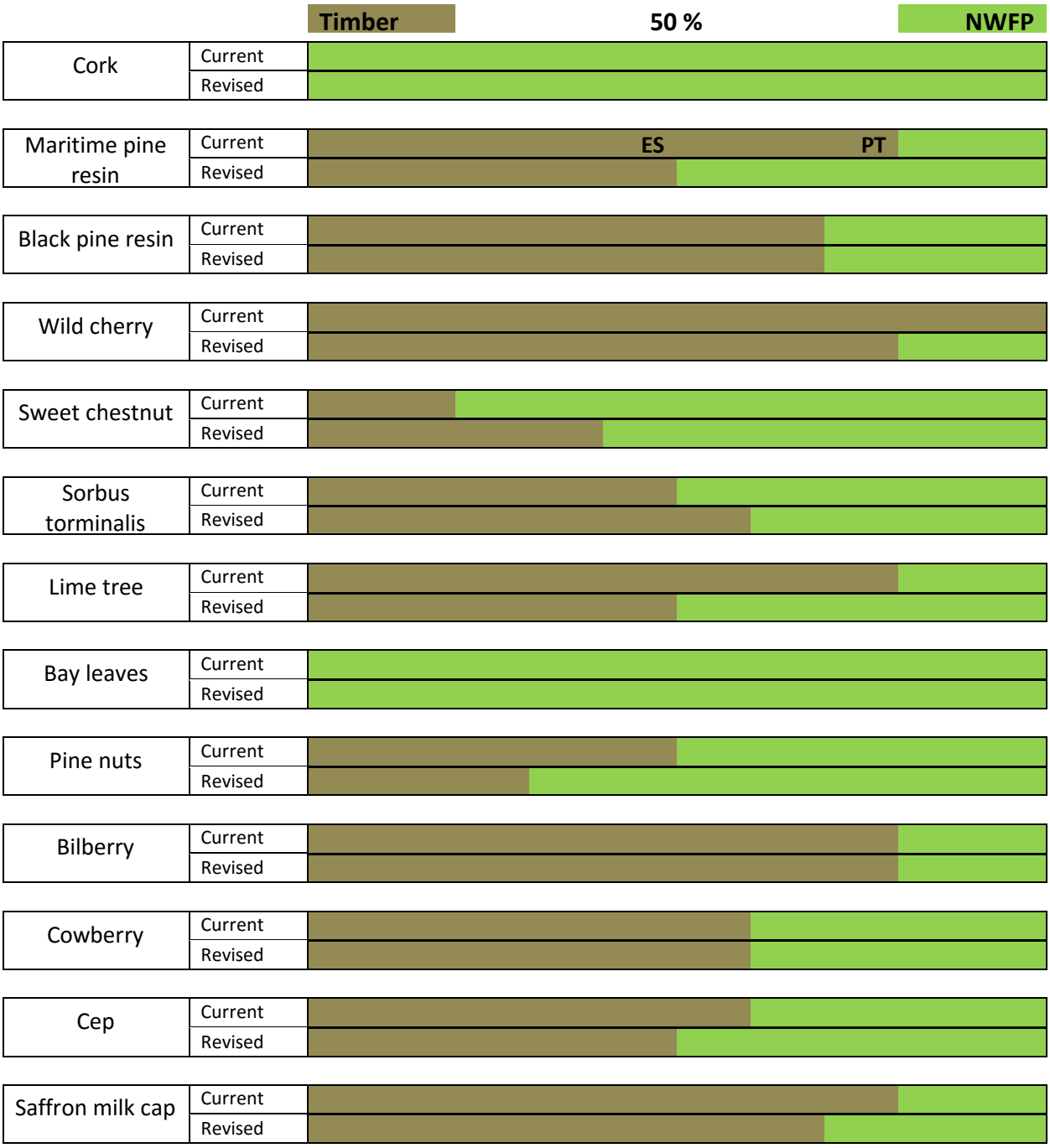
Table 3.2: Proportion of timber and NWFP (as the stand production goal) produced under current silvicultural systems and the revised system for each NWFP type. Rating is unitless and based on expert knowledge.



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