D2.1. State of the art, review of silviculture, models and decision support tools for multipurpose trees (MPT) and non-wood forest products (NWFP)

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List of abbreviations
DM decision maker
DSS decision-support system
FMU forest management unit, e.g. forest holding
MTP multi-purpose tree
NWFP non-wood forest product
PFQ professional foresters questionnaire

Consortium partners included in task:
METLA, BOKU, CTFC, ISA, INIA, KTU, IWW, SILAVA and all CSRs
Executive summary

The objective of this deliverable is to make the state-of-the-art of forest management in Europe when multipurpose trees (MPT) and non-wood forest products (NWFP) are among the management objectives. Three strands related with tree management – silviculture, models for forest growth and NWFP prediction and decision support systems for forest management – were initially identified of relevant for this deliverable that is therefore organized taking these three strands into account.

The information on silviculture, models and decision support tools for multipurpose trees (MPT) and non-wood forest products (NWFP) in Europe was first gathered for the 14 regions on the basis of a questionnaire that was prepared at the start of the project, the so-called professional forester’s questionnaire (PFQ). The questionnaire targeted professionals working within the forestry sector within StarTree’s 14 case study regions. The aim was to gain a better understanding of the state of the art of NWFP production as practiced in these areas by professionals managing forest holdings. It is expected that the results from the PFQ will somewhat reflect the European situation, covering most of the products and species. It has been found that the application of silvicultural management for the production of NWFP is varied across Europe. The PFQ has captured well known industries such as the cork and pine nut production industries in Mediterranean regions. Lesser known NWFP industries have been harder to distinguish. Mushroom collection is reportedly widespread across Europe, although the survey was unable to capture specific details towards their production. Hunting and game was a widely reported product between regions, although beyond the remit of the project. At present it is apparent that NWFP collection is a largely informal sector across Europe. However, the questionnaire has confirmed that timber production remains dominant. It was evident that the majority of management operations are conducted for the increase and improvement in quality of timber products. NWFP production is already established, but there are less cases where silvicultural management is adapted for the production of a new or additional NWFP production goal.

The following chapter describes existing silvicultural systems for some selected MPS and NWFP. The selected species and NWFP, based on their importance in the case studies associated with the institutions that participate in WP2, cover several tree fruits (walnuts, chestnuts, pine nuts, and several tree berries), other tree products (cork, resin, lime flowers and laurel leaves), mushrooms and understory berries. Given the inherent difference in viewpoint between the silvicultural requirements for NWFP and timber production two frameworks for the description of existing silvicultural practice were devised, the first from the viewpoint of timber production and the second from that of NWFP production. It was considered that a one-size-fits-all approach was inappropriate. A combination of frameworks was also suggested to be applicable. This approach has been applied for all selected MPT and NWFP. The data collection and subsequent analysis of current silvicultural systems has engaged two approaches, the professional forester’s questionnaire and a desk-based study. The professional forester’s questionnaire (PFQ) allowed the data collection from forestry professionals to augment the silvicultural ‘state of the art’ for NWFP management in the 14 StarTree case study regions. In the desk based study the WP2 partners (7 institutions) were directed to collate basic data under a series of headings designed to permit a full description of the autecology of the species under investigation as well as information about the associated NWFP incorporating product characteristics, utilisation and yield. Special attention has been given to the description of silvicultural systems for each species including timber production (product requirements, stand initiation, bole formation and pruning, diameter growth and crown thinning, rotation/age of harvest), NWFP production (stand initiation and formative pruning, ongoing maintenance and thinning) and where possible combined timber and NWFP production (product requirements, stand initiation, bole formation
and pruning, diameter growth and crown thinning). Information was also sought regarding other potential (e.g. other options such as intercropping or agroforestry). The report required a summary of key points and knowledge gaps and is concluded by a general discussion about the plans and perspectives for the StarTree project in relation to the improvement/development of silvicultural systems for MPT and NWFP.

Next chapter focus the identification and description of forest models that include NWFP within their outputs. For this purpose all available sources, such as institutional knowledge, peer reviewed papers, thesis and grey literature were consulted, for the selected tree species, understory plants and. In addition, forestry professionals were consulted by the PFQ. From the information given in this chapter we want to get an idea of the model’s focus and complexity in order to identify the gaps and needs for improvement. The EFORWOOD European Project, funded by the 6th Framework Program of the European Commission, led to the creation of a database for forest growth models, the FORMODELS database (www.efiatlantic.efi.int/portal/databases/formodels/), which registers and describes available models and simulators which represent either forest growth and yield, or the dynamics of tree populations. The FORMODELS database contains information for each forest growth model about several topics such as model identification, modelling approach, range of applicability, model structure (with modules for state variables, sub-modules for natural processes, modules for silvicultural practices and modules for environmental driving variables), inputs, outputs, availability of stand simulator, availability of landscape/region simulators or decision support systems, and the relevant references. The StarTree project consortium thinks that an effort to include NWFP models into the FORMODELS database is of high interest, so all the partners were asked to complete the database with the models they have developed/known about. Furthermore, if new models or simulators will be developed under StarTree, they should be filled into the database. The data collection and subsequent analysis of forest models and simulators that include multiple products and/or NWFP has used a methodology similar to the one used for silviculture. Data sources were the professional forester’s questionnaire (PFQ), in order to allow data collection from forestry professionals related to forest management in the 14 StarTree case study regions and the enquiry to the web-based database FORMODELS. A desk based study complemented this information. In this study, WP2 partners (7 institutions) were directed to collate basic data on two topics: 1) identification of prediction equations for NWFP; 2) identification and description of stand simulators that include NWFP. The study has identified and described some forest models – either simple prediction equations or more or less complex stand simulators – that provide information about NWPF within their outputs. However, most of the respondents to the PFQ (220 out of 239) do not know of any model for NWFP. From the thirteen regions only the professional foresters from Alentejo, Catalonia and Valladolid know models for NWFP, in the other regions all the respondents answer negatively to this first question. Most of the professional foresters think that models would be useful for any NWFP from their region except in Eastern Scotland, Latvia, Styria, Waldmärker and West Wales and The Valley. The identification and description of existing forest models showed that is the need to develop prediction models for several of the products, such as walnuts, chestnuts, tree berries, and resin. In relation to other products models area available for specific regions/countries and it will be very interesting to join data in order to check the possibility to understand the influence of environment and silviculture on the NWFP yield and to integrate the acquired knowledge into models with a broader range of applicability. The StarTree project is expected to give a relevant contribution for the improvement of the situation in relation to the availability of models to predict NWFP as well as to the improvement of some of the existing models. Based on the results obtained, several actions were planned for that: 1) data collection for the NWFP that have no yield equation available; 2) development of new statistical models – for the NWFP in relation to which no prediction model is available and new data is being collected under StarTree, new models will be developed, taking advantage of the large modelling expertise of some of the partners that may collaborate with other partners with less experience; 3) development of new expert-based models, again taking advantage of the expertise of some partners that have developed expert models for the NWFP important for their regions. This expertise may
be shared with other partners in order to develop models for the same or other products of interest in their own regions; 4) combination of data bases from different countries to check the possibility to develop models with a larger range of applicability and that may take advantage of the strengths of different data bases; 5) Analysis of the existing stand simulators to check if it will be possible to share/complement computer code in order to obtain more user-friendly interfaces that are apppellative for forest owners and forest professionals that are responsible for forest management. To summarize, it is expected that StarTree will represent a big advance in the quality of forest management when NWFP are part of the management objectives.

Finally, the deliverable identified and described decision support systems (DSS) to support planning and decision making for a sustained provision of NWFP. Forest-DSS are needed to support forest owners’ decision making in different contexts. Forest owners have varying and various forest management goals. When they make decisions regarding the management of their forests, they need information on how the management affects the provision of different products and services from their forests and also on trade-offs between different products and services. For these purposes forest-DSSs are useful tools in developing a feasible set of management alternatives for planning units and then supporting the decision-making situation in which the right ones are picked up among them. In this chapter, the availability of forest-DSS that include modules to deal with NWFP, was analysed considering an European level scope. This analysis considered the PFQ and a desk-based study mainly based on the analysis of the FORSYS wiki that describes existing forest management DSS. The results of professional forester’s questionnaire show that in particular in private family owned forests the most commonly applied decision support is a printed forest plan. Forest owners rarely use themselves modern planning approaches (computerized DSSs including e.g. forest simulators for predicting tree growth, optimizers for selecting an appropriate harvesting schedule etc.). The professional foresters rarely know forest planning systems that include considerations of NWFP or MPT in their region. However, they show the need to have Access to such systems. IN what concerns the enquiry of the FORSYS wiki, it has been found that the computerized forest-DSSs that include NWFP or MPTs are rather rare. In our search, we could find altogether seven FMU or regional level forest DSSs. The deliverable describes the forest DSS with NWFP capabilities, emphasizing their differences, advantages and disadvantages. At the end of the chapters, two examples of existing DSS with NWFP capabilities are presented. These examples clearly show that StarTree can have a strong impact on the improvement of forest management towards a sustained production of NWFP in the different regions involved by supporting the development and implementation into “real world” of appropriate DSS.
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1 Introduction

Authors: MT

The objective of this deliverable is to make the state-of-the-art of forest management in Europe when multipurpose trees (MPT) and non-wood forest products (NWFP) are among the management objectives. Three strands related with tree management – silviculture, models for forest growth and NWFP prediction and decision support systems for forest management –were initially identified of relevant for this deliverable that is therefore organized taking these three strands into account.

The objective of the first chapter is to get a general overview of forest management for MPT and NWFP in Europe. It has been achieved by preparing a questionnaire (available in StarTree data portal) to be made to forest professionals in the 14 case studies that are being run under StarTree. The questionnaire covers different topics from the identification of MPT and NWFP relevant in each one of the regions, details about forest ownership, role of the respondent in forest management, scale of application of silvicultural prescriptions, production goals and management activity. At the end, the questionnaire had some questions directed to the there strands: silviculture, forest models and decision support systems.

In order to go in-depth in the analysis, some MPT and NWFP were selected based on their importance in the case studies associated with the institutions that participate in WP2. This selection had already preliminarily been made in the project DOW, but it has been refined after the project initiation. In-depth analysis were made for these selected MPT and NWFP in relation to each one of the three strands previously identified – silviculture, models and decision support systems.

The in-depth analysis combined several sources of information, the most important being: 1) the forest professional’s questionnaire; 2) identification and consultation of existing data bases; 3) desk-based studies based on existing literature, including grey literature (reports, Msc thesis in native language and other relevant materials).

The amount of information that was found during this research was enormous and some work had to be done to sort out, select and summarize it in order to obtain the overview that was expected for this deliverable, objective that, in our opinion, was fully achieved.
2 Overview of silviculture, models and decision support tools for multipurpose trees (MPT) and non-wood forest products (NWFP) in Europe

Coordination: JS, MS, MK, MT

Authors: JS, MS, MK, MT

The information on silviculture, models and decision support tools for multipurpose trees (MPT) and non-wood forest products (NWFP) in Europe was gathered for the 14 regions on the basis of a questionnaire that was prepared at the start of the Project, the so-called professional forester’s questionnaire (PFQ). The questionnaire targeted professionals working within the forestry sector within StarTree’s 14 case study regions. The aim was to gain a better understanding of the state of the art of NWFP production as practiced in these areas by professionals managing forest holdings. It is expected that the results from the PFQ will somewhat reflect the European situation, covering most of the products and species.

Table 2.1 StarTree case study regions outlining important NWFP and MPT species

<table>
<thead>
<tr>
<th>Region</th>
<th>Important NWFP</th>
<th>Important MPT species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alentejo Region, Portugal</td>
<td>Cork, pine kernels, mushrooms</td>
<td>Cork oak, holm oak and stone pine</td>
</tr>
<tr>
<td>Bursa province, Turkey</td>
<td>Mushroom, chestnut, lime tree flowers</td>
<td>Chestnut, stone pine, lime tree, bay tree and cherry laurel</td>
</tr>
<tr>
<td>Catalonia, Spain</td>
<td>Mushrooms, black truffles, aromatic plants, honey, cork, pine nuts.</td>
<td>Several pine species, holm and cork oaks and chestnut trees.</td>
</tr>
<tr>
<td>Eastern Scotland, United Kingdom</td>
<td>Mushrooms, berries, game, foliage, moss</td>
<td>Not relevant</td>
</tr>
<tr>
<td>Latvia</td>
<td>Mushrooms, berries, wild honey, birch juice, foliage, hunting products, sauna scent</td>
<td>Scots pine, norway spruce, silver birch, rowan, lime, juniper, willow, chokeberry, elder, hazel, buckthorn, bird/ wild cherry and alder</td>
</tr>
<tr>
<td>North Karelia, Finland</td>
<td>Mushrooms and berries</td>
<td>Birch and pine, but of minor importance</td>
</tr>
<tr>
<td>Osrednjeslovenska region, Slovenia</td>
<td>Chestnut, mushrooms, blueberries, honey</td>
<td>Chestnut</td>
</tr>
<tr>
<td>Styria Region, Austria</td>
<td>Berries, mushrooms, Christmas trees, Schnapps</td>
<td>Cherry, walnut</td>
</tr>
<tr>
<td>Suceava, Romania</td>
<td>Berries, mushrooms, hunting</td>
<td>Norway spruce. beech, oak, ash</td>
</tr>
<tr>
<td>Šumadija and Western Serbia</td>
<td>Mushrooms, berries and herbs</td>
<td>Wild apple, common hazel, silver lime</td>
</tr>
<tr>
<td>Trentino-Alto Adige, Italy</td>
<td>Mushrooms (including truffles), chestnuts, aromatic products and essences, herbs and wild berries</td>
<td>Chestnut, other broadleaves and conifers (e.g., scotch pine, dwarf pine, larch, spruce, fir) for essences, aromas, medicinal and aromatic plants.</td>
</tr>
<tr>
<td>Valladolid, Spain</td>
<td>Pine nuts, resin tapping, mushrooms</td>
<td>Stone pine, maritime pine</td>
</tr>
<tr>
<td>Waldmärker region, Germany</td>
<td>Beer kraut, Christmas trees, berries, game, foliage.</td>
<td>Walnuts, wild fruit trees such as cherry, apple, pear, sorbus species, chestnut, oak/ pine stands to be explored</td>
</tr>
<tr>
<td>West Wales and the</td>
<td>Foliage, moss, timber by-products e.g.</td>
<td>Not relevant</td>
</tr>
</tbody>
</table>
Valleys, bark, game birds
United Kingdom

Expected important NWFP and multipurpose tree (MPT) species from each case study region as compiled at the outset of the project are noted in Table 2.1. The most important NWFP and MPT species identified (see Table 2.2) are analysed in more depth in chapters 3 (silviculture), 4 (models) and 5 (decision support tools).

Table 2.2 Summary of MPT and NWFP species studied

<table>
<thead>
<tr>
<th>NWFP</th>
<th>Latin binomial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walnut</td>
<td>Juglans regia, Juglans nigra, Juglans. intermedia</td>
</tr>
<tr>
<td>Sweet Chestnut</td>
<td>Castanea sativa</td>
</tr>
<tr>
<td>Wild Cherry</td>
<td>Prunus avium</td>
</tr>
<tr>
<td>Sorbus</td>
<td>Sorbus aucuparia, S. torminalis, S. domestica</td>
</tr>
<tr>
<td>Cork</td>
<td>Quercus suber</td>
</tr>
<tr>
<td>Pine Nuts</td>
<td>Pinus pine</td>
</tr>
<tr>
<td>Lime Flowers</td>
<td>Tilia spp.</td>
</tr>
<tr>
<td>Wild Mushrooms</td>
<td></td>
</tr>
<tr>
<td>Bilberry/ Cowberry</td>
<td>Vaccinium myrtillus/Vaccinium vitis-idaea</td>
</tr>
<tr>
<td>Bay Leaves</td>
<td>Laurus nobilis</td>
</tr>
</tbody>
</table>

2.1 Methods

A template questionnaire was drafted and made available to each case study region: if required this was translated into the native language(s) within each respective region, then distributed by the case study responsible (CSR). Dissemination to respondents was carried out using web based survey platforms, e-mail, and through face-to-face interviews. Participants were sought by CSRs through a variety of methods including members of professional bodies, attendance at trade fairs and by word of mouth.

Within the survey information was sought including background information detailing number and size of forest holdings, types of NWFP produced and whether such products are directly managed for or rather collected coincidentally. Detail was also collated towards current silvicultural practice. Respondents were asked to report on the target crop tree species cultivated within their holdings, whether species that produced NWFP were deliberately retained and whether there has been a change in silvicultural practice during the last 10 years to promote the production of NWFP. Further detail was sought regarding thinning, pruning and harvesting practices.

Responses were collated through StarTree’s dedicated data portal, overseen and validated by nominated domain experts. This allowed for remote data entry and report formation by nominated data analysts.

2.2 Results and Discussion

A total of 239 questionnaires were returned from 13 of the 14 case study regions ranging between 1 and 61 responses per region (Figure 2.1). Mean response rate totalled 18 unique responses per case study region. One region (Osrednjeslovenska, Slovenia) was unable to provide any data due to a zero response return rate, this may be attributed to a particularly severe winter causing a lot of damage to local forest holdings, and it is presumed that local foresters in this region were occupied with coordinating with salvage cuts and similar operations.
2.2.1 Forest Ownership

Respondents were asked who owns the forests that they work in. Table 2.3 shows the results from the survey. Multiple responses were possible, therefore responses for ownership category do not equal the number of total unique responses (n=239).

The majority of ownerships reported fell under state, private or a combination of the two ownership categories. The ‘other’ ownership category encompasses forest ownership by church and community group organisations.

Table 2.3 Forest Ownership

<table>
<thead>
<tr>
<th>Common</th>
<th>Municipal</th>
<th>Private</th>
<th>State</th>
<th>Corporate</th>
<th>Other</th>
<th>No Response</th>
<th>Total Unique Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alentejo</td>
<td>---</td>
<td>2</td>
<td>10</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>36</td>
</tr>
<tr>
<td>Bursa</td>
<td>---</td>
<td>---</td>
<td>0</td>
<td>14</td>
<td>---</td>
<td>---</td>
<td>10</td>
</tr>
<tr>
<td>Catalonia</td>
<td>3</td>
<td>13</td>
<td>18</td>
<td>8</td>
<td>---</td>
<td>---</td>
<td>119</td>
</tr>
<tr>
<td>Scotland</td>
<td>3</td>
<td>5</td>
<td>11</td>
<td>5</td>
<td>7</td>
<td>---</td>
<td>119</td>
</tr>
<tr>
<td>Latvia</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>1</td>
<td>---</td>
<td>---</td>
<td>119</td>
</tr>
<tr>
<td>North Karelia</td>
<td>3</td>
<td>5</td>
<td>16</td>
<td>2</td>
<td>5</td>
<td>6</td>
<td>61</td>
</tr>
<tr>
<td>Styria</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>---</td>
<td>119</td>
</tr>
<tr>
<td>Suceava</td>
<td>5</td>
<td>5</td>
<td>8</td>
<td>9</td>
<td>---</td>
<td>---</td>
<td>119</td>
</tr>
<tr>
<td>Sumadija and Western Serbia</td>
<td>---</td>
<td>---</td>
<td>11</td>
<td>50</td>
<td>---</td>
<td>---</td>
<td>123</td>
</tr>
<tr>
<td>Trentino Alto Adige</td>
<td>1</td>
<td>4</td>
<td>6</td>
<td>14</td>
<td>2</td>
<td>---</td>
<td>123</td>
</tr>
<tr>
<td>Valladolid</td>
<td>6</td>
<td>9</td>
<td>3</td>
<td>5</td>
<td>---</td>
<td>---</td>
<td>119</td>
</tr>
<tr>
<td>Waldmärker</td>
<td>11</td>
<td>17</td>
<td>18</td>
<td>1</td>
<td>5</td>
<td>---</td>
<td>119</td>
</tr>
<tr>
<td>West Wales and The Valleys</td>
<td>2</td>
<td>5</td>
<td>15</td>
<td>12</td>
<td>8</td>
<td>4</td>
<td>123</td>
</tr>
</tbody>
</table>

Total Responses per category | 36 | 67 | 119 | 123 | 28 | 10 | 7 | 239

Figure 2.1 Number of responses per case study region (n=239)
2.2.2 Role of respondent in Forest Management

Respondents were requested to specify their broad role within the management of the forests reported on within the PFQ. Explanatory text was also provided with the PFQ, operations was defined as a responsibility for day to day operations, manager as a role of the coordination of activities, planner as someone who prepares forest management plans, lastly an advisor was defined as someone who is able to give guidance on forest management. A response defining more than one role was possible. Results of the survey regarding the respondent’s forest management roles can be seen in Table 2.4. 99 unique responses were seen to report that the PFQ responder had multiple roles while two responses declined to report their role in forest management.

<table>
<thead>
<tr>
<th>Role</th>
<th>Owner</th>
<th>Operations</th>
<th>Manager</th>
<th>Planner</th>
<th>Advisor</th>
<th>Other</th>
<th>No Response</th>
<th>Total Unique Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alentejo</td>
<td>4</td>
<td>---</td>
<td>---</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>---</td>
<td>10</td>
</tr>
<tr>
<td>Bursa</td>
<td>7</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>---</td>
<td>3</td>
<td>---</td>
<td>15</td>
</tr>
<tr>
<td>Catalonia</td>
<td>11</td>
<td>6</td>
<td>7</td>
<td>9</td>
<td>14</td>
<td>11</td>
<td>---</td>
<td>28</td>
</tr>
<tr>
<td>Scotland</td>
<td>5</td>
<td>5</td>
<td>12</td>
<td>6</td>
<td>10</td>
<td>2</td>
<td>---</td>
<td>19</td>
</tr>
<tr>
<td>Latvia</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>1</td>
</tr>
<tr>
<td>North Karelia</td>
<td>2</td>
<td>15</td>
<td>17</td>
<td>14</td>
<td>14</td>
<td>---</td>
<td>2</td>
<td>19</td>
</tr>
<tr>
<td>Styria</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>3</td>
<td>---</td>
<td>---</td>
<td>3</td>
</tr>
<tr>
<td>Suceava</td>
<td>1</td>
<td>6</td>
<td>4</td>
<td>1</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>12</td>
</tr>
<tr>
<td>Sumadija and Western Serbia</td>
<td>---</td>
<td>32</td>
<td>9</td>
<td>22</td>
<td>3</td>
<td>1</td>
<td>---</td>
<td>61</td>
</tr>
<tr>
<td>Trentino Alto Adige</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>9</td>
<td>9</td>
<td>1</td>
<td>---</td>
<td>15</td>
</tr>
<tr>
<td>Valladolid</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>---</td>
<td>9</td>
</tr>
<tr>
<td>Waldmärker</td>
<td>5</td>
<td>18</td>
<td>19</td>
<td>---</td>
<td>18</td>
<td>11</td>
<td>---</td>
<td>19</td>
</tr>
<tr>
<td>West Wales and The Valleys</td>
<td>13</td>
<td>9</td>
<td>17</td>
<td>12</td>
<td>11</td>
<td>1</td>
<td>---</td>
<td>28</td>
</tr>
<tr>
<td>Total Responses per category</td>
<td>56</td>
<td>99</td>
<td>94</td>
<td>80</td>
<td>87</td>
<td>39</td>
<td>2</td>
<td>239</td>
</tr>
</tbody>
</table>

2.2.3 Scale of application of silvicultural prescriptions

Respondents were asked on which scale do they apply silvicultural prescriptions. 227 unique responses were received (12 respondents refused to answer this question). The majority of respondents report management planning and silvicultural prescriptions to be applied at stand level Figure 2.2. 11 % of all respondents suggested that there was no silvicultural prescription applied to the forest holdings that they oversee, for example one response suggested that trees were left to grow naturally once deemed established, this is possibly a reflection on the desired management goal. 31 responses report silvicultural planning at multiple scales. Management planning can take a variety of scales within one holding depending on location and species mixture. Often management prescriptions are set at the stand level but the management planning is done at the FMU level with the overall goals of production also defined at the FMU level.
2.2.4 Production goals and management activity

Considering the production goals of forest stands, respondents were requested to quantify as a percentage of the total holding the proportion of each production goal. This was sub divided between timber (including all grades of timber), NWFP, game, utilisation for recreation, for conservation or other usage. Figure 2.3 outlines the results for this question. Timber provided the highest percentage production goal (62%) with NWFP and game representing 6% and 9% respectively.

Respondents were able to give detail towards the percentage of their respective forest holding that was actively or passively managed for the production of one or more NWFP. Active management constituted a direct management operation that targeted the production or an increase in production of a particular NWFP. An opportunistically harvested NWFP is a product that is not specifically managed for but is sought and harvested, by an undisclosed user group. The third category signifies those areas which are not managed for NWFP production and no specific management is carried out. Figure 2.4 shows that a total of
73% of forest holdings across all case study regions were stated as being opportunistically harvested. 19% were not managed for NWFP production, only 8% was reported to be actively managed for NWFP production. 54 responses were excluded from analysis due to incorrectly reporting percentage of forest holdings.

![Circle diagram showing the percentages of actively managed, opportunistically harvested, and not managed or formally harvested forest holdings.]

**Figure 2.4** Active or passive NWFP management (n=185)

### 2.2.5 List of crop trees

A list of crop trees for the forests that respondents worked in was requested, the results are shown in Table 2.5 where the most frequent response for each case study region is highlighted in a darker shade of green. In Mediterranean regions crop tree species frequently reported are *Pinus pinaster*, *Pinus pinea* and *Quercus suber*. In central European regions targeted crop trees are as expected consisting of *Abies* spp., *Picea* spp. and *Pinus* spp. often with *Fagus* spp. or *Quercus* spp.. In Northern case studies *Betula* spp. were often reported. In many cases only genus name was provided and thus presented in this way in Table 2.5.

### 2.2.6 List of NWFP harvested

The survey asked respondents to list any NWFP that where harvested or produced from the forest(s) in which they worked. Table 2.6 shows the main findings grouped into categorical clusters, namely

1. edible fungi (all species),
2. animal products (including honey and game),
3. tree products (including bark, leaves, fruits and nuts),
4. decorative products (include seasonal branches, florist’s greenery, and Christmas trees),
5. forest fruits derived from the understory,
6. edible, medicinal and aromatic plants,
7. seeds for tree and wildflower propagation.

A further group included the null responses where no NWFP was reported (totalling 24 cases), the darker green colour within Table 2.6 represents a higher proportion of responses received.
Table 2.5  Crop trees by region

<table>
<thead>
<tr>
<th>Tree Species</th>
<th>Alentejo</th>
<th>Bursa</th>
<th>Catalonia</th>
<th>Scotland</th>
<th>Latvia</th>
<th>North Karelia</th>
<th>Styria</th>
<th>Sočava</th>
<th>Samdžija</th>
<th>Predjama</th>
<th>Trentino</th>
<th>Wladowland</th>
<th>Waldmärker</th>
<th>W. Wales</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abies sp. *</td>
<td></td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>8</td>
<td>19</td>
<td></td>
<td></td>
<td>10</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Abies alba</td>
<td></td>
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<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abies grandis</td>
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<td>10</td>
<td>1</td>
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</tr>
<tr>
<td>Alnus sp. *</td>
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<tr>
<td>Betula pendula**</td>
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</tr>
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<td>Betula sp. *</td>
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</tr>
<tr>
<td>Buxus sp. *</td>
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</tr>
<tr>
<td>Carpinus betula</td>
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<td>8</td>
<td>11</td>
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<td>4</td>
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<td>14</td>
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</tr>
<tr>
<td>Castanea sativa</td>
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All case study regions reported the production of edible fungi (78% of all responses) the term edible fungi includes a number of named species: Tuber spp., Lacararius spp., Morchella spp., Boletus spp. and Armilaria spp. the collection of Inonotus obliquus was also mentioned, in many responses the generic term ‘mushrooms was used’. Mediterranean case studies (Alentejo, Bursa, Catalonia and Valladolid) can be seen in Table 2.6 to harvest a large proportion of ‘tree products’, including cork, resin and pine nuts. Bursa also
reported on the collection of bay leaves and chestnuts. Central and Northern European case studies reported a greater proportion of NWFP production on ‘forest fruits’ including many understory berries such as *Vaccinium* spp. and *Rubus* spp..

**Table 2.6  Categorical clusters of NWFP by region**

<table>
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<tr>
<th></th>
<th>Alentejo</th>
<th>Bursa</th>
<th>Catalonia</th>
<th>Scotland</th>
<th>Latvia</th>
<th>North Karelia</th>
<th>Styria</th>
<th>Suceava</th>
<th>Sumadija and western Serbia</th>
<th>Trentino Alto Adige</th>
<th>Valladolid</th>
<th>Waldmärker</th>
<th>West Wales and The Valleys</th>
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2.2.7  Conclusions

The PFQ has provided the opportunity to establish the state of the art concerning NWFP within StarTree’s pre-defined case study regions as outlined. The application of silvicultural management for the production of NWFP is varied across Europe. The PFQ has captured well known industries such as the cork and pine nut production industries in Mediterranean regions. Lesser known NWFP industries have been harder to distinguish. Mushroom collection is reportedly widespread across Europe, although the survey was unable to capture specific details towards their production. Hunting and game was a widely reported product between regions, although beyond the remit of the project. At present it is apparent that NWFP collection is a largely informal sector across Europe.

Timber production remains dominant. It was evident that the majority of management operations are conducted for the increase and improvement in quality of timber products. Although it must be noted that the PFQ targeted professionals working within the forestry sector, the vast majority will have a timber orientated sphere of activity. Co-production of timber and non-timber in established forests is a minority production goal. However, the modification of silvicultural practice is apparent, especially in cases where NWFP production is already established, but there are less cases where silvicultural management is adapted for the production of a new or additional NWFP production goal.

It is necessary to briefly evaluate the success of the PFQ within the framework of the StarTree project. The dissemination of this survey to CSRs provided a number of valuable lessons as outlined in Table 2.7. The inclusion of the survey allowed for regional levels to be taken into consideration as defined within the StarTree concept. With this in mind, the use of such a survey was successful in taking a limited snapshot of silvicultural systems that are applied for the production of NWFP in Europe.
<table>
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<th>Risk</th>
<th>Reason</th>
<th>Impact</th>
<th>Solution</th>
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</thead>
<tbody>
<tr>
<td>Low response rate</td>
<td>Disinterest, low motivation, ignorance towards subject</td>
<td>Small, unrepresentative sample size. Bias within the dataset</td>
<td>Created interest, provide information about the wider topic. Empower respondents by indicate what they are contributing to</td>
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<tr>
<td>Variability between Case study regions within target respondents, number of respondents and method of survey dissemination</td>
<td>Template provided to CSRs with loose instructions of how to proceed</td>
<td>Large variability in sample size and quality with a risk of bias within the dataset.</td>
<td>Enhanced instruction from WP and task leaders to assist CSRs</td>
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<td>Respondents are influenced by survey method</td>
<td>Translation and delivery method may create guided answers</td>
<td>Bias within the dataset</td>
<td>Greater guidance to CSRs about how survey should be disseminated, transcribing of survey should retain original format.</td>
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<tr>
<td>Respondents are not a representative of the region</td>
<td>Low number, low variability of respondents targeted</td>
<td>Bias within the dataset</td>
<td>Alternative methods of survey dissemination, wider scope</td>
</tr>
<tr>
<td>Questions incorrectly answered</td>
<td>Questions are misunderstood</td>
<td>Low quality dataset, excessive data cleaning necessary</td>
<td>Considered question design. Pilot study which allows for the revision of questions.</td>
</tr>
<tr>
<td>Large number of null responses</td>
<td>Questions are misunderstood, too complicated or irrelevant</td>
<td>Low quality dataset</td>
<td>Considered question design. Pilot study which allows for the revision of questions.</td>
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</tbody>
</table>
3 Description of existing silvicultural systems for some selected MPTs and NWFP

Coordination: HS, JS

Authors: EZB, DMK, IC, JAB, JAP, JG, JM, JS, KS, LF, MK, MS, MT, PS, SdM, SM

3.1 Introduction

3.1.1 Task/ Rationale

The production of non-wood-forest-products (NWFP) can be influenced by management intervention (Hemery, Savill and Thakur 2005; Miina et al. 2010; Bonet et al. 2012). Silvicultural practice can present both positive and negative impacts on the production potential of forested land. Selected multipurpose tree (MPT) species and associated NWFP (see Table 2.2) have been examined in order to promote their production through silvicultural management. Silvicultural techniques through the whole production cycle have been described according to a protocol prepared in the early stages of the project. Examples of silvicultural practice for the production of NWFP have been highlighted and knowledge gaps identified.

The goal has been to provide a broad based, yet targeted species-wise scope arranged from a product perspective for the evaluation of current silvicultural prescriptions within differing management objectives and production goals for the production both of timber and NWFP. This has been carried out under the assumption that the prerequisites of a particular NWFP species product are known in addition to the established silvicultural practice employed for timber production. Adjustments and suggestions towards updated silvicultural guidelines can be made in later stages of the project to allow for supplementary NWFP production with known consequences to existing practice.

3.1.2 Scope

Forest management objectives are often outlined at a variety of scales, within forest management units (FMUs), at a stand level or even on an individual tree basis. Management guidelines for the production of NWFP should follow the same structure. The production of both timber products and NWFP within the same MPT is sometimes not possible, as the silvicultural prescription is opposing each goal, therefore, management prescriptions should offer a flexible approach. Within the StarTree project the question of scale has been addressed at an early stage to allow for targeted data collection and assessment. Information in some cases has been sought on a worldwide basis under the assumption that a silvicultural prescription applied to trees of the same genus elsewhere might be applicable to European species. One such example of this approach is the examination of management applied to Juglans nigra in the United States of America which may be appropriate for the management of Europe’s native Juglans regia (section 3.3.2.1). On a local scale, information has been sought within StarTree’s 14 defined case study regions through the use of a questionnaire aimed at professionals working within the forest sector (section 3.3.1). Given the European scope of the project, the ecology of NWFP producing species has been described so that silvicultural assessment can be carried out with known differences between site factors such as climate. In relation to which applicable information has been sought for species with a wide distribution within Europe. Nevertheless, silvicultural prescriptions applied for a specific objective are often site specific (Kerns et al. 2003), a fact that must be recognised within data analysis. However, as suggested by Tomé (2001), often the realisation of maximised production rate of a specified product within managing forested
ecosystems is attained by employing the best combination of site condition, genetic potential and stocking density.

3.2 Methods

Given the inherent difference in viewpoint between the silvicultural requirements for NWFP and timber production two frameworks for the description of existing silvicultural practice were devised as outlined below, the first from the viewpoint of timber production and the second from that of NWFP production. It was considered that a one-size-fits-all approach was inappropriate. A combination of frameworks was also suggested to be applicable.

**Framework 1)**
The examination of existing silvicultural techniques employed within the production system of defined MPT species. Highlight species site requirement, usage and common silvicultural practice for defined production goals (most often timber oriented). Note that there may be more than one goal and such a species may be utilised within more than one production system. All scenarios should be analysed. Highlight associated NWFP if applicable and relevant, consider synergies and conflicts between the existing management of the tree with current or potential NWFP production. Identify knowledge gaps in theory and practice, provide preliminary suggestions for study.

**Framework 2)**
Consider stand management for the particular production aim of producing NWFP from species which grow within a forestry stand. State production requirements for the NWFP species such as light conditions, micro-climate etc. Take into account how management practices affect the production of the NWFP when in combination with other management goals (as the production of a particular NWFP is rarely the sole production goal within a particular site). Examine what conflicts and synergies exist, consider compatible management strategies. Identify knowledge gaps in theory and practice, provide preliminary suggestions for study.

The data collection and subsequent analysis of current silvicultural systems has engaged two approaches (Figure 3.1). The professional forester’s questionnaire (PFQ) was devised as a first approach (Figure 3.1) to allow data collection from forestry professionals to augment the silvicultural ‘state of the art’ for NWFP management in the 14 StarTree case study regions. The questionnaire was devised and disseminated to the case study responsible (CSRs) who translated and disseminated the questions. Data was collected and transmitted to designated domain experts through the dedicated StarTree data portal for analysis. The methods and results concerning silvicultural state of the art are provided in section 3.1.

The second, a desk based study where project partners (7 institutions) were directed to collate basic data under a series of headings designed to permit a full description of the autecology and silviculture of the species under investigation. This integrated information about the species (including geographic range, climate, light requirement, soils, growth characteristics, reproduction, pests and diseases) and associated NWFP products incorporating product characteristics, utilisation and yield. Information was sought regarding current silvicultural prescriptions for growing the species in question, this aimed to include timber production (product requirements, stand initiation, bole formation and pruning, diameter growth and crown thinning, rotation/age of harvest), NWFP production (stand initiation and formative pruning, ongoing maintenance and thinning) and where possible combined timber and NWFP production (product requirements, stand initiation, bole formation and pruning, diameter growth and crown thinning). Information was also sought regarding other potential (e.g. other options such as intercropping or agroforestry). The report required a summary of key points and knowledge gaps.
For the desk based study, species allocation was outlined in the project description of work. The species studied can be seen in Table 2.2. Species were allocated to institutions with regional expertise. Species-wise reports arising from this exercise are presented describing tree products in section 3.3.2, tree dependent products in section 3.3.3 and detailing forest understory products in section 3.3.4.

![Figure 3.1 Silvicultural state of the art work flow.](image)

### 3.3 Results

The results obtained on silviculture that is used/planned when NWFP and MPT are one of the objectives of management, are presented according to the source used to obtain them: the professional forester’s questionnaire or the desk based study (see Figure 3.1).
3.3.1 *Professional Forester’s Questionnaire*

The most general results obtained from the PFQ have been described under chapter 2. Here we focus the questions related to the silviculture.

3.3.1.1 *Thinning, pruning and harvesting operations*

Respondents were asked to describe the thinning regimes in use within respondent’s forest holdings. Respondents were requested to differentiate between non-commercial and commercial thinning operations (if used) and elaborate their response noting frequency and intensity. Responses were varied and couldn’t be linked to a specific product. Thinning was carried out by the majority of responders, exclusively for the production of timber. Frequency and intensity were a result of individual production targets and site conditions. No mention of NWFP was made, further investigation is needed to ascertain how thinning affects NWFP production.

Furthermore, respondents were asked whether during thinning or harvesting operations whether NWFP producing tree species were deliberately retained for the production of a NWFP within the forest holding. Figure 3.2 shows 224 unique responses. Marginally more than half of all respondents (119) do not deliberately retain NWFP producing species during the course of normal forest management. 15 respondents declined to provide an answer.

![Figure 3.2](image_url)

**Figure 3.2** Are NWFP producing species specifically retained during thinning and harvesting operations?

95 positive responses were received to the question “do you carry out pruning operations in your forest”, 80 reasons were provided when asked to provide more detail (plus 34 responses, 30% of the total, where no explanatory reasons were given). The results are shown in Figure 3.3 the formation of a knot free bole to increase the value of the log was reported to be the most common reason for applying a pruning regime to forest holdings. Forest fire protection was a common response from case study regions in Spain and
Portugal, pruning here is often carried out to prevent the spread of wildfires into the tree canopy. The returned responses showed that pruning is sometimes carried out for a public benefit: to improve vistas, to improve accessibility, for health and safety reasons and as a form of conflict control between neighbouring landowners. Within the PFQ only 5% of pruning operations could be attributed to the production of NWFP. The reasons for pruning for NWFP were twofold, firstly to promote greater fructification through the construction of a stable scaffold of branches and secondly to aid harvest, for tree products this may be in the form of a mechanised tree shaker which requires a branch free stem section to hold. A further 2% of responses suggested that pruning was carried out to increase the amount of light reaching the forest floor, this may have been carried out for forest regeneration purposes but although unspecified possibly also to allow for mushroom species to flourish.

![Figure 3.3 Reasons given for pruning](image)

### 3.3.1.2 Harvesting of the forest products

Respondents were asked how the harvesting of forest products is carried out, it is apparent that the vast majority of NWFP are harvested by manual methods, these include aromatic and medicinal plants, nuts and berries and mushrooms. Such products require a level of skill for their correct identification and developmental stage. Other products such as mosses or decorative greenery must be selected on the basis of their outward appearance. The harvesting of cork in Mediterranean regions is a skilled job where to-date has included little mechanisation. Dogs are employed in the hunt for truffles both within and beyond plantations. Motor manual and fully mechanised methods are largely reserved for the production of timber products. Exceptions include pine nut harvesting using mechanised tree shakers in Spain and Portugal. It was reported in Valladolid that the uptake of mechanised tree shaking implements has been very fast, often as there is a clear return on investment. Over a two year period it was suggested that an increase of nearly 100 machines were working in the Valladolid region. In Turkey, bay leaf production was reported, here bay laural plants are coppiced to obtain the leaves, and then the plant is allowed to regenerate before the process is repeated. Further examples of NWFP ‘friendly’ harvesting practices were given such as the...
use of horses for timber extraction in Catalonia, and the use of cable based timber extraction systems in Wales, here extraction only resorting to tracked vehicles in necessary cases.

**3.3.1.3 Modifying silvicultural practice to include NWFP**

When asked the question: “Have you changed your silvicultural practice in the last ten years to promote NWFP production?” 26 respondents from 225 unique responses replied with a positive answer. Those that replied yes to this question were required to provide further detail.

Mediterranean case study regions of Alentejo (n=3), Catalonia (n=5) and Valladolid (n=3) included increased cultivation and advancement of applied methodology concerning stone pine and cork oak and holm oak as discussed below

An increase in stone pine cone price (from the year 2000) has lead to a clear intensification and improvement of stone pine plantations especially in public forests (Valladolid), an intensification in the practice of grafting where scion wood from proven stock is grafted onto established rootstock was mentioned. Also modifications to plantation density either towards denser plantations (Alentejo) and sparser plantations (Catalonia) the latter aiming to improve crown growth and regeneration of new stock. Modifications to thinning and pruning regimes were also mentioned with the aim of improved cropping, for higher individual cone yields and to aid mechanical cone harvest.

Up until 1970, the management applied in maritime pine (*Pinus pinaster*) stands were oriented towards the production of resin rather than timber or to the production of both. The resin sector declined and was practically abandoned by 2010, many forests were reoriented towards a timber priority or even converted to stone pine plantations. Since 2010, when world market prices for resin products increased considerably and labour costs dropped due to high unemployment rates, resin tapping has recovered its relevance in maritime pine forestry. Both pine nut from stone pine and resin from maritime pine are best exploited in even aged, pure stands for reduced harvest/transport costs.

Changes to current silvicultural practice mentioned in the PFQ include better soil management practices in cork oak plantations, such as a shift from the use of disc harrows towards the use of hammer harrows to promote soil conservation coupled with irrigation of young stands in order to increase survival rate and to anticipate the age of the first debarking. Modification to standard forest thinning practice to promote the removal of stone pine in order to favour cork oaks was suggested (Catalonia). Changes to cork harvesting technique have also been made: an increase in the debarking rotation (longer than the standard 9 years) and to reduce the total height of debarking both to increase the amount of usable cork (thickness) for bottle stoppers. The utilisation of new motor manual tools has also been introduced this may decrease cork losses and minimise tree wounds that are related to traditional manual extraction methods.

Catalonia reports an increase in the establishment of black truffle plantations utilising inoculated trees such as the holm oak. In Valladolid modification of species mixture is practiced with the removal of conifers which surround black truffle producing trees. Experimental modified forest thinning regimes have been reported in order to increase mushroom yields (*P. pinaster, Q. ilex, Q. pyrenaica*). One response suggested that foresters in Valladolid were increase effort for the integration of the production of boletus spp and chanterelles in management plans through schemes such as licence systems for mushroom picking.

Case studies within Central, Western and Northern Europe provided less targeted changes to silvicultural prescriptions. The integration of game management was reported in two cases (North Karelia and Suceava). It was suggested that the inclusion of grafting provides a useful tool to the practitioner, a technique commonly used in orchard production systems to obtain stronger trees with better fruiting characteristics. Many comments were generalised suggesting that MPT were retained and/or encouraged
within the species mixture such as targeted planting of tree species for the production of decorative greenery or the plantings of shrubs at forest edges in order to harvest berries (Walddarmer).

In many cases the silviculture has not changed, whether this be due to a decrease in demand for a particular product (moss and foliage: Wales) or that pesticides have been less frequently used (North Karelia) or that cultural practices that were used in former times fell out of favour due to political changes (the collapse of the former Soviet union) coupled with damage incurred to the trees by the extraction process (Resin production in Suceava). Best practice and close to nature forestry was also mentioned as a way of increasing the naturalness of a forest stand, primarily for biodiversity benefits, but also providing an increase in NWFP (Scotland and Wales).

3.3.2 Tree products

3.3.2.1 Walnut

*Juglans regia* L., common/ English/ Persian walnut (EN); Walnuss (DE); Noyer commun (FR); nogal común (ES); noce da frutto (IT). *J. nigra* L., Eastern black walnut (EN); Schwarznuss (DE); Noyer noir (FR); noyer negro Americano (IT), nogal Americano (SP), Nogueira Americana (PT). *J. x intermedia* CARR., Hybrid walnut (EN).

This review intends to describe the ecology and the state of the art of current silvicultural prescriptions applied to the production of walnut. The discrepancies of growing walnut for timber and for nuts are examined with special focus on combined systems where both products are produced on the same land area. This paper does not focus solely on the native European *Juglans regia*, but also includes information taken from the literature concerning *J. nigra* (black walnut) and *J. x intermedia* (hybrid walnut). The intention is to provide a broad overview with a world wide scope that can identify both knowledge and knowledge gaps in the culture of this species.

3.3.2.1.1 The tree

While cultivated throughout Europe, the natural distribution of the English or Persian walnut *Juglans regia* L. extends in a thin band from the eastern Mediterranean in Turkey through the mountain ranges of Central Asia (Figure 3.4). The black walnut (*J. nigra* L.) native to North America has a natural distribution across the southeast of the continent, this species is commonly planted in Europe.

![Figure 3.4 European and North American distribution of *J. regia* (left) and *J. nigra* (right) (Evans, 1984)](image-url)

In Europe, *J. regia* is an important species for the production of high value timber, either in the form of veneer or for the production of furniture or gun stocks where the hard dark wood is able to fetch a high price. Its nuts are frequently grown for human consumption. In the United States of America *J. nigra* is
grown and utilised in the same way. The species can naturally form a hybrid that is also commonly cultivated.

The ecology of walnut species is well described within current available literature; the following provides a short summary. *J. regia* is best suited to deep loam or alluvial type soils (Mohni et al. 2009; Russell and Garratt 2009) furthermore, it is recommended that light sandy, shallow soils over chalk or peaty type soils should be avoided when establishing walnut (Mohni et al. 2009). The species is not tolerant of waterlogged sites (Clark et al. 2008; Indiana Division of Forestry 2002; Mohni et al. 2009). *J. Regia* much prefers soils which are well aerated (Mohni et al. 2009; New Zealand Walnut Industry Group 2013). Hybrid walnut (*J. x intermedia* Carr.) is however reported to be more tolerant of both drier and wetter conditions (marginal sites) and is reportedly more winter hardy than *J. regia* (Pollegioni et al. 2008; Russell and Garratt 2009). The hybrid combines advantageous characteristics from the parental species such as vigour, resistance to disease and a superior wood quality (Pollegioni et al. 2008). The species requires near neutral soil pH (Mohni et al. 2009; Russell and Garratt 2009), at higher pH walnut may display signs of chlorosis.

Annual precipitation sum should fall between 700-800mm, and be well distributed throughout the year with a minimum of 100 – 150mm during the growing season (Mohni et al. 2009). The species is particularly sensitive to late spring frosts which can cause damage to the emerging nut crop (Mohni et al. 2009; Olsen 2006). *J. regia* displays strong phototropism and is extremely light demanding. Seedlings are more tolerant to shade than the mature tree, but poor form may result due to a prolonged underexposure to sufficient light (Mohni et al. 2009). Such growth response to environmental variables makes the silvicultural prescription for this species important, especially when stem form is crucial. This therefore is a central aspect when choosing the silvicultural prescription to be applied.

**Species specific growth characteristics**

*J. regia* is a long-lived tree species, under favourable conditions the species can reach 150 to 200 years of age, individuals in natural stands however, have been recorded to reach 300 to 400 years old (Mohni et al. 2009). In commercial operations rotations of 50 to 80 years are commonplace when a suitable bole diameter has been reached, commonly 80+ cm at 1.3m from the ground (DBH) (Russell and Garratt 2009).

Tree height is commonly 25-30m (Mohni et al. 2009), while the crown of *J. regia* averages between 8 to 10m in diameter but diameters of 12 to 15m are frequently possible (Mohni et al. 2009). Meanwhile, the crown of a mature *J. nigra* can equally reach diameters of approximately 12m across (Garrett et al. 1991). It has been suggested that the walnut species produces one of the greatest stem to crown ratios of any hardwood (Hemery et al. 2005b; Russell and Garratt 2009).

### 3.3.2.1.2 NWFP products

Besides the demand for walnut timber as a high quality product used for veneer, solid wood furniture and gun stocks, the applications for non-timber products derived from walnut are numerous. The most obvious and important NWFP is the edible kernel (Ciesla 2002), both from *J. regia* and *J. nigra* are edible and considered to be part of a healthy diet. Nuts can be also used to produce nut wine or oil for cooking, their consumption reportedly contributing to a lowering of cholesterol in the blood. Besides the edible nutmeat the nut shell is also widely utilised. Crushed and ground shell material can be used as an abrasive as an alternative to sandblasting within industrial applications (Brauer et al. 2006; MacDaniels and Lieberman 1979; Williams 1990), it can be added to drilling fluids in the oil drilling industry (MacDaniels and Lieberman 1979), utilised as an inert filler in dynamite and as a filter in chimney scrubbers (Williams 1990). Chemicals derived from the drupes (juglone, plumbagin, tannin), from the leaves and from the bark can be used as natural dyes. Green walnuts, walnut shells, kernels, bark, drupes and leaves have also been used in both cosmetic and pharmaceutical industry, as they have antioxidant and antimicrobial properties; they can be used for the production of natural antioxidants and natural antimicrobial compounds and represent a good
alternative to artificial antibiotics and chemical preservatives (Oliveira et al. 2008). Walnut leaves have been “intensively used in traditional medicine for treatment of venous insufficiency and haemorrhoidal symptomatology, and for its anti diarrhoeic, antihelminthic, depurative and astringent properties” (Pereira et al. 2007). The same chemicals has also be utilised at herbal remedies for the treatment of skin disorders or as a mild laxative. In Portugal and in some other European countries, dry walnut leaves are still used as an infusion, especially in rural areas. The most abundant phenolic compounds found in walnut leaves are naphthoquinones and flavonoids; these phenolic compounds are considered beneficial for human health because decrease the risk of degenerative diseases (Pereira et al. 2007).

**Nut Yield**

It has been suggested that the nut yield from *J. nigra* is hard to predict, both within and between stands due to variation in environmental and site conditions as well as genetics, inter and intra-species competition (Ares and Brauer 2004). Management of a stand and the applied silvicultural prescription will also provide a large affect on nut yield, since variables such as crown area will be proportionate to nut yield (van Sambeek and Rink 1981). It is, however, possible to make an approximation of nut yield in *J. nigra* by using DBH as a predictor variable. This must be calculated using data collected over two or more years to negate the influence of alternate or sporadic bearing of nuts, the best predictions can be made when observations are made over 4 years or more (Brauer et al. 2006) Yield predictions for individual trees have been analysed by means of linear regression providing the following models using DBH as the predictor variable, where *J. nigra* yield (kg/tree) = Y (see Table 3.1). It must be noted that no such yield models have been found in the literature concerning *J. regia*, however speculative yields between 18 and 180kg ha⁻¹yr⁻¹ have previously been implied (Lewis 1906).

<table>
<thead>
<tr>
<th>Walnut Yield Model</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y = -36.91 + 2.55 DBH</td>
<td>(Ares and Brauer 2004)</td>
</tr>
<tr>
<td>Y = -9.94 + 0.732 DBH</td>
<td>(Brauer et al. 2006)</td>
</tr>
</tbody>
</table>

It has been suggested that the minimum individual stem DBH to produce a viable quantity of walnuts is 14.5 cm (Ares and Brauer 2004) general consensus is that commercial nut production begins in year 20 for *J. nigra* (van Sambeek and Rink 1981) for ungrafted stock.

**3.3.2.1.3 Silvicultural prescriptions for growing *Juglans***

Walnut can be considered a truly multipurpose tree, since it provides the opportunity for the production of multiple products. Namely high value timber and nuts. However, timber production utilises disparate silvicultural systems to that found within nut commercial production practices. Both are often considered incompatible and are rarely seen grown together in modern cultivation systems given inherent differences in planting material, optimal location, management and temporal pressures as described below:

Phenotypes for timber and nut production are generally seen as incompatible for duel use production (Hemery et al. 2005a). Physiologically trees grown for high value timber production utilise provenances with long straight stems with small diameter branches that do not affect wood quality. Provenances utilised within nut production feature a short bole with heavy spreading branches that are able to support a heavy crop. Additionally, within nut orchards a cultivar is exploited, specifically bred for its form and nut yield.

The consideration of species choice between the native European *J. regia*, the north American *J. nigra* or a hybrid cultivar, can firstly be considered a cultural choice, native species are prevalent in their native range. However, the use of *J. nigra* is gaining interest within Europe as an alternative to growing *J. regia*, for example as suggested in Romania (Nicolescu 1998). Species choice will secondly be influenced by consumer
requirements. Such requirements for product properties (whether nuts or timber), will influence the species or cultivar choice, either in terms of taste, oil content or the ease of processing in the case of nuts, or in the ability to produce straight, branch free stems in the location of choice when considering the timber market.

Plantation location is similarly much dependents on product goals. Choice of flat, and fertile valley floors verses steeper slopes with poorer quality or stonier soils will favour nut production for the former and timber for the latter, simply due to operational constraints equating to differences in silvicultural and harvesting costs. A consideration towards production system must be made whether in a forest (generally only a timber product), an orchard (nut production) or an agroforestry system. The latter can be advocated as a both a timber orchard (Dupraz 1994) or as a combined production system (Mary et al. 1998).

Large discrepancies occur between timber and nut production, the shaping and pruning regimes applied are the main management difference, these present the polar opposite in management between product goals. Risks to an established walnut crop within a plantation include bacterial blight caused by Xanthomonas campestris pv. Juglandis (PIERCE) DYE., fungal decay (for example Armillaria mellea (VAHL) P.KUMM.) and disease such as walnut anthracnose are common (Hemery et al. 2010). Possible damages to stem and branches may be caused by grazing animals, especially after establishment, guarding may be required during early phases. Equally care should be also taken to avoid stem damage through bark stripping or rubbing (American Walnut Manufacturers Association 1998; Ares and Brauer 2004). Insufficient understory vegetation control constitutes the most common limitation for growth (Ares and Brauer 2004).

Finally the management of a forest stand for a high value timber product is a long term goal, often in the region of 70 years before a financial return is realised. The production of nuts can be considered a medium term goal with many years providing a sustained return on investment, only the employment of an intercropping regime can a short term return be accomplished, often of extreme importance to smaller scale growers.

Timber production

Commercial requirements for veneer logs in the United Kingdom are stated to be: 45 cm top diameter, 2.7m in length for the highest quality, medium quality logs can have a top diameter of 40 cm and be 1.8 m in length. Both must have knots restricted to an 8 cm core (Russell and Garratt 2009). To achieve a high quality product a constant and steady rate of growth must be achieved (American Walnut Manufacturers Association 1998) this can be obtained through effective tending and thinning of the stand (Bohanek and Groninger 2003). It is therefore, desirable to attain stem with a length of at least 2.5 m of clear knot free timber (Mohni et al. 2009) or a multiple thereof. To achieve this objective, pruning is of absolute necessity (Balandier 1997).

For the production of a quality timber product a number of initial stocking densities have been proposed as a common spacing for J. nigra, ranging from 1,077 to 1,683 trees ha⁻¹ (American Walnut Manufacturers Association 1998; Indiana Division of Forestry, 2002). This reflects a pure stand, however, it is commonly understood that interplanted mixed stands produce better results. Initial stocking densities have been experimentally investigated, where a low density planting of 160 J. nigra ha⁻¹ with 625 Alnus glutinosa (black alder) ha⁻¹ and a high density alternative of 331 J. nigra ha⁻¹ interplanted with 1,372 A. glutinosa ha⁻¹ (Bohanek and Groninger 2003). Such interplanting produced better results at a high density at a point in time mid-rotation following two thinning operations to remove a percentage of the black alder. In the USA J. nigra is often interplanted with native broadleaves such as red and white oaks, yellow poplar, cherry and white pine (American Walnut Manufacturers Association 1998). Lower stand densities are also advocated, within an agroforestry system valuable timber trees were planted at a density of 67 trees ha⁻¹ (Garrett and
Kurtz 1983), such a system provides sufficient space between the rows for alley cropping (Balandier and Dupraz 1998; Dupraz 1994) or alley coppice (Morhart et al. 2014).

A prescribed series of progressive pruning operations that are both targeted and timely are necessary. Pruning too early or too hard equates to a reduction in the rate of diameter growth, an increase in the chance of development of epicormic branches and can lead to lack of stem rigidity which may reduce the tree’s resilience to adverse weather conditions (Bohanek and Groninger 2003; Mohni et al. 2009). Likewise, the application of a late or light pruning operation will reduce the value of the stem as branches will be of a larger diameter, these will be evident outside the knotty core of the marketable bole, they will also callus slower providing a entrance point for devaluating rot and pathogens rendering the log unsalable. It has been recommended that limbs of *J. nigra* over 7.5cm are too large to prune (American Walnut Manufacturers Association 1998) others suggest this is also to great and encourage pruning of limbs with diameters of no greater than 3 cm (Springmann et al. 2011). Intensity of pruning in a single operation should not exceed two thirds of the total tree height, it has been advised that this can be extended to a maximum of one half of total tree height for isolated trees (Mohni et al. 2009). Pruning should be carried out in July to prevent the bleeding of wounds which can weaken the tree (Hemery 2011).

A variety of pruning methodologies have been recommended:

- **Flagpole pruning** (Mohni et al. 2009):
  - The systematic and repeat removal of stem shoots.
  - Only apical shoot not pruned.
  - Results in rapid stem elongation, but has the potential to result in unstable trees.

- **Progressive or classic whorl-wise pruning** (Mohni et al. 2009; Springmann et al. 2011):
  - Trees are permitted to initially grow without any form of intervention.
  - Followed by the progressive raising of the crown base.
  - The aim is to achieve a minimum branch free stem before the stem diameter at breast height reaches 10cm (simultaneously branches should be cut before they reach 3 cm diameter at the branch collar).

- **Reiterative pruning** (Mohni et al. 2009):
  - Allows the control of whole crown structure.
  - Apical shoot is retained without branches.
  - Intermediate stem with small diameter dense branching which gives the stem a degree of self shading.
  - Development of a clear bole to the desired height at sawmill’s requirement.
  - This method is applied at differing intensities dependent of rate of height increment.

- **Selective pruning** (Springmann et al. 2011):
  - Larger diameter branches (over 3 cm) are removed over the whole extent of the desired future clear bole length.
  - Steeply angled branches (less than 40°) are removed in the same way.
  - Repetitive pruning over a number of growing seasons is applied until a clear stem is achieved in lengths that are multiples of 2.5m.

In stands where a shorter bole is required, or a longer bole is not so relevant then the specific timing of thinning operations are not so crucial (Bohanek and Groninger 2003). Early thinning may leave the stand under-stocked resulting in a higher frequency of epicormic branches, thus lowering the final value of the stemwood. Such early intervention should be avoided.

A simple way to determine crown diameter in *J. nigra* has previously been reported: \( K = (2\text{dbh}) + 5 \) (Indiana Division of Forestry, 2002), where \( K \) (in feet) is the crown diameter and dbh (in inches) is the diameter of the stem at 1.3m above ground.
Crown competition factor (CCF) (Krajicek et al. 1961) can be utilised as a measure of crown density in relation to that which would be found using the example of an open grown tree (a CCF value of 100). It had previously been reported that the productivity of J. nigra peaks at a CCF of 82 (Schlesinger 1987). Recommendations to thin a stand when CCF reaches 90 have also been made (van Sambeek and Rink 1981). The intention being, to maintain the stand growing at the optimal rate.

Nut production

Similarly to a sawmill’s requirement for timber, the walnut industry demands a number of quality standards from walnuts both the kernel and in-shell walnuts (United Nations, 2007, United Nations, 2010). Such standard provide a quality benchmark outlining moisture content, size and to be free of fungi and pest species. Consumers have a requirement for the taste and quality of the kernel, while producers will select for trees and utilise cultivars that produce large nuts of high quality with thin shells to facilitate processing.

Three options on for the planting of walnut stock have been presented concerning J. nigra (Reid et al. 2009), such methodologies ensure a high yielding tree with desirable nut characteristics, an essential assurance required within a commercial venture:

1. Plant pre-grafted trees
2. Plant seedlings and graft them 2 to 3 years later
3. Plant nuts and graft 3 to 4 years later

The general consensus with the literature is to plant 100 to 200 trees ha⁻¹ in pure stands either in a square spacing or with wider between row spacing for the opportunity for intercrops (American Walnut Manufacturers Association 1998; Lewis 1906; Olsen 2006; Reid et al. 2009), however stocking density can be as low as 30 trees ha⁻¹ for the single objective of nut production (Schuster 1947).

Formative pruning should be carried out early after establishment (Lewis 1906) to correct structural problems such as steeply angled branches or multiple central leaders and to initiate a strong branch scaffold and a well balanced crown that can support the nut crop while facilitating simplified harvest operations, various systems are employed including the modified central leader system and tip pruning (Olsen 2006; Reid et al. 2009). Pruning of lower limbs can be carried out to facilitate the movement of machinery below the trees (Olsen 2006).

Thinning of nut orchards may be required to maintain sufficient space for individual crowns. Progressive thinning is advocated, while a final density of up to 30 trees ha⁻¹ is considered satisfactory (Lewis 1906; Reid et al. 2009). Periodic formative pruning must also be carried out to ensure the overall health and structure of the trees. Timber derived from a nut orchard is considered undesirable for the timber market (Schuster 1947), however, small niche markets may utilise small volumes for furniture, carving or craft work.

Combined timber and nut production

In Europe timber production and nut production are commonly separate enterprises and as previously discussed. The production of both timber and nuts within the same system can be problematic and present the need to make compromises in species choice and plantation design. However, such a production goal is not impossible and examples can be found where a silvicultural compromise has been achieved. Such a concession is often in a form of agroforestry, producing trees with larger crowns and shorter boles than those managed for valuable timber production goals, thus facilitating nut production (Garrett et al. 1991).

In the Dauphiné Province in south-eastern France, where nut and timber is combined notably a revival of a traditional system. Such a system provides the opportunity for intercropping and an increase of assets (Mary et al. 1998). In Italy within the Campania region, low density (50 stems ha⁻¹) multipurpose walnut is intercropped with vegetables and often combined with C. avellana which provides a training effect and an NWFP in its own right (Eichhorn et al. 2006).
The ‘streubost’ system as found throughout central and eastern Europe or the ‘pré-verger’ in France can frequently utilise walnut as a multipurpose species (Herzog 1998). Such a system utilises trees at a very low density (20 to 100 stems ha\(^{-1}\)), of disparate age and within no regular arrangement on cropland, meadow or pasture (Lucke et al. 1992). In addition to the annual or biannual nut production such trees within a ‘streubost’ or system are able to produce a clear log of 1.6m to 1.8m (Herzog 1998). Besides the advantages of a combined system where the opportunity for intercropping can increase or supplement grower’s income in the short term (Ares and Brauer 2004). Disadvantages can also manifest: including a delay in nut production (Mary et al. 1998; Reid et al. 2009), increased costs for additional silvicultural intervention (pruning) and the long term investment of capital (ca. 70 years).

For combined systems utilising J. nigra a 4.5 to 6m square spacing (478 to 269 trees ha\(^{-1}\)) is advocated in comparison with a denser stocking density utilised for timber production (van Sambeek and Rink 1981) this allows for greater crown development in early developmental stages, while retailing a relatively close spacing that can provide a training effect, encourage self pruning and still provide a degree of selection of final crop trees for timber production (Garrett et al. 1991; Kurtz et al. 1984). Lower initial densities are utilised in south-eastern France where 100 to 200 trees ha\(^{-1}\) (J. regia) are commonly planted (Mary et al. 1998).

Within a combined system for the production of both timber and nuts pruning operations must reach a compromise between pruning for a clear bole and for the provision of a strong scaffold of branches and thus canopy area enabling a large photosynthetic capacity and large volume of nuts. In combined systems utilising J. nigra branches are often removed from first 1.5 to 2.0 m to allow access by farm machinery for the harvest of nuts and for intercropping purposes, it has been suggested that is this is done in the correct manner then this can produce one length of veneer quality timber (New Zealand Walnut Industry Group, 2013).

In south-eastern France J. regia nut bearing varieties are grafted onto a sapling rootstock in situ, such rootstock has been managed to produce a clear bole, the graft is placed at a height of 2.5 to 3 metres, in the following years the crown is pruned to a goblet shape allowing for a strong scaffold of branches to develop (Mary et al. 1998).

Concerning J. nigra in the US employed within a combined Timber and nut system, trees are formatively pruned early in development to correct any structural defects and to present a straight central stem, by the 10th year after establishment they are pruned to 7 m and to 11 m by the 20th year (Kurtz et al. 1984). Flagpole pruning is reportedly utilised in the South of Italy and France for combined timber and nut systems with J. regia (Mohni et al. 2009). Other guidelines are more specific, stating that sequential pruning should commence during the fifth year when the walnut is between 3 and 4.5m tall proceeding to a height of 2.7m while at all times ensuring that the crown remains between one half to one third of total tree height (Garrett et al. 1991).

Utilising J. nigra in the US with a rotation length of 60 years where the target diameter of crop trees is 50 cm dbh with a clear bole of 3.0 m and in the best sites approx 76 cm with a clear bole amounting to 4.3 m. Initial stocking density was 269 tees ha\(^{-1}\), pre-commercial thinning at year 25, followed by two commercial thinning operations at years 36 and 48 to ensure sufficient room for crown development (Kurtz et al. 1984). It has been recommended that the crown competition factor (CCF) should not exceed 90, thinning operations should be carried out at this point, which an aim for a final stand density of approximately 27 to 35 crop trees ha\(^{-1}\) (Garrett et al. 1991), such a release thinning is an efficient way to increase the available light thus allowing an increase in productivity.
Other potential

Much research agrees that the inclusion of other species within the planting design provided strong benefits to the growth of Juglans spp. Two such species that are repeatedly advocated as companion plants are black alder (*Alnus glutinosa*) and autumn olive (*Elaeagnus umbellate*) (Bohanek and Groninger 2003; Clark et al. 2008; Funk et al. 1979; Schlesinger and Williams, 1984; van Sambeek and Garrett 2004). Both species are nitrogen fixing, their presence shades the stem and aids natural pruning of lower branches. Furthermore both are marketable black alder as timber and the edible berries produced by the autumn olive as an NWFP, the later however being non-native to Europe and may in some areas be classed as an invasive species (CABI 2013).

Various plantation designs have been proposed utilising companion planting, for the production of high value timber square spacing of 3m between black walnut has been proposed with black alder and autumn olive planted at 1.5 m between the rows (American Walnut Manufacturers Association 1998). Meanwhile black walnut has been shown (mid-rotation) to have the potential to produce a high quality bole when planted at 5.5 m square surrounded with black alder at 2.7 m square (Bohanek and Groninger, 2003). Greater rates of growth and trees were of a better form when investigated in the United Kingdom when *J. regia* was grown with hazel (*Corylus avellana*) and autumn olive. It was found that crop trees remained single stemmed and had fewer and finer branches (Clark et al. 2008).

The utilisation of companion planting provides benefits for timber production but can be considered incompatible on a practical level for the production of nuts, since the presence of such species will hinder yearly nut harvest, the inclusion of such species within a silvicultural prescription much be factored towards practical aspects of production.

The potential for intercropping between widely spaced walnut has been frequently discussed (Gold and Hanover 1987; Dupraz 1994; Mary et al. 1998; Chifflet et al. 2006). The application the intercropping of agricultural crops, or other NWFP provides a short term source of income during the otherwise profitless establishment and tending phases of timber production.

A number of intercropping system have been proposed, some of which provide benefits to the timber crop while constituting a second (or third) product source:

- Traditionally in south-eastern France intercropping with lavender, winter cereals and sunflowers has been practiced for ten to twelve years after establishment, thus constituting the only income generated during this time for the growers (Mary et al., 1998).
- The largely redundant system ‘Joualle’ traditionally employed in southern France was composed of vines with rows of peach (*Prunus persica*) walnut and olive (*Olea europea*), while similar systems are still maintained in parts of Greece (Eichhorn et al. 2006).
- Christmas trees have been planted between *J. nigra* crop trees with an aim to increase density in early stages of growth providing a better stem form (Campbell et al. 1991) this aids by encouraging self pruning and discouraging the growth of epicormics post pruning.
- In Campania, Italy where the combined cultivation of walnut for timber and nuts is common place, walnut trees are planted with a very low density (about 50 stems ha⁻¹) and are intercropped with *C. avellana* or with vegetables. The interplanted *C. avellana* is also grown to produce both for wood and nuts and acts as a trainer tree for the improvement in the form of the valuable walnut stems (Eichhorn et al. 2006).
- Other innovative approaches include a recently proposed alley coppice system, where short rotation biomass crops such as willow (*Salix* spp.) and poplar (*Populus* spp.) can be grown between the rows of timber trees (Morhart et al. 2014).
3.3.2.1.4 Summary of key points and knowledge gaps
- Inherent incompatibility of silvicultural system for timber and nut production
- But combination is possible: see (Mary et al. 1998)
- Few models available
- Recommendations for further research
  - Yield assessment
  - Assessment of growth
  - Berry yield of autumn olive below walnut
  - Native alternative to autumn olive: N-fixing
  - Native alternative to autumn olive: NWFP producer in own right
- Look towards yield models produced for other nut species e.g. pecan (Brauer et al. 2006)

3.3.2.1.5 Suggested silvicultural prescription for combined timber and nut production in Europe utilising Juglans regia
- Plant autumn olive (or suitable alternative) during establishment
- Removal of companion plants at onset of commercial nut production, autumn olive (or other) provides NWFP until that point and can be planted in tree rows in agroforestry setting, while still allowing for an intercrop between rows
- Once nut cropping has commenced it can be assumed that crown cover is sufficient to shade stem
- Land managers should assess nut yields over 2 or more consecutive years before thinning operations are carried out as to maximise nut production and not thin out high bearing trees (Brauer et al. 2006).

3.3.2.2 Chestnut

*Castanea sativa* Mill., sweet chestnut/ European chestnut/ Spanish chestnut (EN); châtaignier vulgaire/ chêtaignier commun (FR); Castagno domestico/ Marrone (IT), Esskastanie, Marone (DE), castaño (ES), castanheiro mano (PT).

The chestnut tree (*Castanea sativa* Mill.) is considered part of the European culture; timber and nuts production in 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. Dual-purpose chestnut varieties for both fruit and timber production are quite common in some European regions (Conedera and Krebs, 2010).

3.3.2.2.1 The tree

The chestnut (*Castanea sativa* Mill.) 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) (see Figure 3.5). It has been speculated that the occurrence of chestnut in Scotland is possibly the most northerly incidence of the species (Braden and Russell 2001). Chestnut can be found concentrated in a few countries with a long tradition of chestnut cultivation, such as France and Italy which account for nearly 80% of European chestnut cultivation with Spain, Portugal, and Switzerland providing a further 10% (Conedera and Krebs 2010). Natural Chestnut forests occupy nearly 262,000 ha areas in Turkey. European chestnut is estimated to cover a total of 2.5 million hectares, of which 2.2 million hectares are chestnut dominated forests and the remaining 0.31 million hectares classified as mixed forests with chestnut. (Conedera and Krebs 2010).
Many soil types are noted as suitable for the culture of sweet chestnut (Everard and Christie 1995; Gallardo-Lancho 2001; Braden and Russell 2001; Haltofová et al. 2003), however, the best height development can be seen on sandy soils with a high loam content (Savill 1991; Oosterbaan 1998; Urbisz and Urbisz 2007). Soils should be moderately acidic (pH 5-6.5), deep and contain a wide range of nutrients and preferably with few stones (Everard and Christie 1995; Bottema 2000; Gallardo-Lancho 2001; Haltofová et al. 2003; Urbisz and Urbisz 2007; Álvarez-Álvarez et al. 2010; Martins et al. 2010). Chestnut displays poor growth on sites with a high water table and soils with poor drainage, including areas which 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) as it doesn’t grow on calcareous soils. C. sativa demands fair to high annual rainfall sum (Evans 1984; Gallardo-Lancho 2001) with summer precipitation greater than 130mm with no more than 200mm of precipitation deficit (Álvarez-Álvarez et al. 2010; Fioravanti et al. 2010).

The ideal climate for the successful culture of C. sativa are those areas that experience a temperate humid climate with mild winters (Haltofová et al. 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 frost 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. 500m to 1200m) (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.

It has been reported that C. sativa 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, C. sativa can also tolerate some degree of shading illustrated by its occurrence with Fagus orientalis (Oriental beech) in Turkey.

The species has been documented to live for 500 years or longer (Urbisz and Urbisz 2007), exceptions include one individual in the UK that is estimated to be 1,200 years old (Braden and Russell 2001) such
veteran trees have an extremely important ecological role to play which can be argued to outweigh any productive value.

C. sativa is a fast growing species, (Fioravanti et al. 2010) and can grow to 30m in height with a diameter of 80cm at 1.3m under favourable conditions (Oosterbaan 1998; Urbisz and Urbisz 2007). Furthermore, DBH measurement of 30 to 40cm can be reached within 30 to 40 years, (mean annual increment (MAI) growth of 9.5mm (Fioravanti et al. 2010), but after this point MAI is suggested to decline (Oosterbaan 1998). It has been noted that there is little differences between C. sativa and hybrid chestnut cultivars regarding the rate of growth (Álvarez-Álvarez et al. 2010). Meanwhile, C. sativa boasts a high capacity for resprouting, hence a coppice style management is prevalent in many areas both in the past and present (Evans 1984; Pereira Lorenzo et al. 2010).

The major diseases affecting chestnut cultivation are chestnut blight (Cryphonectria parasitica), a pathogenic fungus thought to have originated from China and ink disease which is caused by the soil-born pathogen (Phytophthora cambivora.) (Evans 1984; Diamandis and Vannacci 2010) it has been proposed that some mycorhizal species Amanita muscaria, Boletus luridus and Hebeloma radicosum may present an antagonistic effect towards P. cambivora in chestnut (Landi et al. 2006). Furthermore, some interspecific hybrids have been bred that display some resistance to ink diseases (Pereira Lorenzo et al. 2010). Common pest species include the chestnut gall wasp (Dryocosmus kuriphius) (Conedera and Krebs 2010), the chestnut leafroller (Pammene fasciana), the beechn moth (Cydia fagiglandana), the chestnut tortrix (Cydia splendana) and the chestnut weevil (Curculio elephas) (Alma and Quacchia 2010). The suitable and sustained management of chestnut plantations can provide adequate resilience towards the abovementioned pests and diseases, through the application of tending operations (Martins et al. 2010).

3.3.2.2.2 NWFP products

C. sativa has historically been known as the “bread tree” (Bellini and Vannacci 2010), Chestnut fruits are a good source of dietary carbohydrates, fibre and essential minerals. They have a very low fat content, are cholesterol-free, and have high amounts of vitamin C and E (Di Renzo et al. 2010). Fruits can be also used for the production of chestnut flour for pasta and pastry (a gluten free alternative to wheat flour), and chestnut beer (Conedera and Krebs 2010).

The nuts, leaves, flowers and bark of the C. sativa have been extensively used in the cosmetics industry, in natural and homeopathic medicine, and the nutraceutical sector (Abrudan et al. 2010; Di Renzo et al. 2010), the shell and leaves can be utilised as a source of natural antioxidants and phenolic compounds (Calliste et al. 2005; Vázquez et al. 2008; Vasconcelos et al. 2010). The residues resulting from the processing of nuts such as the pericarp (the outer shell) and (inner membrane) contain compounds that have anti-diabetic, antitumor, antioxidant, antimicrobial and anti-malarial properties (Abrudan et al. 2010; Di Renzo et al. 2010), and have also been proposed as a means of absorbing heavy metals (Vázquez et al. 2009).

Tannins extracted from wood and bark of C. sativa can be used in the leather processing industry (Braden and Russell 2001), and in the cosmetic industry; moreover, chestnut tannins can be used to improve the stability of wines, as antioxidant compounds, and as an animal feed (Fioravanti et al. 2010). Tannins can also be added to fibre panels to improve bonding. In particular, the production of tannins and panels (specifically MDF and HDF panels) can be easily integrated, since the production of boards can utilise the shredded material that has been stripped of tannins (Bellini and Vannacci 2010).

Other indirect NWFPs can be associated with the culture of chestnut including honey and edible wild mushrooms such as Boletus spp. and Amanita cesarea which commonly grow underneath the crown (Bellini and Vannacci 2010). In particular, chestnut orchards are a favorable habitat for the growth of the edible and highly valuable mushroom Boletus edulis (Ciesla 2002).
Chestnut Yield

Estimates of chestnut yield have been proposed but are most frequently quoted on a country and European level. For example the average European fruit production is estimated at approximately 130,000 tonnes yr⁻¹, (coincidentally, the average price paid to producers has been in the region of 1,500 € per tonne equating to ca. 200M € per year (Bellini and Vannacci 2010). But due to a limited economic return, a decrease in nut production is predicted (Gallardo-Lancho 2001). Worldwide chestnut production is estimated to amount to 2,014,736 tonnes yr⁻¹ (FAO 2012), produced in orchards with an estimated total area of 349,000 ha. Chestnut production in Asia is almost eight times that of Europe with China being the dominant producer producing 1,700,000 tonnes yr⁻¹ (84% of world-wide production) in 2012. Meanwhile Japan, Turkey, and Korea produce approximately 25,000, 60,270, and 78,000 tonnes yr⁻¹ respectively (Pereira Lorenzo et al. 2010; FAO 2012). After China and Korea, Turkey is the third largest producer of Chestnut. It is documented that fruit production commences after 20 to 30 years in non-cultivars, increasing to 40 to 60 years in dense forest stands (Bottema 2000), but little information is available on specific yield of an individual tree. Kapucu et al. (2002) developed an empirical yield table for C. sativa. According to the authors, the mean annual increments at the reference age of 50 for site classes I, II, III, IV, and V are 13.3, 12.4, 11.0, 9.3 and 7.9 m³ respectively. As such, the chestnut stands appear to be one of the fastest growing broadleaved species in Turkey.

3.3.2.2.3 Silvicultural prescriptions for growing Castanea sativa

Three main management practices can be found in Europe concerning the cultivation of chestnut, high forest, coppice and orchards (Pereira Lorenzo et al. 2010) 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). 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 or in an orchard (Abrudan et al. 2010), which is defined by the desired product or product mixture. Such silvicultural differences will be outlined and discussed below.

Timber production

The light brown chestnut wood is used for veneer, wine barrels, construction works, finger-jointed beams, poles, stakes for vineyards, furniture, doors, window frames, solid wood panels, medium/high density fibreboard (MDF and HDF), wood flooring, outdoor products, fuel wood, and tannin production (Pereira Lorenzo et al. 2010; Fioravanti et al. 2010). Thanks to its inherent durability, chestnut timber can be also used in outdoor applications and does not require applications of chemical preservatives (Fioravanti et al. 2010) thus representing a more environmentally sensitive product. Chestnut wood has good strength properties with a high ratio between strength, stiffness and density (the average density being lower than 600 kg/m³). The natural durability is high (class 2 as defined within EN 350-2) and the heartwood is abundant even within young stems (Fioravanti et al. 2010). Due to the species’ fast growing nature (up to 24 m²ha⁻¹yr⁻¹) (Fioravanti et al. 2010), chestnut could also be considered as a mean of supplying energy wood in the form of wood chips and wood pellets, akin to established biomass production systems (Pereira Lorenzo et al. 2010). It has been reported that small scale production for pulp has been trialled in Wales where C. Sativa is grown on a 25 to 30 year rotation (Evans 1984).

A major problem with chestnut timber is that of ring shake (Kerr and Evans 1993), its exact cause has not been defined but may be an effect of predisposed genetic factors, soil nutrient availability or climate (Fonti et al. 2002). The occurrence of ring shake within logs is totally devaluing, therefore to limit its extent the application of dynamic and timely silvicultural operations is required allowing for the production of a high
quality wood product (Fioravanti et al. 2010). Biomass modelling has been undertaken for C. Sativa with models derived for different biomass compartments including total above ground biomass, bole wood, bole bark, branches, leaves and flowers as a function of DBH in northern Portugal (Patricio et al. 2004).

High forest production

The utilisation of high forests as a production system for timber is reported to play only a minor role for C. sativa (Pereira Lorenzo et al. 2010). Timber production is often focused on steep and stony ground where nut production is neither practical nor profitable due to mechanised nut harvesting methods (Álvarez-Alvarez et al. 2010). Establishment can take the form of either planting or natural regeneration, in the UK natural regeneration methods have been reported to be unsuccessful (Braden and Russell 2001), this circumstance may be representative of a situation at the fringe of the tree’s climatic range. However, small area shelterwood regeneration method seems to be successful in Turkey when the soil is tilled and the seeds are protected from informal picking (Anonymous 2013). Furthermore, under such conditions planting is utilised as the common establishment method, local provenances are used where available (Braden and Russell 2001) in Spain, hybrids are also used such as the clone ‘125’ yielding acceptable results (Pereira Lorenzo et al. 2010). A further stand establishment method is the conversion from abandoned coppice to high forest by a process known as ‘storing’ (Braden and Russell 2001). Here the reduction of the number of sprouts from a stool is reduced to a single upright stem which displays a suitable form for timber production. When planting at lower elevations a stocking density of 400 trees ha⁻¹ is advocated, reduced by half some years later (Pereira Lorenzo et al. 2010). Rotation length is markedly shorter than other broadleaf species, rotation lengths of 40 to 50 years are commonly employed, this is to limit the occurrence of ring shake defects, within this time DBH can reach more than 40cm (Kerr and Evans 1993; Everard and Christie 1995; Braden and Russell 2001; Pereira Lorenzo et al. 2010). In Turkey rotation of 40-70 years are reported (Kapucu et al. 2002). Higher quality and larger dimension timber is reported in Galicia utilising longer rotations of 80 to 90 years (Pereira Lorenzo et al. 2010), however, it is unclear on the occurrence and frequency of wood defects. Nevertheless a careful and considered silvicultural prescription can go some distance towards the prevention of ring shake (Oosterbaan 1998).

The application of sequential pruning operations will increase the value of the bole, the highest prices will be realised for stems that are branch free to a height of at least 7m (Everard and Christie 1995; Pereira Lorenzo et al. 2010). Crop selection should be carried out at approximately 10 to 13 years of age. When trees are 10 to 12m high, a pre commercial thin should be carried out to remove competitors. At 18m in height (approximately 20-25 years) all but the crop trees should be coppiced (Everard and Christie 1995), such management would constitute a coppice with standards regime at this developmental stage. The prediction of crown diameter (K) from DBH for chestnut follows a linear form (K = 10.668DBH + 2.793 \( r^2 = 76.1 \) ) (Savill 1991). Such a function can be used to calculate number of trees ha⁻¹ at a given DBH to facilitate thinning decisions, in the case of chestnut this is proposed to be 151 trees ha⁻¹ at a DBH of 60cm (Hemery et al. 2005), this equates to an approximate 8m x 8m spacing.

Coppice production

The fast growth and high resprouting capacity of sweet chestnut is well known and has therefore been utilised within a coppice culture for centuries for the production of smaller dimension timber and specialised timber products (Castro 2009; Pereira Lorenzo et al. 2010). However in recent years the demand for coppice products has declined, with this, so had the area of active coppice management, without intervention coppice will naturally revert to high forest (Braden and Russell 2001; Pereira Lorenzo et al. 2010).

Establishment of a coppice coupe can be carried out by planting or layering (Braden and Russell 2001) the latter being a method of in-situ vegetative propagation creating a clone of the parent plant, however, this is
spatially limited, dependent on individual shoot lengths used in the layering process. Coppice stand establishment can also be undertaken through the conversion of redundant orchards or in some cases high forest, where chestnut stems are cut back to the base.

Initial stocking density is determined by the planned length of rotation and the desired product. For rotation lengths of between 12 and 16 years a stocking density of approximately 800 to 1,000 trees ha\textsuperscript{-1} is advocated (Braden and Russell 2001). Longer rotations will require a less dense stand to avoid excessive mortality. Classically rotations of 2 to 3 years are employed for the production of walking sticks, 7 years for bean poles and 15 to 20 years for fencing material (Evans 1984; Braden and Russell 2001). Rotations of 12 to 25 years have been commonly practiced in Germany, 14 to 20 years in the south of England and between 20 and 30 years in Turkey (Braden and Russell 2001; Kapucu et al. 2002; Pereira Lorenzo et al. 2010). The resprouting ability of the stool has been suggested to be a function of the competitiveness of the stand (i.e. density) and height and quality of the cut stool (Giudici and Zingg 2005). Timber yields when management within a coppice culture can be expected to be within the region of 7 to 9 t ha\textsuperscript{-1} yr\textsuperscript{-1}.

Chesnut production

"Sativa" literally means "cultivated" possibly a reference to the widespread historical cultivation of the chestnut tree by civilisation. The Marron varieties have been traditionally cultivated in Italy and in a few areas in France for nut production, within pure stands (>80% chestnut). Such stands or orchards represent 19.3% of the European chestnut area total (Conedera and Krebs 2010). In the Bragança region in Portugal a system called Soutos is practiced, widely spaced chestnut are dispersed on pasture for the grazing of sheep (Castro 2009), this is similar to the duel use steuobst system in central Europe and discussed later. Representing the limits of the species' ecological range it has been recognised that there is no commercial nut production in UK since nut quality is often poor with infrequent fructification (Braden and Russell 2001; Everard and Christie 1995).

Fruit 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).

Chesnut 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). It must however be noted, that when grafts are made in the field, the success rate can be variable, for this reason unsuccessful grafts may need to be repeated in the following year, resulting in unequal development within a stand. This consequence can be considered to have a negligible effect given the long productive life of a chestnut orchard; such early effects will have balanced out when commercial production begins (Pereira Lorenzo et al. 2010). Grafted plants are more expensive to produce but their employment creates a more consistent orchard than using non-grafted varieties (Pereira Lorenzo et al. 2010).

Guidance for the establishment of chestnut orchards advocates a wide spacing between trees this provides sufficient area for crown extension required for a commercial crop but also provides sufficient access for annual harvest and tending operations. Often a square spacing of 10m or 12m (70 to 100 trees ha\textsuperscript{-1}) is suggested (Castro 2009; Martins et al. 2010; Pereira Lorenzo et al. 2010). The initial planting of denser stands is also possible but requires a degree to thinning at a later stage (Pereira Lorenzo et al. 2010), this results in greater establishment costs but allows the grower greater freedom of choice in terms of tree
form and rate of growth. Denser stands may also be appropriate for interspecific hybrid rootstocks or Euro-Japanese cultivars (Martins et al. 2010; Pereira Lorenzo et al. 2010).

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 and developing 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).

Harvesting operations are carried out during the autumn months, in non-specialised/ low intensity orchards, chestnuts are manually harvested, this is in contrast to fully mechanised chestnut ‘sweepers’ or ‘vacuums’. It has been suggested that manual harvesting may account for half of the total production costs incurred (Bellini and Vannacci 2010). In turkey the commercial lifespan of an orchard is suggested to be 80-100 years for nut production (Anonymous 2013).

Combined timber and nut production
The combination of timber and chestnut production allows for greater product diversity and income generation, an aspect especially important for small scale land owners and managers. The establishment of a combined system utilises an amalgamation of silvicultural prescriptions developed for the separate production of timber and of chestnuts. Silvicultural aims for both product goals are the production of a straight branch free bole with a length of 7m and a DBH of at least 40cm (Pereira Lorenzo et al. 2010), above 7m a strong branch scaffold must be developed for the production of nuts, this can be carried out by pruning operations. Other dual systems such as that commonly utilised on the Iberian Peninsula require the grafting of desirable chestnut cultivars atop a straight branch free stem at a height of 2m (Conedera and Krebs 2010), similar to practices carried out in mono-use C. sativa production systems. Stocking should be closer than that found within in chestnut orchards, this allows for increased interspecific competition creating a better stem form (Pereira Lorenzo et al. 2010). A 7m square spacing (204 trees ha⁻¹) is advocated for this purpose (Pereira Lorenzo et al. 2010).

Furthermore, the production of chestnuts is possible within a streuobst system (Herzog 1998; Lucke et al. 1992), which is widespread throughout western, central and eastern Europe. Trees are dispersed amongst pasture, cropland or meadow as low density (ca. 20 to 100 trees ha⁻¹). Trees within this system are generally managed to produce a log length of between 1.6 to 1.8m (Herzog 1998).

Since the application of sequential pruning operations are required to create a branch free bole a delay in nut production will result, it is however, suggested that to increase the overall annual chestnut production rotations can be extended to 80 or 90 years resulting in DBH measurements of over 70cm (Pereira Lorenzo et al. 2010). The minimum distance between two crop trees in a duel system at the end of the rotation period should be 12 m (Wilhelm 2004).

Other potential
Five varying ground maintenance systems have been reported for the control of vegetation below pure chestnut orchards: grass for pasture, wheat or rye, two ploughing operations to retain ground bare, herbicides application or the encouragement of natural grass cover which is mown. (Castro 2009; Pereira Lorenzo et al. 2010). The potential for intercropping is also present as is practiced with other species such as walnut (Juglans spp.). Such multifunctional use of a system is essential in order to promote productivity and sustainability (Conedera et al. 2001; Martins et al. 2010). Short rotation biomass crops such as willow (Salix spp.) and poplar (Populus spp.) can be grown between the rows (Morhart et al. 2014), here C. sativa can be managed for the production of both high value timber and NWFP.
3.3.2.4 **Summary of key points and knowledge gaps**
- Established silviculture for both timber, nut and combined systems already practiced.
- Nut production focused towards cultivar varieties, wild forest varieties are less desirable due to the size of the nut.
- Forest varieties are collected informally
- Multiple uses of chestnut fruits
- Maintenance of natural mixed stands
- Timber is highly valued although difficult to grow quality timber without ‘shake’
- Hybrids have been bred with disease resistance

3.3.2.5 **Suggested silvicultural prescription for combined timber and nut production in Europe utilising Castanea sativa**
- A high potential for combined systems.
- Development of the system described as utilised on the Iberian peninsula desirable chestnut cultivars are grafted to an established branch free stem at an approximate height of 2m.
- The above also provides intercropping potential.

3.3.2.3 **Cherry**

*Prunus avium* L., wild cherry/ sweet cherry/ bird cherry/ gean (EN); Vogel-Kirsche (DE); merisier/ cerisier des oiseaux (FR); cerezo Silvestre (ES); ciliegio (IT), cerejeira brava (PT).

*Prunus avium*, the wild cherry is widely cultivated across Europe, either within the forest as a high value timber tree or within an orchard as a grafted cultivar for the production of cherries.

3.3.2.3.1 **The tree**

Wild cherry (*Prunus avium* L.) 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 1998*) (see Figure 3.6). It is difficult to ascertain the natural range of the species due to widespread and long term cultivation (*Joyce 1998*) Distribution at the margins of the range are scattered, while 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*).

![Figure 3.6 European distribution of P. avium (Russell 2003)](image-url)
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 areas (Pryor 1988; Coello et al. 2013; Ducci et al. 2013).

Soils must be moist but not waterlogged or stagnant (Evans 1984; Pryor 1988; Savill 1991; Joyce 1998; Hemery et al. 2010; Ducci et al. 2013). It has been suggested that *P. avium* has a reputation of demanding fertile sites (Savill et al. 2009), (i.e. nutrients present in an available form) specifically requiring a soil with medium to high nutrient content (Joyce 1998; Coello et al. 2013). The species thrives in mildly acidic conditions (Evans 1984; Pryor 1988; Coello et al. 2013). Best growth can be observed on sites with deep podsolised soils allowing for sufficient root development overlaying calcareous parent material (Pryor 1988; Savill 1991; Joyce 1998).

It has been suggested that the species’ distribution is mainly related to summer rainfall in the summer period in both the south and in colder conditions experienced north and eastern Europe (Ducci et al. 2013). *P. avium* has a preference for warm and sunny sites (Joyce 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), the species is intolerant of frequent drought stress (Hemery et al. 2010; Coello et al. 2013), but is tolerant of moderate drought events (Savill et al. 2009). Woody growth is frost hardy (Pryor 1988), but the early blossom is susceptible to early frost events (Joyce 1998). The tree is particularly intolerant to wind exposure once above 4 to 5 m in height (Joyce 1998), this can be partly attributed to root form, especially when coupled with less than ideal soil types.

*P. avium* displays a strong apical dominance and weak phototrophic tendency (Pryor 1988) but can be considered a high light demanding species, increasingly so as it matures (thicket stage onwards) (Pryor 1988; Savill 1991; Joyce 1998; Savill et al. 2009).

*P. avium* is neither a large nor long lived tree, mean dimensions are often quoted as 20 to 30 m in height (Mitchell 1978; Evans 1984; Joyce 1998; Ducci et al. 2013), height growth reaches a peak between 7 and 15 years and dramatically reduces after 30 to 40 years (Joyce 1998). It has been suggested that members of the Rosaceae family rarely live beyond 100 years (Savill et al. 2009). Diameters at breast height of between 50 and 90 cm are achievable within a 70 or 80 year rotation (Evans 1984; Spiecker 2006; Ducci et al. 2013). Current inventory suggests that within the EU, stand age classes are dominated by younger stands (< 40 years). It has been reported in German speaking countries that a high proportion of stands are younger than 20 years (Thies et al. 2009). The species has an increased risk of devaluing heartrot after 60 years (Savill 1991). Maximum mean annual increment has been reported as being 4.9 to 9.1 m³ha⁻¹yr⁻¹ in the UK (Pryor 1988). The crown projection area of a mature wild cherry ranges between 80 and 100 m², crown/stem ratios have been calculated for *P. avium* by means of regression analysis to facilitate the planning of thinning operations (Hemery et al. 2005).

The reproductive strategy of *P. avium* is twofold, both able to propagate through vegetative suckering (Pryor 1988) and through insect pollination (Joyce 1998), the production of seed (cherries) that are dispersed by birds and animals (Ducci and Santi 1997). It has been suggested that the trees use vegetative propagation utilising root sprouts when the ecosystem is in juvenile phases, while long distance spread by seeds is dominant when the ecosystem is mature (Ducci et al. 2013).

There are a number of pest and diseases that affect the culture of *P. avium* in both forest and field locations, Bacterial canker (*Pseudomonas syringae*) (Lang 2001b; Pryor 1988; Joyce 1998), Silverleaf (*Stereum purpureum*) (Lang 2001b; Pryor 1988) but this is suggested to be of lower concern in the forest, and can be minimised by timely silvicultural operations (Pryor 1988; Joyce 1998), *Phytophthora* spp. are common on waterlogged soils (Pryor 1988) and the Cherry leaf roll virus (Pryor 1988). Leaf curl can also be caused by the cherry black fly (*Myzus cerasi*) (Pryor 1988; Joyce 1998), and damage to stem can be brought
about by wildlife, particularly deer (Pryor 1988; Joyce 1998). The European cherry fruit fly, (*Rhagoletis cerasi*) is a highly destructive pest of cherry fruit. The low tolerance for damaged fruit within the consumer market requires extensive preventive insecticide treatments to realise a marketable crop (Daniel and Grunder 2012).

3.3.2.3.2 NWFP products

Product characteristics and utilisation

*P. avium*, the wild cherry is the source of all cultivars (Joyce 1998), domesticated and bred for desirable fruit traits over centuries. The consumer market requires cherries to be large and blemish free, fruit averaging 29mm in diameter is worth almost twice as much as fruit that is less than 24mm in diameter (US) (Whiting et al. 2005; Zhang et al. 2010), this control of fruit traits are only possible with the growth of cultivar varieties. The fruits have multiple culinary uses, often jellies and jams but can also be used in cooking, juiced or made into a liquor or schnapps, combinations of which, such as the black forest gateau (Schwarzwälder Kirschtorte) are a winning combination! Cherry stones, a by-product of the cherry processing industry are a potential source of biomass for energy recovery (González et al. 2003). The early flowering nature of the tree is an important nectar source for the production of honey (Ciesla 2002)

Yield

Within a forestry setting it is suggested that a viable cherry crop for seed production, is usually achievable within 10 years, thereafter a good crop occurs every one to three years (Pryor 1988; Philipson 1990; Joyce 1998). Yield can be dependent on external climatic factors such as late spring frosts which can damage the early flowers (Joyce 1998), fruits can be lost and damaged by rain cracking and herbivory by birds (Lang 2001a). No yield models could be found within current literature for the fruiting capacity of *P. avium*.

3.3.2.3.3 Silvicultural prescriptions for growing Prunus avium

Timber production

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 branch free log lengths of 8m or more, but this has been reported to range between 4 and 15m (Thies et al. 2009; Hein and Specker 2009) with a mean mid underbark diameters greater than 40cm and with a Knotty core of less than 10cm in diameter (Joyce 1998). Furthermore, logs should be rot-free or that any rot is confined to the afore defined knotty core. Such a butt log length can be achieved within 20 years after which the silvicultural operations focus on diameter growth. Timber volume of between 6 and 10 m³ ha⁻¹ yr⁻¹ are attainable on most sites (Savill 1991). *P. avium* accounts for 0.7% of annual removals within the EU, with the proportion of high value timber increasing with increasing demand (Thies et al. 2009).

Provenance choice can be considered crucial within forestry applications (Joyce 1998), such choice allows for the best pairing between site and climatic conditions with other important factors such as stem form. Although natural regeneration is prevalent, 54% of stands rely on natural regeneration (Thies et al. 2009) with a reported 80% germination rate from 5,100 seeds per kg of fruit (Savill 1991), artificial regeneration through planting is the norm when establishing a plantation, in a questionnaire 74% of plantations were reported to be planted within German speaking countries (Thies et al. 2009), furthermore, clonal reforestation is commonplace due to much planting stock being derived from root suckers. Seeding is not commercially practiced (Thies et al. 2009). It has been suggested that most intensive wood production plantations using mixtures of 5–10 geographically distant clones may lead to greater variability than most natural stands (Ducci and Santi 1997). Planted saplings usually consist of 2+0 or 1+1 or 2+1 stock that is 50 to 120cm in height (Joyce 1998).
Planting density is commonly promoted as being lower than other broadleaves, frequently at 1100 trees ha\(^{-1}\) (3x3m) (Pryor 1988; Savill 1991; Kerr and Evans 1993). Wider spacings are also suggested at 5x5 m (400 trees ha\(^{-1}\)) (Coello et al. 2013). Early growth is hindered by excessive weed growth, timely maintenance can double early height growth (Evans 1984; Pryor 1988; Savill 1991).

The average rotation period for wild cherry stands ranges between 50 and 80 years (Kerr and Evans 1993; Joyce 1998) and has been reported to be as wide as 40 to 120 years (Thies et al., 2009). Extended rotation periods increase the chance of a devaluing rotted of the heartwood (Pryor 1988; Coello et al. 2013).

*P. avium* is a tree species that do not self-prune well (Pryor 1988), shaded branches quickly die and can result in the formation of dead knots. Therefore, in order to obtain high quality butt logs, artificial pruning is necessary (Thies et al 2009). Conventional pruning consists of removing branches whorl-wise (most side branches are arranged in annual whorls) (Pryor 1988), which results in a branch free stem up to a selected height or by the number of whorls. On the other hand, selective pruning removes only all branches with a diameter of about 3 cm from the entire length of the potential veneer log and small branches that form steep angles with the stem; such branches need to be removed quickly because they tend to grow faster in diameter. Only small branches should be pruned because the risk of fungal infection increases with the size of the branch due to the exposure of heartwood (Pryor 1988; Joyce 1998). All small branches that have not been removed continue to contribute to the tree growth and they will eventually be pruned in the following years (Springmann et al. 2011). Pruning should be carried out between June and August to minimise infection from bacterial canker and silverleaf (Evans 1984). The average annual diameter increment is significantly lower when conventional intensive pruning is applied (leaving only the top 3 whorls intact) than selective pruning (Springmann et al. 2011). Moreover, selective pruning has a higher potential to minimise the negative impact of secondary shoot production on the butt log, secondary shoots are more numerous on more intensively pruned trees. It should be aimed to retain a crown length of at least half or two thirds total tree height (Joyce 1998; Kupka 2007), as overpruning can lead to a 10% reduction of diameter growth in the following 5 years after pruning. It can be advocated that annual formative pruning should commence early on all trees (2 to 6 years) (Coello et al. 2013), while later concentrating on the best 150 to 200 trees at approximately 4 to 9 years after establishment (Joyce 1998; Coello et al. 2013), when finally after 10 to 14 years prune only the chosen crop trees (approx 70-80 tree ha\(^{-1}\)) to 6m (Joyce 1998; Coello et al. 2013). Serving or trainer trees are also recommended to aid the formation of a branch free bole and to prevent epicormic branching (Thies et al. 2009), species such as lime (Tilia spp.) or hornbeam (*Carpinus betula*) have been suggested for this purpose.

Progressive thinning should be carried out, as *P. avium* responds strongly to timely release (Spiecker 1994). The species is particularly intolerant of lateral competition; as a result diameter growth can become severely restricted (Pryor 1988). Maintenance of canopy closure between 100% (full closure) and 70% provides the best conditions for maximal diameter growth (Pryor 1988). Table 3.2 outlines suggested numbers of trees per hectare by DBH after thinning to 65% canopy closure.

<table>
<thead>
<tr>
<th>dbh (cm)</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>P. avium (stems ha(^{-1}))</td>
<td>437</td>
<td>236</td>
<td>147</td>
<td>100</td>
<td>72</td>
</tr>
</tbody>
</table>

Seedlings and suckers are relatively shade tolerant for the first few years post establishment (Pryor 1988). Negative selection should be practiced in early stages (Thies et al. 2009), common practice is to commence
thinning operations at 6 to 8 m of height, favouring 200 to 250 trees ha\(^{-1}\) (Kerr and Evans 1993; Joyce 1998; Coello et al. 2013), 160 trees ha\(^{-1}\) at 23 years (12m), 100 trees ha\(^{-1}\) at 31 years (16m) eventually favouring 70 crop trees ha\(^{-1}\) at approximately 40 years of age (19m) (Coello et al. 2013). Positive selection of crop trees should note diameter, form, top height and the length of branch free bole (Thies et al. 2009).

A simple species based thinning rule utilising a constant value based on the arithmetic mean of trees with a diameter at breast height of 30 and 60 cm, assuming a 50% crown cover for wild cherry. The mean distance between crop trees or standards, is dependent on the mean radial increment. It should be set at between 25 and 28 times the target diameter at breast height (Hein and Spiecker 2009). Therefore, for a target diameter of 50 cm DBH for wild cherry this rule dictates a final distance of 12.5 m between trees.

Final cutting of crop trees takes place when a target diameter of approximately 50cm DBH (Thies et al. 2009; Hein and Spiecker 2009) within 50 to 80 years (Thies et al. 2009; Hein and Spiecker 2009; Coello et al. 2013). By this point each tree should occupy an area of 100m\(^2\) (Savill et al. 2009).

**Fruit production**

The commercial production of fruit (cherries) occurs exclusively within orchard systems, there is no value to the timber. Tree form is concentrated on providing a suitable, economical platform for the greatest production of cherries. Production shifts from vigorous large trees to highly productive, simplified, uniform trees in high efficiency orchards (Lang 2011). Cultivars are utilised in combination with grafted and often dwarfing rootstocks, as this has been proven to be an effective method of controlling tree vigour and other tree attributes (Lang 2001b) (see Table 3.3). The choice of rootstock will provide some influence over precocity (blossoming before the appearance of leaves and the ability to commence early cropping by year 3 or 4) and greater fruit yields (Lang 2001a; Whiting et al. 2005). The utilisation of certain rootstocks can provide advantages to the grower for example the rootstock ‘Colt’ has a high resistance to *Phytophthora* and F12.1 a resistance to bacterial canker (Long 2009), there is however, a higher risk of disease using clonally produced rootstocks over genetically unique seedlings (Lang 2001a).

**Table 3.3  Selected rootstocks for the production of cherries (Lang 2001a; Long 2009; Lang 2011).**

<table>
<thead>
<tr>
<th>Rootstock</th>
<th>Commercial Name</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semi Dwarfing</td>
<td><em>P. cerasus</em> x <em>P. canescens</em></td>
<td>Gisela 5</td>
</tr>
<tr>
<td>Semi Vigorous</td>
<td><em>P. avium</em> x <em>P. psudocerasus</em></td>
<td>Gisela 6</td>
</tr>
<tr>
<td>Vigorous</td>
<td><em>P. avium</em></td>
<td>Colt</td>
</tr>
<tr>
<td>Very Vigorous</td>
<td><em>P. avium</em></td>
<td>F12.1</td>
</tr>
<tr>
<td>Standard</td>
<td><em>P. avium</em></td>
<td>Mazzard</td>
</tr>
</tbody>
</table>

The choice of rootstock *vis-à-vis* the final size of the tree influences stocking density, Semi dwarfing root stocks such as ‘Gisela 5’ can be planted at a relatively high density of 400-600 trees ha\(^{-1}\) as final height of a pruned bush will be approximately 2.5 to 3m. More vigorous rootstocks are customarily planted at lower densities: The semi vigorous ‘Gisela 6’ at 250-500 trees ha\(^{-1}\) and those that display a vigorous to normal growth habit such as ‘Colt’, ‘F12.1’ and ‘Mazzard’ approximately 120-160 trees ha\(^{-1}\) or less dependent on site specific goals (Long 2009). Smaller trees at higher densities require less labour and less pesticide spray volume equating to savings on investment (Lang 2001a).

A challenge for growers is to prevent overcropping when using overly vigorous rootstocks so the stunting of growth does not occur, overcropped cherry trees tend to promote an even heavier return bloom the following year and therefore suffer further insufficient vegetative growth (Lang 2001b) or even revert to a biannual fruiting pattern with compensatory vegetative growth during the off year (Lang 2001b).
Canopy architecture as determined by rootstock and cultivar has only a moderate effect on vigour and yield (Whiting et al. 2005). But meanwhile formative pruning allows for a tree to be shaped for the maximal production of fruit through the management of leaf to fruit ratio (Lang 2001a), the optimisation of tree heath by the removal of dead and diseased branches and facilitation of fruit harvest by keeping the tree small and compact. A number of pruning styles are advocated within the commercial sector aimed at fulfilling the aforementioned aims. The combination of rootstock and pruning regime affects both tree yield and individual fruit size (Lang 2001b).

Combined Systems

No description of a combined NWFP and timber production system has been found within the literature, this can be attributed to the large differences in the production system in terms of planting material and applied silvicultural systems inherent by a wholly dissimilar production goal.

Other potential

It has been noted that three main strategies have been developed throughout Europe for the use of P. avium: the enrichment of forests for ecosystem services, intensive forest tree farming aimed at growing high quality timber under shorter rotations and agroforestry utilising noble hardwoods such as P. avium, Juglans spp. and Sorbus spp. (Ducci et al. 2013; Morhart et al. 2014).

3.3.2.3.4 Summary of key points and knowledge gaps
- Established system for growing valuable hardwood
- Also an established orchard culture for the production of cherries for the commercial market
- No combined system evident
- Potential within agroforestry system

3.3.2.3.5 Suggested silvicultural prescription for combined timber and cherry production in Europe utilising Prunus avium
- Possibility of grafted cultivars atop an established branch free stem akin to the Dauphiné system of growing J. regia (Mary et al. 1998).

3.3.2.4 Sorbus

Sorbus torminalis (L.) CRANTZ, wild service/ chequer tree (EN); Elsbeere (DE); L’Alisier terminal (FR); Mostajo (ES); Sorbo Ciavardello (IT). Sorbus domestica L., true service (EN); Speierling (DE); Comier (FR); Serbal común (ES); Sorbo domestico (IT). Sorbus aucuparia L., rowan/ mountain ash (EN); Vogelbeere (DE); Sobier des oiseleurs (FR); Serbal de los Cazadores (ES); Sorbo degli uccellatori (IT).

Sorbus torminalis, S. domestica and S. aucuparia are minority trees species with a multipurpose potential. S. torminalis and S. domestica are frequently grown in Europe as a valuable timber species and S. aucuparia grown within the forest mixture to increase ecosystem service benefits. NWFPs are not commercially exploited. Fruits are collected informally and on a small scale. With the threat of a changing climate Sorbus species have the potential to adapt to drier conditions while boasting their potential as a multi use tree, a tree for the future?

3.3.2.4.1 The tree
Sorbus torminalis and S. domestica are often regarded as a south and central European taxa with a range extending into the Caucasus and northern Iran, to southern Sweden and south and eastern England (S. torminalis) and as far south as north Africa (Demasure et al. 2000; Paganová 2008) (see Figure 3.7). S.
domestica had not been previously known as a native species or as a persistent introduction in Britain until the confirmation of a small population in south Wales in the early 1990’s (Hampton and Kay 1995). Meanwhile, S. aucuparia can be considered to be native throughout Europe, ranging from northern latitudes such as in Iceland, northern Russia and as far north as 71°N in Norway and reaching south to the mountains of central Spain and the western Mediterranean (Raspé et al. 2000).

Both S. torminalis and S. domestica produce the best growth rates on sites with deep fertile soils (Hemery et al. 2010; Nicolescu et al. 2009; Paganová 2007; Paganová 2008) but will grow successfully on a wide range of soil types (Demesure et al. 2000; Nicolescu et al. 2009; Paganová 2007; Rasmussen and Kollmann 2004). S. torminalis is frequently found on clay or limestone substrates (Evans 1984; Savill 1991). S. domestica can also be found on shallower and more skeletal soils (Paganová 2008). S. aucuparia on the other hand will grow on relatively nutrient poor sites (Raspé et al. 2000), but is suggested to avoid the clays and limestones favoured by S. torminalis and S. domestica (Savill 1991). All Sorbus species are absent from wet soils, but will tolerate temporary flooding events (Evans 1984; Nicolescu et al. 2009; Raspé et al. 2000). Sorbus in general has been suggested to grow on moderately acid to neutral soils (Nicolescu et al. 2009; Paganová 2008; Raspé et al. 2000; Zerbe 2001), but has also been suggested to prefer calcareous soils within calcareous beech forest (Rasmussen and Kollmann 2004).

Figure 3.7  European distribution of S. domestica (left) (Rotach, 2003) and S. torminalis (right) (Demasure-Musch and Oddou-Muratorio, 2004)

The best growth rates are found in areas with an adequate supply of water (Nicolescu et al. 2009) but are reported to be more tolerant of drought events than other valuable broad-leaved species (Evans 1984; Hemery et al. 2010). S. domestica more than S. torminalis, for this reason Sorbus is often cited as a suitable genus for cultivation under changing climate conditions. S. torminalis has been reported to require an optimal annual temperature ranging between 10 and 17°C with optimal annual rainfall sum of between 800 and 1,500mm, while not falling below an annual figure of 600mm (Nicolescu et al. 2009). The distribution of S. aucuparia has been reported to be limited by high summer temperatures, however, the species is able to tolerate moderately high temperatures if not accompanied by an excessive water deficit (Raspé et al. 2000).

S. torminalis and S. domestica can be considered a scattered species (frequently 0.1 to 30 trees ha⁻¹) natural pure stands are never found, individuals are commonly found at forest edges and within large gaps (Demesure et al. 2000; Rasmussen and Kollmann 2004). This occurrence can be attributed to the low competitive ability of the species (Hemery et al. 2010), through succession Sorbus is often overgrown by more dominant species such as Quercus spp. or Fagus spp. (Demesure et al. 2000).

S. domestica can be considered a shade intolerant species, especially at a young age (Paganová 2008; Savill et al. 2009). S. torminalis is more tolerant in early developmental stages, thus allowing it to compete for longer below the main canopy, but with age it becomes more light demanding as the crown expands
Sorbus and 2,200m above. (Paganová 2009) 2009) (Paganová et al. 2008). Preferential elevation for S. torminalis has been observed to range between 100 and 2,200m dependent on latitude (Nicolescu et al. 2009; Paganová 2007; Paganová 2008). S. domestica has been surveyed at lower optimal elevations of approximately 200 to 500m again dependent on latitude (Paganová 2008). S. aucuparia however, is slightly better adapted to the shorter vegetation seasons in the north and can commonly be found from sea-level to alpine timberline (Kobro et al. 2003), observed at elevations of up to 1,000m in the UK (Evans 1984; Savill 1991).

Sorbus in general are smaller, less dominant trees, their form ranges from small shrubby bushes to tall straight forest trees (Rasmussen and Kollmann 2004; Savill 1991). There are varied estimates of the maximal age of Sorbus species, but it is not an especially long lived group of species (Spiecker 2006). S. aucuparia may average 70 to 100 years and S. torminalis individuals are mostly less than 300 years of age (Nicolescu et al. 2009). S. aucuparia are not large trees and rarely exceeds 15m in height (Evans 1984; Mitchell 1978; Savill 1991). S. torminalis meanwhile are larger with mean heights of 15-20m and can grow up to 30m in height in exceptional circumstances, it has been suggested that height growth lessens after 60 to 70 years (Nicolescu et al. 2009). The cone shaped crown can project and area of between 80 and 100 m². Diameter growth is on average 50 to 60cm DBH reaching up to 80cm in the best instances (Nicolescu et al. 2009; Savill 1991), diameter growth has been recorded at approximately 5 to 8mm per year, reducing after 50 to 60 years, declining sharply at approximately 100 years, producing approximately 1mm MAI after 120 years (Nicolescu et al. 2009). S. domestica shows a faster initial height increment than S. torminalis but the MAI of S. domestica is on average less at 2 to 4 mm per year with peaks of 8 mm possible after coppicing.

The production of berries by Sorbus species represents the sexual reproduction of the species, but in the case of S. torminalis regeneration in the case of from seed is rare (Savill 1991). Fecundity is reported to be reduced at lower temperatures (Rasmussen and Kollmann 2004). Sorbus species also have an ability to propagate asexually through the production of root suckers (Demere et al. 2000; Evans 1984; Pyttel et al. 2013), often a secure method of propagation in areas of sparse population or increased competition from above. Natural hybridisation with other Sorbus species is possible, often with S. aria (whitebeam) (Demere et al. 2000).

European apple canker (Neonectria galligena) which reduces growth and devastates wood quality, apple scab (Venturia inaequalis) that can affect fruit yield and quality and Verticillium wilt (Verticillium spp.) cause wilting and dieback of branches (Hemery et al., 2010). Wild service tree is particularly prone to fire blight (Erwinia amylovora); therefore, it is wise to select not more than 5-8 target trees ha-1 at a minimum distance of 12-15 m apart to avoid the spread of infection.

The apple fruit moth (Argyresthia conjugella) is regarded the most serious pest of Sorbus berries, especially Rowan berries within Scandinavia, reaching throughout boreal regions and within the North American continent (Satake et al. 2004). S. aucuparia also plays host to the apple grass aphid (Rhopalosiphum insertum) which overwinters in the berries before feeding on the roots of various grass crops (Savill 1991) providing the potential to act as a vector for damaging crop pathogens. Young plants are susceptible to browsing pressure, to ensure a marketable stem form the exclusion of wildlife or livestock is essential (Evans 1984; Paganová 2007). It has been suggested that through climate change the threat of such pests and disease will increase (Hemery et al. 2010).

3.3.2.4.2 NWFP products

Product characteristics and utilisation
Informally collected, the fruits of Sorbus species have traditionally been utilised in a number of culinary ways, these include processing as jams and jellies or for the production of or flavouring of alcoholic beverages (Ciesla 2002; Janick and Paull 2008). Berries are rich in vitamins, especially ascorbic acid. Rowan fruits have high tannin content and therefore are not recommended to be eaten fresh, rather, berries should be left ripening on the tree or eaten after they have been sun dried for 15-20 days. Similarly, the fruits of true service tree are edible when overripe or after they have been exposed to frost (Ciesla 2002; Janick and Paull 2008). Meanwhile, the sometimes cultivated Sorbus aucuparia var edulis produces a berry which contain less ascorbic acid for this reason the berry is not so bitter (Janick and Paull 2008) and can be eaten fresh. Due to the high tannin content the bark of S. domestica has in the past been used for tanning leather (Raspé et al. 2000).

**Berry yield**

Fruit production will vary from year to year and site to site. The earliest fruits ripen about mid July and the whole crop is ripe by the end of August (Raspé et al. 2000). A large fruit crop has been observed to occur every second or third year (Kobro et al. 2003), it has been proposed that a large crop in one year will have a substantial effect on the tree’s resources providing a smaller yield in the subsequent year (Wallenius 1999). The highest berry yields for S. torminalis are reported to be derived from trees that lie in sunny and warm positions (Rasmussen and Kollmann 2004). S. aucuparia first fruits at 10 years of age with, profuse fructification occurring at approximately 15 years, it has been estimated that there may be as many as 5,000 seeds per kg of whole berries (Savill 1991).

Rowan berries are reported to be gathered from the forest in a number of European and Near Eastern countries including Belarus, where approximately 1092 tonnes yr⁻¹ are harvested (Ollikainen 1998); Lithuania harvesting 75kg ha⁻¹ equating to a total of 12 tonnes yr⁻¹ (Rutkauskas 1998) and in Poland, with a mean harvest of 670 tonnes yr⁻¹ (1952-1988) (Kalinowski 1998). Reproductive individuals of S. aucuparia vary greatly in size ranging from tall shrubs of 1 to 2 m in height to full sized trees, it has been stated that for each individual tree produces anywhere from 0 to more than 100,000 berries in any given year (Satake et al. 2004) it is also suggested that rowen berry yields in Finland can amount to 10,000 tonnes in a poor year rising to 50,000 tonnes in a good year (Saastamoinen et al. 1998). Furthermore yields of between 50 and 3020 kg ha⁻¹ have been recorded in the region of southern Karelia, Finland demonstrating higher production in open grown situations (Raspé et al. 2000), meanwhile, berry yield is often less at higher altitude (Raspé et al. 2000). It must be noted that measures of berry yield are seen to correlate with picking occurrence which is strongly linked with current market price, thus providing actual yields rather than potential and providing a strong bias in study results (Wallenius 1999).

3.3.2.4.3 **Silvicultural prescriptions for growing Sorbus**

**Timber production**

Sorbus species, in particular S. torminalis and S. domestica are some of the most economically important wild fruit trees in Europe (Demesure et al. 2000), their inclusion within forest mixtures in Europe is increasing (Spiecker 2006) as this sporadic tree species is able to produce a very valuable timber under relatively short rotations (Spiecker 2006; Wilhelm 2008). For example a high quality clear bole of S. torminalis service can demand relatively high prices, for example 9,000 €m⁻³ (2007, France) (Wilhelm 2008). About 80% of European Sorbus veneers come from north-eastern France and nearly all of them are reported to originate from former coppice with standards systems (Wilhelm 2008).

As previously mentioned S. torminalis rarely regenerates from seed, but rather relies on root suckers as a method of vegetative prorogation (Demusere et al. 2000; Paganová 2007). Upon the removal of the main stem root sucker sprouts must be singled up and released to be able to thrive but require less light than a seedling of equivalent size and age (Savill 1991). S. aucuparia on the other hand regenerates freely from
seed (Evans 1984), distribution by birds and other wildlife ensure a wide dispersal. The protection of seedlings and young growth against browsing by livestock or wildlife is essential (Evans 1984; Paganová 2007).

Within high forest for the production of high value timber the rotation period for wild service tree ranges between 120 and 150 years (Makkonen-Spiecker 2009), but is mostly determined by target diameter. If a single-tree silvicultural prescription is applied, the establishing phase may last 20 years, the dimensioning phase to the age of 60 years and the maturing phase continuing after 60 years (Wilhelm 2008). If managed within a coppice culture rotations of 25 to 40 years are advocated (Savill 1991) the objective here is to maintain the species mixture and to avoid the out shading of Sorbus species.

It has been suggested that historically practiced coppice systems have favoured the growth of Sorbus species for centuries since the species possesses sufficient competitive ability in its early growth stages (Giulietti and Pelleri 2009; Paganová 2007; Pyttel et al. 2013). The decline of such a management system had been attributed to a supposed decline in frequency of S. torminalis (Savill 1991). However, experimentally, it has been concluded that coppicing has no effect over the regeneration capacity of S. torminalis as the species presents sufficient capacity for establishment underneath a closed oak canopy (Pyttel et al. 2013).

When grown within a coppice with standards system no more than 10-20 Sorbus trees ha⁻¹ are recommended to be selected as standards (Giulietti and Pelleri 2009), this is to reduce the risk of disease spreading throughout a comprehensive rooting system. Specific silvicultural treatments around this small number of high value timber trees should applied over the whole rotation period, with the aim of increasing the stem quality and the maintenance of a large but steady diameter growth increment. From the outset vigorous saplings with straight stems and symmetrical crowns should be chosen (Giulietti and Pelleri 2009).

For the production of high value timber without the presence of sufficient underwood pruning operations must be applied (Nicolescu et al. 2009). The branch-free butt log of Sorbus species should not be longer than 25% of the final tree height (Wilhelm 2008), often the market will define the length of marketable log in approximately 2.5m sections. The selection of crop trees should avoid heavy forked stems to prevent discolouration of the wood (Wilhelm 2008), however post pruning it has been mentioned that S. torminalis produces few epicormic branches (Nicolescu et al. 2009) an advantage for valuable timber production.

Timely and targeted thinning operations must be applied for the management of service trees to attain a high value timber product. Due to the low competitiveness of the species those trees, release (from above) from more dominant species is essential (Giulietti and Pelleri 2009; Müller et al. 2000), often this is on a different scale of intensity, timing and locality than other more frequently occurring forest species (Spiecker 2006).

It has been reported that S. domestica at maturity requires a crown cover of 80 to 100 m²; therefore, during the qualification phase, crop trees that will produce valuable timber at the end of the rotation period must be selected at a minimum distance of 5-6 m to allow sufficient room for crown expansion (Bastien and Wilhelm 2003).

Fruit Production and combined systems

Scant information is available over the commercial production of Sorbus species for fruit or fruit and timber as a combined system. The picking of fruit is largely and informal practice with individuals souring for wild trees in forests and hedgerows. No instances of commercial Sorbus berry production of any form has been found within the English language literature, it can be surmised that since the product is informally utilised a commercial demand does not exist at present.
Other potential

The inclusion of *Sorbus* species as a minority species within the forest matrix may not provide many direct non-timber benefits but such inclusion is important for the overall biodiversity, heath and structure of the forest (Speckter 2006). *S. terminalis* is noted as an indicator species denoting the presence of ancient woodland sites in the UK (Evans 1984; Savill 1991).

3.3.2.4.4 Summary of key points and knowledge gaps

- No information on commercial *Sorbus* berry production, theory or practice.
- *S. aucuparia* is not commercially cultivated for timber values
- *S. terminalis* and *S. domestica* both increasingly utilised as a highly valuable timber tree, the value of such wood far outweighs any additional fruit production or modification of established silvicultural systems.
- Ability to cope with climate change, so the species should be promoted.

3.3.2.4.5 Suggested silvicultural prescription for combined timber and berry production in Europe utilising *Sorbus* spp.

Possibly aim for a diverse forest structure with the management of the best *Sorbus* trees that exist within the matrix for timber while retaining smaller shrubby species, in a coppiced or pollarded form to facilitate informal berry collection or to augment ecosystem services or for a greater regeneration potential.

3.3.2.5 Cork

*Quercus suber* L., cork tree/cork oak (EN); kork-eiche (DE); chêne liege/surier (FR); alcornoque (ES); sobreiro (PT); sughera (IT).

Cork oak stands are one of the most typical forest stands of the western part of the Mediterranean basin, mostly integrating multifunctional systems, combining the production of cork with cattle grazing, hunting, acorns, fire wood, etc. This paper describes the ecology and the state of the art of current silvicultural prescriptions applied to cork oak stands for the most important NWFP taken from them: cork.

3.3.2.5.1 The tree

The cork oak (*Quercus suber* L.) is characterised by the presence of a thick bark with a continuous layer of cork in its outer part, which gave the cork oak its notoriety and economic importance as a cork producer.

Cork oak stands are one of the most typical forest stands of the western part of the Mediterranean basin, mostly integrating multifunctional systems, combining the production of cork with cattle grazing, hunting, acorns, fire wood, etc.

Cork oak forest and woodlands cover nowadays considerable areas in the southern European Iberian peninsula (Portugal and Spain), being also important in France, Italy, Morocco, Algeria and Tunisia (see Figure 3.8) (EUFORGEN 2009). Altogether more than 2 million ha are cover by cork oak stands, although the natural distribution area of the species is even more extent.

Cork oaks are low-spreading trees with a short stem and thick branches. The trees rarely attain heights greater than 16 m, but open grown trees may have very large crown dimensions, up to 500 m² of crown projection in some mature trees with 150-200 years of age, and large stem circumferences (up to 450 cm). When growing in dense stands, the shape of the tree is strongly influenced by competition, originating trees with narrower crowns and higher stems (Natividade 1950; Pereira 2007).
The amount of acorns produced by one tree has large variation among years, with 2-3 years of high fruit production out of 10 years. Cold spells during flowering may cause catkin damage and may be one of the factors influencing the high inter-annual variability of acorn production (García-Mozo et al. 2001).

The cork oak is ecologically plastic and grows in warm humid and sub-humid conditions from sea level to 2000 m in very specific locations, but with optimum growth occurring until 600 m of altitude. It is considered a semi-tolerant species, well adapted to mild climates, namely to the Mediterranean climates with Atlantic influence, with mild winters and hot and dry summers (Oliver 1980; APA 1984; Correia and Oliveira 2003; Pereira 2007; Serrada et al. 2008).

The cork oak grows well with mean annual precipitations of 600-800 mm, but still survives in years with very low precipitation under 400 mm. The minimum annual precipitation for a balanced tree development should be 500 mm. It admits higher precipitations up to 1700 mm, but it is very sensitive to water logging. As regards the seasonal distribution of rainfall, the cork oak is adapted to the Mediterranean type of climate with precipitation concentrating in the late autumn and winter (October-March) and very few, if at all, summer rains (Pereira 2007; Serrada et al. 2008). The optimum mean annual temperature is in the range 13-16°C, but it survives until 19°C. The mean temperature of the coldest month should not be below 4-5°C and the absolute minimum survival temperature is -12°C (Natividade 1950; Serrada et al. 2008).

In relation to soils, the species is very tolerant with the exception of calcareous and limestone substrates. It may grow on poor and shallow soils, with low nitrogen and organic matter content and it allows a pH range between 5 and 7. It occurs preferentially in siliceous and sandy soils, and prefers deep and well aerated and drained soils. It is very sensitive to compaction and water logging (Montero and Cañellas 2002).

The total annual diameter growth of mature cork oaks in their region of occurrence is little influenced by temperature and water seems to be the main limiting factor (Costa et al. 2001).

3.3.2.5.2 NWFP Products

Cork oak stands usually integrate multifunctional agro-forestry systems (called montado in Portugal and dehesa in Spain), where the production of cork is combined with cattle grazing, acorns production, firewood, hunting, and mushrooms picking. Given the regions where they are distributed, they are also valued for their ecological role to contain desertification, water retention and soil erosion, and for their contribution to biodiversity maintenance. Recently its importance for carbon stocking, both in existing stands (Paulo et al. 2013) and new plantations (Coelho et al. 2012) has been recognized. The next sections present a description of the characteristics, utilisations and yield, for the most important production in cork oak stands, that is, cork.

Cork characteristics and utilisation

Cork is a natural product, with unique properties, obtained from the outer bark of cork oak. The cork layers that are produced in its bark form a continuous envelope with an appreciable thickness around the stem and branches. This cork may be stripped off from the stem without endangering the tree vitality and the tree subsequently rebuilds a new cork layer. This is the basis for the sustainable production of cork during the cork oak’s long lifetime (Pereira 2007).

Cork has attracted the attention of humans since antiquity and has been used since then in various applications. Today, cork is widely known as the closure of wine bottles. However, cork is light and does not absorb water, so it was also an adequate material for floats. The very low thermal conductivity made it a good insulator for shelter against the cold temperatures and its energy-absorbing capacity was also put to practical applications. New products and applications such as bio absorbents of heavy metals in aqueous solutions, composite materials, or even the possibility of using cork for medical applications and pharmacy, have made cork a deeply research material (Pereira 2007).
The annual world production of cork totals about 374,000 tons, mostly from the cork oaks of Portugal and Spain, who produce around 74% of the total (51% and 23%, respectively). The annual production of cork is rather stable, with some oscillations due to climatic or accidental occurrences (Pereira 2007). In economic terms, the manufacture of natural cork stoppers constitutes the most important use, accounting for approximately two thirds of cork revenues.

![Figure 3.8 Natural distribution of Quercus suber in Europe (EUFORGEN.)](image)

**Cork yield**

The growth of cork is one of the most important variables to the forest owner and should be, therefore, one of the main criteria of management. It is also a determining characteristic of the raw material for the industrial processing. Cork quality depends on three main characteristics: cork thickness, cork porosity and the presence of defects such as insect galleries or occasional wood inclusions (Pereira 2007). Any one of these factors may lead to the raw material being rejected by the stopper industry and, consequently, result in a loss of revenues.

Cork production yields depend on the growth of cork, which is different among stands, determining what can be named as site quality for cork, being different from site quality for wood volume yield. As well, it depends on management variables such as the intensity of cork extraction, i.e. the stripped area, and the interval between stripping, variables that are regulated and managers cannot freely select them. The inventory of cork oak forests requires, therefore, additional information in relation to other tree species. Prediction models for cork production have been used for quite some time while modelling of cork oak growth and cork production in a concept of stand management has been developed only recently.

A review on cork weight yield models can be found in Vázquez and Pereira (2008), where 18 references for individual-tree cork weight yield and 5 references for stand cork weight yield are mentioned. Among these, the most important are: cork weight (Montero 1987; Ribeiro and Tomé 2002; Vázquez 2002; Paulo et al. 2011), virgin cork thickness (Tomé 2004; Sánchez-González et al. 2007b), cork thickness for 12 years old cork (Montes et al. 2005), cork thickness for 9 years old cork (Sánchez-González et al. 2007a), cork growth (Sánchez-González et al. 2008; Almeida et al. 2010), and cork thickness (González-Adrados et al. 2000; Almeida et al. 2010).
The first management oriented growth and yield model for the cork oak, the SUBER model, was recently developed (Tomé et al. 1998; Tomé et al. 1999; Paulo 2011). The model allows simulation of the development of cork oak stands for management purposes. In Spain the ALCORNOQUE v.1.0 model (Sánchez-González et al. 2005) was developed for cork oak non-open forests.

3.3.2.5.3 Silvicultural prescriptions for growing Quercus suber

Most of the existing cork oak stands have originated from natural regeneration. The artificial regeneration is relatively recent and it had a great increment in the 90s due to the EU policy and incentives for afforestation of set-aside agricultural lands. Many thousand hectares have been established with cork oaks mainly in Portugal and Spain during the last two decades, as well as, to a lesser extent, in Italy and France. However the success of establishment is not always good and mortality during the first years may be very high. The reasons for this are:

a) Inadequate site preparation. The establishment of an efficient root system is essential to guarantee water and survival during the summer months, thus requiring an adequate soil preparation and a good root quality of the nursery.

b) Climatic conditions. The young plants are sensitive to water stress and the efficiency in developing physiological mechanisms for drought tolerance seems related with the level of light in the environment (Pardos et al. 2005; Cardillo and Bernal 2006).

c) Predatory activity by animals on acorns or plants. The acorns are very palatable to small rodents (Herrera 1995) and the young plants to cattle browsing, thus requiring protection, respectively, by repellents and shelters or suppression of grazing.

d) Low quality of acorns/plant used in afforestation. The quality of the acorn used, and the storage conditions of the seedlings is also a determinant variable for the success of new plantations (Merouani et al. 2001).

Site preparation is very much dependent on site conditions, namely soil type, soil fertility, understory development or previous cultures (Cortina et al. 2009). Generally it includes weeding, usually made by disc-harrowing or trimmer, and the improvement of soil characteristics for development of the root system (e.g. soil fertilization).

Cork oak stands are mainly managed as agroforestry systems, where all the products (namely cork, acorns, fire wood and pasture) are obtained together, usually being cork the most important. Therefore, the following silvicultural prescriptions refer to cork production, including some notes if silviculture is different for other products.

The number of trees at planting in the last decades varied around 625 trees/ha (4x4 m), but stoking densities from 312 (8x4 m) to 1250 trees/ha (4x2 m) are also practiced (Pereira 2007). However, in Portugal there is currently a tendency to plant between 300 and 350 trees/ha to avoid thinning, that are considered expensive operations with little or none return, and the tendency of cork oak trees to growth stump sprouts. The selection of an adequate provenance will ensure climatic adaptation to the site (Díaz Fernández et al. 1995; Gandour et al. 2007). Companion plants are important to help regeneration. A small shrub cover may favour the establishment and development of regeneration during the early years, as it makes difficult the predation of acorns, provides shelter to seedlings, and protects the browsing by cattle (Montero and Cañellas 2002). When plants emerge above the bushes grazing should be limited and the bushes should be removed (Caro 1914; De Benito 1994). Competence from herbs and brushes should be reduced in the early 4-5 years in plantations in areas with a lot of spring rain (Bugalho et al. 2011; Montero and Cañellas 2002). Quercus suber usually grows with other Quercus species in natural stands (e.g., Q. robur, Q. pyrenaica, Q. humilis, Q. faginea, Q. canariensis and Q. ilex) or pine species (P. pinea) (Serrada et al. 2008).
The juvenile phase of a cork oak stand is usually referred to the period until the beginning of cork extraction, which occurs at 20-40 years of age depending on site conditions. The rotation length is usually around 140-150 years (range 125-175 years) (Montero and Cañellas 2002). Cork extraction is done every 9-11 to 14-15 years after the tree reaches the minimum breast height circumference necessary to start cork extraction. The variation of this period is related to national legislation (in Portugal and Spain a minimum of 9 years but in Italy and Tunisia this minimum period is extended to 12 years), and to the growth rates of the tree and of the cork. As growth rates can vary in consecutive cork extractions, this leads land owners to extend the debarking rotation when cork growth is low.

The minimum value of circumference at breast height after which it is allowed to accomplish the tree debarking for the first time is of 60 cm in Spain and Italy, but of 70 cm in Portugal and France. In France cork oaks over 200 cm that have never been debarked cannot be debarked.

Cork harvesting and pruning are known to be stressing activities for trees, thus the law (regardless of fire) establishes a minimum period of time between these two operations (3 years in Spain and 2 years in Portugal), in order to enable tree recovery (Cardillo et al. 2007). Cork extraction usually starts when 40-50% of the trees reach the minimum circumference, but this value is not regulated by law in any country. Instead, cork debarking height is limited by law. Table 3.4 summarizes the law limitations in the most important areas for Quercus suber in Europe.

Formative pruning is necessary to get a straight and smooth trunk, with a height of 2.5 to 3 m. It should start at the age of 3-6 years, pruning less than 1/3 of the total tree height. A second pruning to 1.5-2 m is usually done when trees are 4.5-6 m (12-15 years old). A third pruning to 2.5-3 is usually done 1 to 3 years before or after the first cork extraction (20-25 years old) (Montero and Cañellas 2002) (see Table 3.5 for an example on silvicultural prescriptions used in Portugal and Spain).

The pruning of mature trees does not affect cork production if is moderate. Heavy pruning may reduce cork production (Montero and Curras 1991; Cañellas et al. 2003). Mature pruning does not increment acorn production (Cañellas 1992; Cañellas et al. 2003).

Sometimes trees are pruned for fuel wood. It is not recommended because the pruning of thick branches may lead to healing problems and stem decay (Serrada et al. 2008). If plantation density is high (over 750-800 trees ha⁻¹) or in natural regenerated stands, a first thinning should be carried out together with the second formative pruning to get 450-500 trees ha⁻¹. Then selective thinning should be done during the development of the stand to manage competition (see Table 3.5). This is one of the major concerns of stakeholders, because they cannot do selective thinning based on cork quality as they don’t know cork quality before the first mature cork extraction (3rd cork extraction in the tree). In stands managed for silvopastoral purposes, tree density is usually indicated to vary from 450-500 trees/ha for trees with a breast height circumference of 60 cm, to 65-70 trees/ha for trees with a breast height circumference over 200 cm (Montero and Cañellas 2002) (see Table 3.6). However, as mentioned, nowadays in Portugal there is a tendency to have lower densities, usually from 300 to 350 trees ha⁻¹. These values can be increased in areas managed exclusively for cork production. Research on the effect of stand density and other variables on cork growth are important to support these values since recent research (Sánchez-González et al. 2007a) indicates that cork thickness may not be affected within certain values of stand densities.

Regarding acorn production, thinning should be carried out to get isolated big crowns, but this is always managed together with cork management.

If the pasture production is very important stoking densities are usually lower but always over 40-60 trees ha⁻¹ (Montero and Cañellas 2002), being adapted to the livestock species and to the animal load existing in each site.
3.3.2.5.4 Summary of key points and knowledge gaps

The most important problem for the maintenance of cork oak stands over time is regeneration. Silviculture practices should guarantee that regeneration is achieved. For this purpose, as well as for the sustainable production of cork at management unit level, cork oak stands should be gradually changed from even-aged to uneven-aged clumped stands. Such clumps could or should, however, be even-aged to facilitate management.

The following gaps on the knowledge related to the Cork oak silviculture have been identified:

- Analyse tree growth on mixed stands of cork oak with stone pine
- Impact of the debarking intensity on tree and cork growth and quality
- Impact of the stand density on the cork growth and quality
- Impact of irrigation on the cork growth and quality
- Impact of fertilization on cork growth and quality
- Impact of understory on the cork growth and quality
- Impact of competition on the cork growth and quality
- Relation of management/silvicultural operations to tree mortality
- Relation of management/silvicultural operations to the occurrence of Coroebus undatus and other species related to cork defects and tree damage (e.g. Lymantria dispar, etc.)

3.3.2.5.5 Suggestions for new silvicultural prescriptions for cork production in Europe utilising *Quercus suber*

The most important product obtained from cork oak stands and woodlands is cork. Silvicultural practices are always oriented to cork production and management. The rest of products (e.g., cattle grazing, acorns production, fire wood, hunting, mushrooms piking, etc.) are secondary products that have no real impact on silviculture. Although there is little scientific research in some of the aspects to support the following suggestions, the silvicultural prescriptions for cork oak should include:

- Selection of adequate sites for the installation of new plantations, avoiding calcareous, heavy textures and compact soils.
- Developing soil prospecting activities previously to plantation.
- Site preparation adapted to site conditions (soil characteristics, understory, management objectives)
- Plant around 625 trees/ha (4x4 m). If thinning is not being carried out lower stoking densities may be used in Portugal (between 300-350 trees/ha).
- Select adequate provenances.
- Use of good quality acorns and young plants.
- Use of adequate practices in acorn conservation and plants nursery
- Water of small plants in spring and summer periods during the first years after plantation, if possible, and according to specific climatic conditions.
- Promote natural regeneration when existent.
- Protect seedlings and young plants by browsing by cattle (installation of protectors).
- Reduce the competence from herbs and brushes in the early 4-5 years after plantations in areas with a lot of spring rain.
- Promote formative pruning at young ages (3-6 years), pruning less than 1/3 of the total tree height. Make a second pruning to reach 1.5-2 m of stem height, when trees are 4.5-6 m. Make a third pruning to reach 2.5-3 m of stem height, before the first cork extraction if possible.
- Adapt cork debarking intervals to site and climatic conditions, considering delaying this operation in cases of tree low vigour and/or low cork thickness.
- Manage and improve tree density to values adapted to the management objectives (purely cork production or silvopastoral systems), assuring the existence of a sufficient amount of young trees.
- Monitor the appearance and/or dispersion of species associated to tree decay and cork damage.
### Table 3.4  Most important law limitations for cork extraction in Europe (CAB: breast height circumference above bark)

<table>
<thead>
<tr>
<th>Limitation</th>
<th>Portugal</th>
<th>Spain</th>
<th>Italy</th>
<th>France</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum height for the 1st debarking</td>
<td>2 x CAB after the tree reached 70 cm CAB</td>
<td>2 x CAB after the tree reached 65 cm CAB</td>
<td>2,5 x CAB; the debarking must stop once the diameter reach the 45 cm CAB (upper part)</td>
<td>1.5 x CAB; only in trees that are over 200 cm CAB</td>
</tr>
<tr>
<td>Maximum height for the 2nd debarking</td>
<td>2.5 x CAB; the debarking must stop once the circumference reach the 70 cm CAB (upper part)</td>
<td>3 x CAB</td>
<td>In Extremadura the maximum height for the second debarking is 2.5 x CAB</td>
<td>2 x CAB</td>
</tr>
<tr>
<td>Maximum height for following debarking</td>
<td>3 x CAB; the debarking must stop once the circumference reach the 70 cm CAB (upper part)</td>
<td>3 x CAB</td>
<td>In Sardinia: 2 x CAB after the tree reached the 60 cm CAB at 1.3 m</td>
<td>3 x CAB</td>
</tr>
<tr>
<td>Cork debarking period</td>
<td>May to August</td>
<td>1 June to September 1st In Catalonia: 1 June to 30 September</td>
<td>From 15th of May to 31st of August In Sardinia: From 1st of May to 30th of September</td>
<td>June 15 to September 15 In Corsica: May 15 to August 31</td>
</tr>
<tr>
<td>Pruning period</td>
<td>1 November to 31 March At least 2 years after of before a cork extraction</td>
<td>In Andalucia: 15 November to 15 March</td>
<td>In Sardinia: From 1st November to the 31st of March; it’s allowed to prune the tree till 1/3 of the tree canopy</td>
<td>Not specified in the National Law</td>
</tr>
<tr>
<td>Minimum rotation length for cork extraction</td>
<td>9 years</td>
<td>9 years In Catalonia: 12 years</td>
<td>9 years</td>
<td>10 years in Aquitaine and Corsica regions 12 years in other regions</td>
</tr>
</tbody>
</table>

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Description of existing silvicultural systems

Table 3.5 Example of silvicultural prescriptions for *Quercus suber* used in Portugal (Louro et al. 2002; Alves et al. 2012) and Spain (Serrada et al. 2008) for a medium site-quality stand and a debarking period of 9 years.

<table>
<thead>
<tr>
<th>Year</th>
<th>Portugal</th>
<th>Year</th>
<th>Spain</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Plantation of 300-350 trees/ha</td>
<td>0</td>
<td>Plantation of 625-833 trees/ha</td>
</tr>
<tr>
<td>1</td>
<td>Clearing the bushes between plantation lines</td>
<td>1</td>
<td>Replanting if necessary Clearing the bushes</td>
</tr>
<tr>
<td>3</td>
<td>Clearing the bushes in the plantation lines</td>
<td>3</td>
<td>Clearing the bushes</td>
</tr>
<tr>
<td>4</td>
<td>Formative pruning</td>
<td>6-10</td>
<td>Formative pruning. Prune less than 1/3 of the total tree height</td>
</tr>
<tr>
<td>5</td>
<td>Clearing the bushes between plantation lines</td>
<td>10</td>
<td>Thinning to 450 trees/ha 2nd Formative pruning (Prune to 1.5-2 m and less than 1/3 of the total tree height) Clearing the bushes</td>
</tr>
<tr>
<td>8</td>
<td>Formative pruning</td>
<td>10-15</td>
<td>3rd Formative pruning. Prune to 2.5-3 m Thinning to 250-300 trees/ha Clearing the bushes</td>
</tr>
<tr>
<td>10</td>
<td>Thinning</td>
<td>15</td>
<td>Thinning</td>
</tr>
<tr>
<td>12</td>
<td>Formative pruning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Thinning Formative pruning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>1st cork extraction on trees over 70 cm CAB</td>
<td>20-30</td>
<td>1st cork extraction on trees over 60 cm of breast height circumference 3rd Formative pruning</td>
</tr>
<tr>
<td>25</td>
<td>Formative pruning</td>
<td>36</td>
<td>2nd cork extraction</td>
</tr>
<tr>
<td>28</td>
<td>2nd cork extraction</td>
<td>40-30</td>
<td>3rd cork extraction Thinning to 175-200 trees/ha</td>
</tr>
<tr>
<td>30</td>
<td>Thinning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>3rd cork extraction</td>
<td>45</td>
<td>3rd cork extraction Thinning to 175-200 trees/ha</td>
</tr>
<tr>
<td>45</td>
<td>Continue cork extraction every 9 years</td>
<td>45-130</td>
<td>Continue cork extraction every 9 years Thinning at approximately 63 and 81 years</td>
</tr>
<tr>
<td>110-130</td>
<td>Stand regeneration (natural or artificial) in order to maintain tree density adapted to management objectives</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3.6 Proposition of an average stoking density for cork oak woodlands with a main objective of cork production, depending on its size, expressed by breast height circumference, for Spain (Montero and Cañellas 2002).

<table>
<thead>
<tr>
<th>Breast height circumference</th>
<th>Trees ha⁻¹</th>
<th>Breast height circumference</th>
<th>Trees ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>450-500</td>
<td>140</td>
<td>100-125</td>
</tr>
<tr>
<td>70</td>
<td>350-450</td>
<td>150</td>
<td>95-100</td>
</tr>
<tr>
<td>80</td>
<td>300-350</td>
<td>160</td>
<td>90-95</td>
</tr>
<tr>
<td>90</td>
<td>250-300</td>
<td>170</td>
<td>85-90</td>
</tr>
<tr>
<td>100</td>
<td>200-250</td>
<td>180</td>
<td>80-85</td>
</tr>
<tr>
<td>110</td>
<td>175-200</td>
<td>190</td>
<td>75-80</td>
</tr>
<tr>
<td>120</td>
<td>150-175</td>
<td>200</td>
<td>70-75</td>
</tr>
<tr>
<td>130</td>
<td>125-150</td>
<td>&gt;200</td>
<td>65-70</td>
</tr>
</tbody>
</table>
3.3.2.6 Pine nuts

The pine nut from the stone pine (Pinus pinea L.) is the most important edible fruit in Mediterranean forests. Around the Mediterranean Sea, there are currently about 0.7 million hectares of stone pine-dominated forests, sparsely scattered from the Atlantic coast in Portugal to the shores of the Black Sea and Mount Lebanon. On the Iberian Peninsula alone, stone pine covers more than 550,000 ha (approximately 75% of all stone pine stands), and Spain and Portugal are the main pine-nut producing countries.

Mean cone production varies widely both in time and in space due to masting patterns that can affect several countries at the same. The annual global Mediterranean stone pine nut production is irregular but varies around 30,000 tonnes (t) in shell. On the other hand, mean cone yield varies from 200 to 1000 kg/ha in forests with a render of 8-40 kg/ha shelled pine nuts. The price for Mediterranean pine nuts at international markets is about 2-3 €/kg in shell and 15-30 €/kg for shelled nuts, with a current retail price of 50–60 €/kg.

Most plantations for pine nut production are still managed as extensive forestry or agroforestry systems, and trees are mostly grown from seeds. Nevertheless, the interesting market prices for pine nuts, the crisis of traditional rainfed crops and EU afforestation subsidies for farmers have increased private initiatives to promote intensively managed stone pine plantations for pine nut yield, especially in Portugal, where the benign climate favours high cone yields. In the last 20 years, some efforts have been made to select best-performing clones in each agro-climatic zone for exploring the possibilities of Stone pine as an orchard crop with grafted plantations where are expected to render higher yields. Despite these advances in propagation, the current knowledge about stone pine as a nut crop in specific plantations is still limited.

3.3.2.6.1 The tree

Stone pine is an evergreen, resinous tree that can exceed 20m in height at 40 to 60 years, reaching 35m in some monumental trees with stem diameters up to 2m. Nevertheless, in its natural resource-limited habitat, height growth is quite slower, dominant trees being more likely to be about 10–20m or even less when culminating, with diameters of 30–50cm at the end of the silvicultural rotation (80–120 years). The adult needles are 10–20cm long, flexible, and growing in fascicles (dwarf shoots) grouping 2 (occasionally 3) needles with a persistent basal scale sheath. New needles appear only on elongating new shoots and persist 2–3 years (Mutke et al. 2012).

Stone pine grows in its natural Mediterranean range at low or montane altitudes (up to 1,000 m; 1,500m in Lebanon), although planted stands can be found at 2,000 m, as in Chile. Stone pine is considered thermophilous and xerophilous. The mean annual rainfall in its population ranges from about 400 to 800mm or higher (1500 mm), with 15 to 125mm in summer (4-month summer drought), although often with a very irregular distribution among season and years. Growth and reproductive processes are dependent on the yearly or seasonal rainfall. In years with less than 350–400mm rainfall or after dry springs, shoot elongation, secondary growth, needle length, needle longevity, cone and kernel size, and strobilus induction are reduced, particularly in excessively drained, deep sandy or shallow rocky sites with reduced water-holding capacity. Annual rainfall should be above at least 400 mm (best more than 600 mm) if well-grown cones (about 250-350 g) are aimed, resisting the species strict summer droughts by photosynthetic close-down (Mutke et al. 2007). The mean annual temperature in its natural range is 10°–18°C; the average temperature in the warmest and coldest month is 21°–26°C and 3°–11°C, respectively, with extreme temperatures above 40° and occasionally below -20°C. In dry continental inland provenances, stone pine generally does not suffer any frost damage, and the late blooming date avoids
injury in the reproductive organs, but extreme frosts can damage or even abort developing cones in the first and second year (Mutke et al. 2003).

Soil structure is important for stone pine, because roots prefer well aired soils with loose textures, such as sand, sandy loam, or gravel (with water-holding capacity of at least 60 mm). In compact clay or silt soils (with less than 40% sand and more than 40% silt or more than 30% clay), root development is restricted, especially in the first phase of seedling establishment, and can delay flowering for many years, fixing the plant ontogeny in a stationary juvenile state. The species is quite tolerant to pH ranging from moderately acid to basic (pH 5–9), although neutral soils are preferred.

Like most pines from temperate climates, stone pine is normally uninodal; each apex elongates its terminal bud in a single flush in spring (April–June) into an annual shoot that forms on its tip a new whorl of lateral branch buds (and female cones) and the new terminal bud. This implies that the growth is predetermined the year before within buds that are set at the end of spring, resting for nearly one year. In dominant shoots of young and vigorous stone pines, however, the bud can skip dormancy and start elongating immediately after its formation, completing in early summer a second (and rarely even a third) shoot and whorl, known as Lammas growth. This second shoot is always quite a bit shorter than the first, exceeding rarely 10 cm. The phenology of shoot elongation in spring depends on the air temperature and can be predicted by accumulated degree day sums (Mutke et al. 2003).

The stone pine crown architecture presents also a strong phenotypic plasticity depending on light environment. In open grown stone pines, the lateral branches in full sun-light grow as much as or even more than the leader shoot, sustaining also similar branching ratios and secondary growth that stiffen them in an ascendant, co-dominant position, producing the typical polycyclic crown that is “wider than deep”, spherical in youth and characteristically umbrella-shaped in older trees, bearing cones on the whole upper crown surface. On the other hand, shaded branches in the inner crown or in the closed canopy of denser stands show steep trends to reduce their successive yearly terminal shoot length as well as lateral bud number per whorl, the supported needle mass and diameter increment, and to withdraw also female flowering, tending to masculinility. In consequence, dense-grown stone pines develop a vertical, monopodial crown architecture similar to other pine species with tiers of small, dominated branches (Mutke et al. 2005b). This phenotypic plasticity in response to light is a strategic trade-off, favouring in a closed canopy (competition for light) the height growth forming a narrow single-stem crown and limiting female cone formation to the leader shoot. Once the crown reaches full light conditions, its growth switches to the open polycyclic shape that enhances seed production by maximizing the number of codominant, cone-bearing shoots on the broad expanding crown surface (Mutke et al. 2005b). The low growth rate and poor stem form of P. pinea is determined by the lack of apical dominance. In the absence of regular pruning, Mediterranean stone pine does not produce marketable saw timber but timber usable only for processing to chip- or fibreboard (Mutke et al. 2012).

Pines are monoecious and anemophilous, bearing male (staminate) and female (ovulate) strobili in spring on current-year shoots, although in different axes. In stone pine, female strobili are borne only at the tip of vigorous, orthotropic shoots. In an architectural analysis of stone pine trees, female strobili were found only on new shoots with diameters of about 5–16 mm, the upper end of the general shoot diameter distribution of 2–16 mm, although even in the most vigorous shoots, their probability was less than 40% (Mutke et al. 2005c). The male strobili, on the contrary, are produced on the slender shoots of lateral or dominated branchlets (diameters 2–5 mm, the lower end of the general shoot diameter distribution), many of which are in the lower crown.

Stone pine saplings normally undergo there productive phase change to sexual maturity several years after the vegetative phase change. Although in vigorous leader shoots the first conelets can appear as early as
age 5–8 years, the reproductive effort will be limited for years. During this time, most of the lateral buds in each whorl are vegetative, resulting in four to eight branches per whorl; in reproductively mature trees, a whorl normally bears 2–4 branches and the rest of the lateral bud primordia convert to female conelets (Mutke et al. 2005c). At age 10–15 years, male maturity is reached, and in open grown saplings, the presence of female cones with normally developed seeds is common at 15–20 years of age. The vegetative adult but reproductively immature phase accounts for the most vigorous height and diameter growth of the tree, with higher branching rate and absence of reproductive costs.

The whole process from pollination to cone opening takes 3 years (Mutke et al. 2012), one more than in most other pines. It implies that a singular critical event, such as extreme frosts or summer droughts, might place several consecutive yields at risk (Mutke et al. 2000). Although male and female conelets appear at different times on the developing shoots, blooming is synchronous; hence, no phenological impediment for autopollination exists. During the first year, the cone grows minimally; in the second year, it becomes globular (about the size of a walnut). It does not reach its final size (8–15cm long, 5–10cm wide) until the summer of the third year, when fecundation and embryogenesis have taken place, although the seeds within do not ripen until the end of autumn. Each cone contains about 80–120 large, nearly wingless seeds, 2 per cone scale. These pine nuts are 1–2cm in length, weighing about 0.6 g, pale brown with a powdery coating that is cinnamon brown in autumn and black when the seeds are ripe for harvesting. If not predated by squirrels or gathered by humans in autumn or winter, the cones will open in the spring of the fourth year, and the seeds will be spread or predated during summer and fall (Mutke et al. 2003).

Few pests or diseases affect vigorously growing pines. The larvae of the pine processionary moth, Thyametopoea pityocampa, can cause some defoliation, although stone pine is more resistant to this pest than other sympatric pines. The moth population is easily controlled by chemical treatments, as it is one of the most common pests on pines whose control is habitually from the air at greater scales. In plantations of small, grafted trees, it can be eradicated mechanically by removing its winter nests from the crowns, if an organic-agriculture label forbids pesticide use. Rhyacionia buoliana and R. duplana are pine shoot moths whose larvae can damage or destroy the developing buds in spring by burrowing, impeding the normal shoot growth and female flowering that would have been initiated on the shoot tips. The moth can damage many shoots, especially in young or stressed plantations, but can be controlled chemically in late spring and by pheromone trapping. The cone-boring larvae of two insects, the weevil Plissodes validirostris and the moth Dioctria mendacella, can destroy or diminish yield significantly if populations are not controlled. But the moth larvae remain inside the cones during cone harvest in winter; hence damaged cones, once collected, can be sorted out easily by their different, brownish color, and destroyed. The western conifer seed bug, Leptoglossus occidentalis, is a recently arrived cone pest from North America that is considered an invasive species in Europe, where it is expanding its range. The stings of the nymphae damage cone development and can abort the seeds, causing considerable harm to the commercial cone yield in some regions (Vazquez et al. 2009).

3.3.2.6.2 NWFP products

Product characteristics and utilisation

Pine nuts are currently highly prized in international markets meaning that their cones have become the most important forest product of stone pine forests providing higher incomes to their owners than any other forest resource (timber, grazing, hunting rights, etc.) (Mutke et al. 2005c). The Mediterranean stone pine Pinus pinea produces the genuine pine nuts or “pignoli” used in Mediterranean and Arabian cuisine. Due to their supreme quality (in tasty and nutritional values), they achieve higher prices than lower-quality surrogates like seeds from the Chinese Pinus koraiensis (Mutke et al. 2007). There are more than 20 pine
species that produce large, edible seeds that are (or were) used as staple food by local populations, although pine nuts of only a few species are traded at international markets. Most of them are still wild crops, or gathered from rural groves, not from horticultural plantations or orchards, hence there is a limited supply of wild-collected pine nuts of this and other species with edible kernels that is not sufficient to satisfy the increasing demand (Mutke et al. 2012). China alone makes up for about 80% of international pine nut exports, mainly from P. koraiensis, traded at a current price about US $10 per kg. Other species include American pinyons, Pinus edulis, P. monophylla, and especially P. cembroides but none of them produces kernels as tasty and rich in protein as the genuine Mediterranean pine nuts from Pinus pinea (Mutke et al. 2012). In Mediterranean stone pine nuts, the most abundant fatty acids are unsaturated (85%), mainly linoleic acid (45%–48%) and oleic acid (36%–40%). Pine nuts are also rich in essential minerals, such as magnesium (3,600–4,300 mg/kg), phosphorus (970 mg/kg), potassium (7,500–8,800 mg/kg), iron (70–130 mg/kg), and copper (27–39 mg/kg) (Montero et al. 2004a).

The traditional structure of the pine nut economy resembles the characteristics of a preindustrial sector. EUROSTAT and Codex Alimentarius do not differentiate species, and re-exports among countries hamper the traceability of origin and quality of the product (Mutke et al. 2012) in order to solve the failures of compliance with current legal regulations that aim to cover and trace all stages of the food production chain and set standards (European Council 2002).

International pine nuts market from stone pine varies around 30,000 Mg in shell; 6,000–15,000 Mg in Portugal (mainly from the Setubal district), 6,000–10,000 Mg in Spain (60% from western Andalusia, 30% Castile, and 10% Catalonia); and 1,500–5,000 Mg in Italy and Turkey (Mutke et al. 2012), though official statistics about production, consumption, import, and export are quite imprecise. The price for Mediterranean pine nuts in the shell at international markets is about 2-3 €/kg in shell and 15-30 €/kg for shelled nuts, with a current retail price of 50–60 €/kg (Mutke et al. 2012).

Yield

Nut yields vary annually and it has been demonstrated that this variation is mainly due to climatic factors, the most limiting being water stress. The large variation in cone production means that the average forest-owner’s income for cone crops can vary as much as from 0.67€/ha to 72€/ha from one year to another and from 4€ to 168€/ha between forests in the same growth region in Spain (Mutke et al. 2005b). For example, in the main cone-producing region of inner Spain, the mean annual cone yield was about 200 kg/ha from 1960–2000, but varied from less than 20 kg/ha to more than 900 kg/ha between years (Mutke et al. 2005b). Local means also vary widely, depending on site quality and especially on soil water availability (e.g. forests in the Douro region yield from 60 to 600 kg/ha). Due to its favorable site and climate conditions Portugal has, on average, higher nut yields per unit area than Spain.

Pine and kernel size can vary widely between sites, regions, and years, but the relative kernel output (per cone weight) is a quite stable ratio: 1,000 kg of cones contain about 160 to 200 kg of unshelled pine nuts and 40 kg of shelled kernels (Gordo et al. 1999; Montero et al. 2004b; Calama et al. 2007b; Morales 2009). Another fact to take into account is that in natural stone pine forests, many trees (30%–80% in any year) do not bear any cones and nearly 10% of the pines never produce cones. Factors such as early stand ages, high stocking densities, soils with low water-hold capacity, and dry conditions increase the proportion of trees with null crops (Calama et al. 2010).

Cone harvest takes place in late autumn and winter (November–March). Until recently, the commercial cone harvest was carried out by men climbing the trees (Figure 3.9) in late fall and winter to throw down the ripe but still closed cones, with iron-hooked, 3–6 m long poles, each pine climber collecting about 300–450 kg cones per day (Gordo et al. 1999). In the last decade, cone gathering has been increasingly
accomplished by harvesting machines that vibrate trees, similar to tree shakers used in olive harvests (Figure 3.9), overcoming the shortage of skilled labor for the dangerous climbing on the often frozen or rain-wet pines during winter (Martinez-Zurimendi et al. 2009). In the case of small grafted trees they do not usually exceed 5–6 m in height over several decades, allowing harvesting from the ground without the need to support the high costs of skilled pine climbers. In future commercial grafted plantations, cones might be gathered by harvesting machines, a technological change that began only in this decade in traditional pine forests.

Cones collected from the ground are transported and stored in depositories until summer. Then, the cones open naturally by exposure to the sun, and kernels are extracted similarly to the processing of other nut species (Trueb 1999; Batlle 2006). The sub-product of this process is valued as biomass, sold for use in specific stoves (for seed shells) or transformed into pellets, reaching US $0.05–$0.08 per kg in local markets.

Figure 3.9. Details of cone gathering by harvesting machines that vibrate trees.

3.3.2.6.3 Silvicultural prescriptions for growing Pinus pinea

Timber production

Plantation with the aim of timber production usually starts with a spacing density of 4x3 m. Density varies between 625 and 1650 trees ha⁻¹ (Correia et al. 1999; Montero et al. 2004), reaching a recommended final density between 80-125 trees ha⁻¹ at the end of rotation (Montero et al. 2008). Rotation period varies from 60 to 80 years (i.e. different areas from Huelva and Catalonian forests with this objective), though it can be delayed to reach a minimum diameter exploitable in low-quality site. Non-commercial thinning is recommended at 3-4 years to achieve over 3000-4000 trees ha⁻¹ in natural regenerated stands (Correia et al. 1999).

Since the early 1990s, various tools have been developed in Spain aimed at the multifunctional management of stone pine stands. Site index curves for Pinus pinea have been homogenized in Spain by (Calama et al. 2003). In addition, yield tables were developed for adaptive silviculture based on Reineke’s Stand Density Index and different types of forest management (Calama et al. 2003; Montero et al. 2008). But, in general, there is a lack of information in international bibliography about mean annual increment growth of this species. There are some data from regions in the centre and south of Italy, Portugal, France, Tunisia and Morocco (Table IV book of Serrada).
On the other hand, pruning usually starts at 8-12 years to get a clean stem along 6-8 meters depending on tree height (Correia et al. 1999). This treatment is not recommended for improving best quality wood in stands with more than 50 years old and dbh up to 30 cm (Sanchez Cozar 1963; Montero et al. 2008).

Finally, thinning of these stands can never be too intense because it is necessary to have the conditions to promote natural pruning to achieve a better wood quality. First thinning is recommended at 10-12 years, felling at least 40% of trees of wolf trees. A second thinning should be at the age 18-20 years old with a selection cutting of 50% of trees (Costa et al. 2008).

Silviculture for NWFP production

The current management of *P. pinea* focuses primarily on pine seed production for the purposes of harvesting edible seed. For the same reason of the phenotypic plasticity of crown development, the spacing of the trees within the orchards must be wide enough to avoid lateral shading. Besides, competition limits the vital resources of the tree, especially the water availability, the main limiting factor in Mediterranean climate (Mutke et al. 2007). Plantations for nut production usually starts with a spacing density of 6x5, 6x6, 8x6 m so that stand density varies from 200 to 300 trees ha⁻¹ (Correia et al. 1999; Costa et al. 2008) reaching a final density of 100-120 trees ha⁻¹ in mature stands. Spacing of 6x6 m or wider seems advisable, depending on site conditions. This distance allows for tractor passage for tilling and mechanical harvest by tree shaking (Mutke et al. 2012). In the case of grafted plantation (Correia et al. 1999), recommended a final density of 8x8 m (150 tree ha⁻¹) on the installation.

Nowadays, natural regenerated stands reach the regeneration period with very low densities ranging from 80 to 125 stems ha⁻¹ at age 80–100 years. According to Montero et al. (2008), the shelterwood method is then applied to regenerate the stands, consisting of two intensive fellings (50% reduction of the remaining trees) to be carried out between the first and the 10th year of the regeneration period (preparatory felling and seeding felling) and a final felling that extracts the few stems still standing in the 20th year. This scheme strongly contrasts with the results of a recent study that optimizes management scheduling of regeneration in Central Spain (Manso et al. 2013). This study concluded that stand densities at rotation age are too low to guarantee adequate dispersal, the optimal density of seed-producing trees being around 150 stems ha⁻¹. No preparatory or even secondary fellings should be conducted. In addition, rotation length needs to be extended up to 120 years to benefit from the higher seed production of older trees.

The response of pine cone yield to different spacing has been studied in different thinning experiments to determine optimum intensity (Mutke et al. 2007; Moreno et al. 2013) in artificially regenerated *Pinus pinea* stands (Moreno et al. 2013) and the authors concluded that thinning treatments, on one hand, reduced the density, decreasing inter-tree competition and favouring cone production, and on the other hand, increased diameter growths and, hence, promoted larger crops due to a positive effect of diameter at breast height in cone production in concordance with other authors (Calama et al. 2008 2011; Kranitz and Duralia 2004). In a grafted plantation and clonal trial, Mutke et al. (2007) found that basal arrea, at least in drought-prone environments, should not exceed 10 m² ha⁻¹ to avoid excessive competition. Thus, an initial spacing of 6x6 m is sufficient until the tree mean diameter surpasses 20 cm. Then, an alternate thinning can reduce the density to half, 138 trees ha⁻¹ at 8.5 m between diagonal tree lines, which would be adequate until a mean diameter of about 30 cm. Therefore, when nut production is the main goal, the target of stone pine management, thinning must aim at low densities to encourage crown development and to avoid overlaps and reduction of the crowns. In addition, trees with a greatest yield potential should be selected in the last thinning around the age of 20-25 years old, without exceeding the final density of 100 -120 trees ha⁻¹ (Costa et al. 2008).
First pruning is recommended around of 5/6 years after planting, removing branches from one or two thirds of total height. A second pruning should take place at the age of 10-12 years old. This pruning often coincides with the first thinning, removing branches on the lower third of the stem. Finally, the third pruning should be at 20-25 years old coinciding with the second thinning (Costa et al. 2008).

When the objective of forest management is to optimise the cone nut production, the rotation period can be extended to 150 years, or at least until a decrease in cone nut production is found (Montero et al. 2008). The same rotation could be applied to stands with the aim of protection and recreational use (Yague 1995). The first cones may appear on a tree at 3-4 years. In non-grafted stands, production with economic interest starts around 15-20 years old, increasing until 40-50 years and decreasing from 80-100 years onwards (Carneiro et al. 2007).

As in other fruit and nut tree crops, grafting offers several important advantages (see Figure 3.10). 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 characterization of the crop and the tested genotypes. A second advantage, grafting mature scions also skips the rapid growth juvenile stage and reduces the delay in production from 20 to less than 8-10 years (Carneiro et al. 2007; Mutke et al. 2012).

Freire (2009) has studied the collection of cones from Pinus pinea in stands with different ages and competition status for four campaigns in Portugal and has observed that, despite of the heterogeneity between campaigns, the cone production increased with the basal area per hectare reaching a maximum for a basal area around 12 m² ha⁻¹, decreasing for higher values of basal area due to the competition. Higher cone production occurred in naturally regenerated stands that had always been conducted for cone production, with relatively low density and large crowns with trees regularly distributed over the stand and with no traces of having ever been resined. Mean, minimum and maximum basal area (G), crown cover (Cc) and stand density (N), from Pinus pinea (Pp) and total (including other species, usually cork oak) as well as the pines quadratic mean diameter (dg) and medium height (H) from the the 20th most productive plots are listed below:

<table>
<thead>
<tr>
<th>G (m² ha⁻¹)</th>
<th>Cc (%)</th>
<th>N (ha⁻¹)</th>
<th>Pm cm</th>
<th>Pm m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pp Total</td>
<td>Pp Total</td>
<td>Pp Total</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>10.1</td>
<td>11.6</td>
<td>55.7</td>
<td>61.3</td>
</tr>
<tr>
<td>Maximum</td>
<td>17.0</td>
<td>17.7</td>
<td>75.2</td>
<td>79.6</td>
</tr>
<tr>
<td>Minimum</td>
<td>6.6</td>
<td>6.6</td>
<td>25.5</td>
<td>25.9</td>
</tr>
</tbody>
</table>

Cone production by hectare in weight and number between 2004/05 and 2007/08 is shown below. The cone production in the 2004/05 campaign was very high in some plots with the most productive one with almost seven thousand kilograms of cones by hectare.

<table>
<thead>
<tr>
<th>Cone weight (10³ kg ha⁻¹)</th>
<th>Cone number (10³ ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>2.794</td>
</tr>
<tr>
<td>Maximum</td>
<td>6.739</td>
</tr>
<tr>
<td>Minimum</td>
<td>1.247</td>
</tr>
</tbody>
</table>
Description of existing silvicultural systems

According to the analysis of cone production and tree and stand variables Freire (2009) suggested the maintenance of basal area in the range between 9 and 15 m² ha⁻¹ in adult stands. Where the upper limit is reached thinning should occur to achieve the lower limit of the range. For the early stages of development, the Portuguese National Forest Service suggests that stands for cone production should be established with an initial density ranging between 100 and 300 trees per hectare.

![Grafted plantation in Portugal with scions grafted in 2007 and rootstock in 2004 respectively (left). One year old shoot of P.pinea tip-cleft (needle graft) grafted onto P.pinea (right).](image)

The management of grafted stone pine is similar to other fruit tree orchards, although specific cultural techniques must be adapted for this conifer crop (Batlle 2006). As in any rain-fed woody crop, effective weed control by tilling is important. Yield increments in cone number and size have been achieved by application of fertilizers, especially with dolomite (magnesium) on oligotrophic sands or gravels. However, the optimization and profitability of these interventions is still under study (Castaño et al. 2004; Calama et al. 2007). Pruning of the shade crown has not shown to influence greatly the upper shoots, except in excessively dense plantations, where tree thinning should be applied instead. Although some weak or lower branches might be eliminated to facilitate cultural or harvest operations, pruning as a cultural treatment does not appear to be economically feasible (Mutke et al. 2012). Irrigation improves tree vigour and cone yield. However, even if there is access to a water supply, stone pine irrigation is unlikely to be a profitable investment alternative compared with other irrigated crops (Castaño et al. 2004; Mutke et al. 2007b). If there is no external pollen supply from nearby adult stone pine stands, pollination will depend on male flowering of the orchard. Thus, the weak dominated branchlets of the lower shaded crown will be essential to support a correct cone setting.

Combined timber and NWFP production

Traditionally, the management of stone pine stands has tried to combine multiple objectives: edible pine nut production, timber, firewood, recreational use, landscaping, and protection against wind erosion on sandy soils. However, at present pine cones provide high incomes to the forest owners, often more than that associated with timber or firewood, due to the fact that pine nuts are currently highly prized in international markets. In these sense, pure stands are usually managed forests with a regular structure derived from sowing, plantation, or natural regeneration after clear-cutting or shelterwood cuttings. The stone pine forms a dominant stratum of even-aged trees, either with a nearly closed canopy layer, reaching final densities of 200–250 trees ha⁻¹ at 100 years (if managed for timber production), or sparser to optimize the crown development, thus favouring cone production. In the later scheme, thinning is conducted early
and intensively applied to attain a final density of 75–125 trees ha⁻¹ at stand ages of 50–60 years (Montero et al. 2008) aimed at increasing pine nut production. For this combined timber and NWFP production purpose, densities of plantation should be between 450 trees ha⁻¹ (5x4,5 m) and 650 trees ha⁻¹ (4x3,5 m) (Correia et al. 1999) to reach a final density between 100-175 trees ha⁻¹ (Montero et al. 2008). The end of the rotation is usually ranging between 80-120 years (Montero et al. 2008).

Other potential (e.g. other options such as intercropping or agroforestry)

The high prices obtained for this nut in international markets have made it an attractive opportunity as an alternative crop on rain-fed farmland or in agroforestry systems. Furthermore, its good performance on poor or eroded soils and positive response on better sites, few pests or diseases, reduced need for cultural practices such as pruning, and high resistance to climate adversities such as drought and extreme or late frosts make it a good candidate for conversion to a horticultural crop in contrast to its present use as a gathered crop in natural forests. Anyway, the managed grafted trials with selected genotypes have allowed multiplying several times the productivity of the forest land where they are located, in comparison with traditional stone pine forests. Thus their major potential might be just in the limit between areas with and without agronomic aptitude: marginal stony or sandy Mediterranean farmlands where herbaceous crops or extensive sheep grazing are no longer profitable without subsidies and where traditional afforestations would offer only environmental benefits but no direct incomes for the land owner.

3.3.2.6.4 Summary of key points and knowledge gaps

The current knowledge about stone pine as a nut crop in specific plantations is still limited. The genetic control of seed productivity seems to be largely quantitative; no related major genes are yet known, and genomic approaches for their discovery are lacking. The association of vegetative and reproductive vigour in the same shoots limits any potential selection of highly productive dwarf cultivars for a modern intensive horticultural system. Managed grafted trials with selected genotypes indicate that productivity of forest land can be increased several fold in comparison with yields in traditional stone pine forests. The major potential for stone pine as a crop appears to be both in agroforestry systems that combine isolated pines or tree lines, such as shelterbelts with farmland or pastures, and proper orchard plantations, especially on marginal stony or sandy Mediterranean farmlands where herbaceous crops or grazing are no longer profitable and where traditional afforestation would offer only environmental benefits but no direct income for the land owner.

In farmland afforestation after the CAP reform in 1992, stone pine has been widely used for combining public subsidies with the expectation of future cone production. Nevertheless little research has been carried out during this period and little information is available to support the management of stone pine.

3.3.2.6.5 Suggestions for new silvicultural prescription for combined timber and pine nut production in Europe

Silvicultural prescriptions for combined timber and pine nut production will be determined by the preferred objectives of forest management at the end of rotation length as well as by the healthy status and quality of sites. In naturally regenerated stands, the currently used rotations are also often below the optimal (120 years). It is not uncommon that regeneration in managed forests is perceived as unsuccessful because rotation lengths are too short. In these cases, if parent trees were allowed to remain longer (increasing the length of the regeneration period as well as seed production per tree), the probability of establishment would increase. With the aim of increasing pine nut production, thinning must be conducted early and intensively applied to attain a final density of 75–125 trees ha⁻¹ at stand ages of 50–60 years (Montero et al. 2008).
3.3.2.7 Resin

*Pinus pinaster* Ait. subsp. mesogeensis Fieschi and Gaussen, Mediterranean maritime pine (EN); Seestrandkiefer (DE); Pin de corte/pinastre/maritime (FR); Pino negral/rodeno/Pino resinero (ES); Pinheiro bravo (PT); Pinastro (IT).

This paper describes the ecology and the state of the art of current silvicultural prescriptions applied to the production of resin in Mediterranean maritime pine (*Pinus pinaster* Ait. subsp. mesogeensis Fieschi and Gaussen) forests. Management practice for maritime pine varies depending on priorities for different products like wood and resin, and are always conditioned by the protective character of its forests for soil, watershed, landscape, and wildlife.

3.3.2.7.1 The tree

Maritime pine (*Pinus pinaster* Aiton) is a widespread pine species with its natural range in the western Mediterranean region (see Figure 3.11) (EUFORGEN 2009), where it is broadly distributed, though it has naturalized also to other countries, including England, USA, Chile, Argentina, Uruguay, South Africa or Australia (Oliveira et al. 2000). Two main factors have affected the present natural distribution, resulting in a high degree of fragmentation: the discontinuity and altitude of the mountain ranges where it grows have caused isolation even of nearby populations, and the human impact was twofold; during millennia, farming (swiddens) and especially grazing (pastoral burning) had first reduced widely the natural pine forests, and only since the XIX century forestations have recovered or expanded them.

![Figure 3.11 Distribution of Pinus pinaster in Europe](Source: EUFORGEN 2009, www.euforgen.org)

Maritime pine is one of the most important forest species in France, Portugal and Spain. The main uses and services of its forests and woodlands are related to soil protection, wood and resin production, as well as landscape scenery and recreation. Their presence defines several European Natural Habitat types, one of them even considered priority habitats, 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 Mesogean pines’ (9540), that require special protection because...

Maritime pine is a drought-resistant, light-demanding trees species able to colonise, or to be planted on, bare land in different habitats. Its natural formations appear on coastal or inland sandy areas or dune systems, and on slopes of mountain ranges, where its presence is favoured by frequent thunderstorm (natural wildfire) regimes in Mediterranean mountains. Therefore, several provenances of Mediterranean maritime pine show adaptations to forest fires: early flowering, presence of serotinous cones, and a thick bark. Compared with other Mediterranean pines, it has large cones (8-20 cm long), usually in groups of 2 or 3 per whorl, and long needles (10-25 cm). There exist clear morphological and ecological differences among the different provenances of Maritime pine, resulting in the subdivision of the species into two subspecies (Tutin et al. 1964), usually named atlantica (at the Atlantic coast of Portugal, Spain and France) and pinaster or mesogeensis (in its Mediterranean range). These are also subdivided into several geographical races (atlantica, mesogeensis, corteensis, maghrebiana, renoui,...). Hereafter, we refer to the second subspecies as the Mediterranean maritime pine (Pinus pinaster Ait. subsp. mesogeensis Fieschi and Gaussen).

Maritime pine is considered a fast growing species in the Atlantic region (coastal areas of France, Spain and Portugal), where rotation ages of 40-50 years are common, its main uses in these regions are construction, chipboards, floor boards, palettes, biomass, pulp and paper production. In the Mediterranean regions, growth rates are lower (often less than 3, or even less than 1 m²ha⁻¹year⁻¹) and the rotation ages vary from 80 to 120 years (Ruiz Sánchez 1963; Balbuna and Allué 1998; Serrada et al. 2008). The timber can be of good quality (Leiria, coastal zone central Portugal and Corsica, mountains areas in central Spain), or low, especially owing to the existence of very crooked trees often caused by reiterated leader shoot losses. During the XIX and XX centuries, one of the main uses of the species was resin tapping, being one of the most relevant European resin-producing pine species, along with Pinus brutia. Some specimens can yield more than 20 kg of resin per tree and year, though mean yields are about 2.5-3.5 kg/tree (Alia and Martin 2003; Mutke et al. 2013; Rodríguez-Garcia et al. 2014).

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 use in afforestation programs for soil protection or ecosystem restoration, and, if compatible, for wood and/or resin production. It prefers loam or sandy-loam soils, but it does not tolerate too compact soils with excessive clay and silt. It supports quite variable pH ranges, from moderately acid to moderately basic, some provenance being sensitive to active limestone whereas others grow on calcareous or dolomitic bedrocks. It tolerates calcium levels from 0 to 9%, and soils with medium to high permeability and a water retention capacity from 60 to 310 mm (Alia et al. 1996; Correia and Oliveira 2003; Serrada et al. 2008).

Geographical races of the species can be found in quite different environments: from sea level to 2100 m elevation in the High Atlas (Morocco). The Mediterranean subspecies usually grows from 600 to 1300 m. However, in Portugal for more than 800 meters altitude, the species has serious limitations for growth (Correia and Oliveira 2003). It is considered a light demanding species, well adapted to the Mediterranean climate, growing from areas with more than 1400 mm of annual rainfall and no dry season, to others with 350 mm, exceeding 4 dry months. The Mediterranean subspecies grows well with mean annual precipitations of 400-800 mm, summer rains from 20 to 125 mm, and has a drought tolerance from 2.5 to 4 months. Its root system is very sensitive to water logging (Oliveira et al. 2000; Serrada et al. 2008).

The Mediterranean subspecies rarely attain heights greater than 20 m, although maritime pine can reach 40 m. The crown is usually pyramidal at young stages, while roundly topped and spread open at older ages. When growing in dense stands, the shape of the tree is strongly influenced by competition, originating
trees with narrower, irregular shaped crowns and higher stems (Castroviejo, 1986-2012; Oliveira et al. 2000; Serrada et al. 2008). In stands managed as even-aged, diameter rarely reaches 60 cm before final cutting. Older trees, especially if they are isolated, can pass 100 cm. The ecological relevance of those old-grown trees is high as nesting trees preferred by endangered rare species such as Iberian imperial eagle, black stork or several trunk-cavity dwelling bat species.

The optimum mean annual temperature is in the range 9-15 °C. The mean temperature of the coldest month should not be below 1-7 °C (though occasional frosts of less than -20 °C is tolerated by inland provenances) and the mean temperature of the warmest month is usually from 18 to 25°C (Serrada et al. 2008).

3.3.2.7.2 NWFP Products

Though priority uses and functions of Mediterranean pine forests are mainly soil protection and conservation as natural habitat, some compatible yield of goods like timber, fuel biomass and resin is possible in most Pinus pinea forests. Maritime pine produces resin of high quality for a wide range of industrial products. Until 1980, resin obtained by tapping the trees had been a very important raw material for chemical industry. In Spain, the maximum resin production had been 55,000 ton in 1961, decreasing slowly to 40,000 ton in 1971-75. But after the opening to the world market production reduced drastically, and once Spain joined the EU and its customs union in 1986, during more than two decades Spanish resin output was lower than 5,000 tons per year. A similar trend, though ten years delayed, can be observed in Portugal, where the production, that reached 108,000 ton in 1986 (CESE 1998), reduced very drastically from 63,000 ton in 1990 to approximately 30,000 t in 1995-97 and 5,000 t after 2004 (see Figure 3.12). The main reason for this reduction was that European pine resin couldn’t compete with cheaper imports from resins tapped in tropic pines in China or Brazil, with sub-products from paper mills, or with petrol-based succedanea (Pinillos et al. 2009).

The world production of resin-derivate products reached its maximum in 2007, when the resin production exceeded a million ton and the turpentine production 170 thousand ton (CESEFOR 2009). China produces 55% of the world resin, whereas USA produces 18% and Europe only 8%. However, regarding rosin derivate from resin, China produces 70%, Latin America 10% and Indonesia 7%. Regarding turpentine, China produces around 75% of the world total. The international prices for these products were at a minimum of less than 0.45 €/kg in 1991 to a maximum of 1.11 €/kg for turpentine and 0.76 €/kg for rosin in 2008 (CESEFOR 2009). In recent years these prices were even higher, due to China’s drop as the world’s main natural resin exporter from 0.4 million t in 2006 to less than 0.25 million ton/year since 2009, owing to its need to supply the own growing chemical industry, has forced a strong price increase for natural resins, rosin and derived products. The global economic crisis which has reduced wages and increased unemployment rates, has led to the coming of labor to rural areas, allowing for the current comeback of resin tapping in Spain (Picardo and Pinillos 2013).

The sector has recently experienced additional new momentum with innovation attempts at mechanization (Pinillos et al. 2009; de Diego and Sanz 2013). The development of new tools and extraction methods, combined with breeding programs, could be of importance for this NWFP.

**Product characteristics and utilisation**

Crude resin obtained by tapping living pine trees is a thick, sticky, but usually, still fluid material. It is opaque (due to the presence of occluded moisture), milky-grey in color, and often contains a certain amount of forest debris (pine needles, insects, bark, etc.) when it is collected from the trees (Coppen and Hone 1995).

Most *Pinus* species bleed resin when the stem wood (xylem) is cut or otherwise injured. In the past most European pines have been tapped commercially as a source for rosin and turpentine production, though currently only in *Pinus pinaster* and *Pinus brutia* resin tapping remains playing a significant role as a forest use in Europe.

Turpentine is the volatile oil distilled from pine resin. The solid material left behind after distillation is known as rosin. Both products are used in a wide variety of applications. Traditionally, turpentine has been employed as a solvent or cleaning agent for paints and varnishes and this is still often the case today. There are also some specialized uses, as in the pharmaceutical industry. Turpentine is used as a source of chemical isolates which are then converted into a wide range of products. Many of these, including synthetic pine oil, are employed for fragrance and flavor use, although there are also many important non-aromatic applications such as polyterpene resins. Pine oil is used in disinfectants and cleaning agents. Derivatives such as isobornyl acetate, camphor, citral, linalool, citrinellal, menthol and many others are used either in their own right or for the elaboration of other fragrance and flavor compounds (Coppen 1995).

Rosin is used to obtain derivatives like salts, esters and maleic anhydride adducts, and hydrogenated, disproportionated and polymerized rosins. Their most important uses are in the manufacture of adhesives, paper sizing agents, printing inks, solders and fluxes, various surface coatings, insulating materials for the electronics industry, synthetic rubber, chewing gums and soaps and detergents (Coppen and Hone 1995).
Yield

The socioeconomic importance of tapping has prompted scientific research to increase production by studying the resin secretion structures (Bannan 1936; Wu and Hu 1997; Boschiero and Tomazzello-Filho 2012), the influence of the tapping wound on oleoresin secretion (Ruel et al. 1998; Gaylord et al. 2011), the application of chemical stimulants or fertilizers (Hudgins and Franceschi 2004; Rodrigues et al. 2008; Moreira et al. 2009; Palma 2007), modeling of resin yield (Nanos et al. 2000, 2001) and the development of breeding programs (Prada et al. 1997; Tadesse et al. 2001). The role of resin flow as constitutive and induced defense against pests and disease has also been explored (Berryman 1972; Franceschi et al. 2005; Knebel et al. 2008; Kim et al. 2010).

Due to the long-lasting abandonment of resin tapping in Europe, there have been nearly no recent papers, about resin yield and specific management methods. Recently, Rodriguez-Garcia et al. (2014) related resin yield to dendrometric variables. Such variables, together with radial resin canal frequency could be useful criteria for estimating resin yields in Pinus pinaster and could be applied to improve tapping management.

3.3.2.7.3  Silvicultural prescriptions for growing Pinus pinaster

Although resin production affects the tree bole, as this is grooved to get the resin, pine stands are never managed to only get resin, thus being a combination of timber and resin the main productions. Hereafter we include the silvicultural prescriptions for such combined productions and the particular aspects when only timber is produced in the Mediterranean region. As mentioned before, most 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.). Pine forests remain in the Mediterranean countries mostly only at sites without aptitude for agriculture or other uses (poor or no soils, excessive slopes, etc.) and they are often affected by legally binding norms due to their inclusion in networks of protected areas, such as the Natura 2000 or Catalogues of Forests of Public Interest. Even grown-up pure even-aged plantations from mid-XX century, afforestation programs are today often aimed to be transformed by selective cuttings and enrichment plantations, or to evolve spontaneously, into mixed, even-aged, structurally more complex forest types, given their preferred protective purposes.

Combined timber and resin production

Resin from Pinus pinaster can be obtained in pure or mixed plantations, as well as in natural regenerated stands (very often even-aged). Single species plantations are recommended for resin extraction purposes, however mixed stands are common with Quercus ilex, Q. suber, Q. faginea and Q. pyrenaica (Casado and Herrera 1996; Louro et al. 2000), Eucalyptus globulus, Castanea sativa (Correia and Oliveira 2003) as well as with Pinus sylvestris, P. nigra, P. pinea and P. halepensis (Serrada et al. 2008). Mixed stands with P. pinea might allow both resin and pine nuts exploitation, although this is not a very common situation because for both, harvest costs per hectare depend strongly on target species’ tree density. Pure stands at least at a small scale are therefore required for concentrating labor. Excessive slopes can also be a limiting factor for profitable resin exploitation.

Natural regenerated stands usually have over 2,000 trees/ha. Plantations range from 1,100-1,700 trees/ha in the pure stands managed by the Forestry Service (often protective afforestations) 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 Spain there are 20 provenance regions (Alía et al. 1996; DGCONA 1996), 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. 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 defense against forest fires was the basis of a European project - SUSTFOREST - who participated France, Portugal and Spain, which aimed to multifunctionality, conservation and rural employment in the territory of southern Europe by extracting resin (http://www.sust-forest.eu).

Formative shaping is almost never necessary, because the worse trees will be removed in the first thinnings. A non-commercial thinning before the age of 10-15 years reduces stoking density to 800-1200 trees/ha (Louro et al. 2000). Traditional thinnings aimed at reducing stoking density to 150-250 trees/ha (in Spain) or 300-500 (in Portugal) at 30-40 years to attain the necessary dbh to start resin extraction (Baudín 1963), resulting in a 2 or 3 heavy thinning regime. In Portugal, this minimum diameter is regulated by specific legislation that consider two types of resin extraction: to death - trees are tapped in the 4 years immediately preceding the cut; to life – the incisions extend over several periods of 4 years. The minimum dbh is 19,1 cm (60 cm of perimeter) and 25,5 cm (80 cm of perimeter) to resin extraction to death and to life, respectively (Oliveira et al. 2000). In Spain this minimum dbh is about 30 cm, but it depends 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).

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 a pruning only up to 1,5-2 m is applied to the trees after the first thinning (at 15-20 years, i.e. tree height = 7.5-8 m) and a high pruning (4-5.5 m) is applied only to the 150-200 trees (Spain) or 300-500 (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; Ruiz Sánchez 1963; Balbuna and Allué 1998; Serrada et al. 2008). Mediterranean maritime pine stands exploited for timber or resin are almost always even-aged, to facilitate and optimize resin tapping and harvest operations. Three sub cycles are established through the life of the stand: Regeneration sub cycle (the necessary time to get 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 3 kg tree\(^{-1}\) year\(^{-1}\) (usually from 1 to 10, with a maximum of 30) (Palma 2007; Serrada et al. 2008; Mutke et al. 2013).

Timber production

When stands are managed for timber production, even-aged pure plantations or pure natural regenerated stands are preferred to facilitate management, though more flexibility is possible when other forest functions are priority, because timber harvest is not as sensitive to target tree density per hectare as resin tapping. In this case, in Spain, rotation lengths are shorter, usually from 60 to 80 years for saw logs with a minimum upper diameter of 25 cm (Ceballos and Ruiz de la Torre 1976).

In several cases a high stocking density is maintained to get natural pruning (Serrada 2004; Alves et al. 2012). If possible, a low pruning (when trees are about 15 years old) is applied to all trees and a high pruning (5.5 m) is applied to 400-500 trees/ha (when trees are about 20 years old) (Oliveira et al. 2000; Serrada et al. 2008).

Regarding the thinning regime, in Spain, it is recommended in natural stands to maintain the Stand Density Index (SDI) between 35-60% of the maximum values (this means SDIs from 300 to 675) (del Peso and Bravo
A thinning regime has been recently proposed for plantations, in order to maintain SDI between 25-45% of the maximum SDI (this means SDIs from 406 to 732) (del Río et al. 2005). For this purpose a non-commercial thinning is necessary if stoking density exceeds 1,500 trees/ha. A semi-systematic thinning (usually a row each 7 rows and a low thinning in the rest) is done at an age of 20-30 years. A second thinning from below is done at an age of 30-45 years. A third thinning from below is done at an age of 40-60 years. In good sites a fourth thinning from below is done at 50 years. The final cut is done at an age of 60-80 years (del Río et al. 2005).

### 3.3.2.7.4 Summary of key points and knowledge gaps

As said before, there have been nearly no recent papers about resin yield models and specific management methods, because the long-lasting abandonment of resin tapping in Europe fall together with the only recent strong development of modern forestry research in southern Europe during the last twenty years. On the other hand, maritime pine is one of the best-studied forest species in Spain, Portugal and France, and numerous studies and growth models are available for Pinus pinaster (see Appendix A), that might allow a linking of resin yield by tree size (dbh or crown dimensions) and other covariates as modular complement of single-tree models.

Though 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), environmental risks and priorities possibly will limit its applicability because a genetically narrow-based, production-centered silviculture might involve excessive uncertainties in a scenario of ongoing climate changes towards a warmer and drier Mediterranean area.

### 3.3.2.7.5 Suggestions for new silvicultural prescription for timber production and combined timber and NWFP production in Mediterranean Europe utilising Pinus pinaster

- Plant around 1,000-1,500 trees/ha. Select an adequate provenance.
- Promote natural regeneration when existent.
- Reduce the competition from herbs and brushes in the early years, namely in plantations in areas with a lot of spring rain.

Table 3.7 and Table 3.8 show management regimes for maritime pine grown for timber production and combined resin and timber production.

#### Table 3.7 Management regime for timber production

<table>
<thead>
<tr>
<th>Age</th>
<th>Trees/ha</th>
<th>Operation</th>
<th>Age</th>
<th>Trees/ha</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20</td>
<td>1500</td>
<td>Pre-commercial thinning if N &gt; 1500 Low pruning to 2.5 m when trees are 7-7.5 m tall (900 trees/ha)</td>
<td>0-25</td>
<td>1500</td>
<td>Pre-commercial thinning if N &gt; 1500 Low pruning to 2.5 m when trees are 7-7.5 m tall (1000 trees/ha)</td>
</tr>
<tr>
<td></td>
<td>850-900</td>
<td>Semi-systematic thinning</td>
<td></td>
<td>1000</td>
<td>Semi-systematic thinning</td>
</tr>
<tr>
<td>30</td>
<td>550-600</td>
<td>High pruning to 5.5 m when trees 25-30 are 15 m tall (400-500 trees/ha)</td>
<td>40-45</td>
<td>600</td>
<td>Thinning from below</td>
</tr>
<tr>
<td>40</td>
<td>350-400</td>
<td>Thinning from below</td>
<td>55-60</td>
<td>400-450</td>
<td>Thinning from below</td>
</tr>
<tr>
<td>50</td>
<td>250-300</td>
<td>Thinning from below</td>
<td>80</td>
<td></td>
<td>Regeneration cut</td>
</tr>
<tr>
<td>60-70</td>
<td></td>
<td>Regeneration cut</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3.8  Management regime for combined timber and resin production

<table>
<thead>
<tr>
<th>High site quality</th>
<th>Low site quality</th>
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</thead>
<tbody>
<tr>
<td><strong>Age</strong></td>
<td><strong>Trees/ha</strong></td>
</tr>
<tr>
<td>0-20</td>
<td>1000</td>
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<td>20</td>
<td>500</td>
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<td>25</td>
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<tr>
<td>30</td>
<td>200</td>
</tr>
<tr>
<td>80-100</td>
<td>100-120</td>
</tr>
</tbody>
</table>

3.3.2.8  Lime Tree

*Tilia rubra* DC., *Tilia platyphyllos* Scop., *Tilia tomentosa* Moench, *Tilia cordata*, *Tilia americana* L., *Tilia truncata* Spach, *Tilia pubescens* Aiton (Out of 46, these are the high acceptance level lime trees by the botanists)

The Lime tree (*Tilia rubra* DC.) has been used for both timber and flower production in addition to its use as ornamental trees in Europe and other areas. It grows mostly in mixed forests with both deciduous and coniferous species. Generative and vegetative reproduction systems as well as in-vitro tissue culture reproduction system are used in the regeneration this species.

3.3.2.8.1  The tree

The linden (or lime) tree is a member of *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 height with dense branches and wide crest (Radoglou et. al. 2008). The size of the leaves are 5-10 cm in length. Flowers blossom in June and July and are harvested together with leaves and let to dry in the shade. The linden generally grows in northern part of Turkey, for instance, particularly in the regions of Marmara, Western Black Sea, Central Taurus Mountains and Northern Anatolia. It 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*) 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).

* 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 warm and wet sites with an abundance of nutrients in Italy. *T. tomentosa* grows up to 1000 m in elevation in Romania. In Bulgaria *T. tomentosa* grows in the north-astern part and is found in the flat hills and foothill of the Mizian zone covering 17,273 ha area. In Greece, *T. cordata*, *T. platyphyllos* and *T. tomentosa* 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.
Generative and vegetative reproduction systems as well as in-vitro tissue culture reproduction system are used in regeneration of the tree. It has good root and stump sprouting systems. Lime trees sprout strongly after cut and show no decline in sprouting vigour with age (Pigott 1991). Sprouts can develop from both cut and fallen stems even in old age (Pigott 1989). Branches touching the ground may become rooted producing vertical shoots. The other example of vegetative reproduction is the ability to rejuvenate shoots from layering and pollarding.

Lime regenerates naturally under the stand canopy during the shelterwood cuttings on rich sites. Although *Tilia cordata* regenerates freely in groups in Białowieża Forest, Poland, vegetative reproduction is very important for populations growing on the border of its natural range. 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 (lime is generally shade tolerant tree), their growth in the third and fourth years needs more light for a successful regeneration.

The tree has specific biological and ecological properties such as regeneration by stump/root sprouting, almost annual fructification, and maintenance of soil fertility by the rapid decomposition of litter foliage, shade tolerance.

Flowering and seed production of trees begins at the age of about 25-30 years, but trees originating from sprouts blossom 10-15 years earlier. The tree bears rich seeds generally at 2-3 years intervals. *T. cordata* and *T. platyphyllos* flower in July (T. tomentosa in late June) (Barzdajn 1991) and produce seeds almost yearly (Murakhtanov 1981). Light, drought and frost are very important factors for flower development.

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 (H2SO4), 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 also used to reproduce the lime tree.

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.

Linden requires light and humid areas growing on rich soils, mesotrophic or mesoeutrophic, fresh or moderately moist, with null or moder humus. Such soils have neutral or alkaline pH soil reaction. Lime prefers sites with higher calcium content (Jaworski 1995). According to the review by Radoglou et al., (2008). *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. 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.

*T. platyphyllos* tolerates temperature as low as -3 to -8 °C, and *T. cordata* from -7 to -16 °C (Korotaev 1994) with an upper limit of 44 °C. It is susceptible to flood, especially stagnant water (Lyr 1993). Lime species, especially *T. platyphyllos*, are resistant to drought, dry winds and low temperatures; they are suitable for commercial and protective planting (Biryukov 1991).
3.3.2.8.2 NWFP Products

Product characteristics and Utilization

Linden has volatile oil, tannin, sugar, vitamins C and P, resin and enzymes. Linden flowers are used as herbal tea, as fragrance in perfumes and soaps, essential oils, extracts, botanical facial masks and creams, sun care and body lotions and shampoo, bath and shower gels, and has also been utilized within greater health and well-being syrups and nerve system tranquillizers (see Figure 3.13). Dried leaves and flowers may be taken as a tea one brewed in hot water. Lime-flower tea has a pleasant taste, due to the aromatic volatile oil found in the flowers. Linden trees are also used as medicine for the diuretic, diaphoretic, antispasmodic and sedative properties of their flowers and herbs. Active ingredients in the lime flowers include flavonoids (which act as antioxidants), volatile oils, and mucilaginous constituents (which soothe and reduce inflammation). The plant also contains tannins that can act as an astringent (Bradley 1992).

![Linden flowers are used as herbal tea, as fragrance in perfumes.](image)

Lime trees especially *T. platyphyllos* and *T. cordata* are also important as ornamental trees and are frequently used by urban forestry in streets and parks. Additionally, some parts of lime trees are very important for animals’ diet. Roots, bark, sapwood, leaves, fruit, seeds and shoots are eaten by some (21) species of mammals.

Yield

There is not much information regarding the wood yield of linden tree. Therefore, the yield of beech (*Fagus sylvatica*) is generally used as a proxy for lime. Compared to beech trees, however, lime grows quicker in the first 50 years of life, but by the age of 100 years beech stands yield about 30% more than lime stands. The volume of such lime stands is about 300 m³/ha (Navmar and Spethmann 1986).

Yield tables for Tilia species are rare and those available for *Tilia cordata* in Germany show that the growth shape and patterns of Tilia are totally different to those for beech stands (Böckmann 1990). 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).

*T. cordata* stands have one of the greatest volumes (761-861 m³/ha) among stands of primeval character in the Polish side of the Carpathians. The largest lime trees reached 110 cm dbh and 35.5 m height. Basal area of lime was also very high (55-62 m²/ha) (Jaworski et al. 2005). The standing volume of *T. tomentosa* at the age of 70 years ranged from 308 to 517 m³/ha. The diameter increment reaches its maximum (4.0 cm)
between 20 and 30 years. The volume increment reaches its maximum (11.2 m³/ha/yr) at 35-40 years of age. The mean volume increment of pure *T. tomentosa* stands regenerated by seeds ranges from 7.7 (m³/ha/yr) in the 1st yield class to 3.0 (m³ /ha/yr) in the Vth yield class (Giurgiu and Draghičiu 2004).

### 3.3.2.8.3 Silvicultural prescriptions for growing Lime trees

#### Timber production

The wood of lime species is light colored and straight grained with a smooth uniform texture. Because of its color, even grain and easiness of working, it has been used to manufacture boxes and crates, for wood turning, furniture, trunks, venetian blinds, picture frames, carriage bodies, beehives, plywood, cooperage, pulp, and charcoal. In Greece lime wood is used for temple carving in Orthodox churches as well as inturnery. Other uses include children toys, carving and crafts making, pencils, tennis rackets, beehives and, musical instruments (Tsoumis 2002).

There are not any specific silvicultural prescriptions designed and implemented for lime trees. However, few silvicultural treatments were applied to Lime stands. 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. Only a few scientifically based studies concerning *Tilia* species are available (Radoglou et. al. 2008). Forest managers tend to treat these species either according to their own experience or by using data available for other broadleaved species. For example, couple of silvicultural treatments such as rehabilitation or revitalization and plantation were applied to lime stands in different regions of Turkey (510 ha, 2007-2013) (Personnel communication with the department of Silviculture in GDF, Turkey). Further research on the growth of *Tilia* species will enhance their sustainable forest management in Europe.

In fact, Lime is an auxiliary tree species that plays a very important role in oak plantations. It shades oak stems, influences soils, prevents dense plant vegetation and accelerates litter decomposition. In some counties such as Greece and Turkey lime trees are maintained in mixedwood stands for stand durability and natural structure of the forest during regeneration because of their soil-improving abilities, better site utilization and landscape aesthetics.

Some silvicultural needs for tending interventions related to *T. tomentosa* include the followings:

- it is a fast-growing and vigorous species;
- it produces stump sprouts and root suckers abundantly;
- it is moderately shade tolerant;
- if its stem is exposed to direct sun light (sudden crown release) it produces epicormic branches and can be scorched by the sun, greatly devaluing the net worth of the timber.

Based on these facts, weeding, cleaning-respacing and thinning are applied to silver lime stands. Weeding is applied mainly to protect seeds from sprouts or suckers, over 1-3 years of rotations with a minimum canopy closure of 80% after intervention. The first cleaning-respacing is performed at a stand age of 10-12 years to eliminate non-desirable species and defective trees (forked trees or other undesirable defects) and repeated in 4-6 years of interval. 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 this case the last thinning is applied at 60-70 years of age. The biological rotation age of *T.*tomentosa 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. Aside from sprouting, layering and pollarding, plantation under the shadow of trees is a practical silvicultural prescription.

**Lime tree flower production**

No apparent silvicultural prescriptions were found to be used for the specific management of lime tree flowers. While intensive pruning of the tree for lime flowers are used to collect the flowers as an NWFP, no scientifically proven method of pruning has been found. Trees blossom after 20-30 years. Flowers are collected from the branches of the standing trees or picked from the ground if harvesting occurs later in the season.

**Combined timber and NWFP production**

Tilia is an available species for both timber and flower production. While flower production requires large crown volume, better timber production is achieved with certain density. However, the potential consequences of flower production to the timber production have not been reported.

**Other potential**

Lime trees are used as supporting trees in valued oak stands and used urban areas such parks, streets, and roads as allée trees. Intercropping of the tree has not been reported to date.

3.3.2.8.4 **Key points and knowledge gaps**

- Used for wood, flowers and as ornamental tree
- Established reproduction and silviculture for timber not for flower production
- Lime is palatable therefore in stands heavily populated with deer; they are continuously subjected to extreme browsing damage and repeated bark damage.
- Tilia is becoming rare because of competition with other broadleaved species in coppice forests, the intensive pruning for lime flowers and heavy livestock grazing (Greece).
- No specific collection of flowers without damaging the tree
- Natural mixed stands maintained.
- Instead of pruning, small branches with flowers are to be cut with clippers

3.3.2.8.5 **Suggestions for new silvicultural prescription for combined timber and NWFP production in Europe utilizing Lime trees**

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 favored as practical silvicultural prescription.

3.3.2.9 **Bay laurel tree**

*Laurus nobilis* L., *Laurus azorica* (Seub.) Franco, *Laurus chinensis* Blume, *Laurus melissifolia* Walter (4 high acceptance level Bay trees): Bay laurel, Sweet laurel, Sweet bay (EN), Laurie, Laurier sauce (FR), Lorbeer, Lorbeerbaum (GR), Alloro, Lauro (IT), Laakeripuu, Laakerinlehti (FI), Wawrzyn, Szlachetny (PL), Lavr Brogorodny (RUS)
Laurus nobilis (Family Lauraceae), known as bay laurel, sweet bay or laurel, 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 and in an elliptic shape. Its leaves and oils from both the leaves and fruits are the main NWFP that have been used in the medical, cosmetic and canning industries. The best leaf harvesting method is found to be the combination of coppice and shoot cutting or pollarding at 2-3 years interval. Drying leaves is extremely important process in obtaining NWFP from laurel. Turkey has the 90% of laurel market share in the world.

### 3.3.2.9.1 The tree

The laurel tree grows on the coastal parts of the Aegean, Mediterranean and Black Sea regions in Turkey and native to the Mediterranean region and the Laurate 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 (see Figure 3.14). The tree does not tolerate cold regions. The tree also 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-

Laural trees prefer humid areas from the sea level up to 1200 m in elevation with 131,862 ha area. (Anonymous 2005). 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. 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 – 7.96) with a precipitation between 600mm to 2000 mm per year. It generally grows on shadowed aspects (N, NE, E, NW) 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 between 14-15 °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.

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 resprouting, hence a coppice style management is prevalent in most of the areas. However, there is a germination prevention mechanism that requires special treatment prior to sowing. The seeds are generally removed from the shells (pericarp- the outer shell) 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 1,5x0,66m intervals provide far better results (Chakhaidze. D.Kh; Vadachkoriya. Ts.T 1989).

The laurel has the ability to reproduce itself and thus provides resistance to air pollution. 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.
3.3.2.9.2 NWFP Products

Product characteristics and Utilization

The main NWFP derived from this species are the laurel leaves and laurel oils from the leaves and its fruits (see Figure 3.15). The dark green leaves of bay laurel are fragrant and aromatic. After drying, they are broken, cracked or cooked to release their characteristic aroma and flavour. Dried laurel bay leaves are used as flavouring in soups, fish, meats, stews, puddings, vinegars and beverages. Oil of bay or oil of laurel leaves is an essential (or volatile) oil obtained by steam distillation of bay leaves and oleoresin has replaced the dry leaves in some food preparations (Simon et al. 1984).

The rate of essential oil in the leaves is the highest in August with 1.46%. However, the black or dark blue seeds or fruits (<2cm) matured in late September and early October carry more oils than leaves do (17-25%) (Anonymous 2005). Both essential and fatty oils are present in the fruit. The fruit is pressed and water-extracted to obtain these products. The fruit contains up to 30% fatty oils and about 1% essential oils (terpenes, sesquiterpenes, alcohols, and ketones).
World wide bay leaf production amounts to around 12,200 tons per year. Turkey shares 90-95% of the world laurel market. For example, in 2005 Turkey produced approximately 6,000 tons with a value of nearly 12 million US$. The producers only pay 6.49% of total income from the leaves as stumpage prices to the government (Bilgin et al. 2005). In the last five year period, the percentage share of the total export income of laurel leaves was 7.8% among all the non-wood forest products in Turkey, yet it increased to 10%. Between 1997 and 2003, Turkey has exported to China, USA, Germany, Japan, Poland, Brazil, The Netherlands and France.

Laurel oil has been used in the medical, cosmetic and canning industries. The utilization parts of the are both leaves and its fruits of the Mediterranean laurel are both commonly utilized. The dried leaves are used as a spices or seasoning in canned food, rice, soup and meat dominated food. Bay leaves are collected from both cultivated and wild plants in many Mediterranean countries such as Algeria, France, Greece, Morocco, mainlu Turkey and Portugal and Spain (minor producers). Outside the Mediterranean Basin, bay leaves are produced in the Canary Islands, Central America, Mexico and the southeastern United States (Simon et al. 1984). Laurel oil is used to prevent the reproduction of insects in dried figs and packaged grapes. Furthermore, laurel products are also used to maintain the freshness of fish and overcome the odor of fish in fished cans. Whole bay leaves have a long shelf life of about one year, under normal temperature and humidity. Bay leaves are used almost exclusively as flavor agents during the food preparation stage. Ground bay leaves, however, can be ingested safely and are often used in soups and stocks, as well as being a common addition to a Bloody Mary. Dried laurel berries and pressed leaf oil can both be used as robust spices, and even the wood can be burnt for strong smoke flavoring (Green 2006). In fact, bay leaves are one of the quintessential ingredients in a cook’s arsenal as the product has become a backbone of cuisines from all over the world.

Essential oils from the fruits are generally used in the soap industry and some liquor production. Soaps made from laurel oils are extremely good cleaning product and has been suggested to heal wounds and acne on the head and body, while being a good hair softener and anti-dandruff agent.

Laurel leaves and oils are also used in chemical and pharmaceutical industries due to their properties of rheumatic painkiller and antiperspirant (Göker and Acar 1983). A traditional folk remedy for rashes caused by poison ivy, poison oak, and stinging nettle is a poultice soaked in boiled bay leaves. Specifically, the leaves and berries of L. nobilis have been used for treatment of rheumatism, skin rashes, earaches and other medical problems. Further, they are also used as an insect repellent. The chemical compound lauroside B isolated from L. nobilis is an inhibitor of human melanoma (skin cancer) cell proliferation at high concentrations (Panza et al. 2011).

In addition to food and medicinal use of dried Laurel leaves and the essential oils, the trees are used in gardens for decoration as ornamental trees and fences.

Yield

According to forest inventory the laurel tree occupies nearly 131,862 ha of land area and the amount of leaf production is about 12,200 tons per year with an average 92.5 kg per ha. (500kg – 34 kg/ha) in Turkey (Bilgin et al, 2005). According to data available by (OGM 2009), Turkey produced 7,746 tons of bay leaves in 2006, 11,686 tons in 2007 and 7,025 tons in 2008.

An index was developed for estimating the top surface area of the crown; \( Te = Tc \times Tb \) (Te: Crown index, \( Tc \): The radius of the crown, \( Tb \): Length of the crown surface) (Güler and Baş 2005). The same research developed a regression model \( Y = 3,9304x + 2,7778, R^2=0,65 \) to estimate the weight of fresh leaves shoots \((Y)\) based on the crown index \((x)\).
3.3.2.9.3 Silvicultural prescriptions for growing Laurel trees

Timber production

There is scant information regarding the use of its wood for timber production. Wood may be utilized in an informal way for arts and crafts.

Bay leaf production

Laurel tree is generally initiated for leaf production. The tree can be regenerated with plantation, pollarding and cutting (coppice) management regime. The best plantation interval is suggested to be 1.5 x 0.66 m or 2.0 x 1.0 m with nearly 1000 seedlings for an areas of 1000 m² 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 taken at 15-20 cm in length and 0.8-105 cm in diameter. It takes about 12-14 months before the cutting/shoots begin to sprout, thus additional concentrated nutrients solvent is sprayed to the leaves.

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 noting is left on the site. The rest of the cohorts is left for sprouting within the site. For the production of oil 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 et al. 2009). Commercial bay leaf production starts five years after stand initiation (within plantations). Forest managers tend to treat bay laurel either according to their own experience or by using data available. For example, few silvicultural treatments such as regeneration or revitalization cutting, seedling protection, harvesting with tending and plantation were applied to bay stands in different regions of Turkey (9,773 ha, 2007-2013) (Personnel communication with the department of Silviculture in GDF, Turkey).

The value of one kg of fresh leaves is about 1 TL (ca. 0.33€, 2014) while the dried value per kg is about 4-5 TL (approximate prices in 2013) providing certain income to the villages.

Combined timber and NWFP production

While the agro-forestry system is not exercised, it is highly recommended by some researchers particularly in privately owned areas. Further research should be devoted to this field.

Other potential

Bay leaves are occasionally planted to rehabilitate degraded areas. They are used in parks as ornamental trees. The intercropping of the tree has not been reported but may provide some potential within an agroforestry system.

3.3.2.9.4 Summary of key points and knowledge gaps

Drying leaves is extremely important process. Direct exposition to the sun causes reddish and cracked leaves and thus leaf quality degenerates. Furthermore, sufficient aeration is necessary to stop decay and degradation in leaves during the drying process. Extensive grazing and unconscious utilization are common problems or treats to the management of Laurel areas. Separating leaves from branches and classifications by hand causes costs to increase.

Additionally, there is a lack of information on the process of leaf production among the collectors and damage is an ongoing process in the natural sweet bay areas. Most of the leaves are being delivered to the
brokers by local buyers without any cooperation among the villagers resulting in a low level of income. While most of the farmers think of cultivating sweet bay and its production, there is not any standalone bay production model. Thus, cooperation is needed in training and organization,

3.3.2.9.5 Suggestions for new silvicultural prescription for combined timber and NWFP production in Europe utilizing Laurel trees

Bay leaf production combined with other products as a mixed system (such as agro-forestry) instead of allocating the land for only bay culture is suggested to be an alternative silvicultural system. The production based on contract and quota is encouraged too.

3.3.3 Tree dependent products: Wild mushrooms and truffles

3.3.3.1 Introduction

Forest fungi play a key role in forest ecosystem functioning by contributing to nutrient turnover from litter and wood, tree nutrition and carbon sequestration (Peter et al. 2013). The traditional role of fungi on the nutrient cycle has been recently further highlighted since 50 to 70% of the carbon allocated in the soil may be attributable to fungal activity (Clemmensen et al. 2013). Fungi are also an important piece of the diversity puzzle. Approximately, 12,500 fungal species grow in Europe (Senn-Irlet et al. 2007), which means that fungal species richness is higher than in the case of animals or plants. In addition, wild edible fungi are also considered a valuable non-wood forest product throughout the world. Fungal fruitbodies have been traditionally used by different civilizations up to the point that more than 1,100 fungal species are consumed worldwide as food or medicine (i.e., 2,800 species if uses such as cosmetics or toxicology are also considered) (Boa 2004). However, the knowledge on mushrooms and the species used vary among different regions of the world. Based on the significant between-country differences in the utilization of fungal species in Europe, Peintner et al. (2013) defined the countries as mycophilic or mycophobic, and reported a total of 268 fungal species whose trade is authorised by different European legislations. Thus, despite the between-country differences concerning the use of forest fungi, Boletus edulis and Cantharellus cibarius appear in the lists of authorized species in all the European countries analysed. In addition, other epigeous fungal sporocarps such as Lactarius group deliciosus and Craterellus cornucopioides or hypogeous fungal fruitbodies as Tuber magnatum, Tuber melanosporum and Tuber aestivium are highly appreciated in the European markets.

All the aforesaid species are obligate symbionts of forest trees. The symbiotic relationship is established when the fungus colonises the host plant roots in order to form a partner structure named mycorrhiza. Thus, mycorrhizae enhance the capability of host trees to uptake water and nutrients and, in turn, the trees provide the fungi with carbohydrates derived from their photosynthetic activity (Smith and Read 2008). Ectomycorrhizae are the dominant form of mycorrhizal symbiosis in the European forest ecosystems, up to the point that it is very unlikely to find a host tree without this kind of symbiotic relationship (Smith and Read 2008).

Although fruitbodies from ectomycorrhizal fungal species are commonly found in all the European natural forest systems, only a few have been domesticated in order to enable their cultivation. The oldest attempt to cultivate ectomycorrhizal species was done with Tuber species, due to their high economic value. Nowadays, the cultivation of Tuber melanosporum and Tuber aestivium is the most advanced, but the cultivation of Tuber magnatum still represents a challenge. The cultivation trials conducted with other
3.3.3.2 Factors affecting mushroom and truffle production

Mushroom and truffle yield varies greatly from one year to another and, within the same season, from one site to another. According to Ohenoja (1993), weather factors explain about a half of the annual variation in the biomass of ectomycorrhizal mushrooms. The large variation in fungal yield and species distribution among different forest sites (Mehus 1986; Bonet et al. 2004; Martínez-Peña et al. 2012) makes it difficult to quantify the mushroom and truffle productivity. Thus, the monitoring of permanent inventory plots during many years is usually necessary in order to have reliable estimations of the fungal yield in a given forest ecosystem. In addition to the difficulty of conducting long-term mushroom inventories, a wide range of factors have an influence on the production of fruitbodies. These factors can be classified into three main groups (Martínez-Peña et al. 2012): (a) local site characteristics (e.g., altitude, slope, aspect); (b) stand structure (e.g., tree species, stand density, stand age); and (c) weather variables (e.g., precipitation, temperature).

However, only those variables related to the stand structure can be modified through forest management in order to propose fungal-oriented silvicultural recommendations. The large amount of potential variables related to mushroom productivity and their interdependence makes it difficult to give clear recommendations for managing mushroom yields. Therefore, systematic quantitative analyses based on permanent and experimental plots are required in order to inspect the effect of different variables on fungal yield.

3.3.3.3 Silvicultural prescriptions for wild mushrooms and truffles

To our knowledge, the potential differences in fungal productivity arising from the application of different silvicultural methods have not been studied in depth so far and only partial knowledge is available. Stand age has an influence on the species composition of the fungal community as well as on the fungal yield (Bonet et al. 2004; Martínez-Peña et al. 2011; Martínez-Peña et al. 2012; Miina et al. 2013) (see Figure 3.16). Previous research (Dighton and Mason 1985; Strullu 1991; Frankland 1992) has reported differences in fungal dynamics according to different host-tree ages by distinguishing between early-stage fungi (i.e., more common in young forests) and late-stage fungi (i.e., more common in mature stands).

Stand basal area also affects mushroom yield (Bonet et al. 2008, 2010; Martínez-Peña et al. 2012; De-Miguel et al. 2014) (Figure 3.17). Furthermore, fungal species can be defined as either generalists (i.e., if they can establish mycorrhizal associations with different tree species and under a wide range of growing conditions) or specialists (i.e., if they are specific to a given tree species or to a particular range of growing conditions). Accordingly, the modification of the rotation length, stand basal area or tree species composition through forest management is expected to have an impact on fungal dynamics. Similarly, differences in fungal diversity and productivity may arise from applying either even-aged or uneven-aged forest management methods. The fact that forests stands usually host high fungal diversity (Horton and Bruns 2001; Buée et al. 2009), which is also driven by weather and site conditions, prevents drawing general conclusions about the preference for a given silvicultural method in terms of mushroom productivity.
Figure 3.16 Mean annual yield (kg ha⁻¹ a⁻¹) of edible mushrooms in Norway spruce forests in North Karelia, Finland by stand age classes (Miina et al. 2013).

Figure 3.17 Relationship between the annual yield of Boletus edulis and stand basal area in North-Central Spain (Martínez-Peña et al. 2012).

3.3.3.4 Intermediate treatments (thinning and tending)

- Forest thinning

Forest thinning aims at managing the competition among trees by removing some individuals in order to favour the development of the remaining trees. After tree removal, the remaining trees can increase their photosynthetic activity and allocate more carbohydrates to their root system, which is beneficial for the mycorrhizal fungal species. Other factors such as microclimatic changes in the soil layer and soil
disturbance arising from forestry operations may also affect both productivity and composition of fungal species (Bonet et al. 2012).

Although several studies have reported higher mushroom productivity in thinned stands (Sjöblom et al. 1979; Kirs and Oinonen 1981; Shubin 1986; Ohenoja 1988; Egli et al. 1990), other authors (Kardell and Eriksson 1987) have not found such differences. Indeed, forest thinning may affect the productivity of individual fungal species. For instance, Egli and Ayer (1997) and Egli et al. (2010) reported an increase in Cantharellus cibarius production after forest thinning in Switzerland, whereas Bonet et al. (2012) found an immediate positive effect of thinning on the yield of Lactarius group delicious (Figure 3.18). On the other hand, other studies have observed an initial negative thinning reaction of mushroom yield with a subsequent recovery of the productivity after 3 to 6 years (Pilz et al. 2006; Egli et al. 2010). This apparent contradiction may probably arise from differences in soil disturbance caused by forest harvesting operations, which was minimal in the experiment conducted by Bonet et al. (2012).

![Figure 3.18 Immediate effect of thinning on Lactarius group delicious yield in Catalonia, North-Eastern Spain. Thinning treatment was done in August 2009 (Bonet et al. 2012).](image)

- **Pruning**

Theoretically, pruning techniques may have an impact on mushroom productivity if the removal of living branches affects significantly the total photosynthetic activity of the tree. However, such an assumption is just based on theoretical considerations, since no experiments have been carried out so far.

So far, the only fungi for which the pruning of the host trees is recommended are Tuber species. For the first years of the plantation tree pruning is carried out primarily for correcting structural defects (Sourzat 2002) and for developing the desirable tree form in order to create favourable conditions for truffle development (Ricard 2003). Formation pruning or early training aims at attaining a tree with the shape of an inverted cone or oval shape thereby eliminating lower branches and basal sprouts. This increases the amount of light that reaches the ground and provides additional space for installing an irrigation system, which may increase the efficiency of truffle collection in the future (Reyna 2012). Formation pruning may
begin in the third year depending on the vigour of the plant and should be of low intensity (Bonet et al. 2009).

- Weed and shrub control

Weed and shrub control is only considered as a normal practice in truffle plantations. During the first 2 to 4 years after plantation it is important to keep the area around the plants free of weeds by using manual hoes (Bonet et al. 2009) or mulches (Olivera et al. 2014). This is supposed to increase the survival rate of the host trees by eliminating competition for water and nutrients while increasing the proliferation of mycelium. In the rows between each plant the land should be cultivated with tools that can be controlled for depth to a depth no greater than 15-20 cm (Reyna 2012).

Once the characteristic burnt area provoked by the black truffle activity appears, some landowners further control weed growth by means of a mechanical tools. The weed control is carried out with depth-control tines to a depth not greater than 10 cm, which also helps to aerate the soil.

- Regeneration methods

Generally, the number of fungal species increases with stand age, most pronouncedly until canopy closure, and the fungal community composition stabilizes at the stand reinitiation stage (Dahlberg 2001; Twieg et al. 2007). Differences in colonisation strategies, use of the available water and nutrients, and competitive abilities of different fungi contribute to explaining the aforesaid dynamics. Some fungi are able to rapidly colonise a site after disturbance by spores or resistant propagules, whereas others need an intact mycorrhizal network that connects them to another tree for colonisation (Peter et al. 2013). After disturbances such as clear-cuts, these patterns are most pronounced when no stumps and living roots are left over, from which mycorrhizal fungi could recolonise new roots (Peter et al. 2013). The negative effect of clear-cutting on mushroom productivity (at least on the productivity of mycorrhizal origin) has been documented (Kardell and Eriksson 1987; Ohenoja 1988). However, the potential inoculum in the soil of a clearcut area may be rather similar to the adjacent forest area (Harvey et al. 1980; Dahlberg and Stenstrom 1991; Le Tacon 1997). At the development stage of young thinning stands, mushroom productivity has been found to be recovered (Hintikka 1988). When such vital adult trees are present, as in the case of shelterwood methods (which can be also regarded as a high intensity forest thinning), the mycorrhizal fungal diversity is much higher than in clearcut stands (Peter et al. 2013), since the remnant trees function as a fungal reservoir, which allow to colonize the tree regeneration.

- Other techniques – fertilization

Previous research has observed a positive effect of sporadic fertilization on mushroom dynamics (Hora 1959; Kutafyeva 1975), although other studies have reported a decrease in mycorrhizal productivity and diversity in the third or fourth year after the continuous application of fertility (Termorshuizen 1993; Ohenoja 1989; Cox et al. 2010; Lilleskov et al. 2011). Since ectomycorrhizal symbiosis is generally regarded as an adaptation to conditions of nitrogen (N) scarcity, when N availability increases, trees allocate less carbon to the roots and mycorrhizal partners and more to the aboveground biomass (Peter et al. 2013). Based on these assumptions, Olivier et al. (2012), recommend fertilization of black truffle plantations only if the soil has an exceptionally low concentration of a particular nutrient in order to compensate for such a deficit. However, one common practice in areas with low pH is to gradually add slow-release calcareous corrections with CaCO3 before cultivating the land.

- Other techniques – irrigation

Irrigation is not a common practice in forest stands, although a positive effect on mushroom yield might be expected (e.g. Wiklund et al. 1995; Sarjala et al. 2005; Salo 2007). In black truffle plantations, regular
watering is recommended during the first years until the root system is well established and, later on, in the productive phase in order to stabilize the annual fluctuations in truffle yield caused by changes in the weather conditions (Olivier et al. 2012). However, similarly to the above-mentioned effect of fertilization, an excess of water could cause a decrease in the amount of black truffle (Bonet et al. 2006; Olivera et al. 2011). Recent studies (Olivera et al. 2013) highlighted the need for introducing a moderate irrigation dose in order to increase the presence of Tuber melanosporum. Accordingly, they recommend complementing natural precipitation up to 50% of the evapotranspiration during the first half of the growing season and allowing for some slight water stress before the autumn rains.

### 3.3.3.5 Key points and gaps in knowledge

- The improvement of mushroom yield relies on the maintenance of the mycorrhizal symbiosis. Since the “comfort zone” of this symbiotic interaction is sometimes quite narrow and complex, both the host tree and the target fungi need to be taken into consideration.
- Since fungal diversity is huge, fungal species have their own strategies (e.g., generalists vs. specialists) and fungal succession occurs as forest stands develop, oversimplifications and too general recommendations should be avoided.
- Moderate thinning of fully-stocked stands could have a positive effect on mushroom yield
- Continuous cover forestry might be better than clearcutting regeneration methods in order to avoid sharp fluctuations in mushroom productivity at the stand level.
- Fertilization should be restricted to specific sites and occasions.

**Further research based on the gaps in knowledge:**

- The factors affecting mushroom emergence need to be further understood. Besides the effects of site, stand and weather variables on mushroom yields, also the interaction of these variables needs to be clarified.
- Long-term effects of forest management practices need to be monitored and analysed. Forest management practices which favour mushroom yields need to be identified.
- Besides Tuber species, (semi)cultivation with other ectomycorrhizal species needs to be studied.

### 3.3.4 Forest understory products

#### 3.3.4.1 Bilberry (Vaccinium myrtillus L.)

Bilberry (Vaccinium myrtillus L.) is typical and abundant in conifer-dominated forests of medium fertility in northern Europe. Berry production fluctuates annually with weather conditions. The most critical phase is the period of flowering and pollination in spring; a warm, sunny and frost-free period is needed for a good berry yield.

Bilberry is one of the economically most important wild berry species in Finland, Sweden and Norway, where it is widely collected for both household consumption and sale (see Figure 3.19). In Finnish forests, the total bilberry crops vary from 90 to 310 million. In a good year, the bilberry yield may be about 300 million kg, but only 5–6% of that is picked annually. In 2012, the amount of bilberries offered for sale was 6.8 million kg in Finland, and the average market price paid to pickers was 1.80 €/kg.
The coverage and yield of bilberry is mainly affected by site conditions, but also silvicultural operations affect the berry yields. Bilberry suffers from regeneration fellings, is sparse in seedling and sapling stands as well as in dense and shaded young thinning stands. A moderate supply of light is needed for the good berry production. In pine-dominated stands, the coverage of bilberry is higher than that in stands dominated by spruce or deciduous trees. Especially in spruce stands, the bilberry yield decreases heavily when the stand basal area exceeds a certain level. To increase the bilberry yields, longer rotation lengths, higher thinning intensities, more frequent thinnings, and higher share of pine in mixed stands could be applied in even-aged management system. Uneven-aged management could be better with respect to bilberry yields especially in spruce stands. In the uneven-aged management of spruce stands, the stand basal area will be constantly at a level that enabled good berry yields. The joint production of timber and bilberry can be optimised by using a stand simulator together with bilberry yield models.

3.3.4.1.1 Growth and reproduction of bilberry

Bilberry (dwarf bilberry, blueberry, mountain bilberry, European blueberry, whinberry, whortleberry, whortles, myrtle whortleberry, tracleberry, huckleberry) is found in most of Europe, but only on mountains in the south (e.g. Nestby et al. 2011). It is one of the most frequent and abundant vascular plant species in acidic (pH < 4), relatively nitrogen-poor (C/N ratio > 30) podsol soils in northern Europe, and thus is an important species in the understorey vegetation of conifer ecosystems (e.g. Ritchie 1956; Kuusipalo 1983; Mäkipää 1999; Salemaa 2000; Coudon and Gégout 2007; Nielsen et al. 2007). Bilberry is a low-growing, perennial dwarf shrub in the genus Vaccinium (family Ericaceae), yielding edible, dark-blue berries.

Bilberry is a clonal plant and growing by ramets from a belowground rhizome (Tolvanen and Laine 1997). The age of ramets is typically between 6–15 years, the oldest ones were 30 years old (Rixen et al. 2010).
Bilberry is a deciduous shrub which reaches 10–40 cm in height. The plant reproduces most commonly by vegetative means but also from seed. Pollination is by insects, mainly bees. Bilberry is a major source of food for many herbivores. Berries, leaves and shoots are eaten by many birds and mammals including gallinaceous birds, voles, ungulates and especially brown bear whose diet consists mainly of wild berries in late summer.

In general, pests or diseases rarely cause any serious damage to bilberry; the prevailing weather conditions (e.g. spring frost i.e. temperatures < -3 °C, summer draught) are more important factors controlling annual berry yields. After frost damage, vegetative recovery is rapid, but sexual reproduction may need accumulation of resources for many seasons (Tolvanen 1997). In 2010, Acleris larvae were observed to feed bilberry shoots in some areas in eastern Finland. Based on the permanent sample plots, larvae feeding decreased the number of bilberries by 20–30 % (Kauko Salo, personal communication). However, damage caused by larvae was local and had only a negligible effect on bilberry yields. Phytophthora ramorum fungus is considered to be an important new pathogen infecting bilberry in Europe (Herrero et al. 2011). The fungus has spread to Europe and it has many host plants. In Scotland, Wales and along the west coast of Norway this algae fungus has been found on bilberry. Infected bilberries display necrotic lesions on shoot tips, branching points and around leaf abscission scars.

Manninen and Peltola (2013) found that the berry production of bilberry was not affected by damage caused by any of the picking methods (e.g. long-handed metal rakes). Even the powerful metal raking did not result to diminished berry production.

In Finland, bilberry is typical and abundant in spruce- and pine-dominated heath forests of medium fertility (Salemaa 2000; Turatiainen et al. 2007; Miina et al. 2009). Bilberry also occurs and produces yields in many marginal types of forest, and on pristine and drained peatland sites. It is also known that bilberry thrives on poorer soils in northern Finland than in southern Finland. The coverage on less fertile sites should increase towards the north due to the more humid climate and increasing soil moisture (Kardell 1980; Salemaa 2000).

It has been noted that the coverage of bilberry has decreased, on average, in Finnish and Swedish mineral soil forests due to e.g. intensive forestry with clear-cuttings and soil preparation (Salemaa 2000; Dahlgren and Fridman 2012). Consequently, the proportion of young forests has also increased which has led to a more even distribution of the different age classes and had a negative effect on the abundance of bilberry. However, in more humid conditions in south-central Norway, the growth and reproduction of bilberry is not negatively affected by clear-cutting (Nybakken et al. 2013). On the other hand, on Finnish drained peatlands the coverage of bilberry is increasing along with the post-drainage succession phases, meaning for example that the coverage of Sphagnums is decreasing and that of vascular plant species is increasing (Salemaa 2000).

The site type significantly affects the coverage of bilberry. The highest coverage is found on mesic heath sites, i.e. in the Myrtillus type group (e.g. Salemaa 2000; Miina et al. 2009). Bilberry is also abundant in sub-xeric and herb-rich heath stands; the coverage values were 62 % of that for mesic heath stands. On sub-xeric, and especially on xeric sites, bilberry probably suffers slightly from a shortage of water, whereas in fertile herb-rich heath and especially herb-rich forests, competition from grasses and herbs limits its abundance (Kuusipalo 1983). Manninen et al. (2009) found that the growth of slow-growing Vaccinium species is not limited by nitrogen availability in boreal forests. In their experiments, nitrogen fertilization decreased the biomass of bilberry and benefited grasses, and thus increased the competition from grasses.

The bilberry abundance increases along with secondary succession; i.e. the coverage is the higher, the higher the age and basal area of the stand up to certain limits; after which the effect of stand age and basal
area gradually decreases (Salemaa 2000; Dahlgren and Fridman 2012). Bilberry suffers from clear-cuttings and subsequent soil preparation in extensive areas of Fennoscandia (e.g. Tälvänen 1994, Atlegrim and Sjöberg 1996a, 1996b; Salemaa 2000; Bergstedt and Milberg 2001; Nielsen et al. 2007). During the first decade after clear-cutting in Sweden, the coverage of bilberry was about 70 % lower than the situation before the final felling; clear-cutting combined with soil preparation decreased the abundance by 80 % (Kardell and Eriksson 1990). Consequently, bilberry is sparse in seedling and sapling stands as well as in dense and shaded young thinning stands (e.g. Kardell 1980; Salemaa 2000; Miina et al. 2009). In direct seeded and planted stands, bilberry is not as abundant as in naturally regenerated stands, where the light conditions are more suitable for bilberry and soil preparation is not so intensive.

The tree species composition also has an effect on the coverage of bilberry (Kühlmann et al. 2001; Miina et al. 2009). In the pine-dominated stands, the coverage of bilberry is higher than that in stands dominated by spruce or deciduous trees. In fertile, well-lighted deciduous forests, herb and grass vegetation is the predominant understorey vegetation. The proportions of pine, spruce and deciduous trees affect the light conditions in the field vegetation layer. It seems evident that a moderate supply of light is an essential factor affecting the abundance of bilberry (e.g. Salemaa 2000; Nielsen et al. 2007). Hence it follows that, in pine-dominated forests in Finland, bilberry may be the predominant species and a good competitor, and have a strong effect on all the vegetation. In spruce forests, more shade-tolerant herbs and other plants, and in well-lighted deciduous forests, herbs and grasses may gain benefit from the lower competitive ability of bilberry. Thus, even if the site quality is equal, the abundance relationships between bilberry and other components of the field layer vary over wide ranges.

3.3.4.1.2 NWFP product characteristics, yield and utilisation

Berry production fluctuates annually with weather conditions (Kardell and Eriksson 1990; Wallenius 1999; Selås 2000; Miina et al. 2009). For example, spring frosts damage flowers and threaten pollination by bees, and summer droughts damage unripe berries. Bilberry is sensitive to high temperatures in the preceding autumn. Bilberry yield is typically good in favourable, warm and moist years, but also during bad years bilberries can be found from the most favourable places. In addition, the buds of bilberry are vulnerable to damage by low winter temperatures. Thus, bilberry shoots require a layer of snow thick enough to allow a good bilberry yield during the next summer.

Bilberry is one of the economically most important wild berry species in Finland, Sweden and Norway (e.g. Kardell 1980; Salo 1995; Saastamoinen et al. 2000; Kangas 2001). Bilberry is widely collected for both household consumption and sale. A hand rake is used to harvest berries (Manninen and Peltola 2013). The picking of wild berries is of great economic significance to many regions in Finland due to the right of public access to all forest land (e.g. Kangas 2001; Turtiainen et al. 2011). In addition, the income earned from the sale of e.g. wild berries, herbs and mushrooms is tax-free in Finland.

It has been estimated that the total bilberry crop in Finnish forests in a good year may be about 300 million kg (on average, 180 million kg), but in a poor year considerably lower (Turtiainen et al. 2011). In 1997–1999, Finns have picked 5–6 % of the total annual crop for domestic use and commercial sale (Turtiainen et al. 2011). During the recent years, commercial wild berry picking by foreign pickers has most probably affected the utilisation rate of wild berries in Finland.

In 2011, 48 % of all Finnish households were engaged in bilberry picking and the total harvest was 14.3 million kg (5.7 kg/household) (Vaara et al. 2013). Bilberries were collected mainly for household use (87 %); the share of commercial picking was only 13 %.

Based on the latest statistics on the amounts of bilberries offered for sale was 6.8 million kg in 2012 in Finland (MARSI 2012). The average market price paid to pickers was 1.80 €/kg for non-cleaned and 2.90

**Description of existing silvicultural systems**
€/kg for cleaned bilberries. Wild berries are commonly picked also for domestic use which is not included in these statistics.

Only about 5–10% of the annual bilberry yield is picked in the Nordic forests every autumn. Thus, it seems that there are a lot of bilberries to be utilised in household consumption and industry. However, the large variation in annual berry yields causes problems, especially for the berry industry. In poor berry years, the lack of berries raises prices in the international market, and there is a risk that international customers will buy raw material from other countries also in the following years (Paassilta et al. 2009). Also the quality of berries varies between years according to weather conditions during the growing and picking season.

Another problem is how to increase berry picking, as well as supply and utilisation of bilberries in the Nordic wild berry sector (Paassilta et al. 2009). The sector is rather heterogeneous and most companies are small and medium-sized. A special emphasis should be given to increasing and strengthening cooperation among the berry sector’s actors at both national and international level. The targets of cooperation could be on e.g. berry supply, logistics, marketing, research and development.

It has been estimated that 20% of the annual bilberry yields could be utilised, if berry picking was organised more efficiently. The main part of increased berry supply would be used by the berry industry. That would ensure the industry more reliable access to raw material, possibilities to develop new berry products and tighter the relationships with customers (Paassilta et al. 2009).

In the Nordic countries, there are hundreds of companies in the wild berry sector (Paassilta et al. 2009). Many of them just buy berries from pickers and sell fresh berries at the local market or to larger companies. Some food companies use the berries to make jam, juices, yogurt, etc. However, the largest amount of fresh wild berries is gathered by a small number of companies, which clean and freeze them and sell the frozen berries to national and international industrial customers.

On the international markets, bilberry is competing with cultivated blueberries (Vaccinium corymbosum and V. angustifolium) coming from the US and Canada. In general, blueberry/bilberry is the most well-known functional berry and consumers make no difference between blueberries and bilberries. However, bilberry has gained more interest in e.g. China and Japan due to its higher amounts of bioactive compounds, and thus better health-promoting properties. For example, bilberry contains exceptionally high amounts of anthocyanins (over 500 mg/100 g) compared to cultivated blueberries (less than 200 mg/100 g) (Törrönen et al. 2008).

3.3.4.1.3 Silvicultural prescriptions for growing bilberries

In the Nordic countries, forest management is multifunctional so that the aim is to produce high-quality raw material for forest industry and simultaneously to safeguard the biological diversity of forests and the potential for the non-wood forest products and services (Yrjolä 2002). Due to a high number of private forest owners and their widely differing needs and expectations as well as relatively small-scale variation in site characteristics, forested landscape is fragmented and mosaiclike. The three economically most important tree species growing in the Nordic counties are Scots pine (Pinus sylvestris), Norway spruce (Picea abies) and birch (silver birch, Betula pendula and downy birch, B. pubescens).

In boreal zone, forests are typically managed as stand-based and even-aged. Depending on the tree species, geographical location and site characteristics, the recommended rotation period varies from 60 to 130 years. The average diameter of trees is typically 25–30 cm at breast height. Earlier, uneven-aged management systems have been applied only at special sites, such as landscape areas and forests dedicated for recreational use. Since 2014, uneven-aged forest management can be applied in all kind of...
forests in Finland. However, uneven-aged forest management will not be applied widely and it seems to be most feasible in spruce forests on sites of medium fertility (i.e. mesic site).

Seedling stands are managed by cleaning and thinning. Commercial thinnings are done 1–3 times during the rotation period; each thinning removes about 30 % of the growing stock. For natural regeneration, seed or shelterwood trees are left standing to seed the site; natural seeding may take place by trees on the forest edge surrounding small regeneration areas. Artificial regeneration by seeding or planting is needed if there are no possibilities for natural regeneration. The success of regeneration and early development of seedlings is ensured by mechanical soil preparation. The majority of Finland’s current forests have regenerated naturally. About 35 % are planted or artificially seeded, but also in those stands a varying amount of trees is naturally regenerated.

The coverage of bilberry is mainly affected by site type, and there are no major differences between pine, spruce and birch stands on the same site type (Salemaa 2000; Miina et al. 2009). Some studies indicate that the coverage and yield of bilberry are higher on sunny than on shady growing conditions (Kuusipalo 1983; Atlegrim 1991). The coverage is the higher, the higher the age and basal area of the stand up to the age of 191 years and a density of 25 m2/ha, after which the coverage gradually decrease (Miina et al. 2009). Stand density affects even more on bilberry yields. The yield of bilberry is the higher, the higher basal area of the spruce stands up to a density of 14 m2/ha, after which the berry yield strongly decrease with increasing stand basal area. According to Raatikainen et al. (1984), the highest berry yields are found in mature conifer stands with the canopy coverage between 10–50 %.

Thinnings increase temporally the coverage of bilberry by decreasing the stand density and thus increasing the amount of light in forest ground. The coverage is slightly higher in the stands in northern Finland than in southern Finland due to the lower stand density in northern Finland. This indicates that both growth and reproduction of bilberry are limited by light in dense forests, especially in dense spruce forests (Miina et al. 2009).

Based on simulations conducted by using the bilberry models (Miina et al. 2009), on mesic heath sites in southern Finland the annual bilberry yields increase with increasing stand age and reach the level of 20 kg/ha after the first thinning in a pine stand and 10 kg/ha in a spruce stand. In a mature spruce stand, the bilberry yield decreases heavily when the stand basal area is above the optimal level (14 m2/ha), and increase temporarily when the stand is thinned. In a pine stand, stand basal area affects the bilberry yield only slightly. At the end of rotation period, the annual yield of bilberry is about 25 kg/ha in a pine stand and about 10 kg/ha in a spruce stand. Taking into account the annual variation in the bilberry yields, the 95 % confidence interval of these figures is 9–73 kg/ha in a mature pine stand and 3–35 kg/ha in a mature spruce stand.

The between-year variation in the number of bilberries has been studied using the permanent sample plots (so called MASI data) measured by Metla in 2001–2007 in different parts of Finland (Miina et al. 2009). According to the MASI data, the bilberry yield in pine stands has been two times higher than that in spruce stands. Also, the between-year variation in bilberry yields in spruce stands was 1.5 times higher than in pine stands.

Bilberry yield models developed by Miina et al. (2009) has been included in a stand growth simulator and the joint production of timber and bilberry has been optimised by maximising soil expectation value (SEV) with 3 % discounting rate, and assuming that 75 % of the bilberry yield is harvested (Miina et al. 2010). The effect of bilberry production on the optimal stand management increases with increasing price paid for berry pickers. With a relatively high bilberry prices (4–8 €/kg) it is optimal to manage mixed stands of pine, spruce and birch, and pure spruce stands so as to promote bilberry production. In pine stands, where
bilberry yields are higher, bilberry production affects optimal stand management already with a price of 2 €/kg, which corresponds to the average price of bilberries offered for sale in Finland. Compared to wood production, joint production leads to longer rotation lengths, higher thinning intensities, more frequent thinnings, and higher share of pine in mixed stands. The contribution of bilberries to the total SEV increases with increasing bilberry price and discounting rate. In mixed stands and pine stands the SEV of bilberry production, calculated with 3% discounting rate, exceeds the SEV of timber production when bilberry price is 4 €/kg. With 4% discounting rate this happens already with bilberry price of 2/€ kg. As a conclusion, forest management which promotes bilberry yields is the most profitable in pine stands where the potential bilberry yields are high.

Pukkala et al. (2011) have compared even-aged and uneven-aged forest management systems in spruce and pine stands in terms of timber and bilberry benefits. Management was optimized by maximizing the total net present value (NPV) of these benefits in a steady-state situation. Uneven-aged management is better with respect to bilberry benefits (NPV of bilberry harvesting). Especially in spruce stands, the bilberry yield is very sensitive to the management system so that the optimal uneven-aged management yields far more bilberries than the current even-aged management. In the current even-aged management of spruce stands, bilberry yields are good for a few years. First, spruce stands are too young and the stand basal area is too low, and then the stand basal area is too high for good bilberry yield. In the optimal uneven-aged management of spruce stands, the stand basal area will be constantly at a level that enabled good berry yields. Differences in bilberry yields of pine forests were minor.

The main objective of forest management in Finland is to optimise the timber production. However, both industrial and non-industrial forest landowners give increasing weight on non-wood forest products and services, for instance wild berries. A profit-oriented forest owner considers in forest management only those products for which she can expect a market price. Both timber and bilberries are assumed to have a market price also in the future, but in Finland people have the right to gather wild berries and utilize them, regardless of the ownership, as a source of income (so called everyman’s rights). Therefore, it is not guaranteed that a private forest owner can herself harvest the bilberry yield of her forest. So far, there are no initiatives to charge fees to bilberry pickers or to restrict the right of public access. Therefore, bilberry is an externality produced by private forest, and above results should be taken as social optima.

To date wild bilberries are collected from forests, but in Nordic countries there are some attempts to semi-cultivate V. myrtillus in the similar way as blueberries in the North America (Åkerström 2004; Martinussen et al. 2009; Nestby et al. 2011; Vanhanen et al. 2012). An agroforestry system or forest fields with a combination of timber and understory bilberry production could have potential for future V. myrtillus cultivation.

3.3.4.1.4 Summary of key points and knowledge gaps

Bilberry is frequent and abundant species in the understorey vegetation of conifer ecosystems in northern Europe. The coverage of bilberry has decreased, on average, in Finnish forests due to intensive forestry with clear-cuttings and soil preparation. The highest coverage is found on mesic heath sites and corresponding peatlands (the Myrtillus type group). In pine-dominated stands, the coverage of bilberry is higher than that in stands dominated by spruce or deciduous trees.

Berry production fluctuates annually with weather conditions; especially spring frosts may damage flowers and summer droughts unripe berries. Bilberry is widely collected for both household consumption and sale, but it has been estimated that only about 5–10% of the annual bilberry yield is picked in the Nordic forests. A lot more of bilberries could be harvested and utilised in household consumption and industry. It has been
estimated that 20% of the annual bilberry yields could be easily utilised, if berry picking was organised more efficiently.

In the Nordic countries, the availability of bilberries may be a problem only in poor berry years and locally in certain forests. Bilberries are picked efficiently from the forests that are easily accessible for people and where the potential bilberry yields are known to be high, for instance in mesic heath pine stands and pine-spruce mixtures located near urban centres. Some simulation-optimisation results are available on the effects of different forest management systems and schedules on the joint production of timber and bilberries. In public and communal forests, the results obtained can be utilized directly for developing optimal management prescriptions.

Preliminary calculations suggest that uneven-aged management could favour the bilberry yields especially in spruce forests compared in the even-aged management system currently applied in northern Europe.

3.3.4.1.5 Suggestions for new silvicultural prescription for combined timber and bilberry production in Europe

In conifer forests on mesic heath sites and corresponding peatlands, some changes to the current even-aged management practices are recommended to promote the joint production of timber and bilberries. More frequent and heavier thinnings that remove especially spruces are needed to reduce canopy shading to a level that is favourable for bilberry. In addition, 10–20 years longer rotation lengths are recommended because the bilberry yields are highest in mature stands. In the optimal uneven-aged management of spruce stands, the stand basal area will be constantly at a level that enabled good berry yields. The simulation studies conducted so far suggest that in the future when the uneven-aged management system is more commonly applied in boreal conifer forests, the potential bilberry yields will be higher than under the current even-aged management system.

3.3.4.2 Cowberry (Vaccinium vitis-idaea)

Cowberry (Vaccinium vitis-idaea L.) is an abundant evergreen understorey plant in conifer-dominated forests on nutrient-poor mineral soil sites in northern Europe. This species has adapted to a wide range of different site and land types in coniferous ecosystems and, therefore, is widely distributed in different parts of Europe and in northern Asia. In Finland, cowberry is at its most typical in light pine-dominated dryish heath forests.

Cowberry is one of the economically most important wild berry species in Finland, Sweden and Norway, where it is widely collected for both household consumption and sale. In Finland, it provides annual crops varying from 130 to 390 million kg. From the annual crop, less than 10% is picked. In 2012, the amount of cowberries offered for sale was 8.7 million kg in Finland, and the average market price paid to berry pickers was 1.30 €/kg.

The abundance and yield of cowberry are mainly affected by site conditions, but also silvicultural operations affect strongly the berry yields. Thought cowberry is shade tolerant and well adapted to grow under a tree canopy, a good supply of light is needed for good berry production. Cowberry suffers from regeneration fellings combined with soil preparation. However, the best yields are obtained few years after regeneration cutting in dryish heath pine forests. The cowberry yield is at its highest in the beginning of the forest rotation in seed-tree stands and in small seedling stands, where plants produce high yields around tree stumps. The cowberry yields are low in dense and shaded stands. To increase the cowberry yields, longer rotation lengths, higher thinning intensities and more frequent thinnings could be applied in even-aged management system. In soil preparation, less intensive methods could be applied not to severing the rhizome connections and thus protecting ramets growing from a belowground rhizome.
3.3.4.2.1 Growth and reproduction of cowberry

Cowberry (lingonberry) is one of the most abundant dwarf-shrubs in the boreal regions of northern Europe, but also in the mountainous areas of central Europe. Cowberry is a low-growing, perennial understorey plant in the genus Vaccinium (family Ericaceae), yielding edible, red berries. It is widespread both in the understorey of conifer forests and in treeless open habitats (Mäkipää 1999; Salemaa 2000). Mäkipää (1999) has reported very similar ecological optima for bilberry (Vaccinium myrtillus) and cowberry along gradients of soil N- and P-contents in Finnish forests (e.g. acidic, relatively nitrogen-poor podsol soils).

Cowberry is a clonal plant and growing by ramets from a belowground rhizome (Tolvanen and Laine 1997). The age of ramets is typically between 3–6 years, the oldest ones were 10 years old (Salemaa 2000). Cowberry is an evergreen shrub which reaches 10–30 cm in height (Ritchie 1955). The plant reproduces through seed and by vegetative means being of primary importance. Pollination is by insects, mainly bees. Berries, leaves and shoots are eaten by many birds and mammals.

Pests or diseases rarely cause any serious damage to cowberry (e.g. Pehkonen and Tolvanen 2008) the prevailing weather conditions (e.g. spring frost and summer drought) are more important factors controlling annual berry yields. Cowberry flowers in June, two weeks later than bilberry, and thus the risk of damage by spring frost is low and there are pollinating insects present. Also, as an evergreen plant it is relatively tolerant against dry periods in summer, though its growing sites are vulnerable to drought.

In Finland, the habitats of cowberry include xeric, sub-xeric and mesic heath forests, but it is common also on pine mires (e.g. Raatikainen 1978; Turtiainen et al. 2007) and heaths on fell tops. On drained peatlands, the coverage of the species increases along with the post-drainage succession phases. During the recent decades, the average coverage of cowberry has declined from 16 % to 6 % (Salemaa 2000). In Sweden on mineral soil forests, no such decrease in the average coverage of cowberry has been observed (Dahlgren and Fridman 2012). Clear-cuttings combined with soil preparation as well as increased stand density and proportion of young forests has negative effects on the abundance of cowberry (Salemaa 2000). Thought there are large and rapid decreases in the biomasses of the dwarf shrubs (e.g. V. myrtillus and V. vitis-idaea) after cutting, values returned to their initial levels in 3–4 years (Palviainen et al. 2005, see also Bergstedt and Milberg 2001).

According to Kardell and Eriksson (1990), during the first decade after clear-cutting, the coverage of cowberry was about 30 % lower than the situation before the final felling. Clear-cutting combined with soil preparation decreased the abundance by 40 %. Cowberry suffers from regeneration cuttings and soil preparation less than bilberry: cowberry adapts better to new conditions and recovers from such disturbance within a few years. However, competition by herbs and grasses cannot be too severe at the beginning of stand rotation.

The site type significantly affects the coverage of cowberry (e.g. Turtiainen et al. 2013). The highest coverage can be found on sub-xeric heath forests and oligotrophic spruce mires. Cowberry is also abundant on xeric and mesic heath forests; the coverage values were about 66 % of that for sub-xeric heath forests. On more fertile sites, competition from grasses and herbs limits its abundance (Salemaa 2000).

The cowberry abundance increases along with secondary succession; i.e. the coverage is the higher, the higher the age and basal area of the stand (Salemaa 2000, Dahlgren and Fridman 2012, Turtiainen et al. 2013). The coverage decreases temporarily after thinnings. Tree species composition has a significant effect on the abundance of cowberry. On mineral soils and spruce mires, the coverage of cowberry was higher in pine-dominated stands than in stands dominated by spruce or deciduous trees (Turtiainen et al. 2013). The priority of pine over other tree species is not a surprise since the best cowberry sites are mainly pine-dominated in the Finnish forests.
3.3.4.2.2 NWFP product characteristics, yield and utilisation

Cowberry is the economically most significant wild berry species in Finland (MARSI 2012). It also provides the most abundant annual crops, on average, 260 million kg, varying 130–390 million kg depending on the crop level of the year (Turtiainen et al. 2011). Cowberries are picked for both household use and sale. In 2011, 34 % of all Finnish households were engaged in cowberry picking and the total harvest was 16.1 million kg (6.5 kg/household) (Vaara et al. 2013). Cowberries were collected mainly for household use (64 %); the share of commercial picking was 36 %. A hand rake is used to harvest berries (Manninen and Peltola 2013).

Berry production fluctuates annually with weather conditions (Raatikainen 1978, 1984; Wallenius 1999). According to Turtiainen et al. (2013), in a seed-tree Scots pine stand located in southern Finland, the mean annual cowberry yield is about 75 kg/ha, but the 95% confidence interval of that is as wide as 25–234 kg/ha. After the regeneration phase of stand development (between the ages of 5 and 30 years), the crop level decreases strongly with increasing stand basal area (see also Raatikainen et al. 1984), after which it is relatively constant and increases only temporarily after thinnings. According to empirical studies, at the end of the rotation period sparse mature pine stands are again more suitable for cowberry collection than young and advanced thinning stands (e.g. Raatikainen 1978, 1984; Eriksson et al. 1979; Jäppinen et al. 1986; Ihalaisten et al. 2003).

In dense pine stands, cowberry yields may remain low though the coverage of cowberry would be high. Raatikainen et al. (1984) found that cowberry produces the highest crops when the crown cover of trees is less than 40 %. They also found that when the crown cover exceeds 40 %, the cowberry production decreases. Though Raatikainen et al. (1984) found a strong positive correlation between the cowberry coverage and yield, cowberry plants grow as sterile under the closed canopies of mature trees.

The total cowberry crop in Finnish forests varies from 130 to 390 million kg (Turtiainen et al. 2011). From the annual crop, less than 10 % is picked. In 2012, the amount of cowberries offered for sale was 8.7 million kg in Finland, and the average market price paid to berry pickers was 1.30 €/kg. During the recent years, commercial wild berry picking by foreign pickers has most probably affected the utilisation rate of cowberry as well. Similar to the utilisation of bilberry yields, a higher share of crops could be utilised in household consumption and industry.

Problems involved in increasing the picking, supply and utilization of wild berries in the Nordic wild berry sector are described in the Bilberry section 3.3.4.1 (see Paasilta et al. 2009). However, it should be noted that cowberry and bilberry are in different competition situations on the international market, especially in Asia. The northern bilberries have been successful due to their good reputation on the high amounts of bioactive compounds. Cowberry is not as well-known as ‘similar’ berry cranberry (Vaccinium oxycoccos and V. microcarpum). So far, cowberries are mainly used as raw material in the food industry in Central Europe, though cowberry has also positive health effects. For example, cowberries are rich in polyphenols and cowberry juice was found to affect vascular health by lowering blood pressure (Kivimäki et al. 2013).

3.3.4.2.3 Silvicultural prescriptions for growing cowberries

In the Nordic countries, forest management is multifunctional so that the aim is to produce high-quality raw material for forest industry and simultaneously to safeguard the biological diversity of forests and the potential for the non-wood forest products and services (Yrjölä 2002). Due to a high number of private forest owners and their widely differing needs and expectations as well as relatively small-scale variation in site characteristics, forested landscape is fragmented and mosaiclike. The three economically most
important tree species growing in the Nordic counties are Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*) and birch (silver birch, *Betula pendula* and downy birch, *B. pubescens*).

In boreal zone, forests are typically managed as stand-based and even-aged. Depending on the tree species, geographical location and site characteristics, the recommended rotation period varies from 60 to 130 years. The average diameter of trees is typically 25–30 cm at breast height. Earlier, uneven-aged management systems have been applied only at special sites, such as landscape areas and forests dedicated for recreational use. Since 2014, uneven-aged forest management can be applied in all kind of forests in Finland. However, uneven-aged forest management will not be applied widely and it seems to be most feasible in spruce forests on sites of medium fertility (i.e. mesic site).

Seedling stands are managed by cleaning and thinning. Commercial thinnings are done 1–3 times during the rotation period; each thinning removes about 30 % of the growing stock. For natural regeneration, seed or shelterwood trees are left standing to seed the site; natural seeding may take place by trees on the forest edge surrounding small regeneration areas. Artificial regeneration by seeding or planting is needed if there are no possibilities for natural regeneration. The success of regeneration and early development of seedlings is ensured by mechanical soil preparation. The majority of Finland’s current forests have regenerated naturally. About 35 % are planted or artificially seeded, but also in those stands a varying amount of trees is naturally regenerated.

The coverage of cowberry is mainly affected by site type so that the highest coverage can be found on sub-xeric (dryish) heath forests and oligotrophic spruce mires (*Turtiainen et al. 2013*). The dominant tree species growing on these sites is pine but also spruce is present as mixture. Also silvicultural operations affect strongly the cowberry yields. Thought cowberry is shade tolerant and well adapted to grow under a tree canopy, a good supply of light is needed for good berry production.

The average coverage of cowberry has decreased from 16 % to 6 % in Finnish forests during the last 40 (Salemaa 2000). Reasons for the decline are clear-cuttings combined with soil preparation (e.g. *Tolvanen 1994, 1995*), increased forest density and proportion of young forests, which all have had negative effects on the abundance of cowberry.

Cowberry suffers from regeneration fellings combined with soil preparation. However, good berry crops are reached few years after regeneration cutting in dryish heath pine forests. The cowberry yield is at its highest in the beginning of the forest rotation in seed-tree stands and in small seedling stands, where plants produce high yields, especially around tree stumps. The cowberry yields are low in dense and shaded stands. According to *Raatikainen et al. (1984)*, the highest cowberry yields are found in mature pine stands with the canopy coverage between 1–40 %.

Based on simulations conducted by using the cowberry models (*Turtiainen et al. 2013*), in dryish heath forests in southern Finland the annual cowberry yields were highest in seed-tree stands and in small seedling stands. The crop level decreased with increasing stand basal area and increased only temporarily after thinnings.

To increase the cowberry yields, longer rotation lengths, higher thinning intensities and more frequent thinnings could be applied in even-aged management system. In soil preparation, less intensive methods could be applied not to severing the rhizome connections and thus protecting ramets growing from a belowground rhizome.

Cowberry yield models developed by *Turtiainen et al. (2013)* could be included in a stand growth simulator in order to optimize the joint production of timber and cowberry in the similar way as was done with the
bilberry yield models by Miina et al. (2010). The comparison of even-aged and uneven-aged management systems in relation to cowberry yields could also be conducted (see Pukkala et al. (2011) for bilberry).

Uneven-aged management could possibly favour the cowberry yields especially by decreasing the stand density in pine forests compared to the even-aged management system currently applied in northern Europe.

In the Nordic countries, rich cowberry crops are produced in forests, but also field cultivation has been studied (Hiirsalmi 1989; Gustavsson 1999; Saario 2003). In Europe, cowberry is cultivated for example in Estonia and Germany. Cowberry is cultivated also in the North America. Good results have been achieved using cowberry cuttings and seed plants, but cowberry cultivation is not profitable and competitive if wild cowberries are available in forests.

3.3.4.2.4 Summary of key points and knowledge gaps

Cowberry is frequent and abundant species in the understorey vegetation of conifer ecosystems in northern Europe. The average coverage of cowberry has decreased in Finnish forests partly due to intensive forestry with clear-cuttings and soil preparation, and partly because stand density and proportion of young forests has increased. The highest coverage is found on dryish heath forests and corresponding peatlands (the Vaccinium type group). On these sites, the dominant tree species is usually pine.

Cowberry production fluctuates annually with weather conditions. In addition, there is a large geographical variation in berry crops. Cowberry is widely collected for both household consumption and sale, but only less than 10 % of the annual crop is picked in the Nordic forests. A lot more could be harvested and utilised in industry, if berry picking was organised more efficiently.

In the Nordic countries, the availability of cowberries may be a problem only in poor berry years and locally in certain forests. Berries are picked efficiently from the forests that are easily accessible for people and where the potential berry yields are known to be high, for instance in recently regenerated pine stands on dryish heath sites located near urban centres.

Some simulation results are available on the effects of forest management schedules on the production of cowberries. However, results on the joint production of timber and cowberry production are missing, but they can be obtained by applying the existing berry yield models and stand simulators. The simulation-optimization results could be utilized for developing optimal management prescriptions, for example, for public and communal forests. In addition, the comparison of even-aged and uneven-aged management systems in relation to cowberry yields are also missing. So far, it is not known whether the stand basal area is constantly at a level that enabled good cowberry yields in pine forests managed as uneven-aged.

3.3.4.2.5 Suggestions for new silvicultural prescription for combined timber and cowberry production in Europe

In pine forests on dryish heath sites and corresponding peatlands, some changes to the current even-aged management practices are recommended to favour the production of cowberries. The highest berry yields are produced in recently regenerated, young pine stands. In forest regeneration, less intensive soil preparation methods would protect ramets growing from a belowground rhizome. During the phase of young and advanced thinning stands, the stand density is usually too high to allow berry production. Therefore, at the end of rotation, heavier thinnings would reduce canopy shading to a level that is more favourable for cowberry. Treeless open habitats are suitable for cowberry production, and therefore regeneration cuttings (clear-cutting or seed-tree cutting) would increase the cowberry yields in pine
3.4 Discussion: Plans and perspectives for the STARTREE project in relation to improvement/development of silvicultural systems for MPTs and NWFP

Section 3 of the deliverable has outlined current silvicultural systems that are applied to both direct NWFP species and NWFP-associated species. The silvicultural state of the art was established through a questionnaire targeting forestry professionals (PFQ) in StarTree’s 14 case study regions and by a review of literature and institutional knowledge with a species specific focus. A number of direct NWFP producing species were scrutinised: wild cherry (*Prunus avium*), walnut (*Juglans regia*), chestnut (*Castanea sativa*), rowan, true service and wild service trees (*Sorbus aucuparia*, *Sorbus domestica* and *Sorbus terminalis* respectively). Cork oak (*Quercus suber*), maritime pine (*Pinus pinaster*), lime (*Tilia spp.*) and bay leaves (*Laurus nobilis*). Furthermore, a number of indirect NWFP were reviewed: wild mushrooms and truffles as well as forest understory berries such as bilberry (*Vaccinium myrtillus*) and cowberry (*Vaccinium vitis-idaea*). The aim was to review such products on a European if not, world-wide basis to examine potential silvicultural practice that could be applied to Star Tree’s case study regions. The application of a silvicultural treatment will alter forest floor conditions concerning light, temperature and moisture availability, these variables are directly affected by the degree of canopy cover, harvest intensity, slash disposal approach and timber extraction method. The presence of NWFP species can be both positively and negatively influenced by the rate of consequent understory growth and modified environmental conditions brought about by the silvicultural operation.

It is evident that NWFP and timber production are largely separate operations utilising disparate production systems and silvicultural management. Direct silvicultural operations for the production of timber will affect the shape and form of the tree reducing potential NWFP yield. When timber is produced there are few examples where silvicultural practice is modified to enhance productivity by adding a NWFP production goal. Many respondents in the PFQ suggested that mushrooms were collected from the forest, although there were no indications of special management undertaken to enhance the production of this NWFP. The root of this may lie within property rights. If there is a common right to harvest, then individuals have less incentive to contribute effort when economic benefits are not present. Forests or forest plantations that have a NWFP goal such as cork or pine nuts are orientated around that single product; timber is a secondary product often for low quality applications or firewood. The PFQ reinforced this viewpoint, cork production for example in Mediterranean areas is well established, the systems utilised for its production are specific to the desired product, co-production is less possible.

Ideal co-production methodologies would include a level of compromise built into production goals, something that is currently not commonly practiced. Therefore, the following aims must be accomplished:

1. The location of the best compromise between the production of timber (branch-free bole length), crown shape, and the production and harvesting of NWFP.
2. The prescription of innovative silvicultural regimes for the synergistic production of multiple forest products.

This will culminate in a set of revised silvicultural guidelines for selected MPT and NWFP for an increase in the profitability of NWFP management in Star Tree’s 14 regional case study regions.
4 Description of existing models and simulators for some selected MPTs and NWFP

Coordination: MS, IC, MT
Authors: FC, JAB, JAP, JM, MS, MT, RC, SM

4.1 Introduction

The objective of this chapter is to identify and describe the existing models and simulators for some selected multipurpose (MPT) and non-wood forest products (NWFP) occurring in the case study regions (see Table 2.2). For this purpose all available sources, such as institutional knowledge, peer reviewed papers, thesis and grey literature were consulted, for the selected tree species, understory plants and, in addition, forestry professionals were consulted by the questionnaire described in chapter 2. From the information given in this chapter we should be able to get an idea of the model’s focus and complexity in order to identify the gaps and needs for improvement.

Despite the relevance of NWFP in Europe, forest management and planning methods have been traditionally wood oriented, because most forest management models and silviculture schemes were developed to ensure a sustained and maximum yield of timber (Calama et al. 2010). Nowadays, it is well known that maximizing wood production does not necessarily maximize the production of NWFP and services (Calama et al. 2007b, Bonet et al. 2008, Palahi et al. 2008, Miina et al. 2010). Moreover, in some cases, it is possible to identify some incompatibilities among silvicultural practices for promoting NWFP and timber yield and quality (Calama et al. 2010). Although there are approaches for explicitly consider NWFP as management objectives in forest planning (Pukkala 2002), specific models are needed for assessing their production in different forest scenarios and for different management approaches (Calama et al. 2010). However, up to the present, only very few models have been developed for a limited number of NWFP in Europe, due to the lack of systematically collected data, and to some challenges that make it difficult to develop predictive models for NWFP.

The EFORWOOD European Project (www.innovawood.com/eforwood/), funded by the 6th Framework Program of the European Commission, led to the creation of a database for forest growth models, the FORMODELS database (www.efiatlantic.efi.int/portal/databases/formodels/), which registers and describes available models and simulators which represent either forest growth and yield, or the dynamics of tree populations. The FORMODELS database contains information for each forest growth model about several topics such as model identification, modelling approach, range of applicability, model structure (with modules for state variables, sub-modules for natural processes, modules for silvicultural practices and modules for environmental driving variables), inputs, outputs, availability of stand simulator, availability of landscape/region simulators or decision support systems, and the relevant references. The StarTree project consortium thinks that an effort to include NWFP models into the FORMODELS database is of high interest, so all the partners were asked to complete the database with the models they have developed/known about. Furthermore, if new models or simulators will be developed under StarTree, they should be filled into the database.

Since a forest model can be an isolate production equation or an integrated growth and yield model the terminology related to the forest modelling tools defined in the EFORWOOD project and that will be followed in STARTREE, is provided in Box 1.
Box 1: A note on the terminology related to forest models
The EFORWOOD Project defined the following concepts related to the forest modelling tools (Tomé et al. 2003):

State variables
Set of variables (at stand and/or tree level) that characterize the forest at a given moment and whose evolution in time is the result (output) of the model. State variables can be:
- Principal variables if they are the output of the growth modules
- Derived variables, if they are indirectly predicted based on the values of the principal variables

Driving variables
Variables that are not part of the forest but that influence its behaviour:
- Environmental variables (e.g. climate and soil variables)
- Human induced variables/processes (e.g. silvicultural treatments)
- Hazards (e.g. pests and diseases, storms, fire)

Forest model
A dynamic representation of the forest and its dynamics, at whatever level of complexity, based on a set of (sub-) models or modules that together determine the dynamic of the forest as defined by the values of a set of state variables. The forest responses to changes in the driving variables are reflected by the predicted dynamic of the forest. Modules, and therefore the models, can be deterministic or stochastic.

Model module
Set of equations and/or procedures that led to the prediction of the future value of a state variable.

Module sub-module or component
Equation or procedure that is part of a model module, contributing to the prediction of a state variable but not having a state variable as output.

Forest management alternative (prescription)
Sequence of silvicultural operations that are applied to a stand during the projection period.

Scenario
Conditions (climate, forest policy measures, management alternatives, etc.) present during the projection period.

Forest simulator
Computer tool that, based on a set of forest models, makes long term predictions of the status of the forests within a well-defined region under a certain scenario of climate, forest policy or management alternatives. Forest simulators usually predict, at each point in time, wood and non-wood products from the forest.

Stand simulator
Forest simulator focused on the simulation of a stand.

Landscape simulator
Forest simulator focused on the simulation of all the stands included in a certain well defined region in which the stands are spatially described in a GIS. The simulation is made on a stand by stand basis but outputs for the whole landscape are also provided, namely sustainability indicators. It allows for the testing of the effect of spatial restrictions such as maximum or minimum harvested areas or maximization of edges.

Regional/National simulator – not spatialized
Forest simulator focused on the simulation of a large region, based on forest inventory data, without individualizing each stand, not connected to a GIS. Outputs are usually given by forest type but focused on the whole region.

Regional/National simulator – spatialized through a grid
Forest simulator focused on the simulation of a large region, based on forest inventory data aggregated according to a spatial grid connected to a GIS. Outputs are usually given by forest type but focused on the whole region.

Decision support system
Computational infrastructure integrating database management systems with analytical and operational research models, graphic display, tabular reporting capabilities and expert knowledge. The model base management system includes simulators and optimization algorithms that point out for a solution – list of forest management alternatives for each stand.
The chapter is organized as follows. First, the methods used to gather the available information about forest models and simulators that are used to predict multipurpose products and NWFP are briefly presented in section 4.2. Results are presented in section 4.3 beginning with the presentation and analysis of the model-related questions of the PFQ, followed by a description of the existing equations for the prediction of fruits and nuts, cork, resin, mushrooms and understory berries; then we describe the stand simulators for forest ecosystems that provide NWFP. Based on these results we discussed the plans and perspectives for the StarTree project in relation to models and simulators improvement/development in section 4.4.

4.2 Methods

4.2.1 Data sources

The data collection and subsequent analysis of forest models and simulators that include multiple products and/or NWFP has used a methodology similar to the one used in chapter 3 for silviculture (Figure 3.1). Data sources were the professional forester’s questionnaire (PFQ), in order to allow data collection from forestry professionals related to forest management in the 14 StarTree case study regions and the enquiry to the web-based database FORMODELS. A desk based study complemented this information. In this study, WP2 partners (7 institutions) were directed to collate basic data on two topics: 1) identification of prediction equations for NWFP; 2) identification and description of stand simulators that include NWFP.

The desk based study focused the set of selected species that was outlined in the project description of work and that can be seen in Table 2.2. Species were allocated to institutions with regional expertise. Species-wise reports arising from this exercise are presented in section 3.3, listing prediction equations and section xxx briefly describing stand simulators and presenting a detailed list of references.

4.2.2 FORMODELS database description

The database FORMODELS is an existing database for the register and description of forest models and simulators that was first developed by IEFC (European Institute of Cultivated Forests) and later restructured and complemented under the EFORWOOD project (Tomé et al. 2003; Meredieu et al. 2011). The objective of this free access database is to describe and provide information about forest modelling tools in a straightforward, simple and hierarchically structured way. Model description catalogues the ability of models to estimate sustainability indicators as well as the improvements needed in order to improve model performance in this respect. Most forest growth models, even if not published as such, have several publications related either with the development of some of the modules or with their integration into simulators and/or decision support systems. The description of the models is not a repetition of the related publications but rather a standardized characterization of several topics, such as model range of applicability, model type, description of model structure, etc, that are easily stored in this relational database. The database also identifies most of the relevant publications as well as the description of their content.

The topics to be described are:

1. Model identification
2. Modelling approach
   2.1. Model type
   2.2. Model sub-type
   2.3. Primary unit of simulation
   2.4. Time step

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2.5. Time scale
2.6. Stochasticity

3. Range of applicability
3.1. Region
3.2. Site
3.3. Forest composition
3.4. Forest structure
3.5. Tree species
3.6. Silvicultural system
3.7. Tree range
3.8. Stand range

4. Model structure – modules for state variables
5. Model structure – sub-modules for natural processes
6. Model structure – modules for silvicultural practices
7. Model structure – modules for environmental driving variables
8. Inputs
  8.1. State variables
  8.2. Human induced driving variables (silvicultural practices)
  8.3. Environmental driving variables
9. Outputs
  9.1. State variables
  9.2. Products
10. Stand simulator
  10.1. Software and hardware requirements
  10.2. Software characteristics
  10.3. Estimation of sustainability indicators
  10.4. Visualization module
11. Landscape/region simulators/dss
  11.1. Software and hardware requirements
  11.2. Software characteristics
  11.3. Identification of simulators/dss
  11.4. Estimation of sustainability indicators
12. References
Details for each one of the selected topics can be seen in Tomé et al. (2003) and the description of the web implementation of the database in Meredieu et al. (2011). The FORMODELS database is hosted by the EFIATLANTIC website (www.efiatlantic.efi.int/portal/databases/formodels/).

Under Startree an effort was made to include NWFP models into the database FORMODELS in order to have them accessible to other scientists but also to forest professionals.

4.3 Results

4.3.1 Professional foresters responses to models related questions
The professional foresters’ questionnaires (PFQ) had four questions related to models. The first one asked the respondent if he/she knew any model developed for predicting the production of any NWFP; if the answer was yes the respondent had to answer the next two questions, otherwise he/she had to go to the
last question about models where the respondent had to state if there is any NWFP for which models would be useful in his/her region.

Most of the respondents (220 out of 239) do not know of any model for NWFP. From the thirteen regions only the professional foresters from Alentejo, Catalonia and Valladolid know models for NWFP, in the other regions all the respondents answer negatively to this first question. Regarding the last question about models, most of the professional foresters think that models would be useful for any NWFP from their region except in Eastern Scotland, Latvia, Styria, Waldmärker and West Wales and The Valley. Figure 4.1 shows for each region those NWFP suggested by the respondents and the number and percentage of respondents who affirmatively answer to this question. There were no suggestions from Latvia and Styria (Austria).

The models identified by the respondents from Alentejo, Catalonia and Valladolid are shown in Table 4.1. The number of professional foresters that suggested any model in each of those regions was 4 (40%), 8 (40%) and 7 (78%), respectively. In addition, most of them considered that models are useful tools for the management of NWFP in their region by supporting management decisions.

Figure 4.1  NWFP for which a prediction model was considered be useful by professional foresters. For each region the numbers and percentages of respondents who affirmatively answered to this question is also shown.
Table 4.1  Specified models by foresters professionals and NWFP to which they applied

<table>
<thead>
<tr>
<th>Region</th>
<th>NWFP</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alentejo</td>
<td>Cork</td>
<td>SUBER (Tomé et al. 2001; Paulo JA 2011)</td>
</tr>
<tr>
<td></td>
<td>Stone pine nuts</td>
<td>Corkfits (Ribeiro and Surovy 2011)</td>
</tr>
<tr>
<td></td>
<td>Mushrooms</td>
<td>Empirical equations (Freire J 2009)</td>
</tr>
<tr>
<td>Catalonia</td>
<td>Stone pine nuts</td>
<td>PINEA (Calama et al. 2007)</td>
</tr>
<tr>
<td>Valladolid</td>
<td>Stone pine nuts</td>
<td>PINEA (Calama et al. 2007)</td>
</tr>
<tr>
<td></td>
<td>Cork</td>
<td>García-Guemes (1999)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mutke et al. (2005)</td>
</tr>
</tbody>
</table>

4.3.2  Equations for the prediction of NWFP

This subchapter is intended to briefly describe the existing equations for the prediction of some of the most important NWFP in Europe: fruits and nuts, cork, resin, mushrooms, understory berries and sap. In this section the formulation of most used equations is included irrespective of the fact that are or not included in a stand simulator because some of them can be, and actually are, used isolated.

4.3.2.1  Fruits and Nuts

Nut yields are hard to predict, both within and between stands, due to variation in environmental and site conditions, genetic differences, inter and intra-species competition, non-accuracy of traditional site index, as well as other statistical-related problems as abundance of zeroes in dataset and non-normality (Ares and Brauer 2004; Calama et al. 2010). Some of the requirements that have been suggested for data collection are: the need for soil and climate data, long term series at tree level, extended nets of plots, and the need to monitor quality attributes.

Although there are some available models in the literature for the nut yield from American Juglans nigra (Ares and Brauer 2004; Brauer et al. 2006), no such yield models have been found concerning J. regia, the most important species for the genera Juglans in Europe. The same happens for other important forest species in Europe in terms of fruits or nuts production, like Castanea sativa, Prunus avium, and Sorbus spp. (S. terminalis, S. domestica, S. aucuparia). The only species that deserves a special mention in this sense is the Mediterranean stone pine (Pinus pinea L.).

Stone pine nut is the main edible nut collected in Mediterranean forests, having been consumed by humans since ancient times (Mutke et al. 2012). Cones are collected manually (climbing the trees) or mechanized (tree shaker harvesters), mainly from natural stands, though an important effort is made to install and manage clonal grafted high productive plantations (Mutke et al. 2007). Since the 80’s, a large effort has been made on modelling stone pine cone and nut production in Spain, Portugal and Italy. Concerning spatial variability, it has been mainly explained by: tree size factors, as tree basal section or crown diameter (Calama and Montero 2007; Freire 2009; Cañas 2000; Carrasquinho et al. 2010), pointing to larger productions in larger trees; tree-level competition (Calama et al. 2008a; Freire 2009), with dominant trees reaching large cone crops; stocking attributes, indicating that larger yields per tree are
attained in stands with low density (Calama et al. 2008a; Freire 2009; Cañadas 2000); site characteristics such as site index or soil attributes (Calama et al. 2008b); as well as a moderate to high degree of genetic determination of fruitfulness (Mutke et al. 2007). While first efforts were carried out to develop stand level models (Castellani 1989; García-Güemes 1999), tree level models have performed better to model fruit production (Calama and Montero 2007; Freire 2009), since these model type allows taking into account both between and within-tree variability in production (Calama et al. 2010). On the other hand, stone pine cones, the same as most other fruits or seeds, show a clear masting habit with irregular crops between years, depending mainly on climatic and endogenous factors such as rainfall shortcomings, frost damages or resource depletion (Mutke et al. 2005a; Calama et al. 2008a; Calama et al. 2011). This implies a huge uncertainty of actual cone yield (and of the forest owners income) in a given management period, independently from the average yield of his forest.

In Italy Castellani (1989) developed production tables to predict weight of cones at stand level. In Portugal, Freire (2009) developed an individual tree model for stone pine that includes a cone production model that uses two stages: the a first stage uses a cone production probability model to decide if the tree is producing cones, and then, in case it is producing cones, a cone weight production model is used for cone weight prediction. In Spain, the most important are those models for regional or individual based cone yields developed by Mutke et al. (2005b) and by Calama et al (2008b; 2011). Calama et al. (2008b) constructed an individual tree model for cone yield based on tree and stand variables. This model is included in the stand simulator PINEA (Calama et al. 2007b). Mutke et al. (2005b) developed a model for predicting the regional annual average production of cones taking into account the three-year delayed negative influence on cone production associated with resource depletion and exhaustion of reserves after a bumper crop. Taken into account not only that influence, but also the abundance of zeroes in fruiting events, Calama et al. (2011) developed a model for predicting annual cone crop at tree level formulated as a zero inflated model. This model was developed considering fruiting as a two-phase process one ruling the presence of cones through a probability model, and other controlling the abundance through a cone weight model. Finally, Morales (2009) studied the influence of cone weight in variables related to nut quality such as: number of nuts per cone, average nut weight (with and without shell), the ratio between nuts weight in shell and cone weight; percentage of empty nuts and the ratio between kernel weight in shell and nuts in shell weight. Based on these results, the author develops models for each of those variables (only those which a R2 equal or higher than 0.4 are shown in Table 4.3). The abovementioned models are showed in Table 4.3.

### 4.3.2.2 Cork

Cork is a natural product obtained from the outer bark of cork oak (Quercus suber L.). The cork layers that are produced in its bark form a continuous envelope with an appreciable thickness around the stem and branches. Cork may be stripped off from the stem without endangering the tree vitality and the tree subsequently rebuilds a new cork layer. This is the basis for the sustainable production of cork during the cork oak’s long lifetime (Pereira 2007). Cork is usually commercialized on the basis of weight. The weight of cork extracted in one harvest (hereafter designated as cork weight) is the ultimate objective of cork modelling. Other variables that are important for cork modelling are cork growth and cork thickness, as well as cork quality (being this variable still a modeling challenge nowadays).

Since the first cork weight models were developed in Portugal in the 50’s (Natividade 1950; Guerreiro 1951; Alves 1958; Alves and Macedo 1961; Ferreira et al. 1986) using fresh cork weight as dependent variable a lot of different models have been developed in Portugal and Spain. Vázquez and Pereira (2008), who showed 18 references for individual-tree cork weight yield prediction and 5 references for stand cork weight yield prediction, present a very detailed review, including a critical appraisal of the problems that
recent research found in the development of such models. More recently Calama et al. (2010) review the existing models for cork, not only cork weight models but also cork thickness models for virgin and mature cork, and cork growth models. Since then no new models were published.

In order to avoid repeating the information given in the aforementioned review papers (Vázquez and Pereira 2008; Calama et al. 2010) in this section we are going to focus on the simplest and/or more used equations for the prediction of cork in Portugal and Spain. Regarding cork weight models, in Spain the only cork weight equation and then the most used is the one developed by Montero (1987). It is a linear model that uses fresh cork weight as dependent variable and circumference at breast height and the debarking height as regressors. In Portugal the most used cork weight models are the ones developed by Ribeiro and Tomé (2002) and Paulo and Tomé (2010). Ribeiro and Tomé (2002) developed four models for air dried cork weight estimation before debarking, from simpler models, using variables easy to gather in the field, to more complex ones that maximize the prediction ability. Paulo and Tomé (2010) developed four models for cork biomass prediction for 9 years old corks, from low to high measurement effort, any of these models allows jointly with a diameter growth model (Tomé et al. 2006) and a cork growth model (Almeida et al. 2010) to predict the evolution of cork weight. All these models are used within the stand simulator SUBER (Tomé 2004). Table 4.4 shows the simpler ones, other models, more complex, can be seen in the original publications.

Another cork weight model also used in Portugal is the one developed by Ribeiro and Surový (2011) that also developed a model to predict cork radial increment assuming the potential increment modifier principle. The potential growth is multiplied by a reduction factor (the modifier) as function of a spatial competition index and the intensity of debarking. These two models are used inside the stand simulator CORKFITS (Ribeiro and Surový 2011; Surový et al. 2011).

Two models for cork growth were developed, one in Spain, by Sánchez-González et al (2008b) that is used inside the stand simulator ALCORNOQUE (Sánchez-González et al 2007a), and another one in Portugal by Almeida et al (2010) that is used in the SUBER simulator. These authors also developed a model that predicts the thickness of mature cork complete rings (cork thickness) at initial age given the values of cork caliber measured in the forest inventory at the respective age. In Spain González-Adrados et al (2000) developed a model that predicts mature cork thickness at a given cork age as a function of cork thickness the year before. Virgin cork thickness models have also been developed, one in Portugal by Tomé (2004), as part of the stand simulator SUBER; and another one in Spain by Sánchez-González et al (2007) that predicts virgin cork thickness at different heights using a taper equation and a linear relationship between cork thickness at a given height and the corresponding diameter over cork.

### 4.3.2.3 Resin

Resin tapping has been an important traditional forest activity in Northern countries (Pisarenko and Strakhov 1996) as well as in the Mediterranean basin. Russia is still one of the main producers of resin in the world, with Pinus sylvestris being the main species tapped (FAO 1995), while in Finland there exist an increasing demand for Norway spruce (Picea abies) resin, due to its medical properties (Jokiaho 2010). However, little information is available about the management of this resource in these northern countries. In Mediterranean countries resin tapping was a main rural activity until the 1970s when the international crisis in natural resin prices rendered this traditional labor no longer profitable. During that period, the resin from Pinus pinaster (and other Pinus species as Pinus halepensis or Pinus brutia) was one of the most important non timber products from Mediterranean forests, namely in Spain, Portugal, France and Greece (Calama et al. 2010). Recently, China, the world’s main natural resin exporter, has dropped from 0.4 million t
in 2006 to less than 0.25 million t/year in 2009, owing to its need to supply the own growing chemical industry, as well as an increasing prevalence of the pine wilt nematode spreading over Chinese pine forests. The shortage of resin in the global market has led to a shift in the international price for turpentine, from a minimum of 0.75 €/kg in 1991 to more than 2 €/kg in 2011. The strong price increase for natural resins, resin and derivates allowed for a current resurgence of resin tapping, reaching in 2012 already 7.5 million € as primary value for raw resin only in Spain (Picardo and Pinillos 2013).

The socioeconomic importance of tapping has prompted wide scientific research to increase production by studying the resin secretion structures (Bannan 1936; Wu and Hu 1997; Boschiero and Tomazzello-Filho 2012), the influence of the tapping wound on oleoresin secretion (Ruel et al. 1998; Gaylord et al. 2011), the application of chemical stimulants or fertilizers (Hudgins and Franceschi 2004; Rodrigues et al. 2008; Moreira et al. 2009), modeling the distribution of resin yield (Nanos et al. 2000) and the development of breeding programs (Prada et al. 1997; Tadesse et al. 2001). The role of resin flow as constitutive and induced defense against pests and disease has also been extensively explored (Berryman 1972; Franceschi et al. 2005; Knebel et al. 2008; Kim et al. 2010).

Due to the long-lasting abandonment of resin tapping in Europe, there have been nearly no recent papers, about resin yield and specific management methods. Genetic control and site conditions have been identified as the factors largely affecting spatial variability in Pinus pinaster resin production (Nanos et al. 2000). Large variability has been detected at both within and between stands for the Northern Plateau of Spain. Within stand variability was approached by modelling resin distribution at stand level (Nanos et al. 2000); while between stand variability was approached using geostatistical modelling followed by ordinary kriging (Nanos et al. 2001). These last techniques would be very useful when such distributions can be related to easy-to-measure forest variables.

Concerning empirical predictive models for resin production, already in 1940 (Simão), based on 190 trees, has developed a resin yield table as a function of diameter, height and crown width (R^2 = 0.55).

Spanos et al. (2009) modelled annual tree-level resin yield production on Aleppo pine (Pinus halepensis) in Evia (Greece), and found a weak correlation (R^2=0.315, p=0.0001) between resin production and tree size:

\[ w_r = 0.202 + 0.09467 \cdot d \]

where \( w_r \) is the weight of resin (kg tree\(^{-1}\)) and \( d \) is the diameter (cm) at breast height (1.3 m).

This weak correlation between resin production and tree diameter was already observed by several authors (Palma 2007) (see Table 4.2).

<table>
<thead>
<tr>
<th>Local</th>
<th>Reference</th>
<th>Number of trees</th>
<th>( R^2 )</th>
<th>Amplitude of dbh (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portugal</td>
<td>Viana (1999)</td>
<td>47</td>
<td>0.01</td>
<td>22.0-36.6</td>
</tr>
<tr>
<td>Spain</td>
<td>Carneiro (2002)</td>
<td>14</td>
<td>0.24</td>
<td>25.5-38.2</td>
</tr>
<tr>
<td>Turky</td>
<td>(Acar, 1998)</td>
<td>30</td>
<td>0.01</td>
<td>25.0-65.0</td>
</tr>
<tr>
<td>Portugal</td>
<td>(Palma, 2003)</td>
<td>200</td>
<td>0.16</td>
<td>21.0-44.7</td>
</tr>
<tr>
<td>Portugal</td>
<td>(Palma, 2003)</td>
<td>40</td>
<td>0.32</td>
<td>19.8-41.8</td>
</tr>
</tbody>
</table>

Recently, Rodríguez-García et al. (2014) related resin yield production to tree diameter (\( R^2 =0.38, p=0.001 \)), tree height (\( R^2=0.21, p=0.023 \)), total resin canal volume (\( R^2=0.26, p=0.014 \)), radial resin canal frequency (\( R^2=0.23, p=0.016 \)) and early wood radial length (\( R^2=0.18, p=0.036 \)) in Castile and Leon, although they did
not report estimated parameters for such relations. Such variables could be useful criteria for estimating resin yields in Pinus pinaster and could be applied to improve tapping management.

4.3.2.4 Mushrooms

Wild edible fungi are valuable non-wood forest products throughout the world and have a clear potential for commercial use (Boa 2004), being higher than the value of timber in many forests (Alexander et al. 2002; Palahi et al. 2009). Mushroom picking has also become one of the most important forest recreational activities in many parts of Europe (Lund et al. 1998; Mogas et al. 2005; Martínez de Aragon et al. 2007; Turtiainen et al. 2012). Consequently, there is nowadays a high interest to inventory, predict, and manage forests to improve the production of marketed mushrooms (Pilz and Molina 2002).

However, the large amount of potential variables related to mushroom productivity and their interdependence makes it difficult to give clear recommendations for managing forests to maximize mushroom yield. Systematic quantitative analyses on the effect of different variables are thus required (Martínez-Peña et al. 2012). The inclusion of mushroom yield as an explicit objective in forest management and planning requires models for assessing, in a quantitative way, the production of mushrooms in different forest stands and management approaches. Such models can be developed with statistical methods, using empirical data on mushroom production and forest stand characteristics (Bonet et al. 2008; Bonet et al. 2010; Miina et al. 2013). Once predictive models are developed, they can be included in forest simulators to provide quantitative information on mushroom production and its economic effects in alternative forest management approaches (Palahi et al. 2009).

Forest management oriented models based on long historical data series of annual measurements in many locations can be used to model mushroom yield as a function of different types of predictors. This kind of studies are rather recent, and only a few models for mushroom yield, and in a restricted area, have been published so far (Table 4.5).

According to such models the highest production of edible mushrooms occurs for medium stand basal areas of 10-20 m²ha⁻¹ in more mediterranean forest sites (Bonet et al. 2008; Bonet et al. 2010), whilst in other continental areas as central Spain, Martínez-Peña et al. (2012) obtained the highest probability of Boletus edulis annual yield with a stand basal area around 40-50 m²ha⁻¹. Since geographical features of the forest stand (altitude, aspect or slope) correlates with weather variables, in the Mediterranean area, where water is a limited factor (Bonet et al. 2008, 2010) northern aspects have the highest productions and southern ones the lowest while increasing slopes decreases the total mushroom production. Similarly, elevation has been positively related to mushrooms production (Bonet et al. 2010) till a certain altitude in which decrease of temperature restricts the fruit-body emergence (Martínez-Peña et al. 2012). In eastern Finland, the production of Boletus edulis is higher in spruce forests with age of 20-40 years and stand basal area of 20–30 m²ha⁻¹ (Miina et al. 2013).

Palahi et al. (2009) demonstrated how mushroom yield models can be linked to a forest simulation and optimization system in order to optimize the joint production of timber and mushrooms. Their results showed that mushrooms produce more profit than timber in most P. sylvestris and P. nigra stands of central Catalonia (north-east of Spain). In P. sylvestris stands with good site conditions for mushrooms the soil expectation value of mushroom harvesting was often 10 times higher than the soil expectation value of timber production.
4.3.2.5 Understory berries

Wild understory berries are valuable non-wood forest products collected for both household consumption and sale in Northern Europe. The picking of wild berries is one of the most important forest recreational activities especially in Nordic countries, but also of great economic significance to many regions due to the right of public access to all forest land (e.g. Kangas 2001, Turtiainen and Nuutinen 2012). The public and private forest landowners, both industrial and non-industrial, place a high value on the multiple-use aspects of forests, and thus objectives other than wood production have got increasing weight in forestry decision-making.

Production functions suitable for planning calculations are needed when integrating e.g. wild berries in numerical forest planning. Some production functions have been formulated for wild berries in Finland on the basis of expert estimates (Ihalainen and Pukkala 2001; Ihalainen et al. 2002; Ihalainen et al. 2005). The first empirical berry yield models developed were based only on regional yield data (e.g. Ihalainen et al. 2003), but recently also the datasets covering the whole of Finland have been used to estimate bilberry (Miina et al. 2009) and cowberry yields (Turtiainen et al. 2013) (Table 4.).
### Description of existing silvicultural systems

#### Table 4.3 Most important stone pine cone and nuts production models for Europe

<table>
<thead>
<tr>
<th>Reference</th>
<th>Dependent variable</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mutke et al. (2005b)</td>
<td>Cone yield [kg/ha]</td>
<td>$Wc = 9.740 - 0.487 \log(Wc_{0.5}) + 0.0025 P_{5-7,4} + 0.0076 P_{10-4} + 0.0053 P_{1-5,3} - 0.277 T_{6-7,3} + 0.0024 P_{9-8,1}$</td>
</tr>
<tr>
<td>Calama et al. (2008b)</td>
<td>Cone yield [kg]</td>
<td>$wc = \exp \left( 1.135 + 4.55 g + 0.524 \frac{d}{dg} - 0.1956 \log N + UN \right) - 1$</td>
</tr>
<tr>
<td>Freire (2009)</td>
<td>Cone yield [kg]</td>
<td>$\pi = \frac{1}{1 + e^{-\log(\text{it}(\pi)}} \logit(\pi) = 1.121 - 5.219 \frac{15}{d} + 0.009 P - 0.003 G^2 + 3.981 \frac{10g}{G}$ $wc = \exp \left( -1.515 - 20.032 \frac{g}{G} + 0.031 dg - 0.088 G + 0.007 P + 0.059 d \right)$</td>
</tr>
<tr>
<td>Calama et al. (2011)</td>
<td>Cone yield [kg]</td>
<td>$\log \left( \frac{\pi}{1 - \pi} \right) = 1.7062 - 0.0131 P_{5-6,3} - 0.0111 P_{10-11,3} + 0.1003 \text{nhel}$ $+ 0.5664 \ln(N) - 0.0754 \text{SI} + 2.7243 T_{20} + 0.3298 T_{50} - 2.2421 d/dg + \text{UN}<em>{1} + u$ $\ln(wc) = -2.8930 + 0.0089 P</em>{5-6,3} + 0.0055 P_{10-11,3} + 0.0030 P_{7-9,2} + 0.0036 P_{2-5} - 0.0425 \text{nhel} - 0.2673 \ln(N) + 0.0421 \text{SI} + 0.0454 d + 0.5895 d/dg + \text{UN}_{2} + v$</td>
</tr>
<tr>
<td>Mutke et al. (2005b)</td>
<td>Mean cone weight [g]</td>
<td>$mcw = (18.8 + 0.305 (P_{9,12,1} + P_{1,8,1}) + 0.687 P_{5-7,1} + C)$</td>
</tr>
</tbody>
</table>
### Description of existing silvicultural systems

Table 4.2  Most important stone pine cone and nuts production models for Europe (cont.)

<table>
<thead>
<tr>
<th>Morales (2009)</th>
<th>Nut yield [kg]</th>
<th>With shell: ( w_{nc} = 0.285 + 0.002w_c )</th>
<th>Without shell: ( w_{nc} = 0.125 \cdot \exp(-0.001w_c) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuts per cone</td>
<td>( n_{pc} = 107.684 \cdot (1 - \exp(-0.016w_c))^3.659 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nuts weight in shell/cone weight</td>
<td>( n_{pcw} = 0.2899 \cdot (1 - \exp(-0.023 \cdot w_c))^4.732 )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\( d \): breast height diameter (cm, 1.3 m above ground); \( dg \): quadratic mean diameter (cm); \( g \): individual-tree basal area (cm²); \( N \): stand density (trees ha⁻¹); \( SI \): site index (m); \( P_{i,j,k} \): rainfall from month \( i \) to month \( j \) \( k \) years before (mm); \( T_{i,j,k} \): average temperature from month \( i \) to month \( j \) \( k \) years before (°C); \( T_{20} \) and \( T_{50} \) are dummy variables (1 if stand age is lower than 20 or 50 years, respectively; 0 otherwise); \( UN \): soil and climate-based stratification of the territory; \( UN_1 \) and \( UN_2 \) values corresponding to edaphic and climatic stratification; \( V_{sjk} \): number of viable seeds produced by the tree \( j \) during year \( k \); \( W_c \): annual average regional cone yield (kg ha⁻¹); \( mcw \): mean cone weight (g); \( wc \): average annual cone yield (kg) cropped from a single tree; \( W_{c,k} \) is the average regional production \( k \) years before.
### Table 4.4  Most important cork production models for Europe

<table>
<thead>
<tr>
<th>Reference</th>
<th>Dependent variable</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Montero (1987)</td>
<td>Cork weight [kg]</td>
<td>$wcm = a + b(\text{cob} \cdot \text{hmax})$ where $a$ and $b$ are different for the 6 ecoregions defined</td>
</tr>
</tbody>
</table>
| Ribeiro and Tomé        | Cork weight [kg]   | Before debarking: $\ln(wcma) = 2.37 + 2.27 \ln(\text{cob}) + 0.44 \ln(\text{hds})$  
After debarking: $\ln(wcma) = 2.01 + 0.75 \ln(\text{cob}^{2} \cdot \text{hdt}) + 0.15\text{hds}$ |
| Paulo and Tomé          | Cork weight [kg]   | Cork biomass prediction for 9 years old corks: $wcm_{9} = 0.0203 \cdot \text{du}^{1.9843}$  
Cork biomass prediction for $t$ years of growth: $wcm_{t} = \frac{ctab_{t}}{ctab_{9}} + \frac{wcm_{9} - cbp_{9}}{100}$ |
| Tomé (2004)             | Virgin cork thickness [mm] | $ct_{vc} = \frac{ct_{1 ct}}{1 - \exp(0.09463 ct_{1 ct} - 0.1239 icc - 0.1194 tc1)}$ |
| Sánchez-González et al. (2007) | Virgin cork thickness [mm] | $ct_{i} = 1.268 \left[1.876 \left(\frac{h - h_{i}}{h}\right) - 2.701 \left(\frac{h - h_{i}}{h}\right)^{2} + 2.273 \left(\frac{h - h_{i}}{h}\right)^{3}\right] \cdot \text{du}$ |
| Sánchez-González et al. (2008a) | Cork growth [mm] | $ct = ct_{0} \left(1 - \exp(-0.04t)\right)^{0.47+1.86}$  
$X_{0} = \frac{1}{2} \left(\ln(1 - \exp(-0.04t))\right)^{2}$  
$L_{0} = \ln(1 - \exp(-0.04t))$ |
| Almeida et al. (2010)   | Cork thickness [mm] | $ct = \frac{cc - 4.572}{1.058}$  
Cork growth $ct_{w} = ct_{0} \frac{1 + 19.50(tc_{0} - 1)}{1 + 19.50(tc - 1)}^{1.088}$ |
| González-Adrados et al. (2000) | Cork thickness [mm] | $ct_{wc} = 0.7002 + 1.052 \cdot ct_{wc-1}$ |
### Table 4.3  Most important cork production models for Europe (cont.)

<table>
<thead>
<tr>
<th>Model Source</th>
<th>Variable</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ribeiro and</td>
<td>Cork dry weight</td>
<td>( \ln(w_{cm}) = a + b \cdot \ln(cub) + c \cdot \ln(hd_{max}) + d \cdot \ln(ct) )</td>
</tr>
<tr>
<td>Surový (2011)</td>
<td></td>
<td>where ( a, b, c ) and ( d ) are different for all combinations of soil and sectional area at 1.3m before and after debark</td>
</tr>
<tr>
<td>Ribeiro</td>
<td>Cork radial increment [mm]</td>
<td>( ic_{cc} = \frac{a \cdot b \cdot d \cdot x^d}{x \cdot (b + x^a)^2} \cdot e^{-a \cdot HD_{2}^{+}a} )</td>
</tr>
<tr>
<td>Surový (2011)</td>
<td></td>
<td>where ( a, b ) and ( d ) are different for all combinations of soil and sectional area at 1.3m before and after debark</td>
</tr>
</tbody>
</table>

\( w_{cm} \) is \( t \)-years mature cork biomass (kg); \( cub \) is over bark circumference at breast height (m); \( hd_{max} \) is maximum debarking height (m); \( wcma \) is air-dried cork biomass (kg); \( cub \) is under bark circumference at breast height (m); \( hds \) is debarked height in the stem (m); \( hdt \) is total debarked height (m); \( du \) is diameter under bark at breast height (cm); \( ct_{cc} \) is cork thickness (mm) at \( tc \) years; \( tc \) is cork age (years); \( ct_{t1} \) is cork thickness (mm) in \( tc_{1} \) complete years; \( cc \) is cork caliber (mm); \( ct_{0} \) is cork thickness (mm) at an initial cork age \( tc_{0} \); \( ic_{cc} \) is cork radial increment; \( HD_{2} \) is Hegyi spatial competition index; \( idf \) is intensity of debark over stem.
Table 4.5  Most important mushrooms yield models for Europe

<table>
<thead>
<tr>
<th>Reference</th>
<th>Dependent variable</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Martinez de Aragón et al. (2007)</td>
<td>Fungi fresh weight (Pinus nigra, P. sylvestris and P. halepensis forests, NE Spain)</td>
<td>17 models for single mushroom species, 1 model for non-edible production, 1 model for edible production, 1 model for edible non-marketed production, 1 model for edible marketed production, and 1 model for annual total production, all based on climate variables ($R^2$ from 0.20 to 0.78). 12 models for single mushroom species, 1 model for edible production, 1 model for edible marketed production, and 1 model for annual total production, all based on forest stand variables ($R^2$ from 0.16 to 0.53). 9 models for single mushroom species, 1 model for non-edible production, 1 model for edible production, 1 model for edible non-marketed production, 1 model for edible marketed production, and 1 model for annual total production, all based on combined climate and forest stand variables ($R^2$ from 0.40 to 0.68).</td>
</tr>
</tbody>
</table>
| Bonet et al. (2008)           | Fungi fresh weight [kg/ha-year] (P. sylvestris plantations, Central Pyrenees, Spain) | $\ln(wm) = 0.981 + 2.483 \ln(G) - 0.128G + 0.934 \cos(Asp) - 0.0135Slo^{1.5} + u_i + u_j$  
$\ln(wm_{edible}) = -4.329 + 1.966 \ln(G) - 0.118G + 0.636 \cos(Asp) + 0.00331Alt + u_i + u_j$  
$\ln(wm_{marketed}) = -6.236 + 1.246 \ln(G) - 0.0599G + 0.00459Alt + u_i + u_j$  
$\ln(wm_{Ld}) = -0.192 + 1.016 \ln(G) - 0.106G + 1.489 \cos(Asp) - 0.0151Slo^{1.5} + u_i + u_j$ |
| Bonet et al. (2010)           | Fungi fresh weight [kg/ha-year] (Pinus nigra, P. sylvestris and P. halepensis forests, NE Spain) | $\ln(wm) = -23.960 + 4.590 \ln(G) - 2.375G^{0.5} + 3.441 \ln(Ele) + 0.445 \ln(Slo + 1) \cdot \cos(Asp) + u_i + u_j$  
$u_i = 0.101 - 0.473 \cdot planted - 0.004Slo^{1.5} + 0.863 \cdot sylvestris$  
$u_j = -16.833 + 3.151 \ln(P_{azon})$  
$\ln(wm_{edible}) = -26.232 + 4.274 \ln(G) - 2.356G^{0.5} + 3.824 \ln(Ele) + 0.435 \ln(Slo + 1) \cdot \cos(Asp) + u_i + u_j$  
$u_i = 0.115 - 0.405 \cdot planted - 0.003Slo^{1.5} + 0.662 \cdot sylvestris$  
$u_j = -16.854 + 3.155 \ln(P_{azon})$  
$\ln(wm_{marketed}) = -26.232 + 4.274 \ln(G) - 2.356G^{0.5} + 3.824 \ln(Ele) + 0.435 \ln(Slo + 1) \cdot \cos(Asp) + u_i + u_j$  
$u_i = 0.275 - 0.985 \cdot planted - 0.008Slo^{1.5} + 1.628 \cdot sylvestris$  
$u_j = -21.490 + 4.025 \ln(P_{azon})$ |
Description of existing silvicultural systems

Table 4.4 Most important mushrooms yield models for Europe (cont.)

<table>
<thead>
<tr>
<th>Bonet et al. (2012)</th>
<th>Fungi fresh weight [kg/ha-year] (Pinus pinaster forests, NE Spain)</th>
<th>( \text{wm}<em>{Ld} = \exp(0.48026 + -0.09318G</em>{thin} + 0.87365 \ln(G_{thin}) + 0.02819P_{as}) )</th>
</tr>
</thead>
</table>
| Martínez-Peña et al. (2012) | Fungi fresh weight [kg/ha-year] (Pinus sylvestris forest, north-central Spain) | \( \text{wm} = \exp(-2.389 + 0.008P_{as} + 0.164T_{sol} + 0.664 \ln(H\text{dom}) - 0.005t) \)  
\( \text{wm}_{Ld} = \exp(-3.309 + 0.008P_{as} + 0.106T_{sol} + 0.653 \ln(H\text{dom}) - 0.018G) \)  
\( \text{wm}_{Be} = \exp(-14.706 + 0.007P_{as} + 0.129T_{sol} + 0.05049 \ln(G) - 0.121G) \) |
| Miina et al. (2013) | Number of Boletus edulis fruitbodies [fruitbodies/400 m²-year] (Picea abies forest, eastern Finland) | \( \text{n}_{Be} = \exp(-3.4085 + 0.1589G - 0.0044G^2 + 4.0766 \frac{G}{t+5}) \) |

\( \text{wm} \) is the total fungi fresh biomass (kg/ha-year); \( \text{wm}_{Ld} \) is the Lactarius group deliciosus fresh biomass (kg/ha-year); \( \text{wm}_{Be} \) is the Boletus edulis fresh biomass (kg/ha-year); \( \text{n}_{Be} \) is the number of Boletus edulis fruitbodies (fruitbodies/400 m²-year); \( P_{as} \) is the sum of total precipitation in August and September (mm); \( P_{aau} \) is the sum of total precipitation in August, September and October (mm); \( T_{sol} \) is the autum temperature (°C) (sum of the mean temperature in September, October and November); \( H\text{dom} \) is the stand dominant height (m); \( t \) is the stand age (years); \( G \) is the stand basal area (m²/ha); \( G_{thin} \) is the removed basal area (m²/ha) in thinning; \( u_{i} \) is a dummy variable equal to 1 for planted \( P. \text{sylvestris} \) stands and zero otherwise; \( u_{j} \) is a dummy variable equal to 1 for \( P. \text{sylvestris} \) dominated stands and zero for \( P. \text{nigra} \) and \( P. \text{halepensis} \) dominated stands.
### Table 4.5 Most important berry yield models for Europe

<table>
<thead>
<tr>
<th>Reference</th>
<th>Dependent variable</th>
<th>Model</th>
</tr>
</thead>
</table>
| Ihalainen and Pukkala (2001)      | Bilberry yield score [0–10] | \[
\ln(Score + 1) = 0.243 + 0.594SiteIII – IV + 0.0016H^2 \\
- 0.0137G_{P_a} - 0.189P_d
\] |
| Ihalainen et al. (2002)           | Priority of the stand in terms of bilberry yield | \[
\ln(v) = 0.0074T - 0.0108G + 0.0347H_{dom} + 0.0015V_p \\
- 0.0020V_d - 0.2102SiteV
\] |
| Ihalainen et al. (2003)           | Bilberry [kg/ha-year] yield | \[
\ln(v + 1) = 0.0830 + 0.0103T + 0.9904SiteIII + 0.4997SiteIV
\] |
| Ihalainen et al. (2005)           | Bilberry [kg/ha-year] yield | \[
\ln(v + 1) = 3.657 + 0.610SiteIII + 0.288SiteIV + 0.282Spruce \\
- 0.0014T - 0.0247N
\] |
| Miina et al. (2009)               | Coverage of bilberry [%] | \[
\begin{align*}
Cov &= 100 \times (1 + \exp[-f(\cdot)])^{-1} \\
&- 1.5053SiteV + 0.1209Pine - 0.4770Birch \times SiteII \\
&- 0.2588ArtRegen - 1.4715FormerAgrLand + 0.0029Alt \\
&+ 0.0080T - 0.0021T^2/100 + 0.0947G - 0.1916G^2/100
\end{align*}
\]  
Number of bilberries [berries/m²]  
\[
Berries_{ps} = \exp\{-0.5359 + 0.2398Cov - 0.2812Cov^2/100\}
\]  
\[
Berries_{pa} = \exp\{-4.2024 + 0.3635Cov - 0.4798Cov^2/100
\]  
\[
+ 0.3742G - 1.3447G^2/100\}
\]  
| Ihalainen and Pukkala (2001)      | Cowberry yield score [0–10] | \[
\ln(Score + 1) = 0.311 + 1.699SiteIV - V + 0.518Pine - 0.0224G \\
+ 0.0048t - 0.626SiteIV - V \times \ln(H + 1) + 0.0499SiteIV - V \times H
\] |
| Ihalainen et al. (2002)           | Priority of the stand in terms of cowberry yield | \[
\ln(v) = 0.00607 + 0.0027V_p - 0.0035V_d + 1.7817SiteIV - V \\
- 0.1756SiteIV - V \times D + 0.0052SiteIV - V \times D^2
\] |
### Table 4.5  Most important berry yield models for Europe (cont.)

<table>
<thead>
<tr>
<th>Reference</th>
<th>Dependent variable</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ihalainen et al.</td>
<td>Cowberry yield</td>
<td>( \ln(y + 1) = 1.0560 + 0.0005 SiteIV - V \times D^2 - 0.1196 \sqrt{G} )</td>
</tr>
</tbody>
</table>
| (2003)               | Cowberry yield     | \( \ln(y + 1) = 2.209 + 1.539D3 + 0.000058T^2 + 0.54\text{Pine} - 0.155N \\
|                      |                    | - 0.122D3 \times \ln(D + 1) + 0.218FC_{1B} \times N - 0.592FC_3      |
| Ihalainen et al.     | Coverage of cowberry | \( Cov = 100 \times (1 + \exp[-f(\cdot)])^{-1} \)                        |
| (2005)               | [\%]              | \( f(\cdot) = -4.7902 - 5.173SiteI - 2.569SiteII - 0.4216SiteIII \\
|                      |                    | - 0.4185SiteV - 2.0679SpruceMireI - II - 0.7984SpruceMireIII \\
|                      |                    | - 1.8198PineMireI - III - 0.5644PineMireIV \\
|                      |                    | - 1.7620PineMireV - 0.9438FormerAgrLand \\
|                      |                    | - 0.4327Spuce \times (SiteI - III or SpruceMireI - III) \\
|                      |                    | - 0.7528Birch \times (SiteI - III or SpruceMireI - III) \\
|                      |                    | + 2559.2/Temperature + 0.0039Alt + 0.0106T + 0.0157G \\
| Turtiainen et al.    | Number of cowberries | \( Berries_{Ps,Pa} = \exp[6.7253 + 0.0966Cov - 0.0837Cov^2 / 100 \\
| (2013)               | [berries/m²]       | - 0.4716\ln(G + 1) + 0.007\lnAlt - 462.64 / \text{TS}] \)               |

Score and \( y \) are, respectively, the score value (0-10) and priority of the stand in terms of berry yield based on expert evaluations; \( y \) is berry yield (kg/ha-year); \( Cov \) is the mean percentage coverage of berry plant in the stand (\%); \( Berries_{Ps} \) and \( Berries_{Pa} \) are the mean number of berries per m² in \textit{Pinus sylvestris} and \textit{Picea abies} stands, respectively; \( T \) is stand age (years); \( D \) is mean diameter (cm); \( H \) is mean height (m); \( G_0 \) and \( G_p \) are stand basal area and basal area of \textit{Picea abies} (m²/ha), respectively; \( H_{dom} \) is dominant height (m); \( N \) is the number of trees (1000 trees/ha); \( V_p \) is the volume of \textit{Pinus sylvestris} (m³/ha); \( V_d \) is the volume of deciduous trees (m³/ha); \( P_d \) is the proportion of deciduous trees of the total volume (0-1); \( Pine, Spruce \) and \( Birch \) are indicator variables for \textit{Pinus sylvestris}, \textit{Picea abies} and \textit{Betula p.}, respectively; \( FC_3 \) are indicator variables for regional Forestry Centres; \( Alt = \) altitude (m); \( TS = \) temperature sum (dd); \( SiteI = SiteV \) define the mineral site as follows: \( SiteI \) = herb-rich forest, \( SiteII = \) herb-rich heath (\textit{Oxalis-Myrtillus} group), \( SiteIII = \) mesic heath (\textit{Myrtillus} group), \( SiteIV = \) sub-xeric heath (\textit{Vaccinium} group) and \( SiteV = \) xeric heath forest (\textit{Calluna} group); \( SpruceMireI \) = \textit{V} and \( PineMireI \) = V define the peatland site as follows: \( I = \) eutrophic, \( II = \) herb-rich (mesotrophic), \( III = \) \textit{Vaccinium myrtillus} and tall-sedge (meso-oligotrophic), \( IV = \) \textit{Vaccinium vitis-idaea} and small-sedge (oligotrophic), \( V = \) cottongrass and dwarf-shrub (poor ombro-oligotrophic bogs); \( ArtRegen \) and \( FormerAgrLand \) are indicator variables for artificial regeneration methods and stand history (former agricultural land), respectively.
Description of existing silvicultural systems

4.3.3 Stand simulators for forest ecosystems that provide NWFP

According to the EFORWOOD project a stand simulator is a computer tool that, based on a set of forest models, makes long term predictions of the status of the forests within a stand under a certain scenario of climate, forest policy or management alternatives. The aim of this subchapter is to briefly describe those available stand simulators that directly predict NWFP or that have been used to predict a NWFP.

4.3.3.1 Cork oak

The desk based study identified 3 stand simulators for cork oak, two in Portugal – SUBER and CORKFITS – and one in Spain – ALCORNOQUE. Each one of these models is briefly described in the following sections, including a detailed list of references where the details about the models can be found.

4.3.3.1.1 SUBER

In spite of the importance of cork oak stands in Portugal, the first management oriented growth and yield model for this species, the SUBER model, was only developed in 1997 (Tomé et al. 1998, 1999). Due to the particular characteristics of this forest, a growth and yield model for cork oak stands, able to predict also cork yield and quality, is more complex than a model to estimate just wood production. The SUBER model is an individual tree model that, in its present version (v5), includes the following modules:

1. Estimation of site productivity
2. Model initialisation
3. Simulation of the growth of each tree
4. Simulation of cork variables
5. Simulation of silvicultural practices
6. Non-wood products
7. Ecosystem services

The SUBER model currently runs on sIMfLOR a Portuguese platform for forest simulators (Faias et al., 2012). A brief description of each one of the modules is given in the next paragraphs. More details can be seen in the literature (Tomé et al. 1999, 2001, 2004, 2005, 2006; Almeida et al. 2010; Paulo et al. 2005, 2011; Paulo and Tomé 2010).

1. Estimation of site productivity

The first difference in relation to the models for wood-oriented species is related to the definition of site index. In a cork oak stand, site characteristics may affect not only tree growth but also cork yield and quality, so the selected index to express site productivity should reflect both effects. Not much is known at the moment on the effects of site characteristics on cork parameters, therefore at the moment site index is defined on the basis of tree growth.

The SUBER model may be used to simulate even or uneven-aged stands. In even-aged stands of known age, site index is estimated using the site index curves from Sánchez-González et al. (2005) that allows to predict the dominant height for the stand at a given age using as predictor current dominant height. When age is not known or in uneven-aged stands, site index is estimated with one of the prediction equations developed by Paulo et al. (submitted).

2. Model initialisation
Characterisation of the stands, besides the characterisation of the trees, includes the selection of the area of the unit of simulation, site information and indication of the type of stand (even or uneven-aged, naturally regenerated or planted, spatial arrangement of the trees, etc). Characterisation of the trees includes: age, dbh, tree form (height of branching, number of main branches, type of cork (virgin, second or mature), date of last cork extraction for each tree, caliper (cork thickness) expected after 9 years, cork quality (including porosity and defects). The users can give these characteristics as an input to the model. Some of these characteristics, more difficult to obtain in practice, can be simulated by the model on the basis of the relative frequency distribution given by the user or predicted as a function of stand characteristics such as number of trees per ha and stand basal area.

3. Tree growth simulation

Tree growth simulation takes into account 3 stages of tree development: 1) regeneration, until the tree attains a height of 3 meters; 2) juvenile, until the first debarking; 3) mature, after the first debarking. Tree height growth is the variable used to project tree growth in the regeneration stage. Tree height is initialized using simulation of tree height distribution and the trees are grown in height until they attain a height greater or equal to 3 m. At that point the dbh is predicted with an equation that uses tree height, stand characteristics and inter-tree competition as predictors and the tree moves to the juvenile stage. The model for individual tree dbh under cork growth (Tomé et al. 2006) is the core for individual tree growth simulation of trees in the juvenile and mature stand. Individual tree height is predicted with a heightdbh curve (Paulo et al. 2011), although this variable is not very important at this stage as cork yield does not depend on total tree height but on the height of debarking, a silvicultural decision (with some restrictions fixed by Portuguese legislation). Crown diameter is an essential variable as it is the basis for the more commonly used thinning rules, and is estimated as a function of tree dbh under cork and stand characteristics, a new improved equation to predict crown width has just been developed (Paulo et al. working paper). The simulation of the definitive stem form (last pruning occurs usually at the time of the second cork extraction) is a silvicultural decision and therefore associated to each tree according to a pre-defined distribution that can be modified by the user.

4. Simulation of cork growth and yield

Cork oak is debarked during the growing season, starting the growth of new cork shortly after the extraction. This is the reason why the first and last growth rings are not complete. Figure 4.2 shows an example of a cork with 9 years of age (8 complete growth rings). The first cork growth ring, located adjacent to the cork back, is usually smaller than the subsequent rings as it corresponds to the growth of cork in the growing season during which cork was extracted, after debarking. Therefore it is not a complete growth ring and is usually called the 1st half ring. Similarly, the last cork growth ring corresponds also to a partial growing period, before cork extraction, and is called the last half ring. The production of new cork is more intense in the years immediately after debarking and decreases from then on. The caliber of a cork plank with tc years (cork age is designated by tc in order to distinguish from stand/tree age that is usually designated by t) is equal to the sum of the thickness of the tc-1 complete rings plus the thickness of the two half rings (initial and final) and of the cork back thickness. For sake of clarity, the term cork caliber (cc) is used here for the total cork thickness while the thickness in complete rings is designated by thickness of cork complete rings or simply by cork thickness (ct) as did other authors (Sánchez-González et al. 2008).
Cork growth modelling in SUBER focus just the complete years of growth. Cork growth is modelled with growth functions formulated as difference equations, using a methodology similar to the one used for dominant height growth (Almeida et al. 2010). These authors also modelled the prediction of cork caliber using the cork thickness (complete years) as regressor and vice-versa. In order to express tree cork growth rate, the authors proposed the use of a cork growth index defined as the cork thickness (complete years) of a cork with 9 years which corresponds to 8 complete growth years.

The SUBER models uses a methodology for cork weight prediction that allows for the prediction of cork weight for different cork ages. This methodology (Paulo and Tomé 2010) is supported on the homogeneity of the density of the cork tissue between the inner and outer cork rings (Barbato 2004) as opposed to cork back that has about three times the density of cork: 150-225 kg m⁻³ in cork layers and 495-608 kg m⁻³ in cork back (Pereira 2007). The method for prediction of cork weight for a cork with t years of growth (wcmt) is based on the estimation of cork biomass if the cork had 9 years of growth (wcm9). It includes three steps:

i. Estimate tree cork biomass for 9 years of age (wcm9)

This estimation implies the use of the diameter growth model (Tomé et al. 2006) to estimate diameter when cork will have 9 years. If the cork weight model includes cork thickness as regressor, the cork growth model (Almeida et al. 2010) is needed in order to estimate cork thickness at 9 years of age (ct9).

ii. Estimate the cork back weight proportion at nine years of age (cbp9). Estimate cork biomass at 9 years free from cork back (wcm9_b):

$$wcm_{9_b} = wcm_9 \left(1 - \frac{cbp_9}{100}\right) = wcm_9 - \frac{wcm_9 \cdot cbp_9}{100} \text{ biomass of cork back}$$

iii. Estimate cork biomass for t years of growth (wcmt):
\[
\text{wcm}_t = \frac{\text{wcm}_{t,b}}{\text{ctab}_{t}} + \frac{\text{wcm}_0 \times \text{cbp}_0}{100}
\]

where \( \text{wcm}_t \) is cork biomass with \( t \) years of growth, \( \text{wcm}_{t,b} \) is cork biomass with \( t \) years free from cork back, \( \text{ct} \) is cork thickness with \( t \) years of growth and \( \text{cbp} \) is cork back proportion.

All the models described above refer to mature cork. There are just a few models for the virgin cork (the first cork produced by the first periderm). Tomé (2004) presents an equation to predict diameter over bark, essential to compute stand basal area that, for cork oak, is computed under bark. Tomé (2004) also presents an equation to predict virgin cork weight in juvenile trees.

5. Simulation of silvicultural practices

The simulation of the several practices involved in cork oak stands management is considered. Thinning is a particularly important operation. Its simulation implies the definition of criteria to decide for the opportunity of thinning as well as a rule to select the trees to be thinned. SUBER uses crown cover (%) to define the need for thinning, but in the current stand simulator this operation just takes place on years previously defined by the user. Two thinning types may be applied, respectively for even-aged and uneven-aged stands. In both cases, trees may be thinned using a distance-dependent algorithm (based on the Hegyi competition index) or a equation that predicts the probability for a tree to be thinned. Other important practices are pruning and debarking intensity. Pruning is simulated by modifying tree and stem form. The debarking intensity is assessed by the coefficient of debarking, the relationship between the height of debarking (in m) and tree cbh (in m). Usually applied values of coefficient of debarking are in the range 1.5 to 2.0. This last value is the maximum allowed by the Portuguese legislation.

Wood from thinnings is computed and used as a product that is gaining importance in the industry.

8. Non-wood products

This module is still not very complete but it is considered very important and is therefore one of the focus of current research. At present, the model allows for the consideration of the income from deer that implies restrictions on the percent crown cover and therefore on the cork yield.

9. Ecosystem services

The SUBER model includes a system of equations for the prediction of tree biomass, total and per ree component. Carbon stock and carbon sequestration are therefore one of the outputs of the models that has already been used in studies related to carbon sequestration (Cañellas et al. 2008; Coelho et al. 2012).

4.3.3.1.2 ALCORNOQUE

In Spain, there is available a stand simulator for cork oak called ALCORNOQUE, which is an integrated growth and yield model at individual tree level for high density cork oak forests (as opposed to woodlands which are associated with lower densities). The model consists of a system of mathematical functions which allow the evolution of growth and yield to be simulated under different silvicultural regimes. The simulator is available as a MS Excel complement currently, but shortly it will be included in a web application designed to facilitate the management of Spanish cork oak forests.

A flow chart displaying the structure of the ALCORNOQUE is shown in Figure 4.1. The stand simulator is composed by the following modules:
1. **Missing variables module:** This module includes a generalized height-diameter equation and a crown diameter prediction equation (Sánchez-González et al. 2007c). The former allows a height prediction to be made for any tree in a stand as long as the conditions are within the same range as those of the data set; and the latter provides reliable estimations of crown width and is sensitive to quadratic mean diameter variations.

2. **Site quality module:** It is composed by the height growth model for dominant cork oaks developed by Sánchez-González et al. (2005) that allows predict the dominant height for the stand at a given age using as predictor current dominant height. Since height is a variable that is not always available in cork oaks inventories, this module also count with a diameter growth model for dominant cork oaks (Sánchez-González et al. 2005).

3. **Simulation module:** This module allows defining the size of trees and cork production of each tree in any year within the debarking period. It includes a submodel that predict the annual diameter increment of each tree as a function of initial diameter, site productivity and stand density (Sánchez-González et al. 2006); and a cork growth model capable of estimating the final cork thickness at any year during the cork rotation with more than 80% reliability, or nearly 90% if the prediction is made in the second half of the rotation (Sánchez-González et al. 2008a). In addition, the module count with a stochastic model to predict cork thickness and weight (Sánchez-González et al. 2007b; Sánchez-González et al. 2007a).

![Figure 4.1 Structure of the ALCORNOQUE simulator](image)

**4.3.3.1.3 CORKFITS**

CORKFITS is a cork oak tree spatial growth simulator for cork oak woodlands in Portugal. It is composed by sub growth models (cork, stem, tree height and crown), cork production models and mortality models. The simulator was built assuming the potential increment modifier principle: \( z = z_{pot} \times \text{modifier} + \epsilon \), where \( z_{pot} \) is the potential growth as function of site; modifier is the reduction
factor as function of spatial competition index and the intensity of debark; $\varepsilon$ is a random error. It is time independent being growth dependent on growth driver variables. A structure generator STRUGEN, based on a filtered Poisson process (Pretzsch 1992, 1997), whose filters were parameterised for cork oak stands natural spatial structure. The STRUGEN is used to simulate virtual stands as well as regeneration (Ribeiro et al. 2001).

![Flow chart from CORKFITS simulator](image)

**Figure 4.1** Flow chart from CORKFITS simulator

### 4.3.3.2 Stone pine

#### 4.3.3.2.1 PINEA2

The first stand simulator for *Pinus pinea* L. in Europe is PINEA2 v1.0 that implements PINEA2 model, an integrated model for the multifunctional management of pure even-aged stands of *Pinus pinea* in the Spanish Northern Plateau. As a single tree-level model, PINEA2 v1.0 stand simulator simulates the evolution and yield of a stand by simulating the growth, dynamics and production (timber, cones, biomass, fixed CO$_2$) of every tree within the stand in five-years steps. Management alternatives currently allowed to the user are low thinning application (defining intensity and frequency) and the length of the simulation cycle. PINEA2 v 1.0 is programmed as a Microsoft Excel complement (.xla file), compiled under Visual Basic for Microsoft Application (VBA) programming language. Basic requirement for using PINEA2 v 1.0 is to have available a PC incorporating MS Excel. Current version of the software can be used uniquely in pure even-aged stands of *Pinus pinea* within the Northern Plateau (Madrigal et al. 2009).
PINEA2 model is an integrated distance independent single-tree level model for predicting growth and yield in natural pure even-aged stands of Pinus pinea in Spain (Calama et al. 2007a; Calama et al. 2007b). Current extensions to uneven aged stands (Calama et al. 2008a) and afforestation (Calama et al. 2009) are nowadays available. A new version for heterogeneous mixed stands, including mixtures with species as Quercus ilex, Quercus faginea, Juniperus turifera, J. oxycedrus and Pinus pinaster is under construction. PINEA2 substituted former PINEA model, a diameter distribution model developed by García-Güemes (1999).

PINEA2 is a modular system which enables to simulate the growth and yield (timber and cones) of a pure stand of Pinus pinea under different management scenarios. As a single tree model, PINEA2 simulates the evolution of every tree within the stand at five year steps. Input variables for PINEA2 include breast height diameter of all the trees within the stand (or a diameter distribution function for the stand) and current stand density, age and dominant height. PINEA2 is composed by the following modules (Figure 4.3):

1. **Auxiliary module:** Includes all the basic functions required to run the model from the input parameters: basal area, competition indices, crown cover factor, mean squared diameter, mean height, Reineke and Hart-Becking stocking indices.

2. **Site quality module:** Based on the site index model by Calama et al. (2003), this module allows predicting the dominant height for the stand at a given age using as predictor current dominant height.

3. **State module:** This module includes the following four submodules:
   - **Tree size submodule:** includes basic size functions which enable to define the state of the stand for every instant of simulation: height-diameter function (Calama and Montero, 2004) and crown dimensions (width and height) functions (Cañas 2000).
   - **Timber submodule:** includes a stem taper curve, which allow volume prediction with end timber use classification.
   - **Biomass submodule:** includes the whole tree and tree fractions biomass equations for the species (Ruiz-Peinado et al. 2011) as well the factors in order to transform biomass into fixed CO2.
   - **Cone production module:** PINEA2 includes a function to predict the average annual cone production produced by a tree during the five year step period (Calama et al. 2008b), including as predictor covariates tree diameter, stand density, site index, competition and a soil and climate based stratification of the territory. The more recent version of the model involves a new classification of the territory and new reparameterization of the model.

4. **Transition module:** This module is designed to define the state of the stand at an age t+5 based on the state of the stand at age t. It includes a model (Calama and Montero 2005) to predict diameter increment as a function of current diameter, site index, stand density and a distance independent index (ratio between breast height diameter and mean diameter). Self-thinning mortality can be simulated by means of Reineke index, showing mortality on values over 600 (Montero and Candela 1998). However, natural stands hardly attain this high level of stocking, so only random mortality – assumed to occur at a rate of 1% every 5 years up to an age of 100 years, and at a rate of 3% over this age – is considered.

5. **Management module:** PINEA2 allows the simulation of different management approaches defined by (i) thinning: type (from below, high selective or systematic/random), intensity (number of stems/ha or basal area), instant and frequency for thinning application; (ii) rotation length.
The output of PINEA2 includes, for each 5 year period of simulation; (i) stand attributes (stand density, basal area, mean diameter, diameter and height distributions, mean and dominant height); (ii) accumulated and standing volume, classified according to its end use (saw timber, pulpwood and fuelwood); (iii) annual and accumulated cone production per ha; (iv) accumulated and standing biomass defined by tree components and CO2 stock; (v) current and mean annual volume and biomass increments.

PINEA2 v 1.0 is freely available at https://sites.google.com/site/regeneracionnatural/pinea2

4.3.3.2.2 StandsSIM-PINEA

Freire (2009) developed a set of equations that allow the projection of Pinus pinea stands either even and uneven-aged stands. These equations were implemented into the Portuguese Stand Simulator StandsSIM that projects a series of stands using pre-defined prescriptions. Prescriptions are defined on the basis of the concept of Forest Management Approach (FMA). A FMA defines the set of operations that take place in a rotation (even-aged stands) or a cycle (uneven-aged stands). A prescription defines all the operations that take place in a planning horizon. In StandsSIM a prescription is defined by a succession of FMAs. It allows for clearcuts, land use changes, species conversion, etc.

The model is structured in a way similar to the SUBER model. It includes the following modules:

1. Estimation of site productivity
2. Model initialisation
3. Simulation of the growth of each tree
4. Simulation of silvicultural practices
5. Non-wood products
6. Ecosystem services

A brief description of each module follows. More details can be seen in Freire (2009).

1. Estimation of site productivity
In StandsSIM-PINEA, site productivity is defined by a growth index as defined by Trasobares et al. (2004b). This growth index (Gindex) compares the growth observed in the plot that is being simulated (increment cores taken in 5 model trees) with the average growth expected for trees of the same size and located in a similar stand:

\[
G_{\text{index}} = \frac{1}{5} \sum_{i=1}^{5} \left( \frac{d_i - \hat{d}_i}{\bar{d}} \right) = \begin{cases} 1 - \text{ good site} \\ 0.5 - \text{ average site} \\ 0 - \text{ poor site} \end{cases}
\]

where \(d_i\) and \(\hat{d}_i\) are, respectively, the observed and estimated average increment for each model tree.

2. Model initialisation

Not yet implemented

3. Simulation of the growth of each tree

The growth of each tree is driven by an individual dbh growth model that predicts the growth of each tree using tree size, site productivity (Gindex), stand density and inter-tree competition as predictors (Freire 2009). Tree height and crown variables are predicted with prediction equations.

4. Simulation of silvicultural practices

At present thinning is the only silvicultural treatment that is simulated. The need for thining is checked according to a schedule previously fixed by the user and two criteria may be used to decide if thinning is applied: a limit basal area or a limit percent crown cover. Low thinning is then applied until a user-defined residual basal area or percent crown cover are attained.

Wood from thinnings and clearcut (if this is part of the silvicultural approach selected) are estimated with volume equations.

5. Non-wood products

Pine nuts are the most important revenue of stone pine and therefore special attention has been given to its prediction. Pine nuts yield is predicted in two steps (Freire 2009): 1) first it is decided, based on the prediction of the probability for each tree to produce pine nuts, which trees are considered for the cones production; 2) the cones production of each tree (average production, masting is not taken into account) is predicted with an equation that uses tree size (dbh and crown variables) and stand density as regressors.

6. Ecosystem services

The model includes a system of equations (Correia et al. 2010) that is used to predict individual tree biomass, total and per tree component, that allows the estimation of carbon stocks and carbon sequestration.

**4.3.3.3 Maritime pine**

The inquiry of the FORMODELS data bases showed that there are several stand simulators available for maritime pine (considering all stand structures and composition 15 stand simulators are listed). Maritime pine has been one of the best-studied forest species in Spain, Portugal and France, and numerous growth models are available (see Appendix A). However, none of the stand simulators include NWFP (in this case resin) as one of the outputs.
4.3.3.4 Scots pine

A large number of stand simulators for Scots pine have been developed in Europe in the last decade (e.g. Chertov et al. 2006; Diéguez-Aranda 2004; Chumachenko et al. 2003; Pretzsch et al. 2002; Hynynen et al. 2005; Rasinmäki et al. 2009; De-Coligny et al. 2002), however only in Finland and Spain the stand simulators for Scots pine include the prediction of NWFP yield, namely berries in Finland and mushrooms in Spain.

4.3.3.4.1 Berries production

In Finland, Miina et al. (2010) include the bilberry yield models developed by Miina et al. (2009) in an anonymous stand growth simulator to optimize the joint production of timber and bilberry on sites where the potential bilberry yield was high. Stand development was simulated using the models of Hynynen et al. (2002) for site index, dominant height development, diameter increment, crown height, height increment and tree survival. The taper models of Laasasenaho (1982) were used to calculate assortment volumes of removed trees.

Turtiainen et al. (2013) run MOTTI simulator (Hynynen et al. 2005) to describe initial characteristics, development and management of various stands, and then predict the coverage of cowberry and the cowberry yield and its annual variation in those stands as a function of simulated stand characteristics. MOTTI is a stand-level decision support tool for assessing the effects of forest management practices on stand dynamics and the profitability of forest management. It also includes model components that predict biomass production, carbon sequestration and biodiversity.

Hynynen et al. (2005) described the MOTTI simulator in the following way: „MOTTI is designed to be compatible with the sort of information that is usually available in forest inventory databases. As input data, MOTTI requires information about the site, location and treatment history of a stand, and either stand-level or tree-level data of the growing stock. In the simulation, both static and dynamic model components are applied. The static models are applied to update tree and stand characteristics during the simulation, such as tree and stand volumes, biomass, and tree crown characteristics. Dynamic models are applied to predict tree growth and mortality rates for 5-year growth periods. MOTTI includes several user-defined treatment options for thinning, fertilization and ditching with their respective costs and revenues. Management practices can be defined either during the simulation or in the beginning of a simulation by defining the stand management regime for the entire simulation period. With MOTTI, part of the analysis of the results can be obtained directly from stand simulation, such as growth and yield information, mortality and biomass production. Financial analysis, and analyses of carbon sequestration and biodiversity, are produced by analysis components that apply the information produced by the stand simulator. For financial analyses, MOTTI includes several user-defined parameters, such as the costs of management practices, timber prices, financial time horizon, and interest rate.“

4.3.3.4.2 Mushrooms production

In Spain, Palahí et al. (2009) examined the optimal economic management for both timber and mushrooms in managed Scots pine and Black pine stands in Catalonia. Stand growth was simulated using the models for Pinus sylvestris L. and Pinus nigra Arn. developed by Trasobares and Pukkala (2004) which consist of individual tree diameter growth, height models and survival functions. Annual mushroom yields were predicted with the mushroom yield models of Bonet et al. (2010). These mushroom yield models were integrated in an anonymous stand growth simulator, which was
linked with an optimization algorithm to find the optimal management schedule for Scots pine and Black pine stands on different sites and with different mushrooms prices.

4.4 Discussion: plans and perspectives for the STARTREE project in relation to models and simulators improvement/development

The previous sections show that there is the need to improve and enlarge the models that are available to predict NWFP in Europe. In some cases, as is the case of fruits, there is no model available. In other cases, as for cork, models available are already quite sophisticated but still have some weaknesses. This situation reflects the difficulty of modelling NWFP that results from the difficulty in obtaining data but also from the complexity of modelling them. In what concerns data there is the need to have long term series of data (due to the masting habit) covering a large range of sites and stand characteristics (to be able to catch the spatial variability that can be found in nature for NWFP yield). Calama et al. (2010) summarized these difficulties as follows:

- NTWP data are usually non-normal, showing asymmetric distributions with a heavy, right tail and abundance of zeroes. Given the nature of the inventories, spatial and temporal correlations among observations are also common.
- High inter-annual and spatial variability, which require the systematic collection of long annual data series as well as a good characterization of weather/climate conditions and soil attributes.
- Site index constitutes the main driver of empirical growth and yield models, devoted to timber production. However, traditional site index (defined as the dominant height of the stand at a given index age) does not usually indicate the potential productivity of NWFP. Other ecological attributes, such as topography, climate or soil conditions, are required to estimate the site potential productivity.
- If compared with timber harvesting, NWFP show a high frequency (annually, monthly) of collection, and, in several occasions, the products are perishable with a short picking period. In other occasions, these products are threatened of unauthorized or uncontrolled collections. Therefore NWFP data collection requires intensive monitoring systems, with a great effort of field work.
- The production of NWFP like fruits, barks or resins involves several complex physiological processes such as allocation of carbohydrates to growth, flowering and fruiting, or other traits. These processes are generally scarcely known, making it difficult the development of process based models for this purpose.
- When referring to NWFP, quality requirements are usually as important as the total amount of production. Therefore, models for NWFP should also consider quality attributes as main response variables.

The StarTree project is expected to give a relevant contribution for the improvement of the situation in relation to the availability of models to predict NWFP as well as to the improvement of some of the existing models. Several actions that are planned will contribute for that:

1. Data collection – some partners have planned the gathering of data in relation to some products (e.g. berries, pine nuts, mushrooms)
2. Development of new statistical models – for the NWFP in relation to which no prediction model is available and new data is being collected under StarTree, new models will start to be developed as soon as the data are enough for model development. This will take advantage of the large modelling expertise of some of the partners that may collaborate with other partners with less experience.
3. Development of new expert-based models – inside the StarTree team there are partners that have developed expert models for the NWFP important for their regions. This expertise may be shared with other partners in order to develop models for the same or other products of interest in their own regions.

4. Combination of data bases from different countries to check the possibility to develop models with a larger range of applicability and that may take advantage of the strengths of different data bases.

5. Analysis of the existing stand simulators to check if it will be possible to share/complement computer code in order to obtain more user-friend interfaces that are appealing to forest owners and forest professionals that are responsible for forest management.

To summarize, it is expected that StarTree will represent a big advance in the quality of forest management when NWFP are part of the management objectives.
5 Description of existing decision support systems that include production of NWFP

Coordination: MK
Authors: MK, JM, JB, SdM, KS, EZB, HV

5.1 Introduction

5.1.1 What are Forest-DSS?

Planning and decision making for a sustained provision of NWFP can be supported in many ways. Decision support can include anything from a simple look-up table to a simulation model or even a flow chart on paper. Drawing on various definitions that have been suggested, DSS are seen as particularly useful for unstructured, ill and semi-structured problems (Vacik and Lexer 2013). Ill-structured and semi-structured problems typically deal with situations where, human judgement is vital for problem solving and limitations in human information processing may impede the decision making process (Rauscher 1999; Martinsons and Davison 2007). Accordingly, Mc Nurlin and Sprague (2004) define DSS as “computer-based systems that help decision makers confront ill-structured problems through direct interaction with data and analysis models”.

According to Watson and Sprague (1993), a DSS includes three major components: a dialog subsystem, a data base subsystem, and a model base subsystem. The components of this model-driven definition can be related to the trilogy of interface subsystem, knowledge subsystem, and problem processing subsystem as proposed by Holsapple and Whinston (1996). The three-component core architecture (Watson and Sprague 1993; Holsapple and Whinston 1996) is capable of managing data, fitting data to models and providing methods to reach decisions. For that purpose, in a forestry framework, the knowledge subsystem is typically sub-divided into three components: one that holds data (e.g. data on the forest concerned); one that holds models (e.g. models for predicting growth and yield); and one that holds methods (e.g. for calculating key statistics or a solver for optimizing a problem) (Eriksson et al. 2013). More pragmatic approaches attempt to categorize the huge number of different DSS developed according to the degree that DSS’s output could directly determine the decision (Alter 1980). Power (2007) classified DSS into five broad DSS categories including communications-driven, data-driven, document driven, knowledge-driven and model-driven decision support systems.

As DSS have proved to be suitable platforms for integration of information, models and methods supporting complex forest management problems (e.g. Reynolds et al. 2005), the ultimate purpose of the activities of STARTREE project related to DSSs is to improve existing and develop new DSS for optimizing forest management alternatives combining timber production and NWFP. In accordance with Leung (1997) and Rauscher (1999) we use in the context of the STARTREE project a combined functional and technical approach and define Decision Support Systems (DSS) as computer-based tools which provide support to develop the framework and solve ill-structured decision problems by integrating database management systems with analytical models and operational research techniques, graphic display, tabular reporting capabilities, and the expert knowledge of scientists, managers, and decision makers to assist in specific decision making activities. This definition is consistent with the findings by a recent review of computerized tools to support forest management word-wide (Borges et al. 2014) in the framework of the FORSYS Network and the follow up Community of Practice on Forest Management Decision Support Systems (www.forestdss.org). Such
Description of existing silvicultural systems

5.1.2 Principle of including NWFP in DSS

In Europe tree growth simulators have become available for practical forest management decision support after the 1990s (e.g. Hasenauer et al. 1995; Monserud et al. 1997; Hynynen et al. 2002; Pretzsch et al. 2002). They allowed assessing the effects of adopting alternative silvicultural measures on production and vegetation structure in a flexible manner (Figure 5.1). Forest growth models are often used in combination with optimization and multi-criteria decision support (MCA) methods to support the comparison phase that is essential in forest planning (e.g. Diaz-Balteiro and Romero 2008). While tree-growth models have been extended with GUI and visualization for numerous tree-species and forest management environments in different countries (e.g. Pretzsch et al. 2006), they have also been linked with OR and MCDA routines to assist in solving forest planning problems. These components have been integrated technically and functionally in simulator systems (e.g. Pukkala and Kangas 1993; Borges et al 2003; Wikström et al. 2011). Forest models have further been extended to estimate the yield or value of NWFP (see chapter 4). Typically, these models predict the yield of NWFP based on the value of stand-level biometric variables (e.g. basal area, density, age etc.) that are controllable by forest management. Therefore they provide the information needed to assess the impact of management options on the provision of NWFP. In addition, it is evident that also environmental variables reflecting the topographic and climatic conditions which cannot be controlled by the forest manager affect the yield of NWFP.

Figure 5.1 The conceptual outline of DSSs with NWFP and MPT capabilities.
5.1.3 Aim of the chapter

Forest-DSSs are needed to support forest owners’ decision making in different contexts. Forest owners have varying and various forest management goals. When they make decisions regarding the management of their forests, they need information on how the management affects the provision of different products and services from their forests and also on trade-offs between different products and services. For these purposes forest-DSSs are useful tools in developing a feasible set of management alternatives for planning units and then supporting the decision-making situation in which the right ones are picked up among them.

In this chapter, we analyze the availability of forest-DSSs that include modules to deal with NWFP, considering an European level scope. Specifically, we aim at providing information on:

- What is the availability, actual use and demand towards forest DSSs in practical forest management based on professional foresters questionnaire carried out in 14 regions in Europe.
- What is the actual supply of forest-DSS and what NWFP they cover - for this question, we will analyse the properties of existing forest-DSS e.g. how they are able to deal with NWFP
- Following this state-of-art review, an example of an advanced forest-DSS shows the potential avenues for the further development of forest-DSSs in different parts of Europe

The chapter is organized as follows. After this introductory section, in which the basic definitions were given, the next sub-chapter (5.2) shows the professional foresters responses to availability and use of DSSs. This is followed by description of the data collection procedure from forest-DSS wiki database and the description of characteristics of existing forest-DSSs with capabilities related to NWFP and MPTs. Finally, we show an advanced example and provide guidance on developing and improving the capabilities of DSSs for dealing with NWFP.

5.2 Availability and use of forest DSS in practical forest management

If the results of the StarTree project are aiming to affect the forest management and silvicultural practices in different parts of the Europe, it is important to know what kind of decision support and planning tools forest owners currently use when they make their forest management decisions.

The results of professional forester’s questionnaire show (Figure 5.2) that in particular in private family owned forests the most commonly applied decision support is a printed forest plan. It is the most often applied tool in Alentejo, Bursa, Catalonia, North Karelia, Suceava and Wales. Thus, forest owners make their forest management decisions on the basis of forest management plans that provide the prescriptions based forest inventory data from their holdings. Forest owners rarely use themselves modern planning approaches (computerized DSSs including e.g. forest simulators for predicting tree growth, optimizers for selecting an appropriate harvesting schedule etc.). This situation is quite common in Austria and in Finland, where a large proportion of the forest owners are small scaled, which often prevents the use of more sophisticated planning tools. In forests of other ownerships (state, municipality and common forests), the situation does not surprisingly differ that much, although in these ownership group general instructions apply more commonly and situation specific considerations are more rare.
Description of existing silvicultural systems

Figure 5.2  The decision support forest owners are most commonly applying when they are making forest management decisions, based on forestry professionals responses from 13 regions. Other forest ownerships includes forests owned by state, municipalities, companies as well as commonly owned forests.

The professional foresters rarely know forest planning systems that include considerations of NWFP or MPT in their region. Some professionals in Alentejo, Catalonia, North Karelia Styria, Trentino and Valladolid could name one or several planning systems that are able to consider some MPT or NWFP product(s) (Table 5.1). The planning systems are able to consider rather often mushrooms (4 regions), berries and cork (both in two regions).

Table 5.1  Professional foresters’ knowledge on forest planning systems that include consideration of NWFP in their regions (N=232).

<table>
<thead>
<tr>
<th>Region</th>
<th>n</th>
<th>no/ null</th>
<th>yes</th>
<th>Name of the planning system</th>
<th>NWFP or MPT product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alentejo</td>
<td>10</td>
<td>100 %</td>
<td></td>
<td>PROF</td>
<td>Cork, stone pine, mushrooms</td>
</tr>
<tr>
<td>Bursa</td>
<td>15</td>
<td>100 %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Catalonia</td>
<td>28</td>
<td>59 %</td>
<td>41 %</td>
<td>PNIN of Poblet, ORGEST, &quot;forest management plans&quot;</td>
<td>Cork, oak, mushrooms, genciana, fir cons, black truffle, A. uva ursi</td>
</tr>
<tr>
<td>Eastern Scotland</td>
<td>19</td>
<td>100 %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Latvia</td>
<td>1</td>
<td>100 %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North Karelia</td>
<td>19</td>
<td>84 %</td>
<td>16 %</td>
<td>Unknown system</td>
<td>Berries</td>
</tr>
<tr>
<td>Styria</td>
<td>3</td>
<td>67 %</td>
<td>33 %</td>
<td>Austrian forest charta</td>
<td></td>
</tr>
<tr>
<td>Suceava</td>
<td>5</td>
<td>100 %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sumadija and Western Serbia</td>
<td>60</td>
<td>98 %</td>
<td>2 %</td>
<td>Berries, herbs, mushrooms</td>
<td></td>
</tr>
<tr>
<td>Trentino</td>
<td>16</td>
<td>87 %</td>
<td>13 %</td>
<td>Forest management regional plan (CYL), private forest management plan</td>
<td>Pine nuts, wood, resin, chestnut, truffel, others</td>
</tr>
<tr>
<td>Valladolid</td>
<td>9</td>
<td>56 %</td>
<td>44 %</td>
<td>PORF, Jcyl, GESFOR</td>
<td>Pine nuts, mushrooms, pinecones, resin, pastures, gaming, medicinal wild herbs</td>
</tr>
<tr>
<td>Waldmärker</td>
<td>19</td>
<td>100 %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>West Wales and the Valley</td>
<td>28</td>
<td>95 %</td>
<td>5 %</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Positively, professional foresters indicate in eight regions that they would need information on how forest management affects the yield of different NWFP and MPTs (Table 5.2). The information needs are rather broad in regions where this information is considered important. In three regions, some professionals answered “all”, potentially indicating increasing needs to consider NWFP and MPTs in forest management. In different regions, when compared to abilities of the current planning systems (Table 5.1), new NWFP and MPTs are for example aromatic and medicinal herbs/plants (4 regions) and wild fruits (2 regions).

Table 5.2 Professional foresters opinion related to the need of information on how forest management operations would affect the yield of different NWFP and MPTs (N=232).

<table>
<thead>
<tr>
<th>Region</th>
<th>N</th>
<th>no / null</th>
<th>yes</th>
<th>NWFP or MPT product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alentejo</td>
<td>10</td>
<td>100 %</td>
<td></td>
<td>Cork</td>
</tr>
<tr>
<td>Bursa</td>
<td>15</td>
<td>8 %</td>
<td>92 %</td>
<td></td>
</tr>
<tr>
<td>Catalonia</td>
<td>28</td>
<td>18 %</td>
<td>82 %</td>
<td>Aromatic plants, black truffle, cork, grassland, honey, medicinal plants mushrooms, nuts, pine, resin (all)</td>
</tr>
<tr>
<td>Eastern Scotland</td>
<td>19</td>
<td>37 %</td>
<td>63 %</td>
<td>Fruits, hazel, mushrooms</td>
</tr>
<tr>
<td>Latvia</td>
<td>1</td>
<td>100 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>North Karelia</td>
<td>19</td>
<td>58 %</td>
<td>42 %</td>
<td>Berries, game, mushrooms,</td>
</tr>
<tr>
<td>Styria</td>
<td>3</td>
<td>100 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suceava</td>
<td>5</td>
<td>100 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sumadija and Western Serbia</td>
<td>60</td>
<td>15 %</td>
<td>85 %</td>
<td>Berries, herbs, mushrooms,</td>
</tr>
<tr>
<td>Trentino</td>
<td>16</td>
<td>100 %</td>
<td></td>
<td>Lime tree flowers</td>
</tr>
<tr>
<td>Valladolid</td>
<td>9</td>
<td>100 %</td>
<td></td>
<td>Medical wild herbs, mushrooms, pinecones, pine nuts, resin, wild fruits, (all)</td>
</tr>
<tr>
<td>Waldmärker</td>
<td>19</td>
<td>67 %</td>
<td>33 %</td>
<td>Decorative green brances, game, herbs</td>
</tr>
<tr>
<td>West Wales and The Valley</td>
<td>28</td>
<td>68 %</td>
<td>32 %</td>
<td>Moss, mushrooms, willow, (all)</td>
</tr>
</tbody>
</table>

5.3 DATA collection procedure using the forest-DSS wiki database within FORSYS

The analysis of available forest-DSSs builds on the recently finished FORSYS COST action (FP0804). In this action, information on numerous forest-DSS was collected. The group of experts took part in the conceptualization of the semantic wiki (i.e. identification of wiki properties and forms), provided content and developed queries to analyse the information gathered. The Semantic MediaWiki (SMW) is an extension of the open-source wiki software MediaWiki (e.g. Krötzsch et al. 2006). The SMW is similar to content management systems that allow simple semantic editing and searching features just by mastering a set of basic elements thus without the need to be a specialist in knowledge representation and ontology development. The resulting wiki gives an overview of the current use, development and application of forest decision support systems worldwide. However, at the beginning of year 2014, the wiki-materials were relocated under the webpages of the Community of Practice “ForestDSS” (http://www.forestdss.org/wiki/index.php?title=Category:DSS) so that the wiki-database of forest-DSSs can be maintained up-to-date also after the finalized COST-action.

The descriptions of DSSs in the forestDSS wiki database include the following information:
- Name of the DSS and contact
- Software identification
- Description (has description, has modelling scope, has temporal scale, has spatial context, has spatial scale, has objectives dimension, has related DSS, has goods and services dimension, has decision making dimension, has forest management goal, support tree species, support silvicultural regime)
- Concrete application (has typical use case, has user profile, has country, has references about examples of application, has number of users, has number of real-life applications, has utilization in education, has research reference, has tools dissemination)
- Decision support techniques
- Support of knowledge management
- Support of social participation
- DSS development
- Documentation (website, online demo, manual, technical documentation, reference)
- General system description

As these descriptions cover very well the properties of about 60, mainly European, forest-DSSs, this database was considered a useful starting point for the analysis of the existing DSSs with respect to NWFP-related properties. However, the DSSs descriptions included only one field, namely “Description - has goods and services dimension” where “Market non-wood products” can be selected. Also in “Description - supports silvicultural regime” where e.g. agroforestry, berries, mushrooms etc. could be manually added. Therefore, it was decided that additional information on NWFP and MPTs would be included in the SMW (Figure 5.3) to better report the capabilities of forest-DSSs. Semantic queries may then be built directly by interested StarTree members directly in the wiki using SMW native features.

5.4 Results

5.4.1 Forest DSS with NWFP capabilities

The computerized forest-DSSs that include NWFP or MPTs are rather rare. In our search, we could find altogether seven FMU or regional level forest DSSs (see Table 5.3). In addition to this, Practi-SFM includes MCA capabilities that can be utilized so that the user sets specific goals and monitors how much the predicted timber and non-timber outcomes are from these goals, i.e. how the desired future conditions are met (Barrett et al. 2004). These DSSs enable to consider mushrooms (ETCAP, Monsu and Monte), berries (Monsu) and (mule)-deer (VDDT-Path and PractiSFM). EMDS is a generic DSS that can be adapted to specific needs. These DSSs can be grouped to two main groups according to their main characteristics (see Figure 5.4) as follows:

ETCAP, SADfLOR, Monsu and Monte are simulator-optimization based systems as in the comparison phase they use optimization methods to find the best solution for the planning area. In principle, the use of these systems follows three steps: 1) Management scheduling; 2) Planning model; and 3) Solution presentation. As the starting point of the planning calculations, the forest under planning is divided into compartments, and each compartment is inventoried in the field. The field data (from both living and dead trees) are imported to a compartment database. Then, alternative treatment schedules for the future planning period are simulated for the forest stand compartments. Each treatment schedule is described by treatments attached to it, timber removals, and development of the growing stock characteristics. In addition, in this phase, the NWFP models included in the DSSs calculate the yield or indicator value for the NWFP in question for each treatment schedule. For creating a planning model, the systems have planning model writers which,
based on the preferences of Decision Makers (DM) and sometimes feedback coming from stakeholders, create a planning model which expresses the objectives and constraints of the planning situation in a form that can be utilized by optimisers. The systems include various optimisation methods e.g. linear programming and goal programming models, as well as heuristic methods (see Kangas et al. 2008 for more details). The systems may also include visual interfaces as well as landscape visualisers to interactive optimisation that improve preconditions for comparisons, improvement of the solution and thus enable reaching an optimal decision.

EMDS, PractiSFM and VDDT-Path are simulators, but differences between them relate to their spatial capabilities and evaluation methods. EMDS is a GIS-based simulator for landscape analyses. When using EMDS, the user constructs a data catalog that identifies the sources of all GIS themes that can enter into an assessment, and constructs a knowledge base that describes the relations among all the ecosystem states and processes of interest to the assessment (http://www.spatial.redlands.edu/emds/). Following this, the MCA component of the system can be used to prioritize particular landscape feature when planning possible management activities. PractiSFM and Path Landscape Model (former VDDT) are non-spatial simulators that allow users to predict and evaluate how vegetation may change over time, in response to possible natural processes in the future and anthropogenic activities, as part of landscape-level ecological restoration and planning (Essa 2014). Two main approaches to consider NWFP and MPTs in these tools are 1) to make expert evaluations regarding the goodness of the scenario from the perspective of the NWFP in question and 2) the NWFP or MPT model can be included in the system (e.g. habitat model of the deer) and the system calculates the availability of the habitat in alternative scenarios (e.g. http://www.forestdss.org/wiki/index.php?title=Ireland-PractiSFM_multi-resource_inventory_and_decision_support_for_private_forest_owners). In addition to this, Practi-
SFM includes MCA capabilities that can be utilized so that the user sets specific goals and monitors how much the predicted timber and non-timber outcomes are from these goals, i.e. how the desired future conditions are met (Barrett et al. 2004). In addition to this, Practi-SFM includes MCA capabilities that can be utilized so that the user sets specific goals and monitors how much the predicted timber and non-timber outcomes are from these goals, i.e. how the desired future conditions are met (Barrett et al. 2004).

**Table 5.3  Forest-DSSs that support decision making related to NWFP**

<table>
<thead>
<tr>
<th>DSS name</th>
<th>Country</th>
<th>Type</th>
<th>Included NWFP</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMDS</td>
<td>USA</td>
<td>simulator (GIS)+MCA</td>
<td>any (based on expert evaluations)</td>
<td></td>
</tr>
<tr>
<td>ETCAP</td>
<td>TUR</td>
<td>simulator+optimization</td>
<td>mushrooms</td>
<td>Under development</td>
</tr>
<tr>
<td>Monsu</td>
<td>FIN</td>
<td>simulator+optimization</td>
<td>bilberry, cowberry, mushrooms</td>
<td></td>
</tr>
<tr>
<td>Monte</td>
<td>SPA</td>
<td>simulator+optimization</td>
<td>mushrooms</td>
<td></td>
</tr>
<tr>
<td>PractiSFM</td>
<td>IRE</td>
<td>simulator + MCA</td>
<td>deer</td>
<td></td>
</tr>
<tr>
<td>Path-Landscape</td>
<td>USA</td>
<td>Simulator</td>
<td>mule-deer</td>
<td></td>
</tr>
<tr>
<td>model (former</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VDDT_path)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SADflor toolbox</td>
<td>PT</td>
<td>Simulator + optimization + MCA</td>
<td>umbrella pine cones</td>
<td></td>
</tr>
</tbody>
</table>

The DSS have different capabilities to deal with NWFP (Table 5.44). The EMDS DSS use the input from experts in order to evaluate the performance of different NWFP scenarios (expert evaluation). The other DSS allow the optimization of different combinations of NWFP and other ecosystem services. In some cases the NWFP can be used as a goal variable in the optimization procedures (endogenous), in some case the value is shown but it cannot be minimized or maximized (exogenous). Sometimes MCA based trade-off analysis is supported for a given area and the DM evaluates it against other goal variables. Tables, graphs and maps support the interpretion of the results. All the NWFP calculations in the named forestDSSs are deterministic, i.e. uncertainty analyses are only possible through sensitivity analyses.

### 5.4.2  MCA methods and tools for NWFP

MCA methods are generic tools that are able to deal with decision problems in which DM’s utility or benefit is considered to consist of several attributes or objectives. In a typical situation of the use of MCA methods, the problem is formulated so that there is a set of distinct decision alternatives. The description of the alternatives is based on the performance of the alternatives with respect to all decision criteria (for more details see e.g. Kangas et al. 2008 and Diaz-Balteiro and Romero 2008). In this way, the starting point for using MCA methods is typically so called outcome table, in which the numerical outcomes of alternatives for the decision criteria are given. However, for some methods, such as e.g. AHP, it is also possible to use quantitative information in describing the performance of alternatives. For example, the DM can be asked to compare e.g. thematic maps and evaluate, in a pairwise manner, which one of the maps performs better with respect to the evaluated criteria, for example the habitat of some game animal. On the other hand the contribution margin or the opportunity cost (€/m³) for a given set of options could be used to describe the performance of alternatives in a quantitative way.
The essence in the use of MCA methods is the evaluation of the importance of the decision criteria. How this is carried out depends on the method used (Diaz-Balteiro and Romero 2008). These evaluations then allow trade-off analyses, which is an important part of MCA. Trade-off analysis means estimations concerning how much the DM is willing to give up one criterion in order to improve the performance with respect to another criterion by some fixed amount. These decisions on trade-offs are based on subjective personal judgement which means that they also require subjective evaluations from the DM or from the participants of the DM process. Table 5.5 presents a group of MCA methods and tools suitable for these kinds of analyses.

**Table 5.4  The characteristics of Forest-DSSs related to NWFP (all deterministic)**

<table>
<thead>
<tr>
<th>DSS name</th>
<th>NWFP description</th>
<th>NWFP integration</th>
<th>Uncertainty</th>
<th>Results</th>
<th>additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMDS</td>
<td>expert evaluation</td>
<td>expert evaluation</td>
<td>NO</td>
<td>-trade-offs between other goal variables</td>
<td>-thematic maps</td>
</tr>
<tr>
<td>ETCAP</td>
<td>Yield (kg/ha) of mushrooms</td>
<td>endogenous</td>
<td>NO</td>
<td>Under test preformatted tables and figures</td>
<td>Probably spatial optimisation of mushrooms</td>
</tr>
<tr>
<td>Monsu</td>
<td>- yield (kg/ha/a) (berries) - indicator (1-10) mushrooms</td>
<td>endogenous</td>
<td>NO</td>
<td>-preformatted tables and figures - thematic map</td>
<td>tables spatial optimisation (clustering of good bilberry forests)</td>
</tr>
<tr>
<td>Monte</td>
<td>-yield (kg/ha/a)</td>
<td>output variable</td>
<td>NO</td>
<td>-preformatted tables and figures</td>
<td>tables</td>
</tr>
<tr>
<td>PractiSFM</td>
<td>- indicator for deer habitat</td>
<td>output variable</td>
<td>NO</td>
<td>- preformatted tables and figures - trade-offs between other goal variables</td>
<td>-trade-offs between other goal variables</td>
</tr>
<tr>
<td>Path-Landscape model (former VDDT_path)</td>
<td>-indicator for mule deer habitat</td>
<td>output variable</td>
<td>NO</td>
<td>-Preformatted tables and figures, -Visualization through thematic maps</td>
<td>Includes both a regional simulator and optimization/MCD M functionalities that may be used complementarily</td>
</tr>
<tr>
<td>SADfLOR toolbox</td>
<td>-yield (kg/ha) of pine cones</td>
<td>endogenous</td>
<td>NO</td>
<td>- preformatted tables and figures - trade-offs between other goal variables</td>
<td></td>
</tr>
</tbody>
</table>

*NWFP integration: endogenous – can be used as a goal variable in optimization, exogenous – the value is shown but it can not be minimized or maximized, MCA based trade-off analysis – value is given for the area and the DM evaluates it against other goal variables, expert evaluation – expert evaluates the solution for the NWFP in question.

Nevertheless, the approaches reported in the literature typically require the decision-maker to either specify the desired level of achievement or specify the preferences for the various criteria (Martins and Borges 2007). As often there is little information about what is possible to achieve (e.g. NWFP
supply target values), defining a priori the goals and preferences may not be realistic and lead to poor management decisions (Tóth et al. 2006). Shortcomings of mechanistic approaches to the specification of the levels of achievement of various objectives as well as of the decision-makers preferences have been pointed out by Tóth and McDill (2009) and Romero (2004). Borges et al. (2014) presented an interactive approach to generate the Pareto frontier of forest management planning problems encompassing up to seven objectives to provide information about the set of efficient solutions to help the decision-maker understand the trade-offs between competing objectives. The analysis of these trade-offs may provide further insight about the forest management planning problem and help set adequate levels of achievement for various objectives, namely NWFP supply target values.

<table>
<thead>
<tr>
<th>Method</th>
<th>Essence</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHP</td>
<td>Multi-criteria method in which priorities are defined for the decision elements and alternatives</td>
<td>Saaty (1977)</td>
</tr>
<tr>
<td>ANP</td>
<td>Extension of AHP supporting independence and feedback capabilities between elements</td>
<td>Saaty (2001)</td>
</tr>
<tr>
<td>Fuzzy MA</td>
<td>Fuzzy membership functions used to define the approval borders</td>
<td>Kacprzyk et al. (1992)</td>
</tr>
<tr>
<td>Influence Matrix</td>
<td>Graphical presentation of influences between several decision elements that affect the decision</td>
<td>Ulrich and Probst (1985)</td>
</tr>
<tr>
<td>Mesta</td>
<td>Web-based multi-criteria tool to participatory discrete choice situations</td>
<td>Hiltunen et al. (2009)</td>
</tr>
<tr>
<td>Multicriteria Approval (MA)</td>
<td>Group technique based on simple approval voting</td>
<td>Fraser and Hauge (1998)</td>
</tr>
<tr>
<td>Rich decisions</td>
<td>Web-based value tree analysis decision support software including imprecise preference statements</td>
<td>Salo and Punkka (2005)</td>
</tr>
<tr>
<td>SMART</td>
<td>MCA method with rather simple ratings of criteria and alternatives</td>
<td>von Winterfeldt and Edwards (1986)</td>
</tr>
<tr>
<td>WINPRE</td>
<td>Multi-criteria decision support program able to deal with imprecise preference statements</td>
<td>Mustajoki et al. (2005)</td>
</tr>
<tr>
<td>Web-HIPRE</td>
<td>Multi-criteria decision support program applying AHP and SMART, SMARTER and SWING</td>
<td>Mustajoki and Hämäläinen (2000)</td>
</tr>
<tr>
<td>Voting methods</td>
<td>Group of different techniques for making choices between given alternatives</td>
<td>Kangasläinen (2000)</td>
</tr>
<tr>
<td>Pareto Frontier</td>
<td>MCA adaptive search technique that generates the Pareto frontier to help the decision-makers assess trade-offs between criteria and set levels of achievement that reflect their preferences.</td>
<td>Borges et al. (2014)</td>
</tr>
<tr>
<td>Goal Programming</td>
<td>MCA and optimization technique that minimizes unwanted deviations between target criteria values specified a priori by the decision makers and the actual figures achieved by the respective criteria</td>
<td>Diaz-Balteiro and Romero (2008)</td>
</tr>
</tbody>
</table>

In Figure 5.4, the use of MCA method Mesta (Kangas et al. 2008; Hiltunen et al. 2009) is given for FMU level in Finland, as an example. In this situation, the DM wanted to see the different impacts of forest plan alternatives through seven criteria. Six forest plan alternatives were created for the holding – these plans outline how the forests of the FMU are managed during the forthcoming three decades. The impacts of the different alternatives have been calculated using the Monsu forest planning software (Pukkala 2006). In Mesta, the essence of the evaluations is the acceptance thresholds of the decision criteria. Through the interactive GUI, the DM defines these thresholds...
based on his/her evaluations. In this way, the importance of the decision criteria are defined only indirectly as it can be considered that the higher is the acceptance threshold, the more important the criterion is.

![Mesta MCA Internet-Software](http://mesta.metla.fi/)

**Figure 5.4** Example of Mesta MCA Internet-Software (http://mesta.metla.fi/) in which both bilberry and cowberry yield from the forest management unit has been used as a decision criterion. In the figure above, forest plan alternatives 3 (uneven-aged management) and 6 (max cowberry production) have been accepted with respect to all decision criteria (i.e. these two alternatives are above the acceptance threshold - white area - of each decision criterion). The numbers below each bar indicate the value of the current threshold (black line). The user finds explanation on the numbers behind the question marks.

### 5.4.3 Examples of existing DSSs with NWFP capabilities

#### 5.4.4 Example I: Monsu forest planning system from Finland

The example shows how the yield of two NWFP can be dealt with alongside other forest use objectives in the Finnish forest planning system Monsu (Pukkala 2006). Monsu includes the yield models of bilberry (Miina et al. 2009) and cowberry (Turtiainen et al. 2013) along with several other ecosystem services. Therefore, the use of the system for showing the interdependencies between potential goal variables in different holding-level solutions is straightforward. The planning area was...
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A rather large private forest holding in Finland. The creation of the alternative forest plan followed the principle presented in Figure 5.5 until the comparison phase.

Figure 5.5 Results from the Monsu forest planning software exported to spider-web diagram. Six alternative forest plans were created with the system and the spider-web shows the profiles of the alternatives to decision maker so that the DM can evaluate their outcomes with respect important goal variables. Please note that the axis are in relative scale where minimum theoretical value of the goal variable gets the value 0 and the maximum value is equal to 1.

5.4.5 Example II: The Pareto Frontier module within the SADfLOR toolbox from Portugal

The example (Figure 5.6) shows the efficient frontier of a four-criteria planning problem under a cork-flow regularity constraint of 20% generated by a Pareto Frontier module within the SADfLOR toolbox. This DSS functionality to assess trade-offs between NWFP and wood products and other ecosystem services that may support negotiation and consensus building between decision makers and forest stakeholders. This module encapsulates the Feasible Goals Method/Interactive Decision Maps (FGM/IDM) technique to develop an interactive visualization of the Pareto frontier. The latter describes the limits of what is possible in terms of competing decision criteria. It illustrates the degree to which improving one particular criterion (e.g. increasing the supply of a NWFP) requires accepting sacrifices in the achievements of others. It thus further provides information about trade-offs between competing decision makers preferences.
5.5 Discussion: Towards improved situation (what can STARTREE project do in relation to DSSs improvement/development)

The process of designing and developing DSS is of high interdisciplinary nature (Figure 5.7). Researchers, software engineers and decision analysts from different fields of expertise have to collaborate jointly in order to address the demands of the decision maker on solving decision problems. This effort needs a collaborative approach in bringing together experts from forest modelling, software engineering, forest ecology and management as well as from social sciences. The role of forest ecologists is essential when forest DSSs are developed so that they can better incorporate NWFP and MPTs.

Developing a DSS to integrate NWFP and start applying it in practical decision making is a great challenge at least from a forest management planning perspective. In principle, the same challenges that are met when modelling the yields of NWFP (Calama et al. 2010) are met also in a situation where their yields or even monetary outcomes should be considered together with timber yields, for example. As the rotation periods for timber are typically decades, the richness and also the challenge
of NWFP is the possibility to get revenues more often, sometimes annually. Therefore, there are needs to find ways to combine production processes of forest products with very different life spans.

In principle, the framework of DSS is a suitable basis to consider the management of NWFP as an additional feature (see Figure 5.7). The challenges are related to e.g. modelling aspects, that were dealt with earlier in section 4. Following the construction of models for the yields of NWFP, an existing DSS need to be modified to accommodate these models. Typically in simulator based DSSs, the yield of NWFP is related to the stand parameters. However, many other aspects (e.g. browsing impact, intensity of collection, ...) affect the yield of these products, which brings additional uncertainties to the predictions. Therefore, one important aspect to consider would be the capabilities to show how uncertain the predictions are. For this, the planning and implementation of GUI is also important from the users perspective. It must be remembered that the information is delivered to users, who do not typically have expertise in using empirical models or computerized forest DSSs.

Forest DSSs are typically mentioned to be used by professional foresters. They are the persons, who in practice collect the forest inventory data, input it to database of forest DSSs and make simulations and calculations based on the forest management problems. The information goes often to actual decision makers or stakeholders for consideration and finally for decision making. In this information production and delivery process, the forestry professionals knowledge and attitude towards NWFP have a crucial role. Even if the forest DSS capabilities would allow, professionals negative attitude may result in missing considerations and information on NWFP in the information or guidelines or printed forest plan that is delivered to private forest owner who actually makes the forest management decisions for his/her forest.
Figure 5.7 Possible pathways for developing improved forest DSS including NWFP.
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6.1 Chapter 3


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6.3 Chapter 5


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APPENDIX A

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