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Modelling bilberry and cowberry yields in Finland: different approaches to develop models for forest planning calculations

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Academic dissertation

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ABSTRACT

The aim of this research was to create yield models for the two most significant wild berry species in Finland, namely, the bilberry and the cowberry. In particular, the aim was to develop models applicable to multi-objective forest planning calculations. The models were developed using approaches based on both expertise and empirical measurements. In expert-knowledge-based studies, different methods of data collection were used: experts evaluated berry production of different forest stands (i) from slides, (ii) visually in the field and (iii) using a questionnaire. Data for empirical studies were also collected using different methods: measurements (i) of systematically placed sample plots and (ii) of forest stands found to be advantageous with respect to berry production. Statistical analyses of data and modelling techniques varied from study to study. Thus, another aim was to test different methods of data collection and different modelling techniques and also assess their usability.

According to the results, the best bilberry yield can be found in a mature stand which is not too dense and is located on a mineral soil site of medium or rather poor fertility. It is also obvious that pine-dominated heath forests of rather poor or poorer fertility have the highest cowberry yields. A stand suitable for cowberry picking should not be dense. These results are very much in line with previous studies on the effects of site and stand characteristics on berry production. However, it is concluded that there is still a need to for further research to explore the dependence of cowberry crops on stand characteristics on poor mineral soil sites.

Comparisons of the results of this thesis with empirical berry yield studies and also with earlier berry models indicate that modelling expertise is a reasonable way to create production functions for different wild berry species. This finding encourages the utilization of expertise in other applications for the development of models for different non-wood forest products. In particular, the method based on visual assessments conducted in the field was found to be a promising one.

Keywords: modelling empirical measurements, modelling expertise, multi-objective forest planning, non-wood forest products, *Vaccinium myrtillus* L., *Vaccinium vitis-idaea* L.

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This research was conducted in two phases. The first phase was initiated at the beginning of 1999 as part of the project “Between Subsistence and Global Markets: Grassroot Economies, Social Structures and National Policies in Sustaining Non-Wood Forest Products”, of the Finnish Biodiversity Research Programme FIBRE and funded by the Academy of Finland. This project was completed at the end of 1999. After that, I continued my research under contracts to the Faculty of Forestry of the University of Joensuu (since 2010 School of Forest Sciences, University of Eastern Finland, UEF) and the Graduate School in Forest Sciences (University of Joensuu). I also received grants from the Finnish Society of Forest Science, Faculty of Forestry (University of Joensuu), the Finnish Concordia Fund and the Finnish Cultural Foundation, North Karelia Regional fund. As a result of the first phase of my research in 2003, I finished my licentiate thesis entitled “Modelling resource dynamics of wild berries in Finland” (at that time, my family name was Ihalainen). The licentiate thesis included the first four studies of this doctoral thesis (at that time, Study IV was just a manuscript).

The second phase of the research commenced in 2011 when I started to prepare Study V of this thesis. At first, the research was supported by the strategic funding of UEF as a WP 4.3 of the “Changing Climate and Biological Interactions Related to Forests” project (CABI). In 2012–2014, I received funding from the Alfred Kordelin Foundation, Niemi Foundation, School of Forest Sciences (UEF) and CABI-project.

I did this work at the School of Forest Sciences (UEF). Prof Timo Pukkala, Emeritus Professor Olli Saastamoinen and Dr Jari Miina (Finnish Forest Research Institute, since 2015 Natural Resources Institute Finland) were supervisors of my doctoral thesis. I would like to thank them warmly for their help and continuous support. In addition, I am grateful to all other co-authors for their valuable contribution. I express my gratitude to the preliminary examiners of this thesis, Docent Mikko Kurttila (Natural Resources Institute Finland) and Associate Professor Joachim Strengbom (Swedish University of Agricultural Sciences), for their comments and constructive criticism.

The second phase of the research coincided with a deep, difficult time in my personal life. I wish to thank my closest colleagues, Mr Matti Vaara and Ms Marjoriitta Möttönen, as well as my closest friends outside the university, for their friendship and support.

Finally, I wish to express my gratitude to my parents and sister for all they have done for me. Above all, I thank God for having my lovely daughter, Sara, in my life. I dedicate this publication to her.

Joensuu, January 2015

Marjut Turtiainen

LIST OF ORIGINAL ARTICLES

This thesis is a summary of the following articles, which are referred to in the text by the Roman numerals I–V. The articles are reprinted here with the kind permission of the publishers.

I	Ihalainen M., Alho J., Kolehmainen O., Pukkala T. (2002). Expert models for bilberry and cowberry yields in Finnish forests. Forest Ecology and Management 157: 15–22. http://dx.doi.org/10.1016/S0378-1127(00)00653-8
II	Ihalainen M., Pukkala T. (2001). Modelling cowberry (*Vaccinium vitis-idaea*) and bilberry (*Vaccinium myrtillus*) yields from mineral soils and peatlands on the basis of visual field estimates. Silva Fennica 35(3): 329–340. http://dx.doi.org/10.14214/sf.588
III	Ihalainen M., Salo K., Pukkala T. (2003). Empirical prediction models for *Vaccinium myrtillus* and *V. vitis-idaea* berry yields in North Karelia, Finland. Silva Fennica 37(1): 95–108. http://dx.doi.org/10.14214/sf.513
IV	Ihalainen M., Pukkala T., Saastamoinen O. (2005). Regional expert models for bilberry and cowberry yields in Finland. Boreal Environment Research 10: 145–158. http://www.borenv.net/BER/pdfs/ber10/ber10-145.pdf
V	Turtiainen M., Miina J., Salo K., Hotanen J-P. (2013). Empirical prediction models for the coverage and yields of cowberry in Finland. Silva Fennica 47(3). 22 p. http://dx.doi.org/10.14214/sf.1005

In the articles, Marjut Turtiainen (née Ihalainen) was responsible for all the stages of the studies, with the exception of the following. Study I was based partly on existing data (slides of forest stands, stand characteristics), Alho and Kolehmainen were responsible of the theoretical part of the method, statistical analyses were carried out jointly with Kolehmainen, and Kolehmainen and Pukkala participated in writing the report. In Study II, data was collected by three forest planners of the Forestry Centre of North Karelia. In Studies III and IV, Miina and Pukkala gave guidance in the statistical analyses. In Study V, Miina was responsible for the theoretical part of the methods and also participated in statistical analyses and conducted the simulations, while Hotanen provided expertise in the post-drainage succession phases of forested peatland site types. Studies III and V were based on existing data, and Salo provided expertise in the berry yield data for both studies, and Hotanen on the vegetation data (V). Each study was designed in cooperation with other authors.

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1 INTRODUCTION

1.1 Background

Forests provide numerous products and other benefits, which have for a long time been dealt with under the concept of multiple-use of forests (e.g. Saastamoinen 1982; Hytönen 1995), and now increasingly within the framework of forest ecosystem services (e.g. Kniivilä et al. 2011; Saastamoinen et al. 2013a). Wood has traditionally been regarded as the most important product obtained from forests. Other products (i.e. non-wood forest products – NWFP) include, for example, wild berries, mushrooms, herbs, decorative lichen and game. Besides material goods, forests also provide a number of non-material services related to, for example, their scenic beauty and outdoor recreational activities. In Finland, forests have a great significance for people’s identity and many forests also have spiritual value (e.g. Kainulainen 2013). Furthermore, forests are important for biological diversity, carbon sequestration, erosion control and regulation of water resources.

Among the multiple benefits that forests in Finland can bring, wild forest berries have a special status. They are the most common NWFP utilized by people. Recent studies have confirmed that 54% of Finnish households (Vaara et al. 2013) and 58% of the whole population (Sievänen and Neuvonen 2011) participate annually in berry picking. The popularity of berry picking is due to the fact that according to the customary law (the so-called “everyman’s right”) berries are an open-access resource and are not part of the property rights of the forest landowner. Substantial amounts of berries are collected for households’ own consumption every year, although the subsistence needs of the past have nowadays largely been replaced by recreational motives. Picking berries for additional income also has a long tradition in Finland (e.g. Luttinen 2012), although since around the turn of the millennium an ever larger part of commercial picking has been done by pickers from other countries (e.g. Richards and Saastamoinen 2010; Lacuna-Richman 2014; Maaseutuvirasto 2014). In many parts of Finland, particularly the sparsely populated east and north of the country, berry picking still provides important additional tax-free income for the population, although most probably this is much less than in the late 1990s (e.g. Kangas 2001; Maaseutuvirasto 2014).

During the last decades, the preferences of many forest landowners – as well as public opinion in general – about forests and forestry have become increasingly diversified; that is, income from timber is no longer considered to be the only goal of forest management, since goals related to nature conservation and the multiple-use aspects of forests have increasingly been gaining in importance (e.g. Kangas and Niemeläinen 1996; Karppinen 1998; Karppinen et al. 2002; Laitila et al. 2009; Valkeapää et al. 2009; Hänninen et al. 2011; Rämö et al. 2013). In the middle of the 1990s, Kangas and Niemeläinen (1996), among others, studied Finnish forest owners’ values with regard to their own woodlots and found that forest vitality, scenic beauty and biodiversity were the three values people found most important about the forests. Wood production and income from wood sales were relegated, on average, to fourth place among ten alternatives. Collecting wild berries and mushrooms was placed fifth (Kangas and Niemeläinen 1996). A survey of private Finnish forest owners conducted in 2009 indicated that about one third of the owners had set several forest management goals, both monetary and non-monetary (Hänninen et al. 2011). One quarter of the owners were interested in the recreational aspects of their forests, one fifth emphasized working opportunities and one sixth emphasized the economic security that the forest estate provides. The rest of the owners were uncertain of their goals (Hänninen et al. 2011).

Changes in people’s preferences have resulted in the need to develop forest planning from traditional rule-based single-objective planning towards multi-objective and customer-oriented planning (e.g. Saastamoinen and Pukkala 2001; Pukkala 2004). According to Oksanen-Peltola (1999), the era of multi-objective forest planning (planning of multiple-use forestry, multi-functional forest planning) was initiated in Finland in the 1980s. Before that, multiple-use research in forest economics or silviculture had focused, for example, on forest recreation (e.g. Jaatinen 1973; Saastamoinen and Sievänen 1981), landscape preferences (e.g. Savolainen and Kellomäki 1981) or the economic analysis of several forest uses (e.g. Saastamoinen 1982).

It is worth noting that the changing preferences are not the only reason behind the changes in forest planning. Forest ownership structure is also an important factor that needs to be reflected in forest planning since today the majority of forest landowners are non-farmers whose livelihood is not usually dependent on timber sales and who may have forest management goals other than maximizing income or profitability (e.g. Pukkala 2004; Hänninen et al. 2011). Also, during the recent decades forestry legislation has stressed the importance of nature conservation and the multiple-use aspects of forests. In the beginning of 2014, new forest legislation came into force in Finland and increased the freedom of forest owners (Ojala and Mäkelä 2013; Ministry of Agriculture and Forestry 2014), which means that forest owners have now more opportunities to take into account their own values in the management of their forest property.

Thus, in forest planning today the goals of forest owners may typically be quite different in different planning situations, and there can be several simultaneous and sometimes conflicting goals. For example, the owner may seek a form of management which guarantees, besides income from timber sales, good berry crops (despite the fact that the owner does not have an exclusive right to the berries growing on his/her land). In this kind of situation, the traditional planning aimed only at high timber production does not work for the benefit of the forest owner.

The basic method in forest management planning in Finland is to produce a set of alternative management plans and then evaluate these preliminary plans in terms of the variables important to the landowner or the public (e.g. Pukkala 2007). The evaluations are based on predicted income, timber yields and the future states of the forest. If the berry yield – or recreation through berry picking – is one of the most important forest products and services, the forester should be able to assess the future berry yields after implementing a provisional plan. In the search for the best management plan, optimization may be used, and preliminary plans may be produced in an automated process. Thus, the predictions of berry yields should also be produced automatically. The best way to achieve this is to rely on numerical models. This requires that such models are made available for forest planning purposes. However, there has been a lack of models for different non-wood forest products and services (NWFPS) and, therefore, the development of such models has been among the central research topics in the field of forest planning during the recent decades (e.g. Kangas 1998; Pukkala 2004, 2008).

1.2 What are models suitable for multi-objective forest planning like?

The first models created for the purposes of numerical multi-objective forest planning can be found in the 1980s (e.g. Hull and Buhyoff 1986; Pukkala 1988; Pukkala et al. 1988). Since the 1990s, research on the issue of integrating non-timber benefits into forest planning has been rather vigorous; models and methods required in forestry practice have been developed in Finland and in many other countries. So far, planning models have been developed at least for scenic beauty (e.g. Hull and Buhyoff 1986; Pukkala et al. 1988; Kangas et al. 1993a; Silvennoinen et al. 2001; Blasco et al. 2009), recreational value (e.g. Pukkala et al. 1988), yields of forest berries and mushrooms (e.g. Pukkala 1988; Muhonen 1995; Bonet et al. 2008; Miina et al. 2009; Bonet et al. 2010, 2012; Miina et al. 2013; de-Miguel et al. 2014), habitat suitability for wildlife (e.g. Kangas et al. 1993b; Store and Kangas 2001; Ukkola 2003; Store and Jokimäki 2003; Hurme et al. 2005), biodiversity (e.g. Kangas and Mononen 1997), carbon balance of forestry (Dias-Balteiro and Romero 2003), forest stand’s vulnerability to fire (González et al. 2006, 2007a) and fire damage (González et al. 2007b). Calama et al. (2010) have also reviewed some other existing models for the main NWFP in Europe.

When considering, for example, wild berries in a certain geographical area, one finds that a great number of factors affect the quantity of berry yields (e.g. Salo 1995). Besides factors outside human control (e.g. site fertility, weather conditions in the growing season in question and of the previous season, thickness of snow blanket, pollination success), silvicultural and management activities may have significant effects on berry yields. Such factors include tree species’ composition, stand age and stage of stand development, growing stock volume and density. In the 1980s Raatikainen et al. (1984) developed preliminary models for the yields of bilberry (*Vaccinium myrtillus* L.) and cowberry (*Vaccinium vitis-idaea* L.) and used site and stand characteristics, and the characteristics of the berry vegetation (i.e. height and coverage of berry plants) as explanatory variables. However, the state of ground vegetation is not routinely estimated in the inventory associated with forest planning in Finland and there are no models for predicting the future states of ground vegetation, although data on past long-term changes of vegetation are available from three national forest inventories (NFI) and associated vegetation surveys (Reinikainen et al. 2000). Therefore, the models of Raatikainen et al. (1984) cannot be used in forest planning.

Thus, it is obvious that the prospective use of the model can determine a reasonable set of predictors to be used. A model applicable to forest planning calculations should contain information on the effects of those factors which are under the control of the decision maker and which are known in planning calculations. In forest planning, the site and stand characteristics are known, and the future stand characteristics can be predicted using current models. Therefore, these characteristics are the most reasonable predictors when constructing models for forest planning purposes. Yet, this kind of modelling omits several factors that are important to the output in question. This kind of model for berry yields, for example, does not consider such factors as weather and the initial state of the ground vegetation. However, these models contain information that is highly relevant for forest planning; they indicate how alternative ways of managing the stands will affect the future state of the output in question.

In principle, models for forest planning purposes can be created using two different approaches. Firstly, models can be based on the empirical measurement of the output variable in question and site and stand characteristics. The models of Pukkala (1988) are an example of this kind of modelling. Pukkala (1988) collected existing data from different sources and prepared prediction models for bilberry and cowberry yields. However, berry yields vary greatly both temporally and spatially (e.g. Salo 1999; Wallenius 1999), a fact that was not taken into account by Pukkala (1988). To construct models that reliably describe the effect of trees and the site on the berry yield, one needs to gather a huge amount of empirical data over many years. If one fails to do so, it is likely that the individual study sites and years of data collection largely determine the models and make them biased. In some other modelling tasks such as modelling the habitat requirements of certain species, the problem may be that the available information is only descriptive and scattered in different case studies not directly exploitable in the forest planning area in question (Kangas and Leskinen 2005).

Another approach is to use expert knowledge as the basis of modelling. This approach is based on the assumption that interested parties may have practical experience or educated information about the relationships between specific forest features and the forest output in question, and this knowledge can be converted into an expert model (e.g. Pukkala 2002). Muhonen (1995) was among the first researchers to apply this approach to modelling NWFP. In Muhonen's study (1995), experts compared slides representing different stands in a pairwise manner in terms of their bilberry and cowberry yields. The calculation procedure of the Analytic Hierarchy Process (AHP; Saaty 1977) was used to convert the verbal assessments into numerical priorities measured on the ratio scale. These priorities were regressed against the site and stand characteristics measured in the field. It is worth noting that the models of Muhonen (1995) do not produce predictions in terms of kilograms, but they do provide relative priorities. However, this is not a problem in practical forest planning; what is relevant is that the decision maker understands the numerical measure and can use it to value the output of different forest stands and management schedules.

Expert knowledge has been commonly utilized for forest planning purposes, not only for modelling NWFP but also for many other tasks (e.g. Kangas and Leskinen 2005, p. 127) and several methods have been introduced to elicit and analyse expert judgements (e.g. Pukkala 2002; Kangas and Leskinen 2005). One reason for this situation is the lack of readily usable empirical data. Compared to empirical modelling, the approach based on expertise is both quick and cheap. However, it is assumed that expert models are not as reliable as those based on empirical measurements because of the many possible sources of uncertainty that expert judgements contain (e.g. Kangas 1998; Kangas and Leskinen 2005). For this reason, it has been suggested that expert models should only be used as a temporary measure until more reliable empirical models become available (Kangas 1998).

Finally, it is worth noting that the models of both Pukkala (1988) and Muhonen (1995) have their own problems; therefore, they can be regarded as quite tentative attempts to model wild berry yields. As mentioned above, Pukkala's models (1988) are based on scattered data. The principal problem with Muhonen's models (1995) comes from the methodology used. In the study of Muhonen (1995), 81 stands were assessed in a pairwise manner. The priority calculations of the original AHP required a complete set of paired comparisons; every stand needs to be compared with all other stands. In the case of 81 stands, the total number of pairs would have been 81 × 80 / 2 = 3240. To avoid an excessive number of comparisons, Muhonen (1995) divided the stands into sets of five and comparisons were carried out separately within each set. Then the sets were scaled through paired comparisons of one stand per set. The scaling made the priorities of all stands in a set highly dependent on the scaling comparisons, which emphasized these comparisons over the others (see also Kangas et al. 1993a; Tahvanainen et al. 1996). In other countries, one cannot find berry yield models that would be suitable for Finnish conditions although research on wild berries has been done, for example, in Sweden, Russia and the Baltic countries (e.g. Kolupaeva and Skrjabina 1979; Eriksson et al. 1979; Kardell and Carlsson 1982; Männi 1988; Belonogova and Zajceva 1989; Grjaz'kin et al. 2006).

1.3 Bilberry and cowberry – the most significant wild berry species in Finland

The bilberry and cowberry (also known as lingonberry) are the most frequent and abundant forest berry species in Finland (Hotanen et al. 2000). These species have adapted to a wide range of different site and land types in coniferous ecosystems and, as a result, are widely distributed across different parts of Europe and northern Asia (e.g. Ritchie 1955, 1956; Landolt 1996; Coudun and Gégout 2007). In North America the related species of *V. myrtillus* and the subspecies *V. vitis-idaea* spp. *minor* are found (Ritchie 1955, 1956).

In Finland, bilberry is typical and abundant, especially in heath forests of medium site fertility (i.e. mesic heath forests) and dominated by spruce (*Picea abies* (L.) Karst.) or pine (*Pinus sylvestris* L.). Cowberry has adapted to drier and lighter growing conditions and is most typical in light pine-dominated dryish (sub-xeric) heath forests (e.g. Raatikainen et al. 1984; Laakso et al. 1990; Salo 1995; Hotanen et al. 2000). However, very often these two species grow side by side at the same sites (e.g. Vuokko 2005). Bilberry and cowberry also occur and produce yields in many marginal types of forest (e.g. fell forests), and on pristine and drained peatland sites (e.g. Salo 1995; Hotanen et al. 2000). On drained peatlands (particularly on drained pine mires), the coverage of both species increases along with the post-drainage succession phases (i.e. recently drained, transforming phase, transformed phase; Hotanen et al. 2000).

Finnish wild berry resources have not been inventoried as they have been in, for example, Sweden (Eriksson et al. 1979; Kardell and Carlsson 1982). It has been estimated on the basis of scattered empirical yield studies and expert assessment that the total yield of wild berries during an abundant crop year may reach approximately 1100 million kg (Salo 1994, 1996). Of this amount, cowberry constitutes 500 million kg and bilberry 200 million kg (Salo 1994). These figures include berry production on both mineral soil sites and peatlands. However, only a small proportion (approximately 5–10%) of the total yield is annually collected (e.g. Metsämarja- ja sienitoimikunnan… 1979; Salo 1995).

According to the most recent nationwide survey in 2011, a total of 34.9 million kg of berries was collected by Finnish households, the quantities of bilberries and cowberries being 14.3 million kg and 16.1 million kg, respectively (Vaara et al. 2013). In 2011, the seasonal crops of bilberry and cowberry were relatively good, while the crop of cloudberry (*Rubus chamaemorus* L.), which is the most significant peatland berry species in Finland, was very poor (Maaseutuvirasto 2012). It is worth noting that these figures do not include those berries that were picked by foreigners – in 2011 it was estimated that about 9 million kg of wild berries (primarily bilberries and cowberries) were collected by foreign pickers (Maaseutuvirasto 2012). Thus, the total harvest of wild berries in Finland was approximately 44 million kg in 2011, which corresponds to an economic value of nearly 100 million euros (Vaara et al. 2013).

1.4 Aims of this research

The main aim of this research was to develop yield models applicable to multi-objective forest planning calculations for the two most significant wild berry species in Finland, namely, the bilberry and cowberry. The models were developed using approaches based on expertise (I, II, IV) and empirical measurements (III, V). In each of the five studies, different methods of data collection and different modelling techniques were applied, with the exception that the same modelling technique was used in Studies III and IV. Thus, another aim was to test different data collection methods and modelling techniques and also assess their usability. The applicability of the methods used for other potential applications was also assessed to some extent.

The models created in Studies I–IV were designed so that they predict bilberry and cowberry yields of an average crop year. In Study V the between-year variation was also included in the yield model. In this particular study, only cowberry yields were examined. Because the coverage of cowberries was used as an explanatory variable in the yield model, a model for the coverage of the species was also derived (V).

The models derived in Studies I–III are regional, as they are based on datasets collected in eastern and central Finland. However, Studies IV and V present models for the area of the whole of Finland. In fact, these two studies are the very first attempts to create national berry yield models. Most of the yield models were developed for mineral soil forests. In Study II, models were not only devised for mineral soils but also for different classes of peatland site (spruce mires, pine mires and open peatlands).

2 MATERIALS AND METHODS

2.1 Expert modelling

2.1.1 Experts' pairwise comparisons on the basis of slides (I)

The main steps of the study were as follows:

1) a group of experts on bilberry and cowberry yield evaluation was chosen;
2) a set of materials consisting of different forest stands was produced (slides of forest stands, stand characteristics);
3) the experts evaluated, in a pairwise manner, the stands with regard to bilberry and cowberry yields; and,
4) prediction models for bilberry and cowberry yields were formulated.

The study material consisted of 100 stands located in central Finland and Karelia (step 2). A photograph (slide) was taken within each stand to represent a typical view in the stand. The stand characteristics of each stand, including the forest type, were estimated in the field. The following variables were assessed separately for each species and the canopy layer: stand basal area or, in young stands, the number of stems per hectare; mean tree age; mean height; mean diameter; and minimum and maximum distribution of the diameter. On the basis of the field data, a set of additional variables was computed by using Monsu forest management planning software (Pukkala 1988). These variables, calculated for each forest stand, were used as explanatory variables in step 4 (I: Table 1).

Bilberry and cowberry yields were assessed in a pairwise manner on the basis of photographs (slides) showing the stands (n = 100) (step 3). The slides were evaluated in three separate sessions organized for three groups of persons: forest professionals (7 persons), berry pickers (10) and members of a nature society (10). These people were expected to be experts in assessing the berry yields of different forest stands (step 1).

Pairwise comparisons were made and analysed using the method of Alho et al. (2001). The number of pairs to be assessed was $(n – 1) + (n – 2) = 197$. For each pair of slides, the experts were first asked to assess which of the two forest stands produced a better bilberry yield and how much better the yield in one stand was compared to that of the other stand. Then the experts were asked to conduct a corresponding assessment with respect to the cowberry yield. In the assessments, a verbal scale was used ranging from equal priority for both stands (1:1) to the absolute priority of one stand over another (9:1 or 1:9). Verbally expressed priorities were translated into numerical values (1:9 through to 1:1 and to 9:1).

In step 4, a regression method proposed by Alho et al. (2001) was used to develop priority models for the bilberry and cowberry. The details of the method appear in Alho et al. (2001; see also I, p. 18). Briefly, the response in the regression analysis was $y(i, j, k) = \ln(r(i, j, k))$, where $r(i, j, k)$ is the evaluation of expert k for the priority of stand i relative to j. For each stand i there were p explanatory variables $x_{i1}, x_{i2},\ldots, x_{ip}$. In the resulting models, the predicted variable is $\ln(v)$ where v is a tree stand's priority with respect to bilberry/cowberry yield. Predictors included in the models had to be logical and statistically significant (the significance level used in this study as well as in Studies II–V was 0.05). The models were fitted using the Mathematica package AHP.m developed by Professors Alho and Kolehmainen at the Statistics Department of the (then) University of Joensuu.

Two prediction models were provided both for bilberry and cowberry: the first model employed the evaluations of all experts (27 persons) and the second the evaluations of the most consistent experts (22). Two types of inconsistency were examined when the evaluations of the five most inconsistent experts were – using subjective consideration – removed from the original data. First, variations in the views of various experts: those experts who differed most from the average were identified by dropping each one in turn from the analysis and then checking whether the degree of determination R^2 increased significantly. Second, the internal inconsistencies of an individual expert's views were located by computing an individual R^2 for each expert.

2.1.2 Forest planners' assessments in the field (II)

The study material was collected during the field inventory of forest stands in 1999 in eastern Finland. Three forest planners evaluated site and stand characteristics and the average annual bilberry and cowberry yields of 627 forest stands so that each surveyor assessed approximately the same number of stands (II: Table 1). Because all three surveyors were experienced foresters and, in addition, interested in berry picking during their leisure time, they were supposed to be experts on berry yields in different forest stands. The evaluations were made on a scale of 0 to 10, where "0" indicated very poor bilberry/cowberry yield, or no berries, and "10" a very abundant yield. The yield estimations were made on the basis of general impression (site and stand characteristics, density of the berry plant vegetation), and only a few minutes were spent at each stand making the bilberry and cowberry yield assessments.

The assessments of site and stand characteristics and berry yields were carried out on privately owned forest holdings so that all stands of the given holding were evaluated.

Consequently, the data contained stands representing four different site categories (i.e. principal site classes): mineral soil, spruce mire, pine mire and open peatland. These were classified into different site fertility classes (II: Table 1). The field data on site and stand characteristics (mainly including the same variables as in Study I) were input into the Monsu forest management planning software (Pukkala 1988), which was used to compute a number of variables for each stand. The variables calculated for each stand were used as explanatory variables in regression analyses (II: Table 2).

The berry yield prediction models were formulated by means of linear regression analysis (SPSS software). The distributions of bilberry and cowberry yield assessments were skewed for most site categories: the proportions with zero and small values were emphasized in the data. In order to enable the skewed distributions of the berry yield evaluations to resemble normal distributions, several potential transformations of the response (y) were tried. Logarithms were found to be the best form of transformation and, consequently, the predicted variable in the regression analyses was $\ln(y + 1)$. Site categories in which the bilberry or cowberry yield evaluations consisted entirely of zeros were excluded from the regression analyses (i.e. open peatlands and, in the case of cowberry, also spruce mires).

The next step was to test whether the relationships between the dependent variable and explanatory variables were different for different site categories. A separate model was created for each category where this was found to be the case; or, alternatively a common model was formulated for several categories. In the modelling, all surveyors were given their own indicator variable to account for possible scale differences between surveyors.

2.1.3 Forest planners' assessments using questionnaire (IV)

The study material was collected by mailing a questionnaire to 13 Forestry Centres in Finland (IV: Fig. 1). The target group for the inquiry were forest planners and other staff members whose work was related to field work in forest planning, and who were therefore assumed to be familiar with the interactions between berry yields and forest characteristics. The questionnaire was addressed to 444 persons and 266 replies were obtained.

In the questionnaire, there were 117 imaginary forest stands, differing in site fertility, dominant tree species, stage of stand development and stand density (IV: Appendix; see also Turtiainen et al. 2009: Appendix 1). The berry yield assessments (bilberry and cowberry separately) for different forest stands were made according to a ratio scale from 0 to 10, where “0” indicated a very poor berry yield, or no berries, and “10” a very abundant yield. It was emphasized that the aim was to evaluate berry yields of an average crop year in the region of the respondent's own Forestry Centre. The respondents were also asked to give absolute bilberry and cowberry yields (kg ha^{-1}) which corresponded, in their opinion, to the maximum value of the scale (10). The aim was to link the maximum score (10) to absolute bilberry and cowberry yields (kg ha^{-1}). This made it possible to develop models for berry yields in terms of kilograms per hectare.

A set of growing stock characteristics (basal area, number of stems, dominant height, stand age, mean diameter, mean height) were estimated for each of the 117 imaginary forest stands using different sources of information (IV: Table 1). These stand characteristics, as well as the site type, were used as explanatory variables in the modelling.

The process of modelling consisted of three steps. First, bilberry and cowberry yield prediction models for 14 districts of Finland (i.e. 13 Forestry Centres, one divided into two districts) and also for the whole country were created by means of linear regression analysis. In each model, the predicted variable was $\ln(y+1)$ where y is berry yield in kg ha^{-1} (cf. II). The models were then compared to each other. Two issues were examined in this comparison: firstly, investigations were made as to whether the same explanatory variables were included in different models; and secondly, a check was carried out on whether the relationships were similar in the different models. After this examination a preliminary conclusion was drawn about whether a common model could be formulated for several districts or whether a particular district needed a model of its own.

In the second stage, common models were created for areas which were preliminarily defined in step 1. After that, investigations were made (by calculating root mean square errors of logarithmic berry yield predictions) to establish whether the common model was exact enough to predict the berry production of the districts. In this phase, it was possible to improve the common model by adding district-specific variables. These analyses resulted in the sub-division of Finland into Kainuu and rest of Finland in the bilberry modelling, and the sub-division of North Karelia, Kainuu and Lapland versus the rest of Finland in the cowberry modelling.

In the third step of the modelling, the final berry yield prediction models were formulated by means of a mixed modelling technique. This approach was applied because it was likely that berry yield assessments given by one respondent were correlated and, therefore, the general assumption of uncorrelated residuals did not hold. The MIXED procedure of the SAS software was used for model fitting. The respondent effect was considered as a random variable and site and stand characteristics were considered as fixed variables. The fixed part of the models was created on the basis of the models developed in steps 1 and 2, so those predictors which became statistically significant were selected for the model.

Normally, logarithmic predictions for bilberry and cowberry yields are calculated using only the fixed part of the mixed models. However, due to the logarithmic transformation, a correction term needs to be applied when the prediction is transformed into the arithmetic scale. Therefore, a ratio estimator for bias correction (Snowdon 1991) was estimated for each model in order to get unbiased back-transformed predictions (IV: p. 151 and 153).

2.2 Empirical modelling

2.2.1 Local berry models (III)

The study material consisted of the bilberry and cowberry yield measurements (n = 362) made on berry sample plots during 1981–1984 and of the site and stand characteristics corresponding to the sample plots measured in 1980. When the occasions on which the berry yield was assessed took place over more than a single year, the same sample plot also occurred more than once in the data.

The study area was located within the Nurmes and Lieksa districts in eastern Finland (III: Fig. 1). As a part of the 7th Finnish National Forest Inventory (7NFI), a network of permanent multi-purpose sample plots (100 m^2) was established in the study area in 1980 (e.g. Salo 1982; Sevola 1983). The berries were inventoried on 40-m^2 berry sample plots which were located within permanent sample plots, which in turn were located in systematically arranged clusters (III: Figs. 2 and 3). On average, the berries were inventoried three times during the growing seasons of 1981 and 1982, twice in 1983 and once in 1984. On each berry sample plot, the number of unripe berries and the number of ripe berries were recorded (counted) by species. The biomass of bilberries and cowberries for each berry sample plot was determined on the basis of ripe berries and on the basis of unripe berries, and the higher biomass was used in the analyses.

All berry sample plots which were located on mineral soil sites were included in the study material. The site and growing stock characteristics were estimated for the stand within which the berry plot was located. The following stand characteristics were available in the data: mean diameter, stand basal area, stand age and dominant tree species (III: Table 2).

In the modelling, the mixed model technique was used because it was assumed that the berry yield observations (y) were correlated both spatially and temporally (cf. IV). The predicted variable in mixed linear models was $\ln(y + 1)$, for the same reason as in Studies II and IV. The fixed part of the models consisted of site and stand characteristics, and the potential variables of the random part included the year, cluster and sample plot, as well as some interactions of these variables (e.g. year × cluster). The MIXED procedure of the SAS software was used for model fitting. A ratio estimator for bias correction (Snowdon 1991) was estimated for each species separately (III: p. 101 and 102).

2.2.2 Nationwide berry models (V)

Data on the percentage coverage of cowberry were collected on the permanent sample plots (300 m^2) of the Finnish National Forest Inventory (NFI) in 1995 (so-called PSP3000 data). The inventory was based on clusters of four permanent sample plots arranged in a north–south direction, located systematically at intervals of 400 m (in northern Finland three plots were 600 m apart). The clusters were arranged systematically throughout the country (Pysyvien koealojen… 1995; Heikkinen and Reinikainen 2000).

Sample plots representing seven different categories (a–g) were included in the study material. Categories (a–e) pertained to forest land and were as follows:

a) Mineral soils
b) Spruce mires – transforming phase
c) Spruce mires – transformed phase
d) Pine mires – transforming phase
e) Pine mires – transformed phase.

On poorly productive land and unproductive (waste) land, only fell forests and summits (i.e. site quality class VIII; see e.g. Pysyvien koealojen… 1995; Tomppo et al. 2011) were considered in the modelling (i.e. categories f and g) (V: Table 1).

A total of 2515 sample plots were included in the data. Most of the plots were completely located within one stand compartment, but 11% of the plots were divided into two or even three stands due to the heterogeneity of the sample plot. As a result, 2801 stands were included in the analyses (V: Table 1). The data had a hierarchical structure because the sample plots were located in 983 clusters, which in turn were located in 367 municipalities and 14 forestry centre regions.

The site and stand characteristics were measured and recorded according to the field instructions of the NFI (Pysyvien koealojen… 1995). On each sample plot, the cover of the individual species, including cowberry, were estimated from four 2-m^2 quadrates, and their averages were used as the sample plot-wise (stand-wise) estimates of abundance. If the sample plot was bisected by a stand compartment boundary, the stand characteristics and species coverages for each stand were estimated separately and used in the modelling.

The yield of cowberry and its annual variation during 2001–2012 were studied using the inventory data (so-called MASI data) collected from permanent sample plots in different parts of Finland (e.g. Salo 1999). In the MASI inventory, the flowering and ripening of cowberries are recorded annually in forest stands found to be good growing sites for the species. In each stand, there are five permanent 1-m^2 quadrates. The mean annual number of ripe cowberries on the quadrates (i.e. a total of 193 annual observations in 34 stands) was used in the analyses (V: Table 2).

The study stands were located in 27 municipalities and in 12 forestry centre regions (V: Fig. 1). The following characteristics were measured and recorded for each stand when a stand was established: site type, dominant tree species, stand age and stand basal area by tree species. In addition, the coverage of cowberry was estimated on the same quadrates that were used for annual monitoring of ripe berries, and the mean coverage on the quadrates was used in the analyses. In the data, all study stands were pine-dominated and most of them represented sub-xeric heath forests (V: Table 2).

Models were prepared for the mean percentage coverage of cowberry (V: Model 1) and the mean number of cowberries in the stand (V: Model 2) using generalized linear mixed models (GLMMs). Model 1 was expressed by the logit-link function with a binomial response, and Model 2 by the log-link function with a Poisson response (McCullagh and Neldel 1989). The GLMMs were estimated using the glmmPQL function of the R software (R Development Core Team 2012).

Modelling of the coverage consisted of three steps. First, GLMMs were developed for each category (a–e) using the site and stand characteristics that were measured during the NFI as fixed predictors. Altitude and mean effective temperature sum (Ojansuu and Henttonen 1983) were used to describe the south–north variation in the growing conditions at the national level. The multilevel hierarchy of the data (stand, sample plot, cluster, municipality, forestry centre region) and subsequently correlated observations were taken into account by including random effects at different levels in the variance component models.

In the second stage, the models created for each of the categories (a–e) were compared with each other. In this comparison, whether the same fixed predictors were included in different models was examined, and whether the relationships were similar in different models was also checked. As a result of these investigations, it was decided to combine categories b and c and develop a common model for *spruce mires*. Correspondingly, a common model was developed for *pine mires* using observations for categories d and e.

In the final stage, a common model was created for categories (a–g) so that a model for mineral soil sites (step 1) and models for spruce mires and pine mires (step 2) were used as the basis of modelling. Categories f and g were considered in the common model by their own indicator variables. In addition, there was a check on whether the temperature sum and altitude became statistically significant predictors for all the categories (also for categories f and g).

In the modelling of cowberry yield, the site and stand characteristics that were known for the MASI stands (including the coverage of cowberry) were used as potential fixed predictors in the GLMM. Because the glmmPQL function did not allow the random cross-effects, the effects of the years 2001–2012 were considered using indicator variables in fixed predictors. The random terms included between-forestry centre region, between-municipality and between-stand effects as well as an additional random term at the bottom level (“pseudo” level).

2.3 Evaluation of the models

The models developed in separate studies (I–V) were evaluated by comparing them with each other and with previous berry yield models of Pukkala (1988) and Muhonen (1995) (in this summary, also with the bilberry yield model of Miina et al. 2009). The results of each study were also compared with empirical research results found in the literature.

For this summary, the correlations between the predictions of different models (I–V; Pukkala 1988; Muhonen 1995; Miina et al. 2009) were calculated employing stands from Study II. In the case of bilberry, 219 stands representing mesic heath forests (site fertility class III) were utilized. In the case of cowberry, 86 stands representing sub-xeric heath forests (site IV) were used. In the latter case, only pine-dominated stands were selected because the yield model of Study V was developed particularly for pine stands. The same stands from Study II were also used when the predictions of different models were presented as a function of stand age (Figs. 1 and 2).

The stands for Study II were located in eastern Finland and, therefore, all the model predictions were calculated for North Karelia. In the case of models derived in Studies III and IV, unbiased back-transformed predictions were calculated by using ratio estimators for bias correction (Snowdon 1991). When considering models for Study II and the models of Muhonen (1995), logarithmic predictions were transformed into the arithmetic scale using the method suggested by Baskerville (1972). The statistical method applied in Study I was quite complicated and, consequently, considerable efforts would have been required to produce unbiased back-transformed predictions. Therefore, it was decided to calculate logarithmic predictions and, for comparison, also uncorrected back-transformed predictions. The mean temperature sum and altitude that were needed in the cowberry yield model of study V were set at 1100 dd. and 100 m, respectively.

In study V, the performance of the estimated models was illustrated by predicting the coverage of cowberry and the cowberry yield and its annual variation in various stands whose initial characteristics, development and management were simulated using the Motti stand simulator (e.g. Hynynen et al. 2005). Corresponding examinations using simulations were not made for the other studies of this thesis. In this summary, the performance of the cowberry yield models of Studies I–IV was also investigated by predicting average annual yields for one of the simulated stands of Study V (i.e. pine stand representing sub-xeric heath forests in southern Finland). In addition, average annual yields of bilberry were predicted using models of Studies I–IV for the simulated pine and spruce stands of Miina et al. (2009). The stands of Miina et al. (2009) represent mesic heath sites and were also located in southern Finland (1200 dd.).

3 RESULTS

3.1 Models for bilberry yield

Table 1 presents bilberry yield prediction models developed for mineral soil sites in Studies I–IV. In the case of Study IV, only the common model for Forestry Centres 1–10 and 12–13 is presented (i.e. IV: Table 3).

On mineral soil sites, increasing stand age was found to affect bilberry production positively. This was the general finding of Studies I–IV, except for the model for Kainuu in Study IV. According to the models, the most abundant bilberry yield may be found in a mature stand which is not too dense. The effect of tree species on bilberry production was not completely unambiguous (Table 1). However, it is quite obvious that good crops are associated with coniferous forests whereas deciduous trees negatively affect bilberry yields.

The site fertility had a significant effect on bilberry crops (Table 1). The highest yields were found on mesic heath sites (site fertility class III, medium fertility) and sub-xeric heath sites (site IV, rather poor fertility) (II–IV). In Study II, these two site fertilities were equally good with respect to bilberry production. However, in Studies III and IV sites of medium fertility had a priority over rather poor soil sites. The effect of site fertility was different in Study I: fertile sites (i.e. sites of medium fertility and more fertile sites) were more favourable for bilberries than poorer sites.

In Study II, berry yield prediction models were not only developed for mineral soils but also for spruce and pine mires. In the case of the bilberry, the prediction model was common for these three principal site classes (II: Eq. 1).

3.2 Models for cowberry

3.2.1 Model for the percentage coverage of cowberry (V)

The model developed for the abundance of cowberry (V: Model 1, Table 3) indicates that the highest coverage can be found on sub-xeric heath forests (site IV). The abundance of the species on xeric heath forests (site V) and mesic heath forests (site III) was approximately 66% of that of site IV. On fertile mineral soil sites (sites I and II), the coverage was scarce.

On mineral soils, the dominant tree species was a significant predictor of the abundance of cowberry (V: Model 1, Table 3). However, the decreasing effect of deciduous trees and spruce (compared with pine) on cowberries was not found at all sites, but only at sites I–III. The stand basal area positively affected the coverage of cowberry. Both the temperature sum and altitude were significant predictors in Model 1. On average, the coverage seems to be higher in northern Finland than in southern Finland.

As mentioned above, the model for the abundance (V: Model 1, Table 3) considers not only mineral soils but also many other sites where cowberry occurs and produces yield (see Ch. 2.2.2, categories b–g). Since the yield model (V: Model 2, Table 4) was created only for mineral soil sites, results concerning categories b–g (V: Model 1, Table 3) are not presented in this summary.

Table 1. Bilberry yield prediction models for mineral soil sites (I–IV).

	Study			
	I [b]	**II**	**III** [c]	**IV** [d), e]
Predicted variable	ln(v)	ln(y + 1)	ln(y_{tk} + 1)	ln(y_{ij} + 1)
Predictor variable [a]	**Estimate**			
Intercept	--	0.243	0.0830	1.519
T	0.0074	--	0.0103	--
G	-0.0108	--	--	--
G_{spruce}	--	-0.0137	--	--
stems	--	--	--	-0.0000972
h_{dom}	0.0347	--	--	--
h^2	--	0.0016	--	--
h_{mean}	--	--	--	0.0568
V_{pine}	0.0015	--	--	--
V_{dec}	-0.002	--	--	--
propdec	--	-0.189	--	--
spruce	--	--	--	0.385
pine	--	--	--	0.161
D_{poor}	-0.2102	--	--	--
D_{34}	--	0.594	--	--
D_3	--	--	0.9904	0.904
D_4	--	--	0.4997	0.505
FC_{1B}	--	--	--	-0.845
$FC_{1B} \times G$	--	--	--	0.0369
FC_4	--	--	--	-0.602
$FC_4 \times spruce$	--	--	--	0.204
FC_{13}	--	--	--	0.474

[a] In the case of mixed models (III and IV), only estimates of the fixed predictor variables are presented.

[b] I: Model (7)

[c] The random part of the model included random effect of year t (e_t), random effect of sample plot k (e_k) and random error (e_{tk}).

[d] IV: Table 3

[e] The random part of the model included random effect of respondent j (e_j) and random error (e_{ij}).

Explanation of the variables are as follows: v = priority of the stand in terms of bilberry yield; y = bilberry yield (score); y_{tk} = bilberry yield in sample plot k in year t (kg ha^{-1}); y_{ij} = bilberry yield in forest stand i estimated by respondent j (kg ha^{-1}); T = stand age (years); G = stand basal area (m^2 ha^{-1}); G_{spruce} = basal area of spruce (m^2 ha^{-1}); *stems* = number of stems (trees ha^{-1}); h_{dom} = dominant height (m); h = arithmetical mean height (m); h_{mean} = mean height (m); V_{pine} = standing volume of pine (m^3 ha^{-1}); V_{dec} = standing volume of birch (*Betula pendula* Roth, *B. pubescens* Ehrh.) and other deciduous trees (m^3 ha^{-1}); *propdec* = proportion of deciduous trees of the total volume (ranges from 0 to 1). *Spruce* and *pine* are indicator variables for dominant tree species: *spruce* = 1, if the dominant tree species is spruce, and *spruce* = 0 otherwise; *pine* = 1, if the dominant tree species is pine, and *pine* = 0 otherwise. D_{poor}, D_{34}, D_3 and D_4 define the site as follows: D_{poor} = 1 for poor sites (i.e. sub-xeric heath forests or sites poorer than that), and D_{poor} = 0 otherwise; D_{34} = 1 for mesic or sub-xeric heath forests, and D_{34} = 0 otherwise; D_3 = 1 for mesic heath forests, and D_3 = 0 otherwise; D_4 = 1 for sub-xeric heath forests, and D_4 = 0 otherwise. FC_d is an indicator variable for district (14 districts in Finland, see IV: Fig. 1): FC_d = 1, if district is d, and FC_d = 0 otherwise.

3.2.2 Models for cowberry yield

It is quite obvious that sub-xeric heath forests (or sites poorer than that) produce the most abundant cowberry yields. Further, pines are characteristic of a stand suitable for cowberry picking. However, the stand should not be too dense. These are the general findings of Studies I–V (Table 2). As an exception, site fertility was not a significant predictor in the yield model developed in Study V. The reason for this is most probably the low number of stands representing mesic and xeric heath forests in the MASI data (V: Table 2).

The results of different studies (I–V) concerning the relationship between the stage of stand development and cowberry production on poor mineral soil sites (i.e. rather poor or poorer sites) were partly in line with each other and partly quite contradictory when compared with each other. The models indicate that high yields can be found in recently clear-felled open areas, small seedling and sapling stands and seed-tree stands (a few exceptions to this general rule are mentioned later in this summary). It was also found that the period of intensive berry production was limited by the formation of young stands (i.e. a stand age of approximately 20–30 years). A significant difference between the models from the different studies was found when cowberry production in mature stands was examined. According to Studies I, II and III and the cowberry yield model for Forestry Centres 1–9 and 12 (IV: Table 4), the most abundant cowberry crops can be found not only in stands that represent the beginning of stand rotation but also in mature stands. However, Study V and the cowberry yield model for Forestry Centres 10, 11 and 13 (IV: Table 5) did not support the above-mentioned result (see IV: Fig. 4, V: Fig. 3). The specific features of the model for Forestry Centres 10, 11 and 13 (IV: Table 5) are presented more in detail later in this summary.

Table 2. Cowberry yield prediction models for mineral soil sites (I–V).

	Study					
	I[b]	**II**[c]	**III**[d]	**IV**[e], [f]	**IV**[g], [f]	**V**[h], [i]
Predicted variable	ln(v)	ln(y + 1)	ln(y_{tck} + 1)	ln(y_{ij} + 1)	ln(y_{ij} + 1)	*Berries* = exp {f(•)}
Predictor var.[a]	**Estimate**					
Intercept	--	0.311	1.0560	2.209	3.0770	6.7253[j]
T	0.006	0.0048	--	--	0.00637	--
T^2	--	--	--	0.0000580	--	--
G	--	-0.0224	--	--	-0.0311	--
$G^{½}$	--	--	-0.1196	--	--	--
ln(G + 1)	--	--	--	--	--	-0.4716
stems	--	--	--	-0.000155	--	--
V_{pine}	0.0027	--	--	--	--	--
V_{dec}	-0.0035	--	--	--	--	--
proppine	--	0.518	--	--	--	--
pine	--	--	--	0.540	0.292	--
D_{poor}	1.7817	1.699	--	1.539	1.0543	--
$D_{poor} \times d_{mean}$	-0.1756	--	--	--	--	--
$D_{poor} \times d_{mean}^2$	0.0052	--	0.0005	--	--	--
D_{poor} × ln(d_{mean} + 1)	--	--	--	-0.122	--	--
$D_{poor} \times h$	--	0.0499	--	--	--	--
D_{poor} × ln(h + 1)	--	-0.626	--	--	--	--
FC_{1B} × *stems*	--	--	--	0.000218	--	--
FC_3	--	--	--	-0.592	--	--
FC_{10}	--	--	--	--	-0.695	--
FC_{11}	--	--	--	--	0.602	--
$FC_{11} \times D_{poor}$	--	--	--	--	-0.594	--
$FC_{13} \times D_{poor} \times d_{mean}^2$	--	--	--	--	-0.000914	--
cov	--	--	--	--	--	0.0966
cov ^{2} / 100	--	--	--	--	--	-0.0837
alt	--	--	--	--	--	0.0071
1000 / *tempsum*	--	--	--	--	--	-4.6264

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[a] In the case of Studies III-V, only estimates of the fixed predictor variables are presented.

[b] I: Model (8)

[c] The model included two surveyor indicators which are not presented here, because they may be taken as zero when applying the model.

[d] The random part of the model included random effect of year *t* (e_t), random effect of cluster *c* in year *t* (e_{tc}), random effect of sample plot *k* (e_k) and random error (e_{tck}).

[e] IV: Table 4

[f] The random part of the model included random effect of respondent *j* (e_j) and random error (e_{ij}).

[g] IV: Table 5

[h] V: Table 4 (Model 2)

[i] The random terms included between-forestry centre region, between-municipality and between-stand effects and an additional random term at the bottom level ("pseudo" level).

[j] The mean value of the fixed year effects (0.1849) is included in this figure (i.e. 6.7253 = 6.5404 + 0.1849).

Explanation of the variables are as follows: *v* = priority of the stand in terms of cowberry yield; *y* = cowberry yield (score); y_{tck} = cowberry yield in sample plot *k* in cluster *c* in year *t* (kg ha^{-1}); y_{ij} = cowberry yield in forest stand *i* estimated by respondent *j* (kg ha^{-1}); *Berries* = mean annual number of cowberries per m^2 and *f*(•) is a linear function of *cov* = mean coverage of cowberry in the stand (%), *G* = stand basal area (m^2 ha^{-1}), *alt* = altitude (m) and *tempsum* = temperature sum (dd); *proppine* = proportion of pine of the total volume (ranges from 0 to 1); d_{mean} = mean diameter (cm); others as in Table 1.

Study V indicated that the yield of cowberry increased when the coverage of cowberry increased up to a coverage of 58%, after which the berry yield decreased. It was also found that the temperature sum and altitude were significant predictors in the yield model (V: Model 2, Table 4). However, the results concerning the effects of temperature sum and altitude on cowberry production can be regarded only as tentative because the number of study stands was relatively low in the MASI data (V: Table 2) and, in addition, the stands were not evenly distributed over the country (V: Fig. 1).

In Study II, a separate model was created for cowberry yields on mineral soils and pine mires. In the case of pine mires, only site fertility and the amount of deciduous trees affected cowberry production. It was found that the yields were best on rather poor sites (site IV) and an increase in the basal area of deciduous trees decreased cowberry yields.

3.3 Variation between plots, regions and years

The between-plot variation in bilberry yield was taken into account in the model developed in Study III. A major part of the residual variation (58%) was caused by the random sample plot effect (III: Table 3). Also, the random year effect was included in the models of Study III, which made it possible to calculate the berry yield indices for the study years 1981–1984 (III: Fig. 10). However, it turned out that the year effect was not a statistically significant component in the random part of the bilberry model and the proportion explained by the year effect was merely a few percentage units. Almost 40% of the variation consisted of random error.

The cowberry yield model derived in Study III suggested that in a given year the level of cowberry yields varied from cluster to cluster (the proportion of year × cluster of the total variation was 9%). In addition, a high variation in cowberry crops was found between different sample plots (III: Table 3). Almost one third of the variation consisted of random error. The proportion of the year effect was 10%, but it was not a statistically significant component in the model.

In Study IV, the regional variation in berry yields was taken into account in two different ways. First, consideration was given to whether a common model could be formulated for several districts or whether a particular district (Forestry Centre) needed a model of its own. Second, it was possible to improve a certain common model by adding district-specific variables. When considering, for example, the cowberry yield model for Forestry Centres 10, 11 and 13 (IV: Table 5) it can be seen that all three “northeast” Forestry Centres had district-specific predictors. North Karelia had a negative indicator variable, suggesting that the yield level in the region is, on average, a bit lower than the corresponding levels in two other regions. Kainuu had a positive indicator variable, indicating the opposite situation. Kainuu also had another district-specific variable, which suggests that the effect of site fertility on cowberry production is not as strongly emphasized in Kainuu as in North Karelia or Lapland. The Lapland-specific predictor suggests that, on poor sites, the best cowberry yields can be found not only in seed-tree stands (which is the case in two other districts) but also in recently clear-felled open areas and young seedling and sapling stands (see also IV: Fig. 4).

In Study V, the multilevel hierarchy of the data was taken into account by including random effects at different levels in the variance component models. It was found that most of the unexplained variation (57%) of the coverage model for the cowberry (V: Model 1, Table 3) was at the stand level. The sample plot-, cluster- and municipality-level residual variations accounted for almost an equal proportion (11–13%) of the total variation. The rest of the variation (7%) was due to the forestry centre region-level variation.

In Models 1 and 2 (V), the temperature sum and altitude were used as continuous fixed predictors to describe the large-scale geographical variation. The results concerning the effects of these predictors on the coverage (Model 1) and yields of cowberry (Model 2) have been reported earlier in this summary. In this context, it is worth noting that the uneven distribution of MASI stands (V: Fig. 1) has most probably resulted in a high proportion of the unexplained variation at the forestry centre region level in Model 2 (V: Table 4).

Annual variation in the cowberry yield was predicted in study V. The effects of the years 2001–2012 were considered using indicator variables as fixed predictors in the cowberry yield model (V: Model 2, Table 4). The mean value of the fixed year effects was 0.1849, and this value should be used as a year effect in Model 2 (i.e. should be added to the intercept) when the average annual yield is calculated for a certain stand (Table 2). The variance of the year effects was 0.0888. Standard deviation of the year effects was employed when 95 % confidence intervals for the average annual yields were calculated (V: corrected Fig. 3).

3.4 Variation related to expert judgements

In Study I, the evaluations of five most inconsistent experts were removed from both the bilberry and cowberry data in order to construct more correct models than those based on the assessments of all the experts. It turned out that in the new models, which were based on more consistent data (I: Models 7 and 8) the predictors were the same as in the models based on the whole data (I: Models 5 and 6). In addition, the impacts of the predictors on bilberry and cowberry yields were similar to those in Models 5 and 6. In the case of bilberry yield prediction models, R^2 increased by eight percentage units when the evaluations of the five most inconsistent experts were eliminated from the data (from 0.28 to 0.36). For the cowberry, the corresponding increase in R^2 was five percentage units (from 0.47 to 0.52).

In Study II, it was assumed that the foresters would have established different criteria for assigning ratings when assessing berry yields of different forest stands. In other words, it was assumed that for one person a rating of “three”, for example, could indicate a medium berry yield, whereas for someone else it could indicate a low yield. This fact was taken into account by the indicator variables when creating the models. However, it turned out that there were no scale differences in the bilberry yield assessments made by the different surveyors (II: Eq. 1). Contrary to this, the cowberry yield evaluations given for mineral soil sites differed from surveyor to surveyor (II: Eq. 2). When considering the cowberry yield prediction model for pine mires, the estimations of one surveyor were considerably higher than those of the two other surveyors (II: Eq. 3).

The random respondent effect was statistically significant in all berry yield prediction models developed in Study IV. In other words, the assessments given by a respondent were correlated and a between-respondent variation was found. In each of the models, approximately one third of the residual variation was accounted for by the random respondent effect (IV: Tables 2-5). The rest of the residual variation was random error.

3.5 Evaluation of the models

Bilberry yield predictions computed using models of Studies I–IV and the models of Pukkala (1988), Muhonen (1995) and Miina et al. (2009) correlated positively and statistically significantly with each other (the significance level used in the two-tailed test was 0.01) (Table 3). In the test data, Model 7 of Study I seemed to produce predictions that were most similar with predictions produced by the other models in this thesis (i.e. II–IV). It was interesting to observe that the way the predictions were calculated in the case of Study I (logarithmic predictions vs uncorrected back-transformed predictions) did not significantly affect the correlations.

Table 3. Correlations between predicted bilberry yields computed using different models (I–IV; Pukkala 1988; Muhonen 1995; Miina et al. 2009), employing mineral soil stands of medium fertility (site III) from Study II. In the case of Study I, both logarithmic predictions (I: Model 7) and uncorrected back-transformed predictions were calculated (in the latter case, see correlations given in parentheses).

	I	II	III	IV	Pukkala (1988)	Muhonen (1995)	Miina et al. (2009)
I	1	0.894* (0.931*)	0.932* (0.926*)	0.916* (0.886*)	0.697* (0.649*)	0.362* (0.329*)	0.884* (0.881*)
II		1	0.798*	0.837*	0.572*	0.195*	0.878*
III			1	0.850*	0.674*	0.413*	0.792*
IV				1	0.629*	0.369*	0.755*
Pukkala (1988)					1	0.570*	0.616*
Muhonen (1995)						1	0.267*
Miina et al. (2009)							1

* Correlation is significant at the 0.01 level (two-tailed).

Fig. 1 indicates that bilberry yield predictions which were calculated for pine- and spruce-dominated stands of Study II (site III) using the models of Studies I, III and IV and the model of Miina et al. (2009) correlated positively with stand age. It indicates also that two of these models (I; Miina et al. 2009) emphasize bilberry yields of pine-dominated stands while the model of study IV (IV: Table 3) emphasizes yields of spruce-dominated stands. In Study III, tree species was not a statistically significant predictor in the bilberry yield model (Table 1); the fact that can be seen also in Fig. 1B.

The correlation matrix for cowberry yield predictions (Table 4) indicates that most of the correlations were positive and statistically significant, but it also indicates a few insignificant, even negative correlations. On average, the cowberry yield model of Study I seems to have the weakest performance when the correlations presented in Table 4 are examined. In other words, cowberry yields computed by means of Model 8 of Study I correlated slightly negatively with the predictions produced by the models of Study V and Pukkala (1988) and, in addition, only weakly positively (*r* = 0.166) with the predictions produced by the model of Study IV (IV: Table 5).

Fig. 2 illustrates some explanations for the weak correlations mentioned above. In Fig. 2 the four cowberry yield models of this thesis are examined. The negative correlation between the predictions computed using the models for Studies I and V was most probably due to the fact that the former produced good crops, particularly at the end of the stand rotation, while the latter produced the best crops at the beginning of the rotation (including seed-tree stands) (Fig. 2). It is also worth noting that there were two seed-tree stands in the test data and predictions for these stands were quite low due to the relatively small mean diameter of the trees (Fig. 2A). However, in the modelling data (Study I) the predicted cowberry yields for seed-tree stands (three stands) were as high as for mature stands and openings.

Table 4. Correlations between predicted cowberry yields computed using different models (I–V; Pukkala 1988; Muhonen 1995), employing pine-dominated mineral soil stands of rather poor fertility (site IV) from Study II. In the case of Study I, both logarithmic predictions (I: Model 8) and uncorrected back-transformed predictions were calculated (in the latter case, see correlations given in parentheses).

	I	II	III	IV	V	Pukkala (1988)	Muhonen (1995)
I	1	0.407* (0.371*)	0.558* (0.567*)	0.166 (0.170)	-0.115 (-0.122)	-0.211 (-0.161)	0.465* (0.445*)
II		1	0.907*	0.879*	0.690*	0.768*	0.698*
III			1	0.857*	0.523*	0.624*	0.810*
IV				1	0.579*	0.813*	0.851*
V					1	0.751*	0.196
Pukkala (1988)						1	0.402*
Muhonen (1995)							1

* Correlation is significant at the 0.01 level (two-tailed).

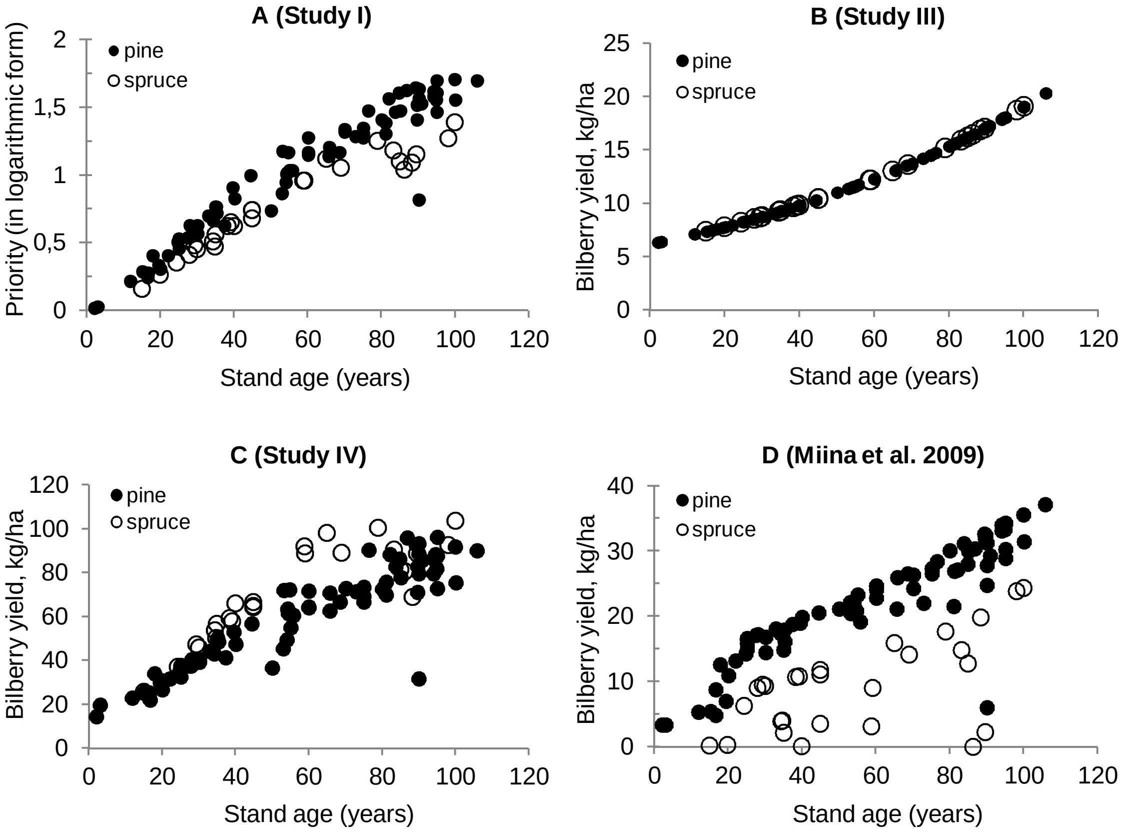

Figure 1. Predicted bilberry yields for pine- and spruce-dominated mineral soil stands (stands of medium fertility) of Study II as a function of stand age. All the predictions were calculated for North Karelia using models of Studies I, III, IV and Miina et al. (2009).

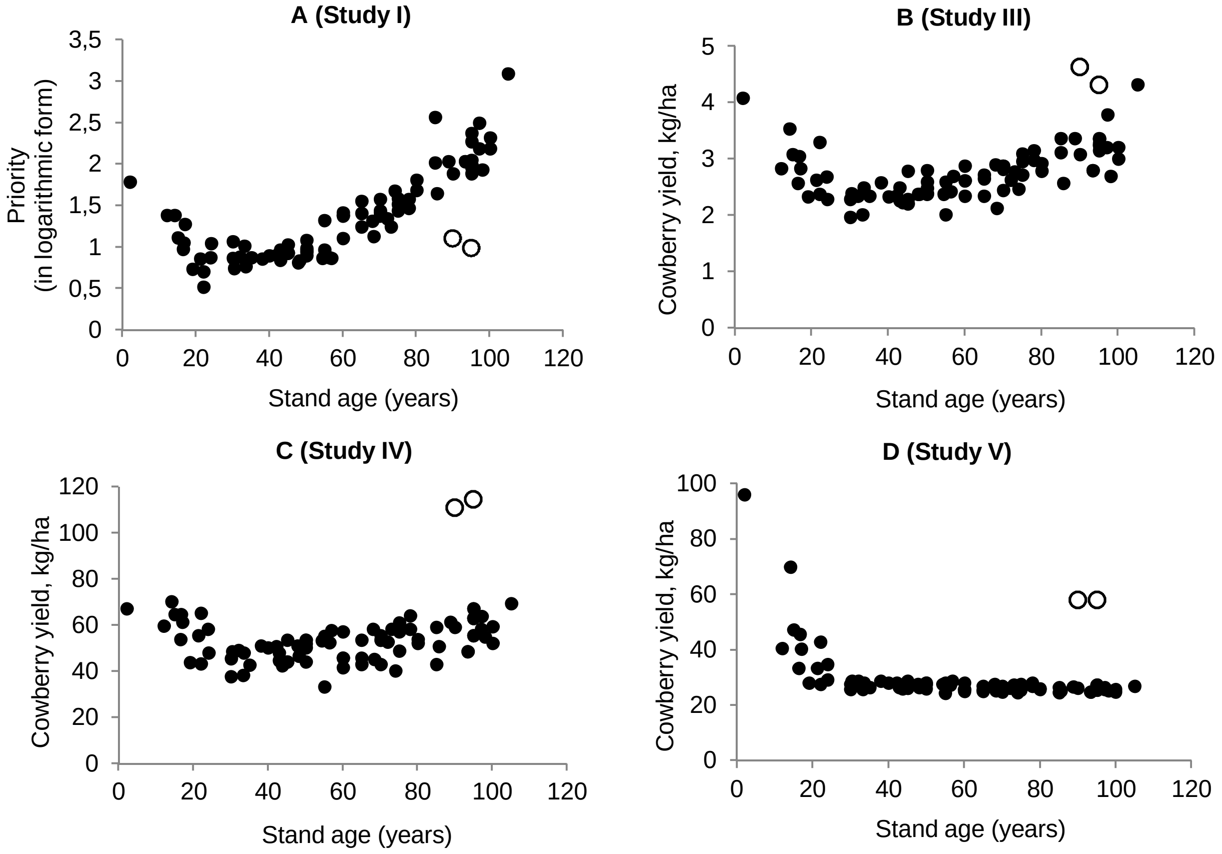

Figure 2. Predicted cowberry yields for pine-dominated mineral soil stands (stands of rather poor fertility) of Study II as a function of stand age. All the predictions were calculated for North Karelia using models of Studies I, III, IV and V. ○ seed-tree stands • other stands

As mentioned earlier, the cowberry yield model for Forestry Centres 10, 11 and 13 (IV: Table 5) gives priority to seed-tree stands over other stands on poor mineral soil sites (this was the case particularly in North Karelia and Kainuu). This result can be seen also in Fig. 2C. Fig. 2C also suggests that openings, small seedling and sapling stands, as well as mature stands are on average, slightly more advantageous for cowberry production than, for example, young thinning stands. This fact was not visible in Study IV (see e.g. IV: Fig. 4) and, therefore, was not mentioned in the results of Study IV.

The simulation results are presented and discussed in Ch. 4.2.

4 DISCUSSION

4.1 Analysis of different data collection methods and modelling techniques

In each of the five studies of this thesis, different methods of data collection and different modelling techniques have been used. In the following, the methods applied are discussed, and the advantages and disadvantages of the methods are pointed out. Although the variations related to expert evaluations were considered in the model construction in Studies I, II and IV, a detailed analysis of the uncertainties of expert judgements was not one of the aims of this thesis and, therefore, this topic is discussed only briefly below.

The expertise elicitation technique employed in Study I, namely, pairwise comparisons as applied in AHP, has been used earlier in forestry applications, for example, by Kangas et al. (1993a, 1993b) and Muhonen (1995). One motive for using pairwise comparisons rather than, for example, direct assessments of the priorities (cf. II and IV) is that the consideration of one pair at time is expected to reduce biases caused by the ordering of the entities (stands) in the elicitation (Alho et al. 2001). Furthermore, pairwise comparisons produce ratio scale values which are needed, for example, in modern planning and decision-making (e.g. Kangas et al. 1993a). The disadvantage of the method comes from the fact that the priority calculations of the original AHP (Saaty 1977) require a complete set of paired comparisons, that is, a set of n entities requires $n(n-1)/2$ pairwise comparisons; consequently, the number of pairs to be compared increases sharply as the number of entities increases. On the other hand, the method based on scaling, which has been used to avoid excessive number of comparisons, suffers from the drawback that the reliability of all priorities heavily depends on the few comparisons made within the scaling set.

To reduce the number of comparisons and to overcome some other limitations (e.g. insufficient uncertainty analyses) of the original AHP, Alho et al. (2001) proposed a regression method for developing a priority model directly from paired comparisons. In this method, the minimum requirement is that each stand belongs to one pair. In Study I, as well as in many other applications (Silvennoinen et al. 2001; Tahvanainen et al. 2001, 2002; Tyrväinen et al. 2003), the number of comparisons was set at $(n-1) + (n-2)$. Although the variations related to expert judgements were considered in model construction (I), the error term still included, besides the between-stand residual variation, also the between-expert residual variation. When the models were computed for the average priority of a stand (the average of priorities given by experts to a given stand), using the same predictors as in Eqs. 7 and 8, the result was that models for the average priority explained 53–63% of the between-stand priority variation. These degrees of determination were higher than those related to Models 7 and 8. In fact, they were quite close to those found in Muhonen's (1995) study, which varied between 0.62 and 0.68.

Direct rating has been used widely to express the priorities of stands or landscapes, particularly in studies focusing on the scenic beauty of different landscapes (e.g. Pukkala et al. 1988; Nousiainen and Pukkala 1992; Tahvanainen et al. 1996). In Studies II and IV, the berry yield assessments for different stands were made on a rating scale of 0 to 10. However, with direct rating it is often questionable whether the priority is measured on the ratio scale or interval scale, as required by the regression analysis (Pukkala 2002). In Study IV, this was not a problem as the instructions for filling in the questionnaire emphasized that the scale used was a ratio scale. In Study II, it was instead *assumed* that the assessments were made using an interval scale. Another problem of the rating method is trying to keep the scale constant over the evaluation period (e.g. Tahvanainen et al. 1996). In Studies II and IV, the variation between the experts was taken into account by including fixed (II) or random respondent effects (IV) in the models. However, internal inconsistencies in individual experts' views were not considered in the modelling, and this type of inconsistency was included in random errors.

In Study I, the slides representing different forest stands were the same as in the study of Silvennoinen et al. (2001). In the latter study, the slides were assessed from the point of view of the stands' scenic beauty. When *berry yields* are assessed on the basis of slides (photos), the problem is that ground vegetation is sometimes difficult to see from the photos, and one photo represents only a small sub-area of a stand, which is usually heterogeneous (see also Muhonen 1995; Kangas and Muhonen 1997). In Study II, the production capacity of bilberry and cowberry were visually estimated for whole stands during the field inventory and, by this means, it was assumed that any problems resulting from an insufficient view or the patchlike occurrence of berry plants would be avoided. This evaluation method was found to be a very promising one; it was also quite cheap and did not require considerable efforts on the part of the forest planners.

In Study IV, the data were collected by means of a questionnaire survey. It is the most straightforward method to collect data on berry yields in different kinds of forest stands over large geographical areas. Sepponen (1984) used a similar method when he examined the production capacity of different berry species on mineral soil sites and peatlands. In his study, forest professionals in northern Finland assessed berry yields as a function of site fertility. The results of Sepponen's study (1984) indicated that berry yields should be examined not only with respect to site fertility but also stand age and density of the growing stock should be taken into account. These findings were considered when the questionnaire for Study IV was developed. Still, one can conclude that assessment of berry yields of different imaginary forest stands is quite a complicated task, when compared, for example, with visual evaluations. This conclusion was drawn, for example, on the basis of comments obtained from many respondents.

Further, many of the 266 respondents stated that it was quite difficult to convert the maximum value (10) of the ratio scale into kilograms per hectare (IV). The high variation in the absolute berry yield given to the score of 10 was most probably one reason for the low degree of determination of the models (varying from 0.07 to 0.23). Despite this difficulty, it was decided to employ the maximal yield estimates (kg ha^{-1}) given by the respondents when evaluations given on the scale of 0 to 10 were converted to absolute berry yields (for each respondent and berry species separately). An alternative way would have been to search for empirical evidence from berry yield studies conducted so far (e.g. Turtiainen et al. 2005, p. 11; also, Issakainen and Moilanen 1998) in order to establish a link between the maximum score (10) and the maximal district-specific yield (kg ha^{-1}). However, the problem with the empirical studies conducted so far is that they do not cover all the districts in Finland. In addition, empirical berry yield studies have been conducted during different crop years. In Study IV, the purpose was to develop regional berry yield models for an average crop year. For the above reasons, an alternative way was not considered in Study IV and the models relied entirely on expertise.

Berry yield models developed in Studies III and V were based on empirical measurements. In the former, the sampling method was objective (systematic sampling) and, consequently, there were a number of sample plots with no berry vegetation or only sterile vegetation. In the latter, the sample plots were placed subjectively in stands found to be good growing sites for cowberry. Thus, it is not surprising that the yield model of Study V produces, on average, higher predictions than the models of Study III (e.g. Fig. 2). An advantage of the sampling method applied in Study III was that the stands that were included in the data covered the whole range of variation in stand age and density, were dominated by different tree species and represented quite widely different site fertilities (III: Tables 1 and 2) and, consequently, the resulting models can be applied widely to different situations (i.e. different kinds of forest stands). The model based on MASI data is more limited in this respect. On the other hand, it is important to bear in mind that the model derived in Study V can be used throughout the country, while the models of Study III are regional.

There is also another significant difference between the inventory methods used in Studies III and V. In the former, the berry yield inventories were not timed to coincide with periods when the berries were ripe. For this reason, the biomass of the bilberries and cowberries for each berry sample plot was determined in two different ways (on the basis of ripe berries and on the basis of unripe berries) and the higher biomass was used. The estimation of berry yields on the basis of unripe berries is difficult. In Study III, it was assumed that 80% of the unripe berries will develop into ripe ones but the truth is that this proportion varies greatly, both temporally and spatially due to weather conditions, plant diseases, pests and so on (e.g. Raatikainen and Pöntinen 1983). In the MASI inventory, special attention was paid to the time when the berries were inventoried. The general rule was that berries were counted as ripe when over half of all berries were blue for bilberries and red for cowberries (Salo 1999). The conclusion is that both the accuracy and the reliability of berry yield predictions can be increased by collecting modelling data during the period when the berries are worth picking. An inventory method like this, however, is very resource-demanding, as different berry species ripen at different times during the growing season and the periods when berries are ripe vary from year to year and region to region (see also Saastamoinen et al. 2013b).

A typical feature of the modelling data of Studies II-IV was that the proportions of zero and small values were emphasised in both the bilberry and cowberry yield data. Due to this problematic feature, the predicted variable in each model of Studies II-IV was in logarithmic form. An alternative way would have been to use a two-step procedure in berry yield modelling. In this procedure, the first sub-model predicts the probability of occurrence of berries by a logistic function and the second sub-model predicts the berry yield in case there is occurrence. The model prediction is obtained as a product of the two sub-models (see e.g. Pukkala et al. 2013). This type of model is commonly used for so-called zero-inflated variables (Calama et al. 2011). In Study V, the problem of non-normal distributions was overcome by applying generalized linear mixed models (see below).

The modelling technique used in Study II was a very traditional one: linear regression analysis. In Studies III–V, it was assumed that the observations were correlated, and this was taken into account by including random effects in the models. However, the modelling techniques employed in Studies III and IV (linear mixed models) compared to V (generalized linear mixed models – GLMMs) differed considerably from each other. Two significant differences between these techniques can be observed. First, GLMMs allow for the dependent variable to have a non-normal distribution (e.g. McCullagh and Nelder 1989). This also means that model predictions are directly unbiased; that is, there is no need to use any kind of correction factor in model applications (V). Second, GLMMs expand linear mixed models so that the dependent variable is linearly related to the explanatory variables via a specified link function, which may become any monotonic differentiable function (e.g. McCullagh and Nelder 1989). In Study V, Model 1 (i.e. model for the coverage of cowberries) was expressed by the logit-link function with a binomial response and Model 2 (i.e. model for the number of cowberries) was expressed by the log-link function with a Poisson response. In future studies, GLMMs should be preferred rather than linear mixed models in cases when random effects are needed to consider the hierarchical and unbalanced structure of the data (see e.g. Miina et al. 2009).

In two out of five studies (IV and V), berry yield prediction models were derived for the whole country. The approaches used in these two studies were completely different. The former was based on expert evaluations that were obtained from forest professionals of the 13 Forestry Centres of Finland. An attempt was made to create regional berry yield models, and the regions followed the boundaries of Forestry Centres. The truth is, however, that the boundaries of Forestry Centres are just administrative and, in this respect, these boundaries are quite artificial when considering the growing conditions and berry production of different wild berry species. In the empirical models of Study V, the large-scale geographical variation in the coverage and yields of cowberry was taken into account by the predictors “temperature sum” and “altitude”. It can be concluded that the latter approach is more reasonable in many ways than the one of Study IV, but it requires that the modelling data is sufficiently comprehensive. Model 1 (V) was based on an extensive dataset and, consequently, the result concerning the south–north variation in the coverage was well in line with the earlier finding of Hotanen et al. (2000). However, the limitations of the MASI data resulted in a yield model that needs to be improved in the future (see also Ch. 5).

It can be presumed that in the MASI data not only average annual yields but also temporal variations in the yields are higher than the average due to the sampling method. In the dataset of Study V, for example, there were a number of stands that produced very high cowberry yields of more than 500 kg ha^{-1} during one or several years (these stand-wise estimates were calculated on the basis of ripe berries on five 1-m^2 sample quadrates; cf. e.g. Veijalainen 1976; Kuchko 1988; Belonogova and Zajceva 1989). On the other hand, it is important to note that crop failures also occur on sites that are usually advantageous for berry picking (see V: Table 2; also e.g. Belonogova 1993). For example, during dry summers cowberry and bilberry yields on mineral soil sites may remain low, and good (or normal) crops may be found on peatland sites, due to the fact that berries growing on peatlands only seldom suffer from dryness (Salo 1988). When the yield model of Study V is applied it is also possible to consider the between-year variation in yield predictions (cf. Miina et al. 2010; Pukkala et al. 2011). However, in long-term predictions the between-year variation will be levelled out.

4.2 Analysis of the main results

The degree of determination of the models for Studies I–IV was relatively low. On average, it was the highest in Study II, varying from 0.40 to 0.62. In Study III it was instead very low: R^2 calculated for the fixed part of the models using back-transformed units ranged from 0.03 to 0.06. It was assumed that this resulted from the problematic features of the modelling data: (1) the abundance of zero observations in both the bilberry and cowberry yield data, and (2) the scarcity of explanatory variables (the number of predictors that could be used in the modelling was the lowest in this particular study). However, all the models of this thesis (including those of Study III) were statistically significant.

According to the results of this research, the best bilberry yield can presumably be found in a mature stand which is not too dense and which is located either in mesic or sub-xeric heath forest. Many previous studies conducted in Finland, Sweden and in the European part of Russia (boreal vegetation zone) support this conclusion (e.g. Eriksson et al. 1979; Raatikainen and Raatikainen 1983; Raatikainen et al. 1984; Belonogova and Zajceva 1989; Raatikainen 1993). However, the effect of tree species on bilberry production is not completely unambiguous. It seems quite obvious that good crops are associated with coniferous forests whereas deciduous trees negatively affect bilberry yields (e.g. Eriksson et al. 1979; Raatikainen et al. 1984; Belonogova and Zajceva 1989). Belonogova and Kuchko (1979), however, have stated that more important than tree species is the amount of light which reaches the bilberry stand. It has been found that a crown density of 10–50% allows bilberry to flower and produce berries optimally (Raatikainen and Raatikainen 1983; Raatikainen et al. 1984). As a mesomorphic plant, bilberry has poor tolerance of the desiccating impact of direct sunlight (e.g. Raatikainen and Raatikainen 1983; Salo 1995; Atlegrim and Sjöberg 1996). Also, the results of Studies I–IV indicated that the poorest crops could be found particularly in openings and in small seedling and sapling stands.

When considering the prediction models for cowberry yield, it is obvious that heath forests of rather poor or poorer site fertility have the highest cowberry production. This result is supported by several earlier studies (e.g. Raatikainen 1978; Jaakkola 1983; Raatikainen et al. 1984; Belonogova and Zajceva 1989; Kujala et al. 1989). Also, the finding that cowberry crops are greater in pine-dominated stands than in stands dominated by other tree species is a well-known result (e.g. Eriksson et al. 1979; Kardell and Carlsson 1982; Raatikainen et al. 1984).

Being a photophilous plant with xerophyte tendencies, cowberry adapts well to conditions of intensive illumination (e.g. Belonogova 1993). Accordingly, the models in this thesis indicated that on poor sites cowberry produces abundant yields in stands representing the beginning of stand rotation (i.e. gaps, small seedling and sapling stands, seed-tree stands), although the coverage of cowberry is often low in these areas (V: Table 3; also e.g. Belonogova 1993). Further, most of the models (I, II, III, IV: Table 4) suggested that abundant cowberry crops can be found not only in stands representing the beginning of stand rotation but also in mature stands. This result is similar to many empirical studies found in the literature (e.g. Raatikainen 1978; Eriksson et al. 1979; Kardell and Carlsson 1982; Raatikainen et al. 1984; Jäppinen et al. 1986; Grjaz'kin et al. 2006). There are also empirical findings emphasizing that open regeneration areas, small seedling stands and seed-tree stands have the highest cowberry yields (e.g. Jaakkola 1983; Belonogova 1993) (cf. IV: Table 5, V). In spite of these findings, it may be that the yield models of Studies IV (IV: Table 5) and V produce underestimates at the end of stand rotation, particularly when calculated for sparse mature stands. However, in dense mature stands it is instead obvious that cowberry yields remain low (e.g. Belonogova 1993). Thus, it seems that there is still a need for further research to explore the dependence of cowberry crops on stand characteristics on poor mineral soil sites.

The performance of the models in Study V was illustrated by the prediction of the coverage of cowberry and the cowberry yield and its annual variation in various pine-dominated stands whose initial stand characteristics, development and management were simulated using the Motti stand simulator. It was found that the coverage of cowberry followed the development of the stand basal area and age in the simulated stands (V: Fig. 2). The coverage increased with increasing stand age and basal area, and decreased temporarily after thinnings. Regeneration felling decreased the coverage to some extent. These results are in line with the earlier empirical findings of, for example, Eriksson et al. (1979) and Kardell and Eriksson (1990). It was also found that thinnings were needed to improve the yield of cowberry, and final felling had a positive effect on the crop level (V: Fig. 3). These general findings, also earlier stated by Eriksson et al. (1979), Raatikainen et al. (1984) and Kardell and Eriksson (1990) can be seen in Fig. 3B–D. It may be, however, that the positive effect of final felling on cowberry production was overestimated in Study V (see discussion above).

In the cowberry yield models of Study I, the stand basal area (or number of stems) was not a statistically significant predictor (cf. II–V, Table 2) and, therefore, the effect of thinning on cowberry production is not reflected directly through stand basal area (or number of stems). Instead, the volume of pine and the volume of deciduous trees were included in the models (I: Eqs. 6 and 8) and, consequently, the effects of the thinnings are reflected through these two predictors. In a stand which consists entirely of pines, the standing volume and also the predicted yield of cowberry decreases as a consequence of thinning (see Fig. 3A). This result is not logical in the light of empirical findings (see above) even though the negative effect of thinning is very small. Instead, if a stand consists, for example, of both pines and deciduous trees, the effect of thinning can be positive. Fig. 3A also indicates that the crop level decreased after regeneration felling. However, in a seed-tree stand the crop level was still higher than in young thinning stands.

Fig. 3D illustrates also how strongly the number of stems affects cowberry yield predictions, which are calculated using the model of Study IV (IV: Table 4). The stand that was simulated in Study V was assumed to be direct seeded for pine and the stem number was set at 2000 stems ha^{-1}. In addition to pines, a number of deciduous trees were naturally regenerated at the beginning of stand rotation so that the total stem number was 6000–7000 stems ha^{-1} at the stand age of 5–20 years. In the first thinning, approximately two thirds of the stems (primarily deciduous trees) were removed. When all the trees (both pines and deciduous trees) were included in the stem number, the cowberry yield model of Study IV (IV: Table 4) produced low yield predictions at the stand age of 5–20 years (Fig. 3D, case a). After the first thinning, the cowberry yield increased significantly (Fig. 3D, case a). For comparison, when only pines were considered in the calculations, the yield predictions were considerably higher at the beginning of stand rotation and the effect of the first thinning was only slight (Fig. 3D, case b).

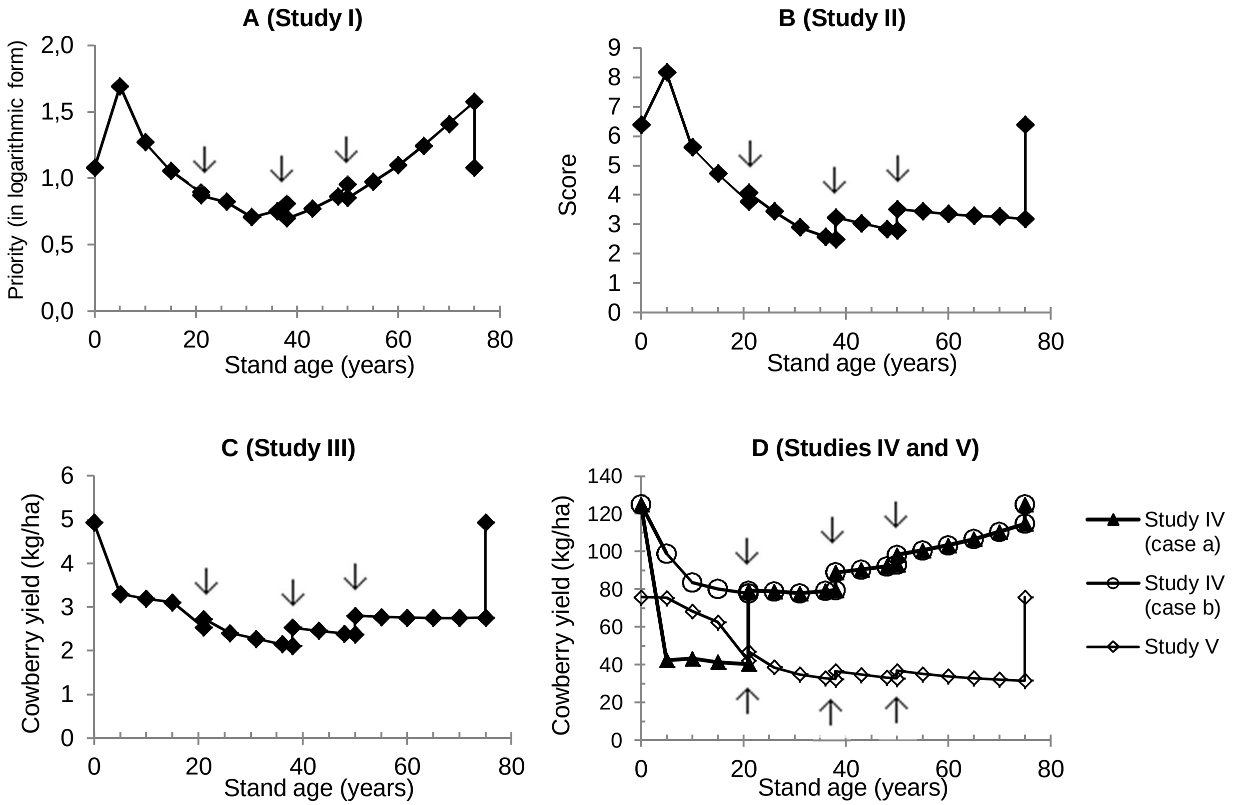

Figure 3. Predicted cowberry yields in a pine stand on site IV (i.e. sub-xeric heath forest) in southern Finland. The development of stand was simulated in Study V using the Motti simulator (arrows indicate thinnings). Predictions were calculated using models for Studies I-III, IV (IV: Table 4) and V. “Case a” means that, in the beginning of stand rotation, all the trees (both seeded pines and naturally regenerated deciduous trees) were included in the number of stems; for “case b”, only pines were considered in the calculations.

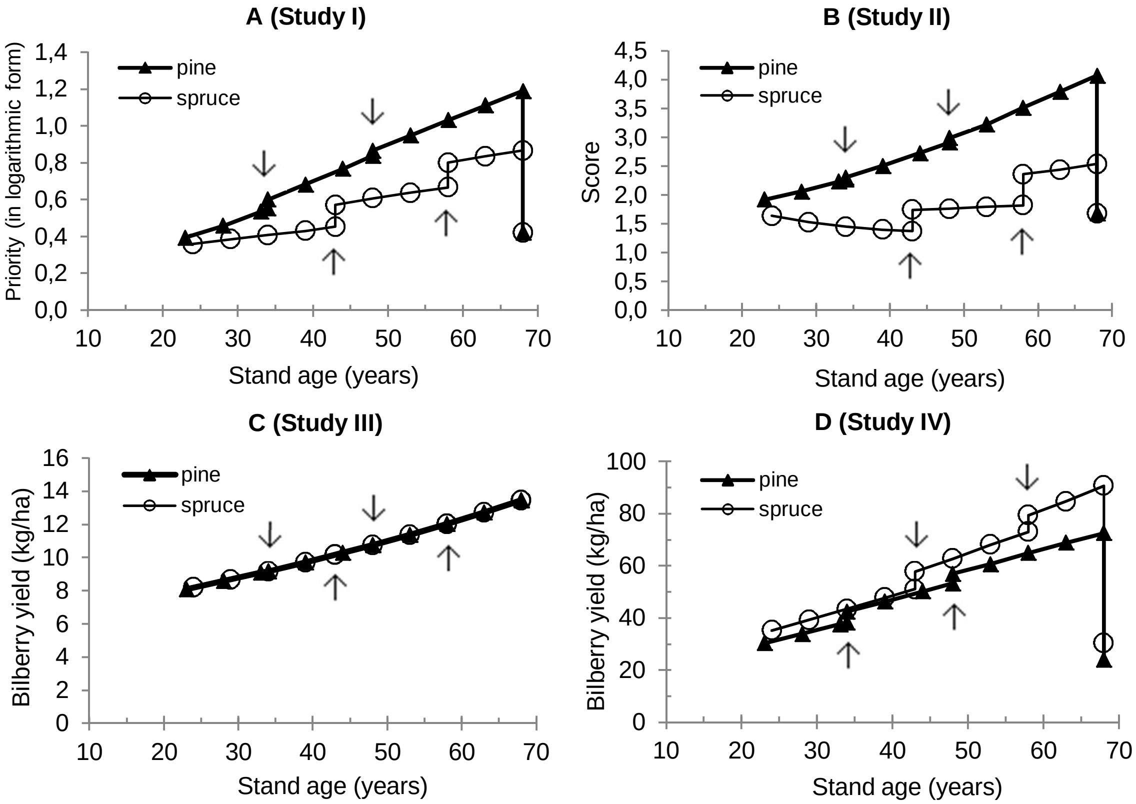

Figure 4. Predicted bilberry yields in pine and spruce stands on site III (i.e. mesic heath forest) in southern Finland. The development of stands was simulated by Miina et al. (2009) using the Motti simulator (arrows indicate thinnings). Predictions were calculated using models of Studies I–III and IV (IV: Table 3).

Calculations made for simulated stands by Miina et al. (2009) indicated that the performance of the bilberry yield models of Studies I, II and IV (IV: Table 3) was quite similar to that of the models of Miina et al. (2009). In other words, it was found that the effect of thinning on bilberry production was positive in a spruce stand located on a mesic heath site (Fig. 4). In a pine stand of the same site fertility, thinnings affected the bilberry yield only slightly or not at all. Many empirical studies have indicated that bilberry benefits from thinning (e.g. Raatikainen and Raatikainen 1983; Raatikainen et al. 1984; Kardell and Eriksson 1990; Belonogova 1993). It may be, however, that the significance of thinnings is more emphasized in spruce stands than in pine stands if the aim is to enhance bilberry yields. This is because spruce shades the ground vegetation considerably more than pine (e.g. Laakso et al. 1990); therefore, pine-dominated stands are naturally lighter than stands dominated by spruce, even though the stand basal area is the same in both types of forest stands. Further, calculations using the bilberry yield model of Study III indicate that thinnings do not affect bilberry yields; this was the situation both in pine and spruce stands (Fig. 4C). This fact can be concluded also on the basis of the regression coefficients of the model (Table 1). In this respect, the performance of this particular model is not logical.

In one of the studies (II), bilberry and cowberry yield models were developed not only for mineral soil sites but also for different peatland site classes (spruce mires, pine mires). There have been no previous attempts to undertake this kind of modelling, despite the fact that peatlands are quite significant for bilberry and cowberry production. On the basis of the results of available berry yield studies conducted on peatlands, it has been estimated that Finnish peatlands could annually produce an average of about 15 million kg of bilberries, which makes up 8% of the total (i.e. mineral and peatland soil) bilberry yield (Turtiainen et al. 2007). The corresponding national figures for cowberry are 13 million kg and 5%, respectively (Turtiainen et al. 2007). During dry summers, these figures may be even higher, as stated above. However, it is important to bear in mind that the models for peatlands (II) are only tentative because of the limitations to the modelling data; the number of observations on spruce mires, in particular, was quite low (II: Table 1). Therefore, these models should be used only provisionally until more reliable models become available.

5 CONCLUSIONS AND FINAL REMARKS

The correlations presented in Tables 3 and 4 and comparisons of the results of this thesis with empirical berry yield studies indicate that modelling expert knowledge is a reasonable way to create production functions for different wild berry species. Models for the yields of bilberry (I–IV) produced predictions that were quite similar to each other (Table 3), although the data used for modelling were collected differently in each study and the explanatory variables and modelling techniques varied from one model to another. In the case of the cowberry, most of the correlations among model predictions were positive and statistically significant, but there a few low and insignificant correlations also occurred, even negative ones (Table 4). It is difficult to conclude to what extent the modelling approach used (i.e. modelling empirical measurements vs modelling expertise) affected the correlations. It is probable that the specific features of modelling data (e.g. in Studies IV and V) and model construction in general have also affected them. Table 4 also indicates that two cowberry yield models of this thesis – the expert-knowledge-based model of Study II and empirical-studies-based model of Study III – had, on average, the best performance when one examines the correlations. This finding, combined with the facts mentioned earlier in this summary, suggests that the method applied in Study II (visual assessments in the field) may be useful also in other applications to develop models for different NWFP.

It has been suggested earlier that expert modelling should be considered only as a provisional solution until sufficient data for empirical models are available (e.g. Kangas 1998). In some cases, however, expert modelling is very useful and may even be the only way of modelling when a NWFP or non-wood forest service (NWFS), such as scenic beauty, recreational value, habitat suitability for wildlife and biodiversity, is difficult or impossible to measure. One basic question to be decided in the preparation of expert models is who the experts are. What sort of person is skilful enough to evaluate the suitability of a stand for a certain purpose? This question is less relevant when modelling scenic beauty or recreational value, which are personal preferences for which every person may be regarded as an expert, especially when the model is used in that person's own forest (Pukkala 2002). Study I indicated that when the evaluations of the most inconsistent experts were removed from the data, the degree of determination increased. Further, Turtiainen et al. (2009) reanalysed the data of Study IV (evaluations made on the scale of 0 to 10) and found that the level of expertise affected the logic of the evaluations. In other words, those forest planners who were used to picking berries quite a lot or a lot gave a higher proportion of logical assessments than those planners who did not pick berries or only seldom picked berries. Also, forest planning experience affected how logically berry yields in different forest stands were evaluated. Thus, it seems quite obvious that by means of a careful choice of experts it is possible to improve the reliability of expert evaluations and models (see also Turtiainen et al. 2009).

In the present research, it was possible to employ only traditional stand attributes, both categorical (e.g. site fertility class) and continuous (e.g. stand basal area, stand age) variables, which usually originated from field work on stand level management inventory. It may be questioned whether these traditional variables reflect the conditions relevant to the bilberry and cowberry adequately enough. However, in Finland these stand attributes are nowadays obtained principally as a result of airborne laser scanning (ALS)-based stand level inventory (Maltamo et al. 2011). One of the most applied ALS metrics as an independent variable in the stand attribute models is the proportion of vegetation echoes, which means the proportion of ALS echoes above a certain height limit, such as 2 metres (e.g. Næsset 2002). This metric can be directly used as a highly accurate estimate for canopy cover without any field reference (e.g. Korhonen et al. 2011). Since ALS data already covers considerable parts of Finland, it would be interesting to also utilize the proportion of vegetation echoes, as well as other ALS metrics, in modelling berry yields and other NWFP.

It was found that there was a large amount of variability associated with non-considered factors in the empirical berry yield models (III, V). In Study III, most part of this variability was acting at stand level. In addition, the annual variation in berry yields was not included in the models of Study III which was the case in the cowberry yield model of Study V (V: Model 2, Table 4). When the variance of the year effects was added to the variance components of Model 2 (V), the total variance was 0.9086, of which the proportion of the year effect was approximately 10 %. In this examination, it is worth noting that there was also an interaction term "stand × year" in the variance component model (V: Model 2, Table 4); its proportion was over half of the total variance. Thus, in future berry yield studies it is worth considering whether and how silvicultural measures could be used to moderate the effects of weather conditions (e.g. frosts) on annual berry yields. Also, it is worth considering what kind of variables could be used as additional predictors in models suitable for forest planning calculations. Besides ALS metrics mentioned above, also soil preparation method and time since soil preparation, for example, could be used as potential predictors. In a Swedish study conducted on permanent sample plots in 1976-1986, it was found that the negative effect of final felling on bilberry production was considerably emphasized if clear-cutting was followed by soil preparation (Kardell and Eriksson 1990). In the case of cowberry, the negative effect of soil preparation in clear-cut areas was not so significant.

The berry yield models of this thesis were developed primarily for the calculations required for multi-objective forest planning. They can be included in present forest planning systems where they enable the assessment of how alternative ways of managing stands will affect future berry yields. Fig. 5 presents an example which illustrates future cowberry yields in a 5750-ha forest area after implementing two different forest plans: one maximizing timber production (Plan 1) and another maximizing cowberry yields (Plan 2). The theme maps of Fig. 5 were produced using the Monsu forest planning program and cowberry yields (kg ha^{-1}) were calculated using the models of Study V. Compared to Plan 1, Plan 2 resulted in a higher number of forest stands producing cowberries at the end of a 30-year planning period. This was due to the fact that the goal of Plan 2 was achieved primarily by maximizing the area of regeneration fellings. Fig. 5 also indicates that stand-wise cowberry yields were, on average, higher in Plan 2 than in Plan 1 (a darker colour implies higher cowberry yields in Fig. 5).

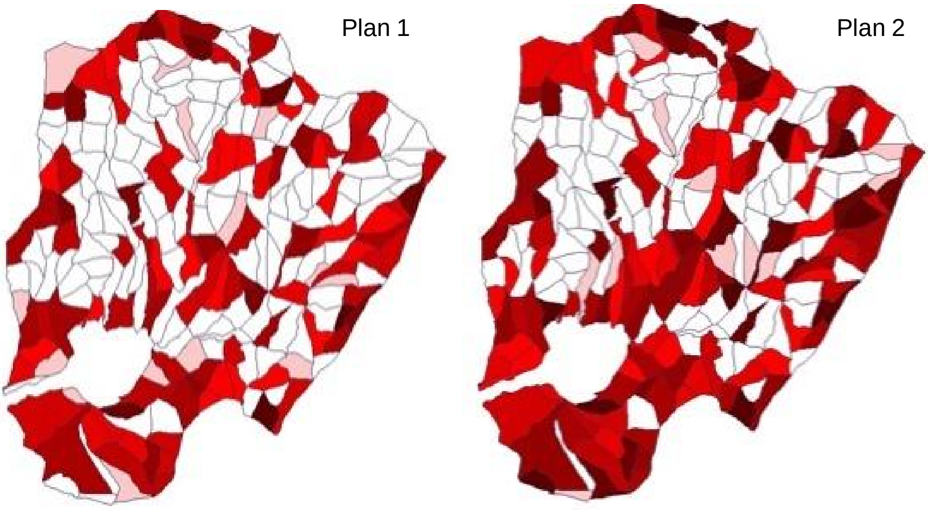

Figure 5. Two theme maps illustrating future cowberry yields after implementing two different forest plans. Plan 1 maximized timber production and Plan 2 maximized cowberry yields. Theme maps were produced using Monsu forest planning program and cowberry yields (kg ha^{-1}) were calculated using the models of Study V. The darker the colour in theme maps, the higher the annual stand-wise cowberry yield at the end of the 30-year planning period.

In Study V, the coverage of cowberry was considered to be one of the predictors of cowberry yields and, therefore, a model for the coverage of this species was prepared (V: Table 3). In fact, Study V was the first occasion on which a model for the abundance of cowberry was developed in Finland (cf. Miina et al. 2009). The model for the coverage can be used not only as a part of the yield model (V: Table 4) but also when assessing different forest stands with respect to their suitability for certain game species. Bilberry and cowberry have been found to be important for many forest dwelling species (e.g. gallinaceous birds) as they provide both food and shelter (e.g. Storch 1993; Grjaz'kin et al. 2006; Lakka and Kouki 2009). Thus, models for the coverage of cowberry and bilberry (Miina et al. 2009) provide possibilities for incorporating game management considerations into calculations of forest planning.

Berry yield models which produce predictions in terms of kilograms per hectare (III–V) can also be utilized when estimating wild berry resources in a certain geographical region. When using the models of Study III, the region should preferably be located in the transitional area between the southern and middle boreal vegetation zone (III: Fig. 1), and when using the models of Studies IV–V, the region can be located anywhere in Finland. However, as indicated by Fig. 2, the models of Studies III–V produced estimates which vary considerably from each other. In Fig. 2, the predicted cowberry yields varied from 2 to 5 kg ha^{-1} when the model from Study III was used and the ranges of variation were 33–115 kg ha^{-1} and 24–96 kg ha^{-1} when the models of Studies IV and V were used, respectively. It is likely that both bilberry and cowberry yield models of Study III produce underestimates, while models of Studies IV and V tend to overestimate average berry yields. In any case, it is obvious that there is a need for calibration of the models if the aim is to estimate the supply of the major wild berries during an average crop year. In fact, Turtiainen et al. (2005) calibrated the models of Study IV with a set of measured yield data from various sources, and then used these corrected models to estimate national and regional yields of bilberry and cowberry. According to the calculations of Turtiainen et al. (2005), mineral soil sites in Finland could produce approximately 168 million kg of bilberries and 244 million kg of cowberries in an average crop year.

In modelling NWFP, it would be possible to combine different modelling approaches (see also Kangas and Leskinen 2005; Calama et al. 2010). In principle, the expert models of Study IV, which were later on calibrated by Turtiainen et al. (2005), can be regarded as an example of this kind of modelling. Calama et al. (2010) gave another example of the use of both expert knowledge and empirical data. In their example, concerning a mushroom modelling task, commercial mushroom pickers would be asked to evaluate which kinds of forests are good for mushroom picking. Imaginary forest stands would be used in the evaluation. After that, field measurements are directed to the most crucial gaps in the knowledge: determining the effect of stand density and thinnings on mushroom yields. Calama et al. (2010) also suggested that the annual variation in mushroom yields could be based, for example, on the statistics on the amount of mushrooms offered for sale, if it is not possible to collect field data over several years.

In Finland, there is extensive data on the trade in wild berries and edible mushrooms (e.g. Maaseutuvirasto 2012). Finland is one of the few countries in Europe which has been able to collect official statistics on these (e.g. Turtiainen and Nuutinen 2012). The berry and mushroom trade statistics referred to by Calama et al. (2010) have been compiled in Finland since 1977 and they cover the most common berry and mushroom species. Still, using these data for modelling the annual variation in mushroom (or berry) yields may be questionable because crop level is only one factor affecting the intensity of commercial picking, the other major factor being the market price of mushrooms (or berries), reflecting inversely the scarcity or abundance of annual crops.

In Finland, the MASI inventory data (e.g. utilized Study V) could most probably provide the best possibilities for considering the annual variation in both berry and mushroom crops. The MASI inventory, which concerns yields of the most economically important wild berries (cowberry, bilberry, cloudberry) and the most common edible mushrooms, was started in 1997 and has been carried out annually since then (e.g. Salo 1999, 2005). The main purpose of the MASI system is to promote Finns' wild berry and mushroom picking by developing annual yield forecasts based on MASI datasets. The observation networks established for monitoring the annual yields of bilberry and cowberry are denser than those established for other species, which has made it possible to utilize the collected data for scientific purposes (V; also Miina et al. 2009; Turtiainen et al. 2011). However, the observation networks for cloudberry and mushrooms are sparse, which has prevented their use in scientific modelling. Therefore, it would be reasonable to allocate considerably more resources to enhance the networks for the latter in future. Also, the findings of this thesis, as well as those of Turtiainen et al. (2011) earlier, suggest that more MASI stands for monitoring the yields of cowberry and bilberry should be established in different parts of the country, preferably as uniformly as possible. Further, it would be appropriate to have MASI sample plots in different kinds of forest stands, not only in stands found to be good growing sites for the species. By means of these improvements in the MASI inventory system, it would be possible to create new national models for the yields of cowberry and bilberry which (i) reliably consider the large-scale geographical variation in berry yields, (ii) do not overestimate berry yields (when models are applied to stands not ideal for berry picking), and (iii) produce reliable predictions for different kinds of forest stands representing, for example, various site fertilities and stand structures.

The models developed in this thesis can also be used for purposes other than those presented earlier in this chapter. For example, they can be utilized to produce maps of potential stands for bilberry and/or cowberry picking (cf. e.g. European Commission 2014, p. 68–70). They also provide new possibilities for optimizing the joint production of timber and NWFPS (also Palahí et al. 2009; Miina et al. 2010; Pukkala et al. 2011). Recently, Miina et al. (2010) studied the effect of bilberry production on the optimal management of various even-aged stands by including the models of Miina et al. (2009) in a stand growth simulator and maximizing the joint production of timber and bilberries. They found that, compared to timber production, joint production led to longer rotation lengths, higher thinning intensities and more frequent thinnings. Similarly, the models of Study V could, for example, be used to integrate the value of cowberry production into the optimization calculations. Optimizing the joint production of timber, bilberries and cowberries would most probably have further impacts on optimal stand management, because bilberry and cowberry differ from each other in many ways, particularly with respect to the need for light (e.g. Raatikainen et al. 1984; Hotanen et al. 2000).

It is recommended that the models developed in this thesis are applied primarily to even-aged forest stands (see modelling datasets). From the beginning of 2014, along with the new forest legislation, the practice of uneven-aged management and continuous cover forestry in Finland has been permitted (e.g. Ojala and Mäkelä 2013; Ministry of Agriculture and Forestry 2014). In uneven-aged forestry, stand age is an undefined concept. When considering the models presented in this thesis, it can be seen that stand age was one of the predictors in almost every study. Similarly, stand age was one predictor of the bilberry coverage model of Miina et al. (2009). Pukkala et al. (2011) found a way to utilize the models of Miina et al. (2009) when comparing the performance of even- and uneven-aged management systems from a multifunctional forest management perspective. They prepared another version of the model for bilberry coverage, using the same data that were used in Miina et al. (2009) and having no stand age as an explanatory variable. The models of Study V, for example, could be easily modified in a similar manner for uneven-aged forests. In fact, such preliminary models have already been developed (but not yet published) and included in Monsu, which is a forest planning program utilized primarily for scientific and educational purposes. In future modelling tasks, it is recommended that explanatory variables should only be used that are known both in even- and uneven-aged forest stands.

All the models (I–V) of this thesis are stand-level models. They do not take into account the interdependencies between different stands. In many cases, however, the surrounding stands and the practices conducted within them affect the berry production of the stand in question. For example, although the bilberry production in openings is poor, high yields can be obtained along the edges of clear-cut areas (Kuchko 1988). Kuchko (1988) stated that the “highly productive bilberry strip” along the clear-cut boundary may be about 40–50 m wide. Forest planning typically uses characteristics calculated for every stand separately when deriving characteristics at the holding level. In Monsu, for example, the holding-level estimates for berry and mushroom yields are computed simply as a sum (or as an average) of individual stands. One could question whether this is an appropriate approach. The answer to this question is “not necessarily”, for the reason mentioned above. Fortunately, Monsu has diverse technical tools to take into account different forest benefits – either spatially or non-spatially – in numerical forest planning (Pukkala 2006). First, however, models should be developed which predict berry yields along the edges of openings, seed-tree stands and small seedling and sapling stands.

One could argue that practically all the forests in Finland have more than one mode of use and that forest planning is, by its very nature, multi-objective (e.g. Kangas 1998; Kangas and Kokko 2001). However, the truth is that numerical forest planning in Finland is still based primarily on economic benefits (i.e. maximizing timber production, net present value or net income from timber sales; e.g. Pukkala 2007; von Boehm 2008; Laitila et al. 2009). Forest planning calculations are made within the limits of official thinning guides and silvicultural instructions. Objectives other than for timber production (e.g. biodiversity conservation, multiple-use aspects of forests) are considered, for example, by applying “softer” silvicultural measures or avoiding abrupt changes in forestry because the risk of making wrong decisions is high (e.g. Kangas and Kokko 2001; Pukkala 2004).

Along with the new forest legislation, silvicultural instructions were revised in 2014 (Äijälä et al. 2014). New silvicultural recommendations include a wide range of different alternatives to manage forest stands so that each forest owner can find an appropriate one (Äijälä et al. 2014). For example, selective felling and small-scale clear-cutting (< 0.3 ha) are now allowed. Earlier, these forestry measures were forbidden, with exceptions. The results presented in this thesis suggest that selective felling, in particular, could be an option which maintains reasonable bilberry production during the regeneration phase of the stand (see also Atlegrim and Sjöberg 1996). In addition to general silvicultural recommendations (Äijälä et al. 2014), other kinds of forest management prescriptions, emphasizing game management considerations, were published in 2014 (Tapio 2014). Similarly, it would be possible to create silvicultural recommendations that enhance berry yields by utilizing, among other things, the results of this thesis (cf. Parlane et al. 2006). In practice, however, it is very laborious to develop different instructions for various groups of forest owners, each of which have different objectives with regard to the management of their own forests (Pukkala 2007).

In some parts of Finland, particularly the sparsely populated east and north of the country, the role of berry picking is more significant than in other parts of the country. In economic terms, Oulu-Kainuu region (IV: Fig. 1, Forestry Centres 11 and 12) has traditionally been the main area of commercial wild berry picking in Finland. During the last 20 years, an average of 45% of the total quantity of bilberries bought by organised trade and industry has come from Oulu-Kainuu region; the corresponding proportion for cowberry is 47% (Malin 2001; Maaseutuvirasto 2014). In regions like this, it would be useful to analyse alternative forest management scenarios in relation to their impact on berry yields at the landscape or regional level (cf. de-Miguel et al. 2014). This kind of analysis would be useful when considering, for example, regional forest policy making or development of natural products sector in a certain geographical region. The analysis based on modelling and simulation techniques (see de-Miguel et al. 2014) could first be applied in public forests, especially in areas which are known to be used for recreational purposes and which are suitable for berry picking. In privately owned forests, forest owners cannot necessarily benefit from the yields of wild berries produced by their own forests because of the rights of public access recognized in Finland. In this respect, policy instruments that support the simultaneous provision of multiple ecosystem services would be beneficial.

Finally, two remarks should be made. First, forest planning always concerns the future and the prediction of the future is always uncertain. In Finland, there is a relatively long tradition of research into timber management planning while research into multiple-use planning is much newer (e.g. Kangas and Kristiansen 1995). Consequently, one could easily presume that the prediction of wood production is significantly more reliable than say the prediction of future berry yields. However, this does not necessarily hold true. For example, the prediction of a forest stand’s development is also quite uncertain, particularly when the stand is naturally regenerated. Thus, uncertainties related to the prediction of non-wood forest benefits cannot be used as an excuse for not taking NWFPS into account in forest planning calculations (see also Pukkala 2006). Still, it would be appropriate that in each planning situation the forest planner is aware of the specific features, assumptions and limitations related to the models used. It would also be appropriate to estimate the reliability of the predictions produced by different models (for example, by providing confidence intervals for the predictions) and clearly describe this to decision-maker(s) (also Kangas and Kangas 1997; Kangas and Kokko 2001).

Second, planning of multiple-use forestry is far more complicated than planning of single-use forestry. Numerical calculations and computerized planning systems have been found necessary in timber management planning. It is obvious that numerical approaches are also needed to solve multiple-use planning problems that have timber production as one output among others. Of course, the results of computerized and other planning calculations are not the whole truth; subjective evaluation, by forest owners and other possible stakeholders, planning consultants and experts will be needed in forest planning process also in the future (e.g. Pukkala et al. 1995; Pukkala 2006, 2008). The main advantage of analytic tools is that they help planners and decision-makers to better understand the decision situation as a whole (e.g. Kangas 1998). It would be informative to analyse, among other things, the trade-offs between different goods and benefits – such as between net income from cuttings and yields of wild berries. Thus, quantitative calculations offer just partial, yet very valuable, information to inform decision-making, which is in any case ultimately based on subjective choices.

REFERENCES

Äijälä O., Koistinen A., Sved J., Vanhatalo K., Väisänen P. (eds.). (2014). Metsänhoidon suositukset. Metsätalouden kehittämiskeskus Tapion julkaisuja. http://www.tapio.fi/files/tapio/metsanhoitosuositukset/Metsanhoidon_suositukset_ver1_netti.pdf. [Cited 9 May 2014]. (In Finnish.)

Alho J.M., Kolehmainen O., Leskinen P. (2001). Regression methods for pairwise comparisons data. In: Schmoldt D.L., Kangas J., Mendoza G.A., Pesonen M. (eds.). The Analytic Hierarchy Process in Natural Resource and Environmental Decision Making. Kluwer Academic Publishers. Managing Forest Ecosystems 3: 235-251.

Atlegrim O., Sjöberg K. (1996). Response of bilberry (*Vaccinium myrtillus*) to clear-cutting and single-tree harvests in uneven-aged boreal *Picea abies* forests. Forest Ecology and Management 86: 39-50. http://dx.doi.org/10.1016/S0378-1127(96)03794-2

Baskerville G.L. (1972). Use of logarithmic regression in the estimation of plant biomass. Canadian Journal of Forestry 2: 49-53. http://dx.doi.org/10.1139/x72-009

Belonogova T. (1993). Changes in bilberry and cowberry yields under the influence of forestry measures. Aquilo Series Botanica 31: 17-20.

Belonogova T.V., Kuchko A.A. (1979). Plodonošenie černiki v bereznjakah Karelii. Rastitel’nye Resursy 15: 415-421. (In Russian.)

Belonogova T., Zajceva N.L. (1989). Ekologo-biologičeskie osobennosti hozjajstvenno cennyh rastenij Karelii. Petrozavodsk. 168 p. ISBN: 5-7545-0311-3 (In Russian.)

Blasco E., González-Olabarria J.R., Rodriguéz-Veiga P., Pukkala T., Kolehmainen O., Palahí M. (2009). Predicting scenic beauty of forest stands in Catalonia (North-east Spain). Journal of Forestry Research 20(1): 73-78. http://dx.doi.org/10.1007/s11676-009-0013-3

Bonet J.A., Pukkala T., Fischer C.R., Palahí M., Martínez de Aragón J., Colinas C. (2008). Empirical models for predicting the production of wild mushrooms in Scots pine (*Pinus sylvestris* L.) forests in the Central Pyrenees. Annals of Forest Science 65(2): 206. http://dx.doi.org/10.1051/forest:2007089

Bonet J.A., Palahí M., Colinas C., Pukkala T., Fischer C.R., Miina J., Martínez de Aragón J. (2010). Modelling the production and species richness of wild mushrooms in pine forests of the Central Pyrenees in northeastern Spain. Canadian Journal of Forest Research 40: 347-356. http://dx.doi.org/10.1139/X09-198

Bonet J.A., de-Miguel S., Martínez de Aragón J., Pukkala T., Palahí M. (2012). Immediate effect of thinning on the yield of *Lactarius* group *deliciosus* in *Pinuspinaster* forests in Northeastern Spain. Forest Ecology and Management 265: 211-217. http://dx.doi.org/10.1016/j.foreco.2011.10.039

Calama R., Tomé M., Sánchez-González M., Miina J., Spanos K., Palahí M. (2010). Modelling non-wood forest products in Europe: a review. Forest Systems 19: 69-85.

Calama R., Mutke S., Tomé J., Gordo J., Montero G., Tomé M. (2011). Modelling spatial and temporal variability in a zero-inflated variable: the case of stone pine (*Pinus pinea* L.) cone production. Ecological Modelling 222: 606-618. http://dx.doi.org/10.1016/j.ecolmodel.2010.09.020

Coudun C., Gégout J-C. (2007). Quantitative prediction of the distribution and abundance of *Vaccinium myrtillus* with climatic and edaphic factors. Journal of Vegetation Science 18: 517-524. http://dx.doi.org/10.1111/j.1654-1103.2007.tb02566.x

de-Miguel S., Bonet J.A., Pukkala T., Martínez de Aragón J. (2014). Impact of forest management intensity on landscape-level mushroom productivity: a regional model-based scenario analysis. Forest Ecology and Management 330: 218-227. http://dx.doi.org/10.1016/j.foreco.2014.07.014

Dias-Balteiro L., Romero C. (2003). Forest management optimisation models when carbon captured is considered: a goal programming approach. Forest Ecology and Management 174: 447-457. http://dx.doi.org/10.1016/S0378-1127(02)00075-0

Eriksson L., Ingelög T., Kardell L. (1979). Blåbär, lingon, hallon. Förekomst och bärproduktion i Sverige 1974-1977. (Summary: Bilberry, lingonberry, raspberry. Occurrence and production in Sweden 1974-1977). Sveriges lantbruksuniversitet, Avdelning för landskapsvård, Rapport 16. 124 p. ISBN: 91-576-0140-2 (In Swedish.)

European Commission. (2014). Mapping and assessment of ecosystems and their services. Indicators for ecosystem assessments under Action 5 of the EU Biodiversity Strategy to 2020. Technical Report - 2014 - 080. http://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/pdf/2ndMAESWorkingPaper.pdf. [Cited 9 May 2014].

González J.R., Palahí M., Trasobares A., Pukkala T. (2006). A fire probability model for forest stands in Catalonia (north-east Spain). Annals of Forest Science 63(2): 169-176. http://dx.doi.org/10.1051/forest:2005109

González J.R., Kolehmainen O., Pukkala T. (2007a). Using expert knowledge to model forest stand vulnerability to fire. Computers and Electronics in Agriculture 55: 107-114. http://dx.doi.org/10.1016/j.compag.2006.12.005

González J.R., Trasobares A., Palahí M., Pukkala T. (2007b). Predicting stand damage and tree survival in burned forests in Catalonia (North-East Spain). Annals of Forest Science 64(7): 733-742.
http://dx.doi.org/10.1051/forest:2007053

Grjaz'kin A.V., Kondratenko N.N., Pona D.S. (2006). Nedrevesnaja produkcija lesa. Izdatel'stvo Politehničeskogo universiteta. Sankt-Peterburg. 338 p. ISBN: 5-7422-1292-5 (In Russian.)

Heikkinen J., Reinikainen A. (2000). Inventointiaineistot ja tulosten laskenta. In: Reinikainen A., Mäkipää R., Vanha-Majamaa I., Hotanen J-P. (eds.). Kasvit muuttuvassa metsäluonnossa. Tammi, Helsinki. p. 44-59. ISBN: 951-31-1963-7 (In Finnish.)

Hotanen J-P., Korpela L., Mikkola K., Mäkipää R., Nousiainen H., Reinikainen A., Salemaa M., Silfverberg K., Tamminen M., Tonteri T., Vanha-Majamaa I. (2000). Metsä- ja suokasvien yleisyys ja runsaus 1951-95. In: Reinikainen A., Mäkipää R., Vanha-Majamaa I., Hotanen J-P. (eds.). Kasvit muuttuvassa metsäluonnossa. Tammi, Helsinki. p. 84-301. ISBN: 951-31-1963-7 (In Finnish.)

Hull R.B., Buhyoff G.J. (1986). The scenic beauty temporal distribution method: an attempt to make scenic beauty assessments compatible with forest planning efforts. Forest Science 32(2): 271-286.

Hurme E., Mönkkönen M., Nikula A., Nivala V., Reunanen P., Heikkinen T., Ukkola M. (2005). Building and evaluating predictive occupancy models for the Siberian flying squirrel using forest planning data. Forest Ecology and Management 216: 241-256.
http://dx.doi.org/10.1016/j.foreco.2005.05.035

Hynynen J., Ahtikoski A., Siitonen J., Sievänen R., Liski J. (2005). Applying the MOTTI simulator to analyse the effects of alternative management schedules on timber and non-timber production. Forest Ecology and Management 207: 5-18.
http://dx.doi.org/10.1016/j.foreco.2004.10.015

Hytönen M. (ed.). (1995). Multiple-use forestry in the Nordic countries. The Finnish Forest Research Institute. 460 p. ISBN: 951-40-1421-9

Hänninen H., Karppinen H., Leppänen J. (2011). Suomalainen metsänomistaja 2010. Metlan työraportteja 208.
http://www.metla.fi/julkaisut/workingpapers/2011/mwp208.pdf. [Cited 3 Sep 2014]. (In Finnish.)

Issakainen J., Moilanen M. (1998). Lannoituksen vaikutus puolukka- ja mustikkasatoihin ja marjojen ravinnepitoisuuksiin kangasmailla. Metsätieteen aikakauskirja – Folia Forestalia 3/1998: 379-391. (In Finnish.)

Jaakkola I. (1983). Rovaniemen maalaiskunnan marjasatoinventointi. Metsäntutkimuslaitoksen tiedonantoja 105: 137-143. ISSN: 0358-4283 (In Finnish.)

Jaatinen E. (1973). Recreational utilization of Helsinki’s forests. Folia Forestalia 186. 35 p. ISBN: 951-40-0088-9

Jäppinen J-P., Hotanen J-P., Salo K. (1986). Marja- ja sienisadot ja niiden suhde metsikkötunnuksiin mustikka- ja puolukkatyypin kankailla Ilomantsissa vuosina 1982-1984. (Summary: Yields of wild berries and larger fungi and their relationship to stand characteristics on MT and VT-type mineral soil sites in Ilomantsi, eastern Finland, 1982-1984). Folia Forestalia 670. 25 p. ISBN: 951-40-0754-9 (In Finnish.)

Kainulainen P. (2013). Metsän teologia. Kirjapaja, Helsinki. 254 p. ISBN: 978-952-247-411-7 (In Finnish.)

Kangas J. (1998). Non-wood forest goods and benefits and the choice of forest management practices. In: Lund H.G., Pajari B., Korhonen M. (eds.). Sustainable development of non-wood goods and benefits from boreal and cold temperate forests. EFI Proceedings No. 23. p. 203-210.

Kangas K. (2001). Commercial wild berry picking as a source of income in northern and eastern Finland. Journal of Forest Economics 7(1): 53-68.

Kangas A., Kangas J. (1997). Mallit, ennusteet ja simulointi metsätalouden laskentajärjestelmissä. Metsätieteen aikakauskirja – Folia Forestalia 3/1997: 389-404. (In Finnish.)

Kangas J., Kokko A. (eds.). (2001). Metsän eri käyttömuotojen arvottaminen ja yhteensovittaminen. Metsäntutkimuslaitoksen tiedonantoja 800. 366 p. ISBN: 951-40-1770-6 (In Finnish.)

Kangas J., Kristiansen L. (1995). Planning of multiple-use forestry. In: Hytönen M. (ed.). Multiple-use forestry in the Nordic countries. The Finnish Forest Research Institute. p. 391-416. ISBN: 951-40-1421-9

Kangas J., Leskinen P. (2005). Modelling ecological expertise for forest planning calculations – rationale, examples, and pitfalls. Journal of Environmental Management 76: 125-133.
http://dx.doi.org/10.1016/j.jenvman.2005.01.011

Kangas J., Mononen A. (1997). Ekologiseen asiantuntemukseen perustuvan numeerisen mallin tuottaminen metsäalueen biodiversiteetin arviointiin. Metsätieteen aikakauskirja – Folia Forestalia 2/1997: 225-238. (In Finnish.)

Kangas J., Muhonen T. (1997). Mustikka- ja puolukkasadon ennustaminen kasvupaikka- ja puustotunnusten avulla – asiantuntemuksen mallinnus. Luonnon Tutkija 5: 136-142. (In Finnish.)

Kangas J., Niemeläinen P. (1996). Opinion of forest owners and the public on forests and their use in Finland. Scandinavian Journal of Forest Research 11: 269-280.

http://dx.doi.org/10.1080/02827589609382936

Kangas J., Laasonen L., Pukkala T. (1993a). A method for estimating forest landowner's landscape preferences. Scandinavian Journal of Forest Research 8: 408-417. http://dx.doi.org/10.1080/02827589309382787

Kangas J., Karsikko J., Laasonen L., Pukkala T. (1993b). A method for estimating the suitability function of wildlife habitat for forest planning on the basis of expertise. Silva Fennica 27(4): 259-268. http://dx.doi.org/10.14214/sf.a15680

Kardell L., Carlsson E. (1982). Hjortron, tranbär, lingon. Förekomst och bärproduktion i Sverige 1978-1980. (Summary: Cloudberry, cranberry, lingonberry. Occurrence and production in Sweden 1978-1980). Sveriges lantbruksuniversitet, Avdelning för landskapsvård, Rapport 25. 139 p. ISBN: 91-576-1154-8 (In Swedish.)

Kardell L., Eriksson L. (1990). Skogsskötselmetodernas inverkan på blåbär och lingon: resultat av en tioårig försöksserie. Sveriges lantbruksuniversitet, Institutionen för skoglig landskapsvård, Rapport 47. 113 p. ISBN: 91-576-4265-6 (In Swedish.)

Karppinen H. (1998). Values and objectives of non-industrial private forest owners in Finland. Silva Fennica 32(1): 43-59. http://dx.doi.org/10.14214/sf.699

Karppinen H., Hänninen H., Ripatti P. (2002). Suomalainen metsänomistaja 2000. Metsäntutkimuslaitoksen tiedonantoja 852. 83 p. ISBN: 951-40-1832-X (In Finnish.)

Kniivilä M., Horne P., Hytönen M., Jäppinen J-P., Naskali A., Primmer E., Rinne J. (2011). Monia hyötyjä metsistä – ekosysteemipalveluiden yhteistuotanto ja tuotteistaminen. PTT raportteja 227. http://www.ptt.fi/dokumentit/rap227_1602111028.pdf. [Cited 1 Sep 2014]. (In Finnish.)

Kolupaeva K.G., Skrjabina A.A. (1979). Urožajnost' brusniki na territorii RSFSR v 1960-1976 godah. Rastitel'nye Resursy 15: 548-553. (In Russian.)

Korhonen L., Korpela I., Heiskanen J., Maltamo M. (2011). Airborne discrete-return LIDAR data in the estimation of vertical canopy cover, angular canopy closure and leaf area index. Remote Sensing of Environment 115: 1065-1080. http://dx.doi.org/10.1016/j.rse.2010.12.011

Kuchko A.A. (1988). Bilberry and cowberry yields and the factors controlling them in the forests of Karelia, USSR. Acta Botanica Fennica 136: 23-25.

Kujala M., Malin A., Ohenoja E., Sipola K. (1989). Oulun läänin luonnonmarja- ja sienivarat, niiden satoarviot, hyödyntäminen ja sivuansiollinen merkitys (OUKA-projekti). Pellervo-Seuran Markkinatutkimuslaitos, Raportteja ja artikkeleita 27. 74 p. ISSN: 0781-2000 (In Finnish.)

Laakso S., Lehtinen P., Raatikainen M. (1990). Kuusen ja männyn vaikutus mustikan esiintymiseen, kukintaan ja marjasatoon. (Summary: The influence of spruce and pine on the cover values, flowering and berry yields of the bilberry (*Vaccinium myrtillus* L.)). Memoranda Societatis pro Fauna et Flora Fennica 66: 47-53. (In Finnish.)

Lacuna-Richman C. (2014). The seasonal migration of Thai berry pickers in Finland: non-wood forest products for poverty alleviation or source of imminent conflict? In: Singh R.K., Turner N.J., Reyes-Garcia V., Pretty J. (eds.). Social-ecological diversity & traditional food systems: opportunities from the biocultural world. New India Publishing Agency, New Delphi. p. 91-105. ISBN: 978-93-83305-36-0

Laitila T., Hujala T., Tikkanen J., Kurttila M. (2009). Yksityismetsien monikäyttöön ja monimuotoisuuteen liittyvät arvot ja asenteet: analyysi metsänomistajien haastatteluista. Metsätieteen aikakauskirja 2/2009: 113-125. (In Finnish.)

Lakka J., Kouki J. (2009). Patterns of field layer invertebrates in successional stages of managed boreal forest: Implications for the declining *Capercaillie Tetrao urogallus* L. population. Forest Ecology and Management 257: 600-607. http://dx.doi.org/10.1016/j.foreco.2008.09.042

Landolt E. (1996). *Vaccinium vitis-idaea* L. subsp. *minus* (G. Lodd.) Hultén (*Ericaceae*), an overlooked circumpolar-arctic taxon of the Alps. Anales Jardín Botánico de Madrid 54: 277-284.

Luttinen J. (2012). Metsän hahmottaminen ja haltuunotto (1500-1850). In: Roiko-Jokela H. (ed.). Ihminen ja metsä – kohtaamisia arjen historiassa 1. Osa 1. Metsäkustannus Oy. Kariston Kirjapaino Oy, Hämeenlinna. p. 17-372. ISBN: 978-952-6612-00-3 (In Finnish.)

Maaseutuvirasto. (2012). Luonnonmarjojen ja -sienten kauppaantulomäärät vuonna 2011. MARSI 2011. http://www.mmm.fi/attachments/mmm/julkaisut/muutjulkaisut/66Y6ezH53/Korjattu_MARSI_2011_MMM_final.pdf. [Cited 19 Apr 2013]. (In Finnish.)

Maaseutuvirasto. (2014). Luonnonmarjojen ja -sienten kauppaantulomäärät vuonna 2013. MARSI 2013. Maaseutuviraston julkaisusarja: raportteja ja selvityksiä 3/2014. http://www.mavi.fi/fi/tuet-ja-palvelut/viljelija/Documents/marsi%202013.pdf. [Cited 8 Aug 2014]. (In Finnish.)

Malin A. (2001). Marjojen ja sienten kauppaantulomäärät vuonna 2000. Elintarviketieto Oy, Food and Farm Facts Ltd. 24 p. + 12 appendices. (In Finnish.)

Maltamo M., Packalén P., Kallio E., Kangas J., Uuttera J., Heikkilä J. (2011). Airborne laser scanning based stand level management inventory in Finland. In: Proceedings of SilviLaser 2011, October 16–20, 2011, Hobart, Australia. http://lidar.com.es/2012/02/16/documentos-proceedings-de-la-conferencia-silvilaser-2011/. [Cited 5 Sep 2013].

McCullagh P., Neldel J.A. (1989). Generalized linear models. 2nd edition. Chapman and Hall, London-New York. 511 p.
http://dx.doi.org/10.1007/978-1-4899-3242-6

Metsämarja- ja sienitoimikunnan mietintö. (1979). Komiteanmietintö 19. Helsinki. 67 p. + appendices. ISBN: 951-46-3050-5 (In Finnish.)

Miina J., Hotanen J-P., Salo K. (2009). Modelling the abundance and temporal variation in the production of bilberry (*Vaccinium myrtillus* L.) in Finnish mineral soil forests. Silva Fennica 43(4): 577-593.
http://dx.doi.org/10.14214/sf.181

Miina J., Pukkala T., Hotanen J-P., Salo K. (2010). Optimizing the joint production of timber and bilberries. Forest Ecology and Management 259: 2065-2071.
http://dx.doi.org/10.1016/j.foreco.2010.02.017

Miina J., Kurttila M., Salo K. (2013). Kauppasienisadot itäsuomalaisissa kuusikoissa – koealaverkosto ja tuloksia vuosilta 2010-2012. Metlan työraportteja 266.
http://www.metla.fi/julkaisut/workingpapers/2013/mwp266.pdf. [Cited 8 April 2014]. (In Finnish.)

Ministry of Agriculture and Forestry. (2014). New forest legislation in 2014. http://www.mmm.fi/en/index/frontpage/forests/legislation.html. [Cited 10 April 2014.]

Muhonen T. (1995). Mustikka- ja puolukkasatojen ennustaminen kasvupaikka- ja puustotunnusten avulla – asiantuntemukseen perustuva lähestymistapa. Master’s thesis of forest planning and economics. University of Joensuu, Faculty of Forestry. 37 p. (In Finnish.)

Männi R. (1988). Biology and berry production of the cowberry in Estonian SRR. Acta Botanica Fennica 136: 33-36.

Næsset E. (2002). Predicting forest stand characteristics with airborne scanning laser using a practical two-stage procedure and field data. Remote Sensing of Environment 80: 88-99.
http://dx.doi.org/10.1016/S0034-4257(01)00290-5

Nousiainen I., Pukkala T. (1992). Use of computer graphics for predicting the amenity of forest trails. Silva Fennica 26(4): 241-250.
http://dx.doi.org/10.14214/sf.a15653

Ojala J., Mäkelä M. (2013). Uusi metsälaki lisää metsänomistajien valinnanmahdollisuuksia ja vastaa toimintaympäristön muutoksiin. Metsätieteen aikakauskirja 1/2013: 71-73. (In Finnish.)

Ojansuu R., Henttonen H. (1983). Kuukauden keskilämpötilan, lämpösumman ja sademäärän paikallisten arvojen johtaminen Ilmatieteen laitoksen mittaustiedoista. (Summary: Estimation of local values of monthly mean temperature, effective temperature sum and precipitation sum from the measurements made by the Finnish Meteorological Office). Silva Fennica 17: 143-160. (In Finnish.) http://dx.doi.org/10.14214/sf.a15099

Oksanen-Peltola L. (1999). Metsäsuunnittelun lähtökohta. In: Heikinheimo M. (ed.). Metsäsuunnittelun tietohuolto. Metsäntutkimuslaitoksen tiedonantoja 741: 8-12. ISBN: 951-40-1690-4 (In Finnish.)

Palahí M., Pukkala T., Bonet J.A., Colinas C., Fischer C.R., Martinez de Aragon J.R. (2009). Effect of the inclusion of mushroom values on the optimal management of even-aged pine stands of Catalonia. Forest Science 55(6): 503-511.

Parlane S., Summers R.W., Cowie N.R., van Gardingen P.R. (2006). Management proposals for bilberry in Scots pine woodland. Forest Ecology and Management 222: 272-278. http://dx.doi.org/10.1016/j.foreco.2005.10.032

Pukkala T. (1988). Monikäytön suunnitteluohjelmisto Monsu: ohjelmiston toiminta ja käyttö. University of Joensuu, Joensuu. 40 p. (In Finnish.)

Pukkala T. (2002). Measuring non-wood forest outputs in numerical forest planning. A review of Finnish research. In: Pukkala T. (ed.). Multi-objective forest planning. Managing Forest Ecosystems 6. p. 173-207.

Pukkala T. (2004). The megatrends of forest planning. In: Opas L.L. (ed.). Finnish Forests. University of Joensuu. Joensuu. p. 87-98. ISBN: 951-708-584-2

Pukkala T. (2006). Muut kuin puuaineiset tuotteet metsäsuunnittelussa. Metsätieteen aikakauskirja 1/2006: 72-81. (In Finnish.)

Pukkala T. (2007). Metsäsuunnittelun menetelmät. Joen Forest Program Consulting Ay. Gummerus Kirjapaino Oy, Vaajakoski. 208 p. ISBN: 978-952-92-1731-1 (In Finnish.)

Pukkala T. (2008). Integrating multiple services in the numerical analysis of landscape design. In: von Gadow K., Pukkala T. (eds.). Designing green landscapes. Managing Forest Ecosystems 15. p. 137-167.

Pukkala T., Kellomäki S., Mustonen E. (1988). Prediction of the amenity of a tree stand. Scandinavian Journal of Forest Research 3: 533-544. http://dx.doi.org/10.1080/02827588809382538

Pukkala T., Nuutinen T., Kangas J. (1995). Integrating scenic and recreational amenities into numerical forest planning. Landscape and Urban Planning 32: 185-195. http://dx.doi.org/10.1016/0169-2046(94)00195-9

Pukkala T., Lähde E., Laiho O., Salo K., Hotanen J-P. (2011). A multifunctional comparison of even-aged and uneven-aged forest management in a boreal region. Canadian Journal of Forest Research 41: 851-862.

http://dx.doi.org/10.1139/x11-009

Pukkala T., Lähde E., Laiho O. (2013). Species interactions in the dynamics of even- and uneven-aged boreal forests. Journal of Sustainable Forestry 32: 371-403. http://dx.doi.org/10.1080/10549811.2013.770766

Pysyvien koealojen 3. mittaus 1995 – maastotyön ohjeet. (1995). The Finnish Forest Research Institute, Helsinki. The National Forest Inventory. 104 p. + appendices. (In Finnish.)

Raatikainen M. (1978). Puolukan sato, poiminta ja markkinointi Pihtiputaan kunnassa. (Summary: The berry yield, picking, and marketing of *Vaccinium vitis-idaea* L. in the commune of Pihtipudas). Silva Fennica 12(2): 126-139. (In Finnish.) http://dx.doi.org/10.14214/sf.a14850

Raatikainen M. (1993). Vaccinium myrtillus yields and environmental factors. Aquilo Series Botanica 31: 21-26.

Raatikainen M., Pöntinen M. (1983). Puolukkasadon ennustamisesta. Metsäntutkimuslaitoksen tiedonantoja 90: 104-115. (In Finnish.)

Raatikainen M., Raatikainen T. (1983). Mustikan sato, poiminta ja markkinointi Pihtiputaalla. (Summary: The berry yield, picking and marketing of *Vaccinium myrtillus* in the commune of Pihtipudas, northern central Finland). Silva Fennica 17(2): 113-123. (In Finnish.)
http://dx.doi.org/10.14214/sf.a15096

Raatikainen M., Rossi E., Huovinen J., Koskela M-L., Niemelä M., Raatikainen T. (1984). Metsä- ja suomarjasadot Väli-Suomessa. (Summary: The yields of the edible wild berries in central Finland). Silva Fennica 18(3): 199-219. (In Finnish.) http://dx.doi.org/10.14214/sf.a15393

Rämö A-K., Horne P., Primmer E. (2013). Yksityismetsänomistajien näkemykset metsistä saatavista hyödyistä. (Summary: Finnish private forest owners' (NIPFs') perceptions of forest ecosystem services). PTT reports 241. http://www.ptt.fi/dokumentit/rap241_2905131020.pdf. [Cited 11 April 2014]. (In Finnish.)

R Development Core Team. (2012). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/. [Cited 21 June 2012].

Reinikainen A., Mäkipää R., Vanha-Majamaa I., Hotanen J-P. (eds.). (2000). Kasvit muuttuvassa metsäluonnossa. (Summary: Changes in the frequency and abundance of forest and mire plants in Finland since 1950). Tammi, Helsinki. 384 p. ISBN: 951-31-1963-7 (In Finnish.)

Richards R.T., Saastamoinen O. (2010). NTFP policy, access to markets and labour issues in Finland: impacts of regionalization and globalization on the wild berry industry. In: Laird S.A., McLain R.J., Wynberg R.P. (eds.). Wild product governance – finding policies that work for non-timber forest products. People and Plants International Conservation Series. Earthscan, London – Washington, DC. p. 287-307.

Ritchie J.C. (1955). Biological flora of the British Isles: *Vaccinium vitis-idaea* L. Journal of Ecology 43: 701-708.
http://dx.doi.org/10.2307/2257030

Ritchie J.C. (1956). Biological flora of the British Isles: *Vaccinium myrtillus* L. Journal of Ecology 44: 291-299.
http://dx.doi.org/10.2307/2257181

Saastamoinen O. (1982). Economics of multiple-use forestry in the Saariselkä forest and fell area. Communicationes Instituti Forestalis Fenniae 104. 102 p.

Saastamoinen O., Pukkala T. (2001). The challenges of small-scale forestry in Finland: policy and planning perspectives. In: Niskanen A., Väyrynen J. (eds.). Economic sustainability of small-scale forestry. EFI Proceedings No. 36. p. 107-117.

Saastamoinen O., Sievänen T. (1981). Keravan ja Rovaniemen lähimetsien ulkoilukäytön ajallinen vaihtelu. (Summary: Time patterns of recreation in urban forests in two Finnish towns). Folia Forestalia 473. 24 p. ISBN: 951-40-0520-1 (In Finnish.)

Saastamoinen O., Matero J., Haltia E., Horne P., Kellomäki S., Kniivilä M., Arovuori K. (2013a). Concepts and considerations for the synthesis of ecosystem goods and services in Finland. Publications of the University of Eastern Finland. Reports and Studies in Forestry and Natural Sciences. No. 10.
http://epublications.uef.fi/pub/urn_isbn_978-952-61-1040-0/urn_isbn_978-952-61-1040-0.pdf. [Cited 7 Aug 2014].

Saastamoinen O., Turtiainen M., Salo K. (2013b). Mustikan ja puolukan sadot ja talteenotto Pohjois-Suomessa – kohti systemaattista marjatalouden tarkastelua. In: Peltola R., Soppela K. (eds.). Luonnontuotealan valtakunnallinen tutkimusseminaari 4.10.2011. MTT Raportti 87. p. 18-20. ISBN: 978-952-487-440-3 (In Finnish.)

Saaty T.L. (1977). A scaling method for priorities in hierarchical structures. Journal of Mathematical Psychology 15: 234-281.
http://dx.doi.org/10.1016/0022-2496(77)90033-5

Salo K. (1982). Metsämarja- ja sienitutkimus Metsäntutkimuslaitoksessa. In: Salo K. (ed.). Metsämarja- ja sienisatotutkimuksen menetelmäongelmia. Metsäntutkimuslaitoksen tiedonantoja 37: 5-7. ISSN: 0358-4283 (In Finnish.)

Salo K. (1988). Soiden monikäyttö, marjat ja sienet. Metsäntutkimuslaitoksen tiedonantoja 308: 187-198. (In Finnish.)

Salo K. (1994). Luonnonmarjat ja -sienet, yrttikasvit sekä palleroporonjäkälä tuovat rahaa ja virkistystä. In: Sulonen S., Kangas J. (eds.). Näkökohtia metsien monikäyttöön. Metsäntutkimuslaitoksen tiedonantoja 488: 19-35. ISBN: 951-40-1352-2 (In Finnish.)

Salo K. (1995). Non-timber forest products and their utilization. In: Hytönen M. (ed.). Multiple-use forestry in the Nordic countries. The Finnish Forest Research Institute. p. 117-155. ISBN: 951-40-1421-9

Salo K. (1996). Peatland berries – a valuable nourishing resource. In: Vasander H. (ed.). Peatlands in Finland. Finnish Peatland Society. Gummerus, Helsinki. p. 39-44.

Salo K. (1999). Principles and design of a prognosis system for an annual forecast of non-wood forest products. In: Niskanen A., Demidova N. (eds.). Research approaches to support non-wood forest products sector development: case of Arkhangelsk region, Russia. EFI Proceedings No. 29. p. 35-44.

Salo K. (2005). Annual forecast and inventory system of wild berry yields in Finland. In: Innes J.L., Edwards I.K., Wilford D.J. (eds.). Forests in the balance: linking tradition and technology. Abstracts. XXII IUFRO World Congress, 8-13 August 2005, Brisbane, Australia. The International Forestry Review 7(5). p. 145.

Savolainen R., Kellomäki S. (1981). Metsän maisemallinen arvostus. (Summary: Scenic value of forest landscape). Acta Forestalia Fennica 170. 74 p. (In Finnish.)

Sepponen P. (1984). Pohjoissuomalaisten metsäammattimiesten käsityksiä metsien ja soiden marjantuotoskyvystä. (Summary: Observations of forest specialists in northern Finland on the berry yield capacity of forests and swamps). Silva Fennica 18(3): 245-253. (In Finnish.)
http://dx.doi.org/10.14214/sf.a15396

Sevola Y. (1983). Metsähallinnon Nurmeksen hoitoalueen voimaperäinen puunkasvatus: seurantajärjestelmä ja tuloksia. (Summary: Intensive timber growing in a state forest district: monitoring system and results). Folia Forestalia 574. 83 p. ISBN: 951-40-0642-9 (In Finnish.)

Sievänen T., Neuvonen M. (eds.). (2011). Luonnon virkistyskäyttö 2010. Metlan työraportteja 212.
http://www.metla.fi/julkaisut/workingpapers/2011/mwp212.pdf. [Cited 3 Sep 2014]. (In Finnish.)

Silvennoinen H., Alho J., Kolehmainen O., Pukkala T. (2001). Prediction models of landscape preferences at the forest stand level. Landscape and Urban Planning 56: 11-20.
http://dx.doi.org/10.1016/S0169-2046(01)00163-3

Snowdon P. (1991). A ratio estimator for bias correction in logarithmic regression. Canadian Journal of Forest Research 21: 720-724.
http://dx.doi.org/10.1139/x91-101

Storch I. (1993). Habitat selection by capercaillie in summer and autumn: is bilberry important? Oecologia 95: 257-265.
http://dx.doi.org/10.1007/BF00323498

Store R., Kangas J. (2001). Integrating spatial multi-criteria evaluation and expert knowledge for GIS-based habitat suitability modelling. Landscape and Urban Planning 55: 79-93.
http://dx.doi.org/10.1016/S0169-2046(01)00120-7

Store R., Jokimäki J. (2003). A GIS-based multi-scale approach to habitat suitability modeling. Ecological Modelling 169: 1-15.
http://dx.doi.org/10.1016/S0304-3800(03)00203-5

Tahvanainen L., Tyrväinen L., Nousiainen I. (1996). Effect of afforestation on the scenic value of rural landscape. Scandinavian Journal of Forest Research 11: 397-405.
http://dx.doi.org/10.1080/02827589609382952

Tahvanainen L., Tyrväinen L., Ihalainen M., Vuorela N., Kolehmainen O. (2001). Forest management and public perceptions – visual versus verbal information. Landscape and Urban Planning 53: 53-70.
http://dx.doi.org/10.1016/S0169-2046(00)00137-7

Tahvanainen L., Ihalainen M., Hietala-Koivu R., Kolehmainen O., Tyrväinen L., Nousiainen I., Helenius J. (2002). Measures of the EU Agri-Environmental Protection Scheme (GAEPS) and their impacts on the visual acceptability of Finnish agricultural landscapes. Journal of Environmental Management 66: 213-227.
http://dx.doi.org/10.1016/S0301-4797(02)90489-5

Tapio. (2014). Riistapainotteiset metsänhoitosuositukset –työryhmäraportti. http://tapio.fi/files/tapio/verkkojulkaisut/Riista_mhs_raportti.pdf. [Cited 15 May 2014]. (In Finnish.)

Tomppo E., Heikkinen J., Henttonen H.M., Ihalainen A., Katila M., Mäkelä H., Tuomainen T., Vainikainen N. (2011). Designing and conducting a forest inventory – case: 9th National Forest Inventory of Finland. Managing Forest Ecosystems 21. 270 p.
http://dx.doi.org/10.1007/978-94-007-1652-0

Turtiainen M., Nuutinen T. (2012). Evaluation of information on wild berry and mushroom markets in European countries. Small-scale Forestry 11(1): 131-145.
http://dx.doi.org/10.1007/s11842-011-9173-z

Turtiainen M., Salo K., Saastamoinen O. (2005). Satomalleilla lasketut Suomen kangasmetsien alueelliset ja valtakunnalliset mustikka- ja puolukkasadot. University of Joensuu, Faculty of Forestry. Research Notes 167.
http://epublications.uef.fi/pub/urn_isbn_952-458-764-5/urn_isbn_952-458-764-5.pdf. [Cited 4 Sep 2014]. (In Finnish.)

Turtiainen M., Salo K., Saastamoinen O. (2007). Mustikan ja puolukan marjasatojen valtakunnalliset ja alueelliset kokonaisestimaatit Suomen suometsissä. (Summary: National and regional estimates of blueberry (*Vaccinium myrtillus* L.) and lingonberry (*V. vitis-idaea* L.) yields on peatlands in Finland). Suo 58(3-4): 87-98. (In Finnish.)

Turtiainen M., Kolehmainen O., Saastamoinen O. (2009). Logicality of expert evaluations of berry yields by the experience and interests of forest planners. Scandinavian Journal of Forest Research 24: 205-216. http://dx.doi.org/10.1080/02827580902717949

Turtiainen M., Salo K., Saastamoinen O. (2011). Variations of yield and utilisation of bilberries (*Vaccinium myrtillus* L.) and cowberries (*V. vitis-idaea* L.) in Finland. Silva Fennica 45(2): 237-251. http://dx.doi.org/10.14214/sf.115

Tyrväinen L., Silvennoinen H., Kolehmainen O. (2003). Ecological and aesthetic values in urban forest management. Urban Forestry & Urban Greening 1: 135-149. http://dx.doi.org/10.1078/1618-8667-00014

Ukkola M. (2003). Liito-oravan esiintymisen ennustamisesta metsäkuvioaineiston perusteella Koillismaalla. Master’s thesis. University of Oulu, Department of Biology. 42 p. (In Finnish.)

Vaara M., Saastamoinen O., Turtiainen M. (2013). Changes in wild berry picking in Finland between 1997 and 2011. Scandinavian Journal of Forest Research 28(6): 586-595. http://dx.doi.org/10.1080/02827581.2013.786123

Valkeapää A., Paloniemi R., Vainio A., Vehkalahti K., Helkama K., Karppinen H., Kuuluvainen J., Ojala A., Rantala T., Rekola M. (2009). Suomen metsät ja metsäpolitiikka – kansalaisten näkemyksiä. University of Helsinki, Department of Forest Economics. Reports 55. http://www.helsinki.fi/metsatieteet/tutkimus/pdf/Report55.pdf. [Cited 4 Sep 2014]. (In Finnish.)

Wallenius T.H. (1999). Yield variations of some common wild berries in Finland in 1956-1996. Annales Botanici Fennici 36: 299-314.

Veijalainen H. (1976). Effect of forestry on the yields of wild berries and edible fungi. Ecological Bulletins 21: 63-65.

von Boehm A. (2008). Vihreän metsäsuunnitelman kysyntä yksityismetsänomistajakunnassa. Master’s thesis. University of Helsinki, Department of Forest Ecology. 89 p. + appendices. (In Finnish.)

Vuokko S. (2005). Metsien yleiset kasvit. Opas kasvupaikkojen tunnistamiseen. Metsätalouden kehittämiskeskus Tapio. Helsinki. 160 p. ISBN: 952-9891-95-4 (In Finnish.)