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Regional expert models for bilberry and cowberry yields in Finland

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This study presents regional berry yield prediction models for the 13 Forestry Centres of Finland. The study material was collected by mailing a questionnaire to Forestry Centres' forest planners and other staff members whose work was related to forest planning in the field. These persons assessed bilberry and cowberry production of 117 imaginary forest stands, differing in site fertility, dominant tree species, stage of stand development and stand density. A total of 266 regional experts evaluated the stands. Using the resulting data, models were prepared which predict the berry yields from those site and stand characteristics which are usually known in forest planning calculations. In bilberry modelling, two separate models were developed: one for the Forestry Centre of Kainuu and the other for the rest of Finland. In cowberry modelling, the statistical analyses resulted in the sub-division of (1) North Karelia, Kainuu and Lapland *vs*. (2) the rest of Finland. Several district-specific, or Forestry Centre-specific, predictors were included in models common to several Forestry Centres. The results of this study, based on unexceptionally wide regional expertise, on the effects of site and tree cover on berry production were largely in line with previous field and other studies conducted in some parts of Finland. The models developed can be utilised in multiple-use forest planning throughout the whole Finland. They also provide possibilities for estimating the regional supply of the major wild berries in Finland. However, there still remains a need to calibrate the models with field data.

Introduction

Among the multiple benefits forests can provide in Finland, wild forest berries have a special status. They are the most common tangible forest product utilised by people. Recent studies confirm that 60% of Finnish households (Saastamoinen *et al*. 2000) and 56% of the whole population (Pouta and Sievänen 2001) participate annually in berry picking. The popularity of berry picking is due to the fact that according to the customary law berries are an open-access resource, not being a part of the property rights of a forest owner. Every person has a right to pick berries even in private forests, but the picker has to avoid areas near houses. Unlike some other countries having common rights to berries and other non-wood forest products, in Finland not only household use but also commercial picking of forest berries is free of charge. Indeed, in many parts of the country, in particular in northern and central Finland, berry picking provides important additional income for the population.

As forest berries have such an importance for the people, it would be logical to take into account the needs of berry production also in forest planning based on the principle of multiple-use and sustainable environmental management. In the 1970s, chemical herbicides, peatland drainage and fertilization caused local conflicts between berry pickers and forestry, but since forestry abandoned these measures, the severity of problems between berry picking and wood production has significantly reduced (e.g. Hellström and Reunala 1995). However, besides macro and micro climatic factors and permanent soil and site properties outside the human control, there are factors being the result of silvicultural and management activities which have significant impact on berry yields. Such factors include tree species composition, stand age and development classes, volume of growing stock and its density, canopy cover and other stand characteristics (e.g. Salo 1995). Practical experience as well as findings of limited research done thus far, provides plenty of evidence that it is not too difficult a task to take the needs of berry production into account in forest management (e.g. Saastamoinen *et al*. 1998). In fact, it seems that wood and berry production on mineral soils have much better possibilities for co-existence than most other forest uses when paired together. However, to fulfil this potential and to optimise the joint production of wood and berries, one must develop production functions not only for timber but also for berry yields.

Constructing strictly empirical production functions would require extensive long-term field measurements (up to ten years as the crops vary a lot from year to year) in different parts of the country, which would be very expensive and time-consuming. Therefore, the focus in recent years has been on building models based on expert knowledge (Muhonen 1995, Ihalainen and Pukkala 2001, Ihalainen *et al*. 2002), although there have been many attempts in empirical research as well (e.g. Eriksson *et al*. 1979, Raatikainen *et al*. 1984, Ihalainen *et al*. 2003). In particular, expert modelling seems to be the only feasible solution to build regional berry yield models in reasonable time. Regional models are needed as the yields of the same berry under the same forest characteristics or after the same silvicultural operation may vary largely in different parts of the country due to the differences in climatic and soil conditions.

This study is the first attempt to develop regional berry yield prediction models for the areas of all Forestry Centres of Finland (or groups of Forestry Centres). It focused on the two most common forest berries, bilberry (*Vaccinium myrtillus* L.) and cowberry (*Vaccinium vitis-idaea* L.), which together cover nearly 80% of wild berries picked in Finland (Saastamoinen *et al*. 2000). Our approach was based on expert knowledge.

A questionnaire survey which is the most straightforward method of collecting data on berry yields in different kinds of forest stands was applied. Sepponen (1984) has earlier examined the production capacity of different berry species on mineral soil sites and peatlands using a similar method. In his study, forest professionals assessed berry yields as a function of site fertility. The results indicate that berry yields should be examined not only with respect to site fertility but also the stage of stand development, i.e. the stand age and density of the growing stock should be taken into account (*see* also Sepponen 1981). These findings were considered when a questionnaire for the present study was developed.

All the models were created for mineral soil sites and their principal use is multiple-use forest planning.

Material and methods

Material

The study material was collected during the first quarter of 2001 by mailing a questionnaire to all of the 13 Forestry Centres of Finland (Fig. 1). The target group of the inquiry were forest planners and other staff members whose work is related to field work in forest planning, and therefore were assumed to be familiar with interactions between berry yields and forest characteristics. The task of the experts was to assess bilberry and cowberry production of 117 imaginary forest stands, differing in site fertility, dominant tree species, stage of stand development and stand density.

The questionnaire was addressed to 444 persons. The number of questionnaires mailed to different Forestry Centres varied quite significantly depending mainly on the size of the Forestry Centre: 75 questionnaires were sent to the two largest Forestry Centres of Finland (Lapland and North Ostrobothnia); the number of questionnaires sent to other Forestry Centres varied from 17 to 42. After one call-back 266 replies were obtained and a response rate was 59.9%. The response rates were quite similar for all Forestry Centres.

The questionnaire was preliminarily tested in 2000 by sending it to the forest planners of the Forestry Centre of North Karelia after which it was improved. The revised questionnaire consisted of six tables; three pertaining to bilberry yields and another three pertaining to cowberry yields (Appendix). There was one table for each dominant tree species, pine (*Pinus sylvestris* L.), spruce (*Picea abies* (L.) Karst.) and birch (*Betula pendula* Roth., *Betula pubescens* Ehrh.). In the present study, a tree species was regarded as dominant if its basal area was at least 80% of the total stand basal area.

The cells of a table referred to forest stands differing from each other in site fertility, density of the growing stock and the stage of stand development (Appendix). For pine, forest site types of rich, medium, rather poor and poor fertility were included in the tables because pine can occur as a dominant tree species on all these sites (Lehto and Leikola 1987). Spruce- and birch-dominated stands on poor forest sites were not considered because they are rare (Lehto and Leikola 1987). In this study, a forest stand was regarded as dense if it is recommended to be thinned according to the thinning model (*see* Luonnonläheinen metsänhoito… 1994). A sparse forest stand has been thinned so that the stand basal area of the remaining growing stock is according to the thinning model on the lowest possible level (*see* Luonnonläheinen metsänhoito… 1994).

The berry yield assessments were entered in the empty cells of the tables 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. All integers of this scale could be used. It was emphasized that the aim was to evaluate berry yields of an average berry year in the region of the respondent's own Forestry Centre. Before starting to fill in the questionnaire the respondents were asked to give the absolute bilberry and cowberry yields (kg ha^{-1}) which correspond, 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.

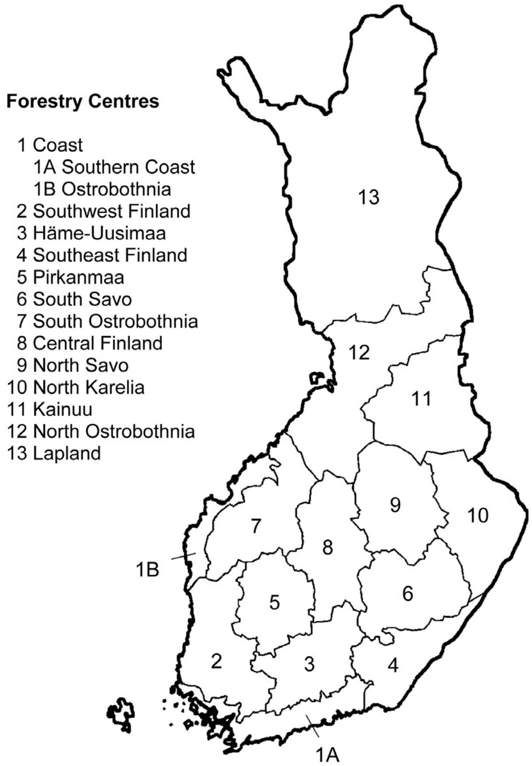

Fig. 1. Forestry Centres of Finland. Forestry Centres 1–10 belong to southern Finland and 11–13 to northern Finland (Metsätilastollinen vuosikirja… 2000).

The questionnaire also asked the respondents' to rank their planning experience (scale from 1 to 3: 1 = under 5 years, 2 = 5 to 10 years, and 3 = over 10 years), and interest in berry picking (scale from 1 to 4: 1 = does not pick berries, 2 = seldom picks berries, 3 = picks berries quite a lot, and 4 = picks berries a lot).

Data preparation

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 forest stands represented in the questionnaire (Table 1). These stand characteristics were used as explanatory variables in the modelling. The values of stand characteristics were estimated separately for southern and northern Finland (Fig. 1) as there exists great variability, for example, in stand densities between the regions.

Several sources of information were used when the characteristics of stands represented by the cells of the questionnaire were estimated (Table 1). The problem that the growth and yield tables (Koivisto 1959) are only available for the southern part of Finland was overcome by taking into account the correspondence of forest site types between northern and southern Finland (Vuokila and Väliaho 1980). For example, a poor mineral soil site in southern Finland is similar to a rather poor mineral soil site in northern Finland with respect to pine wood production (Vuokila and Väliaho 1980).

Bilberry and cowberry yield evaluations given on the scale 0–10 were converted to absolute berry yields (kg ha^{-1}), based on the respondent's absolute yield estimate for scale value 10. This conversion was made separately for each respondent and berry species.

A few respondents (8 out of 266 respondents) gave very high maximal yield values (from 500 kg ha^{-1} to 3000 kg ha^{-1}). These values differed distinctly from the estimates given by the majority of respondents. In addition, no results were found from the literature of such a high bilberry or cowberry yields (e.g. Salo 1991). Estimates higher than 500 kg ha^{-1} were therefore interpreted as outliers. In the case of outliers, a maximum bilberry or cowberry yield estimation was replaced by the mean of the maximal yield estimates given by the other respondents of the same Forestry Centre after which other values on the scale 0–10 (i.e. 1–9) could be converted to absolute berry yields, based on this new maximal yield estimate.

Generally the questionnaires were filled in according to the instructions, i.e. using a scale from 0 to 10. However, there was a few questionnaires which were not filled clearly. For example, a dash was marked in some cells of the tables. In cases like this, it was difficult to determine whether the dash indicated a missing value or zero. Therefore, a small sample of respondents who had returned an unclear questionnaire was interviewed by telephone. Clarifications gained through telephone conversations were generalized to all unclear cases.

Table 1. Sources of information (A–E) used to estimate stand characteristics for different forest stands. The method of calculating stand age is given in parentheses. The mean age of trees in a mature stand is marked with t^*.

Development class	Basal area	Number of stems	Dominant height	Stand age	Mean diameter	Mean height
Open regeneration area (A0)	0 m^2 ha^{-1}	0 trees ha^{-1}	0 m	0 years	0 cm	0 m
Seed-tree stand (S0)	B	A	D	A (t^*)	D	D
Small-seedling stand (T1)	B	E	B	C	0 cm	1 m
Advanced seedling stand (T2)	B	E	D	A ((0.2…0.25) $\times$ t^*)	D	D
Young thinning stand (02)	E	B	D	A (0.5 $\times$ t^*)	D	D
Advanced thinning stand (03)	E	B	D	A (0.8 $\times$ t^*)	D	D
Mature stand (04)	E	B	D	A (t^*)	D	D

A = Luonnonläheinen metsänhoito… (1994), B = computed by using a forest management planning software (Pukkala 1988), C = e.g. Hyvän metsänhoidon… (2001), D = Koivisto (1959), E = definitions for the present study, Luonnonläheinen metsänhoito… (1994).

Methods

The distributions of bilberry and cowberry yield assessments were skewed for most Forestry Centres: the proportions of zero and small values were emphasised in the data. In order to linearize the relationships and convert the residuals to resemble normal distributions, several transformations of the response (y) were attempted. Logarithms were found to be the best form of transformation. To avoid taking logarithms of zeros, one was added to the yield estimate. Thus, the predicted variable in the modelling was $\ln(y + 1)$.

The process of modelling consisted of three steps. First, bilberry and cowberry yield prediction models for each Forestry Centre and also for the whole country were created by means of linear regression analysis. However, in the case of the Forestry Centre of Coast separate models were developed for the districts of Southern Coast and Ostrobothnia as these areas are located quite far from each other (Fig. 1). Stand characteristics listed in Table 1 as well as several transformations of these variables were used as explanatory variables in the modelling. Site types and dominant tree species were included in regression by dummy variables. In addition, some interactions (e.g. site dummy variable × mean diameter) of the variables were used as additional potential predictors.

Models created by means of stepwise regression for each of the 14 districts of Finland (13 Forestry Centres, one divided into two districts) were compared to the one developed for the whole country, and also 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. If different but closely correlated predictors, such as mean diameter and dominant height, entered the models it was examined whether another of these predictors was suitable for each model. The statistical significance of the predictors was used as a criterion when this suitability was determined (the significance level used in this study was 0.05). Secondly, it was checked whether the relationships were similar in different models. After this examination the preliminary conclusion was whether a common model could be formulated for several districts or whether a model of its own is needed for a particular district.

In the second stage, common models were created for areas which were preliminarily defined in step 1. A root mean square error of logarithmic berry yield predictions was calculated separately for every district using (1) the common model (RMSE_1), and (2) the model which was devised for the district (RMSE_2). The formula for RMSE is as follows:

$$\mathrm{RMSE} = \sqrt{\frac{\sum (z_i - \hat{z}_i)^2}{n-1}} \tag{1}$$

where z_i and $\hat{z}_i$ are logarithmic forms of the observed and predicted berry yields, respectively.

If RMSE_2 was less than 5% smaller than RMSE_1 the common model was considered exact enough to predict berry production in this district. If the difference exceeded 5%, the common model was improved by adding district-specific variables, e.g. a district dummy or a new variable essential for the district. A maximum of two additional variables per district was allowed. After that the relative difference between RMSE_1 and RMSE_2 was re-calculated. If the difference was now under 5% for the district in question, the corrections were considered adequate and the revised common model was accepted for this district. In the opposite case, a model of its own was developed for the district in question. The analyses resulted in the sub-division of Finland into Kainuu and the rest of Finland in bilberry modelling and in the sub-division of North Karelia, Kainuu and Lapland versus the rest of Finland in cowberry modelling.

In the third step of modelling, the final berry yield prediction models were formulated by means of 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 SAS software (SAS Institute Inc. 1992) was used for model fitting. Respondent effect was considered as a random variable and site and stand characteristics were considered as fixed variables. The fixed and random parameters of linear models were estimated using the Generalized Least Squares (GLS) technique. The fixed part of the models was created on the basis of models developed in steps 1 and 2 so that those predictors which became statistically significant were selected for the model. The selection criterion for the inclusion of the random respondent effect was its significance.

Since the predicted variable in the modelling was in logarithmic form, there was an inherent bias in the back-transformed predictions (*see* e.g. Baskerville 1972, Snowdon 1991). In this study, a ratio estimator for bias correction suggested by Snowdon (1991) was used since it results in unbiased back-transformed predictions. The proportional bias in logarithmic regression was estimated from the ratio of the mean berry yield added by one $(\overline{y+1})$ and the mean of the back-transformed predicted values from the regression:

$$\overline{\exp\left\{\widehat{\ln(y+1)}\right\}}.$$

Hence, the ratio estimator was:

$$c = \overline{(y+1)} \Big/ \overline{\exp\left\{\widehat{\ln(y+1)}\right\}}.$$

The logarithmic predictions for berry yields were transformed into absolute berry yields as follows:

$$\hat{y} = \exp\left\{\widehat{\ln(y+1)}\right\} \times c - 1 \qquad (2)$$

where $\hat{y}$ is berry yield in kilograms per hectare.

A root mean square error of berry yield predictions (RMSE) was calculated for each model using the back-transformed berry yields. The degree of determination (R^2) indicates the proportion which the fixed model part explains of the total variance in the logarithmic predictions.

Results

Prediction models for bilberry yields

Two separate models were created for predicting bilberry yields: one for the Forestry Centre of Kainuu (Table 2) and the other for the rest of Finland (Table 3). According to the model for Kainuu, forest stands of medium fertility pro-

Table 2. Estimates of the parameters and variance estimates for the random components in the case of the bilberry model for Kainuu. The predicted variable in the model is $\ln(y_{ij} + 1)$, where y_{ij} is bilberry yield in forest stand *i* estimated by respondent *j* (kg ha^{-1}).

Parameter	Estimate	Standard error
Fixed part of the model		
constant	3.657	0.1445
D_1	0.610	0.0429
D_2	0.288	0.0427
spruce	0.282	0.0395
stand age (a)	–0.00140	0.000471
number of stems (trees ha^{-1})	–0.0000247	0.000012
Random part of the model		
e_j	0.282	0.1051
e_{ij}	0.525	0.0182

Explanation of the parameter and variance component codes: D_1 = site dummy: D_1 = 1, if the forest site type is medium, and D_1 = 0 otherwise; D_2 = site dummy: D_2 = 1, if the forest site type is rather poor, and D_2 = 0 otherwise; spruce = dominant tree species dummy: spruce = 1, if the dominant tree species is spruce, and spruce = 0 otherwise; e_j = random effect of respondent *j* (between-respondent variation); e_{ij} = random error (between-stand within-respondent variation).

Table 3. Estimates of the parameters and variance estimates for the random components in the case of the common bilberry model. The predicted variable in the model is $\ln(y_{ij} + 1)$, where y_{ij} is bilberry yield in forest stand *i* estimated by respondent *j* (kg ha^{-1}).

Parameter	Estimate	Standard error
Fixed part of the model		
constant	1.519	0.0674
mean height (m)	0.0568	0.000939
D_1	0.904	0.0175
D_2	0.505	0.0176
number of stems (trees ha^{-1})	–0.0000972	0.00000488
spruce	0.385	0.0191
pine	0.161	0.0174
FC_{1B}	–0.845	0.3454
FC_{1B} × basal area (m^2 ha^{-1})	0.0369	0.004193
FC_4	–0.602	0.3017
FC_4 × spruce	0.204	0.0861
FC_{13}	0.474	0.1468
Random part of the model		
e_j	0.764	0.0694
e_{ij}	1.445	0.0123

Explanation of the parameter and variance component codes: pine = dominant tree species dummy: pine = 1, if the dominant tree species is pine, and pine = 0 otherwise; FC_k = Forestry Centre dummy: FC_k = 1, if Forestry Centre is k, and FC_k = 0 otherwise (*see* Fig. 1); others as in Table 2.

duce the best bilberry yields. Rather poor stands also give good yields (Fig. 2A). Spruce-dominated forest stands which are not too dense are suitable for bilberry collection. It is apparent that increasing stand age slightly decreases bilberry production.

The common model for Forestry Centres 1–10 and 12–13 (Table 3) indicates that site fertility affects bilberry production in Forestry Centres 1–10 and 12–13 similar to the district of Kainuu (Fig. 2B). In most parts of Finland a high bilberry yield may be found in a sparse and mature stand which is dominated by spruce. Pine-dominated stands also produce good yields. The effect of tree size can be seen from Table 3, in which the coefficient of the mean height is positive, and from Fig. 2B, in which the mean diameter of trees correlates positively with bilberry yield prediction.

District-specific predictors were included for three districts: Coast (Ostrobothnia), Southeast Finland and Lapland (Table 3). For the Forestry Centre of Southeast Finland, for example, the constant is considerably lower than the one for the other districts (except for Coast — Ostrobothnia). The coefficient of "spruce", instead, is about one and a half times greater than the one estimated for the other Forestry Centres (Table 3).

The random respondent effect was statistically significant in both bilberry yield prediction models, i.e. the assessments given by a respondent were correlated (Tables 2 and 3). About one third of the residual variation of both models (35%) was accounted for by the random respondent effect. The random error accounted for 65% of the variation.

The degree of determination (R^2) of the fixed model part was 0.07 for the Kainuu model and 0.20 for the common model. The RMSE was 49.8 kg ha^{-1} for the model for Kainuu and 40.5 kg ha^{-1} for the common model. When applying the prediction models of this study in practice, the ratio estimators for bias correction are as follows: 1.3507 (Kainuu) and 1.8892 (common model).

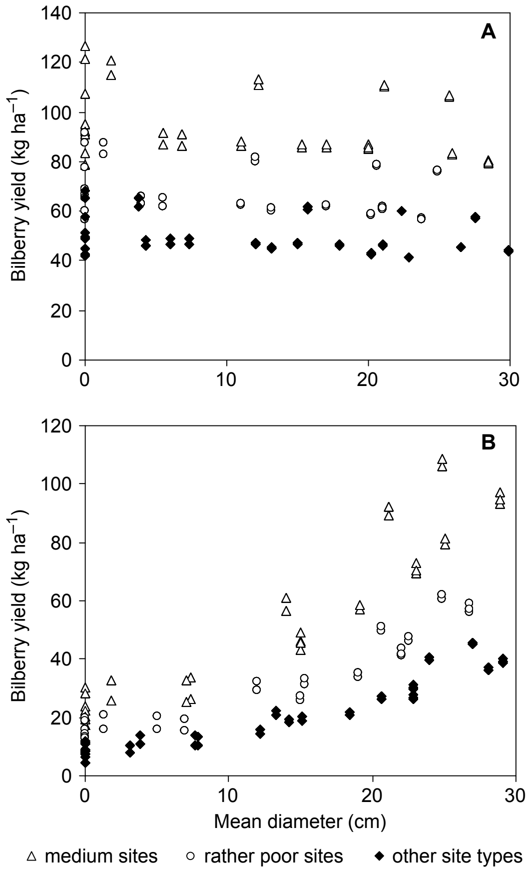

Fig. 2. Predicted bilberry yields for the study stands of (**A**) Forestry Centre of Kainuu and (**B**) Forestry Centre of Pirkanmaa as a function of the mean diameter of the trees. The predictions were calculated by using (**A**) the bilberry model for Kainuu (Table 2) and (**B**) the common bilberry model (Table 3). Medium, rather poor and other site types are marked with different symbols.

Prediction models for cowberry yields

Two separate models were developed for cowberry yields: a model for Forestry Centres 1–9 and 12 ("southwest model"), and a model for Forestry Centres 10, 11 and 13 ("northeast model") (*see* Fig. 1). The first model (Table 4) suggests that forest stands of rather poor or poorer site fertility produce the best cowberry yields in Forestry Centres 1–9 and 12 (Fig. 3). On poor sites, the most abundant yields can be found in mature and seed-tree stands but also openings and young seedling and sapling stands produce high yields (Fig. 3). Sparse pine-dominated stands are suitable for cowberry collection. The southwest model included district-specific predictors for two districts: Coast (Ostrobothnia) and Häme-Uusimaa.

The northeast model (Table 5) indicates that pine-dominated stands of poor fertility produce

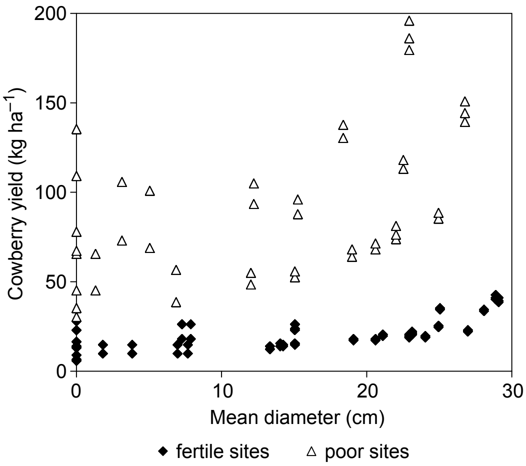

Fig. 3. Predicted cowberry yields for the study stands of Forestry Centre of Pirkanmaa as a function of the mean diameter of the trees. The predictions were calculated by using the cowberry model for Forestry Centres 1–9 and 12 (Table 4). Fertile (i.e. medium or more fertile) sites are marked with different symbols than poor (i.e. rather poor or poorer) sites.

the highest cowberry yields (*see* also Fig. 4A–B). The negative effect of stand basal area is quite obvious (Fig. 4B). The effect of stand age, instead, is reasonable to interpret together with basal area. On the basis of regression coefficients of these two parameters it can be concluded that seed-tree stands produce the most abundant cowberry yields (*see* also Fig. 4A–B where the highest cowberry crops are produced in stands which consist of old trees and have small stand basal area).

All three "northeast" Forestry Centres had district-specific predictors (Table 5). The Lapland-specific predictor suggests that on poor sites the best cowberry yields can be found not only in seed-tree stands but also in recently clear-felled open areas and young seedling and sapling stands (Fig. 4C).

The variance estimates for random respondent effects were statistically significant in both cowberry yield prediction models (Tables 4 and 5). In the model shown in Table 4, 31% of the residual variation was caused by random respondent effect, and the corresponding figure was 29% for the other model (Table 5). The rest of the residual variation was random error.

The degree of determination (R^2) of the fixed model part was 0.23 for the model for Forestry Centres 1–9 and 12 and 0.20 for the model for Forestry Centres 10, 11 and 13. The RMSEs

Table 4. Estimates of the parameters and variance estimates for the random components in the case of the cowberry model for Forestry Centres 1–9 and 12 (southwest model). The predicted variable in the model is $\ln(y_{ij} + 1)$, where y_{ij} is cowberry yield in forest stand i estimated by respondent j (kg ha^{-1}).

Parameter	Estimate	Standard error
Fixed part of the model		
constant	2.209	0.0685
D_3	1.539	0.0310
(stand age)^2	0.0000580	0.00000307
pine	0.540	0.0188
number of stems	–0.000155	0.00000602
$D_3 \times \ln(d + 1)$	–0.122	0.0135
FC_{1B} × number of stems	0.000218	0.000029
FC_3	–0.592	0.2906
Random part of the model		
e_j	0.785	0.0821
e_{ij}	1.748	0.0169

Explanation of the parameter and variance component codes: D_3 = site dummy: D_3 = 1, if the forest site type is rather poor or poorer, and D_3 = 0 otherwise; d = mean diameter (cm), others as in Tables 2 and 3.

Table 5. Estimates of the parameters and variance estimates for the random components in the case of the cowberry model for districts 10, 11 and 13 (northeast model). The predicted variable in the model is $\ln(y_{ij} + 1)$, where y_{ij} is cowberry yield in forest stand i estimated by respondent j (kg ha^{-1}). Explanations of the parameter and variance component codes are as in Tables 2, 3 and 4.

Parameter	Estimate	Standard error
Fixed part of the model		
constant	3.0770	0.1160
D_3	1.0543	0.0353
pine	0.292	0.0270
basal area	–0.0311	0.001877
stand age	0.00637	0.000526
FC_{10}	–0.695	0.2216
FC_{11}	0.602	0.2283
$FC_{11} \times D_3$	–0.594	0.0674
$FC_{13} \times (D_3 \times d^2)$	–0.000914	0.000130
Random part of the model		
e_j	0.564	0.0937
e_{ij}	1.349	0.0211

were 56.4 kg ha^{-1} for the southwest model (Table 4) and 62.2 kg ha^{-1} for the northeast model (Table 5). In model applications, the ratio estimators for bias correction are 1.8675 (for the model in Table 4) and 1.6157 (for the model in Table 5).

Model evaluation

The bias of the models of this study was zero as a result of the ratio estimator used for bias correction. The validity of the models was evaluated by comparing the model predictions with previous models, using the data from the study of Ihalainen *et al.* (2002) (100 forest stands located mainly in central and eastern Finland). The model predictions were calculated for the Forestry Centre of North Karelia, i.e. models shown in Tables 3 and 5 were employed. In the case of bilberry, the correlations with the models of Pukkala (1988), Muhonen (1995), Ihalainen and Pukkala (2001), Ihalainen *et al.* (2002) and Ihalainen *et al.* (2003) were 0.621, 0.162, 0.703, 0.729 and 0.750, respectively. The correlations with the models of Ihalainen and Pukkala (2001), Ihalainen *et al.* (2002) and Ihalainen *et al.* (2003) were significant (Fig. 5A–C).

In the case of cowberry, the berry yield predictions calculated by using the model shown in Table 5 were quite similar to those of the previous models developed by Pukkala (1988), Muhonen (1995), Ihalainen and Pukkala (2001), Ihalainen *et al.* (2002) and Ihalainen *et al.* (2003); the correlations were 0.405, 0.887, 0.937, 0.793 and 0.707, respectively. Especially the model of Ihalainen and Pukkala (2001) correlated very strongly with the model of this study (Fig. 5D). Characteristic to the cowberry yield prediction models of this study was a very clear effect of site fertility on berry production (Fig. 5D–F).

Discussion

This was the first occasion on which regional berry yield models were created for the whole country. Earlier models concern particularly eastern and central Finland (Pukkala 1988, Muhonen 1995, Ihalainen and Pukkala 2001, Ihalainen *et al.* 2002, Ihalainen *et al.* 2003).

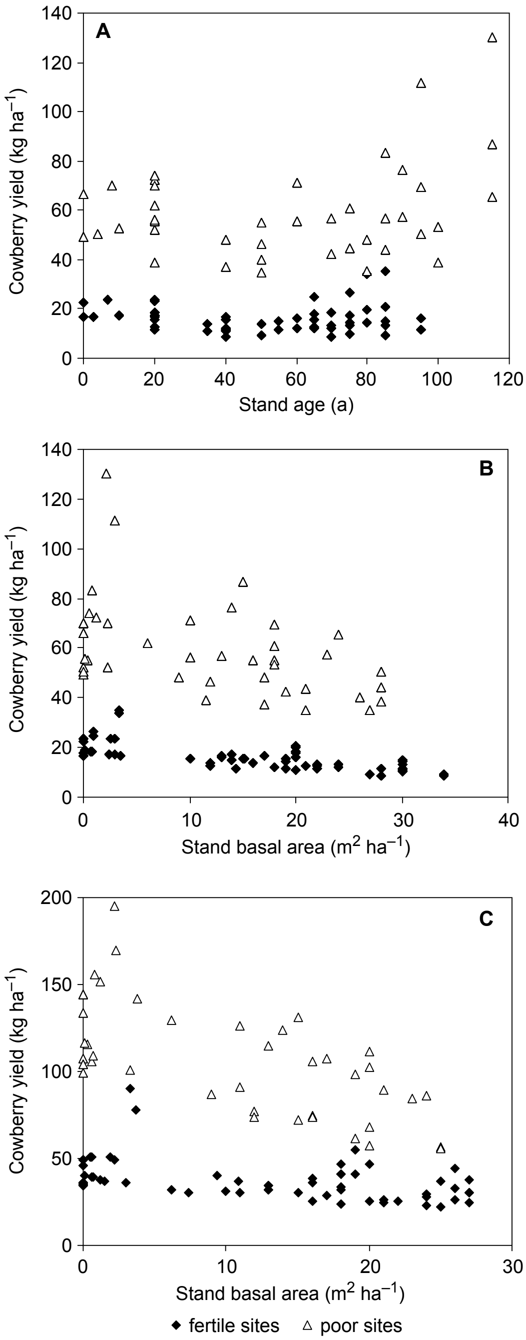

Fig. 4. Predicted cowberry yields for the study stands of (**A** and **B**) Forestry Centre of North Karelia and (**C**) Forestry Centre of Lapland as a function of (**A**) stand age and (**B** and **C**) stand basal area. The predictions were calculated by using the cowberry model for Forestry Centres 10, 11 and 13 (Table 5). Fertile (i.e. medium or more fertile) sites are marked with different symbols than poor (i.e. rather poor or poorer) sites.

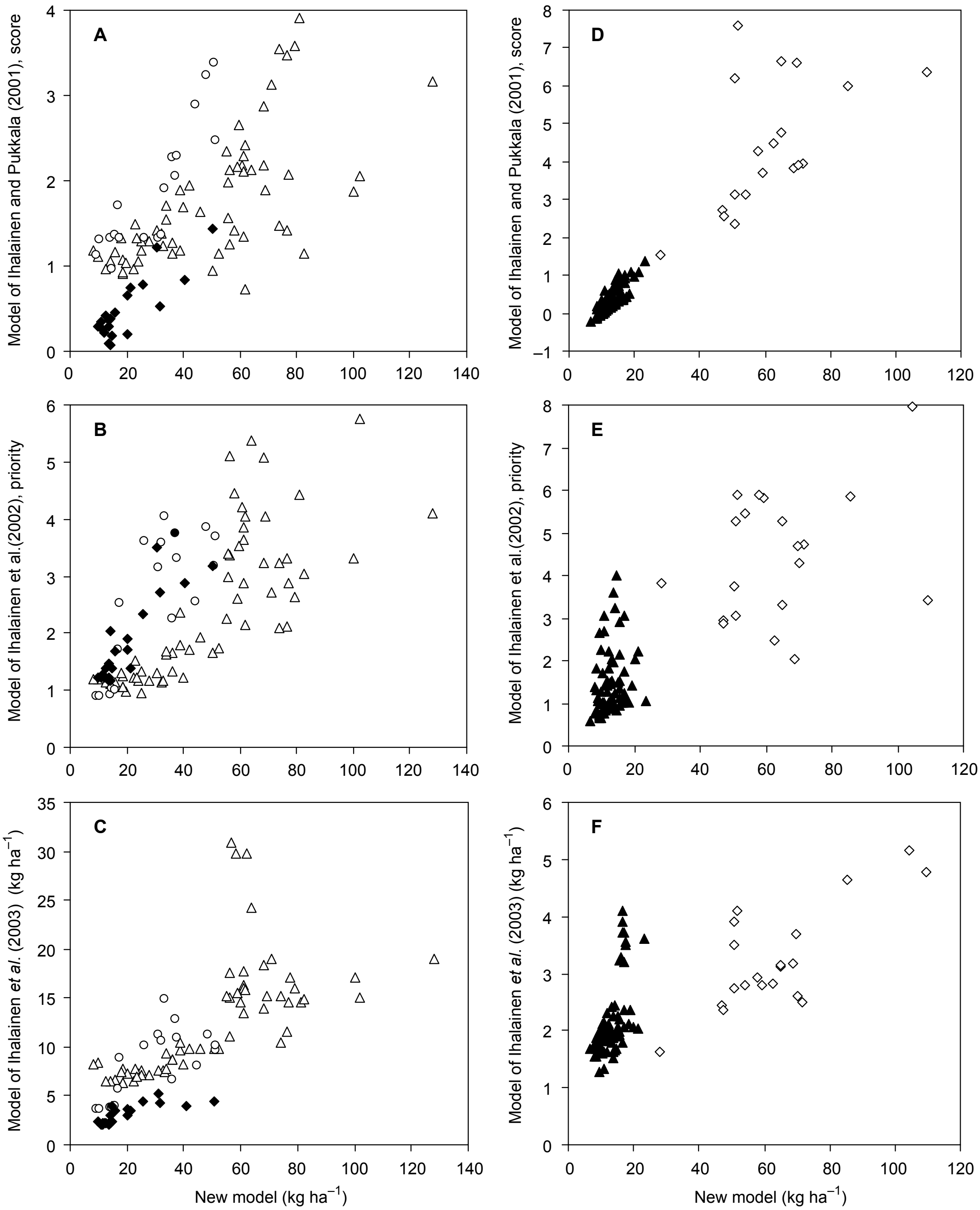

Fig. 5. Correlations between the berry yield predictions calculated by using the models of this study (Tables 3 and 5) and the models of Ihalainen and Pukkala (2001), Ihalainen *et al.* (2002) and Ihalainen *et al.* (2003). In the case of bilberry (**A**, **B**, **C**), medium (△), rather poor (○) and other site types (◆) are marked with different symbols. For cowberry (**D**, **E**, **F**), fertile (▲) and poor (◇) sites are separated from each other.

Most respondents understood and filled in the questionnaire correctly. Only a few of the returned questionnaires had to be eliminated from the data. On average, the respondents had planning experience of over 10 years and most of them (93%) used to pick forest berries. It has been previously found that people who are interested in a given topic and who are involved in the activities under study respond more frequently than less interested or uninvolved people (e.g. Martin 1994, Kangas 2001).

A relatively high response rate was obtained (60%). 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. High variation in the absolute berry yield given to score 10 was most probably one reason for the low degree of determination of the models of this study. The models were, however, statistically significant.

The problem with expert models is the difficulty of evaluating their reliability. With a different elicitation technique (paired comparisons) it would have been possible to analyse the consistency of judgments. The unanimity of experts could have been assessed and improved by using the Delphi technique. In this study the models were evaluated by comparing them to previous models found from literature.

According to the bilberry yield prediction models of this study (Tables 2 and 3), forest stands of medium fertility produce the highest bilberry yields in different parts of Finland. Berry production on rather poor mineral soil sites is also good. This result is similar to many previous studies (Ruuhijärvi *et al.* 1978, Lohiniva and Saastamoinen 1989, Nummi and Hänninen 1997, Ihalainen *et al.* 2003) although there are also findings according to which forests of rather poor fertility are slightly more suitable for bilberry collection than forests of medium fertility (Raatikainen and Raatikainen 1983, Raatikainen *et al.* 1984). Also equal priority of these both site types with respect to bilberry crops has been stated (Jäppinen *et al.* 1986, Ihalainen and Pukkala 2001). One explanation for this variation may be found from the fact that the definition of site types is subjective; the difference between medium and rather poor soil sites is vague and gradual which causes problems in the definition of site types. In addition, in northern Finland bilberry thrives on poorer soil sites than in southern Finland (Hotanen *et al.* 2000). In Lapland, a pine-dominated stand of rather poor fertility may produce similar bilberry yields as a corresponding stand of medium fertility, provided that the seasonal conditions for berry production are advantageous, i.e. there are no frosts, soil is moist enough, pollination is successful etc. In southern Finland, instead, bilberry yields may vary greatly between these two site types; berry production in a spruce-dominated stand of medium fertility is most probably higher than the yield in a pine-dominated stand of rather poor fertility in which cowberry usually grows as a dominant dwarf shrub in the field layer. Thus, the prevailing tree species also affects bilberry yields, as suggested by the results of this study.

This study, like many previous studies (Raatikainen and Raatikainen 1983, Raatikainen *et al.* 1984, Nummi and Hänninen 1997), indicate that a stand suitable for bilberry collection should not be too dense. Further, in most parts of the country, i.e. in the districts of Forestry Centres 1–10 and 12–13, mature stands seem to produce the most abundant bilberry yields. This result is logical and in line with many previous studies (e.g. Jaakkola 1983, Sepponen and Viitala 1983, Raatikainen *et al.* 1984, Nummi and Hänninen 1997, Ihalainen and Pukkala 2001). An opposite result, according to which openings and young seedling and sapling stands give slightly better yields than mature stands in the district of Kainuu, is interesting. There are no earlier findings in the literature of this kind of relationship. In principle, it is regarded that as a mesomorphic plant, bilberry thrives in quite shadowy conditions and does not tolerate the desiccating impact of direct sunlight (Raatikainen and Raatikainen 1983, Salo 1995). In this respect, further confirmation of the bilberry yield prediction model for the district of Kainuu would require empirical measurements on berry yields and site and stand characteristics.

When considering the prediction models for cowberry yield (Tables 4 and 5), it is obvious that forest stands of rather poor or poor fertility produce the most abundant cowberry crops throughout the country. This result is supported by several studies conducted in northern Finland (Jaakkola 1983, Kujala *et al.* 1989, Issakainen and Moilanen 1998), central Finland (Raatikainen 1978, Raatikainen *et al.* 1984) and southern Finland (Nummi and Hänninen 1997). Also the fact that sparse pine-dominated stands are suitable for cowberry picking is a well-known result (e.g. Raatikainen 1978, Kujala *et al*. 1989, Nummi and Hänninen 1997).

The most significant difference between the cowberry yield prediction models of this study can be found when examining the effect of the stage of stand development on berry production on poor mineral soil sites. The model for Forestry Centres 10, 11 and 13 (Table 5) suggests that seed-tree stands produce the most abundant cowberry yields in the districts of North Karelia and Kainuu. However, in the district of Lapland the highest cowberry crops can be found not only in seed-tree stands but also in recently clear-felled open areas and young seedling and sapling stands. In the rest of Finland, all stages of stand development except for young and advanced thinning stands seem to produce good cowberry yields.

The cowberry model for Lapland is in line with earlier results when considering the relationship between cowberry production and the stage of stand development (Jaakkola 1983, Lohiniva and Saastamoinen 1989). The same is true for Forestry Centres 1–9 and 12 (e.g. Raatikainen 1978, Raatikainen *et al*. 1984, Kujala *et al*. 1989, Nummi and Hänninen 1997). Models for North Karelia and Kainuu, instead, produce somewhat unexpected results in the light of previous studies (e.g. Jäppinen *et al*. 1986, Ihalainen and Pukkala 2001, Ihalainen *et al*. 2003) which state that the best cowberry yields can be found in gaps, young seedling and sapling stands and in old forests. Even though there is a finding that sparse forest stands, such as seed-tree stands, produce the best cowberry yields in the district of Kainuu (Kujala *et al*. 1989), yet one should be cautious with the cowberry yield predictions for North Karelia and Kainuu calculated by the models of this study. There is clearly a need for further research to explore the dependence of berry crops on the stage of stand development.

Although the models of this study correlated significantly with the two other models which also predict berry yields in terms of kilograms per hectare, i.e. with the models of Pukkala (1988) and Ihalainen *et al*. (2003), the berry yield predictions of each model differed considerably from each other (Fig. 5C and F). In the case of bilberry, for example, the predicted yields calculated for the Forestry Centre of North Karelia varied from 0 to 43 kg ha^{-1} when the model of Pukkala (1988) was used and the ranges of variation were 2–31 kg ha^{-1} and 8–128 kg ha^{-1} when the models of Ihalainen *et al*. (2003) and this study (Table 3) were used (Fig. 5C). It is likely that the models of Ihalainen *et al*. (2003) produce underestimates for berry yields (Ihalainen *et al*. 2003). In the present study, it may be that the respondents have been a little optimistic when they estimated the maximum absolute berry yields and, therefore, the models may produce overestimates. As a result there still is a need to calibrate the models of this study by means of empirical measurements, if one's interest is to estimate the regional supply of the berries. The principal use of the models developed in this study is, however, multiple-use forest planning, and for this use calibrations are not always necessary.

The models established in the present study are highly relevant with respect to practical multiple-use forestry. New Forestry Act from 1997 requires that all regional Forestry Centres have to create regional forest programmes and monitor their implementation (*see* e.g. The State of Forestry… 2000). The first regional forest programmes were prepared in 1997–1998 and they were revised in 2000. In these programmes also non-wood forest products have been considered. Moreover, at the end of the 2010s a forest planning system of the Forestry Centres will be improved so that also non-wood forest products, like wild forest berries, can be integrated into forest planning calculations (K. Hassinen pers. comm.). This, naturally, requires that production functions describing non-wood forest products and benefits are available. The models of this study have been given to all Forestry Centres of Finland and they can utilize the models freely. Thus, in the future foresters can easily assess how a certain forest management practice (like thinning or clear-cutting) affect bilberry and cowberry yields if forest owner's preferences include not only timber production and income from timber sales but also berry yields or recreation through berry picking.

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Appendix. One of the six tables in the questionnaire.

Dominant tree species: birch
Berry species: bilberry

Development class	Mineral soil site of rich fertility		Mineral soil site of medium fertility		Mineral soil site of rather poor fertility	
A0						
S0						
	dense	sparse	dense	sparse	dense	sparse
T1						
T2						
02						
03						
04						

Development classes (*see* Luonnonläheinen metsänhoito… 1994): A0 = Open regeneration area, S0 = Seed-tree stand, T1 = Small-seedling stand, T2 = Advanced seedling stand, 02 = Young thinning stand, 03 = Advanced thinning stand, 04 = Mature stand.