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ORIGINALPAPER

Optimal multi-product management of stands producing timber and wild berries

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Abstract Northern wild bilberries (*Vaccinium myrtillus*) and cowberries (*V. vitis-idaea*) are increasingly demanded, and forest owners are interested in their contribution to the total income obtained from the forest. In this study, bilberry and cowberry yield models were included in a stand growth simulator and the joint production of timber and berries was optimized by maximizing soil expectation value (SEV) with 3 % discount rate, assuming that 75 % of the berry yield is harvested. The berry prices and picking costs were included in calculations. Management was optimized for the following three stand types: Scots pine stand on *Myrtillus* site, mixed stand of Scots pine, Norway spruce and birch on *Myrtillus* site, and Scots pine stand on *Vaccinium* site. Management was optimized separately for an average and a good berry stand. With the current berry prices and picking costs, the optimal management of average berry stands changed very little from the timber-oriented stand management. When a pine stand growing on *Vaccinium* site produced good cowberry yields, thinnings were heavier and the rotation length was a few years longer than obtained for average berry stands. When both bilberry and cowberry yields were included in optimization, the optimal rotation length was 36 years longer than in timber-oriented management. In pine stands and mixed stands of pine, spruce and birch growing on *Myrtillus* site and having good bilberry yields, about 20 years longer rotation and a heavier first thinning were optimal to reduce canopy shading to a level that is favorable for bilberry crops. With increasing berry prices, it was more profitable to apply still longer rotation lengths and higher thinning intensities and convert the mixed stand into a pine–birch mixture—instead of spruce dominance—toward the end of the rotation. With the current berry prices, the SEV calculated with berries was more than twice as high as the SEV calculated without berries. Valuing forest berries may remarkably change the optimal management of stands, where the berry yields are known to be or can be assumed to become high.

Keywords *Vaccinium myrtillus* · *Vaccinium vitis-idaea* · *Betula pendula* · *Picea abies* · *Pinus sylvestris* · Non-wood forest products

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Introduction

Wild forest berries, including bilberry (*Vaccinium myrtillus*) and cowberry (*Vaccinium vitis-idaea*), are among the most important non-wood forest products (NWFPs) in the Nordic countries (Turtiainen and Nuutinen 2012; Vaara et al. 2013). Bilberries and cowberries are picked for both household use and sale. Wild berries' value as nutritional supplement is recognized, and their good reputation in terms of high content of bioactive compounds is used to market berry-based health products. Due to the increased demand for northern wild berries, especially in Asian countries (MARSI 2014), forest owners may be interested in knowing how much they could increase their income from the forest if they manage forests for berry production. Such knowledge on the optimal management for maximizing the profitability of joint production of timber and berries is, however, limited.

Earlier results suggest that valuing NWFPs may remarkably change the optimal stand management and increase the profitability of forestry (Palahí et al. 2009; de Miguel et al. 2014).When mushroom production was considered in *Pinus sylvestris* and *P. nigra* stands in Catalonia, thinning treatments, which usually are unprofitable, were included in the optimal management schedules to reduce stand density to a level that is favorable for mushrooms (Palahí et al. 2009). De Miguel et al. (2014) optimized the joint production of timber and pine honeydew honey in *Pinus brutia* stands in Turkey and found that especially on medium- and poor-quality sites, longer rotations considerably increase the incomes from the multi-product pine stands.

So far, stand management considering both timber and berries has been optimized only for bilberry (Miina et al. 2010). However, cowberry is economically more significant in Finland (MARSI 2014). Therefore, the joint production of timber and cowberry should also be studied. Miina et al. (2010) did not consider the costs of berry picking, and thus, the existing results for bilberry can be utilized mainly for developing management prescriptions for public forests, which are used for recreational berry picking. Including berries as a source of personal income to the forest landowner suits particularly to situations where the owner can control the utilization of berry yields. Due to the everyman's right, this is seldom the case in Finland. Optimizing the joint production of timber and berries is the most meaningful in public forests where the aim should be to maximize the total benefit that the society gets from the forest. However, results on the joint production would help policy makers to develop instruments that promote forest management which is optimal from the society's point of view.

Bilberry is an abundant plant in conifer-dominated forests of medium fertility, and cowberry on nutrient-poor mineral soil sites (e.g., Raatikainen 1978; Raatikainen and Raatikainen 1983; Raatikainen et al. 1984). However, annual berry crops fluctuate greatly, mainly due to weather conditions (Kardell and Eriksson 1990, 2011; Wallenius 1999; Selås 2000). The abundance and yield of bilberry and cowberry are mainly influenced by site conditions, and silvicultural operations affect the yields. Bilberry suffers from regeneration fellings and does not thrive in sparse seedling and sapling stands or in dense young stands. A moderate supply of light is needed for good bilberry crops, the optimal canopy cover being 10–50 % (Raatikainen et al. 1984). Due to different shading of tree species, the coverage and yield of bilberry is lower in spruce-dominated than in pine-dominated stands (Raatikainen et al. 1984; Miina et al. 2009). To increase bilberry yields, higher thinning intensities, more frequent thinnings, retention of more pine in mixed stands and longer rotation lengths could be applied in even-aged management system (Miina et al. 2010).

Cowberry needs more light than bilberry for maximum productivity. Although cowberry tolerates some shade and is adapted to grow under tree canopies, a good supply of light is necessary for abundant flowering and berry crops; the optimal crown cover is 1–40 % (Raatikainen et al. 1984). Cowberry also suffers from regeneration fellings combined with soil preparation, but the best yields are obtained a few years after regeneration cutting and again at the end of rotation, especially in sparse mature pine forests. Cowberry yields are low in dense and shaded stands.

Despite seemingly optimal site and stand characteristics for berry crops, not all forest stands supply good berry yields. According to Raatikainen (1978, see Table 1), the mean cowberry yield of mature stands on *Vaccinium* type sub-xeric heath site (Cajander 1949) was only 40 kg/ha, whereas the maximum cowberry yield measured was as high as 330 kg/ha. Bilberry can also produce good crops on *Vaccinium* site (Raatikainen 1978). In the same area in central Finland, the mean and maximum bilberry yields of mature stands growing on *Myrtillus*-type mesic heath site were 22 and 140 kg/ha, respectively (Raatikainen and Raatikainen 1983, see Table 1). On *Myrtillus* site, cowberry rarely produces harvestable crops (Raatikainen and Raatikainen 1983; Raatikainen et al. 1984). Due to high between-stand variation in berry yields, it may be profitable to modify the stand management for promoting berry yields mainly in those stands which are known to have high productivity. However, it is not known how stands producing both bilberries and cowberries should be managed in the optimal way.

The aim of this study was to optimize the even-aged management of stands in the joint production of timber and wild forest berries; bilberry (*Vaccinium myrtillus* L.) and cowberry (*V. vitis-idaea* L.). Multi-product management schedules were optimized for two Scots pine (*Pinus sylvestris* L.) stands and a mixed stand of Scots pine, Norway spruce (*Picea abies* (L.) Karst.) and birch (*Betula pendula* Roth) growing on sites most suitable for bilberry and/or cowberry in North Karelia, Finland. The management was optimized separately for an average and good berry stand. The market prices paid to berry pickers and yield-dependent berry picking costs were used in calculations. We analyzed also the effect of berry prices on the optimal stand management. The results are the most applicable to situations where the forest owner directly or indirectly benefits from managing the stands for both timber and berry yields.

Materials and methods

Overview

A simulation software was used in a deterministic way to predict the growth of trees in three initial stands. Due to a large annual variation in berry yields, stochastic simulations were used to predict the berry production during stand development. The incomes and costs of both timber production and berry picking were used to calculate the net present values of all future costs of and incomes from the multi-product management. The stand simulator was linked with an optimization algorithm to find out the management schedule for the stand (i.e., thinnings and rotation), which maximizes the profitability of the joint production of timber and berries (e.g., Palahí et al. 2009; Miina et al. 2010; de Miguel et al. 2014). Management was optimized separately for average and good berry stands.

Simulation of stand development and berry yields

The stand development was predicted using the models of Hynynen et al. (2002) for site index, dominant height development, diameter increment, crown height, height increment and tree survival. The taper models of Laasasenaho (1982) were used to calculate assortment volumes of removed trees. In all simulations, the temperature sum was set to 1200° days, the altitude to 100 m and the proportion of sea and lakes within 20 km to 0 and 20 %, respectively. The values represent the conditions of North Karelia, Finland.

The empirical berry yield models for bilberry (Miina et al. 2009) and cowberry (Turtiainen et al. 2013) were used to predict the berry production. The used model set first predicted the coverage of the berry species as a function of site conditions, e.g., site fertility, regeneration method, stand age and stand basal area. Then, it predicted the annual berry yields from the coverage of the berry species and some other predictors.

The bilberry yield was predicted using the following models (Miina et al. 2009):

$$\begin{aligned} \mathit{Bilberry\ cover} &= 100 \times (1+\exp\{-f(\cdot)\})^{-1} \\ f(\cdot) &= -3.8470 - 2.1815 \times \mathit{OMaT} - 0.4809 \\ &\times \mathit{OMT} - 0.4807 \times \mathit{VT} - 1.5053 \\ &\times \mathit{CT} + 0.1209 \times \mathit{Pine} - 0.4770 \\ &\times \mathit{Birch} \times \mathit{OMT} - 0.2588 \times \mathit{ArtRegen} \\ &- 1.4715 \times \mathit{FormerAgrLand} + 0.0029 \\ &\times \mathit{Alt} + 0.0080 \times T - 0.0021 \times T^2/100 \\ &+ 0.0947 \times G - 0.1916 \times G^2/100 \end{aligned} \tag{1}$$

$$\begin{aligned} \mathit{BilberriesP} = \exp\{&-0.5359 + 0.2398 \times \mathit{Bilberry\ cover} \\ &- 0.2812 \times \mathit{Bilberry\ cover}^2/100 + v + u\} \end{aligned} \tag{2}$$

$$\begin{aligned} \mathit{BilberriesS} = \exp\{&-4.2024 + 0.3635 \times \mathit{Bilberry\ cover} \\ &- 0.4798 \times \mathit{Bilberry\ cover}^2/100 \\ &+ 0.3742 \times G - 1.3447 \times G^2/100 + v + u\} \end{aligned} \tag{3}$$

where *Bilberry cover* is the mean coverage of bilberry in the stand (%), *BilberriesP* and *BilberriesS* are the mean number of bilberries per m^2 in pine- and spruce-dominated stands, respectively; T is stand age (years); G is stand basal area (m^2/ha); *Pine* and *Birch* are indicator variables for pine and birch, respectively (reference: spruce); and *Alt* is altitude (m). The effect of the fertility of mineral soil site is described by indicator variables as follows (Cajander 1949): *OMaT* = *Oxalis–Maianthemum* type, *OMT* = *Oxalis–Myrtillus* type, *VT* = *Vaccinium* type and *CT* = *Calluna* type (reference: *MT* = *Myrtillus* type). *ArtRegen* and *FormerAgrLand* are indicator variables for artificial regeneration methods (reference: natural regeneration) and former agricultural land (reference: former forest), respectively, and v and u are random, normally distributed between-stand and between-year effects with zero means and constant variances.

The cowberry yield was predicted using the following models (Turtiainen et al. 2013):

$$\mathit{Cowberry\ cover} = 100 \times (1+\exp\{-f(\cdot)\})^{-1} \tag{4}$$

$$\begin{aligned} f(\cdot) = &-4.7902 - 5.173 \times \mathit{OMaT} - 2.569 \times \mathit{OMT} \\ &- 0.4216 \times \mathit{MT} - 0.4185 \times \mathit{VT} \\ &- 2.0679 \times \mathit{SpruceMireI-II} - 0.7984 \\ &\times \mathit{SpruceMireIII} - 1.8198 \times \mathit{PineMireI-III} \\ &- 0.5644 \times \mathit{PineMireIV} - 1.7620 \times \mathit{PineMireV} \\ &- 0.9438 \times \mathit{FormerAgrLand} - 0.4327 \times \mathit{Spuce} \\ &\times (\mathit{OMaT} \text{ or } \mathit{OMT} \text{ or } \mathit{MT} \text{ or } \mathit{SpruceMireI-III}) \\ &- 0.7528 \times \mathit{Birch} \\ &\times (\mathit{OMaT} \text{ or } \mathit{OMT} \text{ or } \mathit{MT} \text{ or } \mathit{SpruceMireI-III}) \\ &+ 2559.2/\mathit{TS} - 0.0039 \times \mathit{Alt} + 0.0106 \times T \\ &+ 0.0157 \times G \end{aligned}$$

$$\begin{aligned} \mathit{Cowberries} = \exp\{&6.7253 + 0.0966 \times \mathit{Cowberry\ cover} \\ &- 0.0837 \times \mathit{Cowberry\ cover}^2/100 \\ &- 0.4716 \times \ln(G+1) + 0.0071 \\ &\times \mathit{Alt} - 4626.4/\mathit{TS} + v + u\} \end{aligned} \tag{5}$$

where *Cowberry cover* is the mean coverage of cowberry in the stand (%); *Cowberries* is the mean number of cowberries per m^2; *Spruce* is indicator variable for spruce (reference: pine); *TS* is temperature sum (dd); and the peatland site for spruce (*SpruceMire*) and pine (*PineMire*) mire is defined as follows (Laine and Vasander 1993): I = eutrophic, II = herb rich (mesotrophic), III = *Vaccinium myrtillus* and tall sedge (meso-oligotrophic), IV = *Vaccinium vitis-idaea* and small sedge (oligotrophic), V = cottongrass and dwarf shrub (poor ombro-oligotrophic bogs). Other variables are defined as above.

The effects of the study years were originally included in Eqs. (2), (3), and (5) as indicator variables. We calculated the sample means of the year effects (0.1422, 0.5450 and 0.1849, respectively) and added them to the intercepts of the models. Berry yields measured in North Karelia, Finland (Kilpeläinen et al. 2016) and the berry yields reported by Turtiainen et al. (2005, Table 4) indicated the need to calibrate the berry yield models. It was found that the yield model of Miina et al. (2009) clearly under-predicted the bilberry yields, whereas the yield model of Turtiainen et al. (2013) over-predicted the cowberry yields, especially in the beginning of the rotation. Therefore, the bilberry yield predictions were multiplied by 2.3 on *Myrtillus* site and by 3.5 on *Vaccinium* site, whereas the cowberry yield predictions on *Vaccinium* site were multiplied by 0.8.

In addition, the positive effect of regeneration felling on berry production was overestimated since it takes several years before bilberry and cowberry are fully recovered from cutting (Atlegrim and Sjöberg 1996; Kardell and Eriksson 2011). Because this is not taken into account by the yield models used in this study, the bilberry and cowberry yield was assumed to be 0 and 20 %, respectively, of the yield prediction immediately after regeneration felling (i.e., at stand age of 1 year). Then, the yield reduction was assumed to decrease linearly until it was over in 20 years after regeneration felling for bilberry and 10 years for cowberry. The reduction affected mostly cowberry yield predictions since predicted bilberry yields are very low in young stands.

In a mixed stand, the number of bilberries was predicted first for each tree species using the total stand basal area as a predictor in the models. For birch, the number of bilberries was calculated using the model for pine-dominated stands (Eq. 2). Finally, the number of bilberries was calculated as the weighted average of the species-specific predictions. The proportions of tree species of stand basal area were used as weights.

The number of berries was converted into the berry yield (kg/ha) by multiplying it by the mean fresh weight of one berry; 0.35 g was used for bilberry (Eronen 2004) and 0.23 g for cowberry (Ihalainen et al. 2003). Finally, the berry yield predictions were multiplied by 0.75 assuming that 75 % of the total yield of the season would actually be harvested for sale (cf. Raatikainen and Niemelä 1983).

The annual berry yield was predicted in a stochastic way. For each year, the bilberry and cowberry yields were predicted 200 times by drawing the random between-year effects (u) from the normal distribution (Eqs. 2, 3 and 5), and the annual berry yields were computed as the mean of the 200 outcomes. The variances of the between-year effects (u) of Eqs. (2), (3) and (5) were 0.0712, 0.2004 and 0.0888, respectively. The stand was assigned as a good berry stand by setting the random stand effect (v) to 1.4 for bilberry (Eqs. 2 and 3) and 0.7 for cowberry (Eq. 5). The values were such that the yield predictions for good berry stands were comparable to the good yields measured by Raatikainen and Raatikainen (1983) for bilberry and by Raatikainen (1978) for cowberry. For an average berry stand, the random stand effects were zero.

Initial stands

Three 10-year-old initial stands representing North Karelia, Finland, were used as starting points for the simulations (Table 1). A pine stand and a pine–spruce–birch mixture represent *Myrtillus* site, and a pine stand represents *Vaccinium* site. Pure birch and spruce stands were not included because berry yield models for birch stands are missing, and in spruce stands, berry yields are mostly low and incomes from berries never play a major role in stand management (Miina et al. 2010).

The initial stands were assumed to have been treated with a pre-commercial thinning. The initial growing stock was specified with 2 or 3 cohorts per species, and each

Table 1 Main characteristics of the 10-year-old stands used as initial stands in the optimizations

	N (trees/ha)	H (m)	D (cm)
Pine stand (*Myrtillus* site)			
Cohort 1	600	1.8	1.3
Cohort 2	1200	3.0	2.6
Cohort 3	200	3.4	4.2
Total	2000	3.1	3.1
Pine stand (*Vaccinium* site)			
Cohort 1	600	1.4	0.5
Cohort 2	1200	2.0	1.8
Cohort 3	200	2.6	2.8
Total	2000	2.2	2.1
Mixed stand (*Myrtillus* site)			
Pine cohort 1	210	3.0	2.6
Pine cohort 2	279	3.4	4.2
Spruce cohort 1	442	2.4	2.5
Spruce cohort 2	471	2.8	3.5
Birch cohort 1	211	3.0	2.6
Birch cohort 2	187	3.4	4.2
Total	1800	3.2	3.8

N is the number of stems; H is mean height; and D is mean diameter cohort was represented by ten sample trees. The sample trees were generated by first predicting the diameter distribution of each cohort. The distributions were divided into ten diameter classes of equal width, and the midpoint tree of each class was taken as a sample tree. The frequencies of the sample trees were calibrated in the same way as in Pukkala and Miina (2005). Tree species, mean age, mean diameter and mean height in each cohort were given for each initial stand (Table 1).

Optimization method

The stand simulator was linked with an optimization program to study the effect of berry production on the optimal management of stands. The nonlinear programming algorithm of Hooke and Jeeves (1961) was used to find the optimal combination of decision variables defining the stand management. Since the Hooke and Jeeves' direct search method may converge to local optima, each optimization problem was solved 20 times with different randomly generated initial values of decision variables, and the solution with the highest objective function value of these results was reported. Each direct search run started from the best of 200 random combinations of decision variables.

The objective function was the soil expectation value (SEV) calculated with 3 % discount rate (Price 1989). SEV was defined as the net present value of all future costs of and incomes from both timber and berry production. All costs and incomes of a full rotation were discounted to the beginning of the rotation. Future rotations were taken into account by assuming that the rotation will be followed by similar rotations to infinity.

The decision variables defining stand management were as follows: number of years since regeneration (first thinning) or first thinning (second thinning), removal percentage separately for each tree cohort (for both thinnings), and number of years between the last thinning and final cut. The thinning percentage was the same for every diameter class of a cohort. However, since the thinning percentages of tree cohorts were different decision variables, it was possible to optimize the type of thinning, in addition to thinning intensity. The number of thinnings (i.e., 1 or 2) was given to the simulation–optimization system before solving the problem.

Table 2 Roadside prices and minimum top diameters of timber assortments

	Pine	Spruce	Birch
Log price (€/m^3)	56	56	45
Pulpwood price (€/m^3)	30	29	31
Minimum top diameter of log (cm)	15	16	18
Minimum top diameter of pulpwood (cm)	7	7	8

The average unit costs of silvicultural treatments in 2013 were applied in the calculations (http://www.metla.fi/metinfo). In the beginning of the rotation, a regeneration cost of 1000 €/ha was assumed to accrue from planting on *Myrtillus* site, and 500 €/ha from natural regeneration on *Vaccinium* site. The pre-commercial thinning of young stand (350 €/ha) was assumed to have been done three years after stand height reached 1.3 m.

Roadside prices of timber assortments were used (Table 2). The mean roadside prices of 2013 in North Karelia were used in thinnings and final felling (http://www.metla.fi/metinfo). The entry cost of a cutting was taken as 100 €/ha. The variable costs of cuttings were calculated using the models of Rummukainen et al. (1995).

Based on the statistics on the amounts of wild berries offered for sale in the last five years (MARSI 2014, Table 11), the average market price paid to pickers in eastern Finland was 2.4 €/kg for bilberries and 1.8 €/kg for cowberries. These prices were used in the calculations. In addition, zero as well as twofold and threefold pricing were used to analyze the effect of berry prices on the optimal stand management.

The berry picking costs included travel and harvesting costs. For travel costs, it was assumed that two berry pickers drive together a total distance of 20 km to pick and sell berries (Raatikainen 1978; Kangas and Markkanen 2001). Applying a travel cost of 0.4 €/km and a daily harvest of 40 kg per person, the travel cost per collected kilogram is 0.1 €. Using the wage of 6 € per hour and assuming that 12 kg of berries can be picked per hour, the harvesting cost is 0.5 €/kg. However, it was assumed that the harvesting cost of 0.5 €/kg (corresponding to the productivity of 12 kg/h) holds only when the berry yield is 40 kg/ha. The harvesting cost was multiplied by 41/(yield + 1), resulting in increased cost (i.e., decreased berry picking productivity) when berry yield <40 kg/ha and decreased cost in case of higher berry yields. The total cost of berry picking was 0.6 €/kg when the berry yield was 40 kg/ha. It was assumed that berries were collected only when the berry picking costs were less than the selling price of berries. As a result, years of poor berry yields were not included in the incomes and harvested berry yields.

Results

Optimal management of stands with varying berry prices

The effect of bilberry price (0, 2.4, 4.8 or 7.2 €/kg) on the optimal management of the pine and mixed stands on

Table 3 Effect of bilberry price on the optimal stand management of stands with average berry yields

	Bilberry price (cowberry 0 €/kg)			
	0 €/kg	2.4 €/kg	4.8 €/kg	7.2 €/kg
Pine stand (*Myrtillus* site)				
SEV total (€/ha)	1868	2245	3012	3841
SEV without berries (€/ha)	1868	1836	1830	1776
Additional SEV from berries (€/ha)	[346][a]	408	1182	2065
1. Thinning at age (years)	40	40	40	39
Thinning intensity (%)	27	27	27	31
2. Thinning at age (years)	52	52	52	54
Thinning intensity (%)	78	59	78	75
Rotation length (years)	71	72	89	93
Mean bilberry harvest (kg/ha/year)	[11.5][a]	13.6	15.1	16.1
Mixed stand (*Myrtillus* site)				
SEV total (€/ha)	2075	2129	2414	2722
SEV without berries (€/ha)	2075	2075	2046	1824
Additional SEV from berries (€/ha)	[54][a]	54	369	898
1. Thinning at age (years)	43	43	39	47
Thinning intensity (%)	34	34	15	53
(pine/spruce/birch)	(72/0/100)	(72/0/100)	(0/0/100)	(19/62/79)
2. Thinning at age (years)	58	58	49	57
Thinning intensity (%)	55	55	65	52
(pine/spruce/birch)	(0/61/–)	(0/61/–)	(72/62/–)	(64/47/0)
Rotation length (years)	73	73	75	80
Mean bilberry harvest (kg/ha/year)	[3.1][a]	3.1	5.6	7.8
	Cowberry price, €/kg (bilberry 0 €/kg)			
	0 €/kg	1.8 €/kg	3.6 €/kg	5.4 €/kg
Pine stand (*Vaccinium* site)				
SEV total (€/ha)	2116	3617	5757	7911
SEV without berries (€/ha)	2116	2111	2070	2070
Additional SEV from berries (€/ha)	[1494][a]	1505	3687	5840
1. Thinning at age (years)	39	39	41	41
Thinning intensity (%)	18	18	29	29
2. Thinning at age (years)	51	51	51	51
Thinning intensity (%)	67	81	81	81
Rotation length (years)	63	62	66	66
Mean cowberry harvest (kg/ha/year)	[32.6][a]	33.1	34.4	34.4
	Cowberry/bilberry price, €/kg			
	0/0	1.8/2.4	3.6/4.8	5.4/7.2
Pine stand (*Vaccinium* site)				
SEV total (€/ha)	2116	3937	6734	9659
SEV without berries (€/ha)	2116	2114	1943	1966
Additional SEV from berries (€/ha)	[1494/317][a]	1489/335	3705/1086	5857/1835
1. Thinning at age (years)	39	38	40	39
Thinning intensity (%)	18	18	30	28
2. Thinning at age (years)	51	48	50	50
Thinning intensity (%)	67	60	81	82
Rotation length (years)	63	63	94	92

Table 3 continued

	Cowberry/bilberry price, €/kg			
	0/0	1.8/2.4	3.6/4.8	5.4/7.2
Mean cowberry/bilberry harvest (kg/ha/year)	[32.6/10.9][a]	32.4/11.4	35.7/13.4	35.5/13.3

[a] Berry harvests and the additional SEV from berries were calculated using cowberry and bilberry price 1.8 and 2.4 €/kg, respectively

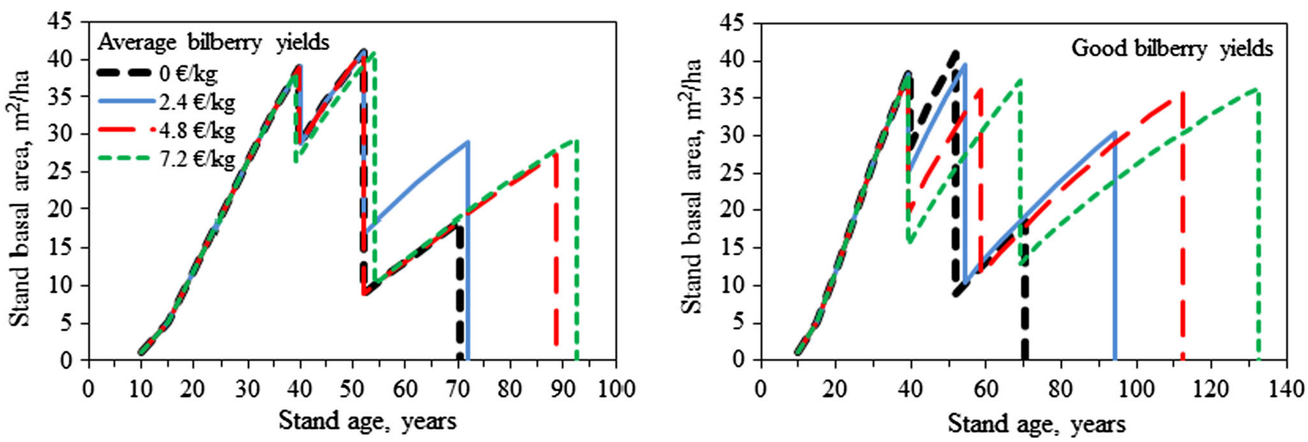

Fig. 1 Effect of bilberry price on the optimal management schedules of the pine stand on *Myrtillus* site with average and good bilberry yields. Cowberries are not harvested

Myrtillus site was studied by maximizing the soil expectation value with 3 % discount rate. It was assumed that cowberries are not harvested on *Myrtillus* site. Without valuing bilberries, the optimal management schedule of the pine stand consisted of two thinnings removing 27 and 78 % of the basal area and a final felling at the age of 71 years (Table 3; Fig. 1). The mixed stand was thinned twice (removals 34 and 55 %) favoring spruce in the residual stand and clear-felled at the age of 73 years (Table 3; Fig. 2).

Assuming that the stand provides average bilberry yields and using the current market price of bilberry (2.4 €/kg), the optimal management of the pine stand on *Myrtillus* site changed only slightly, and the optimal management of the mixed stand did not change at all. With bilberry prices of at least 4.8 €/kg, bilberry picking increased the rotation length of the pine stand by about 20 years. In the mixed stand, a threefold bilberry price was needed to extend the rotation. More spruces were removed in thinnings, resulting in higher proportion of pine (Fig. 3).

In stands growing on *Myrtillus* site and having high bilberry yields, commercial berry picking had a strong impact on optimal management (Figs. 1, 2, 3). In both pine and mixed stand, berry picking affected the optimal management already with the current market price (2.4 €/kg), leading to longer rotation and heavier thinnings. In the mixed stand, it was optimal to make two heavy thinnings in which the stand was converted into a pine-dominated stand (price 2.4 €/kg) or into pine–birch mixture (4.8 and 7.2 €/kg) toward the end of the rotation (Fig. 3). Compared to timber-oriented management, multi-product management with the current market price of bilberry decreased the timber benefit by 8 % in the pine stand and 32 % in the mixed stand (Table 4).

The management of the pine stand on *Vaccinium* site was optimized by maximizing the SEV of the incomes from timber, cowberry and bilberry. When bilberries were not harvested, the optimal management schedule of the pine stand with average cowberry yields changed only slightly, but the proportion of cowberry incomes of the total SEV was as high as 42–74 % (Table 3, Fig. 4). With good cowberry yields, the pine stand was thinned heavier (Table 4; Fig. 4). With the threefold cowberry price, only one heavy thinning was done and the rotation length was more than doubled. When both cowberries and bilberries were harvested, the optimal management of the average berry stand changed only when two- or threefold berry prices were assumed (Fig. 5). In the good berry stand, management changed even with the current market prices (cowberry 1.8 €/kg and bilberry 2.4 €/kg). For example, thinnings were heavier and the rotation length was 34 years longer. This change in stand management decreased the SEV calculated without berry income by 9 %.

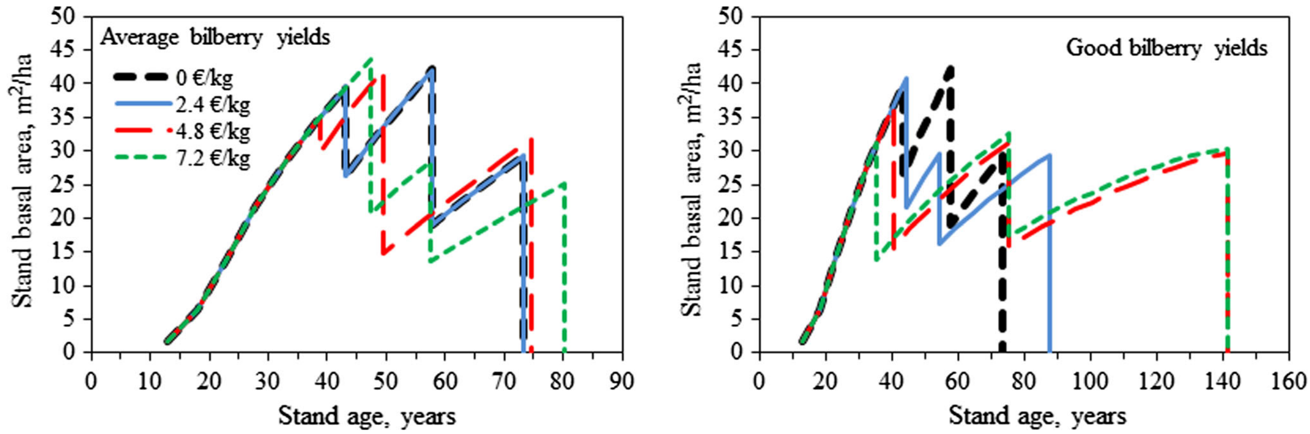

Fig. 2 Effect of bilberry price on the optimal management schedules of the mixed stand on *Myrtillus* site with average and good bilberry yields. Cowberries are not harvested

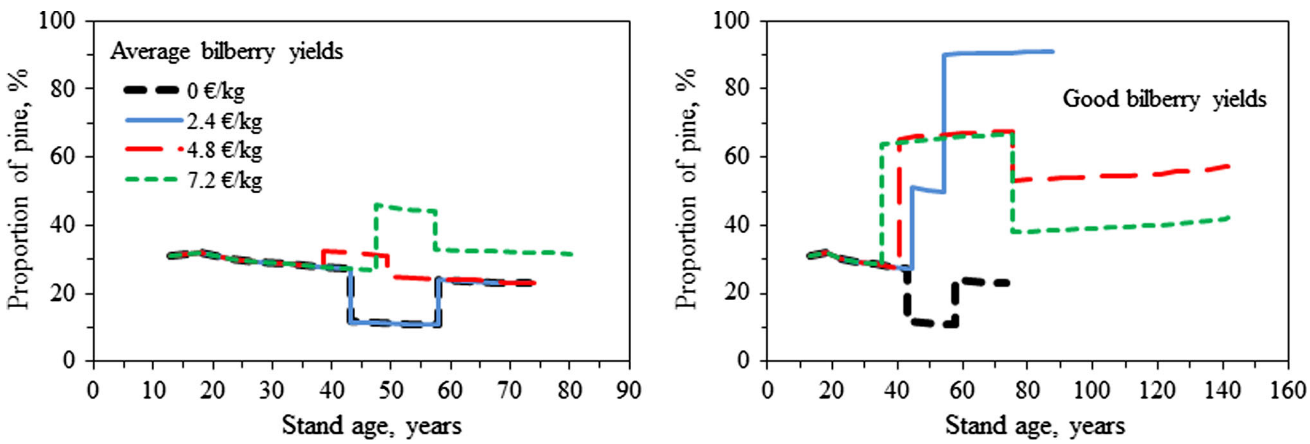

Fig. 3 Proportion of pine of the total stand basal area in the optimal management schedule of the mixed stand on *Myrtillus* site with average and good bilberry yields and different bilberry prices. Cowberries are not harvested

Berry harvests in the optimal management schedules

The highest bilberry harvests were obtained in mature stands at the end of the rotation. In the pine stand with average bilberry yields, the maximum annual bilberry harvests reached 30 kg/ha (Fig. 6). In the pine stand with good bilberry yields, the maximum annual bilberry harvests increased from 110 kg/ha to more than 130 kg/ha along with the increasing bilberry prices. In the mixed stand with average bilberry yields, the bilberry harvests reached hardly 10 kg/ha. In the stand where berry yields were high, the optimal management for joint production resulted in bilberry harvests of about 140 kg/ha (Fig. 7). With the market bilberry price of 2.4 €/kg, the mean annual bilberry harvest of the pine stand during the rotation (67 kg/ha/year) was higher than in the mixed stand (50 kg/ha/year), but with twofold berry price, the mean annual harvest was higher in the mixed stand (Table 4).

The highest cowberry harvests of the pine stand on *Vaccinium* site were obtained in the beginning of the rotation and only a heavy thinning was able to increase markedly the cowberry harvests later during the rotation (Fig. 8). At the early stages of stand development, it was not optimal to thin the pine stand to promote cowberry harvests. When bilberries were also picked from the pine stand with good berry yields and current market prices, thinnings were heavier and regeneration felling was postponed resulting in increased berry harvests (Table 4). Heavier thinnings decreased the stand basal area to a level which enabled increased cowberry and bilberry harvests toward the end of the rotation (Fig. 9).

Discussion

The results of this study are in line with earlier studies showing that valuing NWFPs may remarkably change the optimal stand management. The provision of products and

Table 4 Effect of bilberry price on the optimal stand management of stands with good berry yields

	Bilberry price (cowberry 0 €/kg)			
	0 €/kg	2.4 €/kg	4.8 €/kg	7.2 €/kg
Pine stand (*Myrtillus* site)				
SEV total (€/ha)	1868	4590	8163	11,885
SEV without berries (€/ha)	1868	1722	1410	1140
Additional SEV from berries (€/ha)	[2372][a]	2868	6752	10,745
1. Thinning at age (years)	40	39	39	39
Thinning intensity (%)	27	34	49	59
2. Thinning at age (years)	52	54	59	69
Thinning intensity (%)	78	74	68	65
Rotation length (years)	71	95	113	133
Mean bilberry harvest (kg/ha/year)	[48.5][a]	67.1	75.2	82.9
Mixed stand (*Myrtillus* site)				
SEV total (€/ha)	2073	3154	5753	8781
SEV without berries (€/ha)	2073	1419	461	152
Additional SEV from berries (€/ha)	[831][a]	1736	5292	8629
1. thinning at age (years)	43	44	40	35
Thinning intensity (%)	34	47	58	56
(pine/spruce/birch)	(71/0/100)	(0/62/77)	(0/100/0)	(0/100/0)
2. thinning at age (years)	58	54	76	76
Thinning intensity (%)	55	46	50	46
(pine/spruce/birch)	(0/61/–)	(1/100/0)	(60/–/27)	(70/–/0)
Rotation length (years)	73	88	142	142
Mean bilberry harvest (kg/ha/year)	[18.9][a]	49.8	81.4	82.8
	Cowberry price, €/kg (bilberry 0 €/kg)			
	0 €/kg	1.8 €/kg	3.6 €/kg	5.4 €/kg
Pine stand (*Vaccinium* site)				
SEV total (€/ha)	2116	5659	9985	14,908
SEV without berries (€/ha)	2116	2070	2038	1227
Additional SEV from berries (€/ha)	[3509][a]	3589	7947	13,681
1. Thinning at age (years)	39	41	40	44
Thinning intensity (%)	18	29	27	95
2. Thinning at age (years)	51	51	48	–
Thinning intensity (%)	67	81	81	–
Rotation length (years)	63	66	62	101
Mean cowberry harvest (kg/ha/year)	[65.7][a]	69.2	69.1	88.2
	Cowberry/bilberry price, €/kg			
	0/0	1.8/2.4	3.6/4.8	5.4/7.2
Pine stand (*Vaccinium* site)				
SEV total (€/ha)	2116	8076	15,737	23,541
SEV without berries (€/ha)	2116	1922	1665	1276
Additional SEV from berries (€/ha)	[3509/2298][a]	3606/2548	7998/6074	12,391/9875
1. Thinning at age (years)	39	40	40	42
Thinning intensity (%)	18	32	42	66
2. Thinning at age (years)	51	51	54	82
Thinning intensity (%)	67	80	77	58
Rotation length (years)	63	97	120	148

Table 4 continued

	Cowberry/bilberry price, €/kg			
	0/0	1.8/2.4	3.6/4.8	5.4/7.2
Mean cowberry/bilberry harvest (kg/ha/year)	[65.7/46.4][a]	72.3/55.9	77.0/65.7	85.9/74.7

[a] Berry harvests and the additional SEV from berries were calculated using cowberry and bilberry price 1.8 and 2.4 €/kg, respectively

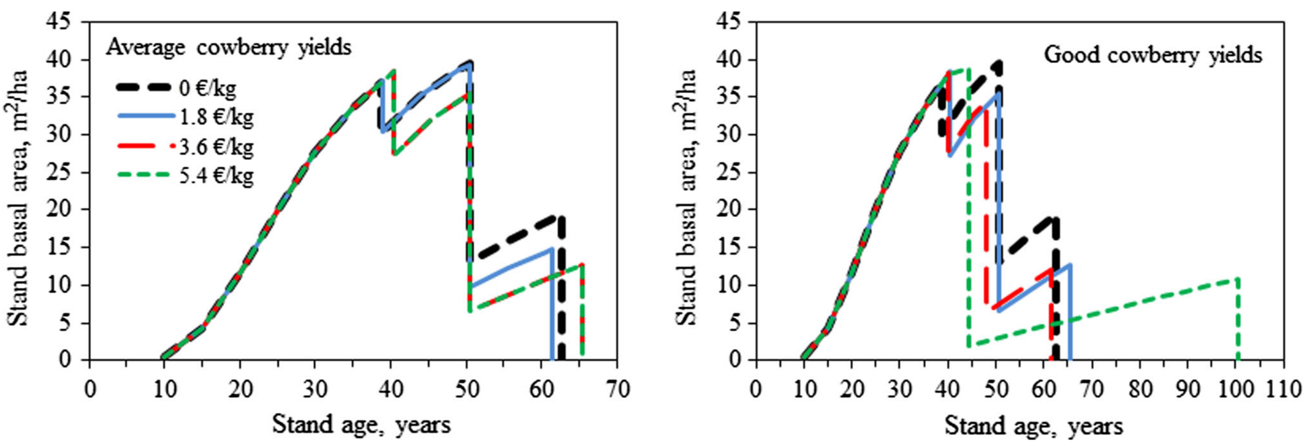

Fig. 4 Effect of cowberry prices on the optimal management schedules of the pine stand on *Vaccinium* site with average and good cowberry yields

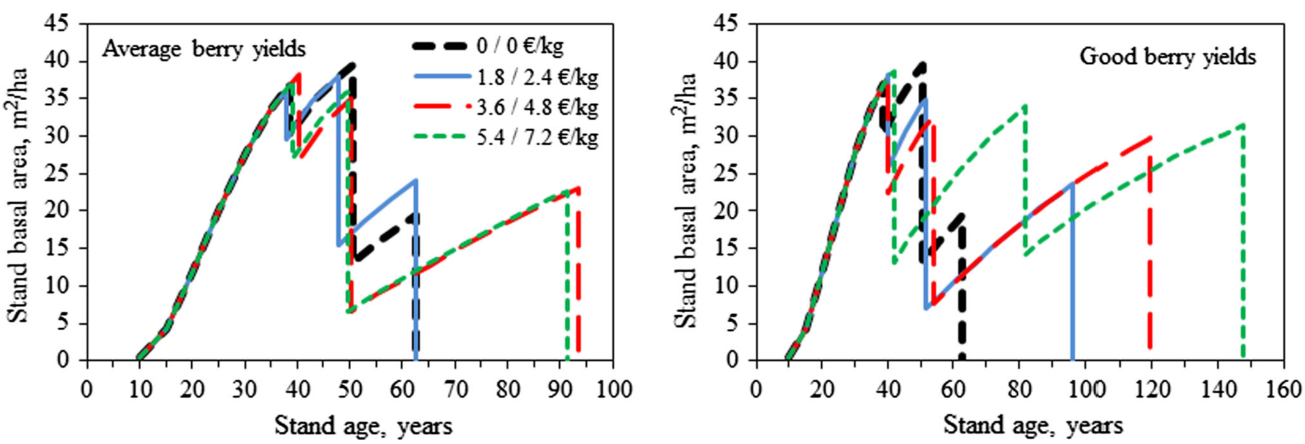

Fig. 5 Effect of berry prices (cowberry/bilberry) on the optimal management schedules of the pine stand on *Vaccinium* site with average and good berry yields

services is diversified, and simultaneously, the overall monetary benefits from forest management are increased (Palahí et al. 2009; Miina et al. 2010; de Miguel et al. 2014). Therefore, knowledge on the multi-product stand management is useful for forest owners who want to optimize the joint production of timber and berries. As far as we are aware, berry picking costs were included for the first time in stand-level optimization in order to better meet the practical conditions and thus enhance the comparison of timber and berry production. This is also the first study where both cowberry and bilberry were taken into account in the optimization of stand management.

With the current market prices and picking costs of berries, the timber-oriented stand management was not or only slightly changed in stands that provide average berry yields. In these stands, the contribution of berries to the SEV varied a lot (3–46 %) and was sometimes significant. In good berry stands, heavier thinnings are recommended to reduce canopy shading to a level that is favorable for berry crops. In addition, longer rotations are favorable in

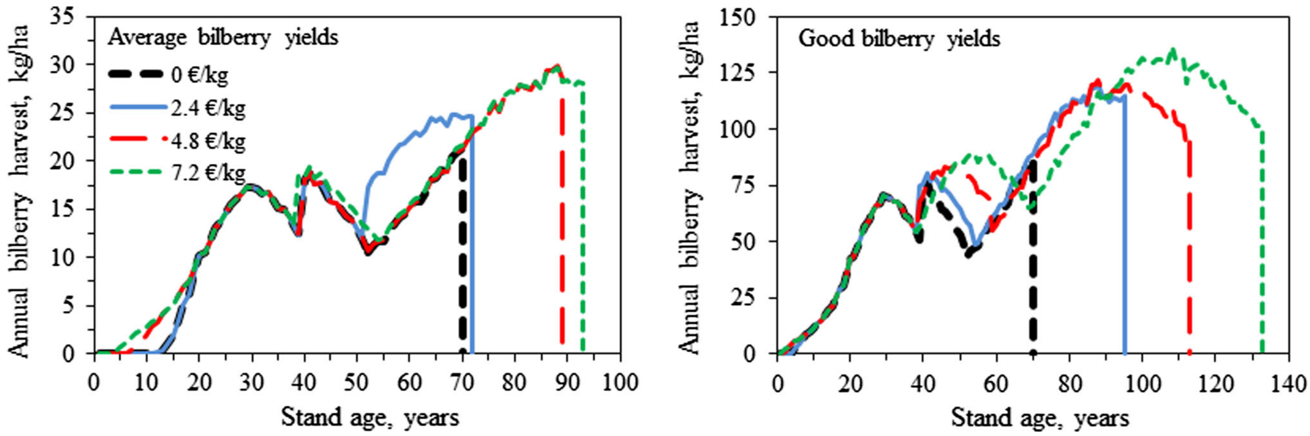

Fig. 6 Predicted bilberry harvest in the optimal management schedules of the pine stand on *Myrtillus* site with average and good bilberry yields and different bilberry prices. Cowberries are not harvested. *Note* Bilberry harvests in the optimal zero-pricing schedules were calculated using bilberry price 2.4 €/kg

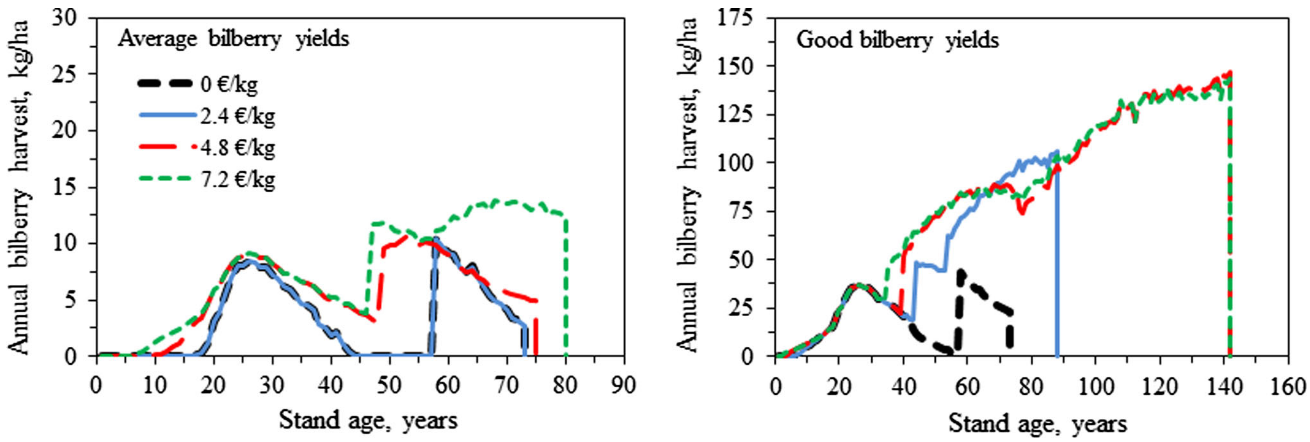

Fig. 7 Predicted bilberry harvest in the optimal management schedules of the mixed stand on *Myrtillus* site with average and good bilberry yields and different bilberry prices. Cowberries are not harvested. *Note* Bilberry harvests in the optimal zero-pricing schedules were calculated using bilberry price 2.4 €/kg

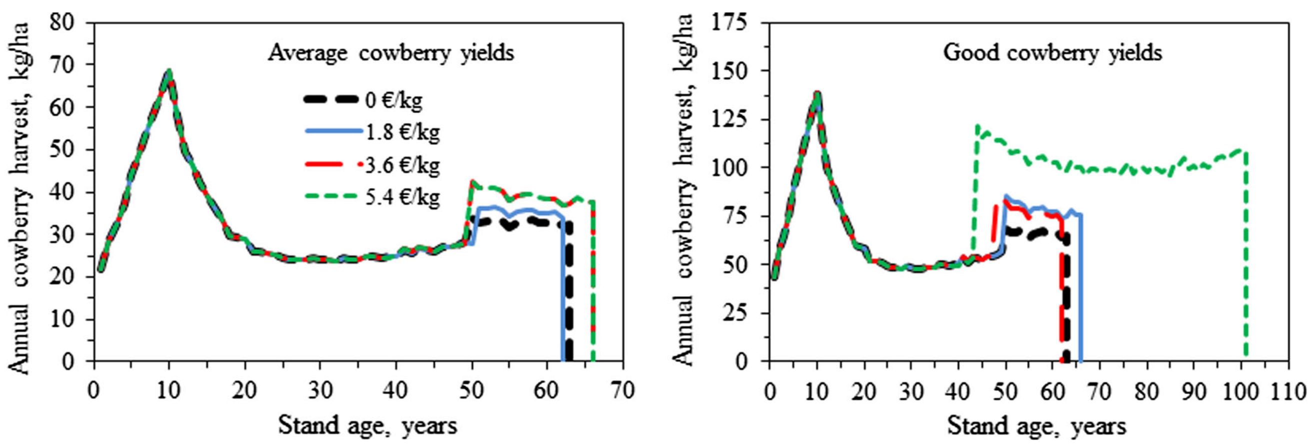

Fig. 8 Predicted cowberry harvest in the optimal management schedules of the pine stand on *Vaccinium* site with average and good cowberry yields and different cowberry prices. Bilberries are not harvested. *Note* Cowberry harvests in the optimal zero-pricing schedules were calculated using cowberry price 1.8 €/kg

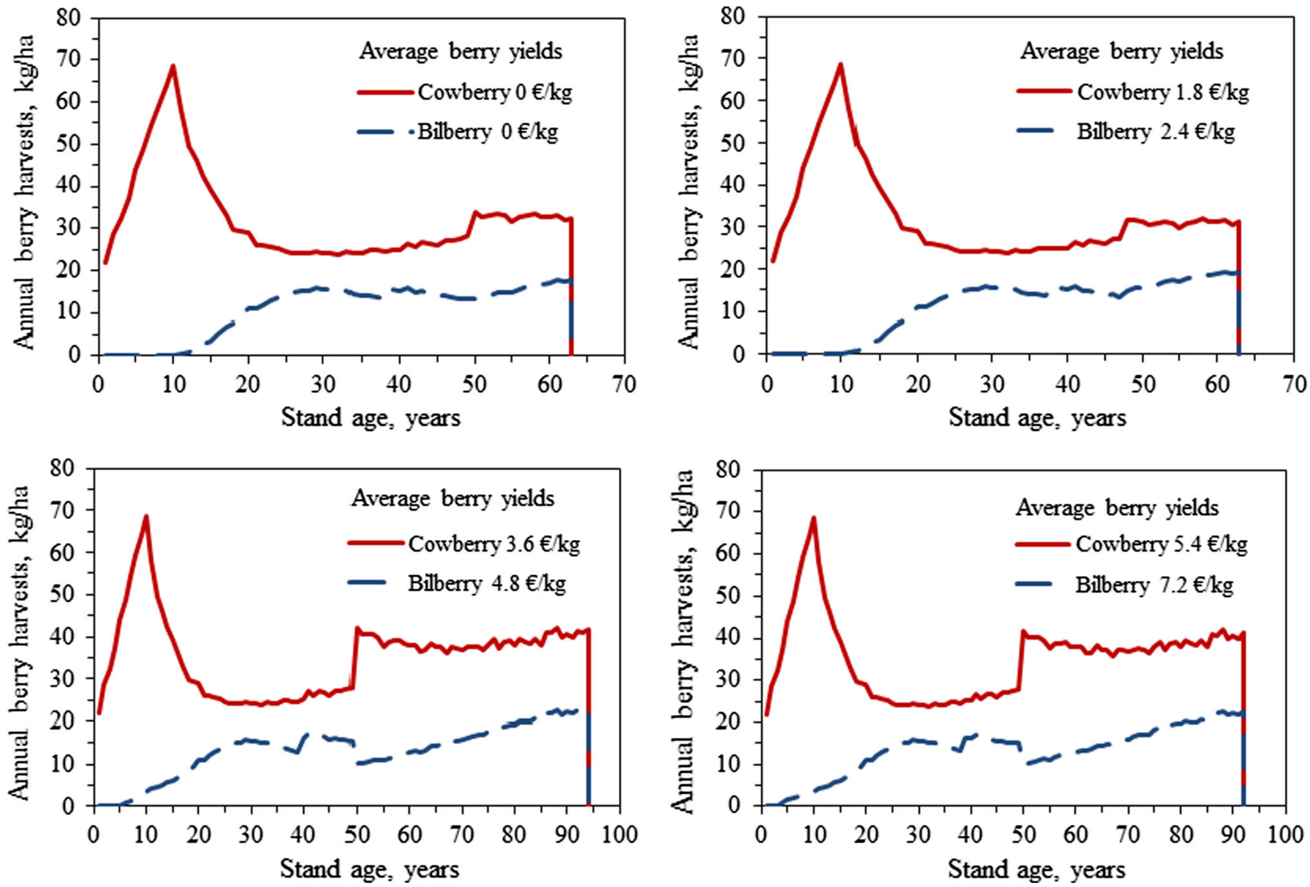

Fig. 9 Predicted bilberry and cowberry harvests in the optimal management schedules of the pine stand on *Vaccinium* site with average berry yields and different bilberry and cowberry prices. *Note*: Berry harvests in the optimal zero-pricing schedules were calculated using cowberry price 1.8 €/kg and bilberry price 2.4 €/kg

joint production since they enable harvesting the good berry yields of mature stands. More pines should be left in the thinning treatments of mixed stands. The optimal stand management changed, and berry harvests increased most significantly in the mixed stand with good bilberry yields. With the current berry prices and assuming good berry yields, the total SEV calculated with berry incomes was more than twice as high as the SEV from timber production only.

Stand characteristics and management (e.g., thinning) greatly affect the development of berry yields along the stand development and the profitability of joint production of timber and berries. Because of the strong influence, the yield predictions of berries need to be reliable. In addition to model predictions, several other parameters, however, affect the profitability of berry production: harvesting rate, the size of berries, berry price, harvesting costs and discount rate. In this study, berry prices and production levels were varied; other parameters were fixed. Earlier, Miina et al. (2010) studied the sensitivity of the optimal stand management to berry price, discount rate and harvesting rate. With increasing values of all these parameters, it was generally more profitable to manage the stands in a way that promotes bilberry production. Besides stochastic berry production, variation in berry and timber prices as well as tree growth—including the effects of climate change—could also be considered in a stochastic way.

Turtiainen (2015) evaluated the berry yield models used in this study by comparing them with other models prepared for bilberry and cowberry in Finland. In addition, Kilpeläinen et al. (2016) recently evaluated the berry yield models by using independent data measured from North Karelia, Finland. The best available berry yield models according to Kilpeläinen et al. (2016) were used in this study after calibrating them on the basis of recent field data. Bilberry yields predicted by the model of Miina et al. (2009) correlated positively and statistically significantly with the predictions of other models. The main difference was that the model of Miina et al. (2009) predicted the highest bilberry yields in pine-dominated stands, while some other models predict the highest yields in spruce-dominated stands. Correlations between cowberry yields predicted by the model of Turtiainen et al. (2013) and other existing models were positive but only weakly significant. The model of Turtiainen et al. (2013) predicted good cowberry yields in the beginning of the rotation, while other models produced good yields for both openings and mature pine stands. That happened also in this study when the pine stand was thinned heavily and the rotation was long (Figs. 8, 9).

The berry yield predictions of this study were comparable to the berry yields measured in Finnish forests. For example, on *Myrtillus* site the mean annual bilberry harvests of the pine stand with average bilberry yields (12–16 kg/ha) correspond to the mean bilberry yields of 22 kg/ha measured by Raatikainen and Raatikainen (1983). On *Vaccinium* site, we predicted mean annual cowberry harvests of 33–34 kg/ha for the pine stand with average cowberry yields, whereas Raatikainen (1978) reported the mean cowberry yield on mature stands on similar site to be 40 kg/ha. Based on the literature survey of Turtiainen et al. (2005, Table 4), the mean annual bilberry yield of *Myrtillus* site in North Karelia was 14 kg/ha, and that of cowberry on *Vaccinium* site was 26 kg/ha. In our simulations, the maximum annual berry harvests were about 140 kg/ha for bilberry and 150 kg/ha for cowberry. According to Raatikainen and Raatikainen (1983), the maximum annual yield for bilberry was 140 kg/ha, and Raatikainen (1978) measured 330 kg/ha for cowberry. Our results were comparable also to those earlier studies in which thinnings were proposed to enhance bilberry yields in Scots pine forests in Scotland (Parlane et al. 2006) and in Scots pine and Norway spruce forests in Sweden (Kardell and Eriksson 2011).

To conclude, the results of this study verified that additional economic benefits can be achieved through modified stand management when a large part of the incomes are generated through utilization of berry yields. By picking berries, forest owners may get also other direct and indirect benefits (e.g., recreational and potential health benefits). Therefore, using the market price to measure the value of berry picking may underestimate the total benefits from the joint production of timber and berries. If the commercial utilization of berries and the recognition of other benefits related to berry picking increase in the future, the practical demand for multi-product stand management guidelines will increase.

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References

Atlegrim O, Sjöberg K (1996) Response of bilberry (*Vaccinium myrtillus*) to clear-cutting and single-tree harvests in uneven-aged boreal *Picea abies* forests. For Ecol Manage 86:39–50

Cajander AK (1949) Forest types and their significance. Acta For Fenn 56(5):1–71

de Miguel S, Pukkala T, Yeşil A (2014) Integrating pine honeydew honey production into forest management optimization. Eur J For Res 133:423–432

Eronen S (2004) Mustikan ja puolukan kukinta ja marjasadot vuosina 1997–2003. Thesis for degree programme in forestry. North Karelia Polytechnic, Joensuu, 64 pp **(in Finnish)**

Hooke R, Jeeves TA (1961) "Direct search" solution of numerical and statistical problems. J Assoc Comput Mach 8:212–229

Hynynen J, Ojansuu R, Hökkä H, Siipilehto J, Salminen H, Haapala H (2002) Models for predicting stand development in MELA System. The Finnish Forest Research Institute, research papers 835, 116 pp

Ihalainen M, Salo K, Pukkala T (2003) Empirical prediction models for *Vaccinium myrtillus* and *V. vitis-idaea* berry yields in North Karelia, Finland. Silva Fenn 37:95–108

Kangas K, Markkanen P (2001) Factors affecting participation in wild berry picking by rural and urban dwellers. Silva Fenn 35:487–495

Kardell L, Eriksson L (1990) Effect of silvicultural measures on bilberries and cowberries: results of ten-year investigations. Sveriges lantbruksuniversitet, Institutionen för skoglig landskapsvård. Rapport 47, 113 pp **(in Swedish)**

Kardell L, Eriksson L (2011) Blåbärs- och lingonrisets återhämtning 30 år efter kalavverkning och markberedning 1977–2010. Sveriges lantbruksuniversitet, Institutionen för skoglig landskapsvård. Rapport 112, 96 pp **(in Swedish)**

Kilpeläinen H, Miina J, Store R, Kurttila M, Salo K (2016) Evaluation of and cowberry yield models by comparing model predictions with field measurements from North Karelia, Finland. For Ecol Manage 363:120–129

Laasasenaho J (1982) Taper curve and volume equations for pine spruce and birch. Commun Inst For Fenn 108:1–74

Laine J, Vasander H (1993) Suotyypit, 3rd edn. Kirjayhtymä, Helsinki **(in Finnish)**

MARSI (2014) Luonnonmarjojen ja -sienten kauppaantulomäärät vuonna 2014. Maaseutuvirasto, Seinäjoki. Raportteja ja selvityksiä 3/2015, 53 pp **(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 Fenn 43:577–593

Miina J, Pukkala T, Hotanen J-P, Salo K (2010) Optimizing the joint production of timber and bilberries. For Ecol Manage 259:2065–2071

Palahí M, Pukkala T, Bonet JA, Martínez de Aragón J, Fischer CR, Colinas C (2009) Effect of the inclusion of mushroom values on the optimal management of even-aged pine stands of Catalonia. For Sci 55:503–511

Parlane S, Summers RW, Cowie NR, van Gardingen PR (2006) Management proposals for bilberry in Scots pine woodland. For Ecol Manage 222:272–287

Price C (1989) The theory and application of forest economics. Blackwell, Oxford **402 pp**

Pukkala T, Miina J (2005) Optimising the management of a heterogeneous stand. Silva Fenn 39:525–538

Raatikainen M (1978) The berry yield, picking, and marketing of *Vaccinium vitis-idaea* L. in the commune of Pihtipudas. Silva Fenn 12:126–139 **(in Finnish with English summary)**

Raatikainen M, Niemelä M (1983) Mustikan poimintatarkkuuden määrittäminen. University of Jyväskylä, Department of Biology, Research Notes 32: 18–23 **(in Finnish)**

Raatikainen M, Raatikainen T (1983) The berry yield, picking and marketing of *Vaccinium myrtillus* in the commune of Pihtipudas, northern central Finland. Silva Fenn 17:113–123

Raatikainen M, Rossi E, Huovinen J, Koskela M-L, Niemelä M, Raatikainen T (1984) The yields of the edible wild berries in central Finland. Silva Fenn 18:199–219 **(in Finnish with English summary)**

Rummukainen A, Alanne H, Mikkonen E (1995) Wood procurement in the pressure of change—resource evaluation model till year 2010. Acta For Fenn 248:1–98

Selås V (2000) Seed production of a masting dwarf shrub, *Vaccinium myrtillus*, in relation to previous reproduction and weather. Can J Bot 78:423–429

Turtiainen M (2015) Modelling bilberry and cowberry yields in Finland: different approaches to develop models for forest planning calculations. Dissertationes Forestales 185. doi:10.14214/df.185

Turtiainen M, Nuutinen T (2012) Evaluation of information on wild berry and mushroom markets in European countries. Small-scale For 11:131–145

Turtiainen M, Salo K, Saastamoinen O (2005) Model-based estimates of regional and national bilberry and lingonberry yields on mineral soils in Finland. University of Joensuu, Faculty of Forestry. Research Notes 167, 44 pp **(in Finnish)**

Turtiainen M, Miina J, Salo K, Hotanen J-P (2013) Empirical prediction models for the coverage and yields of cowberry in Finland. Silva Fenn 47(3), 22 pp

Vaara M, Saastamoinen O, Turtiainen M (2013) Changes in wild berry picking in Finland between 1997 and 2011. Scand J For Res 28:586–595

Wallenius TH (1999) Yield variations of some common wild berries in Finland in 1956–1996. Ann Bot Fenn 36:299–314