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Managing boreal forests for the simultaneous production of collectable goods and timber revenues

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Highlights

- We found a strong conflict between bilberry production and timber revenues, resulting in large losses of timber revenues when increasing bilberry production.
- The conflicts between other collectables (cowberry, cep) and timber production were relatively small.
- With careful forest planning, there is potential to simultaneously produce high levels of collectable goods and timber revenues in the landscape.

Abstract

Timber production is an economically important provisioning ecosystem service in forests, but is often in conflict with the provision of other ecosystem services. In multifunctional forestry, the production of timber and non-timber ecosystem services should coexist in the same landscape. To this end, we explored the capacity of a boreal landscape to simultaneously produce collectable goods – bilberry (*Vaccimium myrtillus* L.), cowberry (*Vaccinium vitis-idaea* L.) and cep (*Boletus edulis* Bull.) – alongside timber revenues. We also identified optimal forest management plans to achieve this. Furthermore, we analyzed trade-offs between collectable good yields and timber production, as well as between their economic values. We ran forest growth simulations under seven alternative management regimes at a landscape level across 50-year planning horizons. Then, we used multi-objective optimization to explore trade-offs and identify optimal forest management plans. The results showed that the strongest trade-off was between bilberry and timber production, resulting in a large loss in timber revenues for a gain in bilberry production. However, the conflicts between other collectables and timber production were relatively small: it was possible to increase the provision of collectable goods 4–15% with small reductions (3–5%) from timber revenues. With careful forest planning, there is the potential to simultaneously produce high levels of collectable goods and timber revenues in the landscape.

Keywords forest management; multifunctional forestry; mushroom; trade-offs; wildberry
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1 Introduction

Forests provide many valuable ecosystem services, such as food, timber, and global climate regulation (Millennium Ecosystem Assesment 2005). Timber production is an economically valuable ecosystem service and, during the last few centuries, many forests have been managed to maximize revenues from timber harvests (Schmithüsen and Rojas Briales 2012). However, intensive management that focuses solely on timber production often has a negative effect on other services, such as a decrease in the quantity of dead wood, which is critical for biodiversity (Siitonen 2001). Therefore, it is crucial to evaluate such conflicts and carefully plan forest management to allow the production of many different types of ecosystem services, such as timber production and collectable goods. Recognizing multiple demands on forest products and services allows progress towards multifunctional forestry, where non-timber values and services of forests are taken into account, alongside the consideration of timber revenues (Schmithüsen 2007). Multifunctional forest management practices tackle different social interests in forests, supporting alternative forestry practices and protecting sustainable use of forests.

Boreal forests extend across Russian Siberia, Fennoscandia, Northern Canada, and Alaska, and cover about one third of the world's forested area (Burton et al. 2010). The boreal region contains more than one third of the terrestrial carbon stored in vegetation and soil and contains more freshwater than any other biome (Burton et al. 2010). In addition, boreal forests provide important recreational services, such as hiking, nature tourism, and picking collectable goods. Timber production is the most economically valuable provisioning service in boreal forests (Vanhanen et al. 2012). For example, in Finland, approximately 86% (26 million ha) of total forest area is managed and the forest sector contributes approximately 4.8% of Finland's Gross Domestic Product (Finnish statistical year book of forestry 2013). Many boreal forests are intensively managed to maximize timber provision, while neglecting the importance of maintaining biodiversity and other ecosystem services (Vanhanen et al. 2012). Focusing on intensive timber production can negatively affect biodiversity (Mönkkönen et al. 2014) and other ecosystem services, such as recreation (Bell et al. 2007), water and soil quality (Laudon et al. 2011), climate regulation through carbon sequestration and storage (Triviño et al. 2015), as well as game and bilberry production (Gamfeldt et al. 2013).

Due to economic importance of timber production, forest management plans that allow the simultaneous production of timber and other ecosystem services are needed. Multi-objective optimization methods can be used to provide efficient options for land use and management of different ecosystem services (Seppelt et al. 2013). For example, previous studies have shown that it could be possible to greatly increase habitat availability for several species (Mönkkönen et al. 2014) or increase carbon sequestration and storage (Triviño et al. 2015) with relatively small reductions in timber harvest revenues by applying a diverse set of forest management regimes in boreal landscapes.

Recent stand-scale studies have shown the importance of identifying profitable forest management regimes for collectable goods. For example, Palahí et al. (2009) and de Miguel et al. (2014) examined the optimal economic management for both timber and mushrooms in Central Pyrenees and Catalonia, respectively. They showed that thinning treatments, which are usually unprofitable, became a profitable management strategy when mushroom production was included in the analysis. Miina et al. (2016) optimized timber and berry production (bilberry (*Vaccinium myrtillus* L.) and cowberry (*Vaccinum vitis-idaea* L.)) in boreal forest stands and found that joint production allowed longer rotation lengths, higher thinning intensities and more frequent thinning than mere timber-oriented management. These studies suggest that the economic value of collectable good yields might even exceed the economic value of timber production in some forest stands. Even though there is increasing awareness that alternative land management can critically affect the capacity of land parcels to provide ecosystem services, the long-term capacity of entire landscapes to provide multiple services under alternative management regimes has not been widely tackled (de Groot et al. 2010). To our knowledge, no previous study has addressed the question of how to reconcile the potential conflict between timber and collectable good production across a large landscape with thousands of forest stands.

Collectable goods are economically valuable in many parts of the boreal zone. For example, Canada is the world's largest producer of wild blueberries (*Vaccinium angustifolium* Ait.) with exports amounting to 184 M€ (207 M$) in 2014 (Natural Resources Canada 2016). In Finland, the most important wild berries collected are bilberry and cowberry, and the total value of the annual harvested wild berry crop may reach about 100 M€ (Saastamoinen et al. 2000). Cep (*Boletus edulis* Bull.) is an economically valuable mushroom species in Finland (Miina et al. 2013) and worldwide (Boa 2004). Wildberry and mushroom picking has a long tradition and, in addition to its economic values, this activity also has recreational value (Boa 2004). In many Nordic countries (Finland, Sweden, and Norway), everyman's rights allows all people to have free access to forests and to pick berries and mushrooms (Salo 1995). Approximately 60% of Finns participate in berry picking and 40% in mushroom picking (Finnish statistical year book of forestry 2013). However, during the last few decades, the yields of many collectable goods, such as bilberries, have declined due to intensified forest management for timber production (Miina et al. 2009).

In this study, we go beyond previous studies by identifying conflicts between timber harvest revenues and several collectable goods in a large forest landscape with several thousands of stands and over a long time period of 50 years. Here, the term "collectable goods" refers to berries (bilberry and cowberry) and mushrooms (cep). We estimate the yields of collectable goods as an indicator of recreational values. In addition, we refer to the combined potential economic value (net present value, NPV) of all three collectables with the term "economic value of collectable goods". We use models based on yield data (Miina et al. 2009; Miina et al. 2013; Turtiainen et al. 2013) to study the effects of different forest management regimes, varying from current recommended management to total protection, on yields at the landscape scale across a 50 year horizon. We use multi-objective optimization (Miettinen 1999) to analyze the trade-offs between the yields of collectable goods and timber production, as well as between the economic value of collectable goods and timber production. We address the following questions: (1) What is the potential of the boreal forest landscape to simultaneously produce collectable goods and timber? (2) Are the trade-offs between targeting different collectable goods and timber production similar? (3) What optimal combinations of forest management regimes maximize the yields and the economic value of collectable goods for given levels of economic returns from timber, and vice versa? Answering these questions is informative in providing management recommendations to produce collectable goods and timber simultaneously in a forest landscape and how to enhance recreational services in an economically sustainable way.

2 Materials and methods

2.1 Study area and data

The study area is located in Central Finland (62°14´N, 25°43´E) and encompasses 68 700 ha. Forests on mineral soil cover 55% of the total area, peat lands cover 13%, lakes cover 16% and farmland settlements cover 15%. Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* (L.) H. Karst.), birch (*Betula pendula* Roth and *Betula pubescens* Ehrh.) and mixed stands dominate forests. Forests are privately owned and are intensively managed for timber production. The data of the forests studied here originates from the confidential forestry data administered by the Finnish Forest Centre, thus details of individual forests are not provided. Data are based on recent field inventories and include stand characteristics, such as the basal area of trees, stand age, and site type for each of the 29 702 forest stands. The average stand size is 1.45 ha and the total area of forest stands is 43 150 ha.

2.2 Forest growth simulation and timber revenues

We ran the simulated forest growth for 50 years in 5 year intervals (11 time steps), using MOTTI-stand simulator (http://www.metla.fi/metinfo/motti/index-en.htm). We applied seven alternative management regimes (Table 1) that ranged from the recommended management strategy (business as usual, BAU) – which aims to maximize timber production through intensive management – to no management at all (set aside, SA). Extended rotations (EXT10 and EXT30) are similar to BAU, but the final harvests are postponed and, together with the SA regime, represent actual policy in Finland, where forest authorities make permanent or temporary conservation contracts with forest owners (METSO Programme 2008–2016). Green-tree retention (GTR30) represents a conservation-oriented management regime, similar to the BAU regime, but 30 trees per hectare are retained at the final harvest, which is above the normal level. Green tree retention is a widely used method to increase structural diversity, and consequently species habitats, in commercial boreal forests (Vanha-Majamaa and Jalonen 2001). No thinnings with long rotation (NTLR) represents a management regime where thinnings are not allowed but the final harvest is executed using the same threshold values (minimum tree diameter) as in the BAU regime, resulting in somewhat extended rotations. No thinnings with short rotation (NTSR), likewise, does not allow thinnings, but in this regime the final harvest criteria were adjusted so that rotation length would be similar to the BAU regime. No thinnings regimes are against current recommendations, but are still commonly applied by forest owners because thinning the harvest does not provide large immediate economic returns, but may incur extra costs. The development of average timber biomass for each time step under alternative management regimes are given in Supplementary file (Fig. S1), available at http://dx.doi.org/10.14214/sf.1672.

Table 1. The different management regimes applied in our study area in central Finland (adapted from Mönkkönen et al. 2014).

Management regime	Acronym	Description
Business as usual	BAU	Current recommended management: 80 year rotation on average; site preparation, planting or seeding trees, 1–3 thinnings, final harvest with green tree retention level 5 trees ha^{-1}
Set aside	SA	No management, no timber production
Extended rotation (10 years)	EXT10	BAU with postponed final harvesting by 10 years; lower timber NPV due to time discounting; represents a short term conservation strategy
Extended rotation (30 years)	EXT30	BAU with postponed final harvesting by >30 years; lower timber NPV due to time discounting; represents a long term conservation strategy
Green tree retention	GTR30	BAU with 30 green trees ha^{-1} left uncut at final harvest; reduced timber production; conservation oriented management used to increase structural diversity
No thinnings long rotation (final harvest threshold criteria as in BAU)	NTLR	BAU with no thinnings; therefore forests grow more slowly, final harvest is delayed and timber NPV is lower; average rotation length 86 years
No thinnings short rotation (minimum final harvest threshold criteria)	NTSR	BAU with no thinnings; final harvest criteria adjusted so that rotations do not prolong; average rotation length 77 years; lower timber NPV due to smaller size of trees at final harvest

We used timber harvest revenues (NPV in €) for each stand and management regime across a 50 year planning horizon calculated in a previous study (Mönkkönen et al. 2014). Timber NPV consists of four harvest revenue components: timber revenues from thinnings, from the final harvest, from the standing timber at the end of simulation, and the soil expectation value (the bare land value). In these calculations, stumpage prices for eight timber assortments (pulp wood and saw logs for each of the four species: Scots pine, Norway spruce and two birch species) were used. The average amounts of harvested pulp wood and saw log from thinnings and final harvest under alternative management regimes are given in Suppl. file (Fig. S2). In addition, timber NPV takes into account costs resulting from five silvicultural actions: natural regeneration, seeding or planting new trees on clear-cuts, tending of seedling stands, and cleaning of sapling stands. We used a 3% interest rate in discounting the timber revenues and costs during the 50 year planning horizon. The prices of harvest revenue components were taken from the Finnish Forest Centre for the region of Central Finland and the prices for the silvicultural costs were calculated from Finnish forestry statistics (for detailed information about the prices and calculations of timber NPV, see Suppl. file Table S1 and Eq. S1).

2.3 Collectable good yields

We estimated the average yields of collectable goods (kg ha^{-1}) across eleven 5 year time steps for the 29 702 stands and seven management regimes using ready-made models based on yield data (Miina et al. 2009; Miina et al. 2013; Turtiainen et al. 2013). We estimated the yields of bilberry using empirical models developed by Miina et al. (2009). First, we predicted the coverage of bilberry as a function of several indicator variables: site type, dominating tree species, regeneration method, altitude, stand age, and stand basal area of trees (Eq. S2). Then, we converted bilberry coverage into bilberry yield as a function of coverage and stand basal area (Eq. S3, S4). We estimated the yields of cowberry using models developed by Turtiainen et al. (2013). First, we predicted the coverage of cowberry as a function of site type, dominating tree species, temperature sum, altitude, stand age, and stand basal area (Eq. S5). Then, we converted cowberry coverage into cowberry yield as a function of coverage, stand basal area, altitude, and temperature sum (Eq. S6). We estimated the yields of cep using a model developed by Miina et al. (2013). The model predicts the yield of cep as a function of stand basal area and stand age (Eq. S7). The development of average yields for each time step under alternative management regimes are given in Suppl. file (Fig. S3). For further information about the calculations of collectable good yields see Suppl. file.

2.4 The economic value of collectable goods

For the optimization of the economic value of collectable goods and timber revenues, we calculated the combined economic value of bilberry, cowberry, and cep yields across a 50 year planning horizon for each stand, under seven alternative management regimes. First, we estimated yields for each year for the 5 year periods and then calculated the economic value of each collectable good for each year. We used average market prices of each collectable good from 2004 to 2013 in Central Finland: for bilberry, 2.23 € kg^{-1}; for cowberry, 1.16 € kg^{-1}; and for cep (the price of *Boletus* spp. used), 3.36 € kg^{-1} (MARSI 2009; MARSI 2014). Finally, we added the annual values of each collectable good to get the economic value of collectable goods across the 50 year planning horizon for each stand as € ha^{-1} (collectable goods NPV). We calculated the potential economic value of each collectable good using the following equation:

$$Collectable\,good\;NPV = \sum_{t=0}^{50} y_{it} v_i e^{-rt} \quad (1)$$

where a collectable good was denoted by *i*; years across the 50 year planning horizon by *t*; yields by *y*; their prices by *v*; and discount rate by *r*. Discount rate was the same (3%) as in the calculations of timber revenues. NPV for collectable goods includes their value for the 50 year period only, and ignores any later yields. However, the value of any later yields would be very small. In addition, we did not include the costs of collecting the berries and mushrooms in the NPV because these vary widely according to the annual yield and the exact locations of the stands (traveling costs). Therefore, our NPV estimate reflects the potential of the landscape to provide economic value from collectable goods across a 50 year planning horizon. We carried out the calculations in R version 3.1.2 (R Development Core Team 2014).

2.5 Multi-objective optimization and analyses

We analyzed alternative forest management plans to reveal trade-offs between timber revenues and the provision of collectable goods. Each management plan was a combination of management regimes (Table 1) selected for all stands. Each management plan was characterized by its outcome, i.e. the vector of economic values of timber and collectable good yields of the landscape resulting from a combination of management regimes applied to the stands. The full set of efficient management plans represents production possibility frontiers among ecosystem services, i.e. bi-dimensional plan outcomes representing maximum achievable values of services. In order to reveal the trade-offs, we identified combinations of management regimes that maximized the yield of collectable goods at different levels of timber revenues, and vice versa, i.e. Pareto optimal plans (Miettinen 1999). We carried out optimization calculations by using IBM ILOG CPLEX optimizer (http://www.ibm.com/software/commerce/optimization/cplex-optimizer/). For further details on the methods of revealing trade-offs and optimization, see Mönkkönen et al. (2014). We ran multi-objective optimizations separately for each yield of collectable goods vs. timber revenues. Additionally, we optimized the economic value of collectable goods vs. timber revenues.

In order to illustrate the optimal combination of management regimes that maximizes the yields of collectable goods, we produced graphs that show how the optimal allocation of management regimes for forest stands changes with increasing yields of collectables and decreasing timber revenues. Then, we obtained analogous results under the constraint that timber revenue does not fall below the level of 95% of maximum possible revenues, i.e. when the forest owner agrees to forego 5% of the maximum achievable timber revenues for collectable good production and recreational values. We selected a 5% level decrease in timber revenues because forest certification rules require that at least 5% of the forest area should be permanently set aside from management to conserve biodiversity (Forest Stewardship Council 2010). It also roughly corresponds with the political decisions taken in Finland regarding biodiversity conservation through the METSO II program (METSO Programme 2008–2016). This same level might be well invested in supporting the considered alternative ecosystem services.

2.6 Model assumptions

The models available to estimate yields of collectable goods vary in their validity. The recent study evaluating the berry models in Finland showed that the bilberry model is more accurate than the cowberry model (Kilpeläinen et al. 2016). The bilberry model might underestimate the yields while the cowberry model might overestimate the yields. The cep model has been validated only for spruce dominated forests (Miina et al. 2013) and, since cep is living in symbiosis with

Norway spruce, the estimated yields for other forest types are less accurate. In addition, the yield models for bilberry and cep have only been validated for North Karelia, eastern Finland, whereas cowberry yield models and the model for bilberry coverage have been validated for the whole of Finland. The forest landscape in Central Finland, to where we apply the model, is only 150 km west of North Karelia, and forest conditions in the two regions are fairly similar.

Bilberry cover and yield are sensitive to regeneration methods, both being lower in artificially regenerated than naturally regenerated stands (Miina et al. 2009). We did not have data on the history of stands, and hence, we assumed that all stands initially originated from planted trees, because planting is the dominant regeneration method after final harvesting. Thus, bilberry yields are underestimated on stands that were naturally regenerated.

Due to potential bias caused by model limitations, absolute predicted yield estimates or their monetary values may be inaccurate (see also 2.4). Therefore, our focus will be on potential trade-offs and on the relative utility of different management plans, rather than on absolute values.

3 Results

3.1 Total yields

The maximum total cowberry yield from the entire landscape was more than four times higher than the maximum total bilberry yield (Table 2). These values translated into 35 kg ha^{-1} year^{-1} and 7.7 kg ha^{-1} year^{-1} for cowberry and bilberry, respectively. The maximum total cep yield from the entire landscape was close to 50 000 kg year^{-1} (Table 2), i.e. on average 1.2 kg ha^{-1} year^{-1}.

The maximum economic value of the three collectable goods across the entire landscape was approximately one quarter of the maximum economic value of timber harvest revenues (Fig. 1, Table 2), i.e. 32 € ha^{-1} year^{-1} vs. 116 € ha^{-1} year^{-1} on average for collectable goods and timber, respectively. Cowberry yields were much larger than bilberry or cep yields and the proportion of cowberry from the combined economic value of collectables was approximately 70%.

Table 2. Potential of the landscape (43 150 ha) in central Finland to provide annual yields of collectable goods, the combined economic value of collectable goods (NPV) across a 50 year planning horizon, and costs related to collectable goods provision. *Max* and *Min* values represent the largest and smallest possible yields or NPV of collectable goods among Pareto optimal solutions that can be achieved when applying combinations of the seven alternative management regimes. *Timber NPV difference* is the reduction in timber NPV in the Pareto optimal sets required to achieve maximum yields (max timber NPV is 250 M€ in all cases).

	Max	Min	Timber NPV difference
Collectable good			
Bilberry yield	331 Mg	257 Mg	75 M€
Cowberry yield	1522 Mg	1452 Mg	7 M€
Cep yield	50 Mg	44 Mg	16 M€
Collectable goods NPV	68 M€	66 M€	13 M€

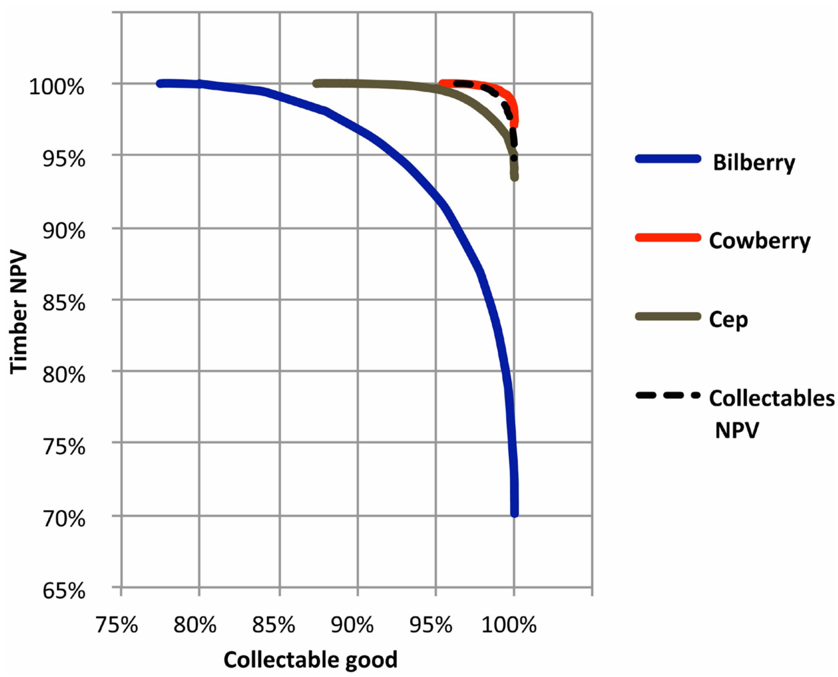

Fig. 1. Curves representing outcomes of Pareto-optimal plans describing the trade-offs between collectable good yields: bilberry, cowberry, cep, the combined economic value of collectable goods, and timber revenues in our study landscape in central Finland. The X-axis shows the difference between the maximum and minimum collectable yields in relative terms. The Y-axis similarly shows the reduction in timber NPV in the Pareto optimal sets required to achieve maximum collectable yields.

3.2 The potential of a landscape to produce collectable goods and timber

Trade-offs between collectable goods and timber NPV showed non-linear relationships in the set of outcomes of Pareto optimal plans and varied depending on the collectable good analyzed (Fig. 1). It is not possible to maximize the yields of collectable goods or the economic value of collectable goods without a decrease in timber revenues, and vice versa. However, because the trade-off curves were convex it was possible to produce simultaneously high levels of alternative services.

In the case of bilberry, the differences between the minimum and maximum yields and in the reduction in timber NPV required to gain the maximum yield were quite large (Table 2, Fig. 1). This means that there is the potential to considerably increase yields of bilberry, but this would result in large losses in timber revenues. The trade-off curve for bilberry versus timber NPV declined more steeply than for other collectables (Fig. 1) indicating that a unit increment in bilberry yield was more expensive than a unit increment in cowberry or cep yields when approaching their maximum values.

In the case of cowberry, there was a small difference between the minimum and maximum yields (Table 2, Fig. 1). Thus, the cowberry yield was affected fairly little by adjusting forest management plans to maximize timber. Moreover, the decline in timber NPV when targeting cowberry was relatively small (Table 2), thus maximizing the cowberry yield was relatively inexpensive. The trade-off curve for cowberry versus timber NPV was fairly flat and short (Fig. 1), further indicating that the conflict between timber and cowberry is negligible.

In the case of cep, the difference between the minimum and maximum yields was smaller than in the case of bilberry and larger than in the case of cowberry (Table 2, Fig. 1). Thus, the cep yield can be moderately affected by adjusting forest management plans to maximize timber. The decline in timber NPV when targeting cep was slightly higher than that for the cowberry but much lower than for the bilberry (Table 2). The trade-off curve for cep versus timber NPV was fairly flat (Fig. 1) indicating that conflict between them is relatively small.

For the combined NPV of collectable goods, there was only a small difference between the minimum and maximum values among Pareto optimal outcomes (Table 2). As in the case of cowberry, collectable good NPV was only slightly affected by adjusting forest management plans to maximize timber. The level of decline in timber NPV when targeting collectable good NPV was lower than for cowberry, but higher than for cep (Fig. 1). These results indicate that the conflict between the economic value of collectables and timber was rather small.

3.3 Optimal combination of management regimes

When a single forest management regime was applied consistently in the landscape the relative utility of the regime varied among different collectable goods (Table 3). None of the single management regimes produced as high values as in their optimal combination selected via multi-objective optimization (cf. Table 2). This means that a combination of different management regimes was always needed to maximize yields of collectable goods. For bilberry, EXT30 was the most beneficial strategy and the two regimes with no thinnings were the least beneficial strategies. For cowberry, BAU was the most beneficial strategy and SA was the least beneficial strategy. For cep, GTR30 was the most beneficial strategy and SA was the least beneficial strategy. For the combined economic value of all collectable goods, BAU was the most beneficial strategy and SA was the least beneficial strategy (Table 3). However, for the economic value of collectable goods, the differences

Table 3. Annual yields of collectable goods on average and the economic value of collectable goods and timber (NPV) across 50 years for alternative management regimes (*BAU* business as usual, *SA* set aside, *EXT10* extended rotation 10 years, *EXT30* extended rotation 30 years, *GTR30* green tree retention, *NTSR* no thinnings short rotation and *NTLR* no thinnings long rotation) if only one management regime is used in all stands of the study landscape in Central Finland. The largest value of alternative management regimes is given in bold. *% of Max* is the proportion of the values compared to the maximum value (Table 2).

	Management regime						
	BAU	SA	EXT10	EXT30	GTR30	NTSR	NTLR
Bilberry (Mg)	266	277	285	**303**	273	223	241
% of Max	80%	84%	86%	**92%**	82%	67%	73%
Cowberry (Mg)	**1491**	1089	1416	1299	1381	1468	1365
% of Max	**98%**	72%	93%	85%	91%	96%	90%
Cep (Mg)	42	35	43	36	**44**	42	41
% of Max	85%	70%	85%	71%	**89%**	84%	82%
Collectable goods NPV (M€)	**67**	54	64	60	63	65	62
% of Max	**98%**	79%	93%	88%	93%	95%	91%
Timber NPV (M€)	**246**	0	230	186	240	242	238
% of Max	**98%**	0%	92%	74%	96%	97%	95%

Table 4. Changes in %-units in the share of different management regimes (*BAU* business as usual, *SA* set aside, *EXT10* extended rotation 10 years, *EXT30* extended rotation 30 years, *GTR30* green tree retention, *NTSR* no thinnings short rotation and *NTLR* no thinnings long rotation) in the Pareto optimal set at the 5% level of collectable good costs (95% of the maximum timber revenues) for the different collectable goods in our study landscape in central Finland. The first row was used as the reference outcome and gives the share (in %-units) of forest area under each regime when the target is to maximize timber NPV. The following rows represent changes for each regime from the reference outcome at the 5% level of collectables costs. *% of Max yield* is the proportion of the yield in the Pareto optimal set at the 95% level of timber revenues compared to the potential maximum yield in the landscape (see Table 2). *Impr. in yield* is how large improvement in yields can be gained if timber NPV is reduced of 5% from the maximum in Pareto optimal set. In the case of cowberry, values are given at the level of 97% of the maximum timber NPV when cowberry yield was already maximized.

	Management regime							% of Max yield	Impr. in yield
	BAU	SA	EXT10	EXT30	GTR30	NTSR	NTLR		
	44.1	0.1	8.6	0.3	6.9	36.1	3.9		
Bilberry	1.5	0.9	8.1	7.9	4.8	–24.1	0.9	92%	15%
Cowberry	15	0.0	–5.8	0.9	–6.6	–5.5	1.6	100%	5%
Cep	–22	0.2	3.9	4.2	25.4	–13.1	1.5	100%	13%
Collectable goods NPV	16.7	0.9	–5.3	2.9	–6.8	–5.4	–2.9	100%	4%

in utility among the regimes were rather small (13 M€). The combination of management regimes that maximized timber production (NPV amounted to 250 M€ across the 50 year planning period) consisted mainly of BAU and NTSR regimes (Table 4). The changes needed in the combination of management regimes when targeting increases in the yields of collectable goods were different for bilberry, cep, cowberry and the economic value of collectable goods (NPV) (Fig. 2) following differences in the relative utility of management regimes (Table 3).

In a situation where the forest owner is willing to forego 5% of the maximum timber revenues, bilberry yields increased 15% (Table 4), but remained about 10% lower than the maximum potential value. This increase in bilberry yield was achieved by decreasing the share of NTSR regime and by increasing extended rotation regimes and the green tree retention regime (Table 4, Fig. 2A). Cowberry yields were already maximized at the 97% timber NPV level, thus improvements in cowberry yields yield at 95% of timber revenue were relatively small (Table 4, Fig. 2B). This level of cowberry yield was achieved by increasing the share of BAU and decreasing EXT10, GTR30 and NTSR regimes. Cep yields were maximized at 95% of the maximum timber revenues (Table 4, Fig. 2C). This was achieved by decreasing BAU and NTSR management regimes and increasing GTR30 and extended rotation regimes.

The combined economic value of collectable goods attained under the 95% timber NPV constraint was close to the maximum attainable in the landscape (Table 4, Fig. 2D). In monetary terms, this means that 13 M€ reduction in timber revenues resulted in 2 M€ increases in the economic value of collectable goods. This was achieved by increasing BAU and EXT30 regimes and reducing EXT10, GTR30 and no thinnings regimes (Table 4).

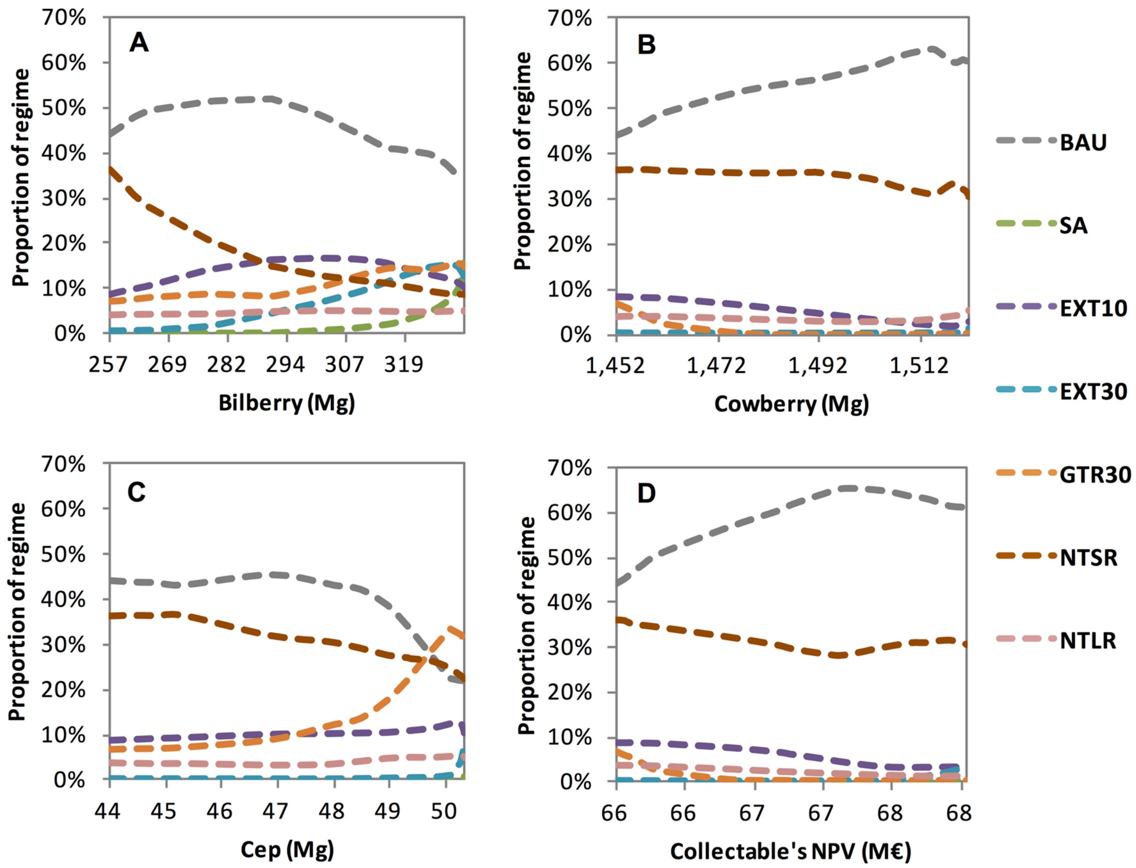

Fig. 2. The proportions of the landscape area in central Finland allocated to different management regimes (*BAU* business as usual, *SA* set aside, *EXT10* extended rotation 10 years, *EXT30* extended rotation 30 years, *GTR30* green tree retention, *NTSR* no thinnings short rotation and *NTLR* no thinnings long rotation) corresponding to the Pareto optimal solutions when optimizing (A) bilberry, (B) cowberry, (C) cep and (D) the economic value of collectable goods vs. the economic value of timber production. The Y-axis describes the share of the landscape area each management regime is allocated to, while the X-axis represents the value of the corresponding collectable good. The left-hand end of the X-axis corresponds to the solution where timber revenues are maximized and the right-hand end of the X-axis corresponds to where a collectable good is maximized.

4 Discussion

Our study revealed that, in boreal forests, there is the potential to produce simultaneously high levels of collectable goods and timber revenues at the landscape level, i.e. the recreational and economical values of collectable goods can be increased with small economical costs in timber revenues. However, the potential to increase collectable goods varied and conflicts between various collectable goods and timber production were case-specific. None of the management regimes, if applied in all forest stands, were able to produce as high yields as an optimal combination of regimes. This indicates the benefits of careful forest management planning at the landscape level and applying optimization tools. Optimal combinations of management regimes were different for different collectable goods and for the economic value of collectables. These results suggest that high yields of collectable goods, together with high timber revenues, is only possible if a diverse set of alternative management regimes is applied at the landscape scale. The potential economic value of collectable goods across the landscape was over one quarter of the economic value of timber revenues.

Increasing bilberry yields was associated with rather high costs, in terms of reducing timber NPV. A similar conflict between bilberry and tree biomass production was also found in a study carried out in the Swedish boreal forest (Gamfeldt et al. 2013). Bilberry yields are highest in mature stands (Miina et al. 2009) and they are sensitive to clear-cuts and soil preparation (Miina et al. 2009; Hedwall et al. 2013), which explains why extended rotation regimes enhance bilberry production and business as usual does not. In addition, it is likely that forests that are too dense decrease bilberry production because there is not enough light, and thus no thinnings regimes provide relatively small bilberry yields. Miina et al. (2010) optimized the joint production of bilberries and timber and also found that, compared to timber production alone, joint production led to 10–40 years longer rotation lengths of trees, higher thinning intensities, and more frequent thinnings. We did not consider regimes that include more intense and frequent thinnings (Miina et al. 2010; Hedwall et al. 2013), or continuous cover forestry (Pukkala et al. 2011; Pukkala 2016), which may be important when targeting bilberry production.

Applying alternative management regimes did not greatly affect cowberry yields, which explains the weak conflict between cowberry and timber production. Moreover, cowberry is not as sensitive to forest management actions as bilberry (Turtiainen et al. 2013). The smallest cowberry yield was achieved with the SA regime, because forest cover in unmanaged stands may be too dense for cowberry, which requires high amounts of sunlight. Therefore, cowberry yields may have benefitted in a management regime with higher thinning intensity, resulting in more light at the field layer (Turtiainen et al. 2013). Recent research revealed that higher thinnings intensities and longer rotation lengths of timber are optimal strategies for producing simultaneously timber and berries (cowberry and bilberry) (Miina et al. 2016). Thus, regimes, such as more intensive thinnings or continuous cover forestry should also be included in future analyses when exploring optimal combinations of management regimes for the simultaneous production of collectable goods and timber.

We found a modest conflict between cep yields and timber NPV. Miina et al. (2013) showed that cep yields were largest in 20–40 year old spruce dominated forests. They applied BAU management with three alternative thinning regimes and found that cep yields were the largest when thinnings were applied earlier, compared to the recommended schedule, and the smallest in the no thinnings regime. Also, Palahí et al. (2009) and de Miguel et al. (2014) found a positive effect of intensified thinning on mushroom production. We did not apply intensified thinning regimes, but found that cep production increased with a decreasing NTSR regime, suggesting negative effects of reduced thinnings. Bonet et al. (2008) found that the highest mushroom production tended to coincide with the stage of stand development, where wood volume growth is the highest. Similar results found by Egli et al. (2010) showed that mushroom fruit body production is positively associated with the growth of host tree. Therefore, it may be that tree growth, which tends to be boosted by thinnings, is the driving factor in cep production, instead of thinning intensity (Hynynen et al. 2005). In fact, any management strategy that sustains tree growth and retains tree cover, e.g. continuous cover forestry, may be beneficial for simultaneously producing mushrooms and timber in forests (de Miguel et al. 2014).

Generally, our results show that increasing the recreational value provided by different collectable goods required a diverse set of management regimes because different collectables benefit from different regimes. These results can be interpreted while considering the concepts of land sparing and land sharing (Mastrangelo et al. 2014): as habitat requirements of different collectables vary, different management regimes for maximizing their production can be applied to different stands in a form of land sparing. For example, bilberry is the most common dwarf shrub in mesic heath forests, therefore applying longer rotation lengths in these forest types might enhance bilberry production.

The proportion of cowberry in collectable NPV was large, which is why the conflict between the total economic value and timber was rather small. When we derived the optimal combination of management regimes to maximize the total economic value of collectable goods within the timber NPV constraint, the solution included an increase in the share of the BAU regime that enhances cowberry yield, and an increase in EXT30 that enhances bilberry yield (Table 4). Cep production seemed to have a relatively small effect on the optimal set, presumably due to lower absolute yields of cep than bilberry and cowberry (Table 2) and because of the small variation among management regimes in the cep yield (Table 3). However, it is important to note that the models used in this study produced considerably larger cowberry yields than bilberry yields and the real differences in total annual yields are not normally so large (Turtiainen et al. 2011). Thus, the proportion of bilberry in total economic value is probably underestimated. In addition, it should be noted that there are many other economically important collectable goods such as raspberry (*Rubus idaeus* L.) and several mushroom species that produce much higher yields than cep. Therefore, the real economic value of non-timber forest products may be much larger than we estimated in this study.

It is also important to consider who benefits from the recreational and economical values of collectable goods. In many Nordic countries, everyman's rights enable all citizens to have free access to pick berries and mushrooms, while selling collectable goods at the market is tax-free (Salo 1995). However, in Finland, companies also sell berries and mushrooms. These companies earned 25 M€ from berry picking and 1 M€ from mushroom picking in 2012 (Finnish statistical year book of forestry 2013). In Finland, approximately 60% of forests are privately owned (Finnish statistical year book of forestry 2013) and the costs of promoting collectable goods yields have to be covered by private forest owners, while all citizens benefit from the increased values of collectable goods. This is a common challenge in the management of ecosystem services: the provision of a service that can be considered a public good depends on land management by the private forest owner (Polasky et al. 2014).

If the forest owner is willing to forego 5% of the maximum timber revenues to promote collectable goods and the recreational value of forest, it would mean approximately 6 € ha^{-1} $year^{-1}$ (5% reduction in 116 € ha^{-1} $year^{-1}$ timber revenues, see 3.1) loss from timber revenues and would result in 3–15% increase in the yields of collectable goods (Table 4). To compensate the cost of promoting the recreational value of forest, approximately 2.7 kg of bilberries or 5.2 kg of cowberries per hectare should be harvested (see average market prices from the Methods 2.5), which is approximately 35% or 15% of our annual estimated bilberry and cowberry yields, respectively. Our estimated bilberry yields are likely underestimated and cowberry yields overestimated (see Methods 2.6). In Finland, the average yield is 22 kg ha^{-1} for bilberry and 23 kg ha^{-1} for cowberry (Turtiainen et al. 2011); with these average yields, 10% of bilberries or 20% of cowberries should be harvested to compensate the cost of promoting the recreational value of forests. Current harvest rates in Finland are 5–6% for bilberries and 8–10% for cowberries (Turtiainen et al. 2011). Thus, in recreational forests, increasing the harvest rate of these berries is possible and can reach profitable levels, particularly when increased annual yields of collectable goods may encourage a greater level of collection.

However, it is not reasonable to attempt to maximize the collection of all collectables goods available, since berries and mushrooms are also a valuable resource for a wide number of species and are therefore biologically important. Berries and mushrooms are important food sources for many herbivores, such as moose (*Alces alces* L.) (Selås et al. 2011). In particular, bilberry is a source of food for game birds, such as capercaillie (*Tetrao urogallus* L.) (Lakka and Kouki 2009). Moreover, fungi with large fruit bodies are important habitats and food for many specialist invertebrate species (Hanski 1989). Thus, ensuring high yields of collectable goods in production forests is not only valuable to humans directly, but also indirectly via maintaining biodiversity and other ecosystem services.

Moreover, a long-term study from Switzerland revealed that systematic harvesting of mushrooms did not reduce future yields of fruit bodies, but forest floor trampling by mushroom pickers reduced fruit body number (Egli et al. 2006). A short-term study of commercial berry picking in Finland showed that current commercial picking methods do not damage berry production (Manninen and Peltola 2013). However, the long-term effects of commercial berry picking are not known and the sustainability of this activity is currently debated.

5 Conclusions

This study shows that it is possible to increase recreational values with small economical costs in the boreal forest by implementing management plans obtained using a multi-objective optimization methodology. At the landscape level, it is possible to simultaneously produce high levels of collectable goods and timber revenues. In addition, our results support the results from previous studies and show that collectable goods are economically very valuable. Nevertheless, both recreational and economical values of collectable goods are notable, which emphasizes the need to move towards multifunctional forestry. It is not optimal to focus only on maximizing one ecosystem service when it is possible to provide multiple services simultaneously in the forest landscape by careful forest planning.

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Supplementary files

S1.pdf, available at http://dx.doi.org/10.14214/sf.1672.