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Managing a boreal forest landscape for the simultaneous production of collectable goods and timber revenues

Maiju Peura

University of Jyväskylä
Department of Biological and Environmental Science
Ecology and Evolutionary Biology
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UNIVERSITY OF JYVÄSKYLÄ, Faculty of Mathematics and Science

Department of Biological and Environmental Science
Ecology and Evolutionary Biology

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Supervisors:	PhD Maria Triviño, PhD Adriano Mazziotta, Prof. Mikko Mönkkönen
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ABSTRACT

Ecosystem services are benefits that people obtain from nature. Often land management that attempts to maximize one ecosystem service reduces the provision of others when there is a trade-off between services. Timber production is economically the most important ecosystem service in boreal forest. However, timber production affects negatively the production of many other ecosystem services and it would be important to know how to minimize the conflicts between them. Collectable goods like berries and mushrooms are also economically important and, in addition, they are recreationally valuable. In this master's thesis, the possibility to produce simultaneously collectable goods and timber was explored i.e., whether or not it is possible to provide recreational and economic values simultaneously. In the thesis, the term "collectable goods" from forest refers to berries (bilberry and cowberry) and mushrooms (cep). The optimal forest management plans to produce collectable goods and timber simultaneously were analyzed. In addition, the economic value of collectable goods was estimated. Furthermore, trade-offs existing between collectable goods and timber and between the economic value of collectable goods and timber were analyzed. The research was done at a landscape level across 50 years planning horizon. Timber revenues were estimated in an earlier study and the yields of collectable goods were calculated in this study using ready-made models based on yield data. The yields were calculated for seven alternative forest management regimes varying from the current recommended management regime to the total protection. A multi-objective optimization method was used to explore the conflicts and identify optimal forest management plans. The results of this study show that the strongest conflict was between bilberry and timber production. The second strongest conflict was between the combined economic value of collectables and timber revenues. The conflict between cep and timber production was relatively small and the conflict between cowberry and timber production was negligible. Optimal combinations of management regimes were different for different collectable goods suggesting that maximizing all collectable good yields together with timber production might require diverse set of alternative management regimes in the landscape. However, it was possible to increase the provision of collectable goods with small reductions from timber revenues. This is relevant even from an economic point of view, as this research shows that the economic value of collectable goods can be as high as one third of the corresponding value of timber.

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TIIVISTELMÄ

Ekosysteemipalvelut ovat hyötyjä, joita ihminen saa luonnosta. Maankäsittely, joka tähtää yhden ekosysteemipalvelun maksimoimiseen vähentää usein muiden ekosysteemipalvelujen tuottoa, jolloin ekosysteemipalvelujen välillä on ristiriita. Puuntuotanto on boreaalisen metsän taloudellisesti tärkein ekosysteemipalvelu. Puuntuotanto vaikuttaa kuitenkin negatiivisesti moniin muihin ekosysteemipalveluihin, joten olisi tärkeää tietää kuinka minimoida nämä ristiriidat. Myös keruutuotteet, kuten marjat ja sienet, ovat taloudellisesti merkittäviä ja ne ovat lisäksi virkistyksellisesti arvokkaita. Gradu-tutkielmassani selvitettiin onko maisematasolla mahdollista tuottaa keruutuotteita ja puuta samanaikaisesti, toisin sanoen, onko mahdollista tuottaa samanaikaisesti sekä virkistyksellisiä että taloudellisia arvoja. Tutkielmassa termi metsän ”keruutuotteet” viittaa: marjoihin (mustikka ja puolukka) ja sieniin (herkkutatti). Optimaalinen metsänkäsittely keruutuotteiden ja puun samanaikaiseen tuotantoon selvitettiin. Lisäksi keruutuotteille laskettiin potentiaalinen taloudellinen arvo. Sekä keruutuotteiden ja puun tuotannon väliset ristiriidat että keruutuotteiden taloudellisen arvon ja puuntuotannon väliset ristiriidat analysoitiin. Tutkimus tehtiin maisematasolla ja 50 vuoden suunnitteluajanjaksolla. Puuntuotantotulot oli laskettu aikaisemmassa tutkimuksessa ja tässä tutkimuksessa laskettiin keruutuotesadot sekä niiden taloudellinen arvo käyttämällä valmiita satomalleja. Sadot laskettiin seitsemälle erilaiselle metsänkäsittelylle, jotka vaihtelivat nykyisestä suositellusta metsänkäsittelystä täysin suojeltuun. Konfliktien ja optimaalisten metsänkäsittelyjen selvittämiseksi käytettiin monitavoitteellista optimointimetodia. Tutkimuksen tulokset osoittavat, että voimakkain ristiriita oli mustikan ja puolukan tuotannon välillä. Toiseksi suurin ristiriita oli keruutuotteiden taloudellisen arvon ja puuntuotannon välillä. Herkkutattien ja puuntuotannon välinen ristiriita oli suhteellisen pieni ja puolukan ja puuntuotannon välinen ristiriita lähes mitätön. Eri keruutuotteet hyötyivät eri metsänkäsittelyistä, mikä viittaa siihen, että eri keruutuotteiden ja puuntuotannon samanaikainen tehokas tuottaminen maisemassa vaatisi monenlaisia metsänkäsittelymenetelmiä. Keruutuotesatoja oli kuitenkin mahdollista kasvattaa vain pienin taloudellisin menetyksin puuntuotantotuloissa. Tämä on merkityksellistä myös taloudellisesta näkökulmasta, sillä keruutuotteiden taloudellinen arvo voi olla jopa kolmasosa puuntuotannon taloudellisesta arvosta.

Contents

1. INTRODUCTION

Ecosystem services are direct and indirect benefits that people obtain from nature (MEA 2003, 2005). The ecosystem services approach integrates ecological, social and economic aspects to help explain the influence of human policies on ecosystems and human welfare. These services can be categorized as follows: supporting, regulating, providing and cultural (MEA 2003, 2005). *Supporting* services are services that enable the production of all other ecosystem services (e.g., soil formation, nutrient cycling and oxygen production). *Regulating* services are benefits obtained from the regulation of ecosystem processes (e.g., climate regulation and water purification). *Providing* services are products (goods) directly obtained from ecosystems (e.g., food, water and genetic resource). *Cultural* services are nonmaterial benefits obtained from ecosystems (e.g., spiritual enrichment, recreation and aesthetic experiences). However, "ecosystem services" is a broad and vaguely defined concept and this can generate different types of interpretations and definitions (Boyd & Banzhaf 2007, Wallace 2007, Fisher et al. 2009).

Modern history of ecosystem services comes from the late 1970s and the representation of ecosystem services in scientific literature increased in the 1990s (Gomez-Baggethun et al. 2010, Braat & de Groot 2012). Research on ecosystem services grew greatly after the publication of the Millennium Ecosystem Assessment (MEA 2003, MEA 2005) which linked ecosystem services to policy and decision making (Fisher et al. 2009, Gomez-Baggethun et al. 2010). Humans have intensively modified ecosystems during the last decades and about 60 % of the examined ecosystem services have been degraded or used unsustainably (MEA 2005). Therefore, more research is needed to stop the ecosystem services degradation. Understanding key characteristics, such as joint production and interactions between different ecosystem services is crucial for managing, maintaining, restoring or evaluating them (Fisher et al. 2009). Even though important improvements have been made, there are still large knowledge gaps in this research field (Nicholson et al. 2009). One challenge is to solve how to integrate ecosystem services in landscape planning and management (de Groot et al. 2010, Portman 2013). Investments in conservation and sustainable ecosystems can generate not only ecological but also social and economic benefits (de Groot et al. 2010). However, also concern exists that the ecosystem service concept might replace biodiversity protection as a conservation goal and the concept is criticized for having a too anthropocentric focus on nature (Schröter et al. 2014).

Valuing ecosystem services is important because it helps to recognize the relevance of different ecosystem services for human well-being (de Groot et al. 2010, Liu et al. 2010). Moreover, policy and decision making, managing and conserving ecosystem services are easier when the values of services are recognized. Ecosystem service values can be divided into three categories: *ecological values* such as integrity or diversity of ecosystems, *socio-cultural* values such as equity or spiritual and recreational values, and *economic values* (de Groot et al. 2002, de Groot 2006). Economic values can be further divided into use values, such as direct value of timber or indirect value of climate regulation, and non-use values, such as natural beauty (de Groot et al. 2010). Often monetary values are easier to use and comparison among different services is simpler when services are valued in the same way (Schröter et al. 2014). Economical valuation methods fall into several different types: market valuation, indirect market valuation, contingent valuation and group valuation (de Groot et al. 2002). Economical valuation is also criticized; the most general critique posits that "for ethical reasons some things should not be for sale and economic valuation could lead to selling out nature" and commodification (Gómez-Baggethun et al. 2011, Schröter et al. 2014). There are alternative valuation methods for ecological and social values, such as number of service's users within a given area (EPA 2009, Liu et al. 2010). For example, Matero & Saastamoinen (2007) used different valuation methods and estimated that the value provided by Finnish forests could reach approximately 2600 million euros (M€) per year.

There can be various interactions between ecosystem services: directional, unidirectional, bidirectional, positive and negative (Bennett et al. 2009). Trade-offs occur when the provision of one ecosystem service is reduced as a consequence of increased use of another ecosystem service (Rodríguez et al. 2005, 2006, Bennet et al. 2009). Land management that attempts to maximize the production of one ecosystem service can reduce the provision of other ecosystem services (Bennett et al. 2009). Land management influences ecosystem functions and properties that are the base for the provision of services, therefore changes in land use make changes in the provision of ecosystem services (de Groot et al. 2010). Generally, management options applied by humans to get provisioning services, such as timber and food, affect negatively on other services and cause trade-offs (Rodríguez et al. 2006, Bennett & Balvanera 2007, Carpenter et al. 2009, Raudsepp-Hearne et al. 2010). Often trade-offs are non-intentional or not known, and occur when there is a lack of knowledge about the interactions among ecosystem services, when there is incorrect or incomplete knowledge of how services work, or when there are no markets for the ecosystem service and its value is not recognized (Rodríguez et al. 2006). Synergies occur when both services either increase or decrease in parallel; this occurs when two services respond simultaneously to the same driver or there is a positive interaction between the services (Rodríguez et al. 2005, Bennett et al. 2009). Synergistic interactions allow the simultaneous enhancement of multiple ecosystem services (Rodríguez et al. 2005). Ecosystem services interactions have three different aspects: spatial, temporal and reversibility (Rodríguez et al. 2005, Rodríguez et al. 2006). *Spatial aspect* refers to whether the effects of the interaction are local or regional/global. *Temporal aspect* refers to whether the effects occur rapidly or slowly. Long-term effects of preferring one ecosystem over others can be different than short-term effects. *Reversibility aspect* indicates the likelihood that the disturbed ecosystem service may return to its original state after disturbance has stopped. Understanding the relationships among multiple ecosystem services is important in order to enhance and maintain positive synergies and to avoid the worst trade-offs whenever it is possible (Rodríguez et al. 2005).

Recent research has attempted to disentangle linkages between biodiversity, ecosystem function and ecosystem services and in most cases, the relationship between biodiversity and ecosystem services is positive (Harrison et al. 2014). It is evident that biodiversity can have multiple roles in the delivery of ecosystem services; it may be a regulator of ecosystem processes, a service in itself (e.g., the genetic diversity of crop) and a good (Mace et al. 2012). Biodiversity loss has an impact on ecosystem functions; it reduces biomass production, decomposition, nutrient recycling and ecosystem stability (Cardinale et al. 2012). Maintaining multiple ecosystem processes at multiple places and times requires higher levels of biodiversity than a single process at a single place and time. Biodiversity is therefore a prerequisite for sustained flow of multiple ecosystem services. For example, in boreal forests, forests with more tree species can offer simultaneously multiple ecosystem services such as higher production of tree biomass, soil carbon storage, berry production and game production than less diverse forests (Gamfeldt et al. 2013).

1.1. Ecosystem services in boreal forests

Many crucial ecosystem services are provided by boreal forests (Kettunen et al. 2012, Vanhanen et al. 2012). Boreal forests contain 32% of the global carbon storage and 22% of the global carbon sinks in forests (Pan et al. 2011). Boreal regions have one of the largest freshwater supplies in the world (Vanhanen et al. 2012). In addition, recreational services of forests, such as outdoor recreation, hiking, nature tourism and picking collectable goods are valuable for boreal areas. Timber production is the most economically valuable *providing service* in boreal forests (Vanhanen et al. 2012). For example, in Finland, about 86% (26 million ha) of the total area is forested (Finnish statistical year book of forestry 2013) and forest sector produces approximately 4% of the Gross Domestic Product (Vanhanen et al. 2012). Many boreal forests are intensively managed for maximizing the provision of timber while neglecting the importance of maintaining biodiversity and other ecosystem services (Vanhanen et al. 2012). Timber extraction can affect negatively other ecosystem services, such as biodiversity, recreation (Kettunen et al. 2012, Vanhanen et al. 2012), water quality, carbon storage (Duncker et al. 2012), game production and bilberry production (Gamfeldt et al. 2013).

In many parts of the boreal forests where the aim is to maximize timber revenues, forests are managed as forest stands and forest rotation in one stand includes a series of silvicultural operations: clear-cutting, soil preparation, planting, brushing, pre-commercial and commercial thinning (Vanhanen et al. 2012). At the landscape scale, this has resulted in the simplification of forest’s structure and dynamics and decrease in the amount of old and decayed wood. The most important features for biodiversity in boreal forests are old and decayed trees (Nilsson et al. 2001). The fundamental idea behind silvicultural methods has been mimicking natural large-scale disturbances such as fires, storm fellings, insects, pathogens and browsing by large carnivores that have played a major role in the dynamics of natural boreal forests (Larsson & Danell 2001). However, boreal forests are more complex and variable than traditionally assumed, and clear-cuttings and the growing of even-aged stands differ from the complexities of the dynamics in natural boreal forests (Kuuluvainen 2009).

Since timber production is economically very important for the society, it would be desirable to know how to manage the forest to produce timber and simultaneously conserve or enhance other ecosystem services (de Groot et al. 2010, Duncker et al. 2012, Vanhanen et al. 2012). Multi-objective optimization methods can be used to provide efficient options for land use and management of different ecosystem services (Nalle et al. 2004, Seppelt et al. 2013, Mönkkönen et al. 2014). The term Pareto-optimal is used to describe a situation when it is not possible to increase one service without decreasing another service. Revealing and resolving these conflicts between different ecosystem services would be informative for improving land use and management. For example, Mönkkönen et al. (2014) showed that it could be possible to greatly increase habitat availability of several species in boreal forest landscape with small reductions in economic returns by refraining from silvicultural thinnings on some forest stands. Miina et al. (2010) optimized timber and bilberry production in boreal forest and Palahí et al. (2009) optimized mushrooms and timber production in Central Pyrenees. Joint production of bilberries and timber led to longer rotation lengths, higher thinning intensities and more frequent thinnings (Miina et al. 2010). Joint production of mushrooms and timber also led to increased thinnings and longer rotation lengths in forest stands (Palahí et al. 2009). Both Miina’s and Palahí’s studies suggested that collectable good yields might even exceed the economic value of timber production in some forest stands.

1.2. Collectable goods in Finland: berries and mushrooms

In Finland, the most important wild berries collected are bilberry (*Vaccinium myrtillus L.*) and cowberry (*Vaccinum vitis-idea L.*), and the total value of the annual harvested wild berry crop may reach around 100 M€ (Saastamoinen et al. 2000). Cep (*Boletus edulis*) is the most economically valuable mushroom species in Finland (Turtiainen et al. 2013). Other valuable collectable goods are i.a., cloudberry (*Rubus chamaemorus*), raspberry

(*Rubus idaeus*), milk caps (*Lactarius sp*.), chanterelle (*Chantarellus cibarius*) and other *Boletus* species (Salo 1995). In year 2013, the revenues from wild berries and mushrooms were 22.1 M€ in Finland (MARSI 2013). Wild berry and mushroom picking has long traditions and in addition to its economic values, this activity has a recreational value (Pouta et al. 2006). In the Nordic countries, everyman’s right allows all people to have free access to forests and to pick berries and mushrooms (Salo 1995). Picking collectable goods is often linked to a rural lifestyle and the use of summer cottages and it is popular especially within older generations (Pouta et al. 2006). In years 2009-2010, 58% of Finns participated in berry picking and 40% of Finns participated in mushroom picking (Finnish statistical year book of forestry 2013). However, during the last decades, yields of many collectable goods have declined due to changes in forest management and its intensity (Salo 2008, Miina et al. 2009, Turtiainen et al. 2013).

The total bilberry crop in Finland may vary around 90–310 million kg (Turtiainen et al. 2011). Bilberry is abundant on mesic heath forest sites but it grows also in sub-xeric heath forest sites and herb-rich heath forest sites (Ihalainen et al. 2003, 2005, Turtiainen et al. 2009, Miina et al. 2009). The main factors affecting bilberry production at forest stand level are site type, dominating tree species, stand basal area and regeneration method (Miina et al. 2009). Bilberry yields increase when stand basal area is large and it is most abundant in pine dominated stands. Bilberry is sensitive to silvicultural operations, such as clear cuttings and soil preparation. Clear cuttings result in too open light conditions since bilberry needs some tree cover. Alternative management strategies like selective logging may improve the bilberry production (Pukkala et al. 2011).

Cowberry is the most economically important wild berry species in Finland providing the most abundant annual crop that may vary around 130–390 million kg (Turtiainen et al. 2011). Cowberry is abundant in dryish heath forest sites and dry heath forest sites (Ihalainen et al. 2003, 2005, Turtiainen et al. 2013). Cowberry produces the highest yields in recently clear-cut areas, near their edges and sparse mature pine-dominated stands since it is dependent on light. The main factors affecting cowberry production at forest stand level are site type, stand basal area and dominating tree species (Turtiainen et al. 2013). Cowberry yields are large when stand basal area is small due to better light conditions. Cowberry is most abundant in pine dominated forest stands.

Around 3–16 million kg of mushrooms are annually picked in Finland, mainly for household usage (Turtiainen et al. 2012). Many edible mushrooms are mycorrhizal, living in a mutualistic symbiosis with Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*) or birches (*Betula*) (Salo 1995). At forest stand level, stand basal area and forest age are the main factors affecting mushroom production (Egli et al. 2010, Miina et al. 2013). Mycorrhizal mushrooms produce more fruit bodies when host trees grow strongly with high photosynthetic capacity and lower stand basal area can promote the growth of trees (Egli et al. 2010). Cep is living in symbiosis with Norway spruce and it is most abundant in mesic heath sites (Miina et al. 2013). The yields of cep have been found to be highest in 20–40 year old forest stands.

Since collectable good yields can be economically, as well as recreationally valuable, it would be beneficial to know how to produce timber and collectable goods simultaneously. The studies of Miina et al. (2010) and Palahí et al. (2009) gave knowledge but the studies included only a few forest stands. Understanding the relationships between different ecosystem services at the landscape scale is crucial for sustainable land management and decision making (de Groot et al. 2010). In addition, studies at landscape scale are important since the provision of many ecosystem services depends on processes that occur at the landscape scale (Rodríguez-Loinaz et al. 2014). Longer time scale is needed to reveal long-term effects of forest managements, like in the studies of Miina et al.

(2010) and Palahí et al. (2009). There are no studies, as far as I am aware, were both spatial and temporal aspects of interactions between several collectable goods and timber production have been considered.

1.3. Study objectives

In the master’s thesis, I study possible conflicts between timber production and collectable goods production in a boreal forest landscape with 50 year time scale. In the thesis the term “collectable goods” from forest refers to berries (bilberry and cowberry) and mushrooms (cep). Yields of collectable goods were considered representing recreational values. In addition, I estimate a combined potential economic value (net present value, NPV) of all three collectables and in the thesis, the term “economic value of collectable goods” refers to it. I use ready-made models based on yield data and study how different forest management regimes, varying from the current recommended management to the total protection, affect yields at landscape scale across a 50 years planning horizon. Multi-objective optimization method (Miettinen 1999) is used in analyzing trade-offs between collectable goods and timber production and between the economic value of collectable goods and timber production. I address the following questions: 1) What is the potential of the boreal forest landscape to produce simultaneously collectable goods and timber, and how the conflict between different collectable goods and timber production varies? 2) What is an optimal combination of forest management regimes that maximizes the recreational values of collectable goods for given levels of economic values of timber, or vice versa? 3) What is an optimal combination of forest management regimes that maximizes the economic value of collectable goods for a given level of economic value of timber, or vice versa? Answering these questions can be informative to provide management recommendations on how to produce collectable goods and timber simultaneously in a forest landscape and further, how to enhance recreational services in an economically sustainable way.

2. DATA AND METHODS

2.1. Study area and data

The study area is located in Central Finland (62° 14 N, 25° 43 E) and its size is 68,700 ha. The area consists of managed boreal forest where the extension of forest on mineral soils is 55% of the total area, peat lands 13%, lakes 16% and farmland settlement 15%. Data on the characteristics of forest are available for each of the 29,702 forest stands in the area (stand average size 1.45 ha). Data originates from the forestry data administered by the Finnish Forest Centre and include stand characteristics such as basal area of trees, stand age and site type (for more information see Mönkkönen et al. 2014).

2.2. Forest growth simulation and timber revenues

The growth of forest stands has been simulated for 50 years using MOTTI-stand simulator applying 7 alternative management regimes (Table 1) (Mönkkönen et al. 2014). Management options vary from the current recommended management regime (business as usual, BAU) to permanent conservation (set aside, SA). Extended rotation represents a conservation strategy where the final harvest is delayed compared with the recommended management regime: an extension of 10 years (EXT10) represents a short term conservation strategy, an extension of 30 years (EXT30) a long term strategy. Green tree retention (GTR30) represents a conservation oriented management attempting to mimic and restore natural disturbance regimes and it is used to increase structural diversity in managed forests. No thinnings with long rotation (NTLR) results in a slower tree growth since it takes more time to reach the recommended diameter for the final harvest. No thinnings with short rotation (NTSR) is a management regime where the final harvest is set to take place approximately at the same time as business as usual and results in smaller size of trees at harvest. Forest growth simulations were run in intervals of 5 years, so 50 years planning horizon included 11 time steps (0, 5, 10, …, 50).

In an earlier work, Mönkkönen et al. (2014) estimated the timber production potential and timber revenues (net present value, NPV) for each stand and management regime across 50 years planning horizon as € ha^{-1}. Timber NPV consists of four revenue components: harvest revenues from thinnings, harvest revenues from the final harvest, harvest value of standing timber at the end of rotation and the soil expectation value. In addition, timber NPV includes silvicultural costs: natural regeneration, seedling, planting, tending of seeding stands, and cleaning of sapling stands. 3% interest rate was used in discounting the timber revenues and costs in 50 years planning horizon (see Mönkkönen et al. 2014 for details). Timber NPV has been corrected afterwards and in this study, the maximum value of timber revenues from the entire landscape is 193.9 M€ which is approximately 6 M€ less than in the results of Mönkkönen et al. (2014).

Table 1. Different management regimes (adapted from the Mönkkönen et al. 2014).

Management regime	Acronym	Description
Business as usual	BAU	Recommended management: 80 year rotation: site preparation, planting or seeding trees, 1-3 thinnings, final harvest with green tree retention level 5 trees/ ha.
Set aside	SA	Set-aside: 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.
Extended rotation (30 years)	EXT30	BAU with postponed final harvesting by >30 years; lower timber NPV due to time discounting.
Green tree retention	GTR30	BAU with 30 green trees/ha at final harvest; reduced timber production.
No thinnings (final harvest threshold criteria as in BAU)	NTLR	BAU but no thinnings: longer rotations and lower timber NPV.
No thinnings (minimum final harvest threshold criteria)	NTSR	BAU but no thinnings; results approximately in rotation length equal to the rotation length in BAU but lower timber NPV.

2.3. Collectable good yields

The yields of collectable goods were estimated for each one of the 11 time steps, 29,702 stands and 7 management regimes using the models described below. For the optimization calculations of each collectable good and timber revenues, collectable good yields were calculated for each stand as an average yield of a collectable good (kg ha^{-1}) across the 11 time steps. Calculations were done using R version 3.1.2 (R Development Core Team 2014).

2.3.1. Bilberry

The yields of bilberry were estimated in every forest stands using empirical models developed by Miina et al. (2009). The methods of Miina et al. (2009, 2010) were followed. First, the coverage of bilberry is predicted as a function *f(bilb1)* of several indicator variables: site type, dominating tree species, regeneration method, history of the stand, altitude, stand age and stand basal area (Table 2) in a model:

$$Coverage\ of\ bilberry = 100\ \times \frac{1}{1+exp\{-f(bilb1)\}}\ . \qquad (1)$$

Coverage is the mean coverage of bilberry in the stand (%). Site type I is herb-rich forest, site type II is herb rich heath (*Oxalis-Myrtillus* group), site type III (reference) is mesic heath (*Myrtillus* group), site type IV is sub-xeric heath (*Vaccinium* group), and site type V is xeric heath forest (*Calluna* group). In the data, there were 49 stands of site type VI, barren heath forest (*Cladonia* group). Barren heath forest is too infertile and dry for bilberry (Miina et al. 2009) and it was assumed that there are no bilberries in those stands. The dominating tree species of a stand was the tree species with the largest stand basal area: Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*) or deciduous trees (*Betula pendula* and *B. pubescens*). Information on the regeneration method was not available so the regeneration method was assumed to be artificial in all management regimes except set aside where regeneration method was natural. Information on the history of stands was not available either and all stands were assumed to be previously forested land. Altitude was the average stand altitude that had been calculated from a 25 m resolution Digital Elevation Model for each forest stand. Stand age was the dominating age of trees. Stand basal area was the sum of basal areas of different tree species (pine, spruce and two birch species).

Table 2. Indicator variables and their estimated coefficients in the coverage model of bilberry (modified from the Miina et al. 2009). Site type I = herb-rich forest, II = herb rich heath (*Oxalis-Myrtillus* group), III (reference) = mesic heath (*Myrtillus* group), IV = sub-xeric heath (*Vaccinium* group), and V = xeric heath forest (*Calluna* group).

Variable	Coefficient
Intercept	-3.8470
Site type (ref. III)	
I	-2.1815
II	-0.4809
IV	-0.4807
V	-1.5053
Dominating tree species (ref. Norway spruce)	
Scots pine	0.1209
Deciduous trees on site type II	-0.4770
Regeneration method (ref. Natural)	
Artificial	-0.2588
History of the stand (ref. Forest)	
Former agricultural land	-1.4715
Altitude (m)	0.0029
Stand age (a)	0.0080
Stand age^2/100 (a)	-0.0021
Stand basal area (m^2 ha^{-1})	0.0947
Stand basal area^2/100 (m^2 ha^{-1})	-0.1916

Bilberry coverage is then translated into bilberry yield as a function *f(bilb2)* of coverage and stand basal area (Table 3) in a model:

$$Number\ of\ unripe\ bilberries\ =\ exp\{f(bilb2)\}. \tag{2}$$

The model gives the yield as the annual number of unripe berries per square meter. The yield was transformed as the annual number of unripe berries per hectare by multiplying the yield by 10,000 (1 ha = 10,000 m^2). There were different models for Scots pine and Norway spruce dominated stands. If the stand was deciduous tree dominated, the coefficients of Scots pine dominated stands were used (Miina et al. 2010). The means of year effects (0.1422 for Scots pine and 0.5450 for Norway spruce) were added to the intercepts. In a mixed stand, the yield was calculated first for each tree species using the total stand basal area as a predictor in the models (Miina et al. 2010). The stand was assumed to be mixed if the proportion of none of the tree species was larger than 80 % of the total stand basal area of trees (Tieteen termipankki 2014). Then, the yield was calculated as the weighted average of species-specific yield predictions, and using the proportions of each tree species of the total stand basal area as weights. 80 % of unripe berries were assumed to become ripe (Ihalainen et al. 2003, Miina et al. 2010). Finally, the prediction of bilberry yield (kg ha^{-1}) was calculated for each stand by multiplying the number of ripe berries by the mean fresh weight (0.35 g) of one bilberry (Miina et al. 2009, 2010).

Table 3. Indicator variables and their coefficients in the yield model of bilberry (modified from Miina et al. 2009). There are different coefficients for Scots pine and Norway spruce dominated stands.

Variable	Scots pine Coefficient	Norway spruce Coefficient
Intercept	-0.6781	-4.7474
Mean of year effects	0.1422	0.5450
Coverage of bilberry (%)	0.2398	0.3635
Coverage of bilberry^2/100 (%)	-0.2812	-0.4798
Stand basal area (m^2 ha^{-1})	–	0.3742
Stand basal area^2/100 (m^2 ha^{-1})	–	-1.3447

2.3.2. Cowberry

The yields of cowberry were estimated in forest stands using models developed by Turtiainen et al. (2013). First, the coverage of cowberry is predicted as a function *f(cowb1)* of site type, history of the stand, dominating tree species, temperature sum, altitude, stand age and stand basal area (Table 4) in a model:

$$Coverage\ of\ cowberry = 100\ \times\ \frac{1}{1+exp\{-f(cowb1)\}}. \tag{3}$$

Coverage is the mean coverage of cowberry in the stand (%). Site types, dominating tree species, altitude, stand age and stand basal area are the same as used in the models of bilberry. The model did not include coefficient for site type VI so, like in the case of bilberry, it was assumed that the coverage and also the yield were zero in site type VI. Again, information of history of the stand was not available and all stands were assumed to be previously forested land. The temperature sum was assumed to be constant through 50 years planning horizon and an average temperature sum from 5 decades was used. The temperature sum was from the output of a forest simulator (Strandman et al. 1993) for each five decades of the 21st century (2010–2019, …, 2050–2059), and has been calculated under business as usual forest management regime hypothesizing stationary climate conditions. Stationary climate means that carbon dioxide concentration is constant across the century and it has the same value as in the 1970–2000 period. The values of temperature sums are given in a grid for the stands of the National Forest Inventory (NFI), and they have been associated to each stand in the study area by calculating the minimum distance between each of the 29,702 stands and the values in the grid of the NFI.

Table 4. Indicator variables and their estimated coefficients in the coverage model of cowberry (modified from Turtiainen et al. 2013). Site types are same as above in bilberry model.

Variable	Coefficient
Intercept	-4.7902
Site type (ref. IV)	
I	-5.1730
II	-2.5690
III	-0.4216
V	-0.4185
Dominating tree species	
Norway spruce on site types I-III	-0.4327
Deciduous trees on site types I-III	-0.7528
History of the stand (ref. Forest)	
Former agricultural land	-0.9438
1000/Temperature sum (dd)	2.5592
Altitude (m)	-0.0039
Stand age (a) on site types I-II	0.0106
Stand basal area (m^2 ha^{-1})	0.0157

Cowberry coverage is then translated into cowberry yield as a function *f(cowb2)* of coverage, stand basal area, altitude and temperature sum (Table 5) in a model:

$$Number\ of\ ripe\ cowberries\ =\ exp\{f(cowb2)\}. \tag{4}$$

The model gives the yield as the annual number of ripe cowberries on square meter area and the yield was transformed to the annual number of ripe cowberries per hectare by multiplying the yield by 10,000. The mean of year effects (0.1849) was added to the intercept. Finally, the prediction of cowberry yield (kg ha^{-1}) was calculated for each stand by multiplying the number of ripe berries by the mean fresh weight (0.23 g) of one cowberry (Ihalainen et al. 2003, Turtiainen et al. 2013).

Table 5. Indicator variables and their estimated coefficients in the yield model of cowberry (modified from the Turtiainen et al. 2013).

Variable	Coefficient
Intercept	6.5404
Mean of year effects	0.1849
Coverage of cowberry (%)	0.0966
Coverage of cowberry^2/100 (%)	-0.0837
Ln(Stand basal area + 1) (m^2 ha^{-1})	-0.4716
Altitude (m)	0.0071
1000/Temperature sum (dd)	-4.6264

2.3.3. Cep

The yields of cep were estimated in forest stands using a model developed by Miina et al. (2013). The model predicts the yield of cep as a function *f(cep)* of stand basal area and stand age (Table 6), as follows:

$$Number\ of\ ceps\ =\ exp\{f(cep)\}. \tag{5}$$

The model gives the yield as the number of ceps in 400 square meters area and it was transformed to the number of ceps per hectare by multiplying the yield by 25 (1 ha = 10,000 m^2 and 10,000 m^2/400 m^2 = 25). The mean of year effects (-0.1027) was added to the intercept. Stand basal area and stand age were the same as used in the models of bilberry. The estimated annual yield of ceps (kg ha^{-1}) was calculated for each stand by multiplying the number of ceps by the mean fresh weight (76.5 g) of one cep (Miina et al. 2013).

Table 6. Indicator variables and their estimated coefficients in the yield model of cep (modified from the Miina et al. 2013).

Variable	Coefficient
Intercept	-3.3058
Mean of year effects	-0.1027
Stand basal area (m^2 ha^{-1})	0.1589
Stand basal area^2	-0.0044
Stand basal area/(stand age + 5)	4.0766

2.3.4. The economic value of collectable goods

For the optimization of the economic value of collectable goods and timber revenues, the combined economic value of bilberry, cowberry and cep yields was calculated across 50 years planning horizon for each stand. Forest stand data and yields calculated for each stand were grouped in 5-year intervals for 11 time steps. It was assumed that yields do not vary much for a short time period and yields of each time step (except time step 0) were repeated 5 times to get estimated yields for each year. Then, the economic values of each collectable good were calculated for each year and stand and management regime. Finally, the annual values of each collectable good were added up to get the economic value of collectable goods across 50 year planning horizon for each stand as € ha^{-1} (collectable goods NPV). The economic value of collectable goods was calculated through the following equation:

$$Collectable\ goods\ NPV = \sum_{i=1}^{i}\sum_{t=0}^{t}(y_{it}\ \times\ v_i)\ e^{-rt}\,, \tag{6}$$

where collectable goods are denoted by i, years across 50 years planning horizon are denoted by t, yields are denoted by y, economic values of yields are denoted by v and discount rate is denoted by r. Economic values were average market prices of each collectable good from years 2004-2013 in Central Finland, for bilberry: 2.23 € kg^{-1}, for cowberry: 1.16 € kg^{-1} and for cep (*Boletus* sp.): 3.36 € kg^{-1} (MARSI 2009, 2013). Discount rate was the same (3 %) as in the calculations of timber revenues.

2.4. Multi-objective optimization and analyses

To reveal the trade-offs between timber production and the production of collectable goods alternative management plans were analyzed. Each management plan is a combination of management regimes (Table 1) selected for stands. Each management plan is 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 alternative management plans was explored to create production possibility frontiers among ecosystem services, i.e. bi-dimensional planes representing maximum achievable values of services. Further, to reveal how to resolve the trade-offs, combinations of management regimes that maximize the yield of collectable goods at different levels of timber revenues, and vice versa were found out by using multi-objective optimization method (Miettinen 1999). These Pareto optimal plans form a Pareto optimal set. The optimization calculations were done by using IBM ILOG CPLEX optimizer and they were carried out by PhD Dmitry Podkopaev. For further details on the methods of revealing trade-offs and optimization, see Mönkkönen et al. (2014).

Multi-objective optimization was done separately for each yield of collectable goods and timber revenues. Additionally, optimization was done for the economic value of collectable goods and timber revenues. The correlations between different collectable goods when only one management regime option was applied in all stands were also explored. Negative correlations probably indicate trade-offs and positive correlations indicate synergies between the studied collectables.

To illustrate optimal combination of management regimes that maximizes the yields of collectable goods, graphs were made showing how the optimal allocation of management regimes for forest stands changes with increasing the yields of collectables and decreasing timber revenues. Then, results were considered with the focus on 95 % level of timber revenues when society is willing to forego 5 % of the maximum achievable timber revenues for collectable good production and recreational values. The 5 % level is reasonable since Mönkkönen et al. (2014) found that using business as usual in all stands produced 95 % of the maximum timber revenues achievable when an optimal combination of management regimes was applied. This means the current recommended management regime do not produce the maximum timber revenues in the landscape and the society already foregoes 5 % of the potential maximal revenues, and the value might be invested supporting alternative ecosystem services such as recreational services.

3. RESULTS

The maximum total bilberry yield from the entire landscape was close to 440,000 kg year^{-1} (Table 7), i.e. 10.3 kg ha^{-1} year^{-1}. The maximum total cowberry yield from the entire landscape was close to 1,520,000 kg year^{-1} (Table 7), i.e. 35.3 kg ha^{-1} year^{-1}. The maximum total cep yield from the entire landscape was close to 50,000 kg year^{-1} (Table 7), i.e. 1.2 kg ha^{-1} year^{-1}. The maximum economic value of collectable goods across the entire landscape and 50 years planning horizon was approximately 72.4 M€ (Table 7), this translates into a maximal value of 33.6 € ha^{-1} year^{-1} on average. The maximum economic value of timber across the entire landscape and 50 years planning horizon was approximately 193.9 M€, this translates into a maximal value of 90.0 € ha^{-1} year^{-1} on average (Table 7). The economic value of collectable goods is approximately 37 % of the economic value of timber.

3.1. The potential of a landscape to produce collectable goods and timber

Trade-offs between collectable goods and timber production showed a non-linear relationship in the set of Pareto optimal plans and varied depending on the collectable good analyzed (Figure 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, there is potential to produce simultaneously high levels of alternative services.

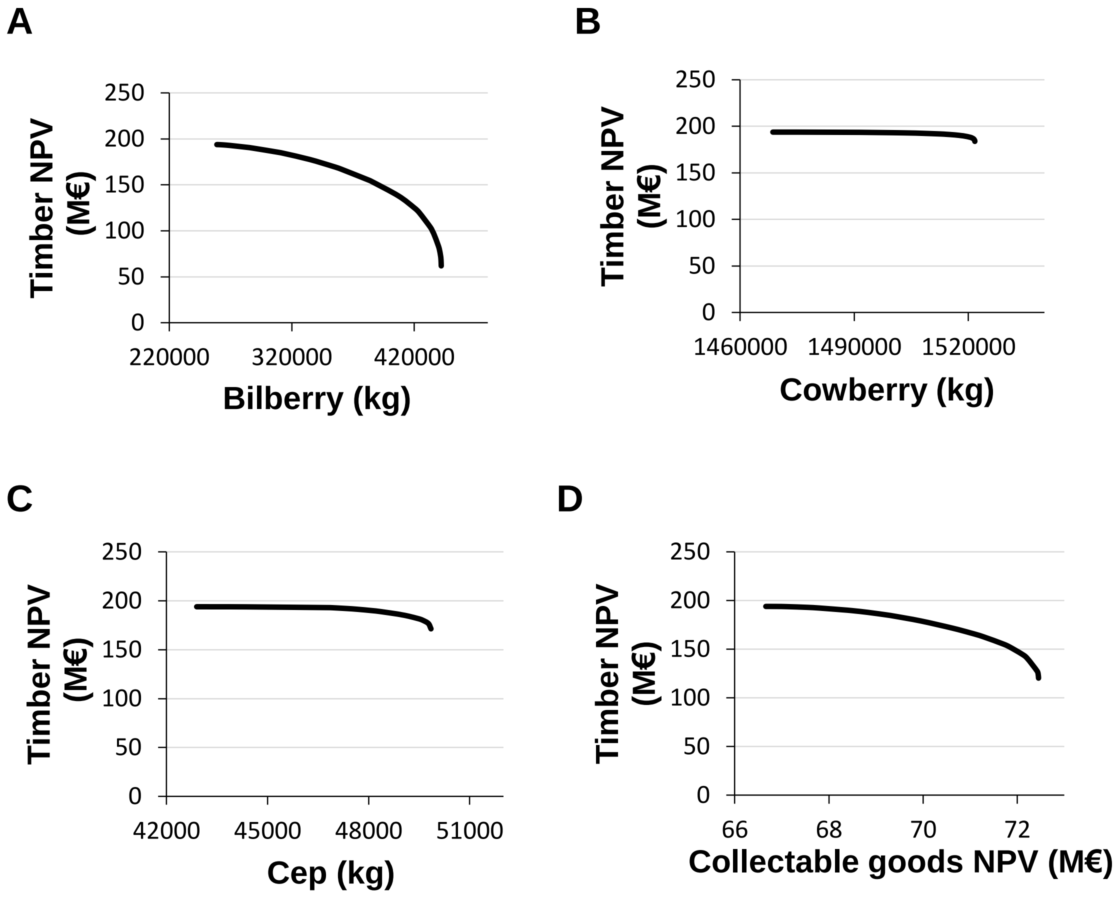

Figure 1. Curves representing Pareto-optimal plans describing the trade-offs between collectable good yields: (A) bilberry, (B) cowberry, (C) cep, (D) the economic value of collectable goods and timber revenues.

In the case of bilberry, differences were quite large between the minimum and maximum yields and between the minimum and maximum timber NPV (Table 7; Figure 1A). This means that there is large potential to increase yields of bilberry but this may result in large losses in timber revenues. The trade-off curve for bilberry versus timber NPV decreased at lower levels of the yield and more rapidly than in other cases (Figure 1A). This means that a unit increment in bilberry yield was more expensive than a unit increment in cowberry or cep yields. In summary, these results indicate that the conflict between timber and bilberry is relatively strong. Relative potential to increase bilberry yield is smaller than the relative timber NPV range which indicates that increasing bilberry yields is more costly for timber production.

In the case of cowberry, there was a small difference between the minimum and maximum yields (Table 7; Figure 1B). Thus, cowberry yield can be affected fairly little by the alternative forest management regimes. Moreover, the difference between the minimum and maximum timber NPV when targeting cowberry is relatively small (Table 7), and thus maximizing cowberry yield is relatively inexpensive. The trade-off curve for cowberry versus timber NPV was fairly flat (Figure 1B). These results indicate that the conflict between timber and cowberry is relatively small.

In the case of cep, there was a relatively small difference between the minimum and maximum yields (Table 7; Figure 1C). Thus, cep yield cannot be much affected by the alternative forest management regimes. The difference between the minimum and maximum timber NPV when targeting cep was higher than that for the cowberry but much lower than for the bilberry (Table 7). The trade-off curve for cep versus timber NPV was fairly flat (Figure 1C). In summary, these results indicate that the conflict between timber and cep is not as severe as for the bilberry.

There was a relatively small difference between the minimum and maximum economic value of collectable goods (Table 7). However, the difference between the minimum and maximum timber revenues was fairly large, and thus maximizing the economic value of collectables was expensive. The trade-off curve between the economic value of collectables and timber was first fairly flat but then declined steeply indicating that in the beginning increasing the economic value of collectables results in small losses in timber NPV but further increments were more expensive (Figure 1D). These results indicate that the conflict between the economic value of collectables and timber is relatively strong.

Table 7. Potential of a landscape to provide the annual yields of collectable goods on average and the economic value of collectable goods (NPV) across 50 years, and costs related to collectable goods provision. *Yield Max* and *Yield Min* -values summarize the range in yields that can be achieved in the landscape at different levels of timber NPV. *Abs. timber NPV diff.* is the absolute difference between the minimum and maximum timber NPV in the Pareto optimal sets (max timber NPV is 193.9 M€ in all cases). *Rel. yield range* and *Rel. timber NPV range* illustrate the potential that exists to improve the yields of collectable goods and the economic value of collectable goods or timber revenues.

	Yield Max	Yield Min	Rel. yield range	Abs. timber NPV diff.	Rel. timber NPV range
Collectable good					
Bilberry	441941 kg	258836 kg	41 %	132.0 M€	68 %
Cowberry	1521692 kg	1468600 kg	4 %	10.1 M€	5 %
Cep	49851 kg	42890 kg	14 %	22.7 M€	12 %
Collectable goods NPV	72.4 M€	66.7 M€	8 %	73.7 M€	38 %

3.2. The optimal combination of management regimes

When a single forest management regime was applied consistently their relative utility varied among different collectable goods (Table 8). None of the single management regimes was able to produce as high values as in the optimal combination of management regimes. This means that a combination of management regimes was needed to maximize the yields. For bilberry, setting aside was the most beneficial strategy and the two regimes with no-thinnings were the least beneficial strategies. For cowberry, business as usual was the most beneficial strategy and setting aside was the least beneficial strategy. For cep, green tree retention was the most beneficial strategy and setting aside was the least beneficial strategy.

For the economic value of collectable goods, business as usual was the most beneficial strategy and extended rotation 30 years was the least beneficial strategy (Table 8). However, for the economic value of collectable goods the differences in the utility among the regimes were rather small (6.7 M€). It is notable that the maximum economic value that can be achieved applying the business as usual regime consistently is equal to the optimized minimum value with a combination of regimes. In other words, optimizing at the landscape level always provides economic benefits in terms of collectables.

Table 8. Annual yields of collectable goods on average and the economic value of collectable goods across 50 years (NPV) for alternative management regimes if only one management regime is used in all stands. The largest yield of alternative management regimes is given in bold. *% of Max* is the proportion of the yield compared to the maximum yield in the Pareto optimal set (Table 7).

	Management regime						
	BAU	SA	EXT10	EXT30	GTR30	NTSR	NTLR
Collectable good							
Bilberry (kg)	265755	**428165**	285367	303468	273022	223485	241150
% of Max	60 %	97 %	65 %	69 %	62 %	51 %	55 %
Cowberry (kg)	**1490555**	1088733	1415946	1299060	1380769	1468249	1365181
% of Max	98 %	71 %	93 %	85 %	91 %	96 %	90 %
Cep (kg)	42449	34514	42587	35539	**44404**	41665	40770
% of Max	85 %	70 %	85 %	71 %	89 %	84 %	82 %
Collectable goods							
NPV (M€)	**66.7**	63.5	63.9	60.0	63.3	65.1	62.3
% of Max	92 %	88 %	88 %	83 %	87 %	90 %	86 %

There were no strong correlations between the yields of individual collectable goods if only one management regime was applied in all stands (Table 9). Bilberry correlated positively with cowberry in set aside regime and positively with cep in the extended rotation regimes indicating weak synergies in those cases. Between cowberry and cep, there were weak positive correlations in set aside regime and negative correlations in other management regimes. These negative correlations indicate trade-offs between cowberry and cep production. Positive correlation was found between all pairs of collectable goods in set aside regime.

Table 9. Pairwise Spearman correlations (rhos) between different collectable goods when one management regime is applied in all stands.

Management regime	Bilberry and cowberry	Bilberry and cep	Cowberry and cep
BAU	0.12	0.24	-0.46
SA	0.41	0.26	0.32
EXT10	0.07	0.37	-0.41
EXT30	0.15	0.38	-0.27
GTR30	0.24	0.15	-0.39
NTSR	0.13	0.25	-0.47
NTLR	0.07	0.23	-0.34

The combination of management regimes that maximized the timber production (NPV) (193.9 M € across the 50 year planning period) consisted of the business as usual, no-thinnings and green tree retention regimes (Table 10). The proportion of alternative management regimes, with increasing yields of collectable goods in the Pareto optimal solutions, was different for bilberry, cep, cowberry and the economic value of collectable goods (NPV) (Figure 2).

If the society is willing to forego 5 % of the maximum timber revenues, bilberry yields increased over 10 % (Table 10, Figure 2A) which is almost as much as in the case of cep that increased the most. However, bilberry yields were still far from the maximum in the Pareto optimal set. This was achieved by decreasing business as usual and no thinning short rotation regimes and by increasing set aside, extended rotation ten years and green tree retention regimes.

Cowberry yields were already maximized if timber NPV level were 95 % but improvement in yield was the smallest (Table 10, Figure 2B). This was achieved by decreasing business as usual and green tree retention regimes and increasing no-thinning short rotation regimes.

Cep yields were almost maximized when timber revenues were 95 % of the maximum and improvement in yields was the largest (Table 10, Figure 2C). This was achieved by decreasing business as usual management regime and increasing green tree retention and extended rotation 10 years regimes.

The economic value of collectable goods was close to the maximum value in the optimal set when timber NPV was 95 % of the maximum (Table 10, Figure 2D). Improvement in the economic value of collectables was about the same as in the case of cowberry. In monetary terms, this means that 9.7 M€ costs in timber revenues result 3.1 M€ increments in the economic value of collectable goods. This was achieved by increasing business as usual and set aside regimes and decreasing green tree retention and no thinnings regimes (Table 10).

Table 10. Changes in units in the share of different management regimes in the Pareto optimal set at the 5 % level of collectable good costs (95 % of the maximum timber revenues) for the different collectable goods. First row gives the share when the target is to maximize timber NPV. *% of Max yield* is the proportion of the yield in the Pareto optimal set at the 5 % level of collectable good costs compared to the maximum yield obtained in the optimal combination of management regimes. *Impr. in yield* is how large improvement in yields (in % units) can be gained if timber NPV is reduced 5 %.

	Management regime							% of Max yield	Impr. in yield
	BAU	SA	EXT10	EXT30	GTR30	NTSR	NTLR		
	64.6	0.1	0.4	0.0	7.8	23.9	3.2		
Collectable good									
Bilberry	-6.2	5.1	3.8	0.4	3.3	-6.7	0.4	71 %	12 %
Cowberry	-4.9	0.0	2.3	1.1	-7.6	7.1	1.9	100 %	3 %
Cep	-30.2	0	5.4	0	25.2	-2.4	1.8	99 %	13 %
Collectable goods NPV	6.2	5.1	1.0	0.1	-7.8	-1.6	-3.1	96 %	4 %

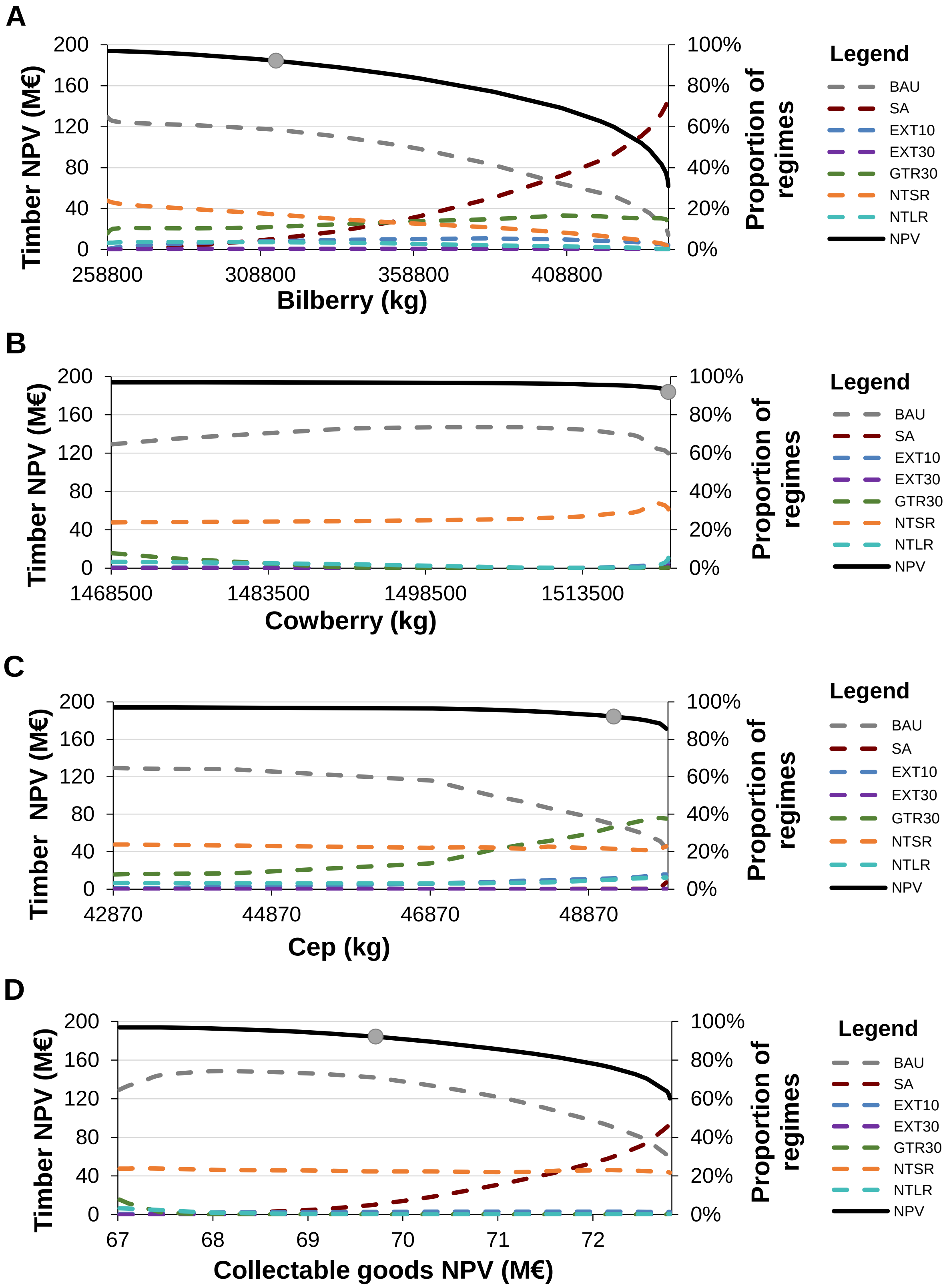

Figure 2. Changes in the proportion of the alternative management regimes with increased levels of collectable goods and the economic value of collectable goods in the Pareto optimal sets. Changes are given for (A) bilberry, (B) cowberry, (C) cep and (D) the economic value of collectable goods (D). Left-hand of the x-axis refers to situations where timber revenues (NPV, the black solid line) are maximized. Y-axis describes how much each management regime should be applied with increased production of collectable goods. Grey dots represent 95 % level of the maximum timber revenues.

4. DISCUSSION

This study revealed that in the boreal forest landscape, there is the potential to produce simultaneously high levels of collectable goods and timber revenues, i.e. there is the potential to increase the recreational and economical values of collectable goods with small economical costs in timber revenues. However, the potential within collectable goods varied and conflicts between different collectable goods and timber production were case specific. The strongest conflict was between the bilberry yield and timber production. A clear conflict was also found between the economic value of collectable goods and timber revenues. A slight conflict was found between the cep yield and timber revenues but for the cowberry yield the conflict was negligible. Thus, cowberry yields can only marginally be affected by modifying the forest management regimes considered in this study.

None of the management regimes if applied constantly in the landscape were able to produce as high yields as the Pareto optimal set. This clearly indicates the benefits of landscape level forest management planning and optimization. Maximizing bilberry yields was most costly in terms of losses in timber revenues. If society is willing to forego 5 % of the maximum timber revenues across 50 years, values close to maximum were obtained for cep yields and maximum values for cowberry yields. Optimal combinations of management regimes were different for different collectable goods. In addition, weak conflicts between collectable goods were found when one management regime was applied in all stands. This evidence suggests that maximizing all collectable good yields with timber production might require diverse sets of alternative regimes in the landscape. The potential economic value of three collectable goods across the landscape was approximately one third of the economic value of timber. The optimal combination of management regimes required for the economic value of collectable goods was also different than the optimal combination for each individual collectable good.

4.1. Conflicts between the collectable goods and timber production

High costs of increasing bilberry yields result from the increased proportion of setting aside management regime, which does not provide any monetary incomes from timber. Timber production was the highest when business as usual, no-thinnings and green tree retention regimes were applied in the landscape. For bilberry, when only one management regime was applied constantly across the all stands, the smallest yields were in those regimes that maximized the timber revenues. The sensitivity of bilberry for soil preparation and clear-cuttings (Miina et al. 2009, Hedwall et al. 2013) can explain these results. Clear-cuttings create too open conditions and bilberry needs tree cover. However, it is likely that too dense forests decrease bilberry production, which can explain why no-thinnings regimes gave small yields. A similar conflict between bilberry and timber production was found in the study carried out in the Swedish boreal forest (Gamfeldt et al. 2013).

Management regimes applied in the study did not affect much the cowberry yields, which explains the negligible conflict between cowberry and timber production. Moreover, cowberry is not as sensitive to forest management as bilberry (Turtiainen et al. 2013) so forest regimes that produce high timber revenues are not so harmful for cowberry. The smallest cowberry yield if only one management regime was consistently applied was in set aside regime, because forest cover is too dense for cowberry as a light-demanding species. Cowberry yields might have been even higher if there had been a management regime with increased thinnings because of better light conditions (Miina et al. 2010). It has been shown that cowberry yields are the highest in young forest stands and after thinnings (Turtiainen et al. 2013). If there had been a management regime that reduces the canopy cover of trees, like a regime with increased thinnings, the conflict between cowberry and timber production might be larger.

The small conflict between cep and timber production is because of the increased proportion of green tree retention regime and the decreased proportion of business as usual regime. Stand basal area and stand age were the only variables in the cep model used in this study. The model assumes that cep benefits from large stand basal area (Miina et al. 2013) and in green tree retention management regime, stand basal area is not so small after clear cuttings because of retention trees, which could explain the result.

The largest contribution to the economic value of collectable goods was provided by cowberry and the second largest contribution was provided by bilberry since the yields (Table 7) and also monetary values of yields of the berries where considerably larger than the values of cep. This means that in the case of maximizing the economic value of collectables, management regimes that maximize the production of cowberry and bilberry are emphasized. Regimes affected cowberry production relatively little and therefore the management regime that maximizes the bilberry production (set aside) is highlighted when increasing the economic value of collectable goods. Set aside regime does not provide any monetary incomes from timber thus the conflict between the economic value of collectables and the economic value of timber is apparent.

4.2. Optimal forest management to maximize alternative ecosystem services

In the optimal set, increasing bilberry yields required increasing setting aside, extended rotation 10 years and green tree retention management regimes (Figure 2A). Miina et al. (2010) optimized the joint production of bilberries and timber and also found that compared to timber production, joint production led to 10–20 years longer rotation lengths but in addition, higher thinning intensities and more frequent thinnings, especially in spruce dominated stands where canopy shading is high. If there had been a management regime, e.g with higher thinning intensity (Miina et al. 2010, Hedwall et al. 2013) or selective logging (Atlegrim & Sjöberg 1996, Pukkala et al. 2010), perhaps the proportion of setting aside regime would had not been so high and monetary costs of timber revenues would be smaller.

Decreasing business as usual and green tree retention regimes and increasing no-thinning short rotation regimes could attain maximum cowberry yields in the optimal set (Figure 2B). Cowberry is a light demanding species and produces the highest yields in clear-cutting areas, near the edges and in sparse mature pine-dominated (Salo 2008). Business as usual, green tree retention and no-thinning short rotation are regimes that provide those characteristics more often. Miina et al. (2010) suggested that increased thinnings could be an optimal management regime for producing simultaneously cowberry and timber because of better light-conditions.

In the optimal set management regimes green tree retention and extended rotation 10 years increased with cep production (Figure 2C). Palahí et al. (2010) studied joint production of mushrooms and timber in Central Pyrenees and joint production led to increased thinnings and also longer rotation lengths. Although short-term effect of thinnings is negative, long-term effect can be positive since mushrooms benefit from lower stand basal areas that affects positively the growth of host trees (Egli et al. 2010). Cep is a symbiotic mushroom which yields are usually highest when the wood volume growth of the host tree is the highest (Bonet et al. 2008). More frequent thinnings and higher thinning intensities can promote the growth of trees (Hynynen et al. 2005). On the other hand, symbiotic mushrooms survive better when host trees are older (Egli et al. 2010) which supports the result of increased proportion of extended rotation regime. However, Miina et al. (2013) found while developing the model also used in this study, that cep yields were the largest in 20-40 years old spruce dominated forests. They had four different management regimes and cep yields were the smallest in no thinnings regime, the second smallest in later thinnings regime, the second largest in business as usual regime and the largest in earlier thinnings regime.

Increasing recreational values provided by different collectable goods requires diverse set of management regimes because different collectable goods benefit from different regimes. Miina et al. (2010) suggested that more frequent thinnings and higher thinning intensities could promote the yields of bilberry, cowberry and mushrooms simultaneously. Interestingly, in set aside regime, there was a synergy between all collectable goods. Set aside is the best management regime for biodiversity (Mönkkönen et al. 2014) so the result supports the hypothesis that maintaining multiple ecosystem services requires higher levels of biodiversity (Cardinale et al. 2012). On the other hand, this result could be interpreted considering the concepts of land sparing and land sharing (Mastrangelo et al. 2013). Synergy between all collectable goods in set aside regime supports the strategy of land sparing; perhaps, there could be separate areas in the landscape for collectable goods and timber production.

Optimal management to maximize the economic value of collectable goods and timber consisted of business as usual, no thinning short rotation and set aside regimes (Figure 2D). Set aside is beneficial for bilberry and other regimes are beneficial for cowberry. However, at the 95 % level of timber revenues, business as usual and set aside regimes increased and green tree retention regime decreased when targeting on the economic value of collectable goods (Table 10). Bilberry benefits from increasing set aside regime and cowberry benefits from decreasing green tree retention regime. Interestingly, none of the collectable goods required the increment of business as usual regime at the 95 % level of timber revenues. A conflicting result can be explained by the fact that maximizing different collectable good yields requires different management regimes and this can be challenging when the budget constraint of timber revenues is 95 %. Increasing business as usual regime can be a compromise solution between different collectable goods that produces average cowberry yields (Figure 2B).

4.3. Reliability of the models

There was variation in the reliability of the models used for this study. Bilberry models have been calibrated for mineral soil sites (Miina et al. 2009) but in this study the models were used for all soil types. The coverage model (Eq. 1) can be applied to whole Finland, but the yield model (Eq. 2) was modelled using data from North Karelia so using the model in Central Finland makes estimated yields less reliable. Information on regeneration type or history of stands was not available. Bilberry is vulnerable to soil preparation (Miina et al. 2009) and it was assumed that all stands were regenerated artificially (planted or seeded) including usual soil preparation. However, in the landscape, there are probably stands that are regenerated naturally (seed trees) and for these stands yield estimates are lower (except in set aside management regime where all stands were assumed to be naturally regenerated). For example, in year 2012, approximately 16 % of forested area was regenerated naturally in Finland (Finnish statistical year book of forestry 2013). It was assumed that all stands had been previously forested land but if there were stands that were formally agricultural land, the yields were overestimated in those stands. However, in Central Finland, there are very few forested areas that have been previously agricultural land. For example, in year 2013, about 190 ha of agricultural land were forested in Central Finland (Metinfo tilastopalvelu 2014). In addition, the model underestimated bilberry yields, especially in mature spruce stands (Miina et al. 2009). These circumstances may underestimate the yields of bilberry in this study as well, and enhance the importance of set aside regime just because of the assumption in the regeneration method (Eq. 1). The proportion of bilberry in the combined economic value of collectable goods (Eq. 6) may be underestimated and the combined economic value of collectables might be even larger.

The coverage model of cowberry (Eq. 3) was calibrated for mineral soils and also many other sites where cowberry grows in the field layer (e.g., mires) (Turtiainen et al. 2013), but estimates of mineral soils were used for all sites. The model of cowberry yield (Eq. 4) was only for mineral soils. Lack of knowledge on the history of the stands creates the same kind of uncertainty than in the case of bilberry. Data used in the model development of cowberry yield model included some limitations and most reliable results are given for pine-dominated stands in sub-xeric heath sites (Turtiainen et al. 2013). Compared to other yield models of cowberry, this model produces higher yield estimations (Turtiainen et al. 2013) and therefore the cowberry yields of this study may also be overestimated. This means that the proportion of cowberry in the combined economic value may be overestimated as well (Eq. 6). However, the market value of cowberry is only about half of the market value of bilberry so probably, the effect of overestimated cowberry yields to the economic value of collectable goods is not as large as the effect of underestimated bilberry yields.

The cep model (Eq. 5) was developed for spruce dominated forest stands in Eastern Finland (Miina et al. 2013). The model was developed based on three years observations and therefore it is still uncertain how robust the model results are for other parts of Finland and for other years. The model was used for all forest stands, not only for spruce dominated stands, so yield estimates of cep should be interpreted with caution. The proportion of cep of the economic value (Eq. 6) was small since the estimated cep yields were considerably smaller than the bilberry and cowberry yields. Thus, the uncertainty of the cep yields does not affect severely the combined economic value of collectable goods.

4.4. Alternative services provided by the collectable goods

Collectable goods production and timber production are both provisioning ecosystem services but collectable goods have also recreational values (Salo 1995, Pouta et al. 2006). Timber production was valued using economic valuation and results are in economic returns. However, collectable goods were in kilograms and yields can be thought to represent recreational values. In Nordic countries, every man’s rights enable all citizens to have free access to pick berries and mushrooms (Salo 1995). In Finland, approximately 60 % of forests are privately owned and in central Finland, even 75 % (Finnish statistical year book of forestry 2013). The costs of promoting e.g., bilberry yields could go for private forest owners and benefits of increased recreational values for all citizens. 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 the land management by the private forest owner (Polasky et al. 2014). Payments for ecosystem services are used to translate non-market values of ecosystem services into financial incentives for local land users to provide the services (Engel et al. 2008). However, the concept of payments for ecosystem services is controversial and should be considered carefully (Schröter et al. 2014). Especially, considering ecosystem services as positive externalities might not be reasonable because defining the minimum level of service provisioning is complex and can generate a situation where all ecosystem services are considered as positive externalities to be rewarded (van Hecken & Bastiaensen 2010) which can lead to commodification of environment even more.

In the case of the economic value of collectable goods, it is also important to consider who might benefit from the economic value that is considerably large, 37 % of the timber revenues. Again, because of everyman’s right, anybody can pick collectable goods from the forest and in addition, selling of collectable goods at the market is tax-free (Salo 1995). Private persons as well as companies can make money from collectable goods. In year 2012, Finnish companies practicing berry and mushroom business earned 25 M€ from berry picking and 1 M€ from mushroom picking (Finnish statistical year book of forestry 2013). In addition to domestic trade, bilberries are exported mainly to Japan and China, and cowberries to Central Europe (MARSI 2013). Almost all commercially picked ceps are exported to Southern and Central Europe. However, the economic value of collectable goods in this study does not include costs related to harvesting or cleaning of berries and mushrooms, while in the economic value of timber costs related to timber production were taken into account. The economic values of alternative services are not directly comparable. In addition, the economic value of collectable goods is only a potential value since picking all collectable goods from the landscape is not possible.

Targeting on collecting all collectables is not reasonable, since berries and mushrooms are also a valuable resource for a number of species and therefore biologically important. Berries and mushrooms are also important food for many herbivores (Selås et al. 2011, Turtiainen et al. 2013). Bilberry is a source of food for game, such as capercaillie (*Tetrao urogallus*) (Stroch 1993, Lakka and Kouki 2009). Gamfeldt et al. (2013) found a synergy between bilberry and game production. Fungi with large fruit bodies are habitats and food for many specialist invertebrate species (Hanski 1989, Shaw 1992) and there are fungal species living in berry species (e.g., Aamlid 2000). One *Boletus* fruiting body includes different stages from its appearance to decay and each stage has different specialized invertebrate species (Hanski 1989). In conclusion, harvesting all the berries and mushrooms from the landscape might not be ecologically sustainable.

Long-term effect of mushroom picking has been studied in Switzerland (Egli et al. 2006). Study revealed that systematic harvesting of mushrooms did not reduce the future yields of fruit bodies. However, forest floor trampling reduced fruit body numbers. Short-term study of commercial berry picking in Finland showed that current commercial picking methods do not damage the berry production (Manninen et al. 2013). However, long-term effects of commercial berry picking are not known and concern over sustainability of picking exists.

4.5. Conclusions

This study showed the opportunity to increase recreational values with small economical costs in the boreal forest landscape by applying multi-objective optimization method. With careful forest management planning it is possible to simultaneously produce high levels of collectable goods and timber at the landscape level. In addition, the results of this thesis support earlier results and prove that collectable goods are economically very valuable. In this study, the economic value of collectable goods consisted of bilberry, cowberry and cep. There are also many other berry and mushroom species so the value of collectable goods in boreal forest might be even larger. However, the combined economic value is only approximate and it is not recommended or realistic to harvest all the berries and mushrooms from the landscape. Nevertheless, both recreational and economical values of collectable goods are notable which emphasizes the potential to move towards multiple use forestry.

The results of this study can be applied to the forest management targeting to produce collectable goods and timber revenues simultaneously, like in communal forests near residential areas. Bilberry is the most abundant in mesic heath forest type where Scots pine is a dominating tree (Miina et al. 2009); set aside, green tree retention and extended rotation management regimes could be targeted for those kinds of stands to promote bilberry production. Cowberry is the most abundant in sub-xeric heath forest stands that are Scots pine dominated (Turtiainen et al. 2013); no-thinning short rotation and business as usual regimes that promote cowberry production could be targeted for those stands. Cep is the most abundant in mesic heath forests that are Norway spruce dominated (Miina et al. 2013); green tree retention and extended rotation by 10 years regimes could be targeted for those kinds of stands.

In the future, it would be important to study how the production of collectable goods and recreational services affect other ecosystem services besides timber production, like biodiversity or regulating services such as carbon storage. Recognizing possibilities of enhancing multiple ecosystem services simultaneously is crucial for stopping the ecosystem services degradation, and for guaranteeing that those ecosystem services indispensable for human wellbeing (e.g., supporting and regulating services) are also available for future generations. This study highlights the importance of understanding the interactions between different ecosystem services and forest managements. It is not sustainable to focus just on maximizing one ecosystem service when it would be possible to provide multiple services simultaneously in the forest landscape with careful forest planning.

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