Silva Fennica vol. 50 no. 5 article id 1672, available at http://dx.doi.org/10.14214/sf.1672

Supplementary file

Maiju Peura, Maria Triviño, Adriano Mazziotta, Dmitry Podkopaev, Artti Juutinen, Mikko Mönkkönen

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

1 Timber harvest revenues

The timber harvest revenues values were taken from the study of Mönkkönen et al. (2014). The net present value (NPV) of timber harvest revenues was calculated using the following equation:

$$\text{Timber NPV} = \sum_{k=1}^{K}\sum_{t=0}^{T} p_k(h_{kt}^{a} + h_{kt}^{b})e^{-rt} + \sum_{k=1}^{K} p_k h_{kT}^{c}\, e^{-rT} + SEV e^{-rT} - \sum_{s=1}^{S}\sum_{t=0}^{T} C_{st} e^{-rt} \qquad \text{(Eq. S1)}$$

All timber assortments (pulp wood and saw logs of pine (*Picea Abies* L.), spruce (*Pinus silvestris* (L.) H. Karst.) and two birch species (*Betula pendula* Roth, *Betula pubescens* Ehrh.)), denoted by *k* are included in the calculation of the NPV. Stumpage price (€ m^{-3}) for timber assortment *k* is denoted by *pk* (Table S1a). Time is denoted by *t* and discount rate by *r*. We consider a 50-year planning horizon (*T*= 50) divided into ten 5-year periods. Three percent (3%) real interest rate was used. The NPV consists of four revenue components. The first component, denoted by superscript *a*, concerns harvest revenues from thinnings, and the second component, *b*, revenues from final harvest (clear-cutting). The third component *c* estimates the harvest value of standing timber at the end of the simulation, *T*. This residual component was added because there are stands in our data that are not final-harvested during the simulation period. Thus, the residual approximates the revenues from future final harvest in those stands. The harvest volumes (m^3) for each timber assortment *k* and time period *t* are denoted for these three components by h_{kt}^{a}, h_{kt}^{b} and h_{kt}^{c} respectively. The fourth revenue component is the soil expectation value (SEV), which takes into account the harvest revenues from all future rotations (Table S1b). In addition, the NPV includes silvicultural costs C_{st} for different work component *s* (s=5, Table S1c).

Reference

Mönkkönen M., Juutinen A., Mazziotta A., Miettinen K., Podkopaev D., Reunanen P., Salminen H., Tikkanen O. (2014). Spatially dynamic forest management to sustain biodiversity and economic returns. Journal of Environmental Management 134: 80–89. http://dx.doi.org/10.1016/j.jenvman.2013.12.021.

Table S1 The values used in timber NPV calculations.

a) Stumpage prices (€ m^{-3}) for pulp wood and saw log of different tree species in thinnings and final cut.

	1st and 2nd thinning		final cut	
	pulp wood	saw log	pulp wood	saw log
pine	14	47	16	55
spruce	15	47	17	55
birches	14	37	16	42

b) Soil expectation values (SEV, € ha^{-1}) for each forest site type.

Herb rich	Herb rich heat	Mesic heat	Sub-xeric heat	Xeric heath	Barren heath
440	440	320	230	170	50

c) Costs related to silvicultural actions (€ ha^{-1}).

Natural regeneration	Planting	Seeding	Tending of seedling stands	Cleaning of sapling stands
0	1,100	550	380	400

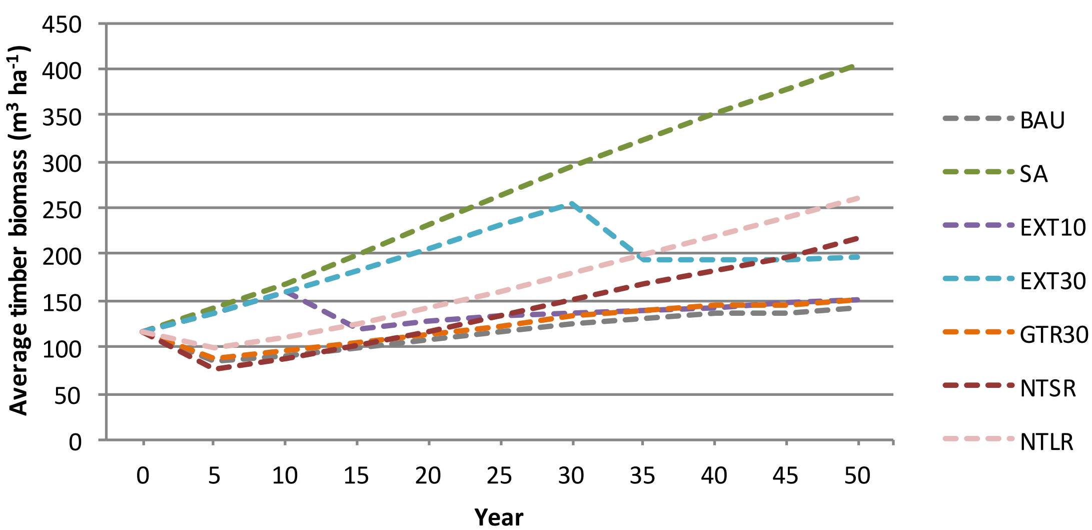

Fig. S1 Average timber biomass (m^3 ha^{-1} $year^{-1}$) per time-step for the 50 years period under alternative management regimes *BAU* (business as usual), *SA* (set aside), *EXT10* (extended rotation 10 years), *EXT30* (extended rotation 30 years), *GTR30* (green tree retention), *NTSR* (no thinnings short rotation), and *NTLR* (no thinnings long rotation).

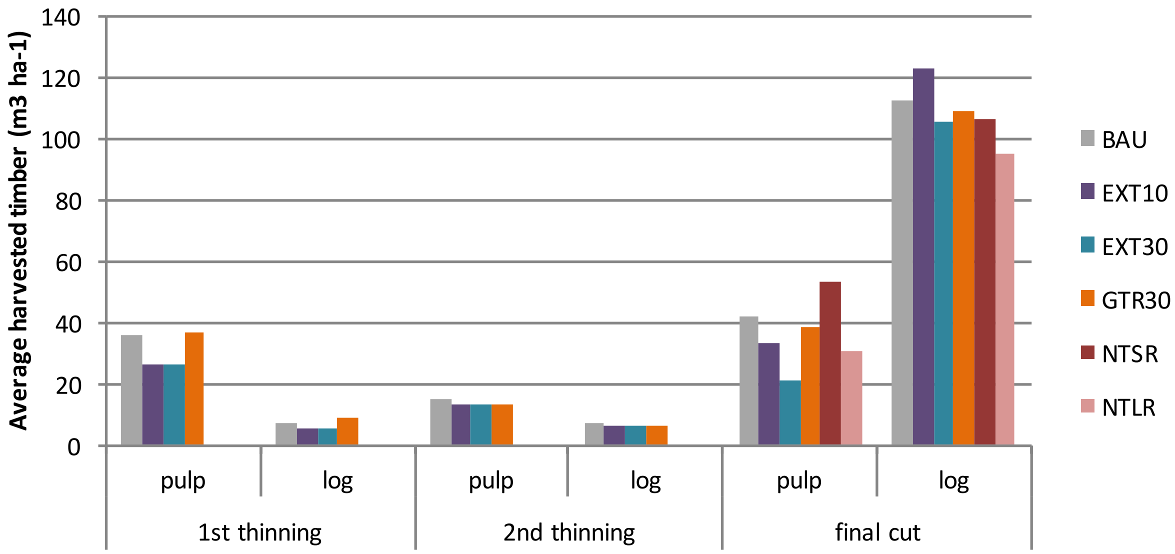

Fig. S2 Average amounts of harvested pulp wood and saw logs from the 1st and 2nd thinning and from the final cut under alternative management regimes *BAU* (business as usual), *EXT10* (extended rotation 10 years), *EXT30* (extended rotation 30 years), *GTR30* (green tree retention), *NTSR* (no thinnings short rotation), and *NTLR* (no thinnings long rotation).

2 Collectable goods yields

2.1 Bilberry

We calculated bilberry yields (*Vaccinium myrtillus* L.) using models developed by Miina et al. (2009). We predicted the coverage of bilberry as a function of several indicator variables (Eq. S2) and then, we translated bilberry coverage into bilberry yield as a function of coverage and stand basal area (Eq. S3,S4) as follows:

$$BilbCov = 100 \times \frac{1}{1+exp\{-f(\cdot)\}} \quad \text{(Eq. S2)}$$

$$f(\cdot) = -3.8470 - 2.1815 \times SiteI - 0.4809 \times SiteII - 0.4807 \times SiteIV - 1.5053 \times SiteV + 0.1209 \times Pine - 0.4770 \times Birch \times SiteII - 0.2588 \times ArtReg - 1.4715 \times FormAgr + 0.0029 \times Alt + 0.0080 \times T - 0.0021 \times T^2/100 + 0.0947 \times G - 0.1916 \times G^2/100$$

$$Bilberries\ spruce = \exp\{-0.5359 + 0.2398 \times BilbCov - 0.2812 \times BilbCov^2/100\} \quad \text{(Eq. S3)}$$

$$Bilberries\ pine = \exp\{-4.2024 + 0.3635 \times BilbCov - 0.4798 \times BilbCov^2/100 + 0.3742 \times G - 1.3447 \times G^2/100\} \quad \text{(Eq. S4)}$$

where *BilbCov* is the mean coverage of bilberry in the stand (%); forest site types are *SiteI* = herb-rich, *SiteII* = herb rich heath (*Oxalis-Myrtillus* group), *SiteIV* = sub-xeric heath (*Vaccinium* group) and *SiteV* = xeric heath forest (*Calluna* group) (reference: *SiteIII* = mesic heath (*Myrtillus* group)); *Pine* and *Birch* are dominating tree species Scots pine and birches (*Betula pendula* and *B. pubescens*) (reference: Norway spruce); *ArtReg* is artificial regeneration method (reference: natural); *FormAgr* is former agricultural land (reference: former forest); *Alt* is altitude (m); *T* is stand age (years); *G* is stand basal area (m^2 ha^{-1}) (Table S2). *Bilberries spruce* and *Bilberries pine* are the mean number of bilberries per m^2 in pine- and spruce-dominated stands. If the stand was deciduous tree dominated, we used the coefficients of Scots pine dominated stands (Miina et al. 2010). In a mixed stand, we first calculated the yield for each tree species using the total stand basal area as a predictor in the models (Miina et al. 2010). We assumed stand 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, we calculated the yield 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. We assumed 80% of unripe berries to become ripe (Ihalainen et al. 2003, Miina et al. 2010). Finally, we calculated the prediction of bilberry yield (kg ha^{-1}) 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).

2.2 Cowberry

We calculated cowberry (*Vaccinium vitis-idaea* L.) yields using models developed by Turtiainen et al. (2013). We predicted the coverage of cowberry as a function of several indicator variables (Eq. S5) and then, we translated cowberry coverage into cowberry yield as a function of cowberry coverage, stand basal area, altitude and temperature sum (Eq. S6) as follows:

$$CowbCov = 100 \times \frac{1}{1+exp\{-f(\cdot)\}} \quad \text{(Eq. S5)}$$

$$\begin{aligned} f(\cdot) = &-4.7902 - 5.1730 \times SiteI - 2.5690 \times SiteII - 0.4216 \times SitetIII - 0.4185 \times SiteV \\ &- 0.4327 \times Spruce \times (SiteI \text{ or } SiteII \text{ or } SiteIII) \\ &- 0.7528 \times Birch \times (SiteI \text{ or } SiteII \text{ or } SiteIII) - 0.9438 \times FormAgr \\ &+ 2.5592 \times 1000/TSum - 0.0039 \times Alt + 0.0106 \times T + 0.0157 \times G \end{aligned}$$

$$\begin{aligned} Cowberries = \exp\{&6.7253 + 0.0966 \times CowbCov - 0.0837 \times CowbCov^2/100 - 0.4716 \times \ln(G+1) - \\ &0.0071 \times Alt - 4.6264 \times 1000/Tsum\} \end{aligned} \quad \text{(Eq. S6)}$$

where *CowbCov* is the mean coverage of cowberry in the stand (%); *Spruce* is indicator variable for Norway spruce as a dominating tree species (reference: Scots pine); *TSum* is temperature sum (dd); other variables are defined as in the case of bilberry. *Cowberries* variable is the mean number of ripe cowberries per m^2. Finally, we calculated the prediction of cowberry yield (kg ha^{-1}) 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).

2.3 Cep

We calculated cep (*Boletus edulis* Bull.) yields using a model developed by Miina et al. (2013). We estimated the yields of cep as a function of stand basal area and stand age (Eq. S7) as follows:

$$Ceps = \exp\{-3.4085 + 0.1589 \times G - 0.0044 \times G^2 + 4.0766 \times G/(T+5)\} \quad \text{(Eq. S7)}$$

where *Ceps* are the number of ceps in 400 m^2 area and we transformed the yield to the number of ceps per hectare; other variables are defined as above. We calculated the estimated annual yield of ceps (kg ha^{-1}) for each stand by multiplying the number of ceps by the mean fresh weight (76.5 g) of one cep (Miina et al. 2013). For more information on all indicator variables, please see Table S2.

Table S2 Variables, their meanings and sources if data is somewhere else than from the output of the forest growth simulator MOTTI used in this study. There is a mark (*) if there were limitations in the data.

Variable	Explanation
Altitude (m)	The average stand altitude that have been calculated from a 25 m resolution Digital Elevation Model for each forest stand.
Dominating tree species	The tree species with the largest stand basal area: Scots pine, Norway spruce or deciduous trees (*Betula pendula* and *B. pubescens*).
History of the stand	Forest or former agricultural land. * Information on the history of stands was not available so we assumed all stands to be previously forested land.
Regeneration method	Natural or artificial (sowing and planting). * Information on the regeneration method was not available so we assumed the regeneration method to be artificial for all management regimes.
Site type	I = herb-rich, II = herb rich heath (*Oxalis-Myrtillus* group), III = mesic heath (*Myrtillus* group), IV = sub-xeric heath (*Vaccinium* group), and V = 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 so we assumed that there are no bilberries or cowberries in those stands.
Stand age (years)	The dominating age of trees.
Stand basal area (m^2 ha^{-1})	The sum of basal areas of different tree species (pine, spruce and two birch species).
Temperature sum (dd)	We assumed temperature sum to be constant through 50-year planning horizon and we used an average temperature sum from five decades. The temperature sum was extracted from the output of the SIMA 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. The values are given in a grid for the stands of the National Forest Inventory (NFI), and we have associated them 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.

References

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

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

Miina J., Kurttila M., Salo K. (2013). Kauppasienisadot itäsuomaisissa kuusikoissa – koealaverkosto ja tuloksia vuosilta 2010–2012. Working Papers of the Finnish Forest Research Institute 266 [in Finnish with English summary]. http://www.metla.fi/julkaisut/workingpapers/2013/mwp266.htm.

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

Strandman H., Väisänen H., Kellomäki S. (1993). A procedure for generating synthetic weather records in conjunction of climatic scenario for modelling of ecological impacts of changing climate in boreal conditions. Ecological Modelling 70: 195–220. http://dx.doi.org/doi:10.1016/0304-3800(93)90057-Y

Tieteen termipankki (2014). http://tieteentermipankki.fi/wiki/Kasvitiede:sekamets%C3%A4 [in Finnish] [accessed 20 Jun 2014].

Turtiainen M., Miina J., Salo K., Hotanen J.P. (2013). Empirical prediction models for the coverage and yields of cowberry in Finland [online]. Silva Fennica 47:22. http://dx.doi.org/doi:10.14214/sf.1005.

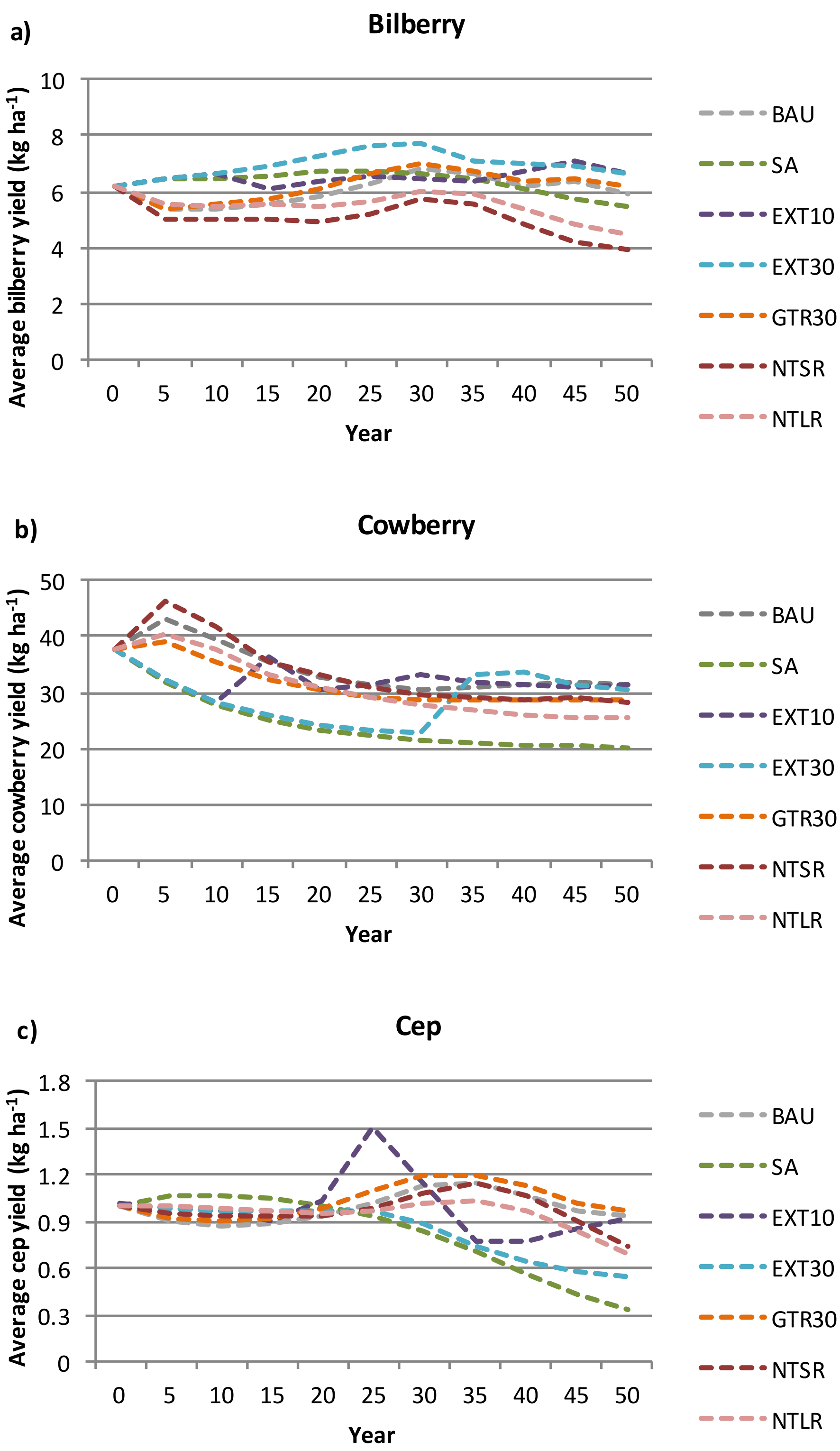

Fig. S3 Average a) bilberry, b) cowberry and c) cep yields (kg ha^{-1}year^{-1}) per time-step for the 50 years period under alternative management regimes *BAU* (business as usual), *SA* (set aside), *EXT10* (extended rotation 10 years), *EXT30* (extended rotation 30 years), *GTR30* (green tree retention), *NTSR* (no thinnings short rotation), and *NTLR* (no thinnings long rotation).