# Decreasing harvesting pressure increases the multifunctionality and biodiversity values of forest landscape – Cost-effective enhancement of forest multifunctionality can also be achieved via landscape level planning

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## Abstract

Commercial forest management can have a great effect to the biodiversity and ecosystem service values produced by a forest landscape. In this forest growth simulation study, the aim was to compare the effect of varying forest harvesting intensity to the forest biodiversity, ecosystem services and bioenergy potential in short (20 year) and long (100 year) time perspective. We also analysed the effect of diversifying forest management regimes by creating an optimal forest management model for two different optimization targets (Max Net Present Value with 4 % discount rate and Max Multifunctionality). For both target models, we produced two alternative optimizations where the forest management options were either restricted to different Business as usual (Rotation Forestry) regimes or not restricted at all, allowing also the use of continuous cover forestry. The economic sustainability of an optimal solution was obtained through constraints that produced constant and steady even flow of timber. As an indicator for multifunctionality we used different ecosystem service indicators (Bilberry yield, Carbon storage) and biodiversity indicators, like the amount of dead wood or the amount of suitable habitat for six different vertebrate biodiversity indicator species. The bioenergy potential was calculated by first determining the maximum harvestable economically sustainable yield for the area of Central Finland, and then by calculating the bioenergy potential in relation to Finnish natural resource institute´s values for the national level maximum suitable yield and bioenergy potential. Our results indicated that the annual maximum economically sustainable yield for roundwood and bioenergy wood with the current Business as usual forest management would be near 6.2 million $m^3$. The maximum sustainable value however increases to 6.4 million $m^3$ of round wood due to the introduction of continuous cover forestry to Business as usual forest management regime. Our results also showed a general increasing trend for multiple ecosystem and biodiversity indicators due to a decreasing harvesting intensity, particularly when using the current Business as usual harvest regime. Some of this positive trend could be further enhanced by implementing a landscape level multi objective forest management planning, which appears to be a cost-effective tool to promote biodiversity and multifunctionality in forest landscape. The decreasing harvesting intensity however diminish forestry related economic value (Net present value) and wood-based bioenergy potential which nevertheless stays over the current use of wood chips even with the lowest (60 %) harvesting intensity. As a conclusion, our results indicate that there is an unavoidable trade-off between forest multifunctionality and timber related goods like bioenergy potential and net present value when altering harvesting intensity. The solution to this trade-off is very much value based and hence requires identification of a set priorities and preferences from society.

# Description of the assignment

According to request for quote by Interreg Baltic Sea Region project Baltic ForBio partner The Regional Council of Central Finland, we produced an analysis describing the future forest structure, biodiversity and bioenergy potential of forest land in Central Finland. Our aim was to answer following specific study questions:

1.) What is the effect of increasing harvesting intensity to the forest biodiversity in Central Finland region.
2.) Is it possible to successfully combine conflicting interests of increasing wood production and forest biodiversity protection by diversifying forest management regimes or by increasing the area of conservation.

In addition, the request for quote, hoped answer to a question, what happens to the forest biodiversity and wood based bioenergy potential of Central Finland under different harvesting intensities:

a) 60 % of maximum economically sustainable harvesting yield
b) 80 % of maximum economically sustainable harvesting yield
c) 100 % of maximum economically sustainable harvesting yield

# Materials and Methods

### Description of the data

The data used in this analysis is a free open source geographic information data, known as forest resource data. "The data consists stand level character information and information about the strata that compose the stands" (Eyvindson et al. 2018). This forest information data is produced by Finnish forest authority - Forest Center - and can be freely downloaded from Metsään.fi. The downloaded data set covers 785 000 hectares (54 %) of all the forest land in Central-Finland. Although, the data set does not cover all the forest land in Central Finland, it is large enough for serving as a reasonable sample of the forest land in Central Finland. The data set is produced and constantly updated by combining information from laser scanning, aerial photos, sample plot measurements, site visits and other forest use information. In general, the reliability of the data set can be considered as good. For example, for the total wood volume the accuracy of the data set is at least the same as it would be in more traditional ground level forest inventories (metsävaratiedon laatuseloste 2016). Also, for other variables the data set has quality standards, for example stands with intermediate or mature forests the accuracy of basal area, diameter, height and total volume is within ± 20 % of the correct value in 8 out of 10 stands. However, the accuracy of remote sensing decreases for younger sampling stands or areas with varying forest structure. The development class, which is a variable used in clustering sampling – see below, is determined based on other characteristics and hence, has the same reliability as other stand character features.

**Study area and Clustering of the sampling frame**

The study area was selected to be Central Finland based on the assignment given by Regional Council of Central Finland. The land area of Central Finland covers 16 700 $km^2$ km (Maanmittauslaitos.fi), which is characterized by production forestry. In Central Finland approximately 86 % of the land area is forest land, from which production forests cover over 90 % (Finnish Forest Center 2016). Protected areas, where no harvesting is allowed, cover approximately 3.3 % (LUKE statistic 2016). Most of the forest are owned by small private landowners with mean size of forest property being about 35 ha (KS Metsäohjelma 2016) and the mean stand size being about 1,4 ha (Forest resource data). This complexity in land owning structure together with varying geographical landform has led to a patchy mosaic like stand structure. In addition, Central Finland is located at a transitional zone of two different biogeographical regions, south and mid boreal region. Due to this diversity in the external conditions of forest stands a special stratum-based sampling was designed.

For technical reasons it is impractical to simulate the whole population of over 600 000 forest stands in Central Finland. Thus, a careful sampling frame of forest stands was designed to reduce the number of stands to be simulated. At first, the study area was divided into two different geographical regions, south and mid boreal. Within each region, the sampling was based on stratified sampling where stratification (division to subgroups) was based on stand level characteristics. The selected stand level features for stratification were 1) fertility class (5 most fertile classes where included) 2) development class (open and under 1.3m height stand were combined) and 3) drainage type as a binary data. These three primary strata's (divided into more detailed classes) were combined in a way that formed all possible combinations (490 combinations). These combinations can be considered as secondary stratums, from each of which, the actual sampling of the stands to be simulated were randomly selected. For all the scarce strata, the number of selected stands was proportional to the size of the stratum, covering 10 % of the strata. However, the maximum number of stands in each secondary stratum was restricted to 100. This approach resulted 243 secondary strata and 11 743 stands to be included into the simulations.

The extrapolation of simulated stands was based on a systematic approach, where from each sampled stand, the one having the lowest variation to a certain unsampled stand, based on mathematic model (table 1), was selected to represent that specific stand. To achieve this, each unsampled stand was compared to all sampled stands in that stratum (maximum amount of comparisons being 100). This systematic selection of sample stands was done to improve the accuracy of the extrapolation.

Formula describing the calculation for variation:

Variation $V_t = D_p + D_s + D_b + F$

$D_p = (A_{pi} - A_{pj}) + (B_{pi} - B_{pj})$

$D_s = (A_{si} - A_{sj}) + (B_{si} - B_{sj})$

$D_b = (A_{bi} - A_{bj}) + (B_{bi} - B_{bj})$

$F = \left|\#S_i - \#S_j\right| * 100$

In this formula $V_t$ stands for total variance and D for difference. A signifies age and B basal area to a specific tree species (p= pine, s = spruce, b = birch) in a certain simulated stand i and unsimulated stand j. F is a Fixed number from conditional expression, where #S is the cardinality representing the number of stratum in simulated stand (i) and unsimulated stand (j).

**Table 1**. Table illustrates the determination of variation between a simulated stand and three unsimulated example stands from same stratum. Variation was determined by calculating the sum of tree species specific differences for age and basal area between the simulated and unsimulated stands. After this, the tree species specific differences were summed, which produced the total difference I.e variation between the stands. If there is a difference in the tree species composition, the difference for one species equals the total difference of 100. The smaller the value is for total difference, the lower is the variation between these stands. If a variation equals zero, these compared stands are identical by age, basal area and species composition. Green colour is used to highlight the most similar (least variation) stand (stand number 1).

| | **Age** | **Difference (Age from simul.stand - age from not simul.stand)** | **Basal area** | **Difference (BA from Simul.Stand - BA from not simul. Stand)** | **Sum of tree species spesific difference** |
|---|---|---|---|---|---|
| **Simulated stand** | | | | | |
| Pine | 35 | | 17 | | |
| Spruce | 25 | | 10 | | |
| | | | | | |
| **Not simulated stand 1** | | | | | |
| Pine | 36 | 1 | 20 | 3 | 4 |
| Spruce | 26 | 1 | 9 | 1 | 4 |
| **Total difference** | | | | | 8 |
| **Not simulated stand 2** | | | | | |
| Pine | 40 | 5 | 19 | 2 | 7 |
| Spruce | 10 | 15 | 7 | 3 | 18 |
| **Total difference** | | | | | 25 |
| **Not simulated stand 3** | | | | | |
| Pine | 35 | 0 | 19 | 2 | 2 |
| Spruce | 25 | 0 | 12 | 2 | 2 |
| Birch | 15 | x | 10 | x | 100 |
| **Total difference** | | | | | 104 |
| | | | | | |

**Description of simulation process**

All simulations in this study are made with an open-source forest management simulation program SIMO (see: Kangas & Rasinmäki 2008). SIMO is a reliable and frequently used tool by forest scientists and biologists for modelling development of forests (Kangas et al. 2013, Eyvindson et al. 2018, Peura et al. 2018). The program enables if-then -type calculations considering forest development under different forest management regimes and time scales. After a specified simulation, the program allows to determine several different variables for describing the simulated forest structure. Based on these different attributes we were able to determine the maximum economically sustainable yield, the bioenergy potential and the state of multifunctionality indicators, described with more detail below. Since, the biomass Atlas does not cover different forest management scenarios, it was necessary to produce different scenario models for us to achieve this kind of study.

For each forest stand, several different futures (chains of management actions) were simulated. These different simulated management regimes were either composed from *Business as usual* (BAU) regimes or *Continuous cover forestry* (CCF) regimes. BAU regime, also known as periodic rotation, which is currently by far the dominant management regime in Central Finland (Tiitinen-Salmela 2019), includes artificial regeneration, commercial thinnings and the final felling, where all the trees (except retention trees (5 per ha, Peura et al. 2017)) are removed from the felling site. In *continuous cover forestry* the final felling is not implemented but is been replaced with more frequent felling of large trees and natural regeneration. Also *set aside* (SA), abstention from all management action*s,* was always an option during the simulation process.

In addition to these three main options, more options to BAU and CCF regimes were created by modifying the time or intensity of different management actions. For example, with BAU regime more options were created by altering the number and timing of commercial thinnings or the time of final felling (- 5 to + 30 years compared to business as usual). Also, a green tree retention (GTR) with 30 retained trees at final felling was used as one modification option to BAU regime. With CCF, different options were based on varying harvesting intervals in relation to Tapio´s instructions (Äijälä et al. 2019, see: https://tapio.fi/briefly-in-english/) for the basal area before harvesting. The basal area after harvesting was always the lowest law limit, that do not require renewal actions. For more detailed description of all the different management regimes, see the supplementary material in Eyvindson et al. (2018). In total, there were 22 different management regime options that were available during the simulation process depending on stand characteristics, from which the optimal set of management regimes were later selected.

For management regimes targeting periodic harvesting cycle, the predictions were based on Hynynen et. al. (2002) growth model. Alternatively, for the management regimes modelling continuous cover forestry, the growth predictions were based on Pukkala's et al. (2013) growth model.

**Optimization and determination of maximum economically sustainable yield**

Based on the simulations above, an optimization tool (IBM ILOG CPLEX, see: https://www.ibm.com/analytics/cplex-optimizer) was used to select for each stand an optimal management regime. The combination of the selected management regimes either maximized the multifunctionality by producing the best possible compromise between different multifunctionality indicators (dead wood, carbon, bilberry and six biodiversity indicator species) or the net present value under different harvest intensities (60 %, 80 %, 100 % and 120 %) of maximal economically sustainable harvest yield. The optimization process created a Pareto optimal solution where no objective could be improved without diminishing the outcome of at least one other objective.

The Maximum sustainable harvest was determined by a simple optimization problem that maintained the maximum even flow of timber. The estimate for the maximum sustainable harvest was obtained through optimization, where we maximized the first period harvest subject to a constraint that all subsequent periods meet the harvest from that first period. The model is relatively consistent with The Finnish Natural resource institute´s (LUKE´s) way of calculating the maximum sustainable harvest levels.

$$\max NPV_0 = \sum_{i=1}^{m} \frac{\sum_{j=1}^{h}\sum_{t=1}^{T}(\sum_{q=1}^{k}(P_q - C_q) w_{ijt}^{q} x_{ij})(1+r)^{5T-(10t-s)} + SEV_i}{(1+r)^{5T}} \quad [1]$$

subject to

$$\sum_{i=1}^{m}\sum_{j=1}^{h} W_{ijt}^{rw} X_{ij} - \sum_{i=1}^{m}\sum_{j=1}^{h} W_{ijt-1}^{rw} X_{ij} = 0, \forall t = 2, \dots, T \quad [2a]$$

$$\sum_{i=1}^{m}\sum_{j=1}^{h} W_{ijt}^{rw} X_{i} - F_{ij}^{rw} * Z \pm 0{,}001 \geq 0, \forall t = 1, \dots, T \quad [2b]$$

$$\sum_{i=1}^{m}\sum_{j=1}^{h} W_{ijt}^{ew} X_{ij} - \sum_{i=1}^{m}\sum_{j=1}^{h} W_{ijt-1}^{ew} X_{ij} = 0, \forall t = 2, \dots, T \quad [3a]$$

$$\sum_{i=1}^{m}\sum_{j=1}^{h} W_{ijt}^{ew} X_{i} - F_{ij}^{ew} * Z \pm 0{,}001 \geq 0, \forall t = 1, \dots, T \quad [3b]$$

$$\sum_{i=1}^{m}\sum_{j=1}^{h}\sum_{q=1}^{k} W_{ijt}^{q} X_{ij} - \sum_{i=1}^{m}\sum_{j=1}^{h}\sum_{q=1}^{k} W_{ijt-1}^{q} X_{ij} = 0, \forall t = 2, \dots, T \quad [4a]$$

$$\sum_{i=1}^{m}\sum_{j=1}^{h}\sum_{q=1}^{k} W_{ijt}^{q} X_{ij} - \sum_{i=1}^{m}\sum_{j=1}^{h}\sum_{q=1}^{k} F_{ij}^{q} * Z \pm 0{,}001 \geq 0, \forall t = 1, \dots, T \quad [4b]$$

$$\sum_{i=1}^{m}\sum_{j=1}^{h} W_{ijt}^{st} X_{ij} - \sum_{i=1}^{m}\sum_{j=1}^{h} W_{ijt-1}^{st} X_{ij} = 0, \forall t = 2, \dots, T \quad [5a]$$

$$\sum_{i=1}^{m}\sum_{j=1}^{h} W_{ijt}^{st} X_{ij} - \sum_{i=1}^{m}\sum_{j=1}^{h} F_{ij}^{st} * Z \pm 0{,}001 \geq 0, \forall t = 2, \dots, T \quad [5b]$$

$$\sum_{j=1}^{h} X_{ij} = a_{i,} \forall i = 1, \dots, m, \forall j = 1, \dots, h \quad [6]$$

$$X_{ij} \geq 0, \forall i = 1, \dots, m, \forall j = 1, \dots, h \quad [7]$$

In this equation $x_{ij}$ is the area of management unit i (i=1,…m) managed according to management regime j (j=1,…h);

$w^{q}_{ijt}$ where q (q=1,…,k) refers to the amount of timber ($w^{rw}$ "saw timber and pulp" belongs to $w^{q}$) or energy wood assortments ($w^{ew}$ belongs to $w^{q}$) produced if management regime j is employed for the area of calculation unit i at period t (t=1,…, T);

$w^{st}_{ijt}$ (part of $w^{rw}$ ) is the amount of saw timber harvested if management regime j is employed for the calculation unit I at period t;

F is fixed value defined from a-type equations that were used for determining the maximum NPV for 100 % harvesting intensity;

SEV is the estimated soil expectation value for management unit i calculated by using faustman formula; and

$a_i$ is the area of management unit i.

The maximum sustainable yield is been determined through the optimization model (1) that maximize the NPV under constrains from equations (2a and b) that are used to maintain non-declining periodic round wood, energy wood (3a and b) supply as well as incomes (4a and b) and saw log flow (5a and b). Area constrain (6) is used to make sure every stand has an area and (7) selected management regime or set a side option. A-type equations are used when determining the maximum sustainable yield for 100% harvesting intensity and b-type equations when reducing the harvesting yield to a proportion of maximum intensity by changing the Z (multiplier for F).

During the analysis process, protected areas were not excluded (protected area cover in Central-Finland is 4,5 % (LUKE tilastotietokanta), and hence our max sustainably harvestable timber value can be a mild overestimate.

The maximum multifunctionality (max MF) is the optimal combined result for the nine different ecosystem service measures or multifunctionality criteria (described below). The max MF is determined through an objective function that maximises the normalized sum of these nine different ecosystem service measures under the same constraints (equations 2-7) with max NPV.

Objective function for maximum multifunctionality is:

$$\max MF = \sum_{e=1}^{E} \left( \frac{M_e - M_{e*}}{M_e^* - M_{e*}} \right) \qquad [8]$$

subject to

$$M_e = \sum_{i=1}^{m} \sum_{j=1}^{h} \sum_{t=1}^{T} \frac{ES_{ijt}^{e} X_{ij}}{T}, \forall\, e = 1, \ldots, E \qquad [9]$$

$$M_{e*} = \operatorname{argmin}_{i \in 1,\ldots,m} \sum_{j=1}^{h} \sum_{t=1}^{T} \frac{ES_{ijt}^{e}}{T}, \forall\, e = 1, \ldots, E \qquad [10]$$

$$M_e^* = \operatorname{argmax}_{i \in 1,\ldots,m} \sum_{j=1}^{h} \sum_{t=1}^{T} \frac{ES_{ijt}^{e}}{T}, \forall\, e = 1, \ldots, E \qquad [11]$$

Where *e* stands for ecosystem service measure and *E* equals to 9.

The equation (8) is used to calculate the sum of normalized ecosystem service measures, when equation (9) evaluates the ecosystem service specific measure for the specific stand level forest management decision.

Equation 10 and 11 are used to calculate the minimum and maximum values for each ecosystem service specific value, used to normalize each ecosystem service in equation 8.

**Description of the simulated and optimized scenarios**

To analyse the effect of set priority in forest management and the possibility to improve forest multifunctionality by expanding the current forest management regimes (BAU) with continuous cover forestry (CCF) four different scenarios were created. The four created scenarios were:

1. NPV/BAU which describes economic orientation in forest management when the management is restricted to different rotation forestry regimes.
2. NPV/BAU+CCF which describes economic orientation in forest management when more diverse set (rotation forestry + continuous cover forestry) of management regimes is used.
3. MF/BAU which describes multifunctional (non-timber related ecosystem service) orientation when forest management is restricted to different rotation forest regimes.
4. MF/BAU+CCF which describes multifunctional orientation when more diverse set (rotation forestry + continuous cover forestry) of forest management regimes is used.

All these scenarios were compared with different harvesting intensities (60 %, 80 %, 100 %) of the maximal sustainable harvesting yield.

For all our scenarios, the selected simulation time was from year 2016 to 2116, resulting in a 100-year time scale with 5-year steps. This kind of relatively long-time scaling and division to shorter steps, allowed us to simulate the changes in forest structure with reasonable temporal accuracy and length and hence, promoted us to avoid conclusions that would seem optimal only in short (for example 20 years) time scale.

The comparison of these different scenarios allowed us to determine:

1.) How the change in harvesting intensity will affect to forest biodiversity and potential of wood based bioenergy

2.) Is it possible to mitigate the negative biodiversity effect of increased harvest intensity by conducting a landscape scale forest planning and hence, diversifying forest management actions.

**Indicators of the forest multifunctionality**

We used several different indicators to represent multiple forest-related values. A recent survey regarding landowner's preferences revealed an economic orientation being the most dominant value among landowners (Haltia & Rämö 2017). Due to the dominant nature of economic orientation, the economic value was used as an independent preference when creating optimal solution. In this study, the forestry related income was evaluated by estimating net present value (NPV) with 4 % discount rate, which is in line with LUKE's calculations for the national maximum sustainable yield (metla.fi). The calculation for NPV was based on the average tree species specific roadside prices from 2009 – 2018 for the simulated proportions of pulp and log (Metla.fi). These prices are consistent with LUKE´s estimate for the maximum sustainable yield (Metla.fi).

We used multiple indicators to reveal other than timber-based economic values of forests. For ecosystem service indicators we selected bilberry *(Vaccinium myrtillus)* yield and carbon storage. Bilberry yield represented collectable goods, and hence hold an economic and recreational value.

The effect of different management actions was evaluated by estimating the amount of bilberry yield produced by the landscape. This estimation was based on Miina et al. (2009) model, which provides estimates of berry yield as a function of stand characteristics based on empirical data from national forest inventory sites. For carbon storage, an important atmospheric $CO_2$ regulating service, the predictions consider both, the carbon stored in woody biomass (50 % of dry biomass) of the growing stock and dead wood, as well as carbon in soil. For estimating the soil carbon flux, separate models were used for mineral soils and for peat lands. For mineral soils the estimation was based on Yasso07 model (Liski et al. 2005, Tuomi et al. 2009, 2011) and for the peatlands model introduced by Ojanen et al. (2014) was used.

For indicators of biodiversity we used the amount and quality of dead wood as well as the amount of suitable habitat for six different vertebrate indicator species. Dead wood is known to be an important feature for many threatened species in boreal forests (Junninen & Komonen 2011, Hyvärinen et al. 2019), and due to forest management it has become a scarce resource in boreal production forests and hence, have a high biodiversity indicator value. In addition to dead wood amount, also the quality of deadwood is an important feature for many highly specialized species (Junninen & Komonen 2011, Juutilainen et al. 2011). Hence, the deadwood availability was measured similarly to Eyvindson et al. (2018) "as a function of total deadwood volume multiplied by the diversity of deadwood". In this approach, the diversity was measured by the proportion of deadwood under different classes (species, diameter, decay class) as an inverse of Simpson´s diversity index (Triviño et al. 2017). Diversity weighted dead wood availability is high when a stand has a high amount of dead wood distributed evenly across all classes.

There is evidence that dead-wood dependent species do not respond linearly to increasing dead-wood availability, and particularly many threatened species only occur in forests that have dead wood more than 20 $m^3$/ha (Junninen & Komonen 2011). Therefore, it is likely that that the current level of dead wood 3,2 $m^3$/ha (Salminen 2015) in a production forest in Central-Finland is not enough to maintain viable specialist populations in a long term. Hence, we developed a specific function to describe a stand suitability for dead wood dependent species:

$$Q_{DW} = \begin{Bmatrix} 0,\ if\ DWi\ \leq 5\ m3/ha \\ 0.067 * DWi - 0.33,\ 5 < DW\ \leq 20 \\ 1, if\ DWi > 20\ m3/ha \end{Bmatrix}$$

According to this function, stand suitability is zero on a stand with diversity-weighted dead wood volume under 5 m3/ha, then increases linearly with the dead-wood volume between 5 to 20 m3/ha and achieves the maximum suitability on a stand with dead wood volume over 20m3/ha.

**Indicator species**

For achieving more comprehensive estimate for the forest biodiversity, also the habitat availability for six different vertebrate indicator species was estimated. The habitat availability was estimated by first determining species-specific habitat suitability index (HSI) to all six species: the Capercaillie (*Tetrao uralensis),* Hazel grouse (*Bonasa bonasia*), Tree toed woodpecker (*Picoides tridactylus*), Lesser-spotted woodpecker (*Dendrocopus minor*), Long-tailed tit (*Aegithalos caudatus*) and Siberian flying squirrel (*Pteromys Volans*). The index relates to the probability of a stand being occupied by a selected species and varies from 0 – 1, where 0 represents unsuitable habitat with a smallest probability for a species to occupy a stand. Conversely, the value 1 represents the most suitable habitat with the highest probability for a species occupancy. Based on the HSI-index we were able to determine the stand area with a high probability of species occupancy (HSI > 0.5).

These selected indicator species cover a wide range of habitat requirements while also serving as an umbrella species (see Mönkkönen et al. 2014) and hence, gives together with dead wood, a reasonable estimate for the overall biodiversity. In addition to biodiversity value, gallinaceous birds hold a social and economic value as game species and so expand our concept of multifunctionality. The ecological significance and habitat suitability modelling of the indicator species is explained in more detail in the appendix of Mönkkönen et al. (2014).

**Bioenergy potential**

In this report the bioenergy potential is estimated indirectly in relation to LUKE´s national level estimate for the maximum sustainable yield for the rough lumber and bioenergy potential (Metla 2015). In practice, this means that, in our analysis the values for the maximum sustainable yield for rough lumber comes directly from our simulation analysis but the bioenergy potential is calculated in relation to LUKE´s national level values for rough lumber and bioenergy wood.

For the NPV/BAU + CCF scenario, the bioenergy potential was not calculated since the economic profitability of energy wood harvest in selection cutting is too low (Heikkinen 2015), and the exact proportion of rough lumber produced form stands managed with BAU regime was not known.

When considering absolute values and compared to the method where the amount of bioenergy wood is a direct estimate from simulation results, this method can be considered as a rough estimate. However, this method can nevertheless be used for evaluating the effect of harvesting intensity on bioenergy potential by comparing different scenarios.

Since the simulated data set was focused on a private lands and hence, did not cover all the forest area in Central Finland, the determined maximum economically sustainable harvesting yield was extrapolated to cover the whole study area by multiplying the value with 1.84 (see page 2). The estimate also includes areas where the forest use is restricted (conservation area cover is 4,5 % of the forest land in Central Finland, (LUKE tilastotietokanta)).

# Results

### The effect of harvesting intensity and selected forest management scenario

Based on our results, it is evident that, harvesting intensity affects greatly to multiple ecosystem service indicators (fig. 1, 2, 3 and 4). However, the exact magnitude and direction of the impact seem to be variable, management regime and time scale specific. Despite of that, some general trends can be seen. For example, for most indicator species the decreasing harvesting intensity will lead to an increasing habitat amount. This is especially true when considering the long time-scale effect for the most dominant management regime (NPV/BAU). This kind of prominent increasing trend be seen with the structure level diversity indicator – dead wood, that shows the increment effect of 87.7 % due to decreasing harvest rate from 100 % to 60 %. For the species level indicators, the most dramatic positive change for the same NPV/BAU regime, can be seen with the Siberian flying squirrel (habitat increment 83.3 %) and Lesser spotted Woodpecker (habitat increment 122 %) for the same decreasing harvesting intensity.

Although, in general the decreasing harvesting intensity seems to lead to an increment of biodiversity. However, for woodpeckers the improvement (or at least notable part of it) is most likely artificial and due to the technical feature of the analysis, that lacks the spatial variation in the amount of dead wood, and hence underestimates the amount of suitable habitat for woodpeckers at the start point of the simulation period. This can also be seen from figure 1 by comparing the results for the area with high dead wood quality from panel A and B, which indicates lower deadwood volume for MF/BAU + CCF -model at the first simulation quartile. Even though, the time scale difference for dead wood is a result of a technical feature, one notable result of the analysis is that sometimes the effect of harvesting intensity can truly vary between short and long time scales, like seen for example with Capercaillie (figure 2.), that in short (20 year) timescale shows reduction in the habitat amount in the NPV/BAU model as the harvesting intensity decreases but reveals the opposite trend with the complete 100-year simulation period.

Other estimated variables, besides harvesting intensity, were the selected management regime and optimization target. Our results indicate that there are ways to further enhance the positive biodiversity effect of decreasing harvesting intensity through the landscape level planning if also the target of forest management is changed towards multifunctionality. In general, the best combination for multifunctionality is created when MF target is combined with diversified forest management (BAU + CCF management regime). For example, for all the ecosystem service indicators, NPV excluded, the models targeting multifunctionality produce the best possible outcome when considering long (100 year) time scale (figure 1, 2, 3, and 4). It seems that the largest potential to benefit from multifunctionality oriented and diverse forest management in a long-time perspective is with Capercaillie (280 %), Lesser spotted woodpecker (435 %) and with high quality dead wood area (only MF model results value > 0) compared to current NPV/BAU regime, with relatively convergent timber supply level (about 350 $m^3$/ha). At the same time, it is worth of noticing that the introduction of CCF itself might not produce general positive biodiversity effect if the management regime is not also targeted to MF. On the contrary, for some indicators like Capercaillie and dead wood, the introduction of CCF to BAU seems to create poorest possible outcome when the forest management is designed to optimize NPV (Figure 1 and 2). This, however, can be explained by the larger timber supply. For other ecosystem services like for carbon storage the result showed more moderate differences between management options and optimization targets, indicating only a relatively mild potential (about 3.5 %) for increasement due to optimal planning (figure 4).

As a contrary to biodiversity indicators the economic value (NPV) decreases due to decreasing harvesting intensity (figure 5) and hence, suggest a reason for a high harvesting intensity when the target is to maximize economic benefits of forestry. The negative effect of decreasing harvesting intensity to the NPV value seems to be relatively stable for all management options and optimization targets. For the most common management combination NPV/BAU this decrement is 37 % when decreasing the harvesting intensity from 100 % to 60 %. The analysis also showed that the most optimal management option for NPV contains both BAU and CCF regimes, indicating the positive effect related to the introduction of CCF for the NPV.

For ecosystem services other than biodiversity or monetary value we modelled bilberry yield and carbon storage. For bilberry the result showed only small differences due to changes in extracted timber volume with the current management regime (NPV/BAU). However, there is a reasonable potential for increased yields with landscape level multifunctionality planning. For carbon storage the scale of positive effect of decreased harvesting intensity (11 %) when decreasing the harvest intensity from 60 % NPV/BAU to 100 % NPV/BAU, seems to be more determinative, since there is relatively little potential for improvement through different management or optimization options (figure 4).

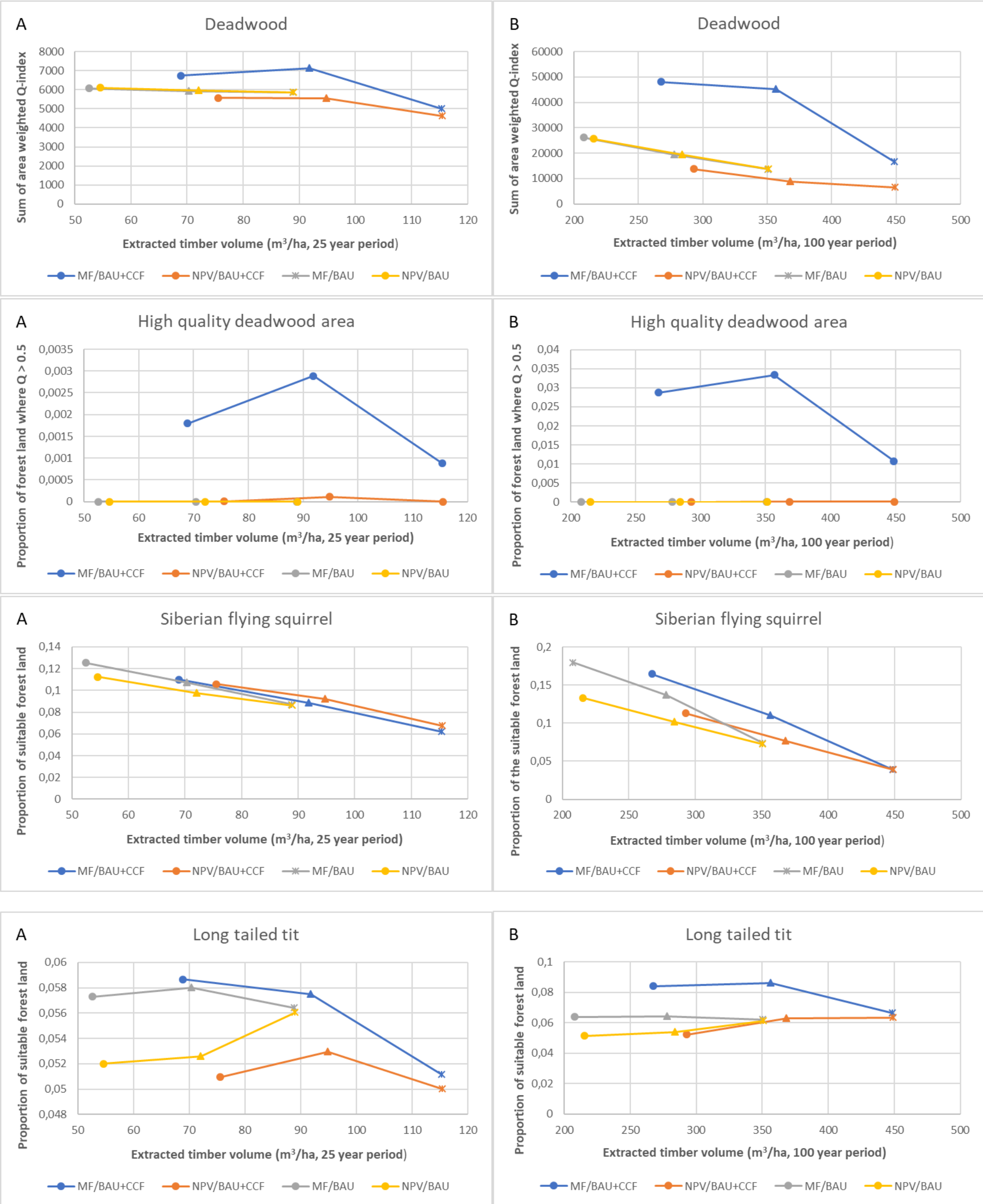


**Figure 1.** Average suitable habitat area where HSI > 0.5 for two different biodiversity indicator species as a proportion of forest land. For the dead wood the results are based on the average volume of diversity weighted dead wood in a hectare from which the deadwood quality index Q is determined. Q = 1 relates to the total volume of dead wood in Central Finland being equal to the area (ha) with dead wood volume ≥ 20 $m^3$. A panel shows the average value for the near future (to year 2041) and B panel to the whole simulation period (100 years). In both panels star figure represent 100 %, triangle 80 % and circle 60 % harvesting intensity.

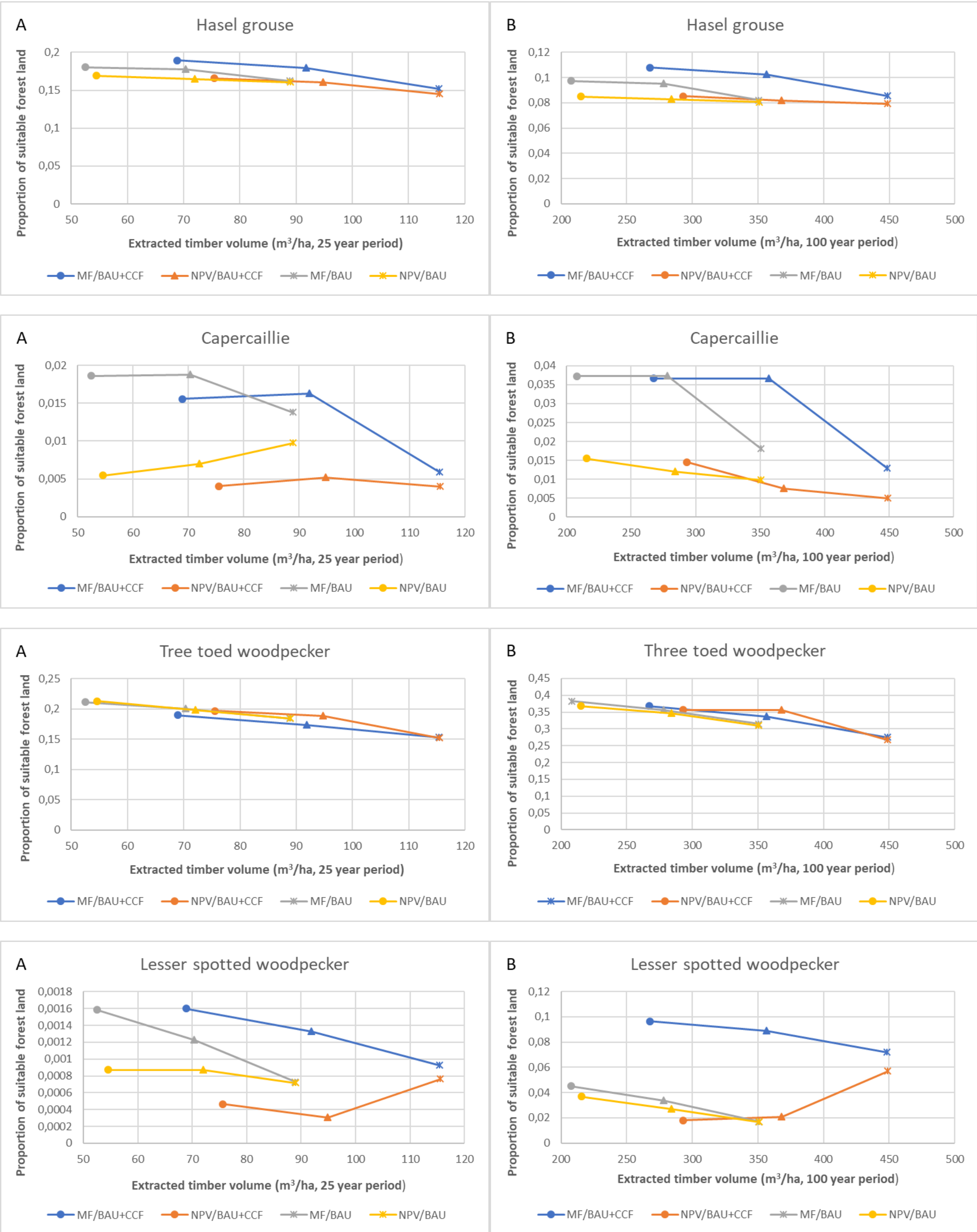


**Figure 2.** Average suitable habitat area where HSI > 0.5 for four different biodiversity indicator species as a proportion of forest land. A panel shows the average value for the near future (to year 2041) and B panel to the whole simulation period (100 years). In both panels star figure represent 100 %, triangle 80 % and circle 60 % harvesting intensity.

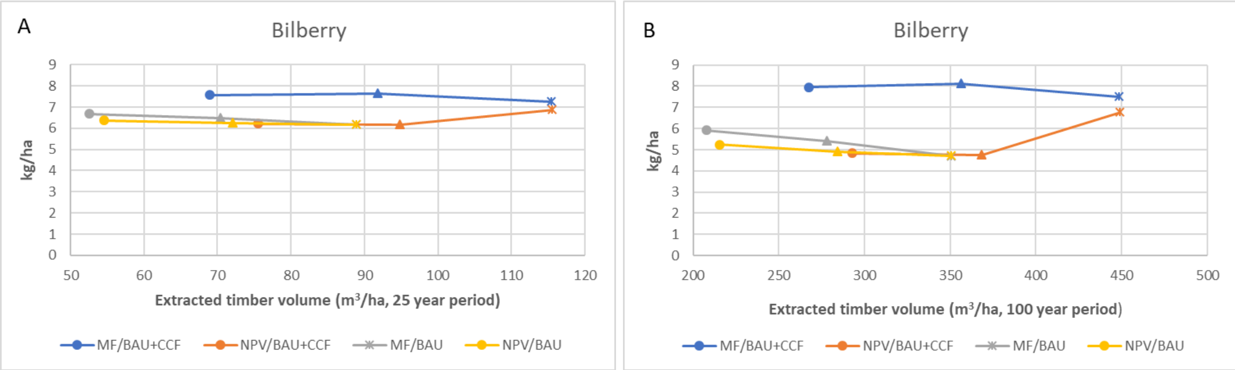


**Figure 3**. Average bilberry yield for different timber extraction volumes (X-axis) as an kg/ha (Y-axis). A panel shows the average value for the near future (to year 2041) and B panel to the whole simulation period (100 years). In both panels star figure represent 100 %, triangle 80 % and circle 60 % harvesting intensity.

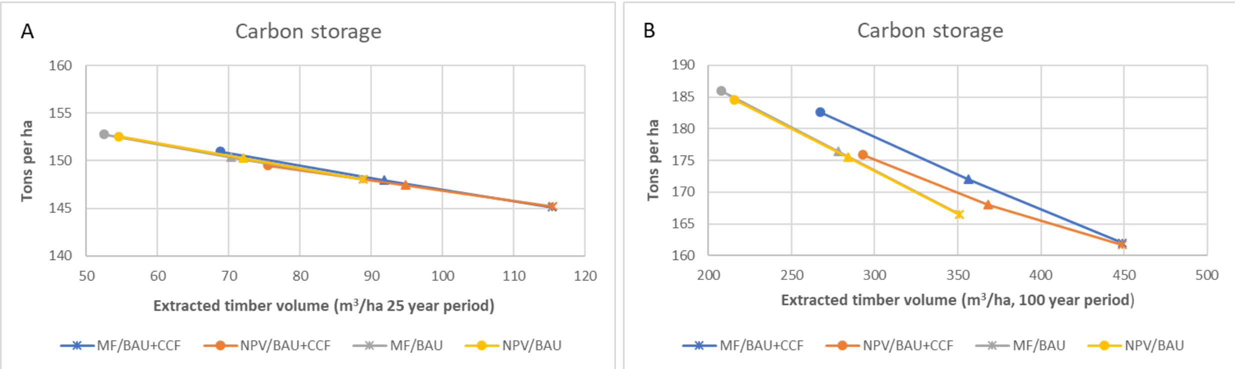


**Figure 4**. The effect of the harvest intensity to the average value of carbon stored in soil and in wood biomass as tons per ha. A panel shows the average value for the near future (to year 2041) and B panel to the whole simulation period (100 years). In both panels star figure represent 100 %, triangle 80 % and circle 60 % harvesting intensity.

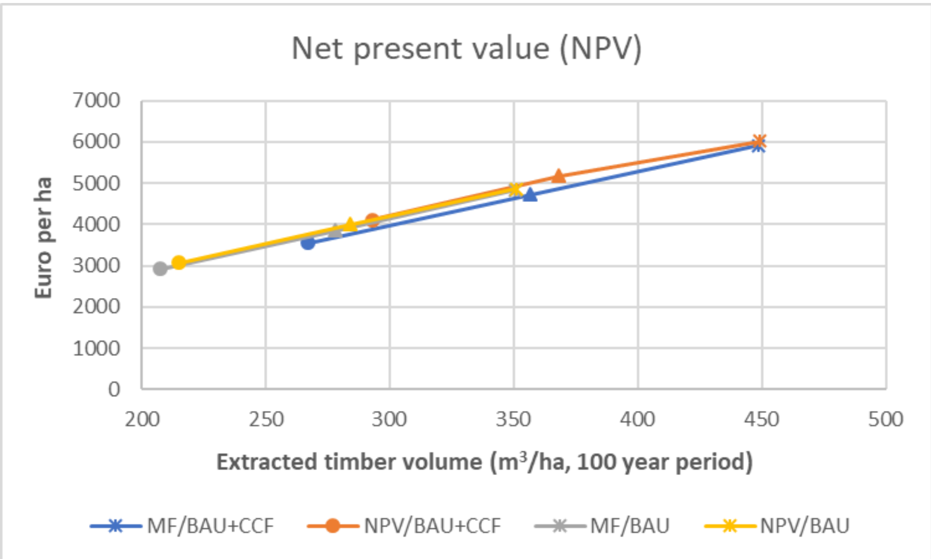


**Figure 5**. The figure illustrates the net present value for varying harvesting intensities and management options as an average value over the whole simulation period (100 years). Star figure represent 100 %, triangle 80 % and circle 60 % harvesting intensity.

## The optimal set of forest management regimes

Our results clearly indicate that for all scenarios the optimal outcome is always a combination of multiple different management regimes, and no single management regime can be considered as optimal for all the stands (figure 1). All the optimal solutions also are composed of both BAU and CCF regimes. The relative importance of CCF regimes increases when the optimization model is targeting to multifunctionality and consistently decreases for NPV targeting models, but still is always present with a considerable proportion. Also, in NPV models the proportion of CCF is high (almost 50 %) when the harvesting intensity is high (100%), indicating the importance of CCF regimes when maximizing the harvested timber per period, but decreases with decreasing harvesting intensity. The lower dominance of CCF in NPV targeting models when harvesting intensity is between 80% - 60 % allows the increment in the proportions of BAU regimes with extended rotation length (brownish colours). This indicates the benefits of these management regimes over the CCF when maximizing NPV at lower harvesting intensities.

With maximum sustainable harvesting intensity, the amount of set-aside (SA) areas is very low (< 0.5 % in both NPV and MF models) only indicating that due to constrains some areas are left outside of forest management. However, notable general potential increase of protected area is seen when decreasing the harvesting intensity. The amount of SA areas increases from < 0.5 % (100 %) to 6.2 % (NPV) - 16.3 % (MF) with harvesting intensity of 80 % and to 24.5 %-35.2 % with harvesting intensity of 60 %.

Similarly to SA and CCF, also the amount of GTR regimes is higher in MF models compared to NPV models. Although, the proportion of GTR regimes increases when decreasing harvesting intensity from the maximum 100 %, it seems to stay at a relatively constant level even when further decreasing the harvesting intensity from 80 % to 60 %.

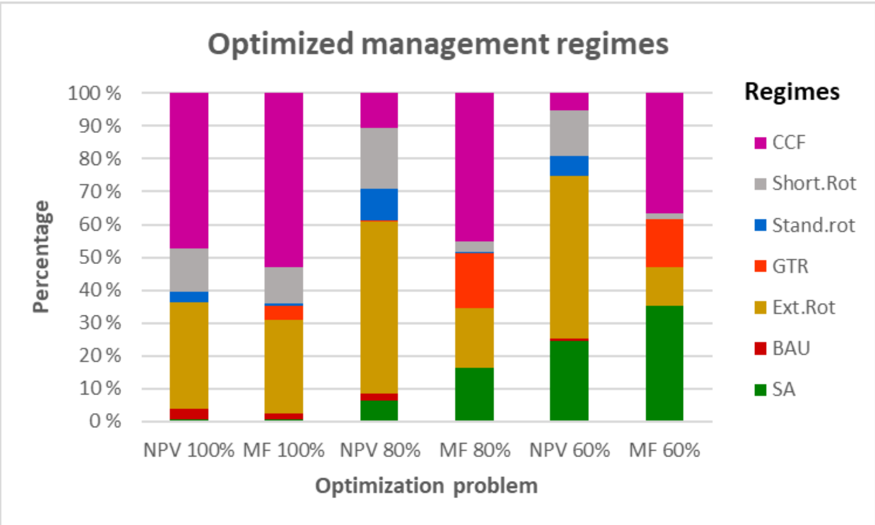


**Figure 6**. Figure illustrates the relative importance of different management regimes. Y-axis represents proportions (%) of management regimes for different harvesting intensities and optimization targets (X-axis). NPV stands for Net Present Value and MF for Multifunctionality. SA refers to Set Aside (no management), BAU = Business as Usual (clear cut based periodic rotation), Ext.Rot = Extended rotation length, GTR = Green Tree Retention, Stand.rot = Standard rotation length with thinning modifications, Short.Rot = Shorter than BAU rotation length, CCF = Continuous Cover Forestry (no clear cutting). Different management options are opened with more details above.

**Opportunity cost of targeting multifunctional forestry**

This analysis (figure 5) also revealed a trade-off between the economic benefits and multifunctionality due to the use of different optimization targets. The economic loss can however be considered relatively modest with BAU-regimes, on average 30 € per hectare during the 100-year simulation period with the current 100 % harvesting intensity. Even though the economic loss increases when decreasing the harvesting intensity, it still stays on a relatively modest scale (154 € per hectare) with 60 % harvesting intensity. The cost for multifunctionality is most notable (560 € per hectare) with BAU+CCF regimes when the harvesting intensity is reduced to 60 %. Although, it needs to be noted that the NPV is higher in MF/BAU+CCF 60 % compared to NPV/BAU 60 % indicating that the MF/BAU+CCF scenario would improve the current state.

**The maximum sustainable yield for timber extraction**

The maximum economically sustainable yield for the rough lumber and bioenergy wood for Central Finland with NPV/BAU management option is 6.5 million $m^3$ (Figure 7). The proportion of rough lumber is dominant (78 % of the total volume) compared to the bioenergy wood that has the maximum potential of about one and a half million cubic meters. The maximum sustainable yield as well as bioenergy potential are directly linked to harvesting intensity, and hence decrease relatively linearly in relation to decreasing harvesting intensity.

The picture also reveals that the diversification of management regimes (addition of CCF to BAU) increases notably the maximum sustainable harvesting yield (6.4 mill $m^3$) for round wood.

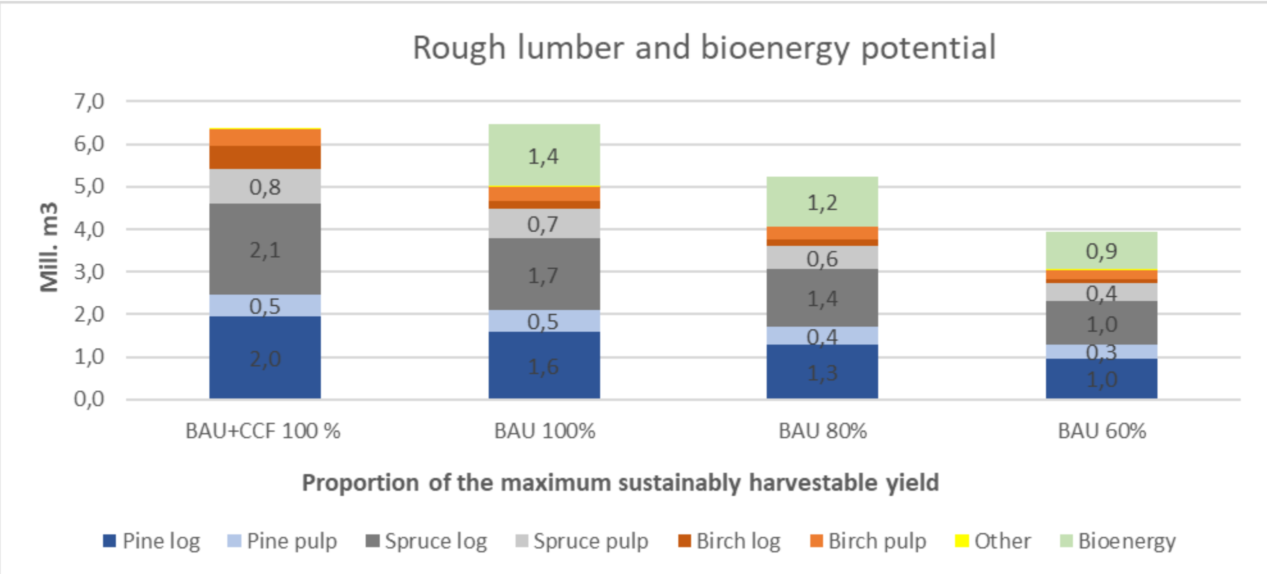


**Figure 7.** The maximum economically sustainable yield for the Central Finland area with NPV targeting options. With NPV/BAU+CCF -option only the 100 % harvesting intensity is shown to illustrate the positive effect of CCF addition to the maximum sustainable harvesting yield. Sustainability analysis was done to cover the whole simulation period (100 years). More detailed description of the maximum sustainability calculation can be found from page 6. Note that bioenergy potential for BAU + CCF regime was not calculated (see: page 11).

# Discussion

**The effect of varying harvesting intensity and potential to increase multifunctionality with landscape level planning.**

Our results based on biodiversity indicators indicate that decreasing harvesting intensity will most likely result an increase in biodiversity. The effect is not uniform for all the species and optimization targets but the increment is the general trend with the most common management option (NPV/BAU). Our results are consistent with other simulation-based studies (Heinonen et al. 2017, Eyvindson et al. 2018), and a government report (Korhonen et al. 2016) that have identified the positive biodiversity effect related to the decreased forest harvesting intensity. Heinonen et al. (2017) showed that the values of biodiversity indicators (volume of deciduous trees, amount of dead wood and area of old forests) are highest at the lowest harvesting intensity and thus concluded that increasing harvest intensity will lead to a loss of biodiversity. Also, similarly to these results, Eyvindson et al. (2018) showed a notable reduction in the habitat availability of indicator species as well as in the amount of diversity weighted dead wood due to increase of the harvesting intensity.

In addition to these results, the commercial forest management has been stated to be the main reason for the declining state of many forest species in Finland (Hyvärinen et al. 2019). When considering our results and other convergent studies, it seems that there is an unavoidable trade-off between increasing commercial forest use and the forest biodiversity, at least with the current way of forest management (NPV/BAU). Despite of the general trend also some indicator species, like long tailed tit and bilberry showed the kind of response which would allow for an increase of the forest harvesting rate without almost any reduction for suitable habitat if managed accordingly.

The landscape level planning targeted to multifunctionality resulted higher values to many non-timber related ecosystem services, offering a way to further enhance the positive trend mentioned above, related to decreased harvesting intensity. This potential of landscape level planning to increase the biodiversity and/or the production of other ecosystem services is also shown by other recent studies (Pukkala 2016, Tahvonen et al. 2019). In addition, Eyvindson et al. (2018) reported similar multi objective optimization effect, with 30-40 % higher values for habitat availability, dead wood, carbon storage and bilberry yield when compared to non-optimized models. Also, Mönkkönen et al. (2014) and Triviño et al. (2017) have highlighted the importance of landscape level planning when the target is to maintain non-timber related ecosystem services like carbon storage and biodiversity. What is also notable in these studies, is that the highest potential for landscape level planning is achieved when the NPV is not maximized, suggesting the importance of lowering the economic pressure for timber revenues in a landscape level when targeting multifunctional forestry. Even though, the landscape level planning offers a way to diminish some of the negative forestry related biodiversity impacts, it needs to be noted that even with the most optimal design the landscape might not be capable to maintain populations in the long-time perspective. For instance, the amount of high dead wood quality stands, with the current harvesting intensity of near 100 % (Tiitinen-Salmela 2019), that would be achievable through multi objective planning, is near to 15 000 ha and covers only 1 % of the total forest area.

Our analysis illustrates the relatively linear negative correlation between carbon storage and harvesting intensity (fig 5). The analysis also revealed that there is only small potential (about 3,5

%) to increase carbon stock through different landscape level management targets, with the current harvesting intensity of near 100 % (NPV/BAU). This results a situation where abstention from harvesting maximum yield seems to be the most relevant practice for maintaining high carbon storage. This idea is in line with Heinonen et al. (2017) conclusion, that the increased harvesting will decrease carbon balance. Also, the recent comparison by Kalliokoski et al. (2019) with different carbon models showed consistent results where the least intense harvesting scenario resulted in the largest carbon storage and carbon sink. In addition, the resent study from Seppälä et al. (2019) indicates that the current displacement factors of wood-based products are not high enough to compensate the carbon loss in forests with the current harvesting yield (78 mill. m3 of round wood in 2018, Luke), and hence "represents a challenge for the Finnish bio-based bioeconomy from the viewpoint of climate change mitigation". Our result is also relatively well in line with Triviño et al. (2017) results that found a strong trade-off between timber and carbon storage, and hence concluded that it is not possible to maintain high level carbon storage and biodiversity if timber revenues (NPV) is being maximized. Nevertheless, in contrast to our results, some studies have reported larger potential to increase carbon storage by diversifying forest management and implementing landscape level planning. For example, Pingoud et al. (2018) showed potential to increase the forest carbon stock by factor of 1.5-2 due to a landscape level planning compared to the current state, although resulting a possible trade-off with harvesting revenues and displacement factor of wood products. Also, in Pingoud et al. (2018) model there was no restriction to produce the same even flow of annual biomass yield, so the result is not directly comparable to our analysis, but indicates that the current way of forest management is far from optimal in the sense of carbon stock. In addition, also the recent study from Díaz-Yáñez et al. (2019) showed that the carbon stock and balance can be affected by forest management. They reported lowest carbon stock and carbon balance for rotation forestry managed with thinning's from below (RFMb) and (RFMa) above. In contrast CCF options and AAF (any aged forestry combining CCF and rotation forestry) managements resulted highest carbon balance and carbon stock. For carbon stock the CCF resulted notably (24 %) higher value after the 100-year simulation period compared to the average value of the other management options.

Even though, based on this study, it seems impossible to increase the carbon storage whitout decreasing the harvesting rate, it is noteworthy, that with all harvesting intensities the carbon storage is increasing in relation to the current state (NPV/BAU 2016). This is explained by the constraints in the equation for the maximum sustainable yield which will restrict the harvesting yield always under the annual growth. In addition, we need to keep in mind that there might be other ways (outside of this study's scope) to enhance carbon storage via landscape level planning. For example, Nieminen et al. (2018) suggested the possibility of a CCF to reduce greenhouse gas emissions from drained boreal peatlands via water level regulation. This however has not been studied with experimental design.

## Optimal set of management regimes

Our results showed that at the scale of Central Finland no single management regime can be considered as optimal, but the optimal result is always achieved by using a diverse set of different management options (fig 1). This is well in line with other similar studies examining the optimal way of producing forest related ecosystem services. For example, Mönkkönen et al. (2014), Nolet et al. (2017), Triviño et al. (2018), Eyvindson et al. (2018), Peura et al. (2018) and Díaz-Yáῃez et al. (2019) have all reported about the benefits of using a diverse set of forest management. Also, the study from Pukkala (2016) showed that AAF (any-aged forestry, that combines management options from CCF and RF) tended to outperform RF in the production of ecosystem services in many cases, and hence supports the idea of versatile forest management. Pukkala also showed, similarly to our results, that the optimal management option was ecosystem service, spatial location and discount rate specific, and for that reason, no single management option can produce optimal result for all ecosystem services.

The increment of SA areas when targeting multifunctionality can be considered conceivable in the light of previous studies, that have shown the relative importance of SA management option for providing ecosystem services and suitable habitats for many species (Mönkkönen et al. 2014, Triviño et al. 2017, Tahvonen et al 2019). Although, the recent study from Tahvonen et al. (2019) actually indicates that the use of CCF, might even offer more suitable habitat for indicator species compared to SA option after approximately 150-year time scale. The studies mentioned above have also reported convergent results, showing that the use of BAU regime alone is not often optimal even for the economic returns from forestry.

## Costs of multifunctionality

Based on our results, it seems that most multifunctionality benefits result from a change of an optimization target from NPV to MF. However, this change does not come without a small compromise for the economic revenues of forestry (fig. 6). In the current state (NPV/BAU 100 %), the economic loss originated from the change of optimization target from NPV to MF is modest, on average only 30 € per hectare during the 100 year simulation period, which is 0.6 % of the value that would be possible to achieve with the NPV/BAU regime. In fact, our results indicate that there might be a win-win situation for the landowner and the forest multifunctionality if the forest management would be optimized using a diverse set of management regimes, including CCF. This result is not completely surprising since, also other studies have suggested the economic potential of CCF management (Pukkala 2016, Tahvonen & Rämö 2016, Peura et al. 2018, Parkatti et al. 2019) and the potential of landscape level planning to cost-effectively promote multifunctionality. For example, Mönkkönen et al. (2014) and more recently Eyvindson et al. (2018) showed the potential of landscape level planning to offer a cost-effective way to enhance biodiversity and multifunctionality in forests. Although, in Mönkkönen et al. (2014) the efficiency was measured in relation to NPV, there was no constrain for the even flow of timber, so the results are not directly comparable. In addition to studies mentioned above, also Pukkala (2016) study indicates the benefits of multi-objective management by concluding that “MF management provides more ecosystem services in addition to harvested timber yield when compared to maximum profit management”. Moreover, also the very recent study from Tahvonen et al. (2019) stated that “moderate deviation from maximum harvesting revenues to further increase forest structural diversity may not be particularly expensive”.

Although, the opportunity cost of changing to even flow MF forestry is not particularly high for a landowner, in practice it might need contribution from society via incentives to be an attractive option. However, for government perspective the allocation of conservation funding needs to be considered in relation to other conservation options, the most relevant being the METSO (voluntary based conservation program for private landowners where the forest value is fully compensated. See: https://www.metsonpolku.fi/en-US) conservation. In METSO the average conservation cost for a permanent SA area has been near 5000 € per hectare (Hohti et al. 2019) which is many times more compared to the opportunity cost with even flow MF forestry, but also offers significantly more permanent SA area, that is proven to be a high quality, and which was the most relevant single management option for enhancing biodiversity (Mönkkönen et al. 2014, Triviño et al. 2017). But since the opportunity cost for MF forestry is relatively low, the landscape level planning could offer a cost-effective way to increase forest multifunctionality and hence, might be an attractive additional tool for forest conservation, especially when used to create buffer zones and corridors for existing conservation areas.

Also, if the society is targeting to 100 % (or more) of the maximum harvesting yield, by definition, there is no possibility to expand the area of SA areas in which case this kind of planning is the only option to enhance forest multifunctionality and biodiversity.

**Harvesting yield and bioenergy potential**

Our estimate for the maximum sustainable yield for the round and energy wood with the dominant management regime (NPV/BAU 100 %) for the 2016 is 6.45 million $m^3$, from which the amount of round wood is 5.0 million $m^3$. When the model also includes CCF regime (NPV/BAU+CCF) the maximum sustainable harvesting yield for round wood was 6.4 million m3. The difference between these values is most likely due to the restriction for the even flow of timber, which benefits CCF management option, since it provides timber more frequently.

Our estimate for the maximum sustainable harvesting yield for round wood (NPV/BAU) is lower compared to the current (year 2018) harvesting intensity of 6.76 million $m^3$ (Tiitinen-Salmela 2019), which if interpreted strictly, indicates a need to reduce harvesting intensity by approximately 1.7 million $m^3$ if targeting to maintain the steady even flow of timber during the next 100 years. However, it needs to be noted that our estimate is lower compared to the other estimates for the same time period. For example, the maximum sustainable yield for round and energy wood for the same year in the regional forest agenda of Central Finland is 6.7 million $m^3$ (Keski-Suomen metsäohjelma 2016), and in the most recent monitoring of the regional forest agenda, the maximum annual sustainable yield (round and energy wood) for the period of 2015-2024 has been estimated to be 7.6 million $m^3$ (Tiitinen-Salmela 2019). These numbers are based on the estimates from the Finnish National Resource Institute (LUKE), that has also published the numerical data for this maximum sustainable analysis. Based on this data set the maximum sustainable yield for the round and energy wood in Central Finland can be calculated to be 9.11 million $m^3$ (LUKE statistics 2017). The difference between the most recent Forest Center and LUKE numbers is caused by differences in the proportion of considered energy wood, in a way that the Forest Center only considers energy round wood but lacks the proportion for stumps and branches. Compared to the number from LUKE´s data set, our result for NPV/BAU model is notably (around 30 %) lower. The largest difference comes distinctly with the amount of estimated total pulp wood (3.48 vs. 1.6 mill. $m^3$), that is 55 % lower in our estimate. A direct reason for this difference is difficult to find, but it is most likely related to the differences in the simulation programs (SIMO vs MELA) and forest management models. An expert opinion from LUKE (Hannu Hirvelä) stated that the difference might be caused by more flexible optimization in MELA compared to SIMO, which allows management actions to be varied after each simulation period and hence results in a higher amount of options during the optimization in contrast to our optimization model, where the simulated management option is fixed during the whole simulation period. Some of the differences could also be caused by different data sets and our longer simulation period (50 years vs. 100 years). Although, comparisons between our selected data set and VMI data revealed only relatively mild differences and hence it is not the likely reason for the difference. Also, it should be noted that the pattern of this pre-defined set of management alternatives has resulted in similar proportions between log and pulp woods, which seems to produce less pulp than the MELA models. As a result, we can expect that the stand level information used in this analysis does not cause this phenomenon. It may be due to less intensive thinning operations in the selected management alternatives, and that these alternatives seem to be geared towards producing higher quantities of log wood.

In addition to official government produced estimates, also Heinonen et al. (2017) has estimated maximum sustainable yield for the national level to be 73 million $m^3$ with the constrain of non-declining volume of growing stock for the 90-year period, which is about 10 % less compared to LUKE's estimate. This indicates together with our results and Kalliokoski et al. (2019) report that the results between different forest growth simulations vary and hence it might be desirable for the society to create a comprehensive view based on different results from different models.

Our estimate for the maximum (100 % NPV/BAU) bioenergy potential of Central Finland (1.4 mill. $m^3$) is again lower compared to LUKE´s estimate (1.89 mill. $m^3$), but significantly over the current use of wood chips (0.69 million $m^3$, 2018 based on Keski-Suomen metsäohjelma (2016)), that is the likely main product of energy wood. This indicates that in Central Finland there is still technical potential to increase the use of energy wood. The increment of energy wood could however have a negative biodiversity effect related to reduced dead wood volume (Eräjää et al. 2010, Juutilainen et al. 2011). Because our bioenergy potential is calculated in relation to LUKE's national estimate for maximum sustainable yield and the amount of bioenergy wood, some of the differences mentioned above can be explained by regional differences. However, it is more likely that the difference in the total maximum yield is the cause for the different bioenergy potential.

**Conclusion**

As a conclusion our results indicate that there is an unavoidable trade-off between timber related and non-timber related ecosystems services (carbon storage) and biodiversity. Maximizing the even flow of timber to the maximum economically sustainable level will increase the per hectare net present value and the amount of bioenergy wood, as was expected. At the same time, it will result a decrease in the amount of non-timber related ecosystem services (carbon storage) and in forest biodiversity. For some of the biodiversity indicators, the landscape level planning offers a way to diminish this decline, with relatively low (NPV/BAU+CCF vs. MF/BAU+CCF) or even positive opportunity cost (currently dominant management (NPV/BAU) vs. MF/BAU+CCF), but the result might still not be good enough for the long-time persistence of the species. Hence, it seems that the solution for this trade-off lies, at least partly, in the harvesting intensity itself. Due to the compromise mentioned above, the decision with a “right” target level is very much value based but requires comprehensive consideration from the society.

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## Why SIMO was selected and how to develop Biomass-Atlas

In our opinion, it was necessary to conduct simulation-based forest growth study for us to be able to answer our study questions. Although there are also other forest growth simulation programs available, SIMO was selected because it is a free open source tool that has been used frequently in scientific peer reviewed papers.

The main benefit of Biomass-Atlas is that it collects GIS-data from multiple sources into one place. It is valuable, that Atlas already has a tool for calculating biomass information and for downloading it as a csv or excel files. However, for scientific research purposes it would be highly beneficial, if it would be possible to download the spatial information data set to one's own computer, in a way that would allow the use of Geographic information software, like ArcMap. This would be beneficial even if the used data set is downloadable to somewhere else. The development work for a new download tool might be expensive, but part of the problem could be solved just by directing the user to other open source web pages, where the data set could be downloaded from. Now there might be a link to other download service in meta information, but it is not highlighted in anyway or easy to find. This might be an issue for some of the users.

The value of Biomass-Atlas would further increase if the service would allow the comparison of wood biomass under different forest management scenarios. In future of forest management could be more diverse compared to current situation, hence there might be interest groups interested to know, for example, how the usage of continuous cover forestry or extended rotation length would alter the biomass potential.

Now the web site works in Finnish, but since it is at least partly developed by governmental institutions it might be fair to translate the service also in Swedish, the other official language.

Since the service is relatively new but already gives value for scientists and other people involved with bio-based materials, enhanced advertisement of the service might be needed. Now the utilization rate might be small just because people do not find the page.