Forest Policy and Economics 80 (2017) 80–98

Contents lists available at ScienceDirect

Forest Policy and Economics

journal homepage: www.elsevier.com/locate/forpol

Scenario analyses for the effects of harvesting intensity on development of forest resources, timber supply, carbon balance and biodiversity of Finnish forestry

Tero Heinonen [a,*], Timo Pukkala [a], Lauri Mehtätalo [b], Antti Asikainen [c], Jyrki Kangas [a], Heli Peltola [a]

[a] School of Forest Sciences, Faculty of Science and Forestry, University of Eastern Finland, PO Box 111, FI-80101 Joensuu, Finland
[b] School of Computing, University of Eastern Finland, Science Park, Länsikatu 15, P.O. Box 111, FI-80101 Joensuu, Finland
[c] Natural Resources Institute Finland, Joensuu FI-80101, Finland

ARTICLE INFO

Article history:
Received 21 October 2016
Received in revised form 9 March 2017
Accepted 10 March 2017
Available online 21 March 2017

Keywords:
Biodiversity
Bioeconomy
Carbon balance
Even-flow harvesting targets
National Forest Inventory
Timber supply

ABSTRACT

We used national scenario analyses to examine the effects of harvesting intensity on the development of forest resources, timber supply, carbon balance, and biodiversity indicators of Finnish forestry in nine 10-year simulation periods (90-year simulation period) under the current climate. Data from the 11th National Forest Inventory of Finland were used to develop five even-flow harvesting scenarios for non-protected forests with the annual harvest ranging from 40 to 100 million m^3. The results show that the highest annual even-flow harvest level, which did not decrease the growing stock volume over the 90-year simulation period, was 73 million m^3. The total 90-year timber production, consisting of harvested volume and change in growing stock volume, was maximized when the annual harvest was 60 million m^3. Volume increment increased for several decades when harvested volume was less than the current volume increment. The total carbon balance of forestry was the highest with low volume of harvested wood. Low harvested volume increased the values of biodiversity indicators, namely volume of deciduous trees, amount of deadwood and area of old forest.

1. Introduction

There is a pressure to increase wood production in Finland and elsewhere in Europe in order to fulfill the increasing demand for wood biomass in the growing forest bioeconomy. Increased wood production is also needed to move towards low-carbon and resource-efficient society in which fossil resources are substituted by renewables to mitigate climate change (The Finnish Bioeconomy Strategy, 2014; Sathre et al., 2010; Scarlat et al., 2015; Kilpeläinen et al., 2016). However, at the same time other ecosystem services, such as forest biodiversity, should be secured and maintained.

The total forested land area in Finland is 26.2 million ha and the current total growing stock volume is 2357 million m^3, of which about 90% is in commercial forests (Finnish Statistical Yearbook of Forestry, 2014). In 2013, the annual gross volume increment of the growing stock was 104.4 million m^3, of which 96.2 million m^3 was in forests available for cuttings. The annual timber harvest was 65.3 million m^3 (Finnish Statistical Yearbook of Forestry, 2014). Both the growing stock volume and the volume increment have increased for several decades, mainly because the harvested volume has been smaller than the volume increment. Also climate change is expected to increase forest growth and timber supply from Finnish forests (Kellomäki et al., 2008). According to the Finnish Statistical Yearbook of Forestry (2014), the maximum annual sustainable drain of timber is 73 million m^3 yr^{-1}, and the drain of energy biomass is 21 million m^3 yr^{-1} (including small-sized stem wood, foliage, stumps and coarse roots) for the period 2010–2019. These figures are clearly higher than the current removal rates.

In the EU, the bioeconomy had a turnover of about € 2 trillion in 2012 and it employed over 22 million people, and these numbers are expected to increase remarkably (European Commission, 2012). According to Scarlat et al. (2015), the bioeconomy market in the EU was about € 2.4 trillion in 2014. In Finland, the current bioeconomy output is approximately € 65 billion and its share from exports is about 25% (The Finnish Bioeconomy Strategy, 2014). More than half of the bioeconomy relies on forest utilization. The Finnish Bioeconomy Strategy (2014) aims at increasing

* Corresponding author.
E-mail addresses: tero.heinonen@uef.fi (T. Heinonen), timo.pukkala@uef.fi (T. Pukkala), lauri.mehtatalo@uef.fi (L. Mehtätalo), antti.asikainen@luke.fi (A. Asikainen), jyrki.kangas@uef.fi (J. Kangas), heli.peltola@uef.fi (H. Peltola).

http://dx.doi.org/10.1016/j.forpol.2017.03.011
1389-9341/

the output of Finnish bioeconomy to € 100 billion and creating 100,000 jobs within the next 10 years. This requires considerable increase in the harvests of Finnish forests. Numerous industrial investments have already been made, are under a way, or are planned in the Finnish forest bioeconomy sector. Depending on realized investments, the Finnish forest industry may need 10–30 million m^3 yr^{-1} more wood in the coming years.

Increasing harvests are likely to increase the environmental impacts of forestry. For example, the amount of dead wood and deciduous wood will most probably decrease, which affects the biodiversity of forests (Juutinen et al., 2006; Tikkanen et al., 2007; Bradford and D'Amato, 2012; Gamfeldt et al., 2013). Especially large dead trees and aspens (*Populus tremuloides*) are key elements for many endangered species and for overall biodiversity (e.g., Sahlin and Ranius, 2009; Similä et al., 2003). In managed forests, the amount of dead wood is usually low from the forest biodiversity point of view compared to unmanaged forests. For example, in southern Finland the quantity of coarse woody debris (CWD) is, on average, <10% (<4 m^3 ha^{-1}) of its amount in natural forests (CWD > 40 m^3 ha^{-1}, Siitonen, 2001; Junninen et al., 2006). On the other hand, climate change is expected to intensify natural disturbance regimes in forests (e.g., by wind storms, forest fires and bark beetle damages), of which biodiversity will benefit while other ecosystem services, like timber production, may suffer (Jönsson et al., 2009; Subramanian et al., 2016; Thom and Seidl, 2016).

In forest-rich countries like Finland, forest-based bioeconomy can play an important role in climate change mitigation. This is because growing forests sequestrate carbon, act as carbon storage and provide wood to substitute fossil-intensive materials, products and energy (Matala et al., 2009; Kärkkäinen et al., 2008; Sathre et al., 2010; Hynynen et al., 2015; Kilpeläinen et al., 2016). The total carbon balance of forestry is affected by changes in several carbon pools, namely the carbon of growing stock (living above- and below-ground forest biomass), above- and below-ground dead organic matter (soil carbon) and wood-based products (Malmsheimer et al., 2011; Verified carbon standard, 2013; Pukkala, 2014). Emissions from fossil fuels can also be reduced by cascade use of wood material, e.g., by recycling waste paper and using wood from demolished buildings as fuel feedstock (Werner et al., 2010).

Previously, Sievänen et al. (2014) studied the carbon balance of Finnish forestry, considering both mineral soils and peatlands. Lundmark et al. (2014) analyzed the carbon balance of Swedish forestry. Matala et al. (2009) and Hynynen et al. (2015) studied temporal variations in the carbon stock of Finnish forests. In the long run, managed forests are expected to be better carbon sinks than unmanaged forests were losses by natural mortality would increase and the net increment in living biomass will eventually turn zero (Smyth et al., 2014; Hynynen et al., 2015; Pukkala, 2017).

Scenario analysis offers a means to study the effects of harvesting intensity on the development of forest resources, timber supply, carbon balance of forestry and biodiversity indicators. A scenario can be considered as a vision of the future, or a projected sequence of events, for instance in a detailed forest management plan. According to a recent national scenario analysis by Hynynen et al. (2015), it is possible to increase the average annual cutting volume in Finland by up to 40% during 100 years, by increasing the intensity of forest management and utilization.

In this work, we used national scenario analyses to examine the effects of harvesting intensity on the development of forest resources, timber supply, carbon balance, and biodiversity indicators of Finnish forestry in nine 10-year simulation periods (90 years in total) under the current climate. The study developed five even-flow harvesting scenarios where the annual harvest ranged from 40 to 100 million m^3, i.e. from clearly lower to clearly higher than the present drain. We used forest data from the National Forest Inventory of Finland (NFI11), excluding protected forests. The impacts of varying even-flow harvesting targets on the carbon balance of forestry were analyzed, including all the carbon pools listed by the International Panel on Climate Change (IPCC, 2000). We used the amount of dead and deciduous wood, and the areas of mature and old forest as biodiversity indicators.

2. Material and methods

2.1. Forest data

Forest data used in this study consisted of a sub-sample of the sample plots of the 11th National Forest Inventory (NFI11) of Finland, conducted between 2009 and 2013. In NFI11, a systematic grid of sample plot clusters covered the whole country. One sample plot (number 3) from every cluster was selected for this study. Plots situated in protected forests were excluded. Sample plots were divided into three groups based on their geographical location so that plots situated in the earlier-applied forestry center areas of southern (1–6), central (7–10) and northern Finland (11 − 13) constituted their own calculation regions. As a result, the dataset included 1890 sample plots for southern Finland, 1393 plots for central Finland and 1402 plots for northern Finland (Table 1). Analyses were performed separately for these three regions, and national results were combined from regional results. The area that one sample plot represents was obtained by dividing the total forested land area of the region used for timber production by the number of sample plots located in that region.

The selected sample plot data were imported into Monsu software (Pukkala, 2011), which was used as the platform for the scenario calculations. Data on trees were imported to Monsu as tree lists. Variables used for sample trees were: tree species, diameter at breast height (dbh), height and number of trees per hectare. However, some of these variables were not collected in the field inventory. The number of trees per hectare, represented by the sample tree, was calculated from dbh and the used basal area factor. In addition, in NFI11 only every 7th relascope-sampled tree was measured for height. To mimic the tree size variation of sapling stands (mean diameter < 8 cm), one NFI11 sample tree was divided into three sample trees, each representing 1/3 of its initial frequency. One tree had dbh and height 20% lower than the original and another had a dbh and height 20% higher.

2.2. Calculation of tree height

The missing heights for trees larger than 8 cm in dbh (46,473 trees) were imputed using a nonlinear mixed-effects model based on the Näslund's (1937) function, which was recently suggested by Mehtätalo et al. (2015) for general use. The model was fitted separately for the three main species using the species-specific sample tree data (3183 Scots pines (*Pinus sylvestris*), 1919 Norway spruces (*Picea abies*) and 1536 silver and downy birches (*Betula pendula* and *Betula pubescens*) and other broadleaved trees). The modeling followed the procedures described in Mehtätalo et al. (2015). The two parameters of the Näslund's (1937) function were modeled using linear submodels and random plot effects. The following variables, with appropriate nonlinear transformations, were used as fixed predictors in both submodels: mean dbh, basal area, altitude, temperature sum and categorical site characteristics.

As the resulting height-diameter (H-D) data are used to simulate forest growth, a realistic description of the variability in the H-D relationship between and within stands is important.