



Mitigating forest biodiversity and ecosystem service losses in the era of bio-based economy

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ARTICLE INFO

Keywords:

Bioeconomy
Trade-off analysis
Ecosystem services
Optimization
Forest management

ABSTRACT

Forests play a crucial role in the transition towards a bioeconomy by providing biomass to substitute for fossil-based materials and energy. However, a policy-policy conflict exists between the desire to increase the utilization of bio based renewable resources and the desire to protect and conserve biodiversity. Increasing forest harvest levels to meet the needs of the bioeconomy may conflict with biodiversity protection and ecosystem services provided by forests. Through an optimization framework, we examined trade-offs between increasing the extraction of timber resources, and the impacts on biodiversity and non-wood ecosystem services, and investigated possibilities to reconcile trade-off with changes in forest management in 17 landscapes in boreal forests. A diverse range of alternative forest management regimes were used. The alternatives varied from set aside to continuous cover forestry and a range of management options to reflect potential applications of the current management recommendations. These included adjustments to the number of thinning, the timing of final felling and the method of regeneration. Increasing forest harvest level to the maximum economically sustainable harvest had a negative effect on the habitat suitability index, bilberry yield, deadwood diversity and carbon storage. It resulted in a loss in variation among landscapes in their conservation capacity and the ability to provide ecosystem services. Multi-objective optimization results showed that combining different forest management regimes alleviated the negative effects of increasing harvest levels to biodiversity and non-wood ecosystem services. The results indicate that careful landscape level forest management planning is crucial to minimize the ecological costs of increasing harvest levels.

1. Introduction

In order to reduce dependence on non-renewable resources, manage natural resources sustainably, mitigate and adapt to climate change, and maintain competitiveness, Europe is moving away from an economy based on use of non-renewable resources and towards a bioeconomy. Forests provide jobs, income and biomass for substituting fossil-based materials and energy, and compared with other sources of biomass forests have the advantage of a large production potential, which does not threaten food security (Ollikainen, 2014; EC, 2012b). Currently, the forest and wood industry together with paper and pulp industry currently cover 30% annual turnover and 22% of the employment in the EU bioeconomy (EC, 2012b). The EU forest strategy and national bioeconomy strategies and policies stress the importance of development of new wood-based materials and products (Finnish Ministry of Employment and the Economy, 2014; EP, 2014; Skog22, 2015). In addition, more forest biomass is needed in the energy transition to meet the renewable energy targets (Beurskens and

Hekkenberg, 2011; Szabó et al., 2011; Bentsen and Felby, 2012). The total energy use of biomass is expected to double from 2005 to 2020 to cover over half of the final renewable energy consumption of 10 exajoules in 2020, and over 55% of the biomass supply is predicted to come from forest (Scarlat et al., 2015). Consequently, national bioeconomy strategies relying on wood, climate and renewable energy policies together with an increasing demand for forest-based products are drivers for an increase in forest harvest levels in Europe (Mantau et al., 2010; Frank et al., 2016).

Intensifying biomass harvests may conflict with multiple other social economic and environmental functions of forests. Forests also contribute to water quality, reduce flooding, provide recreational services and non-wood products such as game, berries and mushrooms, prevent soil erosion, foster biodiversity and mitigate climate change through carbon sequestration and storage (EC, 2012a; Nabuurs et al., 2013). Previous studies have shown trade-offs between intensifying biomass harvesting and climate regulation through carbon sequestration (Schulze et al., 2012; Zanchi et al., 2010; Kallio et al., 2013;

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Triviño et al., 2015), collectable goods (Peura et al., 2016), deadwood and recreational attractiveness (Verkerk et al., 2014), and maintaining high levels of biodiversity (Mönkkönen et al., 2014). Therefore, bioeconomy targets aiming at intensifying biomass harvests may conflict with other policy goals, such as the EU biodiversity strategy, which pursues halting biodiversity loss by 2020. However, previous studies also indicate that careful forest management planning may reconcile these conflicts or reduce the negative impacts (Triviño et al., 2017; Repo et al., 2015), and possibly pave the way for increasing timber harvests while minimizing harm to other ecosystem services.

In boreal Europe wood and forest-based products form the basis of current and future bioeconomy (e.g. Skog22, 2015; Finnish Ministry of Employment and the Economy, 2014). For example, the Finnish forestry, the bioeconomy currently represents 16% of the national economy and wood product and pulp and paper industries cover over 40% of output and 80% of the exports of the current national bioeconomy (Finnish Ministry of Employment and the Economy, 2014). To boost the transition towards an increased bio-based society, Finland aims to diversify wood use and to increase forest harvesting to almost maximum sustainable harvest level from a timber extraction perspective (Finnish Ministry of Employment and the Economy, 2014; Lehtonen et al., 2016). In addition to increased timber harvests, to meet the renewable energy targets agreed in the European Union (EC, 2009), for example Finland is aiming to triple the use of forest harvest residues, such as tree tops, branches and stumps in energy production compared with the year 2009 (Ministry of Employment and the Economy, 2010).

A recent review suggests that intensive production forestry may have substantial effects on numerous ecosystem services, and that these effects may be harmful or beneficial depending on stakeholders (Pohjanmies et al., 2017a). Therefore, bioeconomy policy impacts on alternative stakeholder groups vary, and identifying winners and losers by evaluating the effects of bioeconomy policies on alternative ecosystem functions and services will make political decision-making more transparent. Further, this increased intensification of forest use may promote a homogenization, which may threaten biodiversity at a landscape level (Stein et al., 2014). Since the Finnish forest land area covers 14% of the EU 28 countries (Peltola, 2014), the effects of intensifying biomass harvests on forest ecosystem services and species dependent on forests will have importance on the European scale. As Sweden and Norway utilize a similar form of forest management as Finland, the relevance of this study can be valid for a much greater share of European forests.

Previous studies evaluating the transition to a forest-based bioeconomy have focused on how increasing forest harvest levels impacts either the forest carbon balance, ecosystem services or biodiversity. The increase in timber harvests and forest harvest residue extraction rates reduce the carbon stocks of biomass and soils reducing the carbon sink capacity of the forest (e.g.; Sievänen et al., 2014; Frank et al., 2016). A scenario analysis in Finland to the year 2045 has shown that increasing forest harvests to maximum economically sustainable harvest level reduces the forest carbon sink and this sink may become an emission source if harvests are increased to the maximum economically sustainable harvest level (Lehtonen et al., 2016). At a European level, a scenario approach has been used to evaluate the impact on a variety of ecosystem services due to a shift in policy (Verkerk et al., 2014). From a multi-objective optimization framework questions relating to evaluating the sustainability of ecosystem services (ESS) and biodiversity have been addressed through a direct approach (i.e. Diaz-Balteiro et al., 2016; Wam et al., 2016), or through zonation techniques such as TRIAD (i.e. Montigny and MacLean, 2006; Carpentier et al., 2016). Recently, Heinonen et al. (2017) have conducted a scenario analysis examining the impact differing harvesting intensities will have on a selection of biodiversity indicators. However, comprehensive assessment of the effects of increasing forest harvest levels on different ecosystem services and biodiversity are still lacking. Moreover, we do not know if and how changes in forest management could minimize the possible harm

resulting from increasing harvest levels to the environment.

In this study, we explore the effects of increasing forest harvest levels on biodiversity and non-timber ecosystem services. Using a comprehensive large scale dataset combined with long-term simulation of forests and multi-objective optimization tools we i) study how increasing forest harvest level affect biodiversity, non-wood products and carbon storage in boreal forests, and ii) suggest how landscape level forest planning can minimize these possible conflicts and even produce synergies. This study quantifies the effects of policies promoting increasing harvest levels on biodiversity and ecosystem services. The findings of this study can frame policy discussions on how to determine the most appropriate harvesting level and how to adapt forest management recommendations to increasing harvesting levels, taking into account a variety of environmental criteria.

2. Material and methods

To demonstrate the impact of changing the policy towards fully utilizing the maximum sustainable yield (a quantity of timber products than can be harvested continuously year after year), a regional level analysis is proposed. As forest industries require a stable source of raw materials for production purposes, changing the quantity of timber harvested will influence the ability of industry to source materials from the local region. The region under consideration was comprised of 17 watersheds in central and southern Finland. The specific boundaries of the watersheds were defined as third-level catchment areas, delineated by the Finnish Environment Institute (SYKE, 2010). The watersheds were selected to represent existing variation in overall productivity (variation in soil types) and their current conservation capacity (variation in age distribution). Each watershed has a differing initial state and a different productivity potential for providing timber, ecosystem services (ESS) and biodiversity (BD) (for more detailed description of forests in the selected watersheds, see Pohjanmies et al., 2017b). The entire region is slightly over 48,770 ha and is composed of 32,276 stands (homogenous parcels of forested land). The stand level data used was obtained from the local forest authority. The analysis focuses on understanding how increasing the intensity of the harvests from 60% to 100% of the maximum sustainable yield will impact the potential of providing other ecosystem services and maintaining biodiversity. This range of harvesting intensity was selected because it encompasses the current level (< 70%) (Peltola, 2014) and the targeted level according to the national policy (close to 100%).

A total of five indicators were included in this analysis: timber income, habitat suitability index combined for six indicator species, bilberry yield (*Vaccinium myrtillus* L.), carbon storage in woody biomass and in soil, and deadwood diversity. Income from timber is the summation of the price of the timber assortments multiplied by the quantity of the assortments. This represents the monetary value of the flow of timber from the forest. Because of even-flow constraint in our optimization problem (see below) discounting timber income is not needed. The price of the timber is based on the assortment (i.e. saw logs or pulp wood) for each tree species, and we used the average values from the recent past (Peltola, 2014).

The ecosystem service indicators selected were the carbon storage and the bilberry yield. Carbon storage was evaluated as the total carbon held within the forest. For this analysis we do not consider the potential of carbon storage in the final products of the forest industry. The carbon of standing timber and deadwood was evaluated as 50% of the dry biomass. Soil carbon was evaluated using two models. For mineral soil the Yasso07 model were used (Liski et al., 2005; Tuomi et al., 2009, 2011), and peatland soils were modeled using the carbon flux models proposed by Ojanen et al. (2014). The latter provides an underestimate of the total carbon in the forest, as the initial stocks of carbon in peat soils are not included but still allows evaluating the changes in the soil carbon pool. The quantity of bilberries, an important non-timber product in boreal forests, was calculated by the forest was predicted using

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