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Continuous cover forestry is a cost-efficient tool to increase multifunctionality of boreal production forests in Fennoscandia

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ABSTRACT

Earlier research has suggested that the diversification of silvicultural strategies is a cost-efficient tool to ensure multifunctionality in production forests. This study compared the effects of continuous cover forestry and conventional rotation forestry on ecosystem services and biodiversity in boreal forests in Finland. We simulated over 25,000 commercial forest stands for 100 years under continuous cover and rotation forest management. Forests without management were used as a reference. We compared the effects of silvicultural practices over space and time on ecosystem services, biodiversity indicators and multifunctionality. Our results revealed that continuous cover forestry was better than rotation forest management in terms of timber net present value, carbon sequestration, bilberry production, scenic beauty and the number of large trees. It provided higher habitat availability for indicator species dependent on deciduous trees and mature forest structure. Rotation forest management was better than continuous cover forestry in terms of harvested tree biomass, cowberries, mushrooms, and species dependent on high tree volume. In general, multifunctionality was higher in continuous cover forests than in rotation forests. Therefore, continuous cover forests may have a greater potential to produce simultaneously multiple benefits from forests. However, unmanaged forests often provided the highest levels of services and biodiversity making their role indispensable in delivering forest related ecosystem services and, especially, in the maintenance of biodiversity. Continuous cover forestry does not itself guarantee the maintenance of all ecosystem services and biodiversity in commercial forests but it can be an important part of a successful progression towards more sustainable forestry.

1. Introduction

Forests are crucial in delivering ecosystem services for human wellbeing. During the last decades many forests in the boreal zone have been managed for intensive timber production applying conventional even-aged rotation forest management (hereafter RFM) while largely disregarding management effects on biodiversity and other forest ecosystem services (Burton et al., 2010; Gauthier et al., 2015; Vanhanen et al., 2012). Solely focusing on timber production, RFM has resulted in a biodiversity decline in production forests (Bradshaw et al., 2009; Siitonen, 2001; Östlund et al., 1997). Moreover, RFM can disturb nutrient cycling, increase land erosion and decrease water quality (Laudon et al., 2011). The role of boreal forests in climate regulation is well known as they contain about one third of the global terrestrial carbon stock (Bradshaw and Warkentin, 2015; Pan et al., 2011). However, the common practice of RFM focusing solely on timber production reduces carbon storage in boreal forests compared with optimal forest management (Triviño et al., 2016). Focusing on timber production can also be in conflict with other economically beneficial forest uses, such as recreation and harvest of non-timber forest products (e.g., berries and mushrooms) (Peura et al., 2016). Earlier research has shown that diversifying forest management is a cost-efficient tool for enhancing ecosystem services (Miina et al., 2016; Triviño et al., 2015) and biodiversity (Mönkkönen et al., 2014) in production forest landscapes. In addition, previous studies indicate that alternative silvicultural practices are needed to ensure the delivery of multiple benefits of forests (Puettmann et al., 2015; Felton et al., 2016).

Continuous cover forestry (henceforth CCF) has a long history throughout the world, however has been widely replaced by RFM for decades (Kuuluvainen et al., 2012; O'Hara, 2002; Pommerening and Murphy, 2004). Recently, CCF is returning as an important silvicultural alternative to RFM (Diaci et al., 2011). In CCF, single trees, or small

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group of trees, are removed from the forest usually every 15–20 years (Laiho et al., 2011; Kuuluvainen et al., 2012; Pommerening and Murphy, 2004). Trees regenerate naturally, and the structure of forests is often uneven-aged. Such forest management practice has been called 'near natural forestry' since it may mimic a natural forest state and natural disturbances better than RFM (Kuuluvainen et al., 2012).

Previous research in boreal forests has shown that CCF is better than RFM from the perspective of berry production, the amenity of forest landscape, carbon balances and resistance against wind (Pukkala, 2016a; Pukkala et al., 2016, 2011). Moreover, CCF may be economically more profitable than rotation forest management for forest owners (Pukkala, 2016a; Tahvonen, 2016; Tahvonen et al., 2010; Tahvonen and Rämö, 2016). However, there are also contradictory results, regarding the economic profitability (Andreassen and Øyen, 2002) as well as the effects on climate regulation (Lundmark et al., 2016) and resistance against disturbances (Hanewinkel et al., 2014). Consequently, the debate on the usefulness of CCF is still ongoing (Diaci et al., 2011). Even though CCF may often outperform RFM at the stand level, we do not know the relative performance of these management practices at a large landscape scale nor do we know the potential benefits a combination of these practices may have for ecosystem services and biodiversity across the landscape.

In general, CCF may provide more habitats and resources for species living in mature or late successional forests compared with RFM (Calladine et al., 2015; Kuuluvainen et al., 2012; Pukkala et al., 2012). In boreal forests, CCF has been found to be less harmful than RFM, for example, for understorey vegetation (Jalonen and Vanha-Majamaa, 2001), some invertebrate species (Matveinen-Huju and Koivula, 2008), and soil fauna (Siira-Pietikäinen and Haimi, 2009). Moreover, in comparison to RFM, CCF may provide more resources for dead wood dependent species (Atlegrim and Sjöberg, 2004) as well as for herbivores (Atlegrim and Sjöberg, 1996). However, because different species require differing habitats and resources, it is obvious that no single management can be the best for all species and biodiversity aspects (Calladine et al., 2015; Mönkkönen et al., 2014). Thus, it is important to understand how the different silvicultural practices promote different types of forest structures and species (Felton et al., 2016).

Even though there is evidence that CCF is better than RFM for several forest purposes (Pukkala, 2016a), their relative performance of ecosystem service provisions and of biodiversity is not well known when compared with unmanaged forests (but see Pukkala, 2016b; Sharma et al., 2016). Even if there is a seemingly large difference between the two silvicultural alternatives, they may both appear equally poor relative to forests in a more natural state. If so, then CCF may not be the solution to declining biodiversity and ecosystem services. Therefore, comparing both practices with unmanaged forests generates valuable knowledge about their actual effects on the ability of forest landscapes to provide goods and benefits to humankind.

As forests provide multiple services and benefits, the capabilities of alternative forest management practices should be assessed from a multifunctionality perspective, i.e., their relative performance to provide bundles of services simultaneously (Mastrangelo et al., 2014; van der Plas et al., 2016). Although earlier results demonstrate the high potential of CCF to simultaneously provide multiple services (Pukkala, 2016a), the concept of multifunctionality has not been commonly applied. Multifunctionality of forests can be considered as an index, which highlights the number of services which exceed a specified level of those services (van der Plas et al., 2016). Therefore, when estimating the capacity of different silvicultural practices to provide multiple benefits simultaneously, the effect of desired level of services should be taken into account.

We use a dataset describing a large forest landscape where we apply three alternative management practices — CCF, RFM and set aside (no management) — simulated for 100 years into the future to estimate their relative performance to provide forest ecosystem services and maintain biodiversity. We address the following questions: 1) which ecosystem services and biodiversity measures benefit more from CCF compared with RFM and vice versa? 2) what are the levels of biodiversity and ecosystem services under two alternative forest management practices as well as their optimal combination compared with unmanaged forests? 3) which silvicultural practice provides the greatest forest multifunctionality across large forest landscapes?

2. Methods

2.1. Forest data and simulations

The study areas are located in central and southern Finland, encompassing 39,979 ha. Data consist of 26,024 commercial forest stands on mineral soils with the average size of stands being 1.5 ha. The initial forest data was provided by the Finnish Forest Centre, and are based on laser scanned data with ground-truthing (Maltamo et al., 2007). The data contain forest characteristics, such as forest site type, age, or tree species compositions. In the initial data, Scots pine (*Pinus sylvestris*) was the dominant tree species on 23% of the stands, Norway spruce (*Picea abies*) on 63% of the stands and birches (*Betula pendula* and *B. pubescens*) on 14% of the stands. Mixed stands, i.e., where none of the tree species accounted for > 75% of the total volume, represent 45% of all the stands. The variation in the site type and initial age of stands are given in Appendix S1: Fig. S1.

The development of each stand was simulated 100 years into the future using SIMO-forest simulator (Rasinmäki et al., 2009) under three different forest management regimes: CCF, RFM, and no silvicultural management (set aside, SA). We chose a time scale of 100 years since it is long enough to cover an entire rotation, and thereby to reveal the long-term impacts of silvicultural practices. The forest simulations create forest structural data at 5 year intervals.

In CCF, a selection of the largest trees is removed from the forests approximately every 15 years. Through natural regeneration, the composition of tree species becomes more mixed (Appendix S1; Fig. S2). Over time, CCF changes the forest age structure to uneven-aged containing different age classes of trees. No retention trees were left (trees retained permanently through 100 years). The management rules for cuttings are given in Appendix S1: Table S1 (according to the good practice guidance for forestry in Finland from Äijälä et al., 2014). For CCF regime, the growth models of Hynynen et al. (2002) were used until the first cutting and then the growth models of Pukkala et al. (2013) for uneven-aged forests were used (Appendix S1: Fig. S3). The model set of Hynynen et al. (2002) consists of species-specific individual-tree models for ingrowth, growth and mortality. The model set of Pukkala et al. (2013) consists of species-specific individual-tree diameter increment and survival models, and a stand level model for ingrowth.

RFM is currently the recommended and the most common forest management practice in Fennoscandia (Äijälä et al., 2014). In Finland RFM includes several silvicultural actions: soil preparation, seeding or planting trees, one to three thinnings, and the final clear cut, where approximately five retention trees per hectare are retained (according to the good practice guidance for forestry from Äijälä et al., 2014). The management rules for regeneration cutting are given in Appendix S1: Table S2. The average rotation length of RFM is approximately 80 years in our study region (Appendix S1; Fig. S2). RFM creates forest stands, which are often very homogenous in tree species composition as well as in the age structure. The growth models of Hynynen et al. (2002) for even-aged stands were applied for this regime.

In SA regime, forests are allowed to grow without human intervention (Appendix S1; Fig. S2). In SA, forests are denser, grow slower and there is more tree competition compared with managed forests resulting in higher self-thinning and tree mortality. The models of Hynynen et al. (2002) were applied to simulate forest growth without management actions since they predict better the development of old-growth forests than the models of Pukkala et al. (2013).