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Conflicting objectives in production forests pose a challenge for forest management

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ABSTRACT

Conflicts among different ecosystem services have been shown to be common and potentially exacerbated by management interventions. In order to improve the sustainability of natural resource use, the occurrence of these conflicts and the effects that management actions have on them need to be understood. We studied the conflicts between ecosystem services and the potential to solve them by management choices in boreal production forests. Our study area consisted of nearly 30,000 forest stands which were simulated for 50 years into the future under alternative management scenarios. The study included four ecosystem services – timber production, bilberry production, carbon storage, and pest regulation – and one biodiversity conservation objective defined as availability of deadwood resources. We 1) measured the conflicts among each pair of objectives, and 2) identified a compromise solution for each pairwise conflict defined as one which simultaneously minimizes the losses for both objectives. Our results show that conflicts between timber production and other objectives are typical, severe, and difficult to solve, while non-extractive benefits including biodiversity conservation can be more easily reconciled with each other. To mitigate the most severe conflicts in boreal forests, increased diversity in management regimes is required.

1. Introduction

Evaluating ecosystem services, or the diverse benefits people obtain from nature, may produce information that assists ecosystem managers in balancing the multiple, often conflicting, interests that people place on the environment (Albert et al., 2014; Bennett et al., 2009). Critical aspects of these evaluations include the co-occurrence of multiple ecosystem services, their interactions, and the impacts human activities have on their supply. The complexity of the relationships among different ecosystem services, aspects of biodiversity, and social objectives was recognized already in the Millennium Ecosystem Assessment (MEA, 2005), and considerable effort has since gone into conceptualizing and clarifying these processes (e.g. Kremen, 2005; Bennett et al., 2009).

A key first step in improving the sustainability of natural resource use is to identify patterns of trade-offs and synergies among ecosystem services and how they are driven by management interventions. A trade-off between ecosystem services occurs when the increased utilization of one service leads to a loss in another service, and they may take place at varying spatial and temporal scales (Rodríguez et al., 2006). The Millennium Ecosystem Assessment (MEA, 2005) established that ecosystem management to increase the supply of one ecosystem service may deteriorate the supply of other services, and that these negative trade-offs are particularly common between individual provisioning services and between provisioning and other types of ecosystem services (regulating, supporting, and cultural services). An extreme case is the conversion of natural ecosystems into managed monocultures, but also the extractive use of resources from a (semi-)natural ecosystem may, by altering the structures and functions of the ecosystem, cause more or less persistent changes in other ecosystem services.

Several recent studies have examined the relationships among ecosystem services and the effects of management on their supply in forests, where timber harvesting and other management activities cause changes in ecosystem structures and functions (e.g. Bradford and D'Amato, 2012; Edwards et al., 2014b; Brandt et al., 2014). Forests provide many important ecosystem services: they are a source of food and raw materials, provide recreational opportunities, hold cultural meanings, harbor a variety of beneficial organisms, regulate air, soil, and water quality, and play an important role in climate regulation. Even where forest loss is not a major threat, forests are affected by increasing pressures, such as

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a rising demand for forest biomass, the urgency to utilize forest ecosystems in climate change mitigation, and the need to safeguard biodiversity. Additionally, forests undergo natural disturbances that are expected to intensify in response to global change (Lindner et al., 2010; Seidl et al., 2016). These challenges create multiple objectives for forest management as well as a mounting need to resolve the conflicts among them (Bradford and D'Amato, 2012).

Boreal forests are extensively used for timber production, but are also a source of many locally and globally important ecosystem services. Earlier studies from boreal forests have shown that conflicts between timber production and other ecosystem services are common (e.g. Gamfeldt et al., 2013; Pohjanmies et al., 2017) and that stand management can affect trade-offs among forest services (Triviño et al., 2015; Zanchi et al., 2014). Specifically, maximizing timber harvests has been found to reduce forests' capacity to provide other services, while less intensive use of timber resources can lead to compromise solutions where intermediate levels of several objectives are maintained (Triviño et al., 2015; Zanchi et al., 2014). However, these impacts may be dependent on the ecosystem services in question and the properties of the forest (Biber et al., 2015). Moreover, few studies have examined the occurrence of conflicts among non-timber benefits from managed forests.

In this study, we study the occurrence and severity of conflicts between ecosystem services in a large production forest in Finland. Earlier studies in this landscape have shown that conventional, intensive forest management may cause severe trade-offs between timber production and biodiversity (Mönkkönen et al., 2014), climate regulation (Triviño et al., 2015), and forest collectables (Peura et al., 2016). Here, we measure the conflicts between timber production and non-timber forest benefits but also among non-timber benefits. We thus aim to resolve whether the most severe conflicts are those between a provisioning service (here, timber production) and other objectives, while non-extractive benefits including biodiversity conservation can be more easily reconciled with each other.

Earlier work conducted in our study area has also shown that considerable benefits in terms of biodiversity and ecosystem services can be gained by diversifying forest management regimes and optimizing their application across the landscape (Mönkkönen et al., 2014; Triviño et al., 2015). In these studies, forest management has been optimized at the scale of the entire landscape, recognizing the possibility that only some forest stands can produce high levels of several objectives simultaneously, while some can be disproportionally good for targeting a single objective. Optimal management across the landscape may thus be a combination of 'land-sharing' and 'land-sparing' strategies (e.g. Triviño et al., 2015), the former referring to a high supply of multiple ecosystem services from the same stand and the latter to prioritization of a single ecosystem service in a stand (e.g. Edwards et al., 2014a; Maskell et al., 2013). In our study, we focus on 'land-sharing' strategies and measure the severity of conflicts among pairs of objectives in each individual forest stand. We thus explore how achievable 'land-sharing' strategies are at the stand level. The achievability of good 'land-sharing' solutions at the stand level provides additional information on the severity of the pairwise conflicts and is important from a practical point of view. First, as a stand is the basic operational unit of practical forestry (Mäkelä and Pekkarinen, 2004), the stand level is the most relevant for forest managers. Second, management plans that allow for single-objective prioritization in parts of the target area may be misguided if demand for the objectives is not considered, that is, prioritization of an objective may be assigned to an area where there is no demand for it or *vice versa*. For example, while it may make little difference exactly where the benefits are generated in the case of some ecosystem services such as carbon storage, some ecosystem services may have very local demand (e.g. recreation, forest collectables, and some regulating services). Finally, minimizing trade-offs in every parcel of the landscape may help protect those objectives that are affected by the quality of neighboring stands; particularly, conservation of biodiversity that requires both patches of high-quality habitat and a relatively good-quality matrix (Kremen, 2015).

Our study includes five forest management objectives: four ecosystem services (timber production, bilberry production, carbon storage, and pest regulation) and one biodiversity conservation objective, defined as availability of deadwood resources. First, we measure the supply of each objective and the conflicts among all pairs of objectives under alternative forest management regimes. Second, we identify a compromise management solution for each pairwise conflict, defined as one which simultaneously minimizes the losses in both objectives. Finally, we examine the distributions of alternative forest management regimes among the compromise solutions and infer management recommendations for maintaining diverse benefits. Specifically, we address the following questions: 1) How strong are the conflicts between all pairs of objectives? 2) How efficiently can the pairwise conflicts be solved by optimizing management? 3) What kind of forest management may be required to secure high levels of multiple ecosystem services and biodiversity?

2. Materials and methods

2.1. Forest data and simulations

Our study area is a typical Finnish production forest landscape located in central Finland with forest covering the majority of the land and the rest consisting of a mosaic of lakes, peat lands, small settlements, and cultivated fields (Fig. 1). The total forest area is 431 km^2 and consists of nearly 30,000 individual stands. The stands are dominated by pine (*Pinus sylvestris*), spruce (*Picea abies*), birch (*Betula pendula* and *Betula pubescens*), or a mix of the four species. Most of the landscape has been under active forest management for several decades, and this is reflected in the current condition of the forest. Specifically, the age distribution of the stands is asymmetric with over 30% of the stands being younger than 20 years, over 60% younger than 50 years, and only about 5% older than 100 years.

In order to account for the long-term ability of the forest to provide ecosystem services, we simulated the development of the stands under different management regimes for 50 years into the future. The initial stand-level data was compiled from forest inventory data administered by the Finnish Forest Centre (Finnish Forest Centre, 2016) to include the variables needed for the simulations, e.g. basal area of trees, tree species composition, ages of tree cohorts, and site fertility. Forest growth simulations were implemented with the MOTTI stand simulator (Hynynen et al., 2002; Salminen et al., 2005). MOTTI predicts the development of a stand based on its initial characteristics and the forestry operations applied during the simulation. In MOTTI, a set of empirical-statistical models are integrated into software that predicts the growth and mortality of trees on the basis of the quality of the site, the growth potential of the tree and the competition effects imposed by other trees. We simulated each stand under seven alternative management regimes that form a gradient of management intensity (Table 1): the recommended regime for private forestry in Finland or 'business-as-usual' (Hyvän metsänhoidon suositukset, 2006); the recommended regime modified by increased green tree retention, postponed final harvesting (two options), or no thinnings (two options); and set-aside. The recom-