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Could continuous cover forestry be an economically and environmentally feasible management option on drained boreal peatlands?

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ABSTRACT

Environmental and economic performance of forestry on drained peatlands was reviewed to consider whether continuous cover forestry (CCF) could be a feasible alternative to even-aged management (EM). CCF was regarded feasible particularly because continuously maintaining a tree stand with significant transpiration and interception capacity would decrease the need for ditch network maintenance. Managing CCF forests in such a way that the ground water levels are lower than in clear-cut EM forests but higher than in mature EM forests could decrease greenhouse gas emissions and negative water quality impacts caused both by anoxic redox reactions and oxidation and mineralization of deep peat layers. Regeneration studies indicated potential for satisfactory natural regeneration under CCF on drained peatlands. An economic advantage in CCF over EM is that fewer investments are needed to establish the forest stand and sustain its growth. Thus, even if the growth of trees in CCF forests were lower than in EM forests, CCF could at least in some peatland sites turn out to be a more profitable forest management regime. An advantage of CCF from the viewpoint of socially optimal forest management is that it plausibly reduces the negative externalities of management compared to EM. We propose that future research in drained peatland forests should focus on assessing the economic and environmental feasibility of CCF.

1. Introduction

Peatlands are the most common type of wetlands globally (Joosten and Clarke, 2002) and provide ecosystem services such as timber production, climate regulation, water quality control, flood abatement, biodiversity conservation, as well as recreational benefits (Zedler and Kercher, 2005; Tolvanen et al., 2013). Drainage for forestry, agriculture and peat extraction compromise the multiple ecosystem services, which these peatlands provide in their pristine state (Chapman et al., 2003; Čížková et al., 2013; Bonn et al., 2016). However, little attention has been devoted to analysing economically and environmentally optimal forest management alternatives on peatlands.

Altogether, around 15 Mha of peatlands have been drained for forestry in the boreal and temperate zones, providing an economically important source of woody biomass (Paavilainen and Päivänen, 1995). In Finland, for example, drained peatlands are an integral part of operational forestry, covering about 25% (4.7 Mha) of the total forest land area. Large areas of peatlands have also been drained for forestry elsewhere in the boreal region, e.g., 3.8 Mha in Russia, 1.4 Mha in Sweden, and 0.5 Mha in Estonia.

Thus far, even-aged management (EM) has been the prevailing management principle in drained peatland forests. The purpose of forest management in EM is to achieve a nearly coeval cohort of trees and eventually harvest and regenerate the forest by clear-cutting followed by soil preparation and planting or seeding, rarely using natural regeneration with seed-trees. In the Nordic conditions, EM further involves intermediate thinnings from below to improve the growth and vitality of the remaining dominant trees. Ditch network maintenance (DNM) operations are recommended every 20–40 years to sustain and improve drainage conditions (Sikström and Hökkä, 2016). After clear-

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cutting, some type of soil preparation in conjunction with DNM, e.g., ditch-mounding, is considered necessary to establish a new tree stand and lower the ground water table (GWT) that is temporarily raised by harvesting the tree stand with significant evapotranspiration capacity (Heikurainen and Päivänen, 1970,1982; Lundin, 2000).

A problem in EM on drained peatlands from the economic viewpoint is that major investments are needed to establish the forest stand and sustain its growth. Soil preparation, artificial regeneration, DNM and pre-commercial thinning each incur expenses, which can only be compensated for by the incomes from forest harvestings. From the environmental viewpoint, problems are caused particularly by sediment, nutrient and carbon release to receiving water bodies after DNM (Joensuu et al., 1999; Nieminen et al., 2010) and clear-cuts (Rodgers et al., 2010; Kaila et al., 2014, 2015; Nieminen et al., 2015). A number of options have been proposed to manage water quality after DNM (Nieminen et al., 2017b; Haahti et al., 2018) and clear-cut (Nieminen et al., 2017a). While not necessarily efficient in managing water quality, different water protection structures inevitably further increase the costs of timber production on drained peatlands.

An environmental problem in EM on drained peatlands is also that carbon dioxide (CO_2) emissions from soil may be so high that the drained sites become net sources of CO_2 to the atmosphere, unlike in pristine peatlands and upland forests. This may be the case particularly in the most nitrogen rich sites, and in highly-stocked stands with mature trees, as their transpiration demand results in a low GWT and aerobic decomposition in deep peat layers (Ojanen et al., 2010, 2013).

Since EM has detrimental impacts on several ecosystem services provided by peatlands, and is less profitable on peatlands (Kojola et al., 2012) than in uplands (e.g., Hynynen et al., 2015), the demand for alternative management options, such as continuous cover forestry (CCF), has increased. CCF can have potential on drained peatlands because continuously maintaining a tree stand with significant transpiration and interception capacity could decrease the need for DNM (Sarkkola et al., 2010, 2013). Furthermore, natural regeneration, a crucial factor for successful implementation of CCF, could be a feasible option particularly on peatlands, where ample soil moisture and the occurrence of *Sphagnum* favor seedling germination (Place 1955; Heinselman 1957; Wood and Jeglum 1984) and establishment. Several studies conducted in the Nordic countries have shown successful natural regeneration in spruce mire sites after partial cutting (Lukkala 1946; Hånell 1993; Holgén and Hånell, 2000; Örlander and Karlson 2000).

Except for the studies researching natural regeneration success in small canopy gaps (Hökkä et al., 2011, 2012; Hökkä and Mäkelä 2014), no attempts have been made to study the feasibility of specifically CCF on drained boreal peatlands. By conducting a literature review our aim was to raise the question whether CCF has potential as an economically, environmentally, and socially feasible management option on drained peatlands.

The applied definition for CCF in our review is relatively broad, i.e., all management options which do not aim for an even-aged stand structure, are based on natural regeneration, and retain a significant proportion of the tree stand after harvesting, are considered as CCF. Thus, executing clear-cuts in small patches or narrow strips of trees is considered CCF as long as the purpose is to keep most of the area continuously canopy-covered and artificial regeneration is not applied. Retaining significant proportion of the tree stand after harvesting is particularly important as we hypothesize that such management can significantly decrease the need for DNM. Although strict limits cannot be given to distinguish the tree stands with sufficient and insufficient evapotranspiration capacity for maintaining drainage conditions without DNM (Sarkkola et al., 2010, 2013), it is evident that the conventional seed-tree and shelter-wood systems cannot be qualified as CCF. After harvesting the last shelter-trees or seed-trees, these systems result in seedling stands with plausibly far too low evapotranspiration capacity to have any effect on site drainage conditions.

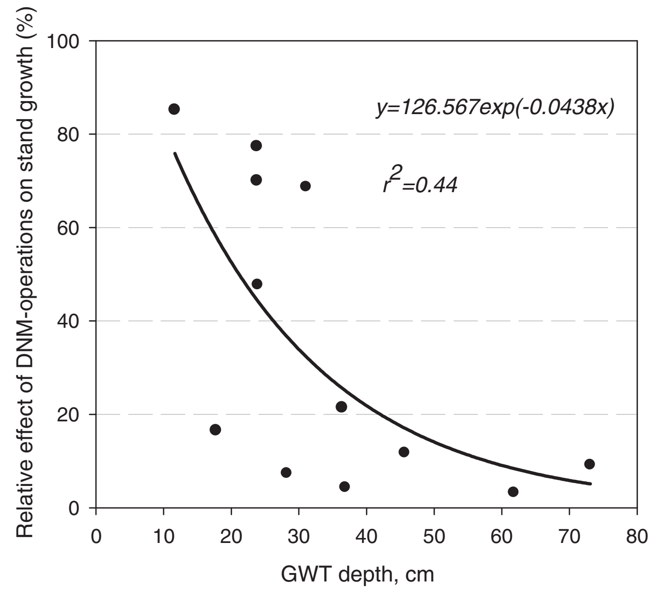

Fig. 1. Relationship between mean annual volume growth increment caused by DNM (% of pre-DNM growth) during 20 years since treatment and the pre-treatment mean late summer (August) GWT depth. Redrawn from Sarkkola et al. (2012).

2. Key management factors in peatland forests

2.1. Sustaining drainage conditions

Drainage conditions play a key role in forestry on peatlands, as the lowered GWT increases the aeration of the root zone and creates more favorable conditions for tree growth. In an EM forest, where stand volume and consequently its evapotranspiration capacity are low during the initial stages of stand development, the need for DNMs is evident. The study by Sarkkola et al., (2010) indicated, however, that the condition of ditches had only a marginal effect on the GWT depth in mature stands where the standing volumes were greater than about 120 $m^3\,ha^{-1}$ in southern Finland and 150 $m^3\,ha^{-1}$ in northern Finland. GWT depth correlated more closely with stand volume than with the condition of ditches, indicating that tree evapotranspiration dominates site drainage conditions in such EM stands. Sarkkola et al., (2012) further showed that when the late summer GWT depth, which is the key-factor for optimal tree growth on drained peatlands, was deeper than 35–40 cm already before DNM, tree growth did not respond to DNM (Fig. 1). Together these findings suggest that DNM may be unnecessary in mature, well-growing EM stands, if tree stand evapotranspiration is dominating water balance during growing season and is able to keep GWT at a level that does not impair tree growth.

A counterargument has been presented that DNM should be done even where it does not markedly lower GWT or improve tree growth (Ahti and Päivänen, 1997). In this context, DNM would be necessary as a precautionary measure to keep GWT low during abnormally rainy summers in order to decrease the risk of biotic diseases, such as pine sprout cancer. The study by Sarkkola et al. (2010) indicated, however, that GWT is high during exceptionally wet summers, irrespective of the condition of ditch networks or the volume of the tree stand (its evapotranspiration demand). The options to control GWT during such wet summers are therefore very limited. It is further noteworthy that lowering GWT by DNM becomes increasingly difficult in the future as increased peat decomposition over time elapsed from initial drainage decreases its hydraulic conductivity (Nieminen et al., 2017a).

The relationship between stand characteristics and GWT depth has not been studied in CCF forests. Tree stand transpiration there may be lower than in EM forests with equal stand volume, at least temporarily