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Ecosystem model analysis of multi-use forestry in a changing climate

Fredrik Lagergren *, Anna Maria Jönsson

Dept. of Physical Geography and Ecosystem Science, Lund University, Sölvegatan 12, SE-223 62 Lund, Sweden

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ABSTRACT

The challenge of multi-use forestry is to fulfil a range of economic, ecologic and social goals in a sustainable way, accounting for synergies and trade-offs among the ecosystem services provided. Climate changes add to the complexity via effects on forest ecosystem processes, such as primary production and respiration, and also by adding a new goal on the agenda: the role of forests in climate mitigation. In recent years, the generation of climate model projections, representing a range of future scenarios, has enabled the development of strategic decisions in relation to risk management, and created a demand for cross-sectorial adaptation and mitigation processes. In this ecosystem model study we address these issues from the perspective of Swedish forest owners, by focusing on climate impacts and forest management effects on the potential harvest level, net income, predisposition to storm damage, biodiversity and carbon storage. The objective was to evaluate alternative management strategies, applicable to northern boreal, southern boreal and nemoral conditions. A general finding is that targeted combinations of forest stand management strategies can lead to a higher degree of goal fulfilment at the landscape level than current forest management practice.

1. Introduction

Climate change will, in combination with anthropogenic development, have a major impact on both the forests' production potential and on the demand of various ecosystem services (Settele et al., 2014). Sustainable forestry should provide a stable supply of a wide range of goods and services over time (UNECE/FAO, 2011), but the challenge of managing forests to obtain ecological, economic and social sustainability is well recognised (Pretzsch et al., 2008; Pryor, 2000; Secco et al., 2011). Development of methods for the identification of pathways towards sustainability is needed, addressing questions on how to adapt to novel environmental changes, contribute to the scopes of COP21 (maximum global warming of 2 °C at the end of 21st century), and fulfil national environmental objectives as well as global sustainable development goals. While the ecosystem capital is both renewable and depletable, it has been viewed as an endless resource for a long time (EEA, 2016). However, a growing population, intensive land use and climate change create multiple pressures on the ecosystems and the services they provide. The flow of forest ecosystem services, including provisioning services (timber, fibre and biofuel), regulation and maintenance services (climate regulation via carbon sequestration), and cultural services (physical, intellectual and spiritual interactions with the forest ecosystems) are all important parts to be included in an accounting of the ecosystem capital (EEA, 2016).

Most of the forests in Sweden are managed, although with varying intensity, goals and perspectives on sustainability (Östlund et al., 1997). The production forest mainly consists of even-aged forest stands, managed through regeneration by seeds or seedlings, regular thinnings and clear cuts by the end of 60–120 year rotation periods. Scots pine and Norway spruce are the two dominant tree species, due to silvicultural, economic and traditional reasons (Ragnarsson, 2012; Swedish Forest Agency, 2009). National forest inventories and forestry legislation have been implemented as tools to support a sustainable supply of wood (Ekelund and Hamilton, 2001; Nylund, 2009), and the Forestry Act emphasis the equal importance of wood production goal and environmental consideration with conservation of nature (Nylund, 2009). The Swedish forest is to a large extent owned by private forest owners (75%, incl. private companies), and most forest owners meet the requirements of the Forestry Act by taking general environmental consideration regarding the production forest and setting aside a relative small fraction (5–15%) of the forested area as unmanaged, according to the so called Swedish model (Beland Lindahl et al., 2015; Swedish Forest Agency, 2009).

Climate change assessments indicate that a warmer climate can increase the Swedish forest production capacity, due to a lengthening of the growing season, elevated CO_2 concentrations and faster

* Corresponding author.
E-mail address: fredrik.lagergren@nateko.lu.se (F. Lagergren).

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nutrient turnover (Bergh et al., 2003; Lagergren et al., 2006; Reyer et al., 2014). Potential negative effects include an increased risk of storm damage as the trees will be less protected from overturning by ground frost, failure of regeneration caused by spring frost or extreme precipitation (both high and low), and an increased risk of damage caused by pest and pathogens that may thrive in a warmer and wetter climate (Eriksson et al., 2016). Suggestions on how to take advantage of the increase in growth potential, without facing substantially higher risks, include a careful selection of tree species and provenience at regeneration time as well as adjustments of thinning programs and expected rotation period lengths (Jönsson et al., 2015; Kellomäki et al., 2008; Swedish Forest Agency, 2009). In addition to the production aspect, the combined effects of climate change on production, risks, biodiversity, carbon sequestration, social and cultural values at the landscape level have to be addressed as a wide range of goals implies that trade-offs may occur and compromises are needed (EEA, 2016).

Dynamical vegetation models (DVM) are commonly applied to assess climate and environmental effects on the performance of plant functional types or species, suitable for examining temporal aspects of ecosystem structure and functioning (Prentice et al., 2007). Ecosystem models are thus better suited for climate impact assessments than empirical forest management models, and while most ecosystem models simulates the development and disturbance regimes of unmanaged forests, recent program development have made it possible to specifically simulate the effect of formal management schemes (Lagergren et al., 2012). In this study we take this approach one step further by using the dynamic vegetation model LPJ-GUESS to provide a landscape perspective on forests ecosystem services. The aim is to assess how the generation of provisioning, regulating and cultural ecosystem services is influenced by the landscape settings and climate conditions, as determined by general practice and variability of forest stand management strategies, of relevance for the development of adaptation strategies within the forestry sector.

2. Material and methods

2.1. Dynamic vegetation model

To assess the long-term effect of different management alternatives and climate change we applied the biogeochemical ecosystem model LPJ-GUESS (Smith et al., 2001), for which specific modules have been developed to account for forest management, forest economy, storm damage risk assessments and indicators for biological values (Jönsson et al., 2015; Lagergren et al., 2012). LPJ-GUESS simulates the climate dependent vegetation development as well as the competition among age and species-specific cohorts (Smith et al., 2001). The capacity to simulate Swedish forest conditions has been validated for vegetation structure (Smith et al., 2001), carbon balance (Morales et al., 2005) and productivity (Lagergren et al., 2012; Smith et al., 2008). European tree species are distinguished by the parameter settings of climatic limits for establishment and survival, temperature response of phenology and photosynthesis, tree allometry and turnover rates (Miller et al., 2008). In this study, three areas in Sweden were selected to assess the northern boreal, southern boreal and nemoral conditions (Fig. 1).

To represent different forest stands (i.e. replications with different disturbance and management history), LPJ-GUESS was set to simulate 50 patches for each grid cell and setting. Nineteen different settings were used to simulate a wide range of management alternatives as well as unmanaged forest (see Section 2.4). For a management setting, the patches differed in timing of management. This generated a simulated landscape with all age classes, and the simulation outputs were aggregated over the 50 patches to represent average states and fluxes for a management scheme, to obtain mean state conditions (i.e. a management specific average value representative for a rotation period). A post-processing optimization routine was developed to assess how to combine a variety of management alternatives at the landscape level to fulfil the goals of multi-use forestry.

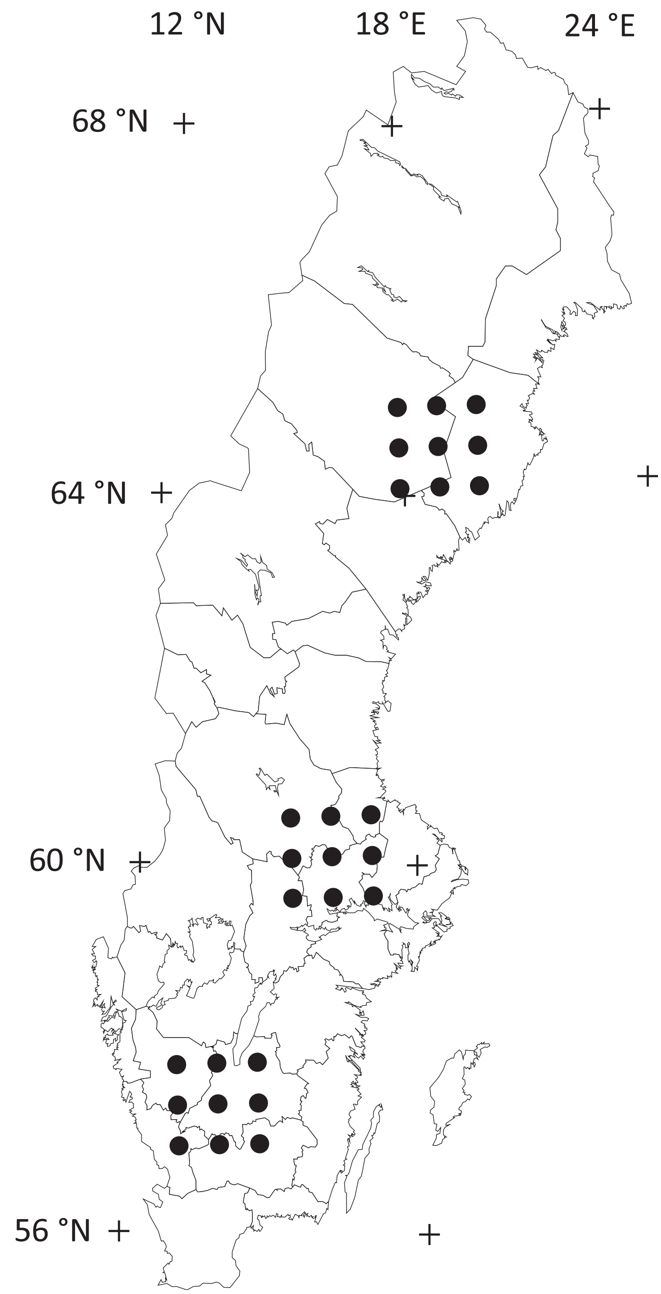

Fig. 1. Map of Sweden, showing the centre of the grid cells chosen to represent the northern boreal, southern boreal and nemoral bioclimatic conditions.

2.2. Climate data

LPJ-GUESS requires input data on temperature, precipitation, incoming shortwave radiation and CO_2 concentrations. State-of-the-art climate model data were selected from the EURO-CORDEX ensemble of regionally downscaled climate model scenario data with a daily temporal resolution and a spatial resolution