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Modelling the effects of management intensification on multiple forest services: a Swedish case study

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ABSTRACT

The study presents a method to evaluate the response of forest ecosystems to increased biomass extraction based on the integrated ecosystem model ForSAFE. It evaluates the effects of residue removal, intensification of thinnings and a shorter rotation period on a forest site in Southern Sweden. The evaluation includes multiple ecosystem indicators for productivity, carbon storage, wood production, water use and water quality. Such integrated assessments can contribute to identify negative or positive impacts affecting ecosystem services provided by forests. Results show that increased biomass extraction reduces the carbon stored in the forests, but at the same time reduces the loss of nitrogen and carbon through leaching. Within one rotation, residue removal affects the carbon stock in the soil, but it does not affect forest productivity and therefore tree carbon stock. Contrarily, the intensification of thinnings and shorter rotation periods reduce carbon stored in trees. In all cases, the amount of wood available for products increases, but the additional harvest from increased thinnings and earlier clear cutting does not compensate for the loss of carbon in trees. A positive consequence of removing the decomposing material from the site is the reduced amount of nutrients lost with runoff. Both leached nitrogen and dissolved organic carbon decrease with intensification. In addition, a positive effect of increased thinnings and a shorter rotation period is a reduced evapotranspiration, i.e. reduced water use. The effect on acidification differed depending on the time frame considered and the applied management scenario, due to different dominating processes regulating acidity. To avoid acidification, management intensification should include measures to prevent loss of base cations in the soil. Overall, under the studied conditions, the risk for negative effects seems to be smaller for residue extraction than for management changes including additional tree harvest.

1. Introduction

Societies face today the challenge to minimize negative environmental impacts produced by human activities. To respond to this need, environmental policies that aim to prevent or reduce such negative effects are promoted from the regional to the international level. These policy measures are usually the result of a process that includes interactions between, monitoring, research, assessment and policy-making (Millenium Ecosystem Assessment, 2005).

Forest management is one of the activities that can produce significant positive or negative effects on environmental resources. For this reason, forestry is expected to contribute to achieve multiple environmental objectives set by policies by providing services such as timber production, biodiversity conservation, carbon storage, supply of bioenergy and water resource protection (COM, 2005; Rayner et al., 2010). However, each management strategy has often impacts on the provision of several services which can conflict with each other (Wang and Fu, 2013). Trade-offs have been identified, for example, between wood production and biodiversity or carbon storage and bioenergy (Parrotta et al., 2012; Vanhala et al., 2013).

Due to the conflicts or synergies between different services, there is an increasing need to evaluate the effects of forestry activities in an integrated perspective and therefore support management strategies that could help countries to comply with multiple environmental objectives. Research studies that perform quantitative assessments of the impact of forestry on multiple forest services are just emerging and are still quite limited (Başkent et al., 2011; Duncker et al., 2012; Gamfeldt et al., 2013; Schwenk et al., 2012).

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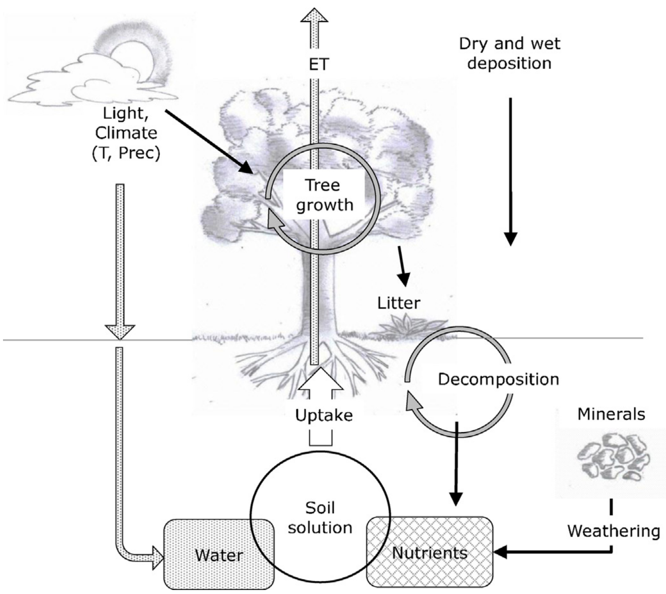

Fig. 1. The ForSAFE model. Climate input parameters (temperature and radiation) drive the potential vegetation growth. Nutrient and water availability constrain the potential growth to actual biomass growth and accumulation.

This study presents a method to evaluate the response of abiotic properties of forest ecosystems to environmental changes, based on an integrated ecosystem model. We focused on the effects of management intensification on indicators of site productivity, carbon storage, wood production, water use and water quality at forest site level. The response of these indicators to management changes can provide information for the identification of trade-offs between different forest ecosystem services and therefore increase knowledge on optimal management strategies. The method has been applied to a forest site, which is part of a long-term monitoring network in Swedish forests. After validating the model results against measured data, we simulated ecosystem responses under different management scenarios in an integrated manner.

2. Data and methods

2.1. The biogeochemical model ForSAFE

ForSAFE is a mechanistic model of the dynamics of forest ecosystems. The model is a mechanical aggregation of interacting but mutually independent processes that constitute the building blocks of the model. Each independent process – chemical, physical or physiological – is based on empirical evidence (Belyazid et al., 2006; Wallman et al., 2005). It was designed for the purpose of simulating the dynamic responses of forest ecosystems to environmental changes. ForSAFE combines the engines of four established models: the tree growth model PnET (Aber and Federer, 1992), the soil chemistry model SAFE (Alveteg, 1998), the decomposition model Decomp (Wallman et al., 2006; Walse et al., 1998), and the hydrology model PULSE (Lindström and Gardelin, 1992). Merging these components brings together the three basic material and energy cycles in a single integrated model: the biological cycle representing the processes involved in tree growth; the biochemical cycle including uptake, litter decomposition and soil nutrient dynamics; and the geochemical cycle including atmospheric deposition and weathering processes (Fig. 1).

2.2. Datasets

In this study, the model ForSAFE was used to simulate the effects of management changes on a forest site in Southern Sweden, Västra Torup (13.51E, 56.14 N). The site is located on a flat area with annual average temperature of about 8 °C and average annual precipitation of about 900 mm. The site is a spruce dominated managed forest on a brown podzolic soil with a mean net annual increment of about 6 m^3 ha^{-1} $year^{-1}$ over the rotation period. The site is part of the Swedish Throughfall Monitoring Network (SWETHRO) (Pihl Karlsson et al., 2011). In the SWETHRO sites, several parameters are measured, including throughfall deposition and soil water chemistry inside forest stands and measurements of air concentrations of sulphur dioxide, nitrogen oxides and ammonia and bulk deposition in nearby open areas. The first sites were initiated in the end of the 1980s.

Västra Torup is also part of the ICP FOREST LEVEL II monitoring programme (International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests, http://www.icp-forests.org). Historical data are available on tree biomass (1996–2010 on a 5 year interval), soil chemistry (from 1995 on a yearly basis) and other parameters such as foliage chemistry and defoliation (1995–2010).

Complementary data on soil chemistry and tree biomass were collected in 2010. Soil samples from five distinguished soil horizons were analysed for soil C, N, pH and exchangeable cations, soil texture and total element contents. The total element contents were used as inputs to the programme A2M to estimate the normative mineralogical composition of the different layers (Posch and Kurz, 2007). The soil data used as inputs to the model are reported in the Appendix A (Table A.1).

The atmospheric deposition scenario used for the simulations is the Current Legislation (CLE) scenario and the Gothenburg protocol of the UN Convention on Long-Range Transboundary Air Pollution provided by the European Monitoring and Evaluation Programme (EMEP) on a 50 × 50 km grid. The EMEP scenario includes data series for sulphur (SO_4), nitrate (NO_3) and ammonia (NH_4) deposition from 1900 to 2100. The original EMEP data set was downscaled according to measurements collected at the site in 1988–2009 (http://krondroppsnatet.ivl.se/). The downscaling is based on the ratio between the average measured deposition and the average modelled deposition over the same period. Deposition of calcium (Ca), magnesium (Mg), potassium (K), chlorine (Cl) and sodium (Na) was assumed constant over the simulation period (1900–2100) and is equal to the average measured deposition for each element. Modelled deposition data were replaced with measured deposition data when available.

The climate scenario in the period 1900–2100 is based on data from the Global Climate Model ECHAM and follows the SRESA2 emission story line of the IPCC. The model data have been calibrated over the historical climate. Historical data are derived from the SMHI weather station data using-spatial interpolation and from the NCEP/NCAR Reanalysis project for solar radiation (1961–2008) (David Ryner, 2010, personal communication).

2.3. Model initialization, calibration and validation

The amount of organically bound carbon and nutrients in the soil affects the forest stand's status. The mineralization of organically bound nutrients can be the most important source satisfying tree uptake requirements, while the decomposition of carbon directly dictates microbial activity and soil acidity. To make sure that the current size of the organic pools of carbon and nutrients in the soil are correct, the initial state of the site has to be calibrated. The initial conditions are set through an iterative process that involves the calibration of simulated values of soil organic carbon against a measured value at present. A fundamental part of the information needed to initialize the model is the past land management that strongly influence the accumulation of nutrients in the soil. Information on the past management in Västra Torup was obtained