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A thinning routine for large-scale biogeochemical mechanistic ecosystem models

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ABSTRACT

Biogeochemical mechanistic models (BGC models) are used to model the carbon balance of forest ecosystems. Since European forests are managed intensively, a crucial part of carbon modelling is integrating management and thinning routines in the modelling process. In this study, forest inventory data are used to derive information concerning forest management practice. Based on this, a harvesting model is calibrated for simulating the 'business as usual' management that can be used in large-scale BGC models. Our approach is based on data from the Austrian National Forest Inventory. The model comprises two submodels: (1) a logistic model to assess the probability of an inventory point to be thinned and (2) a nonparametric model based on empirical probability density maps to assess the thinning intensity. Since BGC models operate on the stand level, only stand level parameters are integrated in the model such as standing timber carbon, site quality, cover type, elevation and age. A comparison of the predicted and observed proportion of thinned points and the thinning intensity suggests that the model is able to correctly mimic the management regime derived from the inventory data. No systematic trends in the results are evident. Using this thinning model in combination with a mechanistic model will enable assessment of the overall carbon stored in managed forest ecosystems, especially in large-scale modelling applications.

1. Introduction

European forests have been managed for several centuries (Spiecker et al., 2004). As a result forest laws were instituted to avoid over cutting and forest management practices such as tending, thinning and shelter wood cutting were developed and applied to ensure sustainable timber production (Assmann, 1970, 1961). Forest management influences the carbon storage in forests and thus strongly depends on tree species, site quality, time of thinning and the intensity of thinning (Assmann, 1970; Hasenauer and Monserud, 1997; Pretzsch, 2005). It is also an important factor determining the mitigation potential of forests to climate change.

Forest growth and yield models have been developed which are specifically designed to address the diameter and height growth response of individual trees according to changes in competition (see Hasenauer, 1994; Monserud and Sterba, 1996; Pretzsch et al., 2002). Although tree growth models have been proven to be important silvicultural management tools they do not explicitly consider the water, carbon, nitrogen, and energy cycles and how these fluxes will change according to different thinnings, expressed as the biomass removal from the forest (Aber et al., 1978; Hix and Barnes, 1984; White, 1974). However an option to understand the impact of thinning on ecosystem fluxes is the application of biogeochemical mechanistic models (BGC models).

Conceptually BGC-models consist of a formal description of ecosystem processes such as photosynthesis, transpiration, allocation and decomposition. They are explicitly designed to study the complex interactions between ecosystems, the lithosphere and the atmosphere and thus they may be seen as diagnostic tools to investigate potential impacts on forest ecosystems. Such potential impacts may be attributed to changing environmental conditions or forest management practices.

An important limitation of BGC models is that they operate on fully stocked even-aged stands. Compared to tree growth models (Hasenauer, 2006) they are not explicitly designed to be sensitive to varying stand density. For certain applications this may be a reasonable approach, however, if we are interested in the carbon balance of managed forests and how this may change under potential climate change, the conceptual integration of thinning is essential. This is particularly important as forest management has been and still is the main driving impact for changes in forest growth within Europe (Kauppi et al., 1992).

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Simulating forest development in managed forests needs algorithms to account for harvesting and thinning. Normally we integrate the management history and the thinning of the current stand based on a defined management history (Petritsch, 2008; Pietsch and Hasenauer, 2002). Usually the thinnings applied to a site have to be either known or fixed management scenarios/ assumptions have to be developed to account for management (Cienciala and Tatarinov, 2006; Eastaugh and Hasenauer, 2011; Petritsch, 2008; Pietsch and Hasenauer, 2002; Tatarinov and Cienciala, 2006).

Key sources for deriving information about the forest are inventory data. Inventory datasets cover large areas and are applied on a rather coarse grid; the Austrian forest inventory for example is defined on a ~3.9 km grid (Gabler and Schadauer, 2008). Usually this kind of data consists of repeated measurements and thus inherently comprises information about the 'business as usual' management. Management information derived from these datasets can be included in the process models to simulate managed forests. One way to achieve this is to develop a thinning model based on the management that was applied in the past (derived from the inventory data) according to different site and stand characteristics. This is a common approach within population models that are specifically designed to integrate thinning operations because they operate on a tree level (Ledermann, 2002; Sterba et al., 2000; Thurnher et al., 2011).

Logistic regression is often used in single-tree based population models to describe the occurrence of harvesting and/or thinning (Ledermann, 2002; Sterba et al., 2000; Thurnher et al., 2011). It is also used to model other dichotomous variables like mortality (Monserud and Sterba, 1999), regeneration (Hasenauer and Kindermann, 2006; Schweiger and Sterba, 1997) or wildfire occurrence (Botequim et al., 2013). The models described in Ledermann (2002) and Thurnher et al. (2011) describe thinning models that use two logistic regressions, one to determine the occurrence of thinning and a second one to model the possibility of removal of each individual tree.

Eastaugh and Hasenauer (2012) proposed a thinning algorithm for process models using spruce-dominated inventory points in Austria. The model comprises a logistic sub-model to estimate the occurrence of thinning on an inventory point and a second non-parametric sub-model to estimate the thinning intensity; the thinning intensity is defined as the proportion of basal area removed.

The purpose of this paper is to develop a stand-level thinning model to be used within large-scale mechanistic or process models using data from the Austrian forest inventory. In Austria, the common management regime is a small scale clear-cut system with thinnings occurring in the first half of the rotation period (Mayer, 1992; Weinfurter, 2013). We develop a thinning model that is able to address the management regime within a given region and that can be integrated into a large-scale biogeochemical mechanistic modelling tool such as Biome-BGC. Since a dual logistic approach is not possible with BGC models, which define the ecosystem as a set of pools rather than single trees, the thinning model is developed and applied at the stand level. A logistic regression is developed to predict the thinning occurrence. For estimating the thinning intensity, the non-parametric approach as described in Eastaugh and Hasenauer (2012) is adopted.

The specific tasks of our study can be summarized as follows:

(i) Definition of the input parameters for the thinning model.
(ii) Development and calibration of a thinning model for large-scale mechanistic ecosystem models.
(iii) Demonstration and validation of the thinning model using the Austrian National Forest Inventory data.

2. Data

The calibration and validation data were obtained from Austrian National Forest Inventory – NFI (Gabler and Schadauer, 2008). The sampling method is based on angle count sampling (Bitterlich, 1948). The dataset consists of 22327 points. The points are organized in groups of four at the corners of a 200 m square. The groups are arranged on a regular square grid across the whole country with a resolution of 3.89 km. The four points in a group are referred as point 00, 08, 16 and 24 counting clockwise from the lower right position. Five measurements are available, covering the years 1981–1985 for the first measurement, 1986–1990 for the second, 1992–1996 for the third, 2000–2002 for the fourth and 2007–2009 for the fifth measurement (Eastaugh and Hasenauer, 2012). The first two measurements are only available for point 00. Only points that have at least one tree measurement in one measurement period are considered in this study. This gives a total of 9747 points. Fig. 1 shows a map of the inventory points that contain at least one tree measurement.

At each sample point, all trees greater than 10.4 cm in DBH are included in the angle count sample. Smaller trees (5 cm $\leqslant$ DBH $\leqslant$ 10.4 cm) are measured in a circular fixed area plot around the point with a radius of 2.6 m ($A = 21.24\ m^2$). Since we are interested in whether a given sample point has (i) experienced any thinning and if yes, (ii) what was the thinning proportion, we need two consecutive measurement periods. Thus we excluded the fifth measurement from further calculations, since we cannot derive the thinning intensities that occurred in the next period. The fifth measurement was used only to obtain the thinning intensities between the fourth and the fifth measurement. Each measurement was treated as an independent observation for the model. A tree was treated as being thinned, when it had a measurement in one period, but no information in the next. Only points with at least one tree measurement are taken into account, so the number of points is not constant across the measurement periods. The summary statistics of our available data are presented in Table 1.

3. Methods

3.1. Biome-BGC

For this study we use the ecosystem model Biome-BGC (Running and Coughlan, 1988; Thornton, 1998; Thornton et al., 2002) as adapted for central European conditions. This includes a species-specific parameterization for the major European tree species (Pietsch et al., 2005), a dynamic mortality routine to simulate virgin forests (Pietsch and Hasenauer, 2006) and a historic land management tool (Pietsch and Hasenauer, 2002). This Biome-BGC model version has been used for a variety of purposes in several studies in central Europe (Eastaugh et al., 2011; Hasenauer et al., 2012; Eastaugh and Hasenauer 2014; Merganičová et al., 2012, 2005; Pietsch et al., 2003).

Biome-BGC operates on a stand level and simulates the cycling of carbon, nitrogen, water and energy within an ecosystem. The ecosystem, in this case the forest, is not seen as a collection of single trees, but as a set of pools and fluxes between the pools. It operates on a daily time-step. The net primary production used within this study is the gross primary production (GPP) minus the maintenance and growth respiration. GPP is calculated with the Farquhar photosynthesis routine (Farquhar et al., 1980). The allocated carbon is partitioned into different plant compartments (leaf, roots and stem). A more detailed description of the model can be found in Running and Coughlan (1988), Thornton (1998), White et al. (2000), Pietsch and Hasenauer (2002, 2006) and Thornton et al. (2002).