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Effect of climate change and nitrogen deposition on central-European forests: Regional-scale simulation for South Bohemia

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ABSTRACT

The simulation of forest production until 2100 under different environmental scenarios and current management practices was performed using a process-based model BIOME-BGC previously parameterized for the main Central-European tree species: spruce, pine, beech and oak and adapted to include forest management practices. Climatic scenario HadCM3 used in the simulations was taken from the IPCC database created within the 3rd Assessment Report. It was combined with a scenario of CO_2 concentration development and a scenario of N deposition. The control scenario considered no changes of climatic characteristics, CO_2 concentration and N deposition. Simulation experiment was performed for the test region – South Bohemia – using a 1 km × 1 km grid. The actual data on the regional forest cover were aggregated for each grid cell in such a way that each cell represented an even-aged single-dominant species stand or non-forested area, and a standard management scenario depending on the stand age and species was applied to each cell. The effect of environmental variables was estimated as the difference of simulated carbon pools and fluxes in 2050 under environmental changes and under control scenario.

The model simulation for the period to 2050 with only climate change under constant CO_2 concentration and N deposition indicated a small decrease of NPP (median values by species reached −0.9 to −1.7% for different species), NBP (−0.3 to −1.7%) and vegetation carbon (−0.3 to −0.7%), whereas soil C slightly increased. Separate increase of N deposition gave small positive effect on carbon pools (0.8–2.9% for wood C and about 0.5% for soil C) and more expressed effect on carbon fluxes (1.8–4.3% for NPP and 1.0–9.7% for NBP). Separate increase of CO_2 concentration lead to 0.6–2.4% increase of wood C pool and 0.1–0.5% increase of soil C. The positive effects of CO_2 concentration and N deposition were more pronounced for coniferous than for deciduous stands.

Replacement of 0.5% of coniferous plantations every year by natural broadleaved stands evoked 10.5% of increase of wood carbon pool due to higher wood density of beech and oak compared to spruce and pine, but slightly decreased soil and litter carbon pools.

1. Introduction

Changing environmental conditions, growing pressure on land use in Central Europe, increased demand of wood and biomass represent serious challenges to traditional forestry. Process models well suited to evaluate the effect of multiple environmental constraints to forest growth. However, their application on regional scale is not easy due to difficulties with the enlargement of the spatial-temporal scales (e.g., Chertov et al., 1999, Ťupek et al., 2010, Gordon et al., 2004). At the same time, there is an increasing need for predictions of forest carbon budget on regional scale. This originates both from policy driven processes such as the ongoing negotiations on future climate regime under United Nations' Framework Convention on Climate Change (UNFCCC) and from forestry practice that requires sound analysis likely management strategies associated with adaptation and mitigation measures (e.g., Nabuurs et al., 2008). There are several scientific questions associated with future projections, specifically those related to adaptability and stability of forest ecosystems, capacity and sustainability of utilization of forest resources. Therefore, an array of modeling tools is being developed, tested and analyzed by the scientific community in order to address these challenges. In European conditions, where forest management is the decisive factor for affecting the actual use of forest resources, regional and national forest analyses used a matrix-based demand-driven forest scenario model EFISCEN (Sallnas, 1990, Nabuurs et al., 2001). However, as this tool is basically empirically driven and lacks a true repre-

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sentation of processes, it needs to be combined with the process models in order to capture the essential agents affecting growth performance and carbon budget, such as nitrogen deposition and temperature increase (Landsberg, 2003; Schelhaas et al., 2004, Hyvonen et al., 2007). On the other hand, process models were developed, parameterized and traditionally applied on a plot scale and their regionalization remains challenging (e.g., Kramer et al., 2002).

This paper follows the earlier studies with the process-based model BIOME-BGC (Thornton, 1998) adapted so as to include forest management routines (Cienciala and Tatarinov, 2006, Tatarinov and Cienciala, 2006) and gradual environmental changes (Tatarinov and Cienciala, 2009). The aims of the present study are (1) the regionalization of this model and (2) its application at the regional scale to the analysis of the effect of environmental and management scenarios (including the changes of climate, CO_2 concentration, nitrogen deposition and partial replacement of spruce monocultures by native species) on the carbon balance of managed Central-European forests.

In general the regionalization of a point model may be done by two ways. (1) All forest-covered areas of the region under study could be divided into relatively homogeneous classes with corresponding areas. Simulations are performed for each class and then summarized using areas of individual classes. Such approach was applied, e.g., by Vetter et al. (2005), Schmid et al. (2006). (2) Alternative approach assumes the division of region of interest into regular grid with cells assumed to be homogeneous, applied, e.g. by Turner et al. (1996) or Mladenoff (2004). This concept was also realized in the present study as outlined below.

2. Material and methods

2.1. BIOME-BGC model

We applied the BIOME-BGC (Thornton, 1998) model version 4.1.1. BIOME-BGC is a process-based model describing water, carbon and nitrogen cycles in a specific type of terrestrial ecosystem with a daily time step. The calculation of biome gross primary production follows Farquhar et al. (1980), distinguishing illuminated and shaded foliage. Autotrophic respiration is separated into maintenance respiration calculated proportionally to the nitrogen content of living tissues (Ryan, 1991) and growth respiration handled as a function of carbon allocated to the different plant compartments. Water cycle includes precipitation, interception, transpiration, evaporation from soil surface and moist foliage and runoff. Nitrogen cycle includes N consumption for plant growth, metabolism of organisms destructing litter and coarse woody debris, mineralization and leaching. Spatial variability within the simulated biome is neglected; model operates with the pools and fluxes per unit ground area, i.e., simulation corresponds to one homogeneous stand. The model requires several sets of input, namely site parameters, eco-physiological parameters, series of daily meteorological data and, optionally, time series of atmospheric CO_2 concentrations. The meteorological data series can be extrapolated from a reference weather station to a given locality via MTCLIM simulation model (Running et al., 1987; Thornton and Running, 1999). This model uses as input time series of daily minimum and maximum air temperature and daily precipitation totals for base weather stations and parameter files with geographic characteristics of base stations and the localities of interest, air temperature lapse rates and precipitation ratio. Based on these data, MTCLIM calculates the series of minimum, maximum and mean daily temperature, daily solar radiation, vapour pressure deficit and precipitation for the locality of interest. If the period of BIOME-BGC simulation exceeds the period of available meteorological data series, then meteorological data are repeated cyclically.

In our previous studies BIOME-BGC model was adapted to include key management routines such as thinning, harvest and new species planting (Tatarinov and Cienciala, 2006) and parameterized for most important Central-European forest tree species: Norway spruce, Scots pine, English oak and European beech (Cienciala and Tatarinov, 2006). Some additional changes were made to handling interception, evaporation, throughfall, fine root mortality and industrial nitrogen deposition (Tatarinov and Cienciala, 2006). The model was also adapted to the implementation of gradual climate changes (the original model provided spasmodic changes only). The effect of changes of climate, CO_2 concentration and N deposition at the level of single sample plots with single-species stands was studied in our last study (Tatarinov and Cienciala, 2009).

Simulation scenario includes spin-up simulation resulting in the biome steady-state (corresponding to the virgin forest before its development by men) and actual simulation. According to our earlier results (Cienciala and Tatarinov, 2006) as well as other studies (Pietsch et al., 2003; Pietsch and Hasenauer, 2002, 2005) the simulation by BIOME-BGC that included several forest rotation cycles showed that soil and litter carbon pools as well as the biomass growth rate usually decreased from cycle to cycle. Consequently the actual simulation of forest dynamics, especially in the regions with long-term colonization history, such as Central Europe, should include probable historical management scenario.

2.2. Regionalization of the model

In order to apply BIOME-BGC in the regional scale we elaborated a multiple point model version. Its concept is the following. Test region is divided into regular 1 km × 1 km grid. Each cell can represent a homogeneous even-aged single-species stand or forest-free area. Model simulates the stand dynamics in each forest-covered cell of this grid. Model output is performed for each grid cell with annual step. Outputs for individual cells may be aggregated for further statistical processing. Input data are prepared for each grid cell, the output is done for each cell, too. In the current version only one even-aged single-species stand per cell is expected.

The simulation parameters are set in three ways: (1) globally (same for all cells), (2) explicitly locally (specific for each cell, given in the cell initialisation file) and (3) implicitly locally (specific for each cell, calculated from cell local parameters using globally defined rules).

Globally defined parameters include time series of ambient CO_2 concentrations and relative (from 0 to 1) industrial N deposition, reference years for N deposition and forest data, rule for historical management scenario determination (see below) and output parameters. Anthropogenic nitrogen deposition until 2000 was set according to Kopaček and Veselý (2005). It gradually increases, reaches maximum in 1990 and then rapidly decreases, reaching 55% of maximum in 2000 (Fig. 1).

Set of explicitly locally defined parameters includes:

- Mean cell elevation, aspect, slope, latitude and mean annual precipitation.
- Soil texture.
- Industrial nitrogen deposition in the reference year.
- Actual forest type (tree species).
- Age of the current stand in the reference year.

Soil texture data were aggregated into several soil types, each one with its predefined proportion of sand, silt and clay. A certain soil type was attributed to each grid cell.