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Long-term simulation of the effect of climate changes on the growth of main Central-European forest tree species

Fyodor A. Tatarinov[a,b,*], Emil Cienciala[b]

[a] Institute of Ecology and Evolution, Leninsky prospekt 33, Moscow, Russia
[b] IFER, Institute of Forest Ecosystem Research, Areál 1. Jílovské a.s. 1544, 254 01 Jílové u Prahy, Czech Republic

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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, and adapted to include forest management practices. Three climatic scenarios (HadCM3, NCAR-PCM, CSIRO) used were taken from the IPCC database created within the 3rd Assessment Report. They were 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.

The model simulations showed a decrease of wood carbon pool (from 2 to 6% relative to unchanged conditions) under HadCM3 scenario for all tree species. Under other climatic scenarios wood carbon pool decreased for coniferous and slightly increased for deciduous stands. The decrease of wood carbon pool under HadCM3 scenario was evidently related to decreasing precipitation during the second part of growing season, which increased soil moisture deficit and, consequently, decreased NPP. Under all scenarios a considerable build-up of litter carbon pool was observed (from 7 to 16% at 2100). The changes in soil carbon pool were small (2–3%), positive for deciduous and negative for coniferous stands.

Imposing changing climatic conditions only (under constant CO_2 and N deposition) resulted in similar trends of carbon dynamics as under the base scenario, but with smaller magnitude of changes. The combination of CO_2 increase and N decrease under constant climate had a positive effect on C pools for deciduous and a negative effect for coniferous species. The simulation using annual means of climate changes gave considerably smaller carbon changes compared to the simulation with climate change imposed in monthly resolution.

1. Introduction

The likely response of forest growth to the changing environmental conditions receives a growing attention, in particular, with respect to carbon sequestration. According to the numerous studies, tree growth in Europe considerably increased during several last decades (e.g., Karjalainen et al., 2002; Mellert et al., 2004). Analysis of factors responsible for the observed increased growth remains challenging. However, it becomes evident that nitrogen deposition may have had the dominant role, with additional contribution of increased temperature and CO_2 concentration (Karjalainen and Schuck, 2007). The change in precipitation can also be an important factor affecting stand growth in different regions (Tatarinov et al., 2005; Vygodskaya et al., 2004; Aber et al., 1995). The likely trends of factors affecting tree grow in temperate Europe differ. While CO_2 concentration and temperature should increase under any scenarios (Climate Change, 1997), the prediction of N deposition as well as of precipitation remains ambiguous. In particular, Kopaček and Veselý (2005) showed that after a rapid increase since 1950s the nitrogen emission in Czech Republic reached its peak in 1990 and then decreased. Changes in precipitation during the 21st century may considerably differ for different regions and seasons within a year.

The main tool for analysis of ecosystem behavior under changing environmental conditions is the application of process-based models. They simulate ecosystem development as a result of ecophysiological processes described mechanistically. This means that such models directly simulate ecosystem responses to changes of environmental variables. During the last decades a considerable number of studies was applied to predict the effect of expected environmental changes on forest growth (e.g., Vaisanen et al., 1994; Aber et al., 1995; Sykes and Prentice, 1995; VEMAP, 1995; Churkina et al., 1999; Kramer and Mohren, 2001; Hanson et al., 2005, etc.).

* Corresponding author at: Severtsov Institute of Ecology and Evolution Problems, Leninsky prospekt 33, Moscow, Russia. Tel.: +7 495 954 7553.
E-mail address: pedro2005@rambler.ru (F.A. Tatarinov).

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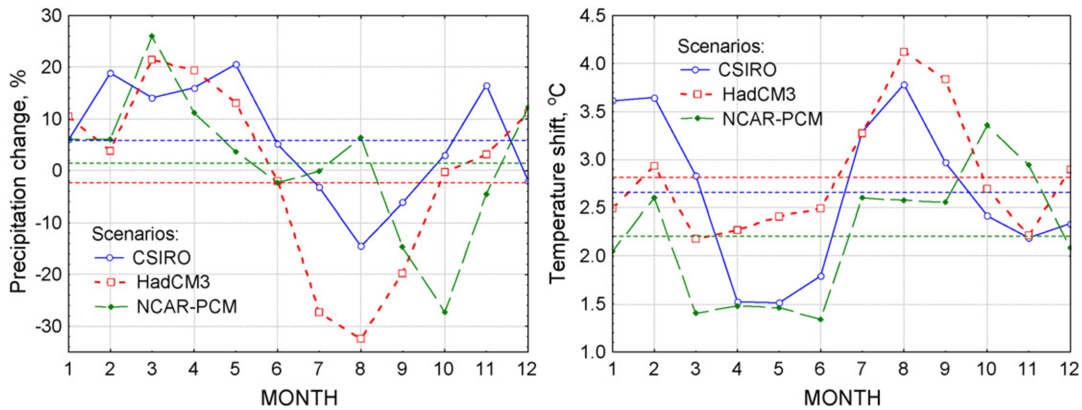

Fig. 1. Applied scenarios of climate changes in 2100 relatively to present time: multiplier of precipitation (left) and shift of mean daily temperature (right). Dashed lines represent annual means.

However, in many models the environmental changes are considered statically, i.e., the steady state under present conditions is compared to another steady state under changed conditions (Sykes and Prentice, 1995; Hong et al., 2005; Hanson et al., 2005). Beside of process models, gap models are often used for such predictions (Hong et al., 2005; Chonggang et al., 2007; Sykes and Prentice, 1995), although these models usually do not include physiological mechanisms driving plant reactions to environmental changes.

This paper follows our earlier studies (Cienciala and Tatarinov, 2006; Tatarinov and Cienciala, 2006) with the process model BIOME-BGC (Thornton, 1998) adapted so as to include forest management routines. The major aim of the current study is to analyze the effect of environmental scenarios (including the changes of climate, CO_2 concentration and nitrogen deposition) on the carbon balance of managed Central-European forests. The analysis was performed on single-species managed stands of the four major tree species important to Central-European forestry, namely spruce, beech, pine and oak.

2. Materials and methods

2.1. Biome-BGC model

We applied the BIOME-BGC (Thornton, 1998) model version 4.1.1, which was specifically adapted to include key management routines such as thinning and harvest, and where some additional changes were made to handling interception, evaporation, throughfall, fine root mortality and industrial nitrogen deposition (Tatarinov and Cienciala, 2006). 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. Model operates with several hundreds of state variables describing pools of carbon, nitrogen and water in different ecosystem compartments and their fluxes. In particular, vegetation is described by carbon and nitrogen pools in sapwood and heartwood of stems and coarse roots, fine roots and foliage. It is a point model and the simulated ecosystem is considered homogeneous, with pools and fluxes expressed per unit ground area. 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 that is handled as a function of carbon allocated to the different plant compartments. Nitrogen cycle includes N consumption for plant growth, metabolism of organisms destructing litter and coarse woody debris, mineralization and leaching. Water cycle includes precipitation (rains and snowfalls separately), interception, evaporation from soil and foliage, transpiration simulated by Penman–Monteith equation, snow sublimation and outflow. The amount of soil is limited by rooting depth parameter: all water input above the maximum soil water capacity within this volume is considered as outflow. The decomposition of organic matter involves coarse woody debris in different stage, four litter pools and four soil pools differed by their decomposition rate. Decomposition rate is driven by soil moisture and temperature. 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). BIOME-BGC model was widely applied for simulation of different biomes all over the world (Churkina et al., 1999; White et al., 1999; Pietsch and Hasenauer, 2002; Pietsch et al., 2003; Bond-Lamberty et al., 2005; Vetter et al., 2005 and others).

2.2. Scenarios of environmental changes

The three climatic scenarios (HadCM3, NCAR-PCM, CSIRO) were taken from the database of IPCC created within the 3rd Assessment Report. They included the changes of monthly means of climate characteristics (minimum and maximum daily temperature, air humidity, precipitation and solar radiation) relative to the observations from 1961 to 1990 (Fig. 1). The scenarios were prepared using the pattern scaling method (Dubrovsky et al., 2005) and interpolated for the location of the study sites (Czech Republic). The prediction of CO_2 concentration dynamics in 2005–2100 was taken as a mean of the available emission scenarios SRES-A1 a SRES-B2. As no prognosis of N deposition was available, we supposed a slight decrease of N deposition in until 2050, prolonging the observed trend during 1990–2000 (Kopaček and Veselý, 2005), with further stabilization thereafter (Fig. 2). The control scenario included no changes of climatic characteristics, CO_2 concentration and N deposition since 2000.

2.3. Review of model upgrades

The changes of the model code made within its adaptation to managed forest conditions were described in details by Tatarinov and Cienciala (2006). The most important changes in the context of the present study were as follows: