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Introduction

Forest ecosystems play a dominant role in controlling terrestrial carbon sinks (Janssens et al., 2003). In order to predict more accurately the response of the carbon balance of forest ecosystems to atmospheric and climate change, the effect of management needs to be more clearly understood. Thornton et al. (2002) had analysed the effects of disturbance history on carbon budgets in evergreen needle-leaf forests. Their results suggested that there was a consistent pattern of early carbon source followed by strong and gradually diminishing sink during recovery from a major disturbance.

Carbon stocking in virgin forests were few investigated in temperate climate (Knohl et al., 2003). In their review, Hyvönen et al. (2007) found that unmanaged stands were either close to neutral or weak carbon sinks. Hollinger et al. (1994) used the eddy-correlation technique to investigate the exchange of CO_2 between an undisturbed old-growth forest and the atmosphere. But they neither gave annual estimate of fluxes nor assess of carbon stocks in soil or wood. More recently, Knohl et al., (2003), found that a virgin beech forest was a large carbon sink over 2 years, with 494 $g_C m^{-2}$ per year in 2000 and 490$g_C m^{-2}$ per year in 2001.

One way to study the effects of management on carbon fluxes is to compare carbon fluxes by modelling or eddy flux measurements on several sites following various management modes or other types of disturbance (Thornton et al., 2002). Another solution is to use process based models and simulates the effect of various modes of thinning (Loustau et al., 2005). The purpose of this study was to compare two beech ecosystems in similar conditions but with different management modes (old unmanaged forest and a managed forest) using both measurements and modelling. The first objective was to assess by the comparison of the two sites the effect of management both on stock and carbon fluxes. The second objective was to provide an estimation of the carbon fluxes in a virgin forest, which are few studied in European countries.

Material and Methods

The sites

The virgin and managed silver-fir–beech forests investigated are located in the northern part of the Dinaric Alps in SE Slovenia (45°20N, 14°30E, 860–890 m). The bedrock is Cretaceous limestone and the soil generally shallow (leptosolic). The climate of the region is typical of Dinaric mountains, with annual precipitation up to 1,500 mm and a mean annual air temperature of 8.4°C. The Rajhenavski Rog virgin forest was officially declared as a virgin forest in the first forest management plan of the area in 1894, but is more precisely defined as a secondary virgin forest.

CASTANEA model and measurements

CASTANEA is a physiological process-based model simulating the carbon and the water balance in forest stands. The canopy is assumed to be homogeneous horizontally and is vertically subdivided into a variable number of layers (i.e. multi-layer canopy model). The main simulated output variables are the canopy photosynthesis, maintenance and growth respiration, growth of organs, soil heterotrophic respiration, transpiration, and evapotranspiration.

The radiation extinction and diffusion are based on the SAIL model. Half-hourly rates of gross canopy photosynthesis are calculated based on Farquhar et al. (1980) coupled with a stomatal conductance model of Ball et al. (1987). Maintenance respiration depends on temperature and nitrogen content of the various organs (Ryan, 1991), while growth respiration depends on biochemical composition of organs. After subtraction of maintenance respiration requirements, the remaining assimilates are allocated to the growth of various plant tissues using a priority rule, which varies with the season. The heterotrophic respiration is calculated using a Soil Organic Carbon (SOC) model (Epron et al., 2001) derived from CENTURY (Parton et al., 1987). Phenological stages (budburst, end of leaf growth, and start of leaf yellowing) and leaf growth depend on degree days (i.e. heat amount accumulated). The big-leaf Penman-Monteith equation is used to calculate both transpiration (Tr) and evaporation (EP). The soil water balance is calculated using a bucket model with three layers. During water stress periods, the slope of the relationship between leaf assimilation and stomata conductance (g_1) is assumed to decrease. Complete description and validation of the model were given in Dufrêne et al. (2005).

In the two sites, in 2005 and 2006, measurements of soil extractable water, leaf photosynthesis, and stand carbon biomass (soil and aboveground) were used to calibrate the model. Soil water content, soil respiration and tree ring increment were used to validate the model.

Results and discussion

The model was applied from 1997 to 2006 to estimate the various carbon fluxes in the two ecosystems: canopy photosynthesis, autotrophic and heterotrophic respirations, wood growth and Net Ecosystem Exchange. The CASTANEA model reproduced the soil water dynamics in 2005 and 2006 both in managed and virgin forest. Stand growth simulated in managed and virgin forest, were compared to tree ring increment measured in the managed forest from 1997 to 2006 (Fig. 1). The canopy photosynthesis was found globally high compared to others studies, respectively 2040 g_C m^{-2} y^{-1} in the virgin forest and 1960 g_C m^{-2} y^{-1} in the managed forest. The higher photosynthesis in the virgin forest (Fig. 2) was counterbalanced by a much higher heterotrophic respiration (+14%), due to higher soil carbon content and a higher wood respiration (+11%) caused by the regeneration. The result is that the managed forest showed a higher stock (+2%: 56 vs 55 t_C m^{-2}), but a lower flux of carbon (-60%: 132 vs 211 g_C m^{-2} y^{-1}).

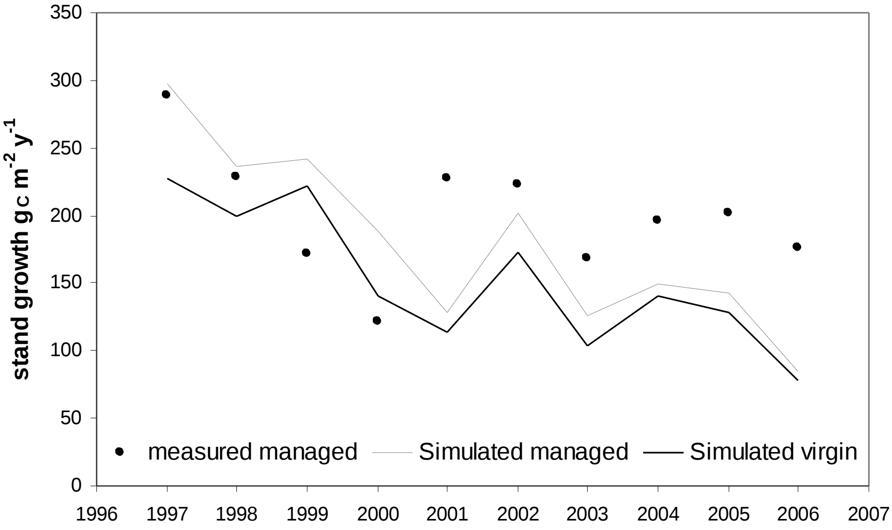

Figure 1: Stand growth from 1997 to 2006 measured from tree ring increment and simulated by CASTANEA in managed forest and simulated in virgin forest.

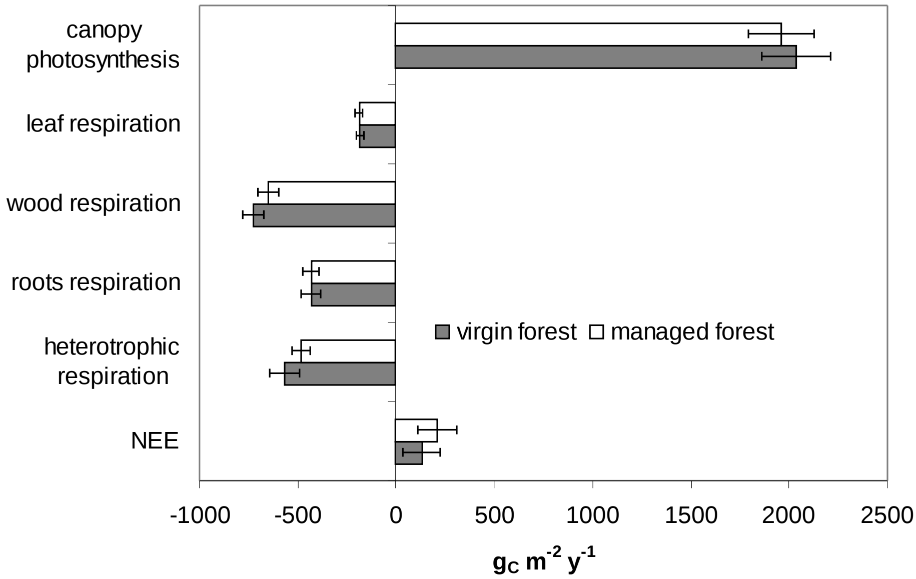

Figure 2: Summarize of average annual carbon fluxes simulated by CASTANEA from 1997 to 2006 in virgin and managed forests.

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