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Soil carbon dioxide fluxes in a mixed floodplain forest in the Czech Republic

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ABSTRACT

Floodplain forests belong among the most productive, dynamic and diverse ecosystems on Earth. Only few studies have focused on the carbon dioxide fluxes of these ecosystems. Therefore, this study investigated the spatial heterogeneity in soil CO_2 efflux in a floodplain forest located in the southeast of the Czech Republic. The study also examined which environmental parameters influence soil CO_2 efflux. Moreover, using these obtained measurements a soil CO_2 efflux model was applied. To achieve the aims of this study, soil CO_2 efflux on 30 positions in 16 campaigns was measured from May to November during the growing season 2016. The efflux during the experiment period ranged from 1.59 to 8.54 $\mu molCO_2\ m^{-2}\ s^{-1}$. The highest soil CO_2 effluxes were observed during the summer period while the lowest values were measured during the autumn. A strong relationship between soil CO_2 efflux and soil temperature was found ($R^2 = 0.79$). The estimated mean Q_{10} for the whole 30 positions was of 2.23. We determined that the spatial heterogeneity of soil CO_2 efflux was 20% during our study. The cumulative amount of carbon forest floor released from our experimental forest site calculated from our model was 7.4 (±1.1) tC $ha^{-1}\ y^{-1}$ for 2016. Such data are important for developing our knowledge and understanding about carbon dynamics and to improve carbon models for these ecosystems types.

1. Introduction

Floodplain forests belong among the most productive, dynamic and diverse ecosystems on Earth [1,2]. Due to fluctuations in river flow and subsequent alternation between flooding and drying, floodplain ecosystems are in a state of dynamic equilibrium [3]. Within the floodplains, floods and geomorphic processes interact to create a shifting mosaic of habitat patches [1] where the vegetation patterns are driven by disturbance intensity, inundation regime and by geological and soil properties. With the exception of the most dynamic and frequently disturbed areas, the majority of floodplain vegetation consists of forests of various age and tree species composition. These floodplain forests are highly productive and provide a wide range of ecosystem services such as high biodiversity, flood water retention, a nutrient sink, groundwater recharge, carbon sequestration, timber production, recreational facilities and aesthetic value [4].

Many studies have investigated floodplain forests from different ecological points of view such as plant composition [5], tree physiology and morphology [6,7], flooding regime and water table variations [8], and soil acidity and nutrient concentrations [9,10]. But few studies have focused on the effect of flood dynamics on the greenhouse gas budgets and carbon storage of riparian ecosystems [11–13]. In large-scale research projects of the last 15 years (CarboEurope IP, Carbomont, Nitroeurope etc.) floodplain forests have been ignored; mostly because they are ecosystems that are not representative of a wider region. Due to their comparatively small areal extension, floodplain forests are rarely captured in monitoring systems along a regular pattern e.g. along transects and grids. Nevertheless, floodplain forests may play an important role in regional carbon cycling and total greenhouse gases (GHG) dynamics.

Floodplain forests in temperate areas are highly productive and store carbon (C) in large quantities when they are compared with upland forests. A detailed assessment also showed that fine root biomass as well as above ground plant biomass significantly varied between flooded and diked areas [14]. However, a move from stock data towards a conceptual understanding of ecosystem C dynamics is necessary to assess the role of floodplain forests in C

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sequestration. The reason for the current lack in detailed C flux data is likely related to obstacles linked to the intensive dynamics of the system, such as additional C import and export by flooding, but might also be attributed to the impracticalities of in situ research in periodically flooded areas. The present pilot study was designed to address the general need for basic information about soil CO_2 efflux heterogeneity and specifically to gain information about the factors influencing soil CO_2 efflux heterogeneity in floodplain forest. Therefore, the aims of our study were i) to quantify soil CO_2 efflux (S_R) and to estimate the spatial heterogeneity in S_R during the growing season 2016 in a floodplain forest located in the southeast of the Czech Republic, ii) to determine the influence of environmental parameters as soil temperature and soil moisture on S_R and iii) to create a model of S_R based on measured data during the vegetation season 2016.

2. Material and methods

2.1. Site description

The experiment site is situated 6.5 km to the north of the confluence of Morava and Dyje rivers (48° 40.09′ N, 16°56.78′ E). It is formed of an alluvial plain. Long-term average annual precipitation is around 550 mm and mean annual temperature is 9.3 °C. The experimental site is composed by typical hardwood species. The main tree species composition is English oak (*Quercus robur* L.), Narrow-leaved ash (*Fraxinus angustifolia* Vahl), hornbeam (*Carpinus betulus* L.) and linden (*Tilia cordata* Mill.). The stand age is 110 years and height 27 m. The herbal layer and understory of the forest site is characterized by *Allium ursinum* L., *Anemone ranunculoides* L., *Lathyrus vernus* (L.) Bernh., *Galium odoratum* (L.) Scop., *Carex sylvatica* Huds. and *Acer campestre* L. The predominating soil types are Eutric Humic Fluvisol, Haplic Fluvisol, and Eutric Fluvisol (according FAO 2014 Classification) with minimal soil depth of 60 cm. The studied floodplain forest, for the past 30 years, has been plagued by hydrological extremes - floods and drought. Particularly drought threatens valuable floodplain forests. The last flood on 2013 was above soil surface only in the lowest parts of the studied site.

2.2. Soil CO_2 efflux measurements

S_R (including vegetation cover — low growing plants covering the ground) was measured in a 150 m long transect on 30 positions planed in 5 m intervals using a closed dynamic chamber system (a portable infrared gas analyzer Li-8100 (Li-Cor, Inc., Lincoln, NE, USA) with a 20 cm survey chamber (Li-8100-103, Li-Cor, USA). At each measured position a PVC collar with 20 cm in diameter was installed into the soil at 5 cm depth. After the chamber closed, a period (dead band) of 15 s was set to allow steady mixing of the air in the chamber. During the following 60 s, CO_2 concentration was measured repeatedly at 1s intervals and a linear fitting was used to calculate S_R. Each measurement took about 3 min and each position was measured two to three times per day. Measurements were carried out once per month from May till November, 16 measurements campaigns were done during this period. Measurements were not realized in September due to malfunction of the pump of the CO_2 analyzer. The 30 measured positions covered the most representative soil surface of the study site, 10 of the measured positions were without vegetation and the other 20 positions with temporary vegetation (*Allium ursinum* L., *Galium odoratum* (L.) Scop., between 10 and 70% coverage). The herbal understory is mainly during spring season.

During each CO_2 efflux measurement, soil temperature at 2 cm (TPD32 penetrate thermometer, Omega, Stamford, CT, USA) and soil moisture in the 0–6 cm profile (ThetaProbe ML2x, Delta-T Devices, Cambridge, UK) were measured at the distance 5 cm outside the collar. Moreover, basic microclimatological parameters of the forest stand such as air temperature/humidity at 2 m height (EMS 33, EMS Brno, Czech Republic) and precipitation (rain gauge MetOne 386C, MetOne, USA) were recorded in 30 min intervals. Soil temperature (Pt100, Sensit, Czech Republic) at 2 cm depth was continuously recorded in 30 min intervals at four different plots close to the measured positions during the whole experiment period.

2.3. Data processing

Two approaches were used to analyze the measured data. The first was using the Q_{10} parameter (the proportional change in respiration resulting from 10 °C increase in temperature) from van't Hoff [15]. Q_{10} expresses the dependence of S_R on soil temperature. In our analysis we determined a mean Q_{10} value on the basis of our measurements on all positions at each measurement campaign. The Q_{10} value was calculated according to equation (1) [16]:

$$Q_{10} = e^{10 \cdot \beta} \tag{1}$$

where β is the regression coefficient obtained from the natural logarithm of the relationship between CO_2 efflux and soil temperature. Then, a reference value of R_{10} (CO_2 efflux normalized to a temperature of 10 °C) for each measured position was calculated as:

$$R_{10} = SR{*}Q_{10}^{\left(\frac{10-T}{10}\right)} \tag{2}$$

where SR is the measured soil CO_2 efflux (μmol CO_2 m^{-2} s^{-1}) at T soil temperature. Data calculation and equations (1) and (2) were done using Microsoft Office Excel 2007. Moreover, the measured S_R data were related to the soil temperature and soil moisture measurements. An exponential regression for soil temperature and logarithmic regression for soil moisture were used in order to determine the dependence of S_R on both environmental variables.

The second approach was to use parameters Q_{10} and seasonal averaged R_{10} (R_{10ave}) for estimating modelled soil CO_2 efflux (R_M) on the basis of daily mean soil temperature at 2 cm depth in the study site during the whole experiment period (from May till November) using the following equation [17]:

$$R_M = \frac{R_{10ave}}{Q_{10}^{\frac{10-Ts}{10}}} \tag{3}$$

The spatial heterogeneity of the soil surface CO_2 efflux was expressed by the coefficient of variation CV − which is defined as the ratio of the standard deviation to the mean.

Moreover, a geostatistical method was applied on S_R data. Autocorrelation was studied by semivariograms [18]. Semivariance was estimated by the following expression

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \left[Z(x_i) - Z(x_i + h)^2 \right] \tag{4}$$

where $\gamma(h)$ is the semivariance of pairs of points separated by h distance; $N(h)$ is the number of observations of each pair of points separated by h distance; $Z(xi)$ and $Z(xi + h)$ are the values of Z variable in points xi and $xi + h$.

The following mathematical models were then fitted on created semivariograms: