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CARBON AND GREENHOUSE GAS BALANCE OF A NORTHERN BOREAL FEN - CONTRIBUTION OF IMPORT AND EXPORT OF AQUATIC TRANSPORT

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SUMMARY

Aquatic export has been recognized as a significant component of the total carbon (C) balance in terrestrial ecosystems. In order to understand the impact of climate warming on the biogeochemistry of C in boreal ecosystems, information on both the greenhouse gas fluxes and the dynamics of the laterally transported C is essential. Continuous measurements of carbon dioxide (CO_2) and methane (CH_4) exchange with the eddy covariance method have been running at the Lompolojänkkä sedge fen in northern Finland since 2005. In addition, aqueous input and output of dissolved inorganic and organic carbon and dissolved CH_4 have been analysed based on soil suction cups, water balance measurements and stream water chemistry sampling. While the methane flux is relatively constant from year to year, the interannual variation in CO_2 exchange is considerable. Combining the atmospheric (6 years) and aqueous (3 years) fluxes for the fen ecosystem resulted in an average C sink of about 26 g C m^{-2} yr^{-1}. The initial results suggest that the import and export components of fluvial fluxes in this fen ecosystem are high, but may cancel out each other. Hence, these fluxes may play a significant role in the C balance of this fen. A small shift in either of the aquatic components may affect greatly the net C balance of the fen.

KEYWORDS: carbon dioxide, dissolved organic carbon, forest, methane, mire

INTRODUCTION

Boreal forest soils and peatlands store a vast amount of carbon (C), therefore having a potential to intensify the climate change. They interact with the atmosphere by exchanging greenhouse gases (GHG) which are relevant to global warming. Besides the ecosystem-atmosphere exchange, the aquatic export has been recognized as a highly significant component of the C balance (Kindler et al., 2011). The lateral fluxes of C constitute a key link between the terrestrial and aquatic ecosystems: surface waters move nutrients from terrestrial system into lakes and finally into oceans. In a boreal catchment with mature forest in Finland, for example, it has been estimated that about 10% of the terrestrial net ecosystem production may be emitted back to the atmosphere by a lake (Huotari et al., 2011). This makes it necessary to reassess the previously estimated carbon balances, which are based on atmospheric fluxes only and thus are likely to overestimate the true terrestrial sink. The significance of the aqueous flux varies with land-use, the contribution being higher in peatland-dominatet catchments (Kindler et al., 2011; Laudon et al., 2004; Rantakari et al., 2010). As approximately 10–30% of the global soil C stock is found in northern peatlands

(Gorham, 1991) and about one-third of the total area of Finland consists of peatlands (Vasander, 1996), it is of crucial importance to better understand the full catchment-scale C and N balances and the significance of peatlands in controlling the distribution of these elements within the aqueous and atmospheric phases. In this presentation we combine atmospheric and aquatic flux data and determine the carbon balance for the Lompolojänkkä aapa mire located in the northern boreal zone.

MATERIALS AND METHODS

The Lompolojänkkä fen is located in Pallas area in Northern Finland (68°N, 24°S). The fen receives surface waters from the surrounding spruce forest located on fluvial till. At the fen, the exchange of CO_2 and CH_4 was measured with the eddy covariance (EC) method. Nitrous oxide (N_2O) fluxes have been studied with the enclosure method. Evapotranspiration was measured with the EC at the fen and above the spruce forest surrounding the fen, these forming the terrestrial part of a catchment. Concentrations of total and dissolved organic C were measured in the bulk deposition and in the percolation water of the forest soil and in the downstream water of the fen. The amount of percolated water from the forested part of the catchment onto the fen and the runoff from the fen into the nearby lake was estimated as a difference between the precipitation and evapotranspiration. From all these data, fluvial import and export of C and N into and from the fen was estimated and compared to the measured ecosystem-atmosphere exchange rates. Aggregated data from years 2007-2009 where used for the aquatic fluxes, whereas the atmospheric flux data covered years 2005-2010 for CH_4 and CO_2.

RESULTS AND DISCUSSION

Water balance

The water balance was calculated for the years 2007-2009, the period for which data on aquatic fluxes were available (Table 1). The precipitation varied considerably among the years, driest year being 2008. Then, the evapotranspiration was highest, probably due to higher atmospheric demand of water vapour.

Table 1. Annual precipitation and evaporation and the amount of percolation water formed in the spruce forest surrounding the Lompolojänkkä fen, calculated as a difference of precipitation and evapotranspiration. All units are expressed in mm.

	Precipitation	Evapotranspiration	Amount of percolation water)
2007	580	255	325
2008	645	237	267
2009	325	408	186

DOC concentration in the soil water

Concentration of dissolved organic carbon (DOC) in the forest soil, at the depths of 20 and 40 cm below the soil surface, was sampled 10 times during 2007-2009. The concentration varied from 8 to 24 mg l^{-1}, being highest in June 2008 and autumn 2009. DOC flux leaving the

mineral soil forest was calculated separately for each year, using the estimated amount of percolation water (Table 1) and the DOC concentrations.

TIC and TOC concentration in the stream water

Although the stream water was analysed for total inorganic and organic carbon, we assumed based on literature that most of this consisted of dissolved species. TOC concentration peaked in summer when the plants are most active and move soluble carbon from their leaves to the soil. TIC, on the other hand, peaked in winter, at a time of the lowest runoff. The concentration dropped during the spring flood which was intensive at Lompolojänkkä, typical to snow-covered catchments.

Aquatic fluxes

The aquatic fluxes from the forest soil to the fen were estimated by two different methods. The flux was obtained by 1) multiplying the annual sum of percolation water and the annual mean concentration of DOC in the soil and by 2) taking into account only the months with mean air temperature being above zero, and multiplying the corresponding soil DOC concentration and the amount of percolation water formed for each month. The results have been collected in Table 2.

Table 2. DOC fluxes from the mineral soil forest to the Lompolojänkkä fen, and fluxes of total organic and inorganic C from the fen to the lake, estimated for the whole year or only for the months with mean monthly air temperature > 0 deg C (Summer).

	Forest to fen		Fen to lake		Difference	
	Whole year	Summer	Whole year	Summer	Whole year	Summer
2007	44	26	60	30	-16	-4
2008	96	34	81	26	15	8
2009	27	16	35	13	-8	3

Greenhouse gas fluxes

The average CO_2 and CH_4 balances or years 2005-2010, as well as annual balances for the years 2007-2009, are shown in Table 3. Mean CO_2 flux was -39 g C m^{-2} yr^{-1}, and that of CH_4 was 15 g C m^{-2} yr^{-1}. Negative sign indicates that the wetland was a sink of CO_2. In 2007-2009, the CO_2 uptake was greater than the 6-years average. The N_2O flux at the fen varied between 0 and 0.8 g N m^{-2} yr^{-1}.

Total fluxes

There was a high interannual variation in the gas balances. However, also the annual aquatic flux varied considerably among the years, and as shown in Table 2, it is highly dependent on different assumptions done during the calculation. Nevertheless, there was no significant difference in the aquatic fluxes when calculated using the “Summer” data or that of the whole year.

When summing up the individual atmospheric and aquatic fluxes, the fen appeared to be accumulating C at rates of 57-62 g C m^{-2} in 2007-2009 (Table 3). However, as the CO_2 sink was significantly higher during those years as compared to 2005-2006 and 2009-2010, we calculated also the average accumulation rate using the 6-years atmospheric flux data. Then,

the net C sink was smaller, 26 g C m^{-2}. This is comparable to other studies on boreal peatlands, e.g. Roulet *et al.* (2007) observed a net sink of 21.5 g C m^{-2} yr^{-1} in a Canadian bog, Nilsson *et al.* (2008) reported a sink of 23.5 g C m^{-2} yr^{-1}, and Koehler *et al.* (2010) found a sink of about 30 g C m^{-2} yr^{-1} in and Irish blanket bog. It is notable that most of the studies so far have concentrated on bog-type mires, where the incoming water consists merely of precipitation. In a fen ecosystem, the aquatic fluxes may form significant proportion of the atmospheric fluxes, but, as our results here indicate, the incoming and outgoing aquatic fluxes may cancel out each other. Our results also showed higher uptake rate than the long-term C accumulation rate determined at Lompolojänkkä, about 13-16 g C m^{-2} yr^{-1} in upper part of the 2.3 m deep peat layer (unpublished data).

Table 3. C balance of the Lompolojänkkä fen. Average fluxes have been estimated using aquatic flux data from years 2007-2009 and gas balance data from years 2005-2010. Here, the aquatic fluxes have been calculated using the "summer" data (see Table 2 and explanations in text). All values are expressed in g C m^{-2} (fen) yr^{-1} and the positive sign indicates accumulation of C by the fen, negative indicates loss.

	2007	2008	2009	average
CO_2 uptake	78	69	74	39
CH_4 emission	-17	-15	-18	-15
incoming aquatic C	26	34	16	25
outgoing aquatic C	-30	-26	-13	-23
Total C balance	57	62	59	26

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