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CARBON FLUX AND ACCUMULATION DYNAMICS IN A NORTH BOREAL PEATLAND-LAKE CONTINUUM

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SUMMARY

We studied contemporary CO_2 and CH_4 exchange, lateral carbon (C) transfer, and long-term C accumulation dynamics in a peatland-stream-lake-continuum in northern Finland. Our catchment C budget showed that the aquatic loss of C equalled ~13% of the terrestrial net C input on an annual scale. The contemporary net C input estimate for the fen (22 g C $m^{-2}a^{-1}$) was larger than the long term carbon accumulation rate based on the peat cores (6.3–16.0 g C $m^{-2}a^{-1}$). This study provides reference values of C exchange and terrestrial-aquatic linkage from boreal-subarctic ecotone, which is prone to ongoing climatic change.

KEY WORDS: terrestrial-aquatic, carbon export, greenhouse gas, carbon dioxide, methane

INTRODUCTION

The soils and biomass of forests and peatlands in boreal and arctic areas form the largest terrestrial long term carbon (C) sink. This landscape has also high number of lakes and streams, which have received less attention in global C accounting than the terrestrial ecosystems. However, there is lateral transfer of C from forests and peatlands to aquatic ecosystems, which then emit CO_2 and CH_4 to the atmosphere and accumulate C into the sediments (e.g. Kling et al. 1992, Kortelainen et al. 2004, Tranvik et al. 2009). This continuity in the matter processing forces to consider whole catchments when estimating C sink strengths, for example, of the peatlands (Billet et al. 2004, Nilsson et al. 2008). Our study synthesizes the C exchange and accumulation dynamics in a basin where peatlands are directly connected with a lake. We chose a site near northern tree line, because this region is sensitive to climatic changes. We quantified the contributions of lake, stream, and peatland habitats on the contemporary CO_2 and CH_4 exchange with the atmosphere, aquatic C transfer out from the lake, long term C accumulation rates to the lake and peatland sediments, and past plant assemblages from several peat cores. We present a catchment C budget using the measured values for the wetland habitats and literature values for the upland sites. Our questions are: how large is the contribution of the aquatic C transfer in this catchment and how it relates to the terrestrial C exchange? How does the current C exchange rate relate to the long-term C accumulation rate at the peatland.

MATERIALS AND METHODS

Lake Kipojärvi catchment (69°11'N, 27°18'E) is situated in boreal Finnish Lapland. The mean annual temperature is -1 °C and mean annual rainfall is 395 mm a^{-1}. The catchment area is 1.6 km^2 of which streams covers 0.06%, lake 6%, fens 31%, and upland forest 63%. The minerotrophic fen slopes gently to the lake and a small stream flows through it to the lake. Lake has a surface area of 0.11 km^2 and maximum water depth of about 1.5 m.

Our gas exchange data covers year 2006 including winter. CO_2 and CH_4 fluxes were measured using chamber method, floating chambers were applied in the stream and lake surfaces. Winter fluxes were estimated using the snow pack diffusion method. The sampling points at the fen, lake and the stream were arranged to cover the spatial variation within each environment. Net ecosystem exchange of CO_2 (NEE), ecosystem respiration (ER) and photosynthesis were measured at the fen (see Laine et al. 2009). Only the ER was measured in the aquatic habitats. Methane fluxes were measured in all sites. The lateral C transfer was estimated on the basis of discharge and concentration (DOC, dissolved CO_2 and CH_4) measurements.

Peat and lake sediment C contents and accumulation rates were quantified for three lake sediment and three peat cores, which were collected along a transect from the deepest point of the lake to the peatland-mineral soil margin. Seven peat cores were analysed for plant macrofossils. In order to calculate carbon accumulation rate estimates basal peat and sediment layers were dated using mixture of plant remains and AMS-technique in dating Laboratories of Helsinki and Poznan. The dates of the fen cores were inconsistent and often inverted and we applied pollen-stratigraphical comparison to other radiocarbon-dated pollen diagrams from the L. Kipojärvi sediments (Väliranta et al. 2011, Siitonen et al. 2011). The synchronization was based on proportions of *Betula*, *Pinus*, and *Sphagnum* pollen. Peat and sediment layers were surveyed systematically and Kriging interpolation was applied for the spatial interpolation to estimate total peat and sediment volumes.

Annual CO_2 and CH_4 exchange between the catchment and the atmosphere was calculated on the basis of ecosystem type specific flux factors per unit area and the total area of each ecosystem type. For the upland forests we adopted annual values of NEE and CH_4 from Christensen et al. (2007). The lateral transfer of C out from the catchment and sedimentation in the lake were included into the budged.

RESULTS

The fen as a whole was a CO_2 sink on an annual scale (NEE 37 g C $m^{-2}a^{-1}$), and CH_4 emissions reduced the C sink by ~27%. The driest plant communities, hummocks and dry lawns, had the highest net intake, photosynthesis and respiration rates. The peatland stream was a CO_2 evasion hotspot having mean flux of 479 g C $m^{-2}a^{-1}$. The mean CO_2 release rate was of the same magnitude than photosynthetic uptake (456 g C $m^{-2}a^{-1}$) or ecosystem respiration (326 g C $m^{-2}a^{-1}$) in the hummocks. Mean CH_4 fluxes were highest in the wet lawn in the littoral and in the stream (up to 17.4 g C $m^{-2}a^{-1}$) and smallest in the sand bottomed littoral and in the hummocks. The lake as a whole was a small source of CO_2 and CH_4 (~15 g C $m^{-2}a^{-1}$). Stream water DOC concentration was similar to that in the lake during summer. In turn, the concentrations of dissolved CO_2 and CH_4 were noticeably higher in the stream and peat bottomed littoral area next to the fen margin than in the other parts of the lake.

Some peat cores were underlain by limnic sediments. Pollen based chronology indicated that the peat accumulation started during the early Holocene before 8000 cal yr BP. Palaeobotanical composition of all peat sequences showed remarkable similarities irrespective of whether the origin was terrestrialization of a small water body or peat formation straight on the mineral soil. Diverse bryophyte communities occurred together with abundant sedges and no apparent general successional patterns were visible. Only in one coring point the vegetation developed towards drier habitat when approaching the modern times. Long-term mean apparent carbon accumulation rates in three coring point were ~8, 6–13, and 8–16 g C $m^{-2}a^{-1}$. The range in the two latter estimates is due chronological uncertainties. Lake sediments started to accumulate about 11 000 years ago and long term mean C accumulation rates were 5 and 13 g C $m^{-2}a^{-1}$ in littoral and deep cores, respectively.

Forests and peatlands contributed 73% and 27% of the estimated annual C input, respectively. Largest aquatic C loss was the downstream transfer of DOC, which equalled 9% of the terrestrial C input of the forests and peatland. Emissions of CO_2 and CH_4 from the lake and stream surfaces, sedimentation in the lake, and downstream transfer of CO_2 and CH_4 equalled 3.4%, 0.6% and 0.2% of the terrestrial C input, respectively. The sum of aquatic C fluxes per terrestrial catchment area was 5.3 g C $m^{-2}a^{-1}$. Taking this to account as a leaching term, the annual net C exchange of the fen was ~22 g C $m^{-2}a^{-1}$.

DISCUSSION

Our study is one of the few studies where terrestrial and aquatic components and short and long term C dynamics are synthesised to construct a carbon budget of a catchment. In line with earlier studies in similar landscapes (Jonsson et al. 2007, Buffam et al. 2010), the pine forests and the fen were relatively strong sinks of C in this catchment. The C losses through the aquatic pathway, however, corresponded ~13% of the terrestrial net C intake decreasing it.

The aquatic fluxes followed a typical pattern where the downstream export (55%) and fluxes to the atmosphere (41%) exceeded the sedimentation in the lake (4%) (Algesten et al. 2003, Jonsson et al. 2007, Buffam et al. 2010). The derived C export estimate (c.f. Algesten et al. 2003) is smaller than export from two subarctic fens, DOC 7–8 g C $m^{-2}a^{-1}$ (Olefeldt and Roulet 2012), and from a mid boreal oligotropfic fen (15–20 g C $m^{-2}a^{-1}$, Nilsson et al. 2008). Our approach did not distinguish transfer from the peatland and upland forest, thus this could lead to too low export term for the fen (e.g. Kortelainen et al. 2006).

The annual net C balance estimate based of gas exchange measurements for the fen was larger than the long-term C accumulation rate estimates based on the peat cores. The mismatch could originate from uncertainty in detection of C storages and fluxes and and/or the possibility that the current rates do not represent the past conditions. The estimated long-term apparent C accumulation rates are reasonable compared to another estimate for Finnish aapa mire (5–27 g C $m^{-2}a^{-1}$, Mäkilä et al. 2001). Contemporary NEE is in the high end of the NEE range, 4–53 g C $m^{-2}a^{-1}$, determined by six years of eddy covariance measurements in a nearby patterned fen (Aurela et al. 2004). However, long and warm growing season in year 2006 possibly enabled a larger than average NEE for this fen site. Palaeobotanical analysis indicated that vegetation at the studied fen has stayed rather similar during its whole history, which suggests stabile C exchange properties too. Due to its location in a depression next to the esker and as a part of wetland chain, the fen has supposedly maintained stable hydrology and unchanged rich fen vegetation.

Our earlier analyses of lake's history revealed that lake water level has been varied and there have been increasing terrestrial inputs to the lake in the late Holocene (Siitonen et al. 2011, Väliranta et al. 2011). The areally weighted C storage in lake sediment and the long-term mean C accumulation rate in L. Kipojärvi correspond well with the relatively high sedimentation rates in the lakes of comparable size in Finland (Kortelainen et al. 2004).

These results support the idea that streams efficiently out gas CO_2 and CH_4 (e.g. Jonsson et al. 2007). Moreover, peatland contributed dissolved gases to the lake via inflowing stream water and through the littoral zone (e.g. Billett et al. 2004). Altogether, areally weighted mean C emission to the atmosphere from the L. Kipojärvi was low, for example, compared to the C efflux from wetland lakes in West Siberian Lowlands, 23–66 g C $m^{-2}a^{-1}$ (Repo et al. 2007). This can be due differences between the peatland types and relatively high pH of L. Kipojärvi. Still, aquatic C fluxes were countable in the catchment scale.

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