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HOW IMPORTANT IS THE EVASION FLUX TERM IN THE CARBON AND GHG BALANCE OF PEATLANDS?

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SUMMARY

Instantaneous measurements of gas exchange from flowing surface waters in six UK peatland sites show that the CO_2 evasion rate per unit area of surface water (median 133, mean 367 µg C m^{-2} s^{-1}) is more than a magnitude higher than the CH_4 evasion rate (median 0.22, mean 1.45 µg C m^{-2} s^{-1}). Scaling to the whole catchment, using measurements of water surface area (0.07-0.41%) we show that the CO_2 evasion flux is a significant component of the aquatic C flux and regularly exceeds the downstream DOC flux, typically 10-25 g C m^{-2} yr^{-1} in most peatland catchments. We conclude that whilst the CO_2 evasion flux is highly variable and difficult to quantify at the catchment scale, it is a significant flux term in the carbon balance of many peatland landscapes, strongly controlled by hydrological extremes. Excluding aquatic CO_2 evasion from calculations of carbon balance may therefore lead to an overestimation of the sink strength of peatland systems.

KEY WORDS: Evasion, carbon dioxide, methane, dissolved organic carbon, flux

INTRODUCTION

Current interest in the carbon balance of northern peatlands and the potential for long-term changes to the various flux terms that make up the peatland carbon budget (principally NEE - net ecosystem exchange and aquatic C fluxes), have resulted in the publication of several complete year-on-year carbon balances from sites in Canada, Sweden and Scotland (Roulet et al., 2007: Nilsson et al., 2008; Dinsmore et al., 2010). A key area of uncertainty associated with the carbon balance of these systems is the magnitude of the evasion flux of CO_2 and CH_4 from surface waters. Evasion (degassing) of gaseous carbon occurs at the water surface-atmosphere interface as a result of inherently high concentrations of dissolved gases associated with turbulence within the stream system. On a global scale Cole et al. (2007) identified evasion as a major “unknown” carbon flux in the terrestrial environment.

Streams and rivers in peatland systems are consistently supersaturated with respect to CO_2 and CH_4 (Hope et al., 2001; Dinsmore and Billett, 2008; Wallin et al., 2011). Both gases are progressively lost down the aquatic pathway as surface water gas concentrations equilibrate with the lower concentrations in the atmosphere. Studies from the UK, N America and Sweden show that significant amounts of gas exchange occur across the air-water interface of peatland streams (Billett and Moore, 2008; Billett and Harvey, in review; Wallin et al., 2011). However, linking evasion fluxes to other flux terms in peat-dominated landscapes has up to now been hampered by a lack of measurements in small headwater streams. This has resulted in the use of estimated or modelled values of gas transfer coefficients or velocities in regional

upscaling (e.g. Teodoru et al., 2009). A recent exception to this has been the publication of 114 measurements of K_{CO2} (the gas transfer coefficient of CO_2) from the headwater regions of the Krycklan catchment in boreal Sweden (Wallin et al. 2011), which show that a combination of slope and stream width/depth can be used to predict K_{CO2}. This is clearly a step forward in understanding, but the question remains, what are the catchment scale fluxes and how do they compare with other important peatland carbon fluxes such as NEE and DOC export? Here we present a new set of 49 measurements of instantaneous CO_2 and CH_4 evasion fluxes from 6 UK peatland sites and compare them with the magnitude of other aquatic C flux terms.

MATERIAL AND METHODS

Between 2004-2006 a series of dual tracer injections using propane and NaCl were carried out on 12 stream reaches across 6 UK peatland sites (Fig. 1). The aim was to measure K_{CO2} and K_{CH4} and calculate instantaneous evasion fluxes on representative sections of peatland stream. These "vertical" aquatic carbon flux measurements were then compared to other "lateral" downstream fluxes of dissolved organic carbon (DOC), dissolved inorganic carbon (DIC), dissolved CO_2 and CH_4. The dual tracer method, which is regarded as the most appropriate way to measure gas transfer in small headwater streams, is described in more detail elsewhere (Hope et al., 2001; Wallin et al., 2011; Billett and Harvey, in review). To capture spatial and temporal variability measurements of instantaneous fluxes were carried out across various peatland sites, at different seasons and under a range of stream flow conditions.

Instantaneous downstream fluxes were calculated by multiplying concentration (mg L^{-1}) by discharge (L s^{-1}) and dividing by catchment area; instantaneous CO_2 and CH_4 fluxes were calculated by multiplying the instantaneous evasion rate from the study reach (µg C m^{-2} s^{-1}) by the catchment water surface area (m^2) and then dividing by the upstream catchment area. This allows both lateral (downstream) and vertical (evasion) fluxes to be compared.

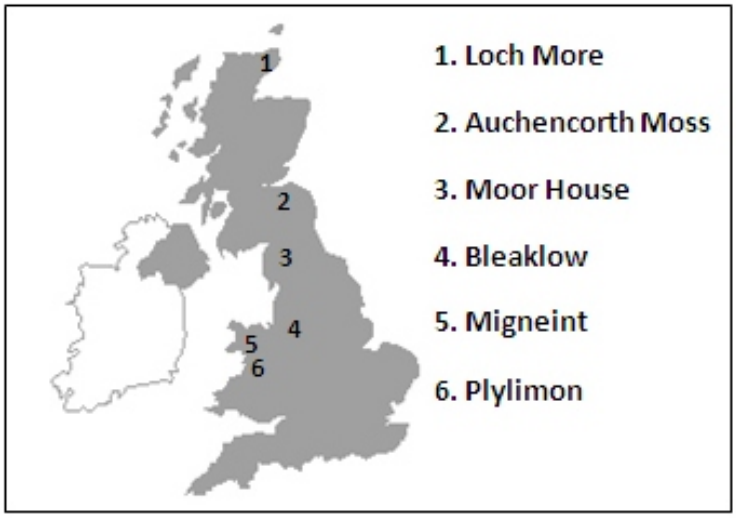

Fig. 1. Location of the 6 UK peatland areas used in the study.

RESULTS

The catchments range in size from 0.17-4.24 km^2 and altitude from 120 (lowest catchment outlet) to 750 m (highest stream source). Annual precipitation at the 6 sites was ca.1100-2700 mm and average air temperature 5-10^oC (Table 1). Mean water surface area in the catchments, calculated by multiplying the length of the upstream drainage water network (including all tributaries) by stream width, was 0.20% (range 0.07 to 0.41%). Discharge at the time the measurements were taken varied from 0.8 to 374.4 L s^{-1} reflecting a wide range of flow extremes (Table 1).

Table 1. Catchment and discharge characteristics of the study sites.

Peatland area	Stream name	Stream reach	No of flux measurements	Catchment area (km^2)	Water surface area (%)	Discharge range (L s^{-1})
Loch More	Achscoriclate Burn	LM10 LM11	2 3	3.81 4.24	0.17 0.20	1.3-30.0 0.8-332.2
Auchencorth Moss	Black Burn	A9 A10	4 4	2.36 3.35	0.09 0.10	1.8-68.6 3.3-93.0
Moor House	Cottage Hill Sike Rough Sike	CHS RS	10 7	0.17 0.83	0.31 0.41	1.9-188.3 6.0-113.8
Bleaklow	Doctor's Gate Clough	DG10 DG11	2 2	0.28 1.39	0.37 0.18	3.1-3.5 9.8-12.2
Migneint	Upper Conwy	C5 C6	4 4	0.68 1.24	0.07 0.10	6.6-150.8 3.1-374.4
Plynlimon	Upper Hafren	UH4 UH8	3 4	0.27 0.93	0.18 0.28	5.4-19.8 9.1-75.3

Mean concentrations (all mg L^{-1}) of the different aquatic C species were 14.1 (DOC), 3.8 (DIC), 1.43 (CO_2-C) and 0.01 (CH_4-C). Mean *ep*CO_2 was 6.0 (range 1.4 to 24.3); mean *ep*CH_4 193 (range -1 to 2600); *ep* represents excess partial pressure with respect to the atmosphere (e.g. *p*CO2 water/*p*CO_2 atmosphere).

The 2 most important flux terms were DOC and CO_2 evasion with the largest instantaneous fluxes occurring at higher flows (Fig. 2); this is particularly true for DOC. Fluxes of DOC tend to remain consistently low at a wide range of low and medium flows, whereas the instantaneous CO_2 evasion flux is much more variable at low-medium flows, suggesting that gaseous evasion is important under a larger range of stream flow conditions.

Table 2. Overall mean, standard deviation and median (n=49) instantaneous aquatic carbon flux values (mg C ha^{-1} s^{-1}).

Aquatic flux term	*Mean*	*SD*	*Median*
Downstream DOC flux	9.24	28.56	1.79
Downstream DIC flux	1.82	6.06	0.28
Downstream CO_2-C flux	0.72	1.68	0.20
Downstream CH_4-C flux	0.004	0.014	0.001
CO_2-C evasion flux	7.38	15.34	2.71
CH_4-C evasion flux	0.030	0.081	0.003

A comparison of the mean instantaneous DOC and CO_2 evasion flux rates at the 12 study sites (Fig. 3) demonstrated significant between-site variability in the relative importance of the 2 fluxes. At about half the sites CO_2 evasion was more important than the downstream DOC flux, whereas at the others the 2 fluxes were either similar or DOC more important.

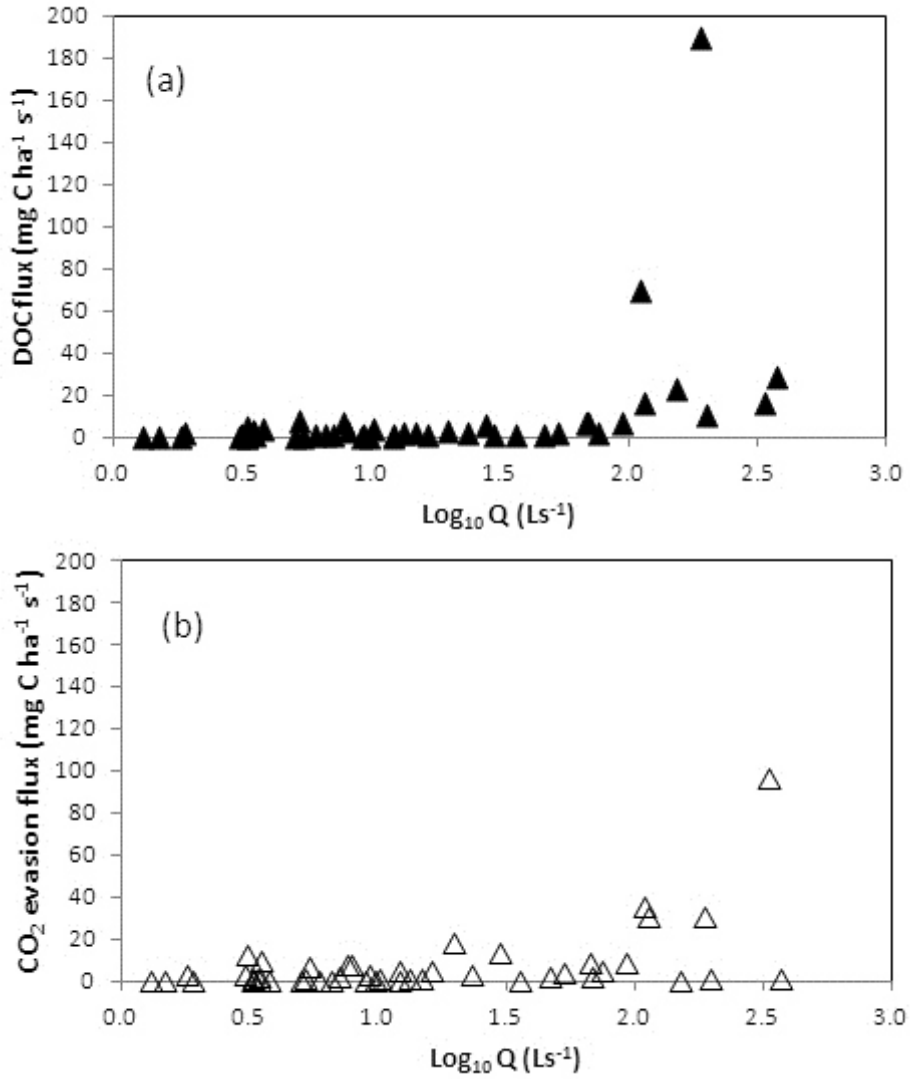

Fig. 2. Relationship between log discharge and (a) instantaneous DOC flux and (b) instantaneous CO_2 evasion rate.

Considering all the flux data from the 49 measurements collectively (Table 2) the highest mean instantaneous flux was DOC (9.24 mg C ha^{-1} s^{-1}) followed by CO_2 evasion (7.38 mg C ha^{-1} s^{-1}). These are equivalent to 29.1 and 23.3 g C m^{-2} yr^{-1} for DOC and evasion CO_2, respectively. The mean downstream fluxes of DIC and CO_2 (1.82 and 0.72 mg C ha^{-1} s^{-1}) were equivalent to 5.8 and 2.3 g C m^{-2} yr^{-1}. Both downstream and evasion CH_4 fluxes were minor compared to CO_2, irrespective of whether the comparison was based on C or CO_2 equivalents from published GWPs. Overall the mean evasion fluxes of CO_2 and CH_4 were about an order of magnitude higher than their downstream equivalent dissolved fluxes, demonstrating the importance of water surface-atmosphere transfer of carbon.

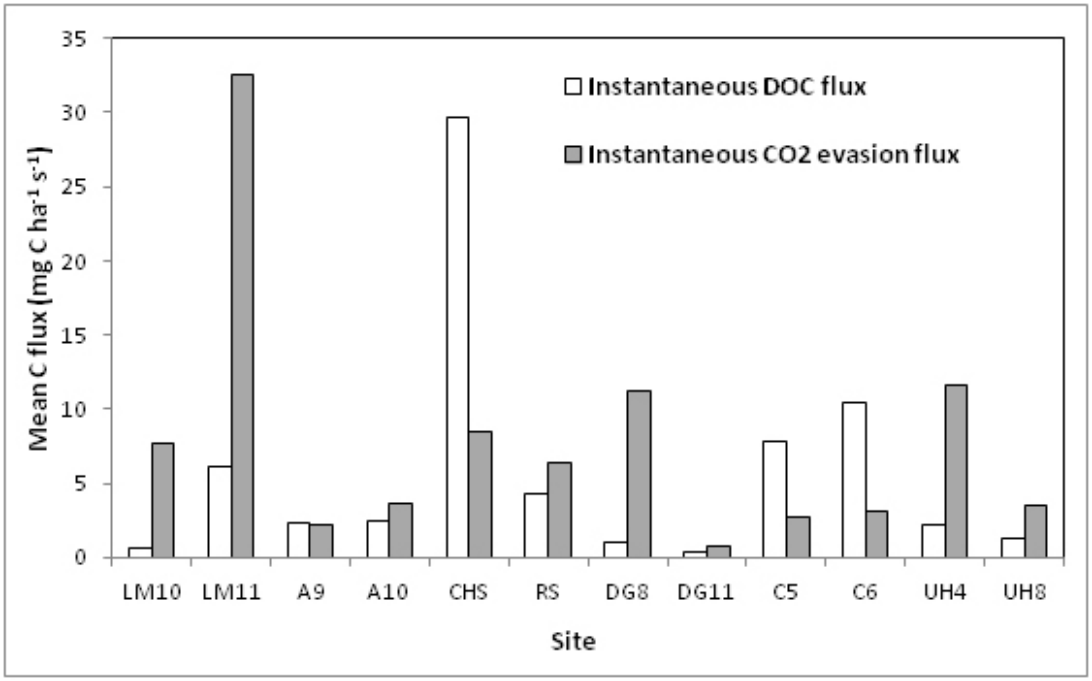

Fig.3. Mean instantaneous DOC and CO_2 evasion fluxes measured at the 12 stream reaches.

CONCLUSION

Our data shows that the CO_2 evasion flux is a major constituent of the carbon balance which in terms of magnitude is comparable to DOC fluxes in UK peatland streams. Although there are clearly dangers in upscaling instantaneous flux measurements to annual values, a DOC flux of 29.1 g C m^{-2} yr^{-1} is consistent with other values from peatland systems in the UK.

The data presented here is an important step in improving landscape scale estimates of the CO_2 evasion flux. More work is needed to better constrain the evasion flux; this will include using scaling approaches based on stream characteristics (e.g. Wallin et al. 2011). Water surface area within the catchment is a key parameter in the calculation of regional evasion fluxes; how it expands and contracts over time will have a significant short- and long-term effect on regional flux values. In addition, evasion varies spatially within drainage systems and this needs to be included in upscaled estimates. The high degree of variability in CO_2 evasion fluxes suggests that estimating specific values for individual headwater catchments is always going to be difficult. Arguably a better approach is to estimate regional fluxes using realistic K_{CO2} values linked to measured stream variables such as slope.

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