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ROLE OF HIGH-FLOW EXTREMES IN AQUATIC CARBON EXPORT FROM PEATLANDS

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SUMMARY

Peatland streams have repeatedly been shown to be highly supersaturated in gaseous carbon and export significant amounts of both dissolved (DOC) and particulate (POC) organic carbon. Export is strongly bias towards high flow events, which may become more frequent under predicted climate change scenarios. Here we bring together 2 separate analyses of the role of high-flow ‘extremes’ on (i) DOC export, and (ii) CO_2 export. Based on 30-day moving Q5 thresholds, we show that in the 5% of time with highest flows between 33-47% of DOC and 6-33% of CO_2 is lost. This demonstrates the disproportional impact of high flow events on C export from peatland aquatic systems.

KEY WORDS: Aquatic Carbon, Storm Flow, Export, DOC, CO_2

INTRODUCTION

Soils represent an important and dynamic store of global carbon which interacts with the atmospheric carbon pool either through direct soil-plant-atmosphere exchange, or transport to and subsequent loss from the surface drainage system. Peatlands alone represent over a third of the world’s total carbon store (Gorham, 1991) and therefore play an important role in regulating global atmospheric carbon. Whilst peatlands are currently considered to be sinks for atmospheric carbon, their biogeochemical functioning is strongly linked to hydrology making them highly sensitive to changes in temperature, precipitation and management practises such as drainage.

Recent studies (e.g. Dinsmore *et al*. 2010; Nilsson *et al.* 2008) highlight the importance of aquatic carbon export to catchment scale budgets with aquatic losses estimated as 41% and 34% of annual net CO_2-C uptake, respectively. Understanding the effect future climatic changes will have on export via the aquatic pathway is therefore essential if we are to accurately predict how peatland sink/source strength will change in the future. Current climate predictions suggest not only an increase in mean annual precipitation across northern regions, but an increase in precipitation extremes (IPCC, 2007). Previous studies have shown that annual aquatic carbon export is strongly bias towards high-flow events (e.g. Dinsmore and Billett, 2008, Dyson *et al.*, 2010). To fully understand the effects of changing precipitation patterns we first need to understand carbon export across the full hydrograph range.

Here we bring together 2 separate analyses of (i) the role of high-flow ‘extremes’ on DOC export based on long term (1993-2007) weekly spot samples across 7 UK upland streams, and (ii) stormflow CO_2 dynamics across 5 headwater streams (UK, Sweden, Finland and Canada) using continuous, in-situ CO_2 sensors. We aim to quantify the relative importance of the different components of flow (“flow sectors”) to total annual downstream carbon export across a range of catchment types (with varying proportions of peatland soils) and to understand how export is likely to change in response to future changes in precipitation pattern.

MATERIAL AND METHODS

DOC Analysis

We utilise 7 long-term datasets across 5 sites provided by the UK ‘Environmental Change Network’ (ECN) where continuous discharge and weekly DOC measurements have been made from 1994 to 2007 (see website for site map: http://www.ecn.ac.uk/). High flow ‘extreme’ classification is based on a moving 30-day Q5 threshold (flow equalled or exceeded 5% of time). Downstream DOC exports were calculated across a range of flow sectors using ‘Method 5’ (Walling & Webb, 1985) which utilises instantaneous concentration and discharge and incorporates average discharge from the continuous dataset.

CO_2 Analysis

For CO_2 we utilise 5 quasi-continuous datasets of CO_2 concentration measured using *in-situ* non-dispersive infra-red CO_2 transmitters (Johnson *et al*. 2010) with sites in Canada, Scotland, England, Sweden and Finland. Continuous discharge was also available at all sites. Flow thresholds are again based on 30-day moving Q5.

RESULTS AND DISCUSSION

DOC Analysis

Annual DOC loads across the study sites ranged from 2.10 g C m^{-2} yr^{-1} in RTB (rough grassland) to 28.0 g C m^{-2} yr^{-1} in RS (blanket peat). During ‘extreme’ high flow events which by definition made up 5% of time, 17.8- 40.6% of water was exported and 33.0-47.3% of the annual DOC load (Table 1). This highlights the relative importance of high-flow to total export.

If the export bias towards high flow was due to increased runoff alone the event runoff and DOC export percents would be the same. However, we see that in almost all cases the DOC export percent is higher than runoff suggesting the dominant event flow-paths are accessing greater source concentrations of DOC than flow-paths which dominate during low flow conditions (only exception is RS where runoff and DOC export in the event category are both 38.4%). When separated into season we find that the greatest difference between runoff and DOC export percent in the extreme flow classification occurred during summer (Spring 4%;

Summer 16%, Autumn 13%, Winter 7%). This suggests that the differences between source concentrations accessed during high and low flows are greatest in summer. Therefore an increase in summer extremes is likely to have a greater influence on annual export than an increase during other seasons.

Table 1. Summary of sites used in DOC analysis with high flow export and runoff contributions

Site	Catchment type	Annual DOC Load (g C m^{-2})	Extreme-event water runoff (%)	Extreme-event DOC export (%)
Birnie Burn (BB)	Semi-natural grassland	6.70 ± 1.76	29.9	46.5
Trout Beck (TB)	Blanket Peat	16.9 ± 3.60	38.4	40.3
Cottage Hill Sike (CHS)	Blanket Peat	24.3 ± 0.87	40.6	44.9
Rough Sike (RS)	Blanket Peat	28.0 ± 0.64	38.4	38.4
Rowantree Burn (RTB)	Course Grassland	2.10 ± 0.41	17.8	44.1
Alderhope Burn (AHB)	Course Grassland	2.56 ± 0.07	17.8	47.3
Nant Teryn (NT)	Acidic Grassland	6.10 ± 0.50	32.7	33.0

Plotting the percent of DOC export which is lost within each individual flow sector gives an indication of the flow proportions which are most important to total DOC export (Fig. 1a). If all flow sectors where equal we would expect catchments to follow the dashed 1:1 line; the point of greatest deviation from the 1:1 line therefore represents the discharge sector with greatest influence over export. Across all catchments, we see the greatest deviation between 10-30% discharge equalled or exceeded, again highlighting the importance of high flow. When percent of total export is plotted against percent of total runoff (Fig. 1b), we can separate how much of this high flow export bias is due simply to an increase in transport through runoff or a change in the source DOC concentration. DOC increase due to runoff alone should follow the 1:1 line. We see that the grassland sites deviate most from the 1:1 line, peatlands the least. This is likely to be due to the degree of DOC stratification within the soil profile. Peatlands have high DOC concentrations throughout their profile leading to typically high aquatic DOC concentrations and high exports, non-peatland sites are likely to have lower DOC concentrations overall and greater stratification with DOC concentrations highest in the surface organic horizon, hence they show the greatest sensitivity to changing flow-paths. Although non-peat sites have lower export rates overall (Table 1), they are more sensitive to extremes and may show the greatest potential for increased DOC export if high flow extremes become more common.

CO_2 Analysis

During high flow extremes (representing discharge equalled or exceeded 5% of time) between 5.79% and 32.9% of CO_2 was exported and 4.88% to 45.5% of total annual runoff (Table 2). Although more variable than high flow contributions to DOC export, there is again evidence of a high flow bias.

In the plot of percent CO_2 export against discharge sector (Fig. 3a) the points of greatest deviation from the 1:1 line and therefore the flow sectors with the greatest influence on annual exports were 30% in the 2 UK peatland sites (AM and CHS) and in MK, 50% in NY and 70% in HY. Therefore unlike the DOC analysis where catchments were similar, the relative importance of flow sectors across the 5 CO_2 catchments was highly variable. The

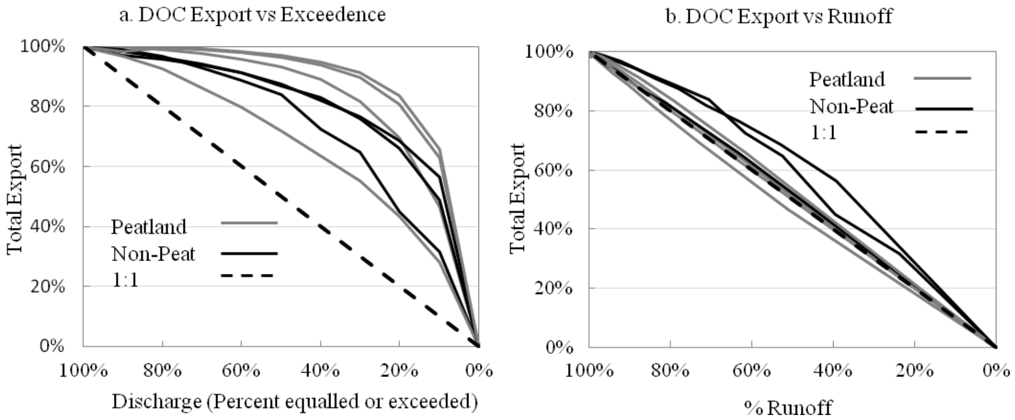

Fig. 1. a) Percent DOC export across flow sectors defined as percent of time discharge equalled or exceeded and b) percent DOC export against percent runoff export.

Table 2. Summary of sites used in CO_2 analysis with high flow export and runoff contributions.

Site	Catchment type	Mean CO_2 Concentration (mg C L^{-1})	Extreme-event water runoff (%)	Extreme-event CO_2 export (%)
Malcom Knapp Research Forest (MK)	Coastal Forest	1.47 ± 0.19	25.3	20.9
Auchencorth Moss (AM)	Blanket Peat	2.13 ± 0.17	19.8	14.3
Cottage Hill Sike (CHS)	Blanket Peat	3.05 ± 0.95	45.5	32.9
Nyänget (NY)	Boreal Forest/Mire	0.96 ± 0.94	15.7	17.8
Hyytiälä (HY)	Boreal Forest/Mire	0.73 ± 0.54	4.88	5.79

reasons for this are unclear. In contrast to the DOC analysis, the plot of percent export against percent runoff (Fig. 3b) showed most catchment responses lie on or below the 1:1 line suggesting CO_2 sources accessed during high flow periods contain lower concentrations than those accessed at low flow. The relative importance of high flows to CO_2 export is therefore primarily due to runoff.

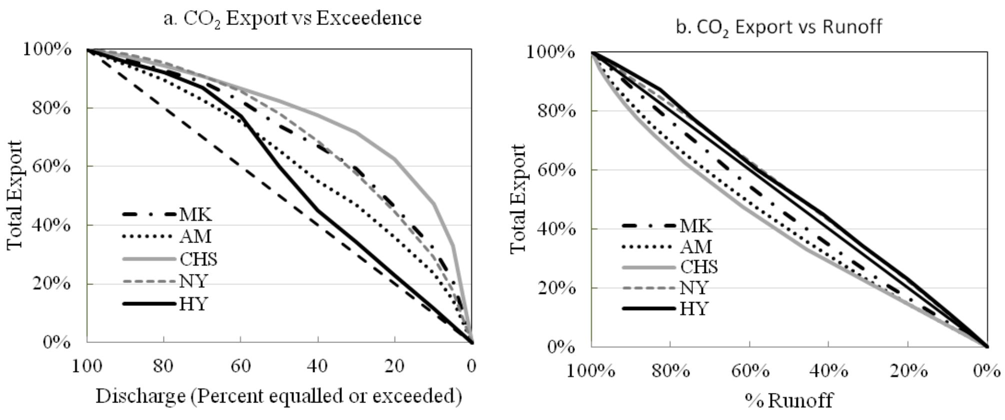

Fig. 2. a) Percent CO_2 export across flow sectors defined as percent of time discharge equalled or exceeded and b) percent CO_2 export against percent runoff export.

CONCLUSION

Periods of high flow are disproportionally important to total annual downstream carbon export across a range of catchment types. For CO_2 this is due almost entirely to the volume of runoff exported during high-flow periods and in some cases this is less than would be expected due to runoff volume alone. This suggests that catchment CO_2 sources accessed during high-flow are less than those accessed at low flow. Conversely, for DOC the volume exported is higher than expected due to runoff volume alone, particularly in non-peat catchments. This would suggest that although DOC export from peatlands is higher than non-peat catchments, they are likely to be less sensitive to changes in precipitation 'extremes'. For non-peats, although mean DOC export is low, the potential for increased export with increased flow extremes is greater; we suggest this is due to soil horizonation with the dominant flow-paths during high-flow accessing surface DOC-rich organic horizons. The flow sector most important for DOC export appeared to be between 10-30% equalled or exceeded, for CO_2 the important flow sectors were more variable ranging from 30-70%. Hence in some catchments, low flow is actually proportionally more important to downstream CO_2 export than high flow. Further work is needed to consider the catchment or hydrological parameters that explain these site-specific differences in flow sector export. Although our analysis is based on only 2 carbon species and we take no account of catchment source limitation or flushing, our results not only suggest a potential increase in aquatic carbon export under more extreme flow regimes, but that these increases are species specific and seasonally dependent.

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