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Land management as a factor controlling dissolved organic carbon release from upland peat soils 2: Changes in DOC productivity over four decades

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ABSTRACT

Increasing DOC concentrations in surface waters have been observed across parts of Europe and North America over the past few decades. Most proposed explanations for these widespread trends invoke climate change or reductions in sulphate deposition. However, these factors do not seem apposite to explain either the fine-scale (within kilometres) or regional-scale spatial variation in DOC concentrations observed across the UK.

We have reconstructed DOC concentrations and land use for one North Pennine and five South Pennine catchments (UK), located in three discrete areas, over the last four decades. Rainfall, temperature and sulphate deposition data, where available, were also collated and the potential influence of these factors on surface water DOC concentrations was assessed.

Four of the six catchments examined showed highly significant ($p<0.001$) increases (53–92%) in humic coloured DOC (hDOC) concentrations in drainage waters over the period 1990–2005. Changes in temperature and sulphate deposition may explain 20–30% of this trend in these four catchments. However, the rapid expansion of new moorland burn on blanket peat can explain a far greater degree (>80%) of the change in hDOC. Far smaller increases in hDOC (10–18%) were identified for the two remaining catchments. These two sites experienced similar changes in sulphur deposition and temperature to those that had seen largest increases in DOC, but contained little or no moorland burn management on blanket peat.

This study shows that regional-scale factors undoubtedly underlie some of the recent observed increases in drainage humic coloured DOC. However, changes in land management, in this case the extensive use of fire management on blanket peat, are a far more important driver of increased hDOC release from upland catchments in some parts of the UK. It suggests that the recent rapid increase in the use of burning on blanket peat moorland has implications for ecosystem services and carbon budgets.

1. Introduction

Increased concentrations of dissolved organic carbon (DOC) in surface waters are a widespread phenomenon having been reported in Canada (Bouchard, 1997), northern and eastern USA (Stoddard et al., 2003), the Czech Republic (Hejzlar et al., 2003), Norway (Hongve et al., 2004) and Finland (Vuorenmaa et al., 2006). Increases have been also noted in the UK (Freeman et al., 2001a), with mean DOC concentrations in rivers and lakes associated with upland catchments rising by 91% over the 15 year period to 2003 (Evans et al., 2005). Longer data series (e.g. Watts et al., 2001; Worrall et al., 2003) suggest that in the UK these are part of a trend detectable since at least the 1970s and represent real increases in carbon loss rather than a result of changes in discharge (e.g. Tranvik and Jansson, 2002) as both DOC concentration and flux have risen (e.g. Worrall et al., 2003; Yallop et al., 2010).

Organic soils are the predominant source of DOC in upland surface waters (Aitkenhead et al., 1999; Billett et al., 2006), primarily resulting from the decomposition of blanket peat (McDonald et al., 1991). There has been considerable debate over the last decade regarding factors that might underlie increased DOC release from these soils, with suggested mechanisms including: climatic change (Freeman et al., 2001a; Stoddard et al., 2003; Worrall et al., 2003; Evans et al., 2005) and associated increases in enchytraeid worm activity (Cole et al., 2002; Carrera et al., 2009); increasing atmospheric CO_2 (Freeman et al., 2004); hydrological change (Hongve et al., 2004; Evans et al., 2005); artificial peat drainage (Worrall et al., 2003); the occurrence of severe drought events (Watts et al., 2001; Worrall and Burt, 2004); and the removal of decomposition-inhibiting phenolic compounds following prolonged water table drawdown (Freeman et al., 2001b). Observations that DOC mobility is inversely related to mineral acidity (e.g. Krug and Frink, 1983) and ionic strength (e.g. Tipping and Hurley, 1988), and that production of SO_4^{2-} following oxidation of sulphur stored in peat during drought has been associated with reductions in interstitial DOC concentration (Clark et al., 2005), have prompted suggestions that

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recovery from acid deposition could lie behind the recent upward trends in DOC concentrations (e.g. Evans et al., 2005, 2006; Vuorenmaa et al., 2006; Monteith et al., 2007).

However, while changes in SO_4^{2-} and Cl^- deposition are highly correlated with DOC trends in north-eastern USA, Ontario/Quebec, Atlantic Canada, and Nordic regions, a statistical model based on changes in SO_4^{2-} and Cl^- could not account for the full magnitude of trend in the UK (Monteith et al., 2007). In addition, changes in regional-scale factors are not obvious drivers for the highly significant variation in DOC concentration found in waters draining adjacent blanket peat catchments (Yallop et al., 2008; Yallop and Clutterbuck, 2009), or the observation that of 315 catchments examined in the UK, 18% have shown significant decreases in DOC concentration over the last ten years (Worrall and Burt, 2007). While it has been suggested that the widespread nature of upward trends in DOC concentrations indicates that global and regional-scale phenomena are important (Evans et al., 2008), these observations in the UK suggest that more localised phenomena may also contribute to the increase in DOC release observed over the recent past (Worrall et al., 2003; Evans et al., 2005; Clark et al., 2010). Land use and management activities, which vary markedly over small distances and change over short time periods, are obvious potential candidates. Many areas of upland blanket peat, particularly in the English Pennines, were extensively drained in the 1960s and 1970s (Holden et al., 2004), and nine percent of UK upland peatlands are now forested (Cannell et al., 1993) following new planting programmes beginning in the 1970s (e.g. Farmer and Nisbet, 2004). However, there are contrasting views regarding the effects of such land management on DOC concentrations. While artificial drainage is suggested to affect water tables within only a few metres of the channel (Stewart and Lance, 1991), and in the short-term, blocking of drains was found to have no significant effect on concentrations in ditch water (Worrall et al., 2007b), Wallage et al. (2006) did identify lower interstitial and ditch water DOC concentrations for catchments where drains had been blocked. Compared to surrounding moorland, some forested peat catchments have shown increased concentrations of DOC in drainage (e.g. Grieve, 1990; Grieve and Marsden, 2001), although increases and decreases in DOC export have been noted from catchments in response to both afforestation and deforestation activities (see Hope et al., 1994 for review).

Controlled heather burning as a management tool for red grouse (*Lagopus lagopus*) husbandry has almost doubled in some areas of the English uplands since the 1970s, with some 114 km^2 of new burning now occurring annually (Yallop et al., 2006). The area of exposed blanket peat surface arising from this management has recently been identified as a highly significant driver of spatial variance in DOC concentration in drainage water from southern Pennine catchments (Yallop et al., 2008; Yallop and Clutterbuck, 2009). Although some studies have found no change (Ward et al., 2007) or lower DOC concentrations (Worrall et al., 2007a) in interstitial water under burns aged 10 yr old, Yallop and Clutterbuck (2009) identified that the most significant effects of burning on DOC concentration occur during the first 3–4 yr, when 70–80% of the peat surface remains exposed. The widespread usage, and rapid increase in application of controlled burning, could indicate a possible link to recent rises in DOC recorded in many parts of the UK where such land management practices have changed.

This study investigates the relationship between DOC concentrations in surface waters from upland peat catchments and changes in meteorological, atmospheric deposition and land use/management factors for six Pennine catchments over the last 40 yr.

2. Methods

2.1. Study areas

The catchment supplying Trout Beck, an upland stream in the North Pennine Moor House National Nature Reserve (NNR), and five reservoir catchments, grouped in two discrete areas of the South Pennines (Fig. 1), were selected as they are covered by a good archive of historical aerial imagery or extensive records of land use. The southern reservoir group comprises three adjacent catchments that supply Agden, Ewden (Broomhead) and Langsett water treatment works (WTW). The two catchments in the northern reservoir group are located less than 5 km apart and supply Sladen Valley (Lower Laithe) and Oldfield (Keighley Moor) WTW. DOC concentration or historical water colour data spanning at least ten years are available for each catchment. All catchments contain substantial cover (22–97%) of blanket peat, are characterised by blanket bog and upland heath habitat and exhibit well defined topography with no ambiguity as to the area collecting and supplying water to each reservoir/measured sample. The geology of Trout Beck catchment is comprised predominantly of Carboniferous Limestone Series, with some Millstone Grit Series at higher altitudes (up to 850 m above sea level (m.a.s.l.); BGS DiGMapGB data 1:625,000). All South Pennine catchments are underlain by the Millstone Grit Series, and range up to a maximum altitude of 550 m.a.s.l.

2.2. Reconstruction of historical DOC record

Since October 1992 stream water chemistry for Trout Beck has been routinely monitored by the Environmental Change Network (ECN). Monthly mean DOC concentrations (mg l^{-1}), derived from weekly samples, were obtained from the ECN database (http://www.ecn.ac.uk/Database) for the period Jan 1993–Dec 2005. At upland WTW, water utilities routinely assess water colour (mainly arising from humic compounds) as Hazen: the colour produced by 1 mg Pt l^{-1} (as K_2PtCl_6) in 2 mg l^{-1} Cobalt (II) chloride hexahydrate (Mitchell and McDonald, 1991/1992). Estimation of DOC concentration from Hazen has been used previously (e.g. Kerekes et al., 1986; Eatherall et al., 1998; Worrall et al., 2003), and this approach was adopted here for the South Pennine catchments. The relationship between DOC concentration and Hazen (1) was derived from regression of these two parameters determined in 181 water samples collected within the study catchments during 2005 (see Yallop and Clutterbuck, 2009).

$$\text{DOC concentration}\left(\text{mg l}^{-1}\right) = 0.044^{*}\ \text{Hazen} + 3.89\left(r^2 = 0.93, p<0.001\right) \tag{1}$$

Monthly mean colour as Hazen was calculated for each catchment for all years of data availability (1974 onwards), and subsequently converted to DOC using the previously mentioned function (1). For the period January 1979 to December 1989, colour data for Agden, Broomhead, Langsett and Keighley Moor catchments were recorded as UV absorbance (measured at 400 nm). Monthly mean absorbance values were firstly converted to Hazen using the relationship between absorbance and Hazen (2) determined for water sampled from Broomhead by Watts et al. (2001).

$$\text{Hazen} = 11.77^{*}\text{absorbance}_{400} \tag{2}$$

Prior to 1984 colour for Agden, Broomhead and Langsett catchments was determined in unfiltered water (apparent colour) and would therefore contain some particulate organic carbon (POC). To determine 'true' colour, correction for the particulate component was performed using the relationship between true and apparent absorbance (3) determined for water sampled from Broomhead by Watts et al. (2001), prior to determination of Hazen.

$$A_T = 1.06 + 0.63^{*}A_A \tag{3}$$

where A_T and A_A are true and apparent absorbance.

In addition to monthly colour data, estimates of annual mean Hazen for Agden, Broomhead and Langsett catchments (southern reservoir group) were produced for 1961–1976 by McDonald et al. (1991). These