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Vegetation management with fire modifies peatland soil thermal regime

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ABSTRACT

Vegetation removal with fire can alter the thermal regime of the land surface, leading to significant changes in biogeochemistry (e.g. carbon cycling) and soil hydrology. In the UK, large expanses of carbon-rich upland environments are managed to encourage increased abundance of red grouse (*Lagopus lagopus scotica*) by rotational burning of shrub vegetation. To date, though, there has not been any consideration of whether prescribed vegetation burning on peatlands modifies the thermal regime of the soil mass in the years after fire. In this study thermal regime was monitored across 12 burned peatland soil plots over an 18-month period, with the aim of (i) quantifying thermal dynamics between burned plots of different ages (from <2 to 15 + years post burning), and (ii) developing statistical models to determine the magnitude of thermal change caused by vegetation management. Compared to plots burned 15 + years previously, plots recently burned (<2–4 years) showed higher mean, maximum and range of soil temperatures, and lower minima. Statistical models (generalised least square regression) were developed to predict daily mean and maximum soil temperature in plots burned 15 + years prior to the study. These models were then applied to predict temperatures of plots burned 2, 4 and 7 years previously, with significant deviations from predicted temperatures illustrating the magnitude of burn management effects. Temperatures measured in soil plots burned <2 years previously showed significant statistical disturbances from model predictions, reaching +6.2 °C for daily mean temperatures and +19.6 °C for daily maxima. Soil temperatures in plots burnt 7 years previously were most similar to plots burned 15 + years ago indicating the potential for soil temperatures to recover as vegetation regrows. Our findings that prescribed peatland vegetation burning alters soil thermal regime should provide an impetus for further research to understand the consequences of thermal regime change for carbon processing and release, and hydrological processes, in these peatlands.

1. Introduction

Temperature plays an important role in soil ecosystem biogeochemistry by directly moderating rates of mineral weathering and soil water solution reactions (Brady and Weil, 2013), and indirectly by influencing the decomposition of organic matter (Davidson and Janssens, 2006; Grosse et al., 2011) and uptake of nutrients by soil dwelling flora and fauna (Allison et al., 2010; Conant et al., 2011; Melillo et al., 2002). Variations in soil thermal regime have been linked to changes in the abundance and diversity of soil microfauna (Allison and Treseder, 2011; Darby et al., 2011), seed germination and vegetation growth/production (Glinski and Lipiec, 1990), and nutrient uptake by plants (Dong et al., 2001; Pregitzer and King, 2005). Soil surface temperature can also influence latent heat fluxes and thus soil moisture (Kettridge et al., 2012), and is crucial for geomorphological processes such as freeze-thaw weathering (Holden, 2007). Soil temperature therefore plays a major role in global biogeochemical cycles, and so a clear understanding of the processes influencing soil thermal regime is a key requirement for ecosystem scientists and land managers to manage terrestrial environments effectively.

Fires are a common occurrence throughout the world, both naturally and for management purposes, in landscapes dominated by forest, grassland (e.g. prairie, moorland) and shrubs (e.g. chaparral, moorland) (Anderson, 1989; Yibarbuk et al., 2001), and in

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wetland and peatland environments in the UK (Ramchunder et al., 2013) and boreal North America, northern Europe and Siberia, and South-East Asia (Aksamit and Irving, 1984; Turetsky et al., 2011). Vegetation removal with fire can significantly alter the energy balance of the land surface by exposing underlying soils to more incoming solar radiation, altering long-wave radiation emission, and increasing exposure to wind thus changing latent heat fluxes. There are also likely to be changes in evapotranspiration which will influence soil moisture and thus specific heat capacity (Kettridge et al., 2012). Observational and modelling studies on soil temperature in some northern hemisphere peatlands have showed increases in temperature for the near-surface parts of the soil profile following wildfire (Harden et al., 2006; Kettridge et al., 2012). However, wildfires may exert more serious damage to peat soils than prescribed vegetation burning because they typically burn at far higher temperatures and often ignite the underlying peat in addition to the surface vegetation. Prescribed burns are utilised by land managers to control vegetation succession but no studies to date have considered their effects on soil temperature in the years after fire. Vegetation burning on UK peatlands has been associated with increased dissolved organic carbon (DOC) release to rivers in several studies with implications for potable water treatment (Holden et al., 2012), but the processes that underpin changes in soil C cycling and DOC release to rivers following fires are still poorly understood.

Peatlands cover around 4.4 million km^2 of the Earth's surface but they store a disproportionate amount of soil carbon (C); an estimated 500 ($\pm$100) Gt has accumulated since the Last Glacial which is equivalent to > 2/3 of the atmospheric store (Yu, 2012). These systems act as a long term C sink at a rate >5 Gt C per century (equivalent to 11 g C m^{-2} y^{-1}; Yu, 2012). In peatland soils, temperature is associated strongly with the carbon balance, and in particular, the production and oxidation of CH_4 which responds exponentially to increased temperature (Yvon-Durocher et al., 2014), the production of CO_2 (Lafleur et al., 2005; Moore et al., 1998) and the production and release of dissolved organic carbon (DOC) in pore waters (Freeman et al., 2001). Management changes to peatlands that lead to alterations in soil temperature can therefore be expected to have significant effects on the C balance of these systems.

Around 15% of the UK is covered with peat, with 87% of this being blanket peat (Baird et al., 2009). An estimated 3150 km^2 (18%) of UK peatlands have been subjected to prescribed burning (Worrall et al., 2010), although the use of this technique is regionally variable (Hester and Sydes, 1992; Yallop et al., 2006). Here, vegetation burning is undertaken mainly to improve production of red grouse (*Lagopus lagopus scotica*) populations but also to benefit grazing livestock and deer (Ramchunder et al., 2013) and occasionally for forest regeneration purposes (Hancock et al., 2005), and typically occurs in 10- to 20-year rotations. There have been several recent studies of prescribed burning effects on peatland vegetation, soil hydrology and soil solution chemistry (e.g. Clay et al., 2009; Worrall et al., 2007), and the evidence suggests that this management practice is altering fluvial C loads in upland peatland streams (Holden et al., 2012). To date, though, there has not been any consideration of how managed vegetation removal with fire and exposure of the underlying peat modifies the thermal regime of the soil mass in peatlands.

This study aimed to assess the role of prescribed vegetation burning on peat soil thermal regime at a series of intensively monitored locations in northern England. Specifically, thermal regimes were monitored across 12 burned peatland soil plots over an 18-month period to (i) quantify thermal dynamics between burned plots of different ages, and (ii) develop statistical models to determine the magnitude of thermal change caused by vegetation management. Soil thermal regimes were monitored in spatially independent soil plots spanning a period of <2 to >15 years since prescribed vegetation burning. Three hypotheses were tested: (H_1) upper soil-profile mean and maximum temperatures would be elevated in recently burned plots compared with areas of mature vegetation, but the effect would decrease as time since burning increased and vegetation cover regenerated; (H_2) upper soil-profile minimum temperatures would be lowest in recently burned plots compared with mature vegetation, which retain their 'insulating' canopy cover, and this combined with H_1 would mean a wider temperature range under recent burn plots; (H_3) enhanced soil surface maxima and minima in burned plots would be transmitted down into the soil at recently burned sites, but strong thermal attenuation would be evident with depth at all monitoring points.

2. Methods

2.1. Study area and field data collection

The study was undertaken in the southern Pennine hills of northern England between 28 March 2010 and 24 October 2011. The main study site was located in the Bull Clough catchment (53°28′24.8″N; 1°42′46.2″W) on Midhope Moor ~16 km SW of Barnsley, South Yorkshire. Much of the catchment is managed using prescribed burning of vegetation patches (typically ranging from 2500 to 5000 m^2) on a 20- to 25-year rotation, and it is considered to be a relatively typical peatland managed specifically for grouse. Soil plots in four age classes were studied: vegetation patches where burning took place <2 years prior to the beginning of the study (B2; recent burn), patches with burning 3–4 years prior to the study (B4; vegetation early growth phase), patches with burning 5–7 years prior to the study (B7; later growth phase) and patches that were burnt 15–25 years prior to the experiment (B15+; mature heather). Patch age was confirmed by the gamekeeper who knew when burning had taken place across the catchment. However, it was not possible to narrow down the age range of the patches that were burnt at some point between 15 and 25 years prior to sampling, although it is thought that most were last burnt around 20 years before our study.

For each age class (B2, B4, B7, B15+), three plots of approximately 400 m^2 were chosen with respect to the topographic index, ln(tanβ/α), where β is the slope and α is drainage length per unit contour width (Beven and Kirkby, 1979). The use of the topographic index allowed us to control for any possible slope position effects, which is important because Holden (2009) showed that slope position can control the proportion of flow through macropores in several soil types, and thus soil moisture movement which would serve to moderate thermal variability. Each burn age class had one plot in a low topographic index setting, one in a mid-topographic index setting and the other in a high topographic index setting. Effectively, this was equivalent to a top-, mid- and foot-slope position. The same topographic index values were determined for plots chosen for each treatment so that slope position effects were controlled and were equal between treatments. Therefore data were collected at twelve spatially independent soil plots in total (4 age classes $\times$ 3 slope positions).

Soil temperature was measured in each plot at four depths: surface layer (0–1 cm), 5 cm, 20 cm and 50 cm. Traditional meteorological station measurements that obtain soil temperature do so at the surface, 5, 10, 20, 50 and 100 cm. However, it was not possible to instrument at all of these depths due to cost constraints and so 10 cm and 100 cm were not included. The depths we sampled conform well to typical plant structure and rooting depths in peatlands for mosses, grasses/sedges and dwarf shrubs. Soil temperature was measured at the end of each 15 min time interval