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Sensitivity of peatland litter decomposition to changes in temperature and rainfall

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ABSTRACT

Changes to climate are projected over the next 50 years for many peatland areas. As decomposition of peat-forming vegetation is likely to be intrinsically linked to these changes in climate, a clear understanding of climate-peat dynamics is required. There is concern that increased temperature and decreased precipitation could increase the rate of decomposition and put the carbon sink status of many peatlands at risk, yet few studies have examined the impact of both climatic factors together. To better understand the sensitivity of peatland decomposition to changes in both temperature and precipitation and their interaction, we conducted a short-term laboratory experiment in which plant litters and peat soil were incubated, in isolation, in a factorial design. Treatments simulated baseline and projected climate averages derived from the latest UK climate change projections (UKCP09) for Exmoor, a climatically marginal peatland in SW England. Regular carbon dioxide flux measurements were made throughout the simulation, as well as total mass loss and total dissolved organic carbon (DOC) leached. The largest effect on carbon loss in this multifactor experiment was from substrate, with *Sphagnum*/peat releasing significantly less C in total during the experiment than dwarf shrubs/graminoids. Climate effects were substrate specific, with the drier rainfall treatment increasing the DOC leaching from *Calluna*, but decreasing it from *Sphagnum*. Partitioning between CO_2 and DOC was also affected by climate, but only for the peat and *Sphagnum* samples, where the future climate scenarios (warmer and drier) resulted in a greater proportion of C lost in gaseous form. These results suggest that indirect effects of climate through changes in species composition in peatlands could ultimately turn out to be more important for litter decomposition than direct effects of climate change from increased temperatures and decreased rainfall.

1. Introduction

Northern peatlands are an important carbon store, holding around one third of the global soil carbon stock (Gorham, 1991). For peatlands to accumulate organic matter, and thus sequester carbon from the atmosphere, the overall loss of carbon from the system through the combined decomposition of plant litter and peat must be lower than C input via litter production and vascular plant root exudation (Frolking et al., 2010; Limpens et al., 2008). Decomposition is the breakdown of organic matter. It can be due to one or a number of physical, chemical or biological processes. Carbon dioxide (CO_2), dissolved organic carbon (DOC), nutrients and stable hummus are among the principal final products of decomposition (Bragazza et al., 2009). Carbon is primarily lost as CO_2 in peatlands (Billett et al., 2010). However, additional losses in the form of methane (CH_4), produced during anaerobic decomposition, and DOC to aquatic systems can be an important component of the peatland carbon balance in some areas (Koehler et al., 2011). The speed and final product of the decomposition process is dependent on the chemistry of the organic matter, and the environment in which it decomposes (Limpens et al., 2008).

Understanding how peat and plant litter decomposition could be affected by climate change, specifically changes in temperature and rainfall, is key to an improved understanding of how the peatland carbon source/sink status could change during the 21st century.

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Northern peatlands are typically dominated by remains of mosses of the genus *Sphagnum*, a bryophyte (Turetsky, 2003). *Sphagnum* has played an important role in peatlands becoming such a large carbon sink. Not only does the recalcitrance of its litter mean that it keeps C in the system for longer, but the presence of *Sphagnum* maintains acidic, nutrient poor conditions which make it difficult for plants with more labile litter to establish themselves (van Breemen, 1995). Climate change may alter vegetation types in peatlands with vascular plants becoming more dominant (Buttler et al., 2015; Dieleman et al., 2015; Fenner et al., 2007; Weltzin et al., 2003). However, many ongoing catchment management programmes aim to encourage *Sphagnum* species over vascular plants as part of peatland restoration programmes (Grand-Clement et al., 2013).

While some authors have studied the effects of climate variables on the treatability of water from different peatland plant species (e.g. Ritson et al., 2014; Tang et al., 2013), little work has so far been conducted on the total flux of carbon and the partitioning between gaseous and fluvial losses from different peatland plant species. This partitioning is an important parameter to include in carbon cycle models, particularly for climate change modelling as there is likely to be a lag between DOC release from the soil and its incorporation into the atmospheric pool, as in-stream processing can lead to the temporary storage of C within the aquatic system (Hope et al., 1994). An understanding of partitioning of carbon losses between aquatic and gaseous fractions from different vegetation sources is also important for predicting whether catchment management programmes aimed at restoring certain species have the desired holistic effects of improving drinking water quality (including enhanced C sequestration) and do not result in environmental problem-shifting.

Decomposition of litters in the field is traditionally measured using the litter bag technique (Bragazza et al., 2009; Wieder and Lang, 1982). Litter of a known mass is enclosed in mesh bags with openings large enough for decomposers to access the food source, but small enough to prevent the physical loss of litters. Samples are incubated in the field, either on, or just below the soil surface (Johnson and Damman, 1991; Moore et al., 2007) and decomposition rate is quantified via mass loss or changing nutrient quotients of the litter (Keuskamp et al., 2013). In situ litter decomposition studies, using this technique, have suggested multiple drivers for increased decomposition rates in peatland systems including: elevated nutrient additions (Bubier et al., 2007), water-table drawdown (Straková et al., 2012), litter quality (Limpens and Berendse, 2003) and temperature (Moore et al., 2007). However, these field-based studies are limited to a single measure of decomposition; mass loss. Mass loss gives a valuable measure of net decomposition, which can be useful for comparing between litters, but does not provide information on the final product of the decomposition process. Carbon dioxide and DOC not only represent different flux pathways (gaseous versus aquatic), but can also be indicative of different processes and stages of decomposition. CO_2 is in effect representative of fully utilised carbon, whereas DOC could be stored in the peat column or utilised by microbes and exported to the atmosphere via respiration (Pastor et al., 2003; Turetsky, 2003).

Laboratory incubations of peatland litters to examine the relationship between decomposition and climate have been limited to date. Studies that have been conducted have tended to concentrate on a single measure of decomposition, have focussed solely on peat rather than vegetation, or have just looked at one environmental variable, such as temperature (e.g. Neff and Hooper, 2002; Moore et al., 2008) or water table (e.g. Freeman et al., 1993), in isolation. The effect of interactions between changes in temperature and rainfall on the decomposition of peatland litter is not currently well understood (Breeuwer et al., 2008). A gradient based mesocosm study measured increased C soil respiration in mesocosms transplanted to a warmer, drier location (Bragazza et al., 2016). However, isolating the effects of climatic variables such as temperature and rainfall from other confounding variables can be difficult in the field as these factors naturally co-vary. It is also difficult to separate the effects on different litters and measure the relative decomposition from different sources in the field or in intact mesocosms. To address this, previous studies have incubated soils or litters from wetland sites in isolation, notably Moore and Dalva (2001), Neff and Hooper (2002) and Wickland et al. (2007). This was the approach taken here.

A better understanding of the sensitivity of different peatland litters to changes in temperature and rainfall regime is needed to enable predictions of the impact of climate change on the stability of peatland carbon stocks, and to support better parameterisations of models that simulate past, current and future climate (Frolking et al., 2010; Smith et al., 2010). Therefore, the objectives of this research were as follows: (1) assess how litter decomposition rates varied between common ombrotrophic peatland plant species (*Calluna vulgaris*, *Molinia caerulea*, *Sphagnum* moss, and mixed litter) compared to peat; (2) determine the relative importance (or partitioning) of gaseous (i.e. CO_2) versus aquatic (DOC) fluxes during decomposition with respect to plant species and peat; (3) evaluate the importance of simulated temperature and rainfall changes on controlling total decomposition, C fluxes and partitioning between CO_2 and DOC. This final objective links to another study (Ritson et al., 2014), which used the same experimental treatments to examine the impact of climate change on the treatability (for potable water supply) of dissolved organic matter.

2. Methods

2.1. Field site and sample collection

In the south-west UK, blanket peat covers large parts of the upland areas and constitute an important store of C (Parry and Charman, 2013). These blanket peatlands represent the southern-most blanket peat in the UK and are considered climatically marginal (Clark et al., 2010). The shallow peat of Exmoor was heavily damaged by intensive drainage during the 19th and 20th centuries, and recent efforts have been made to restore large areas through a programme of ditch blocking (Grand-Clement et al., 2014, 2013). The field sites are dominated by *Molinia caerulea* (purple moor grass) (Gatis et al., 2015) and are classified as UK National Vegetation Classification M25: *Molinia caerulea-Polentilla erecta* mires (Rodwell, 1991). Paleoecological studies indicate that purple moor grass expansion corresponds with the industrial revolution and prior to this, *Sphagnum* was more dominant species within this region (Chambers et al., 1999). Exmoor typically receives precipitation of around 1800–2600 mm yr^{-1} with mean winter and summer temperatures of between 4.5–5.5 °C and 10–12 °C, respectively (Met Office, 2016). Exmoor receives a relatively high input of nutrients through atmospheric deposition, and the mean deposition of total nitrogen and oxidised sulphur for the period 2008–2012 was estimated to be 15.5–16.16 kg N h^{-1} yr^{-1} and 4.41–4.86 kg S h^{-1} yr^{-1}, respectively (DEFRA, 2015).

Samples of vegetation and peat were collected from two catchments, Aclands (51° 07′54.2″ N 3° 48′43.3″ W) and Spooners (51° 07′23.3″ N 3° 45′11.8″ W), within Exmoor National Park, UK, during July 2013. A further description of these field sites, including maps, can be found in Grand-Clement et al. (2014) and Luscombe et al. (2015). Five different substrates were collected: *Calluna*, *Molina* and *Sphagnum*, mixed litter and peat. Fresh leaves and branches were collected from *Calluna vulgaris* and *Molinia caerulea*, avoiding any plants which had been partially eaten by herbivores. Mixed litter (predominantly *Molinia caerulea* but also some *Eriphorum vaginatum*, both at the early stages of decomposition) was collected from the bog surface. Intact *Sphagnum* spp. sods (entire plants) were collected from the centre of stands and peat was collected from the top ca. 30 cm of the soil profile using a screw auger. The samples were transported back to the laboratory in cool boxes within 8 h of collection, and stored at 4 °C prior to their preparation. Sample collection is described fully in Ritson et al. (2014).