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Regional variation in the biogeochemical and physical characteristics of natural peatland pools

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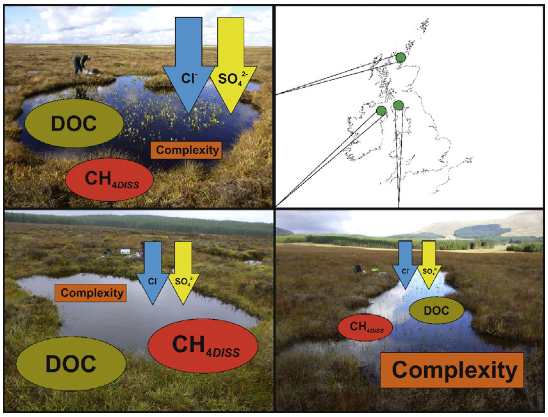
HIGHLIGHTS

- 66 peatland pools were studied across 3 UK regions.
- Between-region variability in pool biogeochemistry was high.
- Proximity to the marine environment is an important factor.
- Pool water DOC, POC and CH_4 concentrations varied significantly by region.
- GHG concentrations were related to DOC composition, pool morphology and vegetation.

GRAPHICAL ABSTRACT



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ABSTRACT

Natural open-water pools are a common feature of northern peatlands and are known to be an important source of atmospheric methane (CH_4). Pool environmental variables, particularly water chemistry, vegetation community and physical characteristics, have the potential to exert strong controls on carbon cycling in pools. A total of 66 peatland pools were studied across three regions of the UK (northern Scotland, south-west Scotland, and Northern Ireland). We found that within-region variability of pool water chemistry was low; however, for many pool variables measured there were significant differences between regions. PCA analysis showed that pools in SW Scotland were strongly associated with greater vegetative cover and shallower water depth which is likely to increase dissolved organic carbon (DOC) mineralisation rates, whereas pools in N Scotland were more open and deeper. Pool water DOC, particulate organic carbon and dissolved CH_4 concentrations were significantly different between regions. Pools in Northern Ireland had the highest concentrations of DOC (mean = 14.5 mg L^{-1}) and CH_4 (mean = 20.6 μg C L^{-1}). Chloride and sulphate concentrations were significantly higher in the pools in N Scotland (mean values 26.3 and 2.40 mg L^{-1}, respectively) than elsewhere, due to a stronger marine influence. The ratio of UV absorbance at 465 nm to absorbance at 665 nm for pools in Northern Ireland indicated that DOC was sourced from poorly humified peat, potentially increasing the bioavailability and mineralisation of organic carbon in pools compared to the pools elsewhere. This study, which specifically aims to address a lack of basic biogeochemical knowledge about pool water chemistry, clearly shows that peatland pools

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are highly regionally variable. This is likely to be a reflection of significant regional-scale differences in peatland C cycling.

1. Introduction

Peatlands play a major role in moderating atmospheric CO_2 concentrations through their ability to sequester carbon, with northern peatlands alone storing an estimated 500–600 gigatonnes of carbon (Yu, 2012). Open-water pools are a common feature of many peatlands and have been reported on every continent except Antarctica (Glaser, 1998). They are prevalent in temperate and boreal peatlands of the northern hemisphere, often forming extensive complexes where their area may equal or exceed that of the intervening terrestrial area (Bragg and Tallis, 2001; Connolly et al., 2014). Pool areas are also rapidly expanding in a warming Arctic (Jorgenson et al., 2001; Vonk et al., 2015; Walter et al., 2007), and they are becoming a more commonplace feature in peatlands undergoing restoration as drains are blocked (Parry et al., 2014). Pools have previously been shown to be sources of CO_2 to the atmosphere and, particularly, hotspots of methane (CH_4) emission, a highly potent greenhouse gas (GHG) (Hamilton et al., 1994; Pelletier et al., 2014; Waddington and Roulet, 1996). Thus, they play an important role in global radiative forcing (Abnizova et al., 2012). The degree to which pools are hotspots of CH_4 may be affected by their physical and chemical properties, but little is known about how such properties vary within and between peatlands.

There are a number of theories on peatland pool formation, but their presence is highly dependent on a combination of factors, including geology, topography, hydrology and climate (Belyea, 2007; Belyea and Lancaster, 2002; Comas et al., 2011; Couwenberg and Joosten, 2005). Pools in bogs (ombrotrophic peatlands) are characterised by low pH, low primary productivity and generally low macrophyte diversity (Lindsay, 1995). Bog water and nutrient sources are dominated by atmospheric deposition, being isolated from mineral groundwater sources. Therefore, bog pool water chemistry may not vary much spatially, except when driven by regional variation in precipitation chemistry. For example, remote bog pool systems located within the range of sea spray-derived deposition (e.g. Coastal British Colombia, western UK, Falkland Islands) have anion concentrations close to that of sea water (Gorham and Cragg, 1960; Proctor, 1992; Vitt et al., 1990), whereas sulphate concentrations in bog pools within the atmospheric influence of heavy industry have been reported as being many times higher than those in more remote areas (Gorham, 1956; Proctor, 1992). However, it is not clear whether peatland pool water chemistry may also be related to variability in other factors such as pool size or vegetation cover. Belyea and Lancaster (2002) have shown that although pools vary in size (<10 m^2 to >1000 m^2) they have consistent size-shape relationships, with an increase in size over time associated with more elongate and convoluted pool shapes. This suggests that pool size could be used as a proxy for pool age or maturity, which may be an important factor in pool biochemical processes such as productivity.

Previous data on pool water chemistry have usually been reported within the context of another research focus, primarily during studies of peatland vegetation and associated physical and chemical gradients, for example in Japan (Haraguchi and Matsui, 1990), Canada (Vitt and Bayley, 1984; Vitt et al., 1990) and the UK (Pearsall, 1956). Other studies have focussed on chemical variability within the same site or region (e.g. Gorham, 1956; Hannigan and Kelly-Quinn, 2014; Kilroy et al., 2008). Some of the older studies may be outdated due to changing trends in atmospheric deposition over recent decades (Waldner et al., 2014). The widest study to date, in geographical terms, reports water chemistry from 39, mainly ombrogenous, sites across Britain and Ireland (Proctor, 1992). Although the author explored spatial variability and the study covered a relatively large geographical spread, no within-site replication was conducted, and carbon concentrations were not analysed. Therefore, it is unclear how variable bog pool water chemistry is and whether any variation could have implications for carbon cycling in ombrotrophic peatlands.

Pools may act as recipients for dissolved and particulate organic carbon (DOC and POC) in water which flows either through or over the surrounding peat into the pools. The source and, therefore, the composition of these compounds affect how they are mineralised both microbially and photochemically, with rates of mineralisation, in turn, affecting rates of CO_2 and CH_4 emissions from bog pools (Cory et al., 2007; Cory et al., 2014; Köhler et al., 2002). Although a limited number of studies have reported the DOC concentrations and DOC composition in peatland/wetland pools (e.g. Bendell-Young, 2003; Billett and Moore, 2008; Hamilton et al., 1994; Hannigan and Kelly-Quinn, 2014; Pelletier et al., 2014), how these factors vary spatially has not been reported.

The mechanisms of CH_4 release to the atmosphere from water bodies are diffusion, ebullition, and plant-mediated transport, and pool vegetation is likely to play a significant role in pool C cycling. Plants containing aerenchymous tissue (e.g. *Eriophorum angustifolium*, *Menyanthes trifoliata*) are common in pools and transport CH_4 directly to the atmosphere (Bridgham et al., 2013), bypassing the zone of potential oxidation. Conversely, bryophytes such as the Sphagna, which can occur as floating mats on peatlands pools, have a mutualistic relationship with CH_4-oxidising bacteria (Putkinen et al., 2014) and may inhibit CH_4 emissions. Surface vegetation also alters the physical characteristics of the air–water interface, changing surface turbulence and open water area and hence influencing the net gas exchange rate. The influence of vegetation on emissions is likely to be strongly seasonal, and related to water depth, with deeper pools less able to support rooting plants. Bog pools are commonly quite shallow (<1 m deep) (e.g. Abnizova et al., 2012; Belyea and Lancaster, 2002; McEnroe et al., 2009) but have been reported at up to 2 m depth (Pelletier et al., 2014). Belyea and Lancaster (2002) also found that pools often have asymmetric depth profiles, with over-deepening, or ‘trench development’ on the down-slope margin. The presence of alternative electron acceptors (e.g. nitrate, sulphate) in pool waters may also have a strong influence on the production and oxidation of CO_2 and CH_4 (Bridgham et al., 2013; Deutzmann and Schink, 2011; Smemo and Yavitt, 2011).

While it is evident there has been some biogeochemical research on peatland bog pools, this has not been conducted systematically over large regions, and thus spatial variability of pool chemistry is poorly understood. Our study is a first step in addressing this research gap. We analysed a range of chemical variables, including dissolved carbon and GHG concentrations, pool depth and vegetation cover from 66 natural bog pools at six sites across north and southwest Scotland, and Northern Ireland (latitudinal range 55° 00′–58° 23′ N). This represents the first analysis of both inter- and intra-site spatial heterogeneity in peatland pool systems of this magnitude. We hypothesise that the chemical composition of bog pools varies spatially, and that relationships exist between pool chemistry, physical parameters, and vegetation cover.

2. Methods

2.1. Study sites

Natural pools ($n = 66$) were sampled at six peatland sites under the same temperate maritime climatic influence (Fig. 1, Table 1). The sites were selected to cover a wide geographical area within the distribution range of natural bog pools in the UK. All the pool complexes occupy a