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Small-scale variability in peatland pore-water biogeochemistry, Hudson Bay Lowland, Canada

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HIGHLIGHTS

- Peatlands of Hudson Bay Lowland exhibit small-scale variability in vegetation microtopography.
- High resolution sampling of surface pore-water revealed considerable geochemical variability.
- Microtopography in bogs was closely associated with differences to some geochemistry.
- Accurate geochemical estimates require a large sample size from consistent microtopographic forms.
- Variability has implications in long-term environmental monitoring and disturbance assessments.

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ABSTRACT

The Hudson Bay Lowland (HBL) of northern Ontario, Manitoba and Quebec, Canada is the second largest contiguous peatland complex in the world, currently containing more than half of Canada's soil carbon. Recent concerns about the ecohydrological impacts to these large northern peatlands resulting from climate change and resource extraction have catalyzed a resurgence in scientific research into this ecologically important region. However, the sheer size, heterogeneity and elaborate landscape arrangements of this ecosystem raise important questions concerning representative sampling of environmental media for chemical or physical characterization. To begin to quantify such variability, this study assessed the small-scale spatial (1 m) and short temporal (21 day) variability of surface pore-water biogeochemistry (pH, dissolved organic carbon, and major ions) in a *Sphagnum* spp.-dominated, ombrotrophic raised bog, and a *Carex* spp.-dominated intermediate fen in the HBL. In general, pore-water pH and concentrations of dissolved solutes were similar to previously reported literature values from this region. However, systematic sampling revealed consistent statistically significant differences in pore-water chemistries between the bog and fen peatland types, and large within-site spatiotemporal variability. We found that microtopography in the bog was associated with consistent differences in most biogeochemical variables. Temporal changes in dissolved solute chemistry, particularly base cations (Na^+, Ca^{2+} and Mg^{2+}), were statistically significant in the intermediate fen, likely a result of a dynamic connection between surficial waters and mineral-rich deep groundwater. In both the bog and fen, concentrations of SO_4^{2-} showed considerable spatial variability, and a significant decrease in concentrations over the study period. The observed variability in peatland pore-water biogeochemistry over such small spatial and temporal scales suggests that under-sampling in northern peatland environments could lead to erroneous conclusions concerning the abundance and distribution of natural elements and pollutants alike.

1. Introduction

Peatlands are wetland ecosystems that sequester large volumes of organic carbon and play a key role in the global carbon cycle (Gorham, 1991), modify the water quality in downstream aquatic ecosystems, and are important habitats for various species (Wieder and Vitt, 2007). Globally, peatlands cover an area of about 4×10^6 km^2 (~3% of the Earth's land surface), with most peatlands occurring in the boreal and subarctic regions (Gorham, 1991). In Canada, 12% of the country's

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total land area is composed of an elaborate mosaic of bogs (67%), fens (32%), and swamps/marshes (1%) (Tarnocai, 2006). Most of Canada's peatlands are located in northern Ontario and Manitoba in the Hudson Bay Lowland (HBL; Fig. 1), the second largest contiguous peatland complex in the world where approximately 147 Gt (56%) of Canada's terrestrial soil carbon is sequestered in an expanse covering 320,000 km^2 *ibidem* (*Ibid.*).

The vast majority of the HBL is covered by a layer of peat, ranging from 0 to ~3 m, and is generally underlain by low conductivity, fine-grained sediments derived of calcite and dolomite from the Paleozoic era (McDonald, 1969; Riley, 2011). Peatland formation is predominantly driven by an interplay of isostatic uplift, climate, and hydrology, beginning with a basal tidal marsh and then rapidly developing into a *Larix*-dominated swamp, *Picea*-forested bog and finally a non-forested bog (Glaser et al., 2004). Bioherms, sedimentary outcrops of karst limestone from the Tyrell Sea, are one of the only upland features in this largely flat terrain, where topographic gradients are very low (typically 0.57 m km^{-1} towards Hudson Bay) (McDonald, 1969). Sporadically discontinuous permafrost, including palsas (elevated regions of peat with a permafrost core), can be found throughout the landscape.

Forecasted changes in temperature and precipitation in Canada's north are expected to decrease total available soil moisture in northern peatlands, affecting their hydrology and biogeochemical cycles, particularly carbon (IPCC, 2007). In addition to climate change, other natural and anthropogenic disturbances (e.g., forest fires, peat harvesting, peatland dewatering, and resource extraction) may superimpose further impacts on peatland hydrology and biogeochemistry. The collection of baseline hydrological and biogeochemical data is therefore essential for detecting environmental change and impacts to biogeochemical processes in the landscape. Moreover, unquantified spatial and temporal variability of pore-water chemistry may lead to difficulties in proper classification, or even misclassification, of peatlands, as water chemistry (e.g., pH) is often used as a classification metric (Bridgham et al., 1996).

Peatland pore-water quality is controlled by many factors, including precipitation chemistry, groundwater chemistry, plant root uptake/release, litter inputs and decomposition, cation exchange mechanisms, and microbial decomposition and mineralization (Vitt et al., 1995). Variations in processes such as these are likely to occur at scales as small as individual peatland microtopographic features (hummocks, hollows, and lawns). Such microtopography can have a profound influence on methane production, oxidation, and emission (Mikkela et al., 1995; Waddington and Roulet, 1996). Branfireun (2004) suggested that peatland microtopography influences sulfate reduction and mercury methylation, based on observed differences in solute chemistry profiles among hummocks, lawns and hollows in surface pore-waters.

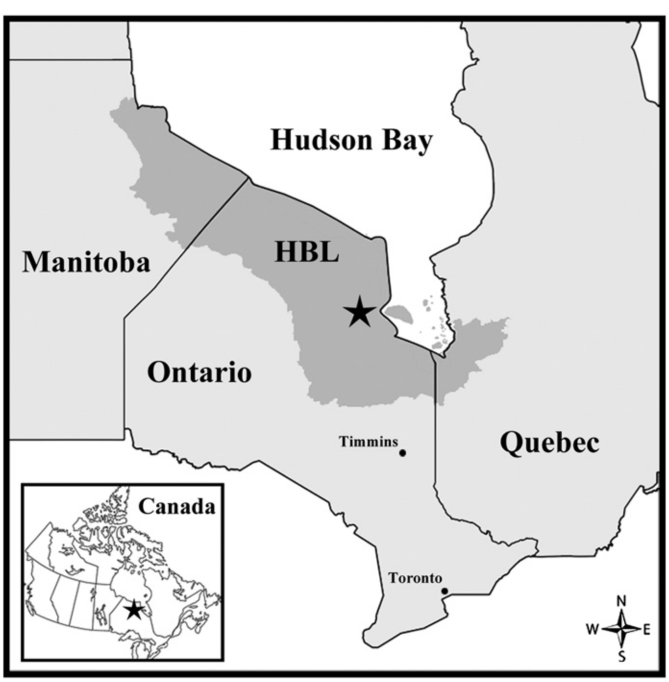

Fig. 1. Location of the study site (shown by star) within the Hudson Bay Lowland (HBL) (dark shading) in Ontario, Canada, approximately 500 km north of Timmins and 90 km west of Attawapiskat, near the Attawapiskat River.

The pattern of this variability may be predictably driven by chemical reactions and transformations, however these processes vary over space and time. Areas and times of disproportionally high reaction rates relative to the surrounding environment have been described as hot spots, and hot moments, respectively (McClain et al., 2003) and are governed primarily by the convergence of hydrological flow paths and the availability of substrates and terminal electron acceptors. Such elevated biogeochemical reaction rates can lead to broad spatiotemporal variability that can impact studies where limited samples are obtained, however studies on hot spots and hot moments are quite limited in peatlands (see Mitchell and Branfireun, 2005; Mitchell et al., 2008).

Those factors which contribute to peatland pore-water variability are multiplied in large peatland complexes such as the HBL, which are highly heterogeneous at a range of nested spatial scales from the local, within-peatland microform, to intermediate/regional-scale gradients in peatland type and permafrost extent. Such enhanced heterogeneity can directly influence the chemistry of peatland surface and groundwaters, particularly shallow peat pore-waters. For example, a fluctuating water table near the peat surface can have a large influence on biogeochemical spatiotemporal variability, as it is susceptible to variations in temperature, redox conditions, infiltration and nutrient loading (e.g., Moore and Knowles, 1989; Moore and Dalva, 1993; Moore and Roulet, 1993; Silvola et al., 1996; Bellisario et al., 1999). The assessment of the spatial and temporal variability of geochemical parameters in peatland pore-waters, particularly at the local sampling scale, is important, however to the best of our knowledge no studies have been undertaken that have quantified the small-scale variability of dissolved pore-water chemistry in northern peatlands. In support of broader research initiatives on the hydrology and biogeochemistry of extensive peatland complexes, the purpose of this study is to examine the implications of sampling frequency in both space and time for sampling pore-water in two dominant peatland classes in the Hudson Bay Lowland, Ontario, Canada. The objectives of this study are to *(i)* quantify the small scale spatial variability of pore-water chemistry in a forested ombrotrophic bog and an open intermediate fen in the Hudson Bay Lowland, *(ii)* measure short-term changes to pore-water chemistry within each peatland type, and *(iii)* evaluate the effects of microtopography on chemistry and patterns of spatial distribution of dissolved solutes.

2. Study site

This study site is located in the HBL, approximately 90 km from the west coast of James Bay near the Attawapiskat River (52.821° N, −83.884° W; Fig. 1). The HBL is characterized as a low-subarctic region with short, warm summers and long, cold winters (National Wetlands Working Group, 1997). The mean daily temperatures are −22.3 °C and 17.2 °C in January and July, respectively. On average, the region experiences 153 days with a minimum air temperature that is greater than freezing (0 °C). The mean annual rainfall at Lansdowne House (the nearest long-term meteorological monitoring station, 250 km southwest of the study site) between 1971 and 2000 is approximately 700 mm, with about 34% falling as snow (Environment Canada, 2011). More than 75% of the rainfall falls between June and September, the peak growing season. For the duration of this study (July 22 to August 10, 2009), the site received 47 mm of total rainfall.