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Impact of rainfall regime on methane flux from a cool temperate fen depends on vegetation cover

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ABSTRACT

Climate change projections forecast an intensification of the precipitation regime for many regions of the globe, including central North America, with fewer, larger events interspersed between longer periods devoid of rain or snow. This shift has the potential to affect the carbon cycling of peatland ecosystems, including the flux of methane from the peat. We conducted a field manipulation experiment where irrigation treatments were used to simulate different seasonal rainfall regimes. The treatments were designed such that total seasonal rainfall was held constant but discrete event frequency and magnitude were altered between treatments in a poor fen in southern Ontario, Canada. The rainfall regime was controlled over three vegetation types: *Sphagnum capillifolium* (moss); *Carex oligoperma* (sedge); and *Chamaedaphne calyculata* (shrub). Decreasing rainfall frequency from thrice-weekly to bi-monthly [coupled with 6X increase in event intensity] led to significantly greater CH_4 flux from the moss and sedge communities in the latter third of the growing season. The shrub communities were unaffected by the changing rainfall regime. A companion lab mesocosm experiment revealed the control the fluctuating water table had on the CH_4 fluxes from the vegetation community, particularly from the moss communities. Overall, there were significantly greater CH_4 fluxes from all communities with increasing days since the previous rainfall event. As precipitation frequency decreases results of this study demonstrate the potential for increased CH_4 flux to the atmosphere from peatland areas dominated by *Sphagnum* and herbaceous species. Wetland restoration and creation projects should consider these effects on peatland carbon cycling and function.

1. Introduction

Peatlands store 1/3rd of global terrestrial carbon yet cover only 3% of the earth's land surface (Limpens et al., 2008). This disproportionate importance to the global carbon cycle is due to water-logged surface soils maintaining anoxic conditions lowering rates of decomposition relative to gross primary production (Dise et al., 1993; Moore et al., 1994). The presence of high water tables and anoxic conditions also lead to high rates of carbon export in the form of dissolved organic carbon (DOC) (Waddington and Roulet, 1997; Blodau et al., 2004;) and in particular gaseous methane (CH_4) (Roulet et al., 1992; Bridgham et al., 2013). CH_4 is a more powerful greenhouse gas than carbon dioxide (CO_2); therefore, high CH4 emissions significantly contribute to the climate warming potential of peatlands. Rising air temperatures increase peatland evapotranspiration, potentially lowering the water table, which will lead to increased aerobic respiration and CO_2 flux to the atmosphere (Tarnocai, 2009). On the other hand the climate-induced lowering of the water table will also limit CH_4 production and efflux (Roulet et al., 1992; Strack and Waddington, 2007). While the response of peatland CH_4 emissions to changing temperatures (Christensen et al., 2003; Tarnocai, 2006; Turetsky et al., 2008) and water tables (Nykanen et al., 1995; Whalen, 2005; Moore et al., 2011) have been the focus of much research considerably less information is known about the impact on CH_4 fluxes due to changing temporal patterns of rainfall as a consequence of climate change.

Climate change projections for temperate and boreal North America and Eurasia predict larger but less frequent precipitation events (IPCC, 2013; Sillmann et al., 2013). Increased temperatures lead to higher evapotranspiration rates and atmospheric moisture content, increasing the intensity of precipitation events and the duration between events (Emori and Brown, 2005; Seneviratne et al., 2012). With a shift in precipitation regime to fewer events of greater intensity soil water dynamics are predicted to become more variable (Knapp et al., 2008). Research on the effects of pre-

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cipitation on methane fluxes is limited to changes in total rainfall amount. Field studies have noted that drier seasons have led to decreased emissions, while particularly wet seasons have increased methane efflux in peatlands (Bubier et al., 2005; Olson et al., 2013; Yang et al., 2014). This is likely due to corresponding changes in the water table. However, studies that have looked at CH_4 flux under low water table position have found that rainfall events led to increases in CH_4 efflux due to the degassing of sub-surface peat (Kettunen et al., 1996; Shoemaker et al., 2012). Other studies (Romanowicz et al., 1993; Glaser et al., 2004) have found that long periods of no precipitation on to peatlands resulted in significant increases of CH_4 efflux due to depressurizing of sub-surface peat. These studies suggest that longer rainless periods interspersed with large events could lead to increased CH_4 emissions in peatlands, but this question remains to be explored.

The role of precipitation on peatland carbon dynamics has most often been explored from an annual or seasonal perspective (Alm et al., 1999; Laiho et al., 2003; Fenner and Freeman, 2011). Bragazza et al. (2016) found that lowered annual precipitation leads to lower carbon accumulation rates in peatlands. However, Waddington and Roulet (2000) suggest the variability of precipitation events may exert a stronger control than total seasonal amounts on peatland carbon. Small (<1 mm) precipitation inputs have been shown to increase *Sphagnum* productivity in peatlands (Strack and Price, 2009; Adkinson and Humphreys, 2011). In a controlled mesocosm experiment, Nijp et al. (2014) found that decreasing the frequency of rainfall events over *Sphagnum* led to greater CO_2 emissions despite all mesocosms receiving the same total rainfall amounts. Despite the apparent importance of short-term droughts, small precipitation inputs, and rainfall timing to carbon cycling in peatlands there is a dearth of knowledge of the direct effects of varying rainfall return periods within a growing season on CH_4 flux from peatlands.

This study aims to quantify the effect of changing the frequency of rain events on CH_4 flux from a cool temperate poor fen. Elucidation of the response, and the environmental controls of the response, will aid land managers and inform land-atmosphere climate models on the role of peatlands in the global carbon cycle. Peatland CH_4 emissions can vary by several orders of magnitude from site to site and even within sites due to the presence of different vegetation (Dise, 1993; Bridgham et al., 2013; Turetsky et al., 2014). We applied our rainfall frequency treatments on representatives of the three dominant plant functional types in poor fens and bogs: *Sphagnum* moss, herbaceous sedge, and ericaceous shrubs. Our specific objectives were 1) to determine the effect of changing rainfall frequency on the flux of CH_4 from the three vegetation communities, and 2) to examine the interaction of the applied rainfall regimes with relevant environmental variables, particularly the fluctuation in the water table. We addressed these objectives through experimentation in the field through the construction of rainout shelters as well as lab manipulation on peat mesocosms.

2. Methodology

2.1. Study site

The field manipulation study was carried out in a portion of a 130 ha undisturbed poor fen (44°15′13.34″N, 80°20′46.83″W) in southern Ontario, Canada. Peat depth throughout the study area averages 2.1 m, and is underlain by sandy silt till (Burwasser, 1974) over dolomite of the Guelph formation. The climate for this region is cool temperate, with a mean annual temperature and precipitation of 6.4 °C and 996 mm, respectively (1981–2010 normal at Ruskview, ON station, data available: http://climate.weather..gc.ca/climate_normals/). In the period of May-October (inclusive), the mean temperature is 15.1 °C and mean precipitation is 517 mm, with rainfall (>0.2 mm) occurring on 43% of the days throughout the growing season.

The peatland vegetation mainly consisted of a relatively continuous carpet of *Sphagnum capillifolium*, *S. rubellum*, *S. fuscum* and *S. magellacicum*. Vascular vegetation covered about 75% of the ground in distinct patches, and was equally dominated by sedges and ericaceous shrubs. The sedge species included *Carex oligosperma* and *Eriophorum vaginatum*, and ericaceous shrubs species including evergreen *Chamaedaphne calyculata*, *Rhododendron groenlandicum* and deciduous shrub *Vaccinium uliginosum*. *Sphagnum* ground cover was ~100% in the sedge-dominated areas, but was relatively sparse (averaging 15% ground cover) in the areas with mature shrubs. More detail on site characterization can be found elsewhere (Radu, 2017).

2.2. Field experimental design

We established a full-factorial field experiment to examine the effect of different rainfall regimes on CH_4 flux among different peatland vegetation communities. The total seasonal rainfall was held constant between rainfall regime treatments and rainfall event frequency was decreased between the three treatments with corresponding increases in rainfall intensity of each event. 27 sample plots were randomly distributed among the dominant plant communities in the peatland: 1) *Sphagnum* moss (mainly S. *capillifolium*) (hereafter referred to as Moss plots) 2) *Sphagnum* with sedges (mainly *Carex oligosperma*) (Sedge plots), and 3) *Sphagnum* with ericaceous shrubs (mainly *C. calyculata*) (Shrub plots). The 9 plots within each community were assigned one of three rain frequency treatments (Table 1), replicated three times. The plots were 9.3 m^2 and spaced at least 10 m apart within a 3000 m^2 study area.

To implement the irrigation treatments, we built fixed-location rainout shelters to block natural precipitation from the vegetation plots throughout the study period. The shelter scaffolding was built the summer prior to field sampling. Rainout shelters were covered with 6 mil transparent polyethylene sheeting (Uline, Brampton, Ontario, Canada). The shelter roofs were found to transmit 90% of incoming solar radiation and exclude 98% of precipitation. The sides of the shelters were left uncovered to minimize effects on the microclimate. Further details of the design and efficiency of the rainout shelters can be found elsewhere (Didiano et al., 2016). Trenches (30 cm deep) were dug around the perimeter of each shelter and lined with reinforced polyethylene sheeting to limit the lateral flow of water between the sample plots and the surrounding peatland.

We tested three rain frequency treatments on the peatland vegetation: 3 events/week (hereafter referred to as "High-Frequency"), 1 event/week ("Medium-Frequency"), and 1 event/2 weeks ("Low-Frequency"). Natural rainwater captured throughout each week was used to water the plots for the following week (or 2 weeks for the Low-Frequency treatment). This resulted in varying amounts of water applied each week depending on the natural precipitation regime. The duration of each irrigation treatment was held constant at 0.5, one, and two hours for the High-, Medium-, and Low-Frequency treatments, respectively, regardless of irrigation amount, and average irrigation event intensity is expressed on a daily scale. Although the *frequency* of the rain events was different, the total *amount* of water in each 2-week period was equal between all treatments.

2.3. Methane sampling and environmental variables

CH_4 fluxes were measured at least weekly from the plots throughout the study period (01- June–12-September 2015) at midday (1000–1700 h) using the dynamic closed chamber method