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Responses of a mountain peatland to increasing temperature: A microcosm study of greenhouse gas emissions and microbial community dynamics

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ABSTRACT

Mountain peatlands often have mineral horizons embedded within or buried below the peat, which affects substrate quality and soil properties in subsurface peat. However, their role in greenhouse gases (GHG) production and GHG responses to temperature and water table changes are uncertain. We conducted a laboratory microcosm experiment to assess the effect of changes in temperature and water table on two peat profiles (with and without mineral sediments) on the GHG emission and concentrations and on the microbial community structure.

Two soil types – sedge peat/mineral/calcareous sediments (PMC) and sedge peat/moss peat (PP) – were incubated for 28 days under four temperature/water table treatments: 15°C/-15 cm, 25°C/-15 cm, 15°C/-40 cm, and 25°C/-40 cm. Surface GHG emissions and GHG concentrations from four depths (surface, above water table, below water table, and above mineral contact) were monitored. Results indicated that increasing temperature had the most significant effect on overall GHG emissions. High temperature increased GHG emission (CO_2 by 28%, CH_4 by 133% and 178% N_2O) and concentrations – at surface and at depth (CO_2 by 32–83%, CH_4 by 200–1600% and N_2O by −61–230%) – in most samples. In contrast, lowering the water table decreased only CH_4 emissions. Soil types also significantly affected GHG emission and concentrations: CO_2 and N_2O from subsurface peat were higher in PP than PMC. Moreover, there was an interaction effect of temperature and soil types for N_2O: concentrations in PP were more increased by high temperature above and below the water table.

To understand how temperature influences GHG, especially N_2O production, 25°C/-15 cm incubated and Background (not incubated) cores were disassembled to measure apparent enzyme activation energy (E_a), and bacterial community structure above and below the water table. Results indicated that higher E_a and less relative abundance of copiotrophs were detected in PMC than in PP, because of less labile C in PMC. High temperature treatment also changed the microbial community structure at the class level in PP but not PMC. These together resulted in less increase of N_2O production with increasing temperature in PMC. Overall, our findings suggest that peat profiles with mineral horizons may produce less GHG – especially N_2O – when temperature increases.

1. Introduction

Boreal and subarctic peatlands store about 30% of global soil carbon (C) and account for 4–10% of global CH_4 emissions (Gorham, 1991; Mikaloff Fletcher et al., 2004). The responses of C and N cycling to temperature and water table fluctuation have been widely studied (Ambus et al., 2006; Dorrepaal et al., 2009; Wunderlich and Borken, 2012; Holmes et al., 2014; Treat et al., 2014). However, current knowledge is mainly based on the study of continuous peat profiles. In mountain peatlands, the peat

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Abbreviations: PMC, sedge peat/silty mineral sediments/calcareous sediments; PMP, sedge peat/silty mineral sediments/moss peat; PP, sedge peat/moss peat; GHG, greenhouse gases; E_a, Apparent enzyme activation energy.

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stratigraphy can be considerably more complex, due to the unstable geomorphic environments (Margalef et al., 2013; Sewall et al., 2015). Peat profiles in mountain areas showed frequent interruptions by mineral or ash lenses during peatland formation (Kubiw et al., 1989; Chadde et al., 1998; Morrison et al., 2015). Previous studies found that mineral sediments affected spatial distribution of soil properties in subsurface peat via influencing groundwater movement and chemistry (Wang et al., 2016b). In addition, peat materials adjacent to mineral sediments show low substrate quality, i.e., are less degradable, as they were more decomposed during historical peat formation and have physicochemical protection via mineral sediments at present (Wang et al., 2016a).

Substrate quality is an important factor regulating greenhouse gas (GHG) emissions (Wright et al., 2011). Labile C forms, such as polysaccharides, are easily used by microbes and readily decomposed via C and N cycling (Preston et al., 2006). In addition, substrate quality can also affect C cycling by impacting microbial community structures. For example, ecologically, microbes can be classified into two groups: copiotrophs (*r*-strategists) and oligotrophs (*k*-strategists) (Fierer et al., 2007). Copiotrophs are usually more abundant in nutrient rich conditions and grow faster than oligotrophs, whereas oligotrophs are more abundant nutrient poor conditions (MacArthur and Wilson, 1967). A switch from copiotrophs to oligotrophs indicates a shift from high C use efficiency to lower level (Fierer et al., 2007).

More importantly, biogeochemical processes in substrates with different qualities show various sensitivities to environmental changes, especially to temperature increase (Davidson and Janssens, 2006). Temperature dependence of a reaction can be reflected in apparent enzyme activation energy (E_a) which is the energy required for a reaction to proceed and is largely dependent on substrate quality (Yavitt et al., 2000). For example, decomposition of recalcitrant materials requires more energy than labile materials, and therefore has higher E_a (Davidson and Janssens, 2006). Other than substrate quality, E_a is also regulated by microbial community structure and function, as different microbial community structures produce different extracellular enzymes, which results in different E_a (Sinsabaugh, 1994; Davidson and Janssens, 2006). In addition, microbial community structure and function are able to rapidly respond to changing environments (Nie et al., 2013; Banerjee et al., 2016). Microbial functions, i.e., enzyme production, can change within several days to a few weeks, while changes of microbial community structure might take a few weeks or more depending on environment factors such as C availability (Bradford, 2013). For GHG production, it has been found that E_a and microbial community structures change with changing temperature, hydrology interactions and substrate quality (Lloyd and Taylor, 1994; Yavitt et al., 2000; Inglett et al., 2012).

Based on the above, differences of substrate quality and soil properties in subsurface peat with mineral sediments indicate that the interaction of peat and mineral layers may make the feedback of GHG emission to global warming more complex. A better understanding of the response of complex peat profile to changing environmental conditions (i.e., temperature and moisture) would help determine whether mountain peatlands would be a source or sink of C and their feedback to atmospheric GHG concentration under climate change. Therefore, we conducted a short-term controlled temperature and water table study to examine the potential response of peat profiles with and without mineral sediments to new extremes under a changing climate. We hypothesized that: 1) high temperature increases GHG emissions, whereas lowering water table promotes CO_2 and N_2O emission but decreases CH_4 emission; 2) GHG emissions from peat profiles with mineral sediments are less affected by temperature and/or water table changes than those from peat profiles without mineral sediments, as subsurface peat in profile with mineral sediments are more decomposed and have affect substrate quality and left with less degradable C; 3) apparent enzyme activation energy and microbial community structure differ between peat profiles and change with temperature and water table fluctuation.

2. Material and methods

2.1. Site description and soil collection

Sibbald Creek research wetland is a hummocky mountain peatland within a relatively level valley basin in the Kananaskis region of southern Alberta, Canada (Latitude: 51.06N, Longitude: 114.87W) (Fig. 1a). The mean air temperature is 14.5 °C for July and mean average precipitation is 653 mm (Janzen and Westbrook (2011); average water table depth during summer is 22.9–26.4 cm below surface (based on 2006 to 2009 data). The study area is located in the southern half of the peatland; the hydrological conditions were described in Wang et al. (2016b). Briefly, this peatland receives surface water from creeks formed by groundwater springs and is drained by Bateman Creek, a 1-m wide channel. The early form of this peatland was a shallow marl lake, surrounded by a sandy beach, surrounded by moss (*Sphagnum*) peat at around 7300 years BP. Over time, peat in-filled the whole landscape, and changed to sedge peat in most locations, coincident with a change in regional climate about 4000 years BP. The accumulation of peat was interrupted more than once over time, with deposition of silty mineral materials that accumulated near the stream channel (C. Westbrook, personal communication).

Three distinct soil types were identified in the peatland: sedge peat/silty mineral/calcareous sediment (PMC) in the southwest zone of the basin; sedge peat/moss peat profiles (PP) in the northeast of the basin; and sedge peat/silty mineral/moss peat (PMP) in the middle (Fig. 1b) as described in Wang et al. (2016b). Only PP and PMC were sampled in this study, because they showed the most significant differences in soil properties, C and N mineralization, and nitrification in previous studies. Basic soil properties were described in Wang et al. (2016b) and are summarized in Table 1. Samples were collected to just above the mineral horizon in PMC or equivalent depth in PP, as no significant difference was found between middle peat and deep peat. Sedges (predominately *Carex aquatilis*) are the most dominant vegetation in PMC; whereas sedges and willows (*Salix* spp.) are co-dominant in PP.

Six representative sampling points were selected from each soil type (PMC and PP). At each sampling point, five intact soil cores were taken from the surface to approximately 50 cm depth (the average depth to mineral sediment) by a hand corer (ID = 9.3 cm). Living plants were removed and cores were assembled into PVC tubes in the field. Of the five intact cores, four were subjected to temperature - water table treatment; the fifth served as a Background (not incubated) core. The Background core was not treated with different temperature – water table; it was kept frozen during the 28 days of incubation, and thawed at 4 °C before use.

2.2. Microcosm experiment set up

To study GHG emissions, a controlled temperature and water table level microcosm experiment was conducted. Experimental conditions, summarized in Table 2, were determined based on published global warming scenarios – an estimated water table decline in peatlands of 7.1–14.4 cm is expected under climate warming (Roulet et al., 1992), commensurate with a 2–3 °C increase in temperature in during the summer growing season in central North America (IPCC, 2007). The high temperature