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Growing season carbon dioxide and methane exchange at a restored peatland on the Western Boreal Plain

Maria Strack*, Arnold Magnus Keith, Bin Xu[1]

Department of Geography, University of Calgary, Calgary, AB, Canada

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ABSTRACT

Boreal peatlands represent globally important long term sinks of carbon; however, horticultural peat extraction disrupts this carbon sink function, converting these ecosystems to large sources of greenhouse gases. Peatland restoration mitigates these emissions but to date no measurement of greenhouse gas exchange has been conducted on restored peatlands in western Canada, a region where continental climate could impact restoration success. We measured CO_2 and CH_4 fluxes during the growing season in a restored, cutover peatland in northern Alberta (Boreal Plain Ecozone) and compared these to fluxes measured on a neighboring unrestored area. Restoration resulted in a shift in mean growing season fluxes from 378 g CO_2—C and −0.2 g CH_4—C at the unrestored site to −30 g CO_2—C and 3.7 g CH_4—C at the restored site, where positive values indicate flux of carbon from the peatland to the atmosphere. Carbon dioxide exchange was correlated to vascular vegetation cover that varied depending on local water table position. Water table was also related to CH_4 flux, with higher emissions from wet sites. Restoration activities should avoid creating very dry microsites where greenhouse gas emissions will remain high, while very wet sites may accumulate carbon as CO_2 but will likely create areas of high CH_4 flux.

1. Introduction

Peatlands are wetland ecosystems where the productivity of the vegetation community exceeds the rate of decay resulting in the accumulation of organic matter, or peat, over thousands of years (Vasander and Kettunen, 2006; Vitt, 2006). This accumulation of peat makes these ecosystems important long-term sinks of atmospheric carbon; however, peat harvesting may degrade the ecosystem sufficiently to turn it into a source of atmospheric carbon (Waddington et al., 2010).

Canada has an estimated 120 million ha of peatland of which 25,000 ha, or 0.02% have been drained for horticultural peat harvesting, with ∼14,000 ha currently in operation (Environment Canada, 2013a). The draining of peatlands typically results in an increase in net CO_2 emission and a decrease in CH_4 efflux, except in drainage ditches where increased CH_4 flux has been reported (Mahmood and Strack, 2011; Waddington and Day, 2007). The majority of ongoing horticultural peat extraction in Canada is by vacuum harvesting, requiring an extensive network of drainage ditches.

Without immediate remediation, cutover peatlands will become persistent sources of CO_2 and result in huge carbon losses to the atmosphere (Waddington et al., 2002). Depending on the hydrochemistry of the residual peat, abandoned cutover peat fields may experience spontaneous recolonization by, predominantly, vascular plants (Graf et al., 2008; Mahmood and Strack, 2011); however, many sites remain poorly revegetated and largely devoid of mosses decades after peat extraction has ceased (Poulin et al., 2005). Spontaneous recolonization of harvested peatlands has been found to increase CH_4 flux (Mahmood and Strack, 2011) by providing an escape through plant pathways, while it may also decrease CO_2 flux (Bortoluzzi et al., 2006) as a result of increased productivity.

Considering CO_2 and CH_4 exchange from northern peatlands it has been concluded that these ecosystems have resulted in net atmospheric cooling over the Holocene (Frolking and Roulet, 2007). Extracted peatlands represent a persistent source of CO_2 (Waddington et al., 2002) and given modern concerns about the role of these greenhouse gases (GHGs) in accelerating climate change, there is a need to develop methods for restoring extracted peatlands. This increase in CO_2 emission results from the removal of vegetation and the drawing down of the water table. Therefore the process of restoring a peatland must include the reestablishment

* Corresponding author at: Department of Geography, University of Calgary, 2500 University Drive, NW, Calgary, AB, Canada T2N 1N4. Tel.: +1 4032205596.
E-mail address: mstrack@ucalgary.ca (M. Strack).
[1] Now at: Boreal Research Institute, NAIT, Peace River, AB, Canada.

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of hydrological conditions typical of a natural peatland system and the re-establishment of natural peatland vegetation communities (Waddington et al., 2010). While spontaneous revegetation of harvested peatlands may be beneficial in restoring a site back to a net carbon sequestering system (Bortoluzzi et al., 2006; Graf et al., 2008; Lavoie et al., 2001), active restoration practices may be necessary to enhance recovery (Rochefort et al., 2003; Waddington et al., 2010). This has led to the development of a North American approach to the restoration of cutover peatlands (Quinty and Rochefort, 2003). This method of peatland restoration involves restoring local hydrology by blocking drainage ditches and resurfacing the cutover peatland; collecting, introducing and protecting collected diaspores (any part of a plant that can generate a new individual); and introducing fertilizer to encourage the growth of vascular plants and *Polytrichum* moss that act as nurse species for *Sphagnum* moss.

Although the North American peatland restoration method has been applied for almost two decades, most restoration has taken place in eastern Canada with application to western provinces only recently. These regions have very different climate regimes. For example, peatlands along the southern shore of the St. Lawrence River in Québec experience mean annual precipitation of ~900 to >1200 mm and mean annual temperature of ~4 °C (Environment Canada, 2013b). In contrast, peat extraction areas in Alberta receive an average of 500–600 mm of precipitation annually and mean annual temperatures of 0–3.4 °C (Environment Canada, 2013b). Given the limited number of restoration projects in western Canada and the lack of GHG flux measurements at these sites, it remains unclear what constraint these climatic conditions place on restoration success and the carbon balance of these restored areas.

The goal of this study was to evaluate the effectiveness of restoration techniques based on Quinty and Rochefort (2003) as applied on a cutover peat bog in northern Alberta. Based on previous research on restored peatlands in Québec (Mahmood and Strack, 2011; Strack and Zuback, 2013; Waddington et al., 2010) we hypothesized that: (1) restoration would decrease the CO_2 source from peat fields and possibly result in a CO_2 sink, (2) restoration would increase CH_4 efflux and (3) water table and plant cover would be significant controls on rates of GHG exchange.

2. Study site

This study was conducted in a cutover peatland north of Wandering River, Alberta, Canada (55.293° N, 112.475° W, Fig. 1). Measurements were made across the ~10 ha restored section and compared to measurements at a neighboring unrestored section. The study site is situated in the Boreal Plains ecozone (Ecological Stratification Working Group, 1996). The 30-yr normal annual precipitation at Wandering River is 522 mm and mean annual temperature is 0.17 °C (The Weather Network, 2013). The restored site is owned and operated by Sun Gro Horticulture and had been previously drained by a series of ditches around the site and crossing it longitudinally along its major axis. This area was previously under active vacuum-extraction and was restored by the site operator in 2008 according to the North American Peatland Restoration Guide by Quinty and Rochefort (2003). Briefly, restoration involved filling ditches on the restored area, spreading diaspores from a neighboring ombrotrophic bog in a ratio of 1:10 (1 ha of collected material over 10 ha of restored area), covering material with straw mulch, adding phosphate rock fertilizer (150 kg ha^{-1}), and blocking perimeter ditches.

Twelve sample plots were established systematically on the restored site (R) in approximately four rows (A–D) of three collars with each row spaced ~100 m apart along a main transect west to east along the site's major axis on the south side of the field (Fig. 1). The first row was ~100 m due east of the site access road. This design was created with the intent of capturing the clearly visible hydrologic gradient at the site, where the west end was dry and the east end was largely ponded. Furthermore, sites were chosen to capture the variety of vegetation on the site (Table 1). Rows A and C were inset ~60 m from the main transect, and each plot was spaced ~40 m apart (Fig. 1). Each sample plot was bounded by a 0.36 m^2 (60 cm × 60 cm) stainless steel collar with grooves, onto which a clear (CO_2) or opaque (CH_4) chamber was placed during flux measurement. Boardwalks were installed across waterlogged areas, and platforms were constructed next to each collar to limit any soil disturbance during C flux measurement.

Three additional plots were established on a neighboring unrestored (U) peat field (Fig. 1) that had experienced no spontaneous recolonization by native vegetation. These were used to establish a baseline for bare peat flux for CH_4 and CO_2 when no restoration efforts are undertaken. Each of these plots was roughly in line with rows A, B and C, respectively, of the restored peatland. Wells were installed at each plot; however, collars were not installed in 2011. Instead, a portable collar was inserted ~9 cm into the peat surface each time C flux measurements were taken. Permanent collars were installed for measurements made in 2012.

Carbon flux measurements were completed between July 13–September 9, 2011 and May 16–July 21, 2012. During this period CO_2 and CH_4 fluxes were measured at each sampling plot seven to eight times.

3. Methods

3.1. Carbon dioxide exchange

Net ecosystem exchange of CO_2 (NEE) was determined using the closed chamber technique. Briefly, a transparent acrylic chamber (60 cm × 60 cm × 30 cm) was placed on the sampling plot and CO_2 concentration in the headspace monitored for 105 s using a portable infrared gas analyzer (EGM-4, PP Systems, Massachusetts, USA). A battery operated fan mixed the headspace during flux measurement. Flux was determined from the linear change in CO_2 concentration over time correcting for chamber volume and ambient temperature as recorded with a thermocouple inserted into the chamber. Short chamber closure times were used to limit heating inside the chamber headspace and data do not provide evidence of a deviation from a linear pattern of concentration change over time.

During each flux measurement photosynthetically active radiation (PAR) was measured with a quantum sensor connected to the EGM-4. The measurement was repeated under a variety of light levels created using shades and under an opaque tarp to determine ecosystem respiration (ER). Gross ecosystem photosynthesis (GEP) was determined as the difference between NEE and ER. At the unrestored site only ER was determined as no vegetation was present. As mentioned above, in 2011 ER was determined using a smaller portable chamber-collar combination (~10 L total volume). In 2012, 60 cm × 60 cm collars were installed and the same chamber was used at both the restored and unrestored sites.

3.2. Methane flux

The closed chamber technique was also used to determine CH_4 fluxes at each plot. An opaque 60 cm × 60 cm × 30 cm chamber was used and equipped with a battery-operated fan to mix the headspace air. Headspace was sampled at 7, 15, 25, and 35 min after chamber closure through tubing sealed with a three-way