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Ecohydrological controls on the carbon balance of a recently restored cutover peatland

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Abstract

A cutover peatland in the Bas-Saint-Laurent region of Québec was partially restored in autumn 1999 – dividing the peatland into restored and cutover catchments. The carbon balance of each catchment was measured for the snow-free periods of 1999 to 2002 using a combination of chamber measurements for CH_4 and CO_2 flux gas exchange, eddy correlation for net ecosystem CO_2 exchange and runoff measurements for the water-borne flux of DOC. In three years post restoration, the recently restored peatland was a significantly greater source of CO_2 and CH_4 than the adjacent cutover site, while DOC export was similar between both catchments. Here we present a discussion on how peatland ecological, hydrological, and subsurface biogeochemical processes are controlling these changes. A simple SVAT model and empirical CO_2 exchange model were used to determine the long-term effects of restoration on the carbon balance of the restored peatland.

Introduction

The importance of undisturbed peatlands to both global trace gas biogeochemistry and local water chemistry is well documented (e.g., Gorham 1991; Schindler & Curtis 1997). Undisturbed peatlands are a net long-term sink of atmospheric carbon dioxide (CO_2) (Turunen et al. 2002) and both a contemporary source and sink of CO_2 (Griffis et al. 2000). The emission to the atmosphere of methane (CH_4) from natural peatlands has been estimated to be at 115 Tg yr^{-1}, which is 20% of that from all terrestrial sources (Cicerone & Oremland 1988). Fraser et al. (2001) note that these peatlands are an annual net source of downstream dissolved organic carbon (DOC) in the range of 5 to 20 g C m^{-2}.

The demand for horticultural peat has recently increased peatland drainage and harvesting activities in Canada (Cleary 2003). Currently, ~12,600 ha of Canada's peatlands are cutover and mined while 950 ha of cutover peatlands are abandoned (Cleary 2003). In some regions of Canada, such as the St. Lawrence Lowlands of southern Québec, peatland losses are in the range of 70% (Van Seters & Price 2001).

Following drainage, surface vegetation and peat is removed by a variety of techniques, most commonly in Canada by vacuum extraction. Drainage and mining reduces CH_4 emissions to the atmosphere (Waddington & Price 2000; Sundh et al. 2000) and increases CO_2 emissions by as much as 400% (Waddington et al. 2002; Nykänen et al. 1995), due to a lowering of the water table and an increase in the zone of aerobic decomposition and CH_4 oxidation. There is some evidence that cutover peatlands remain a source of atmospheric CO_2 when they are abandoned (Waddington & McNeil 2002) indicating that cutover peatlands represent a persistent source of atmospheric CO_2 (Waddington et al. 2002). Abandoned vacuum harvested peatlands have been impacted to the point where the natural regeneration of *Sphagnum* is no longer possible (Campeau & Rochefort 1996) without active restoration (Rochefort 2003). Increased aeration of the upper layers of peat causes the peat to oxidize quickly which leads to an increase in bulk density and lower specific yield (Price 1997). Nevertheless, these changes create major alterations in the hydrological pathways and biogeochemical processes operating in peatlands and their surrounding catchments, impacting water quality downstream and greenhouse gas exchange.

In order to return the natural carbon sink function of peatlands of cutover peatlands, over 300 ha of peatlands are currently being restored in Canada (Cleary 2003). While several studies have examined the net ecosystem exchange of CO_2, internal DOC dynamics (e.g., Glatzel et al. 2003), and CH_4 fluxes (Sundh et al. 2000) at the plot scale, the effects of restoration at a large scale on carbon dynamics are uncertain. Moreover, there is no synthetic knowledgea limited understanding of how the compounding effects of changing hydrological and ecological processes affect/control the carbon balance of recently restored peatlands. The objectives of this paper, therefore, are to: 1) determine the change in the carbon balance (CO_2, CH_4, and DOC) at a recently restored and cutover peatland, and 2) establish a greater level of understanding on how changes in the eco-hydrology of the restored peatland control the different components of the carbon balance.

Study Area

This study was carried out at the Bois-des-Bel (BDB) peatland, a 200 ha treed bog, located 14 km east of Rivière-du-Loup, Québec, Canada (47° 58'N, 69° 25'W) in the Bas-Saint-Laurent region. The mean annual temperature is 3°C and the mean January and July temperature are 12°C and 18°C respectively (Environment Canada 1993). An 11.5 ha portion of the bog was drained in 1972, and vacuum harvested from 1973 to 1980 and then abandoned until 1999. Peatland restoration (see Rochefort et al. 2003 for details) on the abandoned portion of BDB began in the fall of 1999. The extracted peatland was separated into two catchments, a 7.2 ha restored section (peat fields 1 to 8) and a 1.8 ha cutover section (peat fields 9 to 11). Peat field 9 was left as a buffer strip between the two catchments.

The dominant vegetation at the site before restoration was birch (*Bettula populifolia*), tamarack (*Larix laricinia*), ericaceous shrubs (*Ledum groenlandicum* and *Kalmia angustifolia*), cattail (*Typha latifolia*), cotton grass (*Eriophorum vaginatum*), mosses (mainly *Polytricum strictum*, but some *Sphagnum* spp. as well). During restoration all vegetation from the restored site was cut down and the surface of the peatland was milled. The cut vegetation, in many circumstances, was used as fill for the drainage ditches. Canadian reed grass (*Calamagrostis canadensis*), and several agricultural weeds appeared on the restored site by 2001. The areas covered by mosses and other wetland vegetation at the restored site increased to 23% and 10% respectively (Campeau, unpublished data) by 2001.

Methodology

Components of the carbon balance were measured for most of the snow-free period (May to October) in 1999 (pre-restoration), 2000, 2001, and 2002. The eddy correlation micrometeorological technique and chamber technique were used to measure net ecosystem CO_2 exchange. A detailed analysis of the micrometeorological methodology procedure is outlined in Petrone et al. (2001). Water samples were collected three times per week and during storms at the outflow ditch of both the restored and cutover site. DOC was analysed using high temperature catalytic oxidation on a Dohrmann DC-190 Total Carbon Analyzer (in 1999 and 2000) or a Shimadzu TOC 5000A instrument (in 2001). Discharge was determined using continuous stage data and annual stage-discharge rating curves. Measurements of CH_4 emissions and CO_2 respiration were determined using an opaque chamber placed over a PVC collar permanently set into the peat. CH_4 was measured biweekly from 1999–2001 and weekly for 2002 at multiple sites representing pools, ditches, vegetation, and peat located throughout the restored and cutover sites. Respiration measurements were made three times per week. Net ecosystem CO_2 exchange measurements were also made using a clear chamber approach (see Waddington and Warner 2001 for details). Changes in vegetation cover were determined seasonally by members of the Peatland Ecology Research Group at Université Laval.

Results and Discussion

Prior to restoration the restored and cutover sites were both a net source of atmospheric CO_2 during the study season. The restored site lost 276.6 g C m^{-2} while the cutover site lost 265.8 g C m^{-2}. Post restoration NEE at the restored site was 478 g C m^{-2} in 2000 and 468 g C m^{-2} in 2001. The increase in NEE corresponded to the warmest and driest period and ~20% of this increase was due to mulch decomposition (Waddington et al. 2003). Gross ecosystem production also increased post restoration during the peak of the growing season (maximum GEP = –0.13 and –0.27 mg CO_2 m^{-2} s^{-1} in 2000 and 2001, respectively). Cooler and wetter conditions after the month of August in both 2000 and 2001 corresponded to lower respiration rates.

Seasonal CH_4 flux for the restored and cutover sites are summarized in Table 1. The cutover site experienced an increase in CH_4 flux from the site, with the exception of 2002, and experienced a net consumption of CH_4 in 1999. Restored site seasonal CH_4 fluxes were significantly larger (5 to 150 times greater) than the cutover site and increased from 19 mg CH_4 m^{-2} in 1999 to 1352 mg CH_4 m^{-2} 2002 (> 7000% increase).

Changes in the ecohydrological conditions at the restored site provide partial explanations for this trend. Water table levels were lowest in 1999 followed by 2002, leading to greater CH_4 oxidation and a lower mass of CH_4 lost in 1999 but not in 2002. Conversely, the water table position was highest in 2000 and 2001, suggesting that more CH_4 would be produced and less oxidized, thereby increasing the mass of CH_4 lost. Furthermore, from 1999 to 2002, peat coverage decreased while moss and vascular coverages increased. Other studies (e.g. Waddington et al. 1996) suggest that vascular plants can enhance CH_4 flux to the atmosphere through 1) supply of labile C and 2) transport of CH_4 to the atmosphere, bypassing the aerobic zone. Consequently, vascular plants likely enhanced the mass of CH_4 lost in 2001 and 2002, despite the dry conditions in 2002.

Table 1. Seasonal (May–October) carbon balance for Bois-des-Bel restored and cutover sites prior to restoration (1999) and the first three years post restoration (2000–2002). A negative sign indicates a carbon gain to the peatland. Units are g C m^{-2} $season^{-1}$.

	Pre-Restoration	Post-Restoration		
Site	**1999**	**2000**	**2001**	**2002**
Restored				
CO_2	276.6	478.0	468.1	n/a
CH_4	0.01	0.31	0.81	1.01
DOC	4.8	3.4	3.5	n/a
ΔS	281.4	481.7	472.4	n/a
Cutover				
CO_2	265.8	n/a	n/a	n/a
CH_4	–0.07	0.08	0.13	0.01
DOC	10.3	8.5	6.2	n/a
ΔS	276.0	n/a	n/a	n/a

DOC concentrations were highly variable at the outflows of the restored and cutover sites over the three study seasons, with a general trend of increasing concentrations from ~60 to 70 mg L^{-1} in early May to peak concentrations of 150 to 190 mg L^{-1} in mid July to August and decreasing to about 90 to 110 mg L^{-1} once the more frequent fall precipitation events started. Overall, the cutover site exported more DOC than the restored site in all three study seasons, with highest exports in 1999 (10.3 and 4.8 g m^{-2} at the cutover and restored sites, respectively). In 2000, 8.5 g C m^{-2} was released from the cutover site, while the restored site released less than half this amount (3.4 g C m^{-2}) (Table 1). In 2001, the restored site released about the same amount of DOC as in the previous year (3.5 g C m^{-2}) while the cutover site load dropped to 6.2 g C m^{-2} (Table 1).

Conclusions

The mass of CH_4 lost has increased from the Bois-des-Bel peatland since restoration. This is due partially to higher water table levels increasing the zone of CH_4 production and decreasing the zone of oxidation. However, vegetative cover has also enhanced the flux to the atmosphere. Soil respiration was slightly greater in 2001 (warmer air and soil temperatures) than in 2000, when mulch decomposition was presumably at its greatest. However, in 2001 *Sphagnum* and other mosses became more established on the peat surface, reflected by the increase in photosynthesis. The result is that NEE was slightly lower in 2001 than 2000. DOM export decreased when runoff patterns changed after drainage ditches were blocked. DOC concentration increased after restoration due to improved moisture conditions and will probably remain high until water fluctuations in the matrix decrease.

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