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GREENHOUSE GAS EXCHANGE OF CUTOVER MINEROTROPHIC PEATLANDS – EFFECT OF REVEGETATION AND REWETTING

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SUMMARY

Peatlands play an important role in the global carbon cycle storing about one third of global soil carbon. However, peat extraction reduces this soil carbon stock and sites may remain large sources of atmospheric carbon after extraction activities cease. This study was conducted at an abandoned cutover minerotrophic peatland in eastern Quebec, Canada that was abandoned for the last several decades after peat extraction using vacuum harvesting techniques. We studied six revegetating communities that were dominant at the cutover site in 2009, before, and 2010, after rewetting the site. The results showed that revegetation increased the CO_2 uptake at the abandoned site. CH_4 flux was lower than in previous studies. Rewetting showed significant increase in net ecosystem exchange for CO_2 and CH_4 flux.

KEY WORDS: Peatlands, Revegetation, Rewetting, Greenhouse gas.

INTRODUCTION

Peatlands cover 5-8 % of the world's land and freshwater surface (IPCC, 2000). They represent an important component of the global carbon cycle, storing on average 23 g $Cm^{-2}\ yr^{-1}$ as the rate of litter decomposition is very low (Waddington *et al.*, 2002), while emitting a significant amount of methane (CH_4) to the atmosphere (Bridgham *et al.*, 2006). Peat extraction eliminates the carbon sink function of the peatland. Thus, peatland drainage and peat extraction changes natural peatlands from a net carbon sink to that of a large net source due to increased respiration and the removal of CO_2-fixing vegetation. In North America, introduction of diaspores and mulch on harvested sites with blocking the drainage to accelerate *Sphagnum* establishment (Rochefort *et al.*, 2003) is widely used to restore peatlands. However, in fens, or minerotrophic peatlands, the establishment of *Sphagnum* may not be the goal due to hydro-chemical conditions. Establishment of vascular vegetation following harvesting is also generally more extensive than that observed on disturbed bogs (Graf *et al.*, 2008). These spontaneously revegetating species could play an important role in ecosystem recovery. To address this situation we tried to answer whether revegetating species of cutover minerotrophic peatlands are important in restoration from the carbon perspective and whether rewetting alters carbon exchange at these cutover minerotrophic peatlands. The specific research objectives of this study were to - (i) measure the greenhouse gas (CO_2 and CH_4) flux of representative revegetating communities at an abandoned mined peatland before and after restoration; and (iii) compare the greenhouse gas flux of these species with that of bare areas and natural peatland to determine the effect of extraction, revegetation and rewetting.

MATERIALS AND METHODS

Study Site

The study was conducted in the Bic Saint-Fabien (BSF) peatland (48º18' N, 68º52' W) which is located approximately 25 km west of Rimouski, Quebec, Canada. The undisturbed part of the peatland was a moderately rich fen with an average peat depth of 4.5 m. The extracted portion of the peatland has been mined for horticultural peat since 1946, with the vacuum extraction technique employed since 1970. Most of the site has been abandoned during the last few decades and spontaneous revegetation has occurred in some sections. The present harvested portion of BSF is about 22 ha.

Measurement of Greenhouse Gas Flux

The study was conducted in two growing seasons in 2009 and 2010 (May-August). Following a preliminary survey of vegetation communities at the cutover peatland at BSF six revegetating communities were chosen for study. These were each dominated by one species and include – (1) *Scirpus atrocinctus* (Scr_atr), (2) *Equisetum arvense* (Equ_arv), (3) *Calamagrostis canadensis* (Cal_can), (4) *Eriophorum vaginatum* (Eri_vag), and (5) *Carex aquatilis* (Car_aqu) and (6) *Typha latifolia* (Typ_lat). However, Cal_can was not studied in 2010 as all these plots were removed due to restoration activities. Triplicate plots were studied in each vegetation type except for duplicate plots only for Typ_lat, Sci_atr and Eri_vag in 2010 because of removing the third plot to facilitate restoration. Four plots were established on bare peat (P) at the cutover site and studied in both seasons. Six plots were also studied in the natural (N) fen adjacent to the cutover site and arranged to be representative of the hydrologic gradient at the site with three plots on low-lying hollows (Nhol) and three plots at higher, drier hummocks (Nhum).

To determine the instantaneous CO_2 exchange rates and collection of CH_4 gas samples the closed chamber method was used (Alm *et al.*, 2007). Briefly, a permanent 60×60 cm square or a round (d = 30 cm) collar with a groove for water sealing was installed in soil. Small round collars were used only for bare peat. For CO_2 flux measurement a clear acrylic glass chamber (60×60×30 cm) was used. For CH_4 gas sampling an opaque steel chamber of the same size was placed upon the collar creating an air tight seal by adding water in the groove. Ecosystem respiration was measured using the clear chamber by shading it with a black tarp. For measuring the bare peat respiration and CH_4 flux, a round chamber (12.74 cm^3) was used.

To measure instantaneous CO_2 concentration in the air sealed chamber an infrared gas analyzer (PP systems, EGM-4) was used. The measurement period lasted for 75-105 seconds. For CH_4 concentration, four 20 ml gas samples were collected from the headspace with three-way stopcock syringes at 7, 15, 25, and 35 minutes after sealing the chamber. The samples were then transferred to pre-evacuated Exetainers (Labco Ltd., UK). The gas samples were analyzed using a

Varian Gas Chromatograph 3800 (GC) equipped with a flame ionization detector for CH_4 concentration. Water table (WT) from nearby well was measured during both CO_2 measurement and CH_4 sample collection. Soil temperature at 5 cm depth was collected by using a thermocouple thermometer close to the collar.

RESULTS

Environmental Characteristics

This research only investigated the effect of WT and soil temperature at 5 cm depth on greenhouse gas fluxes as environmental variables although it is possible to incorporate many other variables such as temperature at different depths, air temperature, vegetation biomass, precipitation, etc. The mean WT at cutover site before (2009) and after (2010) rewetting was -14.27 ± 13.65 cm and -16.51 ± 14.83 cm respectively. At natural site it was -17.7 ± 14.44 cm (2009) and -26.97 ± 13.53 cm (2010). Despite restoration efforts, dry conditions occurred in 2010 resulting in no WT rise at the cutover site; however, water table was similar to 2009 despite evidence of the large drawdown that occurred in the natural site in response to the dry conditions. Mean (± standard deviation) temperature at 5 cm depth was similar (17.80 ± 1.43 ºC in 2009 and 16.75 ± 2.00ºC in 2010) at the cutover site during the study period. However there was a variation in 5 cm soil temperature at natural site between 2009 (18.13 ± 1.39 ºC) and 2010 (15.44 ± 1.03 ºC).

Greenhouse Gas Flux

The mean (± standard deviation) GEP_{max} (GEP at PAR ≥ 1000 μmol m^{-2} s^{-1}) value for revegetated areas of the cutover site was -33.01 ± 6.06 g CO_2 m^{-2} day^{-1} and -47.04 ± 13.72 g CO_2 m^{-2} day^{-1} in 2009 and 2010, respectively. The value for natural site was -28.82 ± 2.13 g CO_2 m^{-2} day^{-1} in 2009 and -31.690 ± 15.60 g CO_2 m^{-2} day^{-1}. The measured GEP_{max} varied significantly between vegetation communities in 2009 (ANOVA – F = 6.28, P < 0.05; Table - 1) as well as in 2010 (ANOVA – F = 3.85, P < 0.05; Figure - 1). During both years of study GEP_{max} was lowest at Nhum and highest at Sci_atr and it was important to note that the GEP_{max} increased about 1.5 times for Sci_atr, Eri_vag and Typ_lat after rewetting.

Table 1. Mean (standard deviation) GEP_{max}, R_{TOT}, NEE_{max} and CH_4 flux in 2009. GEP_{max}, R_{TOT} and NEE_{max} are measured in g CO_2 m^{-2} day^{-1}. CH_4 fluxes are measured in mg CH_4 m^{-2} day^{-1}.

Plots	GEPmax Mean(±SD)	R_{TOT} Mean(±SD)	NEEmax Mean(±SD)	CH_4 Flux Mean(±SD)
Car_aqu	-30.65(4.05)	13.21(2.97)	-17.44(2.91)	56.12 (13.99)
Cal_can	-34.85(8.81)	20.16(4.92)	-14.68(4.09)	9.95 (5.91)
Equ_arv	-26.39(7.94)	15.54(2.97)	-10.85(4.97)	14.35 (12.03)
Typ_lat	-31.79(5.77)	10.86(0.37)	-20.93(6.04)	231.96 (98.30)
Sci_atr	-42.04(6.64)	19.26(1.69)	-22.78(5.02)	16.23 (1.86)
Eri_vag	-32.36(3.16)	13.39(0.44)	-18.97(3.18)	32.83 (5.70)
Bare peat	--	3.18(0.29)	3.18(0.29)	0.11 (0.32)
Nhum	-15.48(1.79)	18.09(4.20)	2.61(3.81)	3.25 (1.75)
Nhol	-40.09(2.34)	17.83(1.10)	-22.26(3.35)	15.66 (4.66)

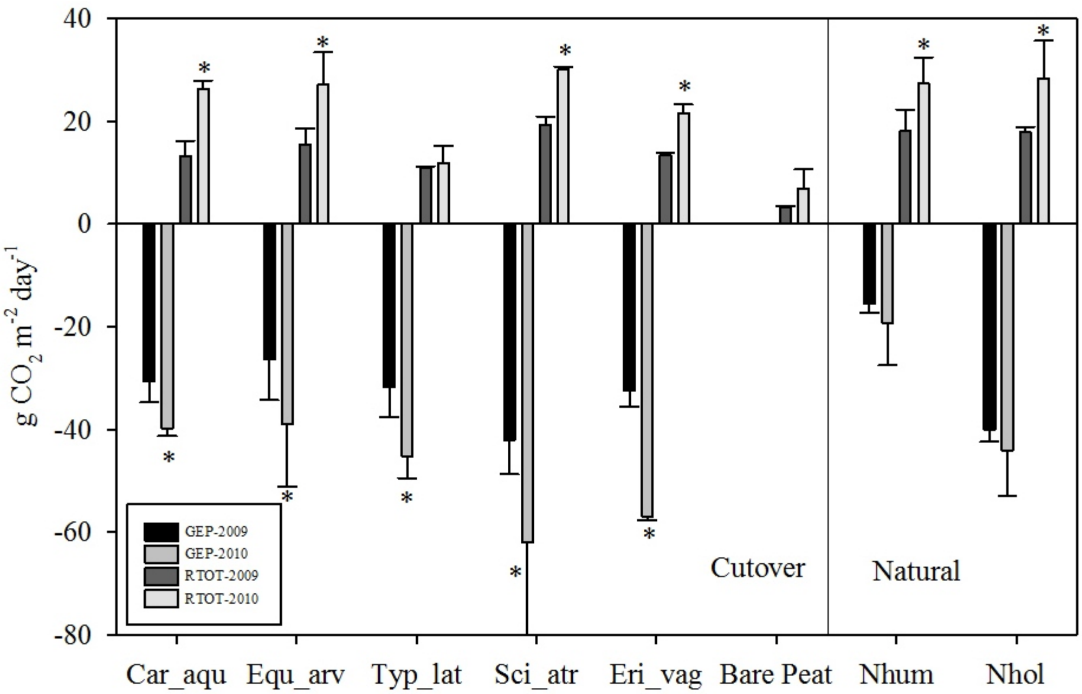

Figure 1. Seasonal mean measured GEP_{max} and R_{TOT} in 2009 and 2010. Error bars are showing ± standard deviation of mean value. * denotes significant difference between the years at that plot.

The mean measured R_{TOT} (i.e. measured CO_2 exchange at complete dark condition) at cutover site was 13.66 ± 1.95 g CO_2 m^{-2} day^{-1} and 19.70 ± 9.74 g CO_2 m^{-2} day^{-1} in 2009 and 2010 respectively. At the natural site it was 18.19 ± 2.44 in 2009 and 27.81 ±5.67 g CO_2 m^{-2} day^{-1} in 2010. One-way ANOVA showed that there was significant difference of R_{TOT} between vegetation species in 2009 (ANOVA – F = 14.57, P = 0.00) and 2010 (ANOVA – F = 2.76, P = 0.00). The lowest R_{TOT} in both years of study was observed at bare peat. The highest R_{TOT} was observed at Cal_can in 2009 and at Sci_atr in 2010 while Cal_can was not measured in 2010. It is important to note that R_{TOT} for all revegetated and natural vegetation as well as bare peat increased after rewetting by as much as two times for few species (e.g. – Car_aqu, Eri_vag and Nhol; Figure - 1). This may be partially linked to the dry growing season of 2010.

The CH_4 flux varied between studied vegetation communities during the study period (Table -1, Figure - 2). Seasonal mean (± standard deviation) CH_4 flux ranged from 0.11 ± 0.32 mg CH_4 m^{-2} day^{-1} to 231.96 ± 98.30 mg CH_4 m^{-2} day^{-1} and -1.19 ± 2.23 mg CH_4 m^{-2} day^{-1} to 190.35 ± 52.00 mg CH_4 m^{-2} day^{-1}in 2009 and 2010 respectively. Among the recolonizing and natural fen communities the median flux was significantly higher at Typ_lat than all other vegetation types in 2009 (Mood's median, Chi-Square =130.52; DF = 9; p = 0.00) as well as in 2010 (Mood's median, Chi-Square =14.67; DF = 7; p = <0.05).

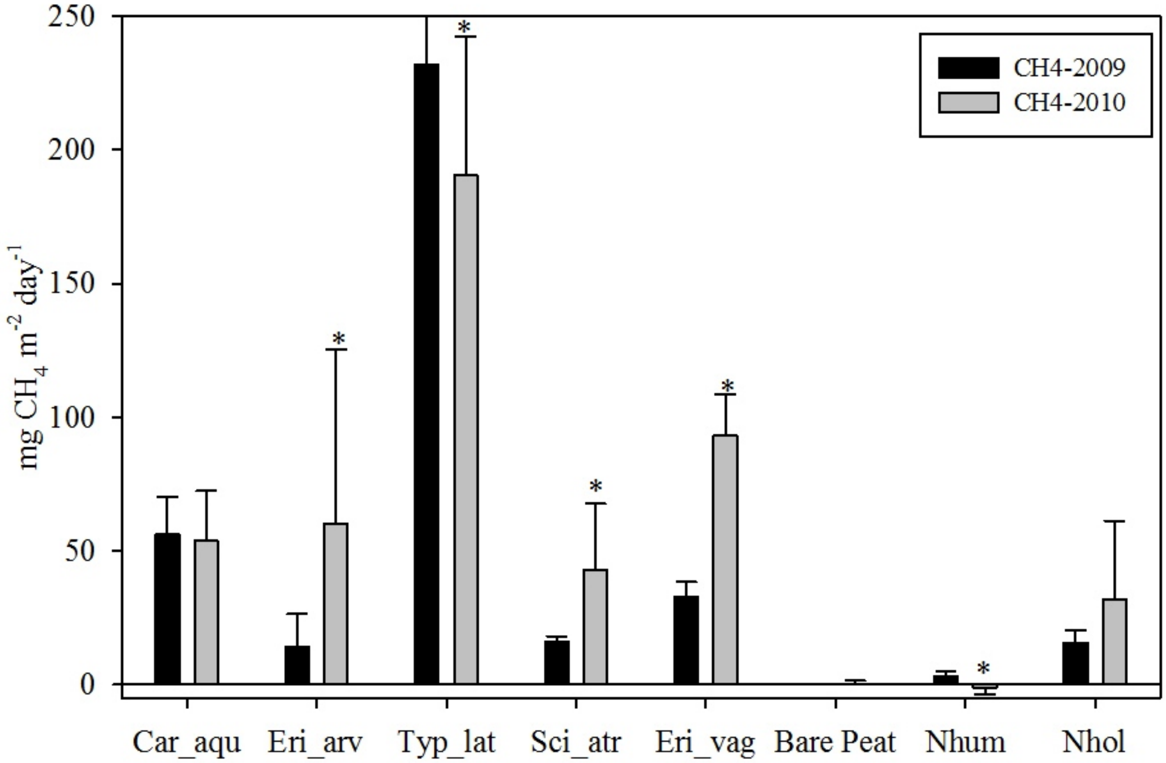

Figure 2. Mean growing season CH_4 flux in 2009 and 2010. Error bars are showing ± standard deviation. * denotes significant difference between the years at that plot.

After rewetting although the CH_4 flux was almost same for Car_aqu, all other species such as Eri_vag and Sci_at showed almost a doubling of CH_4 flux. In contrast, bare peat was actually CH_4 sink in 2010.

Environmental Controls on Greenhouse Gas Flux

The study found significant correlation between average WT and GEP_{max} in natural site only in 2009 (Table - 2). However, the WT was significantly related with R_{TOT} for both natural and revegetated site in 2009 (Table - 2). No statistical significant correlation was observed between GEP_{max} and temperature at 5 cm depth (T5) during the study period. R_{TOT} was only related to T5 in 2009 at revegetated sites (Table - 2).

Table 2. Pearson's correlation coefficient between mean water table (WT), soil temperature at 5 cm depth (T5) and GEP_{max}, R_{TOT}, CH_4 flux at revegetated (Rveg.) and natural site. Values outside and inside the brackets are representing year 2009 and 2010 respectively. Bold letters indicating correlation is significant at $P < 0.05$.

Site	CO_2 - GEP_{max}		CO_2 - R_{TOT}		CH_4	
	WT	T5	WT	T5	WT	T5
Revg.	0.185(-0.067)	0.287(-0.030)	**-0.516**(0.320)	-0.135(**-0.556**)	**0.615**(**0.786**)	-0.147(-0.264)
Natural	**-0.882**(-0.743)	-0.151(-0.623)	**0.889**(-0.028)	0.096(0.443)	0.725(0.679)	0.412(0.560)

During the study period WT was significantly related to CH_4 flux at revegetated sites but no relation was observed at natural site. The study did not observe any important effect of soil temperature at 5 cm depth on CH_4 flux.

DISCUSSION AND CONCLUSION

The average GEP_{max} value reported in minerotrophic peatlands is -19.0 g CO_2 m^{-2} day^{-1} (Frolking *et al.*, 1998). The growing season mean R_{TOT} from many studies shows that it varies from 3.7 to 25.7 g CO_2 m^{-2} day^{-1} (Moore, 2002; Saarnio *et al.*, 2003) and mean measured R_{TOT} for bare peat in both natural and laboratory condition is 5.2 ± 4.2 g CO_2 m^{-2} day^{-1} (Waddington *et al.*, 2010). The seasonal average GEP_{max} at BSF revegetated site was about two and three times higher than literature values both before and after rewetting. However, the value at natural site was only slightly higher than the reported value. Thus, revegetation and rewetting increased the CO_2 accumulation rate under full light condition. On the other hand the R_{TOT} value at recolonized site was within the reported range in both years of study. This value for natural site was also consistent with literature cited value in 2009 but was little higher in 2010. Bare peat R_{TOT} was the lowest of sites studied and similar to the literature value during the study period. The increased R_{TOT} value after rewetting for few species is mainly associated with higher accumulation of CO_2 discussed above (increase in autotrophic respiration) and may also be linked to slightly deeper WT in the dry 2010 growing season (increased heterotrophic respiration, particularly for Nhum and Nhol sites).

According to Saarnio *et al.* (2007) CH_4 flux from natural minerotrophic peatlands ranges from 98.00 mg CH_4 m^{-2} day^{-1} to 249.00 mg CH_4 $m^{-2}day^{-1}$. At BSF, with the exception of Typ_lat, the revegetated plots' CH_4 flux was much lower than this range even after rewetting. However, rewetting increased CH_4 flux at revegetated site. Bare peat's CH_4 flux was close to zero and after rewetting it acted as a sink. This result is consistent with Waddington and Day (2007) where they found similar results for cutover peatlands. From mean seasonal WT it is evident that the water table became deeper after rewetting probably due to the dry characteristics of the study year. Overall revegetation and rewetting increased the CO_2 flux under full light condition. Like CO_2 flux, CH_4 flux also increased but it was still lower than previous studies. In conclusion, although this research found increased greenhouse gas flux because of revegetation and rewetting other factor such as vegetation biomass, soil temperature at different depth, air temperature, relative humidity, precipitation need to be incorporated to explore the actual process and mechanism behind this increased value. Continued study at this site is recommended to determine the effects of rewetting in wetter growing seasons and the response of the vegetation communities to the rewetting efforts over time.

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REFERENCES

Alm, J., Shurpali, N.J., Tuittila, E.-S., Laurila, T., Maljanen, M., Saarnio, S. and Minkkinen, K. (2007). Methods for determining emission factors for the use of peat and peatlands-flux measurement and modeling. *Boreal Environment Research* **12**, 85-100.

Bridgham, S.D., Megonigal,J.P.,Keller,J.K., Bliss, N.B. and Trettin,C. (2006). The Carbon balance of North American Wetlands. *Wetlands* **26**, 889-916.

Frolking, S.E., Bubier, J.L., Moore, T.R., Ball, T., Bellisario, L.M., Bhardwaj, A., Carroll, P., Crill, P.M., Lafleur, P.M., McCaughey, J.H., Roulet, N.T., Suyker, A.E., Verma, S.B., Waddington, J.M. and Whiting, P.J. (1998). Relationship between ecosystem productivity and photosynthetically active radiation for northern peatlands. *Global Biogeochemical Cycles* 1**2**, 115–126.

Graf, M.D., Rochefort, L. and Poulin, M. (2008). Spontaneous revegetation of cutaway peatlands of North America. *Wetlands* **28**, 28-39.

Irish Peatland Conservation Council (IPCC), (2000). Peatlands Around the World. Web: http://www.ipcc.ie/wptourhome1.html

Moore, P.D. (2002). The future of cool temperate bogs. *Environmental conservation* **29**, 3 – 20.

Rochefort L., Quinty, F., Campeau, S., Johnson,K. and Malterer, T. (2003). North American approach to the restoration of Sphagnum dominated peatlands. *Wetlands Ecology and Management* **11**, 3-20.

Saarnio, S., Järviö, S., Saarinen, T., Vasander, H. and Silvola, J. (2003). Minor changes in vegetation and carbon gas balance in a boreal mire under a raised CO_2 or NH_4NO_3 supply. *Ecosystems* **6**, 46 – 60.

Saarnio, S., Morero, M., Shurpali, N., Tuittila, E.-S., Mäkilä, M. and Alm, J. (2007). Annual CO_2 and CH_4 fluxes of pristine boreal mires as a background for the lifecycle analyses of peat energy. *Boreal Environment Research* **12**, 101–113.

Waddington, J.M. and Day, S.M. (2007). Methane emissions from a peatland following restoration. *Journal of Geophysical Research* **112**, G03018, doi:10.1029/2007JG000400

Waddington, J.M., Warner, K.D. and Kennedy, G.W. (2002). Cutover peatlands: A persistent source of atmospheric CO_2. *Global Biogeochemical Cycles* **16**, 1002, doi:10.1029/2001GB001398.