



Assessing the role of ecological succession for peatland methane dynamics: potential climate change feedback

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Summary

It is expected that climate change will result in lower water tables for many boreal peatlands, potentially reducing CH₄ emissions. However, since the presence of vascular vegetation can enhance CH₄ efflux, if lower water tables result in higher vascular plant abundance CH₄ emissions may be maintained or increased. The goal of this study was to investigate the changing role of vascular vegetation for CH₄ dynamics by comparing fluxes between a natural peatland and sites with experimentally lowered water tables. Fluxes were measured across a microtopographic gradient from dry hummocks to intermediate lawns to wet hollows. Methane emissions were lower at sites with lowered water tables. However, while CH₄ flux was substantially lowered at hummocks and lawns, hollow fluxes remained relatively high. This corresponded with an increase in *Sphagnum* cover and sedge biomass following water table drawdown. In general, it appears that increased biomass mitigates the effect of the lower water table at hollows, while abundant above and belowground biomass at lawns contributes to CH₄ oxidation and the reduction in CH₄ flux.

Key index words: climate change, ecological succession, methane, microtopography, water table drawdown

Introduction

Northern peatland ecosystems will likely be affected greatly by climate change (IPCC, 2007), with increasing temperature potentially resulting in lower water table positions (Roulet *et al.*, 1992). Because methane (CH₄) is produced in anoxic conditions observed below the water table and oxidized in the oxic unsaturated zone, these lower water tables could reduce peatland CH₄ emissions (Roulet *et al.*, 1992; Moore *et al.*, 1998). However, shifts in the water table may result in ecological succession with subsequent impacts on CH₄ dynamics. The presence of abundant sedges in peatlands is known to affect CH₄ dynamics by providing fresh substrate for CH₄ production, transporting oxygen below the water table enhancing CH₄ oxidation and transporting CH₄ from below the water table to the atmosphere through aerenchyma (e.g. Waddington *et al.*, 1996; Popp *et al.*, 2000). Generally, increases in sedge biomass result in increased CH₄ efflux (e.g. Bellisario *et al.*, 1999) suggesting that if lower water tables result in enhanced sedge abundance CH₄ emissions may increase despite slightly drier conditions. Finally, because the peatland surface is often differentiated into microtopographic units (microforms) that vary in depth to water table and vegetation type, the response of the vegetation community and CH₄ dynamics to water table drawdown will likely vary spatially (e.g. Strack *et al.*, 2004).

The objectives of this study were to: 1) determine the response of CH₄ efflux to water table drawdown, and 2) investigate correlations between the changing vegetation community and CH₄ efflux and differences in response along the microtopographic gradient and through time.

Materials and methods

Study site

The study was carried out in a poor fen (46°40'N 71°10'W) near St. Charles-de-Bellechasse (SCB), Québec, Canada. Within the fen are several pool-lawn-ridge complexes: 1) the control site had a natural water table position (un-manipulated) throughout the study; 2) the experimental site was monitored in 2001 with a natural water table position, and subjected to a water table drawdown of ~20 cm in June 2002; 3) the drained site was subjected to a water table drawdown of ~20 cm in 1993. Measurements were made along the microtopographic gradient at each site with three gas flux plots at hummocks, three at lawns and three at hollows for a total of nine plots per site.

Methane fluxes and pore water concentration

Methane flux was determined using the closed chamber technique (Tuittila *et al.*, 2000) and CH₄ concentration of gas samples determined on a Varian 3800 gas chromatograph. Fluxes were measured throughout the growing



season in 2001-2004 and have been reported elsewhere. In order to compare fluxes with measurements taken during an intensive field campaign in 2007, only late July – early August fluxes are reported here.

Pore water CH₄ concentrations were determined in sealed mini-piezometers (see Strack *et al.*, 2006) installed at lawns and hollows in 2007. Concentration was determined at 25, 50 and 75 cm below the surface by collecting water from the sampler at that depth, equilibrating it with an equal portion of atmospheric air by shaking for five minutes, and determining the CH₄ concentration in the resulting headspace on the Varian GC. Ambient CH₄ concentration was also determined to correct for CH₄ added with atmospheric air.

Environmental variables

Water table was determined at each plot in perforated PVC wells installed adjacent to the flux sampling locations. The vegetation community at each plot was described by visually estimating the cover of all species. In August 2007 aboveground biomass was determined at each lawn and hollow plot by clipping all vegetation in a representative 7.5 x 7.5 cm quadrat adjacent to the plot. Belowground biomass was determined at lawns and hollows by collecting one 7.5 cm x 7.5 cm x 50 cm deep core at each microform and removing all living roots in 5 cm depth increments. Above and belowground biomass dry mass was determined following drying at 85°C for 48 hours.

Results

On average (\pm standard deviation) the water table was -5 ± 11 cm under natural conditions, -12 ± 13 cm at experimental and -15 ± 13 cm at drained following three and nine seasons of water table drawdown, respectively (Table 1). Water table remained close to the surface at lawns and hollows due to peat subsidence (Whittington & Price, 2006).

The vegetation community shifted in response to water table drawdown with differential responses among microforms (Strack & Waddington, 2007; St-Arnaud, 2007). Comparing the drained and control site, water table drawdown resulted in a reduction in *Sphagnum* moss cover at hummocks, an increase in sedge cover (predominantly *Carex oligosperma*) at lawns and an increase in *Sphagnum* moss cover at hollows. Evidence from the experimental site indicates that the vegetation community

response takes between 2 and 9 years (St-Arnaud, 2007). This changing vegetation community was evident in aboveground and belowground biomass increases at lawns and hollows following water table drawdown (Fig. 1).

Water table drawdown and the changing vegetation community affected CH₄ dynamics at the site. When site averaged CH₄ emissions were considered, water table drawdown resulted in a reduction in CH₄ efflux in both the short (3-4 years) and longer term (8-9 years) (Fig. 2a). However, when microform averages were considered, CH₄ flux was reduced at hummocks and lawns, but maintained similar to natural fluxes at hollows (Fig. 2b). Pore water CH₄ concentrations were reduced following water table drawdown. On August 1, 2007 average concentrations between 25 and 75 cm depth were 5.1 and 6.5, 1.6 and 1.2, and 1.2 and 2.2 mg l⁻¹ at lawns and hollows of the control, experimental and drained sites respectively.

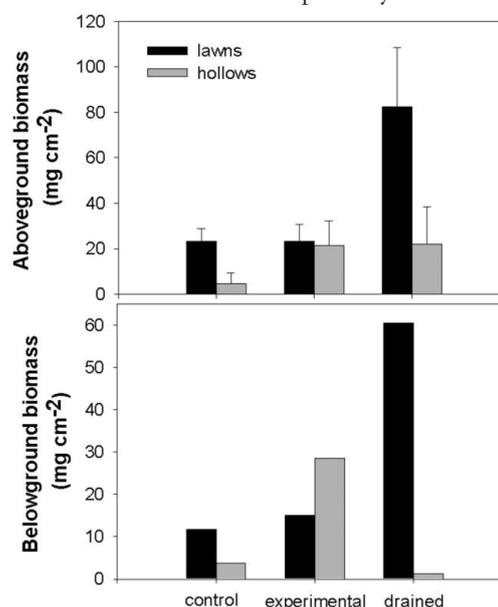


Figure 1. Aboveground (top) and belowground (bottom) biomass at lawn and hollow microforms in 2007. All values are dry weights. Control site has a natural water table position while experimental and drained sites have had the water table lowered for five and 14 years, respectively. Aboveground biomass is the mean of triplicate samples and error bars give standard deviation. Belowground biomass is the sum of all living biomass determined from one 50 cm deep core.

Table 1. July/August water table position at each microform following different lengths of water table drawdown. No measurements were made at hummocks in 2007, so water table is given as not measured (n.m.).

Time since water table drawdown (years)	Site (year)	Water table position (mean \pm std deviation)		
		Hummock	Lawn	Hollow
0 (natural conditions)	Control (2001-2007) & Experimental (2001)	-15.4 ± 4.1	-8.5 ± 4.7	9.0 ± 11.0
1-3	Experimental (2002-2004)	-22.4 ± 7.3	-15.4 ± 2.8	1.4 ± 1.4
5	Experimental (2007)	n.m.	-16.7 ± 3.9	2.8 ± 4.3
8-9	Drained (2001-2002)	-31.6 ± 8.2	-6.5 ± 5.2	-7.9 ± 3.8
14	Drained (2007)	n.m.	-13.4 ± 3.9	-11.5 ± 2.5

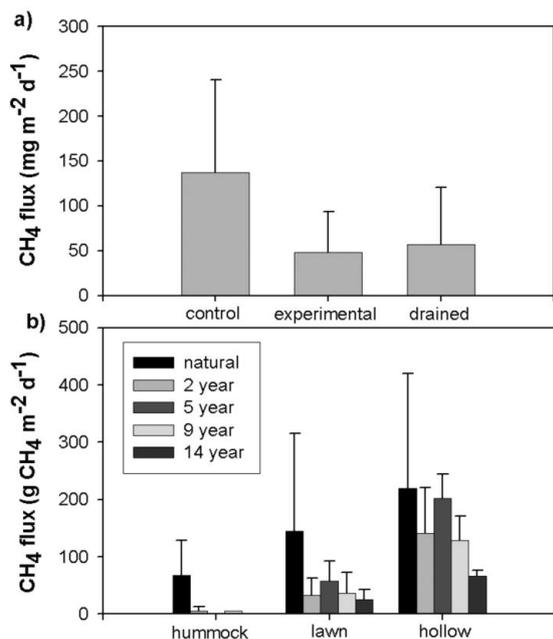


Figure 2. Mean CH₄ flux a) across the microtopographic gradient and b) at individual microforms following varying durations of water table drawdown. All error bars give standard deviations. For (a) control includes all plots with natural water tables (control 2001-2004 and experimental 2001), experimental includes sites following 2-3 years of water table drawdown (experimental 2003-2004) and drained includes sites following 8-9 years of water table drawdown (drained 2001-2002). For (b), 2 and 5 year data are from experimental and 9 and 14 year data, from drained. No measurements were made at hummocks in 2007, so there is no data for 5 and 14 years.

Methane efflux was significantly ($R^2 = 0.36$, $p < 0.001$) related to water table when all microforms in all years were considered (Fig. 3a). Using this relationship, residuals for each point were determined and regressed against average sedge cover at that microform. Although weak, there was a significant relationship between the residuals of the water table – CH₄ relationship and sedge cover ($R^2 = 0.21$, $p = 0.04$; Fig. 3b).

Discussion and Conclusions

On average across the microtopographic gradient water table drawdown has resulted in a reduction in CH₄ emissions. However, the response of microforms varies due to a coupling of ecology and hydrology for controlling CH₄ flux. Although lower water table position reduces the size of the anoxic zone where CH₄ is produced and increases the size of the oxic zone where CH₄ may be oxidized, at initially wet microforms such as lawns and hollows, the overall depth of the oxic zone remains limited. However, this change in peat aeration, and in some cases removal of standing water, enables a shift in the vegetation community. This new vegetation provides fresh substrate that may result in enhanced CH₄ production. Also, when sedge vegetation colonizes the site, roots penetrating below the water table provide a pathway for CH₄ emission that bypasses the oxic

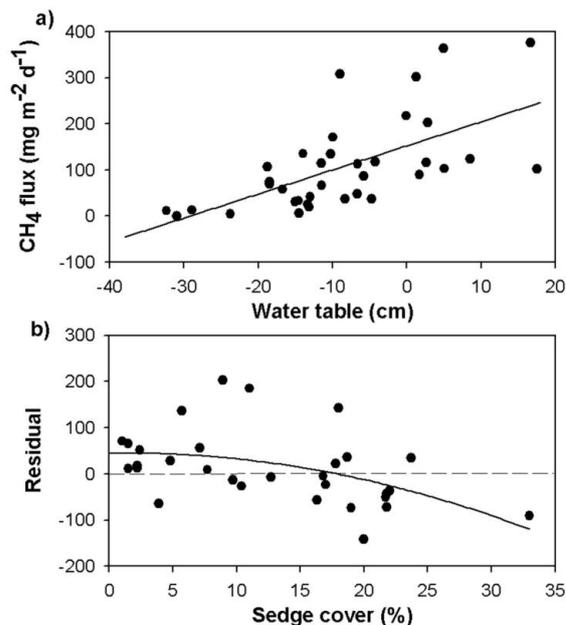


Figure 3. Mean microform CH₄ flux versus mean microform water table position (a). The line represents a significant linear relationship ($y = 5.2x + 152.4$, $R^2 = 0.36$, $p < 0.001$, $n = 36$). Residual around the CH₄ flux-water table relationship versus sedge coverage (b). The line represents a weak quadratic relationship ($y = 0.47x^2 + 0.16x + 44.5$, $R^2 = 0.21$, $p = 0.04$, $n = 30$). This suggests that low to moderate sedge cover increases CH₄ flux above that expected based on water table position whereas sedge cover greater than ~20%, decreases CH₄ flux.

zone, but may also bring oxygen to depth resulting in CH₄ oxidation below the water table.

An increase in belowground biomass was evident following water table drawdown (Fig. 2). Much higher belowground biomass at drained lawns than at experimental lawns suggests that the size of this biomass pool continues to grow even after five years of lowered water tables. At hollows, a reduction in belowground biomass is observed in the longer term (drained), suggesting a possible shift from vascular to moss dominance through time. This is visually evident at the site and has been shown by St-Arnaud (2007). A reduction in vascular vegetation cover at hollows following 14 years of water table drawdown may result in lower CH₄ fluxes (Fig. 2); however, since this reduction is observed in only 2007 measurements, more data is needed to ensure that these lower values are not merely a result of inter-annual variability.

At wet hollow microforms, the observed ecological succession likely helps maintain CH₄ flux despite lowered water tables (Fig. 2). However, as biomass increases beyond some point, CH₄ fluxes are lowered, likely due to the enhancement of oxidation below the water table (Fig. 3b). Reduced pore water concentrations following water table drawdown are consistent with this hypothesis. Moreover, previous clipping experiments at this study site (Strack *et*



al., 2006) suggest that removal of sedges from control lawns where biomass is moderate, resulted in a reduction in CH₄ efflux, whereas clipping at highly vegetated drained lawns enhanced CH₄ flux in many cases.

In the short-term (2-5 years) hollow fluxes may be maintained by increasing the coverage of sedges that can provide labile substrate and mechanism of transport. When sedge cover is high, for example at drained lawns, reduction of CH₄ flux via enhanced oxidation in the anoxic zone may be greater than production and transport effects. Further investigation is required to quantify the relative importance of each role. In the longer term (> 14 years) a reduction in sedge cover in favour of *Sphagnum* moss may result in reduced CH₄ fluxes.

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