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), Quebec, 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

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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 CH$_4$ 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 CH$_4$ concentration in the resulting headspace on the Varian GC. Ambient CH$_4$ concentration was also determined to correct for CH$_4$ 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 (± 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 CH$_4$ dynamics at the site. When site averaged CH$_4$ emissions were considered, water table drawdown resulted in a reduction in CH$_4$ efflux in both the short (3-4 years) and longer term (8-9 years) (Fig. 2a). However, when microform averages were considered, CH$_4$ flux was reduced at hummocks and lawns, but maintained similar to natural fluxes at hollows (Fig. 2b). Pore water CH$_4$ 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.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|}
\hline
Time since water table drawdown (years) & Site (year) & Water table position (mean ± std deviation) \\
\hline
0 & Control (2001-2007) & Hummock: -15.4 ± 4.1 & Lawn: -8.5 ± 4.7 & Hollow: 9.0 ± 11.0 \\
& (natural conditions) & Experimental (2001) & & \\
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 \\
\hline
\end{tabular}
\caption{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.].}
\end{table}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{fig1.png}
\caption{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.}
\end{figure}
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 – CH$_4$ 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 CH$_4$ emissions. However, the response of microforms varies due to a coupling of ecology and hydrology for controlling CH$_4$ flux. Although lower water table position reduces the size of the anoxic zone where CH$_4$ is produced and increases the size of the oxic zone where CH$_4$ 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 CH$_4$ production. Also, when sedge vegetation colonizes the site, roots penetrating below the water table provide a pathway for CH$_4$ emission that bypasses the oxic zone, but may also bring oxygen to depth resulting in CH$_4$ 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 CH$_4$ 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 CH$_4$ flux despite lowered water tables (Fig. 2). However, as biomass increases beyond some point, CH$_4$ 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
suggest that removal of sedges from control lawns where biomass is moderate, resulted in a reduction in CH\textsubscript{4} efflux, whereas clipping at highly vegetated drained lawns enhanced CH\textsubscript{4} 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 CH\textsubscript{4} 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 CH\textsubscript{4} fluxes.

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**References**


