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METHANE FLUX:WATER TABLE RELATIONS IN NORTHERN WETLANDS

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Abstract. Water table position, through the creation of aerobic and anaerobic conditions in the soil profile, plays an important role in controlling CH_4 flux from wetlands. A laboratory study of peat columns revealed that CH_4 emission rates initially increased and then decreased as the water table was lowered from the peat surface to a depth of 50 cm, with the release of CH_4 trapped in pores. There was a strong hysteresis between CH_4 flux on the falling and rising water table limbs (falling > rising). When expressed as seasonal average values, there was a strong relationship (r^2 0.08 - 0.74) between log CH_4 flux and water table position for sites within 5 wetland regions in boreal-subarctic Canada. The regression coefficients were similar among regions (0.022 - 0.037), but there were differences in the regression constants (0.47 - 1.89). CH_4 flux from drained, forested peatland soils decreased as the water table depth increased, and several sites were transformed from sources to sinks of CH_4. Global CH_4 emissions to the atmosphere may have been reduced by $\approx$ 1 Tg yr^{-1} by peatland drainage during the last 100 yr.

Introduction

The atmospheric concentration of methane (CH_4) is increasing at about 1 ppbv yr^{-1} but at a slowing rate (Steele et al., 1992) and, of the annual global emission of 500 Tg CH_4, $\approx$ 110 Tg yr^{-1} is believed to be emitted from wetlands in northern and tropical regions (Fung et al., 1991). Interpretations of the environmental controls on CH_4 emission commonly focus on peat or sediment temperature, water table position, and substrate quality for microbial CH_4 production and consumption. Identification and quantification of the relations between these 3 controls and CH_4 flux from wetlands is important to the understanding of current emissions and to the extrapolation of point measurements to the regional scale, through either measurement of these factors across landscapes (Matson and Vitousek, 1990) or by using indirect features such as vegetation (Roulet et al., 1992a). In addition, predicting the effect of climate variability and change on CH_4 emissions is also dependent on these relationships (Roulet et al., 1992b).

Although some studies (e.g. Crill et al., 1988) have shown strong correlations between CH_4 flux and either temperature or water table position, or a combination of both, many do not (e.g. Moore et al., 1990; Whalen and Reeburgh, 1992). There are several explanations for this indistinct pattern, in addition to the high spatial variability of field flux measurements (coefficients of variation commonly fall between 50 and 100 %) leading to imprecise estimates of flux on individual dates (Bartlett et al., 1989). The temperature dependences of rates of microbial CH_4 consumption and production are different: the former have Q_{10} values ranging from 1.2 to 2.1, whilst the latter fall in the range 2.1 to 6.8 (Dunfield et al., in press). There is a strong temporal association between peat temperature and water table position, with warmer surface and cooler deep temperatures associated with lower water tables, leading to confounding influences on CH_4 flux. Episodic fluxes of CH_4 have been observed, in which the flux on particular days is significantly greater than on the surrounding sampling dates: these have been ascribed to decreases in atmospheric pressure over shallow lakes (Mattson and Likens, 1990) or falls in water table position (Windsor et al., in press).

To better identify the influence of water table position on CH_4 flux from wetlands, we report on a laboratory study of peat columns in which the water table was lowered and raised, the collation of data of field CH_4 fluxes from several wetland regions in Canada, and the effect of lowering the water table through drainage of forested peatlands.

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Results

To establish the effect of a dynamic water table on CH_4 under controlled conditions, columns (70 cm long, 10 cm diameter) of peat representing bog, fen and swamp types were constructed in PVC tubes. After saturation for 20 d, the water table was lowered at a rate of 2 cm d^{-1} until a depth of 50 cm below the peat surface was reached; it was kept at that depth for 15 d and then raised to the surface at the same rate. Flux was measured by determining CH_4 concentration changes in the sealed headspace over periods of 1 - 4 h.

Although the 3 peat types varied in the magnitude of CH_4 flux, they showed the same pattern of increasing fluxes with falling water table from the surface to a depth of 20 cm, then decreased fluxes as the water table fell to 50 cm (Figure 1). The increase in CH_4 flux in the upper part of the peat column is related to increased gas diffusivity (25 - 30 % air-filled porosity after drainage) and the release of CH_4 trapped in pore water

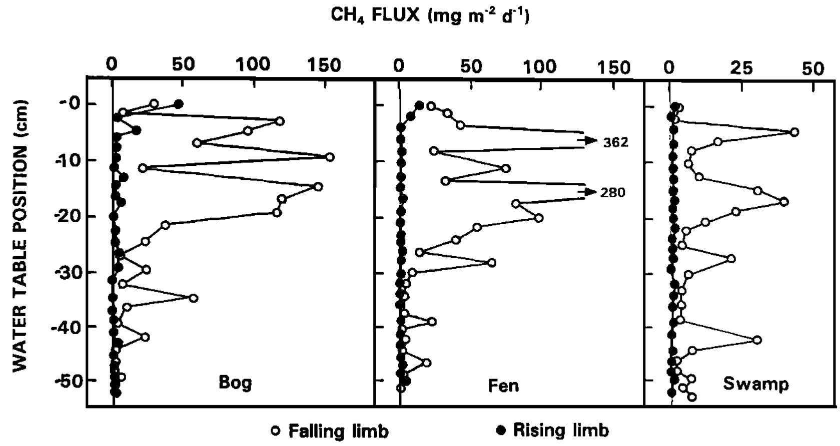

Fig. 1. CH_4 flux from laboratory peat columns of bog, fen and swamp soils, subjected to falling and then rising water table. Each point represents the mean of 5 replicate columns.

(concentration of 2.3 - 9.0 mg CH_4 L^{-1}, equivalent to 0.9 - 3.6 g CH_4 m^{-2} per 50 cm depth of peat). The peak fluxes within the falling limb appeared to be correlated with decreases in atmospheric pressure (Mattson and Likens, 1990). CH_4 fluxes on the rising limb were very small until the water table reached close to the surface, with ratios of CH_4 emitted on the falling to rising limbs varying from 9:1 to 116:1. This strong hysteresis may explain why temporal patterns between CH_4 flux and water table position in field soils are difficult to establish.

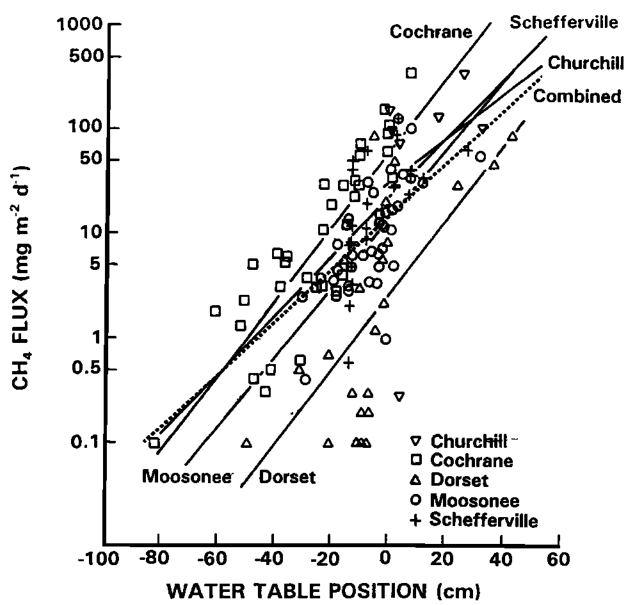

Fig. 2. Relation between the mean daily CH_4 flux (as logarithm) and mean water table position (cm) for wetland sites in 5 regions of boreal and subarctic Canada. Each point represents the mean of between 50 and 120 CH_4 flux measurements at each site during the snow-free season, generally May to September. Data were derived from: Churchill (S. Holland, personal communication, 1992); Cochrane (J. Bubier, personal communication, 1992); Dorset (Roulet et al., 1992a); Moosonee (Moore et al., in press); Schefferville (Moore et al., 1990).

There are stronger relationships between CH_4 flux and water table position when seasonal average values for a range of sites are compared. This pattern is illustrated in Figure 2 for 5 regions in which CH_4 flux measurements have been made: Churchill at the subarctic/arctic border in the Hudson Bay Lowland, Moosonee in the subarctic/high boreal section of the Hudson Bay Lowland, Cochrane in the high boreal region of northern Ontario, Dorset in the low boreal region of southern Ontario and Schefferville in the high boreal/subarctic region of northern Québec. In each region, at between 7 and 38 sites representing the major wetland types, CH_4 flux measurements were made at approximately weekly intervals from spring to fall by a static chamber technique (Moore and Roulet, 1991).

For the combined data set, there is a strong relationship ($r^2 = 0.332$, $p = 0.000$) between the logarithm of the average seasonal CH_4 flux and average seasonal water table depth (Figure 2, Table 1). Within each of the regions, there is also a significant regression, except for the Churchill region, with regression coefficients ranging from 0.022 to 0.037, which are not significantly different. This suggests that, within regional wetland landscapes, there is a very similar functional relationship between CH_4 flux and water table depth. There is, however, a strong difference between the position of the regression lines, illustrated by the regression constant which ranges from 0.47 and 1.89, with significant differences among them. The constant is greatest in the Cochrane and Churchill regions and least in Dorset. Thermal regime in the wetlands (e.g. seasonal average temperature at a depth of 20 cm) did little to improve the regressions. Moreover, peat temperature cannot explain differences among the regression constants, as the coldest soils, at Churchill, have the largest constant and the warmest, at Dorset, have the smallest. Differences in the capacity of the peat and sediment to produce and consume CH_4 in laboratory incubations range over 3 orders of magnitude and provide an explanation for differences among sites and regions (T.R. Moore, personal communication, 1992).

These results have been obtained from sites with an undisturbed hydrologic regime, in which there is a strong

TABLE 1. Regressions between average CH_4 flux and water table depth for the 5 regions and the combined data set depicted in Figure 2. Numbers in parentheses represent the standard error of the estimate for the regression coefficient and constant. Numbers in brackets indicate the number of sites sampled in each region.

Region	Regression Coeff.	Const.	r^2	St. Error Estimate	p
Churchill	0.022	1.54	0.079	1.087	0.541
[7]	(0.034)	(0.53)			
Cochrane	0.037	1.89	0.735	0.435	0.000
[36]	(0.004)	(0.13)			
Dorset	0.037	0.47	0.432	0.820	0.001
[23]	(0.009)	(0.18)			
Moosonee	0.034	1.23	0.446	0.399	0.000
[38]	(0.006)	(0.08)			
Schefferville	0.029	1.41	0.331	0.469	0.004
[23]	(0.009)	(0.11)			
Combined	0.026	1.22	0.332	0.698	0.000
[127]	(0.003)	(0.07)			

association among water table depth, wetland vegetation and peat type. Flooding induced by beaver dams or shallow reservoir construction can raise the water table in wetlands. CH_4 emissions from beaver ponds, where the water surface is 0 to 150 cm above the soil surface, range from 6 to 52 g m^{-2} yr^{-1} (J. Bubier, personal communication, 1992; Naiman et al., 1991; Roulet et al., 1992a). Shallow ponds in peatlands are also a major source of CH_4 (Hamilton et al., in press; Moore et al., in press), whereas CH_4 flux from lakes is controlled by oxidation in the water column and cool sediment temperatures (Rudd and Taylor, 1980).

Lowered water tables in peatlands are established by drainage for crops, peat harvesting or forestry, covering 20 x 10^{10} m^2 in temperate and boreal regions (Armentano and Menges, 1986; Gorham, 1991). We measured CH_4 fluxes at several locations perpendicular to ditches at two sites in a forested peatland at Wally Creek in northern Ontario, in which the water table had been lowered 7 yr previously to stimulate tree growth. CH_4 flux decreased as the depth to water table increased, closer to the drainage ditch, and some locations became overall consumers of atmospheric CH_4 (Figure 3). In drained horticultural peats near Montreal, water tables lowered to depths of 1 m or more reduced CH_4 emissions to < 1 mg m^{-2} d^{-1} (Glenn et al., in press). Several of these drained peats convert from a source to a small CH_4 sink (uptake of < 3 mg m^{-2} d^{-1}), as has been observed in soils in boreal forest, desert, taiga and tundra regions (Steudler et al., 1990; Striegl et al., 1992; Whalen and Reeburgh, 1990; Whalen et al., 1991). Assuming that CH_4 flux from peatlands prior to drainage averaged 5 g m^{-2} yr^{-1}, and a temperate drained peatland area of 20 x 10^{10} m^2 (Armentano and Menges, 1986; Gorham, 1991), the reduction in global CH_4 emissions to the atmosphere from temperate and subarctic wetland drainage during the last century would be ≈ 1 Tg yr^{-1}.

Conclusion

This study has shown there are complex but strong relationships between the position of the water table and the emission of CH_4 in peatland soils. The relationship is complex where the water table moves in the profile, creating difficulties in the interpretation and prediction of seasonal fluxes from field soils. However, the relationship becomes clearer when seasonal average values for flux and water table position are examined for both natural wetland systems and those affected by drainage. The water table:CH_4 flux relationship is relevant to predicting not only regional estimates of CH_4 flux, but also the effect of climatic change on CH_4 fluxes from wetlands. Modelling the position and fluctuations of the water table will probably be of greatest significance in predicting the response of CH_4 flux to climatic change (e.g. Roulet et al., 1992b).

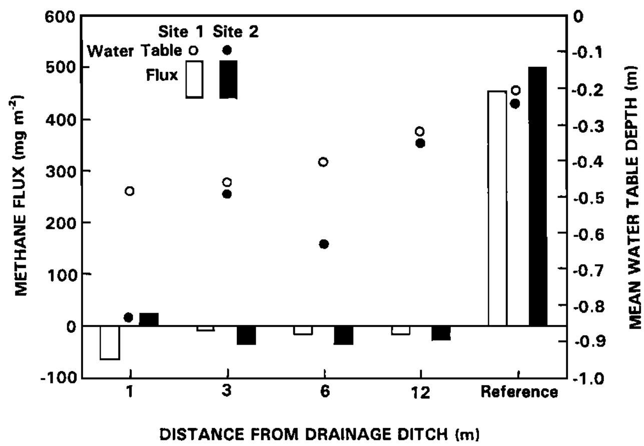

Fig. 3. Relationship between seasonal (May - October) CH_4 flux and mean seasonal water table depth at open bog (1) and treed bog (2) peatland sites in the Wally Creek Experimental Forest, near Cochrane, northern Ontario. The water table depth was lowered by drains installed in the forest 7 yr before measurement of the fluxes. The change in water table position represents the influence of the drainage ditch from undisturbed (reference) to ditch edge (1 m) locations.

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