# NORTHERN CANADIAN WETLANDS: NET ECOSYSTEM $CO_2$ EXCHANGE AND CLIMATIC CHANGE

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**Abstract.** Northern Canadian peatlands represent a long term sink for atmospheric carbon dioxide ($CO_2$), however there is concern they may become a net source of $CO_2$ due to climatic change. Climatic change is expected to result in significant changes in regional hydrology in boreal and subarctic regions of Canada. A hydrologic model predicted a summer water table drop of 0.14 m in northern Canadian fens given an increase in summer temperature and rainfall of 3°C and 1 mm $d^{-1}$, respectively. Moreover, surface peat temperature increased by 2.3°C. Net ecosystem exchange of $CO_2$ was modelled using these modelled hydrologic and thermal changes with respiration:peat temperature and water table:net ecosystem production relationships developed from measurements at wetlands in northern Sweden and near Churchill, Manitoba. Model results indicate that the net atmospheric $CO_2$ sink function of fens may be enhanced under future 2 x $CO_2$ scenarios, while bogs may become a net source of atmospheric $CO_2$. If the net ecosystem productivity response to the new hydrologic conditions was ignored then the model predicts a decrease in summer carbon storage for all peatland types.

**Key words:** wetlands, carbon dioxide, atmosphere, climatic change

## 1. Introduction

Wetlands presently cover 127 million hectares, or 14%, of the terrestrial landscape of Canada, while boreal and subarctic wetlands cover between 20 and 30% of the northern landscape (Zoltai et al., 1988a; Zoltai et al., 1988b). These northern wetlands represent a long term sink for $CO_2$, accumulating approximately 23 g C $m^{-2}$ $yr^{-1}$ (Gorham, 1995). Wetlands store more soil carbon than other ecosystems (Gorham, 1991) despite their low ecosystem productivity (e.g., 2.6 to 7.1 g C $m^{-2}$ $d^{-1}$) (Frolking et al., 1998) because their wet conditions decrease decomposition rates.

Several climate change scenarios suggest that northern regions, which contain the majority of Canadian wetlands, could become much warmer and possibly drier (Mitchell et al., 1990). This is expected to result in significant changes in regional hydrology in the boreal and subarctic regions of Canada possibly leading to higher

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peat temperatures and a lower water table position (Rouse, 1998). Consequently, the large stocks of carbon in northern Canadian wetlands may be particularly vulnerable as respiration may increase through enhanced decomposition from these drier and warmer conditions (e.g., Armentanao and Menges, 1986; Oberbauer et al., 1992). In turn, this could lead to higher levels of atmospheric $CO_2$.

However, recent studies indicate that open water portions of wetlands, while spatially small, represent a significantly large atmospheric $CO_2$ source (e.g., Waddington and Roulet, 1996; Hamilton et al., 1994). It follows that a drop in water table position at these wet sites may lead to an increase in carbon storage as wetland vegetation shifts to re-colonize these presently open water units of the wetland landscape. In this paper, we examine the potential impacts climatic change may have on the wetland-atmosphere exchange of $CO_2$ by paying particular attention to the water table control on wetland productivity. Previous estimates of the potential change in peat temperature and water table position (Roulet et al., 1992) under a $2xCO_2$ scenario are applied to empirical relationships between net ecosystem exchange of $CO_2$ (NEE) and temperature and water table position developed for a subarctic fen near Churchill, Manitoba, Canada.

## 2. Hydrologic Model

Using a simple hydrologic model (Roulet, 1991a), Roulet et al. (1992) estimated the change in summer water table position and peat temperature for northern fens as a function of changes in monthly air temperature (+3°C) and daily precipitation (+1 mm) predicted by a $2xCO_2$ climate scenario (Mitchell, 1989). Roulet et al. (1992) predicted that the 2xCO2 scenarios would change average water storage by -0.71 m for non-floating fens. Based on soil moisture curves for fibric peat (Boelter, 1988) the model predicted a water table drop of 0.14 m.

These hydrologic model results were applied to a fen located 18 km southeast of Churchill, Manitoba (58°45'N, 94°09'W; 22 m a.s.l.). Peat is ~0.25 m deep and overlies silty clay in a zone of continuous permafrost. The active layer generally recedes to a depth of 0.8 to 1.2 m by late summer (Rouse et al., 1992).

Water table position was continuously monitored at five land units representing different vegetation communities of the fen (see Table 1) along a hydrologic gradient from wet to dry. Mean water table position (MWT), in 1996 relative to the peat surface, at the five land units: large hummocks, small hummocks, lawns, shallow hollows and deep hollows was -0.40, -0.25, -0.15, -0.02 and +0.10 m, respectively.

Because the areal coverage of the different vegetation communities (land units) depends to a great extent on the long term MWT, the predicted 0.14 m drop in water table should also (but certainly not instantly) result in a shift to a new relative coverage of community types. To represent this potential shift in land unit coverage, we used 1996 water table position distributions for each of the land units at the sedge fen to determine vegetation community composition for a range of initial MWT (Figure 1). The relative abundance of the plant communities varied from 100% deep hollows (MWT = 0.1 m) to 100% large hummocks (MWT = -0.4 m) (Figure 1). This approach assumes that the present water table control on vegetation community composition remains the same in a $2xCO_2$ climate, however, it is a useful tool to compare possible changes in vegetation community composition and coverage for a range of wet (MWT = 0.0 m) to dry (MWT = -0.5 m) wetlands.

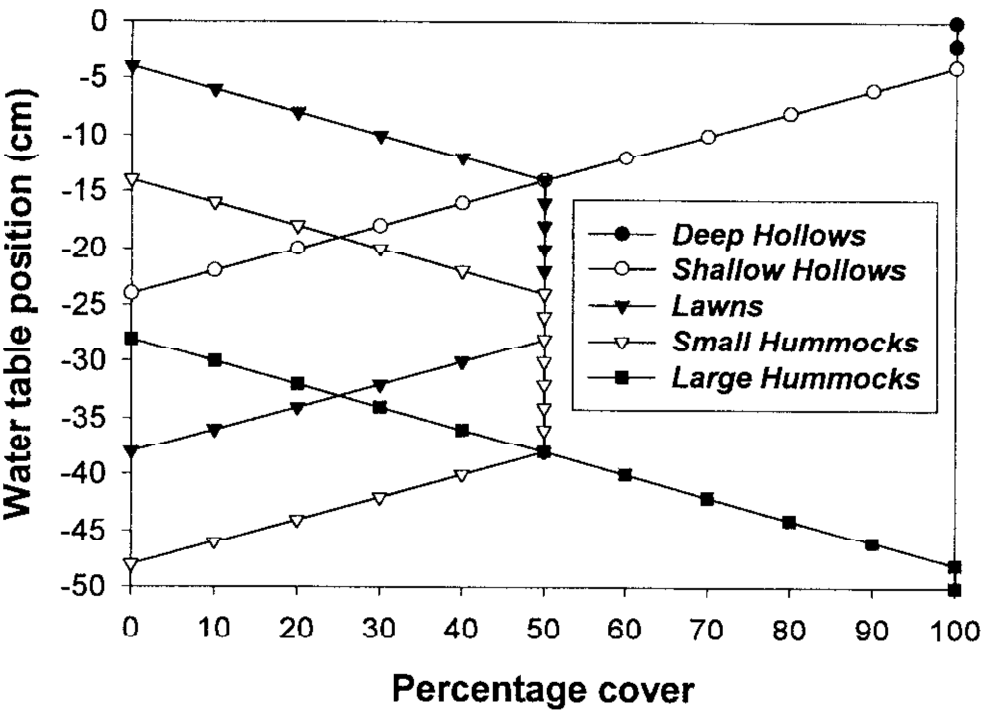


Figure 1. Percentage cover of the five land units for changes in mean water table position (MWT) based on 1996 water table distribution curves at the sedge fen.

### 3. Net Ecosystem ($CO_2$) Exchange

NEE was measured at the five land units at the Churchill wetland and a peatland in northern Sweden (see Waddington and Roulet, 1996 for details). We adopt a sign convention of carbon uptake or productivity as negative NEE and respiration as positive NEE. NEE was measured using dynamic (surface area=0.25 $m^2$, volume=0.125 $m^3$) and static (surface area=0.05 $m^2$; volume=0.019 $m^3$) enclosures. $CO_2$ concentration within the enclosure was measured using an EGM-

1 infrared gas analyzer (PP-Systems, United Kingdom) and a LI-6252 infrared gas analyzer (LI-COR Inc., Lincoln, Nebraska). All enclosures were placed on permanent collars with water seals. Net ecosystem productivity (NEP), which is equal to NEE less ecosystem respiration, was modelled using a rectangular hyperbolic relationship with photosynthetically active radiation (PAR) (see Whiting, 1994 for details) and respiration was modelled with a linear relationship to temperature for four periods (late May to June, July-wet, July-dry, August to early September) during the 1996 growing season. The wet and dry periods in July represented periods during which the water table was above and below the peat surface, respectively. Daily precipitation and water table position and hourly measurements of air temperature, surface temperature, peat temperature 0.05 m below the mean peat surface, water temperature, relative humidity and PAR were measured at a meteorological site at both wetlands.

There were large differences in the seasonal respiration and net ecosystem production (NEP) at the different land units in the wetlands (Table 1). Mean daily respiration at large hummocks and deep hollows were small relative to shallow hollows, small hummocks, and lawn sites. NEP was greatest at the small hummock site and lowest at the large hummocks and deep hollows. Seasonal NEE indicated a net $CO_2$ sink at the hummock, lawn and hollow sites (0.06 to 1.54 g $CO_2$ $m^{-2}$ $d^{-1}$) and a source of $CO_2$ at the large hummock sites (0.91 g $CO_2$ $m^{-2}$ $d^{-1}$). The magnitude of the fluxes reported here are similar to observations reported for other subarctic and arctic environments (e.g., Oberauer et al., 1992).

Table I: Dominant vegetation, mean water table position (MWT), mean daily net ecosystem production (NEP), mean daily respiration under present conditions (RP), and mean daily respiration under future conditions (RF) for the five land units.

| Land unit | Dominant Vegetation | MWT (m) | NEP ( g $CO_2$ $m^{-2}$ $d^{-1}$) | RP | RF |
|---|---|---|---|---|---|
| Large hummocks | lichens | -0.40 | -0.10 | 1.01 | 1.09 |
| Small hummocks | *Carex aquatilis, C. limosa* | -0.25 | -2.22 | 1.82 | 1.89 |
| Lawns | Moss to sedge transition | -0.15 | -3.99 | 2.50 | 3.20 |
| Shallow hollows | *Scorpidium turgescens* | -0.02 | -7.47 | 5.93 | 6.83 |
| Deep hollows | Open water | +0.10 | -1.41 | 1.35 | 1.53 |

## 4. $CO_2$ Exchange Relationships

To estimate the response in NEE to the predicted changes in peat temperature and water table position, empirical relationships between respiration and peat temperature and between NEP, respiration and MWT were developed.

Separate linear relationships between field respiration measurements and peat surface temperature were developed for the five land units (Figure 2). Each relationship was developed by classifying the temperature into small ranges (< 2°C) and then calculating the mean respiration associated with these ranges. The relationship between respiration and peat surface temperature is strongest for the lawn sites ($r^2$=0.80) followed by small hummocks ($r^2$=0.78), large hummocks ($r^2$=0.56) and hollow (shallow and deep) land units ($r^2$=0.47). The slope of the relationship is greatest at the small hummock sites and follows the trend: small hummocks > lawns > large hummocks > hollows. A linear regression between air temperature and peat surface temperature suggests an increase of peat surface temperature of 2.3°C for the 3°C increase in air temperature. The changes in respiration rates associated with this change in peat temperature are presented in Table 1.

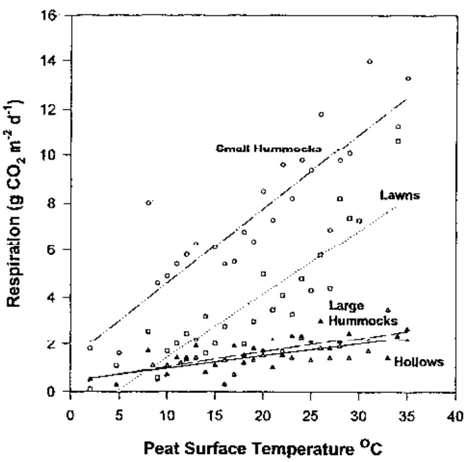


Figure 2. Respiration:peat surface temperature relationship. The solid line indicates the best fit line.

The change in NEE (DNEE) at a particular present MWT can be calculated using:

$$\Delta NEE = \sum_i \sum_j [(X_{i,j}(NEP_i - RF_i)) - (\Phi_{i,j}(NEP_i - RP_i))] \qquad (1)$$

where $X_{i,j}$ is the fractional coverage of plant community 'i' at present MWT, $F_{i,j}$ is the new fractional coverage of plant community 'i' at 0.14 m below present MWT, and present MWT ranges between -0.3 and +0.1 m. NEP, RP, and RF refer to the mean net ecosystem production, present day respiration and estimated future respiration, respectively. Solving equation 1 produces Figure 3.

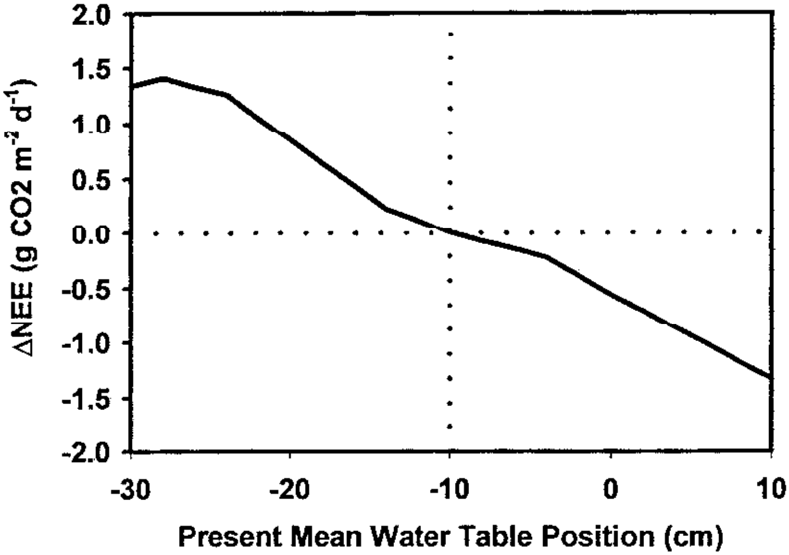


Figure 3. The relationship between present mean water table position and the estimated change in net ecosystem exchange (DNEE).

This NEE-MWT model predicts an increase in the seasonal $CO_2$ sink of ~-0.6 g $CO_2$ $m^{-2}$ $d^{-1}$ for presently 'wet' wetlands (e.g., MWT = 0.0 m) and an increase of ~1.0 g $CO_2$ $m^{-2}$ $d^{-1}$ to the atmosphere for presently 'dry' wetlands (e.g., MWT = -0.2 m) (see Figure 3). The 'break even' present MWT is 0.1 m below the surface suggesting that 'wet' wetlands (i.e., fens) may increase their atmospheric $CO_2$ sink function while 'dry' wetlands (i.e., bogs) may become a source of atmospheric $CO_2$.

## 5. Discussion

While several studies (e.g., Oechel et al., 1993) suggest that northern wetlands may become a source of atmospheric $CO_2$ in a warmer drier climate, results from this study indicate that 'wet' wetlands may increase their net carbon sink function. This suggests that studies that do not consider the importance of the water table position on community composition, NEP and respiration may overestimate $CO_2$ efflux. To demonstrate the importance of the water table control on NEE we also modelled future NEE by ignoring the NEP and respiration variability between the different land units and instead modelled changes in respiration only using relationships between water table position and temperature at the lawn sites (Figure 4). The 3°C temperature increase and 0.14 m water table drop increased respiration 25 and 47%, respectively. Combining the two effects shifted the wetland from the present weak summer $CO_2$ sink (-0.95 g $CO_2$ $m^{-2}$ $d^{-1}$) to a net source 1.35 g $CO_2$ $m^{-2}$ $d^{-1}$ (Figure 4).

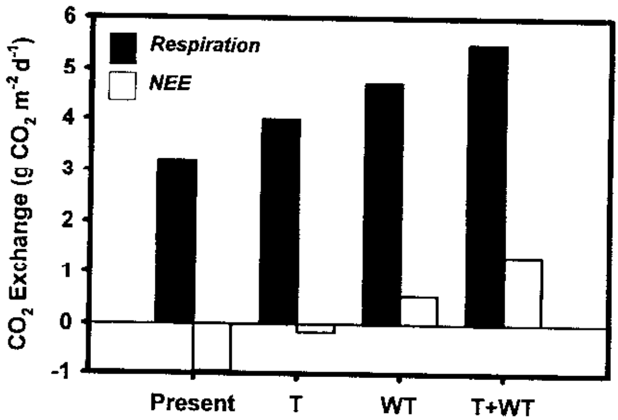


Figure 4. Estimated change in $CO_2$ exchange for the Churchill sedge fen for changes in peat temperature (T), water table position (WT) and both combined (T+WT). White bars represent net ecosystem exchange and black bars are respiration.

This study demonstrates that wetland 'wetness' is important in determining the potential response of the wetland:atmosphere exchange of $CO_2$ under $2xCO_2$ climate scenarios. However, we expect different responses in $CO_2$ exchange in other wetlands where the direct feedback of hydrologic controls on substrate quality, water table position, nutrient supply and, therefore, indirectly on wetland productivity are different. Moreover, a warmer climate should increase the length of the growing season and potentially the storage of carbon resulting from enhanced plant growth. For example, results of a nitrogen fertilization experiment, designed to simulate more luxuriant growth in an environment with higher atmospheric $CO_2$ concentration and larger nutrient supply, at the Churchill fen site indicated a significant increase in productivity at wet sites (Petrone, pers. comm.). Consequently, we believe our results of an enhanced $CO_2$ sink for 'wet' wetlands represents a conservative and realistic estimate.

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