UNCERTAINTY IN PREDICTING THE EFFECT OF CLIMATIC CHANGE ON THE CARBON CYCLING OF CANADIAN PEATLANDS

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Abstract. Northern peatlands play an important role globally in the cycling of C, through the exchange of CO_2 with the atmosphere, the emission of CH_4, the production and export of dissolved organic carbon (DOC) and the storage of C. Under 2 x CO_2 GCM scenarios, most Canadian peatlands will be exposed to increases in mean annual temperature ranging between 2 and 6° C and increases in mean annual precipitation of 0 to 15 %, with the most pronounced changes occurring during the winter. The increase in CO_2 uptake by plants, through warmer temperatures and elevated atmospheric CO_2, is likely to be offset by increased soil respiration rates in response to warmer soils and lowered water tables. CH_4 emissions are likely to decrease in most peatlands because of lowered water tables, except where the peat surface adjusts to fluctuating water tables, and in permafrost, where the collapse of dry plateau and palsa will lead to increased CH_4 emission. There likely will be little change in DOC production, but DOC export to water bodies will decrease as runoff decreases. The storage of C in peatlands is sensitive to all C cycle components and is difficult to predict. The challenge is to develop quantitative models capable of making these predictions for different peatlands. We present some qualitative responses, with levels of uncertainty. There will be, however, as much variation in response to climatic change within a peatland as there will be among peatland regions.

Key words: carbon, carbon dioxide, methane, dissolved organic carbon, peatlands, climatic change

1. Introduction

Wetlands, especially peatlands, play important roles in the global cycling of carbon. They are net sinks of atmospheric carbon dioxide (CO_2) from the atmosphere because their rates of plant production are greater than their rates of organic matter decomposition. Northern peatlands contain about 500 x 10^{15} g of organic carbon (Gorham, 1991, 1995), most of which has accumulated in the last 5000 years, at an average rate of about 100 Tg yr^{-1}. This storage is equivalent to about 100 years of current fossil-fuel combustion and represents a reduction in atmospheric CO_2 concentration of about 40 ppm. This has led to the suggestion that peatlands may play a role in the initiation of the glacial-interglacial cycles (Franzén, 1994; Franzén et al., 1996; Klinger et al., 1996).

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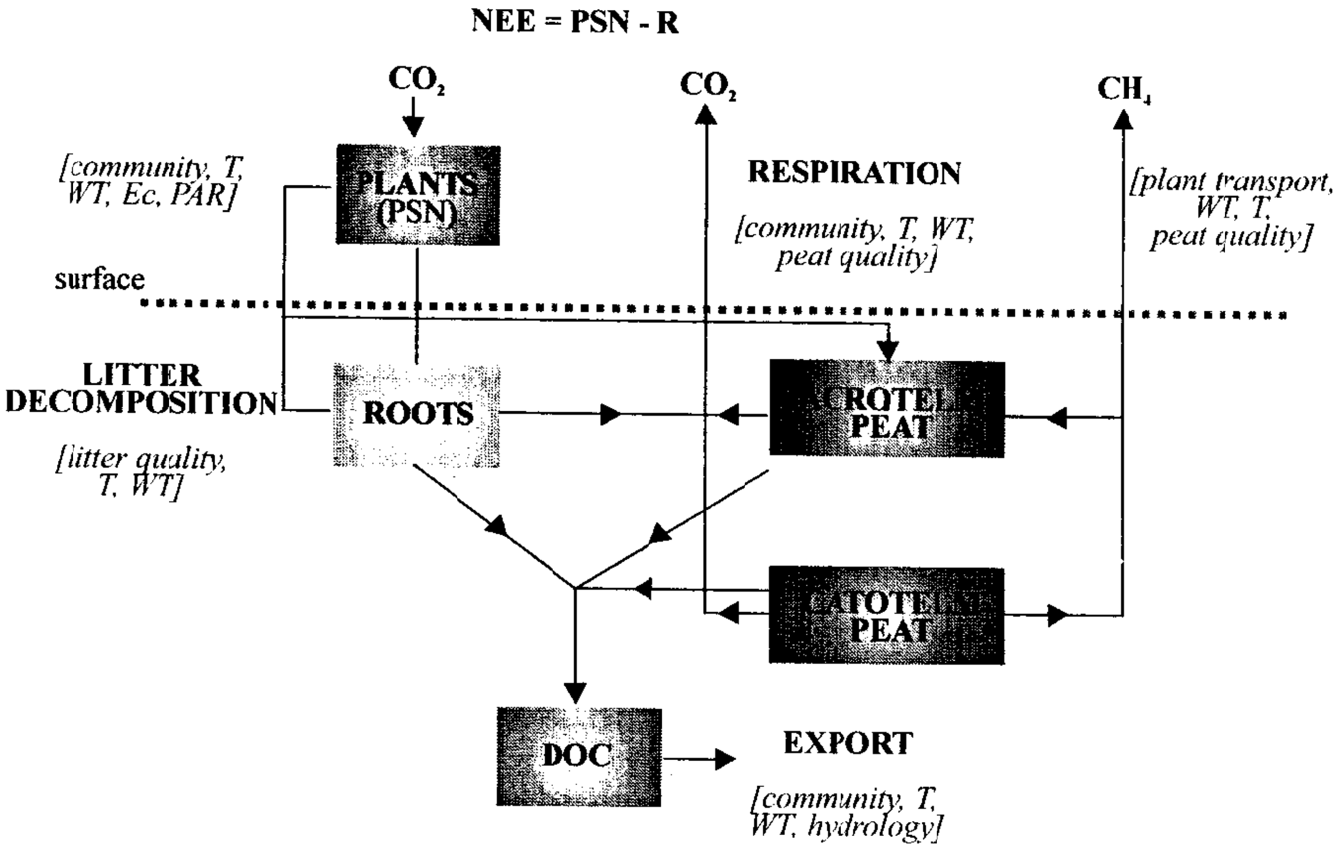

Figure 1. The major components of the C cycle in peatlands and the primary controls on the fluxes of C (in *italics*). NEE: net ecosystem exchange of CO_2; PSN: photosynthesis; R: respiration; T: temperature; WT: water table position; E_c: porewater electrical conductivity; PAR: photosynthetically active radiation.

Conversely, the development of anaerobic conditions within wetland profiles stimulates the production of methane (CH_4), another greenhouse gas. The postglacial development of northern peatlands may have led to an increase in global CH_4 emissions of 10 - 30 x 10^{12} g yr^{-1}, thus increasing atmospheric CH_4 concentrations. Between 6000 and 200 yr ago, the atmospheric concentration of CH_4 has rose from 0.60 to 0.75 ppbv, the increase being ascribed to the development of northern peatlands (Blunier et al., 1995). As CH_4 is 58 times more efficient a greenhouse gas than CO_2 on a mass basis, this results in a net greenhouse enhancement through the postglacial development of northern peatlands. Because CH_4 is short-lived in the atmosphere with a lifetime of about 12 years, the consumption of atmospheric CO_2 by peatlands approximately balances the production of CH_4 in terms of global warming, on a time horizon of 500 years when the global warming potential of CH_4 is 7 times that of CO_2 on a mass basis (Schimel et al., 1995).

The decay of plant material in wetlands results in the production of dissolved organic carbon (DOC), a mixture of complex organic molecules. DOC is exported from the land surface to water bodies, where it can play an important role in water chemistry and the absorption of ultra-violet radiation (e.g. Schindler et al., 1996) and may be evaded to the atmosphere or precipitated in sediments (e.g. Molot and Dillon, 1996). Molot and Dillon (1996) estimate that 66 Tg C is exported from the boreal forest biome to water bodies each year, and most of this is in the form of DOC produced by peatlands.

Few investigators have modelled climatic effects on wetlands, in contrast to other systems, such as forests and grasslands (e.g. Breymeyer et al., 1996) and lakes (McKnight et al., 1996). Progress has been made, however, in Finland (e.g. Laine et al., 1996). As a consequence, wetlands are often excluded from many global models of the effect of climatic change on ecosystem functioning and C budgets (e.g. Melillo et al., 1993), despite their large areal coverage (350 x 10^6 km^2 in boreal and subarctic peatlands [Gorham, 1991]).

In this paper, we examine what is known about the controls on C cycling, especially CO_2 and CH_4 exchange, export of DOC and storage of C in northern peatlands. We suggest ways that these peatlands are likely to respond to climatic change. Although there have been significant advances in our understanding, these are still primarily qualitative rather than quantitative, because of a weakness in the mechanistic understanding of the processes and their linkages. In 1991, Eville Gorham (1991) wrote *given the diversity of possible responses by boreal and subarctic peatlands to climatic warming, it is impossible at present to predict their future contributions to the global carbon cycle*. Seven years later, this statement remains correct.

The present understanding allows for a general conceptual model of the C budget (Figure 1). Atmospheric CO_2 is taken up by plants and this material decomposes upon the death of the plant, either at or beneath the surface. The acrotelm is the surface organic layers in the peat profile that are relatively poorly decomposed, are partially aerobic and usually have a high hydraulic conductivity, allowing the movement of water. It is underlain by the catotelm, comprised of more decomposed peat, with a lower hydraulic conductivity and dominantly anaerobic. CO_2 is released back into the atmosphere through root respiration and the decomposition of both the acrotelm and catotelm. Net Ecosystem Exchange (NEE) of CO_2 is the balance between the photosynthetic uptake (PSN) and respiration components. CH_4 is produced by methanogens in the anaerobic zones of the soil and moves to the soil surface, where it can be consumed by methanotrophs in aerobic zones or emitted to the atmosphere through diffusion, ebullition or plant transport. The leaching of plant material and decomposing peat releases DOC, which can be exported to adjacent water bodies. The difference between inputs (PSN) and outputs (R, CH_4 and DOC) represents the accumulation of C in the peatland soil.

The most important overall controls on the C budget of peatlands are plant community, temperature, hydrology (especially water table position) and chemistry, or quality, of plant tissues and peat (Figure 1). Thus, to evaluate the effect of climatic change on the C budget of peatlands and other wetlands, one needs to be able to predict the change in these controls caused by changing climates, then to assess the extent to which the C budget will change. Some examples of how this might be accomplished are given in this paper.

Several General Circulation Models provide scenarios of likely climatic changes in the regions covered by Canadian peatlands. The postulated changes in winter (December-January-February) and summer (June-July-August) precipitation and temperature are indicated in Table I for three GCMs and five regions in Canada, covering the major types of peatlands. These scenarios suggest that Canadian peatlands are likely to experience, in winter and summer, respectively, temperatures that are between 2 to 5 and 1 to 4 °C higher and precipitation which is 0 to 15 and -10 to 10% higher.

2. CO_2 Exchange

The uptake of CO_2 through photosynthesis (PSN) is primarily dependent on the amount of photosynthetically active radiation (PAR), air temperature and plant community structure and composition. The relationship between PSN and PAR during the summer at several peatland sites has been established recently by Frolking et al. (1998), who found that fens had higher PSN rates than bogs. All peatland communities, however, had much smaller CO_2 assimilation rates than forests, grasslands and agricultural crops (Ruimy et al., 1995): 4 to 5 times smaller at high PAR levels and 2 times smaller at low PAR levels. Low air temperatures restrict photosynthetic capacities during the spring and fall (e.g. Ball, 1996; Carroll and Crill, 1997). One probable major effect of climatic change in northern peatlands will be an earlier start to the growing season, which

Table I

Changes in seasonal temperature and precipitation predicted by three GCM 2xCO_2 scenarios for five Canadian peatland locations, to nearest 0.5°C temperature and *% precipitation*

Location and wetland region	CCC		GFDL		GISS	
	DJF	JJA	DJF	JJA	DJF	JJA
Fort Simpson, NWT, low subarctic	+5.5, *0*	+4.0, *+10*	+3.0, *+15*	+2.5, *-10*	+3.0, *+10*	+1.5, *+20*
Thompson, Man., high boreal	+7.5, *+25*	+5.0, *0*	+3.5, *+15*	+2.5, *0*	+3.0, *+5*	+1.0, *+40*
Dorset, Ont., low boreal	+5.0, *+5*	+5.0, *0*	+4.0, *+15*	+3.0, *-5*	+2.0, *+10*	+1.0, *0*
Kejimkujik, NS, Atlantic boreal	+4.0, *+10*	+4.0, *+5*	+4.0, *+10*	+3.0, *+10*	+2.0, *+10*	+2.0, *-10*
Schefferville, Qué., high subarctic	+7.0, *+15*	+5.0, *-10*	+5.5, *+15*	+2.5, *+15*	+3.0, *+15*	+1.5, *+10*

Key:
CCC - Canadian Climate Centre Model (Boer et al., 1992);
GFDL - Geophysical Fluid Dynamics Laboratory (Manabe et al., 1991);
GISS - Goddard Institute for Space Studies (Russell et al., 1995);
DJF - December, January, February;
JJA - June, July, August.

would occur during periods with high solar insolation. Frolking et al. (1996) developed a model of CO_2 exchange for a spruce-moss forest in northern Manitoba and found that the overall uptake of the site was very sensitive to the start of the growing season: warmer springs and wetter summers lead to increased uptake of CO_2.

Studies on other ecosystems have shown that elevated atmospheric concentrations of CO_2 lead to increased plant production, at least over the short term. We are unaware of similar results for peatlands, though Jauhiainen and Silvola (1996) and Jauhiainen et al. (1996) reported a variable response in CO_2 uptake and production in *Sphagnum* species when grown under elevated CO_2 concentrations, from 350 to 2000 ppmv. Peatland plants may be expected to have a higher productivity, though the magnitude of the response will depend on other changes (such as a lowering of the water table) and increased nutrient availability from the soil. In a study of the effect of climatic change on Alaskan tundra, Shaver et al. (1992) observed that plant production and community responses to changing climate and atmospheric CO_2 concentration were complex, and that increased nutrient availability from the soil, through increased rates of decomposition, was a limiting factor.

Moore et al. (submitted) observed that the mass loss of decomposing litter in Canadian forests is correlated with climate, such as temperature and precipitation, and litter quality, such as lignin and nitrogen content. Using their results, an increase in mean annual temperature by 4° C could be expected to increase litter decomposition rates by 5 to 15 % over 3 years. There is evidence that elevated atmospheric CO_2 concentrations can lead to decreases in tissue nitrogen concentrations, which slows the rate of decomposition and may partially offset the increase in decomposition rates associated with the higher temperatures (Moore et al., submitted). The initial rates of litter decomposition appear to be little affected by water table position, as revealed by litter mass loss at the peat surface over five years at sites ranging from submerged to 20 cm above the water table (Moore, unpub. data).

The emission of CO_2 from the peat surface to the atmosphere is derived from root respiration and the decomposition of peat. The proportion varies among sites and seasons, but root-derived CO_2 generally ranges between 30 and 70 % of the total (Bhardwaj, 1997; Silvola et al., 1996a); changes in this component of the CO_2 flux are likely to be very dependent on plant activity. The proportion of CO_2 flux derived from peat decomposition depends on temperature and water table position. Ratios of the production of CO_2 under aerobic and anaerobic conditions vary, but fall into the range of 2.5:1 to 6:1 (Bridgham et al., 1995; Moore and Dalva, 1997). The effect of temperature on CO_2 fluxes is revealed by Q_{10} ratios falling between 2.1:1 and 2.9:1 (Moore and Dalva, 1993; Silvola et al., 1996b). The strong linear relationship between water table position and CO_2 flux, in both field (Silvola et al. 1996b) and laboratory (Moore and Dalva, 1993) studies suggests that changes in water table position under changing climates will be very important, and the change in CO_2 flux may be predicted, if the hydrological response to changing climate can be established. For example, lowering the water table from a depth of 10 to 30 cm resulted in a 1.5 to 2.5 increase in CO_2 emission rates from fen soils (Moore and Dalva, 1993; Silvola et al., 1996b).

Net Ecosystem Exchange (NEE) measures the difference between CO_2 uptake by plants and the release of CO_2 to the atmosphere through litter and peat decomposition and root respiration. During the summer, daily NEE values are generally negative, with overall CO_2 uptake by the system, commonly falling in the range of 2 to 12 g CO_2 m^{-2} d^{-1} (Ball, 1996; Bellisario, 1995; Bhardwaj, 1997; Carroll and Crill, 1997). In the spring when cold air and peat temperatures retard CO_2 uptake by plants, and again in the fall, when plants senesce and there is still CO_2 production from the relatively warm soil, CO_2 is released to the atmosphere. In a companion paper, Waddington (in press) examines the effect of a 2 x CO_2 scenario climatic change on the summer CO_2 budget of wetlands near Churchill, Manitoba and suggests that the CO_2 sink function of fens will be enhanced, while bogs may become a net source of CO_2. Comparison of summer uptake with the anticipated annual C accumulation in peats suggest that a considerable proportion of the C fixed during the summer is lost during the winter (Alm et al., in press). Warmer winters and deeper snowpacks are likely to increase this over-winter loss of CO_2, because of warmer soil temperatures.

3. CH_4 Exchange

The efflux of CH_4 to the atmosphere from wetlands is dependent on the capacity of methogens to produce and methanotrophs to consume CH_4 in the soil profile, as well as the transmission of CH_4 to the surface through diffusion, ebullition and plant-mediated transport. The dependence of methanogenesis on temperature is generally greater than that of CH_4 consumption (Dunfield et al., 1993), so increased temperatures in the peat profile are likely to lead to increased CH_4 emission. Particularly important is the development of anaerobic conditions, essential for methanogenesis, so that there is a strong relationship between CH_4 flux and water table position in both laboratory (e.g. Moore and Dalva, 1993) and field studies (e.g. Bubier et al., 1995a; Liblik et al., 1997). Frolking and Crill (1994) were able to model CH_4 flux from a temperate fen, showing that temperature and water table position were important controls. Although CH_4 flux shows a great deal of spatial and temporal variability in the field, a strong relationship between average summer CH_4 flux and average water table position has been established for several regions in Canada (Figure 2). The slopes of the regression are similar among the regions, but the intercepts (e.g. CH_4 flux when the water table is at the surface) are significantly different, with the larger CH_4 fluxes occurring in the northernmost regions (Liblik et al., 1997). There is also evidence that where the water table is at or close to the water table surface, vascular plant transport, circumventing the zone of CH_4 oxidation, increases CH_4 flux, so that there is a relationship between CH_4 flux and NEE or sedge biomass (e.g. Bellisario, 1995; Waddington et al., 1996; Whiting and Chanton, 1992, 1993). Increased plant growth in response to elevated atmospheric CO_2 concentrations may lead to increased CH_4 emission, as has been reported for salt marsh communities (Dacey et al., 1994), though Saarnio et al. (1996) were unable to detect a significant response in laboratory monoliths. Based on regional studies of CH_4 flux and the coverage of peatland types, Bachand et al. (1996) estimated that Canadian peatlands emit about 3.5 Tg CH_4 yr^{-1}, mainly from peatlands in the mid- and high-boreal and low subarctic zones.

The response of CH_4 flux to climatic change will be dependent on the changes in microbial CH_4 production and consumption associated with warmer temperatures and changes in the water table position, as well as changes in surface vegetation. There is a strong relationship between CH_4 flux and bryophytes (Bubier et al., 1995b), so that estimated changes in peatland bryophyte distribution (Gignac and Vitt, 1994) could be used to predict changes in CH_4 fluxes. Alternatively, the strong relationship between CH_4 flux and water table position could be used to estimate changes in flux, if the hydrologic response of peatland landscapes to climatic change can be established. In the Canadian Land Surface Scheme (CLASS), the soil-vegetation-atmosphere transfer functions of the General Circulation Models has recently been parameterized for organic soils and wetland vegetation (Comer et al., submitted; Letts et al., submitted). Based on work at subarctic fens, Roulet et al. (1992) estimated the changes in water table position and soil temperature produced by a 2 x CO_2 GCM climate change similar to those reported in Table I and then translated these changes into variations in CH_4 flux. Most sites showed decreases in CH_4 flux, because the effect of a lowered water table was greater than the increase in soil temperature.

Northern wetlands show a great deal of spatial variability in vegetation and water table, so that there will be differential responses of CH_4 emission to climatic change (Table II). Based on the predicted lowering of water table under climate change scenarios, most peatland sites should experience a decrease in CH_4 emissions, though the episodic high rates of CH_4 emission during falling water tables (e.g. Moore and Dalva, 1993; Windsor et al., 1992) may reduce this decrease. Thus, in most peatlands located in the temperate regions of Canada, decreased CH_4 emission may be anticipated, though this may be moderated by the longer growing season. In boreal and subarctic peatlands, sites which have floating peat mats or degrading pools may show an increase in CH_4 emission, because of the maintenance of saturated conditions and the increase in temperature and microbial and plant activities.

The largest change in CH_4 flux is likely to be found in the high boreal and low subarctic zones, where there is discontinuous permafrost. Peat palsa and plateau underlain by permafrost are dry, so that they usually have small rates of CH_4

Table II

Anticipated response of CH_4 emission to climatic change in northern peatlands (from Bubier and Moore, 1995; Roulet et al., 1992)

Peatland type	Predicted change in CH_4 flux	Rationale
Non-floating	Decrease	Decreased CH_4 production from a lower water table has a greater effect than increased CH_4 production from warmer peat temperature
Floating peat	Increase	Peat surface adjusts to falling water table and warmer temperatures increase CH_4 production
Sedge-dominated	Decrease	Higher temperatures may increase plant sites production, but a lowered water table would decouple the rooting zone from the zone of anaerobic CH_4 production
Degrading pools	Increase	Higher temperatures would increase CH_4 production, and a fall in water table would create an aerobic zone only in very shallow pools
Peat palsa/	Increase	Melting of the ice-rich permafrost to create plateau collapse scars would change CH_4 flux from slight uptake to major efflux

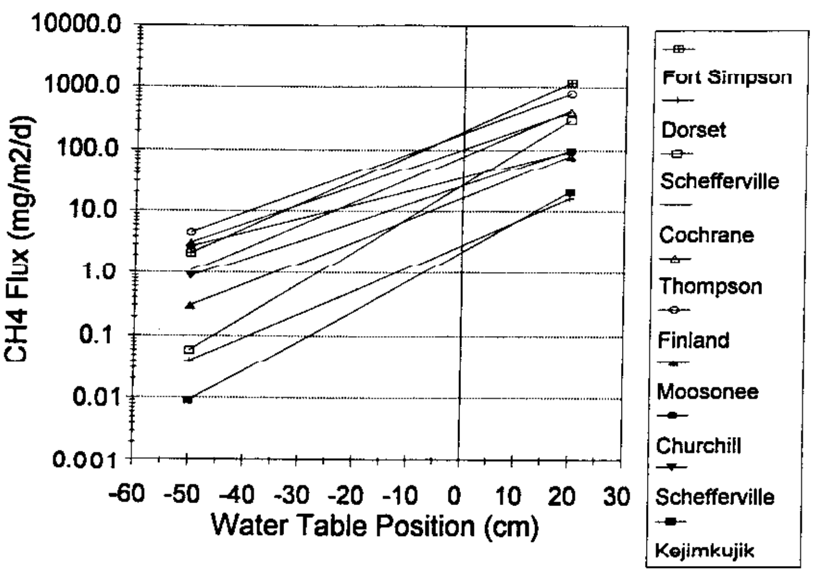

Figure 2. The relationship between average summer CH_4 flux and average water table position from wetland sites in several regions of Canada, plus northern Finland. Each line represents the regression derived from between 20 and 100 measurement sites in each region, and regression characteristics are given in Liblik et al. (1997).

Table III
Average summer emission of CH_4 (mg CH_4 m^{-2} d^{-1}) from wetland types in Fort Simpson, NWT (Liblik et al., 1997) and Thompson, Manitoba (Bubier et al., 1995)

Location	Peat plateau/palsa	Collapse bog	Collapse fen
Fort Simpson	-0.6	110	90
Thompson	-0.2	75	60

consumption (-0.2 to -0.6 mg CH_4 m^{-2} d^{-1}), in contrast to high rates of CH_4 emission (60 to 110 mg CH_4 m^{-2} d^{-1}) from the surrounding bogs and fens (Table III), such as at Thompson, Manitoba (Bubier et al., 1995a) and Fort Simpson, NWT (Liblik et al., 1997). Under climate change scenarios, the permafrost is likely to melt. In continental western Canada, there is evidence of significant permafrost melting to produce collapse scars, in the last century (Vitt et al., 1994). Halsey et al. (1995) have established the relationship between mean annual temperature and the percent of bogs underlain by permafrost in the same region, which can be used to predict permafrost distribution changes in response to climatic change. For example, in the Fort Simpson area, NWT, the mean annual temperature is about -4° C and the GCMs predict an increase of between 2.2 and 4.7° C, under 2 x CO_2 conditions for northwestern continental Canada (Table I). This will result in the melting of much of the permafrost, creating collapse bogs and fens, with much greater CH_4 emissions. An indication of the change in regional CH_4 emission for the Fort Simpson area can be made, using the changes in CH_4 flux suggested in Table 3 and the conversion of two thirds of the permafrost plateau into collapse bogs (Table IV). The result is a prediction of an overall increase in CH_4 emission, even though some specific peatlans would experience decreased emissions. In a Canadian wetland context, CH_4 emissions may be expected to decrease in southern regions, but this may be compensated by increases in northern regions, because of longer growing seasons, warmer peat temperatures and the collapse of permafrost features.

4. DOC Production and Export

DOC production by decomposing plant tissues and soil organic matter is dependent upon a number of controls which will likely change under climatic change (Figure 1). There is little evidence, however, that changes in these

Table IV

Areal coverage, CH_4 flux and landscape CH_4 contribution of landform units in the Fort Simpson area at the present time and predicted response to climatic change scenario

Unit	Areal coverage (%)	Present day CH_4 flux (mg m^2 d^{-1})	Contribution (mg m^{-2} d^{-1})	Areal coverage (%)	Climate change CH_4 flux (mg m^2 d^{-1})	Contribution (mg m^{-2} d^{-1})
Collapse bog	2.5	100	2.5	12.5	100	12.5
Graminoid fen	12.9	110	14.2	12.9	60	7.7
Shrub fen	3.3	10	0.3	3.3	5	0.2
Pool	0.8	250	2.0	0.8	300	2.4
Permafrost plateau	15.4	-0.6	-0.1	5.4	-0.6	0.0
Upland forest	65.0	-0.5	-0.3	65.0	-0.5	-0.3
Total			18.6			22.5

controld will have as large an effect on DOC dynamics as for the other C components. From a laboratory incubation of several tissue and peat samples, Moore and Dalva (unpub. data) found that DOC production was affected little by changes in temperatures or by aerobic versus anaerobic conditions and that soil organic matter, such as peats, was able to release DOC through several flushing episodes. Thus, lowered water tables and higher soil temperatures are unlikely to affect DOC production in peatlands, though the leaching of DOC from increased plant production may result in greater DOC concentrations in porewater. DOC export from peatlands ranges from 5 to 40 g DOC m^{-2} yr^{-1} (Moore 1997) and DOC export from catchments is very dependent on the proportion of the catchment occupied by peatlands (e.g. Molot and Dillon, 1996) and the amount of runoff available to carry the DOC (Clair and Ehrman, 1996; Urban et al., 1989). With the likely decrease in runoff associated with greater rates of evapotranspiration, DOC export from wetlands and wetland catchments will decrease under climatic change scenarios.

5. C Storage

As noted in the introduction, an important consequence of the post-glacial development of northern peatlands has been the storage of large amounts of organic C, effectively reducing the atmospheric concentration of CO_2. Using basal dates and mass of C stored in the peat column, northern peatlands have stored between 5 and 85 g C m^{-2} yr^{-1}, with an overall mean value of 20 to 23 and 29 g C m^{-2} yr^{-1} for Finland and North America, respectively (Gorham, 1991, 1995; Korhola and Tolonen, 1996). These rates represent the balance between the input of C, as the photosynthetic production of plant tissues, and the output as CO_2 from autotrophic and heterotrophic respiration, CH_4 emission and DOC export. The rates of C storage are small compared to the other terms: 100 to 500 g C m^{-2} yr^{-1} for photosynthesis and respiration, 1 to 20 g C m^{-2} yr^{-1} for CH_4 emission and 20 to 50 g C m^{-2} yr^{-1} for DOC expprt. Thus, the reliable prediction of the effects of climatic change on C storage in wetlands will be dependent on our ability to accurately model the response of the individual components to climatic change.

We are nowhere near being able to do this at the present time, even though we now have the ecosystem structure and knowledge of primary controls to develop models. Figure 3 is an example of the likely effects of climatic change, through warmer temperatures and lowered water tables on the C budget. We have ascribed an uncertainty rating to our estimated changes. Although climatic change will likely increase NEE, increases in CO_2 emission from a lowered water table and warmer temperatures suggest that C storage in northern peatlands will decrease. This adds to the conversion of many peatlands from a C sink to source through drainage (Armentanao and Menges, 1986), though the drainage of

Table V
Predicted qualitative response of northern peatlands to climatic change

Hydrologic gradient	Dry	Moist	Wet
Peatland type	hummock/plateau-palsa	lawn/swamp	floating mat/pool
Environmental response to climatic and atmospheric forcing:			
Available CO_2	doubled^{+++}	doubled^{+++}	doubled^{+++}
Peat temperature	warmer^{+++}	warmer^{+++}	warmer^{+++}
Water table position	lower (hummock)$^{++}$ higher (plateau-palsa)$^{+}$	lower^{++}	no change (mat)$^{++}$ lower (pool)$^{++}$
Ecosystem response:			
CO_2 exchange	smaller sink or possible source (hummock)$^{+}$ larger sink (plateau-palsa)$^{+}$	smaller sink^{+}	larger sink^{+}
CH_4 emission	smaller (hummock)$^{+++}$ larger (plateau-palsa)$^{++}$	smaller^{+++}	larger^{++}
DOC export	smaller (hummock)$^{+}$ larger (plateau-palsa)$^{+}$	smaller^{++}	smaller^{++}
C storage	possibly net loss (hummock)$^{+}$ larger (plateau-palsa)$^{+}$	smaller^{+}	larger^{+}

Key to confidence in predicted changes: $^{+++}$ reasonably confident; $^{++}$ moderately confident; $^{+}$ least confident

Finnish peatlands and their conversion to forests has resulted in an increase in C storage, primarily through C storage in biomass and litter (Laine and Minkkinen, 1996). The northward movement of peatlands into new environments may compensate for this, but these changes are likely to be much slower than the changes in C cycling at existing wetland sites.

6. Conclusions

There is evidence that through the current development of a better understanding of the controls of the functional relationships of the carbon cycle in peatlands, we are closer to predicting this reponse. An assessment of the qualitative changes in environmental controls and C cycling components is made in Table V for typical peatland types. The challenge is now to develop quantitative predictive models and the Peatland Carbon Simulator model (PCARS) is one example of such an effort (Honeywill and Roulet, 1997).

However, there will always be the great spatial diversity of wetlands in Canada and their differential position in the landscape, in terms of hydrology and nutrient transfers, so that such predictions can only be made for the broadest categories of wetlands. The response of C cycling to climatic change is likely to be as great within a peatland, such as from hummock, hollow and pool microtopography, as it is among peatland regions. Nevertheless, the large spatial extent of northern wetlands and their role in CO_2 uptake and release, CH_4 emission, C storage and DOC export mean that their role in the global C cycle under future climates needs to be evaluated.

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