PROJECT REPORT 2001-30

FINAL PROJECT REPORT

sustainable forest management network

réseau sur la gestion durable des forêts

Modelling impacts of climate change on peatland carbon stores and fluxes

A Network of Centres of Excellence
Un réseau de centres d'excellence

Dale H. Vitt

For copies of this or other SFM publications contact:

Sustainable Forest Management Network
G208 Biological Sciences Building
University of Alberta
Edmonton, Alberta, T6G 2E9
Ph: (780) 492 6659
Fax: (780) 492 8160
http://www.ualberta.ca/sfm

ISBN 1-55261-141-8

Modelling impacts of climate change on peatland carbon stores and fluxes

by

Dale H. Vitt [1,2]

[1]University of Alberta, Edmonton, Alberta, Canada T6G 2E9
[2]Current Address: Department of Plant Biology,
Southern Illinois University, Carbondale, Illinois, USA

September 2001

ABSTRACT

Northern peatlands have functioned as large sinks for atmospheric CO_2 via peat accumulation during the Holocene. Peatlands of continental, western Canada (Alberta, Saskatchewan, and Manitoba) began to accumulate carbon around 9000 years ago in this region, after an initial deglacial lag, and after 6000 years BP carbon accumulation increased significantly with about half of current stores being reached by 4000 BP. Around 3000 BP carbon accumulation in continental western Canada began to slow as permafrost developed throughout the Subarctic and Boreal Region and the current southern limit of peatlands was reached. Currently, peatlands cover 365,172 km^2 and store 48.0 Pg of carbon representing 2.1% of the world's terrestrial carbon within 0.25% of the global landbase. Macrofossil and physico-chemical analyses of a high-resolution peat record from a western Alberta rich fen suggests that hydrological conditions that affect regional patterns of peatland expansion, also affect local peat accumulation. Detailed investigation of the pattern of carbon accumulation in this core based on 20 AMS ^{14}C dates reveals a convex-shaped peat accumulation pattern that is in contrast to the widely accepted concave model. Estimates of peat decomposition rates for upper and lower portions of the peat profile are made from available radiometrically dated cores and curve fitting exercises. These estimates were used together with available data from western Canada to investigate spatial patterns of peat accumulation variability in response to climate change. Geogenous peatlands (fens) show the greatest variability, and regional patterns of uncertainty in peatland response to potential changes in local hydrology follows the distribution of fens in western Canada.

ACKNOWLEDGEMENTS

Climate Change Action Fund, Mike Apps, Celina Campbell, Ian Campbell, Ilka Bauer, Suzanne Bayley, Dave Beilman, Jag Bhatti,, Dennis Gignac, Linda Halsey, Merritt Turetsky, Markus Thormann, Kel Wieder, and Zicheng Yu.

INTRODUCTION

Peatlands are large sinks for atmospheric CO_2, removing an estimated 0.076 Pg (1 Pg = 10^{15} g) of C from the atmosphere annually through the process of peat accumulation (Gorham 1991). Peat accumulates in wetlands where the rate of biomass production is greater than the rate of decomposition, and it is most abundant in Boreal and Subarctic regions of the circumpolar north where cool and moist climatic conditions favor decreased rates of decomposition (Gore 1983). Clearly, peatlands are an important component of the terrestrial carbon budget, with northern peatland storage representing about 455 Pg of carbon. Peatland carbon dynamics influence atmospheric CO_2 and CH_4 concentrations and thus, future changes in peatland carbon storage have the potential to influence greenhouse gas-induced warming (Post et al. 1992). It is thus important to determine how this peatland carbon is distributed across the landscape, how it has accumulated through time, and how it may respond to future climate changes.

Peat accumulation is a function of the balance between production of living plants atop the acrotelm (surface aerobic layer) and decomposition in both the acrotelm and the catotelm (underlying anaerobic layer) (Clymo, 1984). As litter and new peat in the acrotelm are exposed to aerobic conditions and to varying water levels, they are subject to a high decay rate. Once in the catotelm, the decay rate declines sharply and becomes much more independent of climatic fluctuations. The rate of peat passage from acrotelm to catotelm therefore largely determines net peat accumulation. In the acrotelm, both peatland vegetation production and near-surface decomposition are sensitive to environmental conditions, which together will determine the rate of peat addition to the catotelm, thus long-term peat accumulation.

Different peatlands have different hydrological, chemical, and biotic gradients. Peatlands are either ombrogenous and receive their surface water and nutrients solely from precipitation, or they are geogenous and receive water not only from precipitation but also from surface water and groundwater; the former are termed bogs, while the latter are fens. Fens may be acidic and *Sphagnum*-dominated (poor fens), or alkaline, basic to neutral, and dominated by "brown mosses" (rich fens). Bogs are acidic and are dominated by some combination of *Sphagnum*, lichens, and feather mosses (Belland and Vitt 1995). Water table depths are variable in peatlands, generally in the range of 10 cm above to 40 cm below the surface for fens (cf. Gignac et al. 1991; Nicholson et al. 1997), while bogs are generally drier, with water tables 40 - 60 cm below the surface. Permafrost is an important component of northern peatlands (Vitt et al. 1994), and frozen peat is found approximately 100 cm below the surface (Belland and Vitt 1995). Thus bogs and permafrost peatlands have a relatively thick acrotelm, while in fens the acrotelm is shallower.

This project was undertaken with four general objectives: (1) Estimate the past and present regional carbon stocks of peatlands in western Canada, (2) Investigate the vegetation history, physical peat, and historical carbon accumulation rates of a climatically sensitive rich fen via high-resolution macrofossil, physico-chemical analyses of peat cores, and intensive radiocarbon dating, (3) Analyze available data from western Canada to investigate factors controlling peat decomposition and to estimate rates, and (4) develop a simple peat-accumulation process model to investigate regional patterns of carbon sequestration under climate change conditions.

SUMMARY OF DATA ANALYSIS

Carbon Storage in Peatlands of Western Canada

How carbon is stored in peatlands within the boreal and subarctic landscape in continental western Canada is described in Vitt et al. (2000), and is summarized here. To evaluate current and past carbon storage, eight types of data were assembled from our past work and the available literature. These were: (1) inventory of current peatland distribution by peatland type, (2) estimates of current maximum depth distributions, (3) calculation of surface and below-ground storage volume by peatland type using area and maximum depth adjusted by basin topography, (4) carbon content of organic matter in peat, (5) profiles of organic matter density distinguished by peatland type, (6) above-ground carbon content of biomass by peatland type on a mass/area basis, (7) temporal patterns of peatland initiation and expansion, and (8) long-term catotelm decomposition.

Peatlands cover a substantial amount of the landscape of continental western Canada (365,172 km^2), and presently contain a significant amount of carbon, about 48.0 ± 5.4 Pg (error introduced by different peat depth measurement methods) with an additional 0.10 Pg in aboveground biomass. Most of this peatland carbon is found in the High Boreal and Subarctic regions (Table 1; Figure 1). Together this represents roughly 2.1% of the world's terrestrial carbon within 0.25% of the global terrestrial surface area. This new estimate, utilizing higher-quality, spatially explicit and regionally specific data, exceeds previous estimates by about 20% (cf. Tarnocai 1998).

Table 1: Distribution of carbon in peatlands of continental western Canada (Alberta, Saskatchewan, and Manitoba) in grams. Regions follow those defined by the Ecological Stratification Working Group (1995).

Peatland Type	Arctic	Subarctic	Montane	High Boreal	Mid Boreal	Aspen Parkland	Total	%
Permafrost Bogs	$1.77x 10^{12}$	8.34×10^{15}	0	4.17×10^{15}	1.44×10^{14}	0	1.27×10^{16}	26.5
Nonpermafrost Bogs	0	2.96×10^{14}	0	2.84×10^{15}	8.05×10^{14}	2.01×10^{14}	4.14×10^{15}	8.6
Treed Fens	0	1.36×10^{15}	3.78×10^{12}	9.72×10^{15}	2.25×10^{15}	7.47×10^{14}	1.41×10^{16}	29.4
Shrubby Fens	3.95×10^{12}	4.04×10^{14}	1.40×10^{12}	1.77×10^{15}	3.89×10^{14}	2.65×10^{14}	2.83×10^{15}	5.9
Open Nonpatterned Fens	1.59×10^{13}	4.09×10^{15}	1.71×10^{12}	3.23×10^{15}	9.55×10^{14}	4.51×10^{14}	8.74×10^{15}	18.3
Open Patterned Fens	0	7.09×10^{14}	1.83×10^{12}	2.63×10^{15}	1.59×10^{15}	4.48×10^{14}	5.38×10^{15}	11.2
Total	2.16×10^{13}	1.52×10^{16}	8.72×10^{12}	2.44×10^{16}	6.13×10^{15}	2.11×10^{15}	4.79×10^{16}	100
%	0.1	31.7	0.0	50.9	12.8	4.4	100	

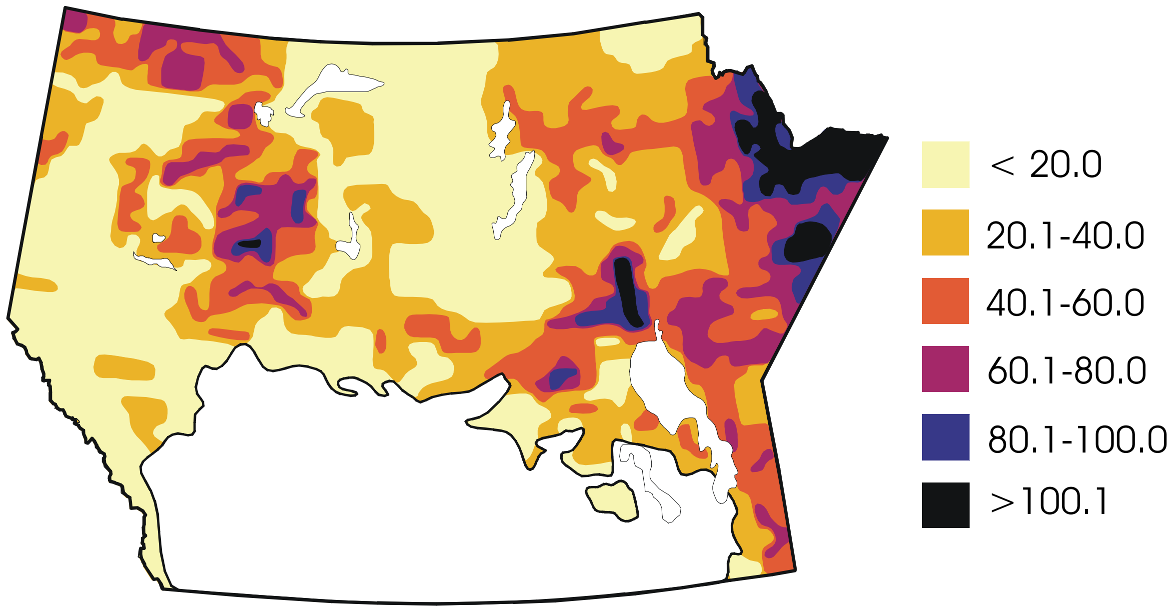

Figure 1. Present carbon storage (in surface vegetation and belowground peat) of peatlands in continental western Canada. Units are kg m^{-2}.

Carbon storage in peatlands has changed considerably over the Holocene. Over a span of 3000 years during the mid-Holocene (6000 to 3000 BP), about half of current stocks accumulated. Since then, peatland carbon stocks have continued to increase with a further one-third accumulating over the last 3000 years. The net increase in carbon stocks over the last 3000 years has declined relative to the mid-Holocene, that corresponds temporally to the expansion of permafrost into continental western Canada (Zoltai 1995), and to the establishment of the current southern limit of peatlands (Halsey et al. 1998).

Although the rate of peatland carbon sequestration is less today than 3000 years ago, this regional study documents that peatlands in continental western Canada continue to function as a carbon sink. This finding follows a similar observation made by Kuhry and Vitt (1996) at the site-specific level. Our estimate suggests that in continental western Canada 7.1×10^{12} g C yr^{-1} (19.4 g C $m^{-1}year^{-1}$) have been sequestered during the past 1000 years. Regional storage is beginning to level off due to increased total catotelm decay as predicted by Clymo (1984), but more important to the decline in net carbon storage is the development of permafrost, and the establishment of the current southern limit of peatlands. It should be cautioned that these estimates are based on limited data on the depth/age relationship of peatland expansion and should be viewed only in the context of the overall trends. Collection of more data on peatland expansion spanning all climatic and physiographic regions is required.

High-resolution radiocarbon dating and macrofossil analysis of rich fen peat cores – carbon accumulation and climate

Connections between Holocene climate variability and peatland carbon dynamics were investigated through detailed analyses of a high-resolution peat record, and of basal dates from over 70 paludified peatlands in western Canada. A high-resolution macrofossil and physico-chemical peatland record was obtained for a hydrologically sensitive headwater fen (Upper Pinto Fen; UPF) in western Alberta (53º35' N, 118º01' W). Macrofossil history shows little change in main assemblage components; a *Scorpidium scorpiodes*/Cyperaceae-dominated vegetation occurred between 6500 and 1300 cal BP. (Fig. 2). However, the percent of unidentifiable debris in the macrofossil record (Fig. 2) and peat bulk density (Fig. 3) are both highly variable through this period. High peat accumulation rates calculated for the UPF core show synchrony with low bulk densities and regional peatland expansion (Fig. 3), which is inferred to occur during wet climatic periods when high water tables reduced decomposition, and when net primary production (NPP) was not moisture-limited.

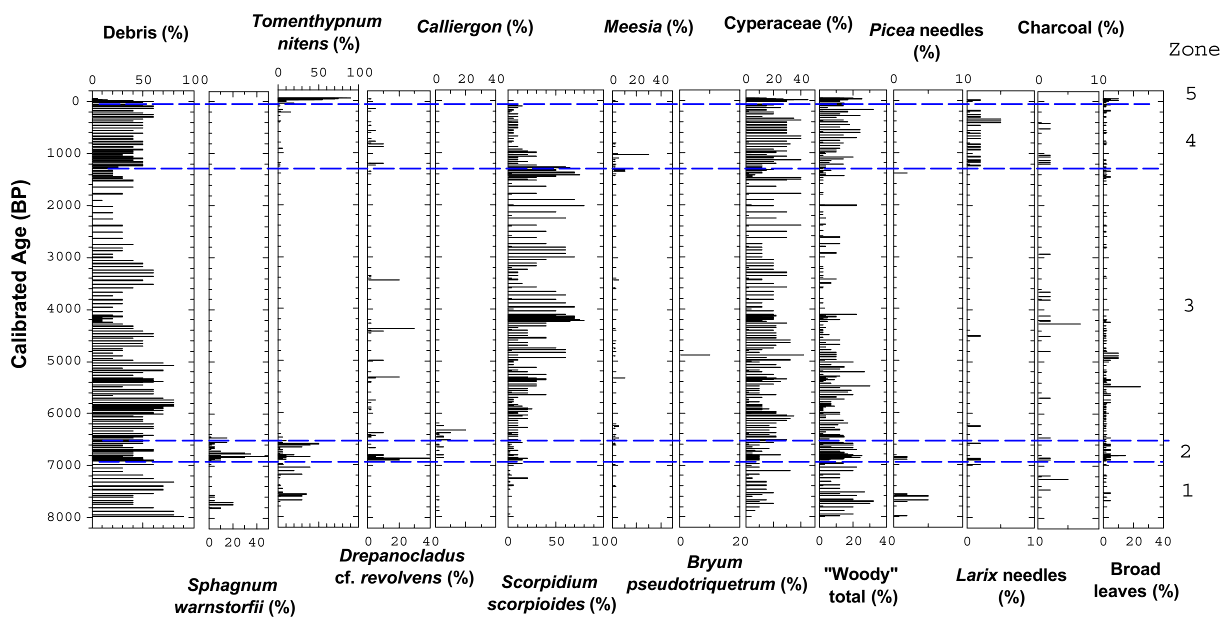

Figure 2. High-resolution macrofossil data from a core taken from a treed rich fen in eastern Alberta (Upper Pinto Fen). Data from Yu et al. (in review).

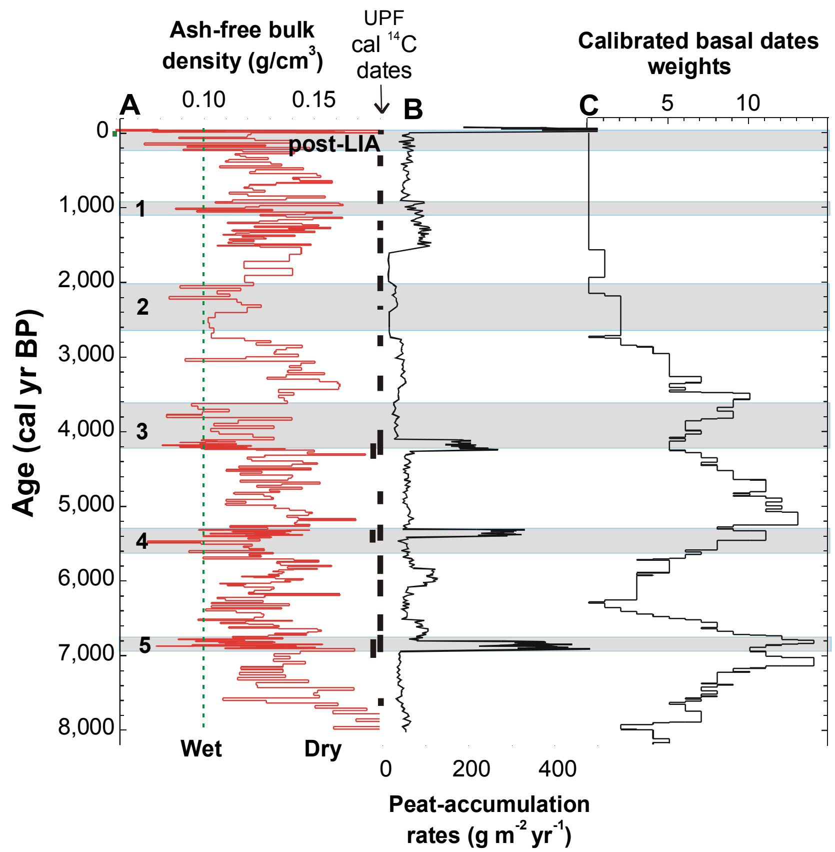

Figure 3. Ash-free bulk density from the UPF core (A). Wet events (shaded) were defined by the lowest ash-free density values. Peat-accumulation rates (B) were calculated by multiplying ash-free bulk density (g/cm^3) and vertical peat-growth rates (cm/yr). Weight of calibrated basal peat dates from 71 paludified peatlands (Halsey et al., 1998; Campbell et al., 2000) in continental western Canada as a measure of probability of peatland initiation. Comparisons between the UPF core and landscape patterns of peatland initiation illustrate the connection between local and regional conditions in response to Holocene climate changes.

The tight dating control of the UPF core (20 AMS ^{14}C dates) allows for detailed analyses of peat accumulation patterns. The classic bog growth model (Clymo 1984) is based upon constant production, and constant decomposition rates. This produces a concave shape to modeled peat mass – age curves due to increasing catotelm mass losses as more material accumulates in the catotelm. Theoretically, once enough peat resides in the catotelm, losses will equal input from the acrotelm and net peat accumulation will reach equilibrium. In the UPF core, however, during the *Scorpidium*-dominated period the peat accumulation pattern is convex (Fig. 4). This is in disagreement with the oceanic bog model. To extend the simple conceptual model of Clymo (1984), an additional exponential modifier for peat addition rate was included in new equation. Curve fitting of this new model to the UPF data shows that a unidirectional, 7-fold decrease in peat addition rate over time (192 to 26 g m^{-2} yr^{-1}) produces a similar convex pattern. It is likely that this pattern results from decreasing production, rather than increasing decomposition in the acrotelm (sensitivity analysis results not shown), and that the decrease in production is related to autogenically (internally) - moderated processes as peat thickness increases, and the connection of surface vegetation to nutrient rich ground water decreases. This extended convex model has important ramifications for peat accumulation models, particularly those strongly influenced by groundwater (rich fens) and moisture-limited climates.

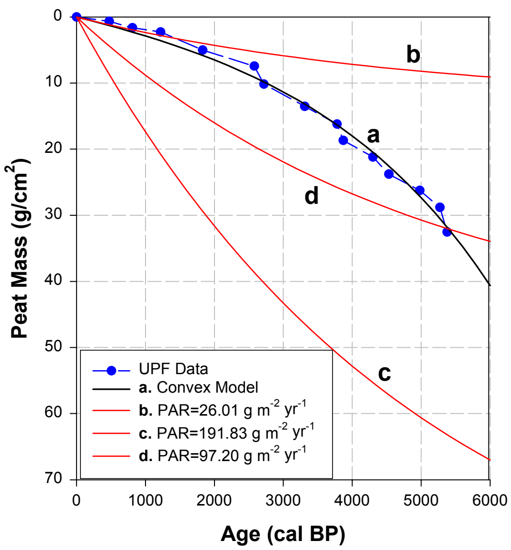

Figure 4**.** The data points (n=15) of the UPF core dominated by *Scorpidium* (dots and dashed line). The curve (**a**) is a fit of the new equation, with a fixed decay constant (0.0002 yr^{-1}), which yields eventual PAR=26.01 g m^{-2} yr^{-1}). The curve (**b**) is results from a Clymo-type model, with constant decay rate of 0.0002 yr^{-1} and constant PAR of 26.01 g m^{-2} yr^{-1}

Evaluation of Acrotelm and Catotelm Decomposition Rates: Inferences From Radiometrically-dated Peat Cores and Curve-fitting

Modelling the impacts of climate change on peatland carbon stores and fluxes requires understanding of the factors controlling peat decomposition, as well as estimates of decomposition rates. Three types of experimental and observational data related to peatlands were evaluated, which are from surface litter, acrotelm peat, and catotelm peat. The ^{210}Pb-dated peat-core profiles for the last 100-200 years are used to understand the oxic decomposition processes; ^{14}C-dated peat profiles for the last several millennia are used for understanding anoxic decomposition processes. Analysis of data from litterbag experiments suggests that a significant portion of the litter is lost in the first few years owing primarily to rapid initial decomposition processes, including movement/leaching of soluble materials. This is also confirmed indirectly by ^{210}Pb-dated peat-core data. Several records of acrotelm peat show similar estimated litter-addition (265 ± 37.3 g m^{-2} yr^{-1}) and decay rates (0.017 ± 0.0047 yr^{-1}), despite the climatic difference among study areas (Table 2). The litter-addition rate of 265 g m^{-2} yr^{-1} is at most, about half of measured net primary production. Warmer climates cause higher production but also higher decomposition. The balance of production and decay processes in the litter and acrotelm determines the peat addition rate to the catotelm, where long-term peat accumulation occurs. Our sensitivity analysis shows that change in the peat-addition rate would affect both young and old peat; in contrast, a change in the decay rate has more influence on old peat. We therefore hypothesize that the wiggles often seen in peat age - depth profiles are caused by changes in peat addition rates, which are determined by climatically sensitive processes including photosynthesis and acrotelm decomposition.

Table 2. Summary of decomposition coefficients and litter-addition rates in the acrotelm based on fitting of ^{210}Pb-dated peat profiles using a single exponential decay model.

Site	Location (lat., long.)	Annual Temperature (°C)	Annual Precipitation (mm)	Decay Coefficients (yr^{-1})	Litter-addition Rate ($g\ m^{-2}\ yr^{-1}$)
Sylvie's Bog Core 1, AB[1]	56°N; 112°32'W	-0.2	472	0.0176	241
Sylvie's Bog Core 2, AB[1]	"	"	"	0.0139	199
Internal Lawn Bog, AB[1]	"	"	"	0.0062	238
Bleak Lake Bog Core 1, AB[1]	56°30'N; 113°W	1.4	490	0.0433	484
Bleak Lake Bog Core 2, AB[1]	"	"	"	0.0164	213
Marcell S-2 Bog, MN[2]	47°32'N; 93°28'W	4.2	670	0.0117	259
Big Run Bog, WV[2]	39°07'N; 79°35'W	8.3	1215	0.0082	221
Mean				0.017	265
Standard Error (SE)				0.0047	37.3

Note:
1. Data from Turetsky et al. (2000)
2. Data from Wieder et al. (1994).

Most of the potential peat organic mass produced as NPP by living plants is decayed atop the acrotelm as litter and in the acrotelm, prior to entry into the catotelm. The rate of peat addition to the catotelm has been estimated at 10-20% of NPP, with a range of 36 – 78 $g\ m^{-2}\ yr^{-1}$ (Clymo, 1984; Gorham, 1991). For a single exponential decay model, the constant decay rate is in the range of 0.7 – 5.5 x $10^{-4}\ yr^{-1}$, based on the compilation by Clymo (1984). There are 14 peat profiles with a minimum of three ^{14}C dates in continental western Canada (Yu and Campbell, 1998; Vitt et al., 2000). These data were used to estimate peat addition rates to the catotelm and decay rates based on a single exponential decay model. Ten of the 14 profiles show concave age – depth (mass) curves for this model, and the remaining four profiles show convex curves and yield biologically meaningless negative decay rates, when the peat-addition rate is held constant through time (Table 3). At Slave Lake bog (Kuhry and Vitt, 1996), the convex age - mass curve suggests a continuously decreasing peat-addition rate over the last 10,000 years. Multiple proxy data from the Beauval Bog site in west central Saskatchewan indicate progressively decreasing moisture over the last 4000 years (Kuhry, 1997). Drying conditions may have decreased NPP and increased litter and acrotelm-peat decay, consequently reducing the peat-addition rate to the catotelm (see Yu et al., 2000).

Table 3. Parameter estimates for the catotelm from sites in continental western Canada using a single exponential decay model (Some preliminary results are presented in Yu and Campbell, 1998 and Vitt et al., 2000; see the latter for data source).

Site Name	**Peat Type**	**# ^{14}C Dates**	**Location (lat., long.)**	**Catotelm peat-addition rate ($g\ m^{-2}\ yr^{-1}$)**	**Catotelm decay rate ($x10^{-4}\ yr^{-1}$)**
Concave sites					
Gypsumville Bog, MB	Bog	3	51°46'N; 98°30' W	33.8	1.9
Legend Lake, AB	Bog	3	57°26'N; 112°57'W	17.3	2.6
Mariana Lakes Site 16, AB		3		18.7	0.16
89-18A, AB	Plateau	4	58°18'N; 119°17'W	20.3	0.89
Wathaman Bog, SK	Bog	3	56°57'N; 103°34'W	26.1	0.99
Steve 81-18A, AB	Patterned fen	3	54°45'N; 115°52'W	44.2	1.4
Steve 89-16A (Zama), AB		3	59°7'N; 118°9'W	27.6	1.7
Buffalo Narrows, SK		3	55°56'N; 108°34'W	17.6	1.3
Steve 81-8A (site 4), AB	fen	3	52°51'N; 116°28'W	23.9	0.43
Steve 81-11A (site 5), AB	fen	3	53°20'N; 117°28'W	47.7	2.3
Mean [and if plot all together]				**27.72** [23]	**1.37** [0.64]
Convex sites					
Beauval Bog, SK (Kuhry, 1997)	Bog, fen	3	54°40'N; 107°49'W		
Steve WC2 (site 7a), AB	Horizontal Fen	3	53°26'N; 116°04'W		
La Ronge, SK.	Bog	3	54°57'N; 105°15'W		
Slave Lake site, AB (Kuhry and Vitt, 1996)	Bog, fen	6	55°01'N; 114°09'W		

Scaling-Up: Regional Peat Accumulation Modelling and Differential Response of Peatland Types

Carbon sequestration rates of northern peatlands have been shown to be variable. Although Gorham (1991) estimated the rate for the world's northern peatlands to be 28.1 $g\ C\ m^{-2}\ yr^{-1}$, more recent regional estimates ranged 14.1-22.5 $g\ C\ m^{-2}\ yr^{-1}$ in Finland (Makila 1997), to 21 $g\ C\ m^{-2}\ yr^{-1}$ in a peatland-rich landscape in boreal Manitoba (Rapalee et al. 1998), and 19.4 $g\ C\ m^{-2}\ yr^{-1}$ for western Canada (Vitt et al. 2000). Shorth-term studies of individual peatlands show even greater variability (i.e., Lafleur et al. 2001), with some peatlands being a net source of atmospheric carbon in dry years (Shurpali et al. 1995; Joiner et al. 1997; Lafleur et al. 1997). Peat accumulation models have been based on behaviour and conditions of oceanic bogs (Clymo 1984), and only recently have begun to address different peatland types (Frolking et al. 2001). Continental peatlands in western Canada have variable plant communities, water chemistry, and hydrology (Vitt 1994). Their peat-accumulating nature is likely also variable (Gorham 1991) and can be expected to respond differently to climate change. Future climate predictions based on greenhouse gas- and atmospheric aerosol- driven climate models are for a warmer and variably wet boreal and subarctic continental western Canada (Boer et al. 2000). In this study, the two-layer, Clymo-type conceptual model (Clymo 1984) was adopted and parameterized for three generalized peatland types with available data from continental western Canada. This model was used to explore how different peatlands may respond to climate changes, particularly potential changes in peatland water table, and how this variability is patterned regionally.

Long-term (9000 yr) modeled peat depths show reasonable agreement with calibrated basal radiocarbon dates/depths from paludified peatlands in western Canada (Fig. 5). Sensitivity analysis using linear changes in model parameters over 100 years show that peat depths and accumulation rates are strongly affected by changes in NPP, acrotelm decomposition rates and changes in WTD (data not shown). Differential response among peatland types related to acrotelm depths, with peat plateaus being more sensitive to increased decomposition rates (deeper acrotelm), and fens being more sensitive to changes in NPP (shallower acrotelm).

Model performance under warmer temperatures (Q_{10} = 2 for both temperature, NPP, and acrotelm decomposition) shows that higher temperatures increase rates of carbon sequestration in all peatland types, despite the effect of increased decomposition (Fig. 6). Although sensitivity analyses show that peat accumulation is less sensitive to WTD fluctuations than NPP and acrotelm decomposition change, addition of conservative WTD changes (± 10 cm) to the scenarios result in either a further increase, or decrease to below baseline carbon accumulation rates (Fig. 6). Fens show the greatest range in carbon accumulation rate between warm/wet and warm/dry scenarios. Total fen coverage in continental western Canada is nearly twice that of peat plateaus and bogs (Vitt et al. 2000) and fens contain the majority of the carbon in the region (Table 1) that compounds the importance of this variability in the region.

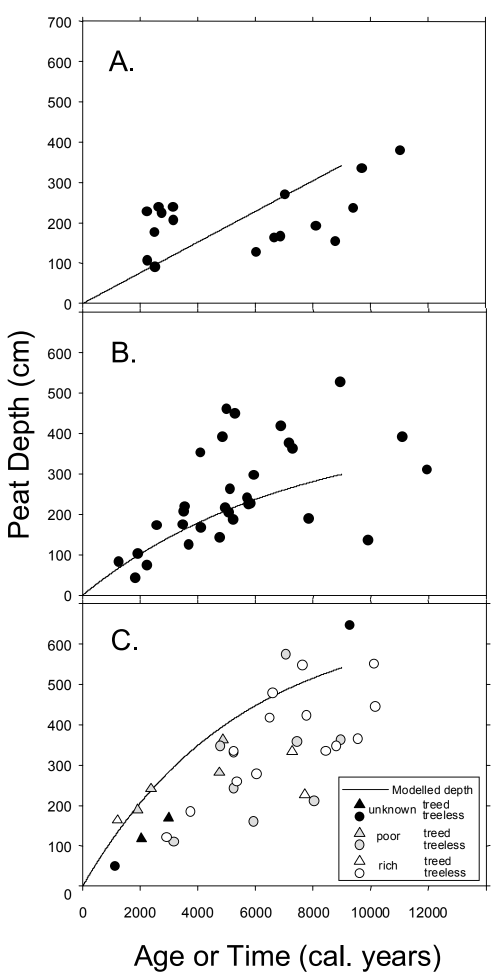

Figure 5. Comparison of modeled long-term peat accumulation (peat depths of 9000 yr simulation) for each peatland type and calibrated basal dates/depths. Peatland types are permafrost peatland (A), Bog (B), and Fen (C). Basal data are from Halsey et al. (1998).

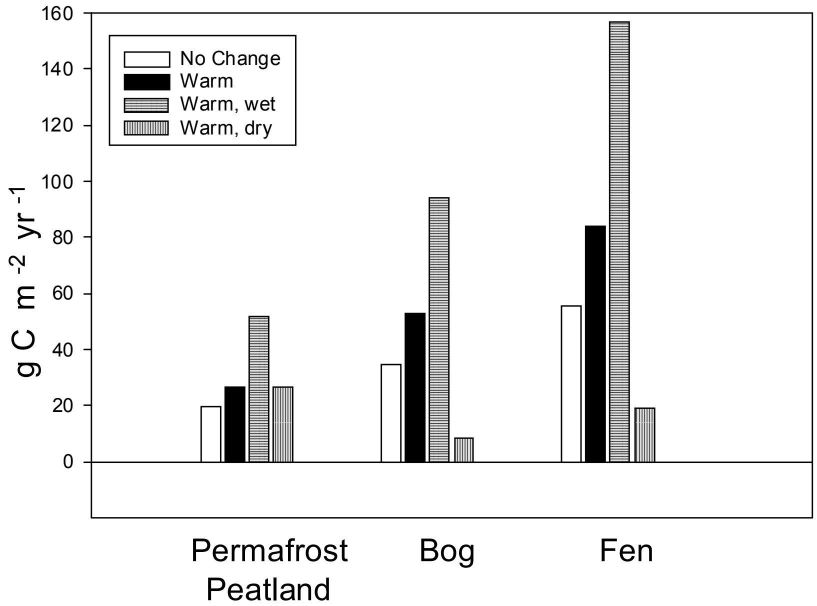

Figure 6. Modeled peat accumulation rates for three generalized peatland types at the end of 100 years of linear temperature and water table changes to climate change scenario conditions. Scenarios are based on the average predicted temperature change across the peatland area of the prairie provinces from a regional climate model for western Canada for a 3 x CO_2 atmosphere (Laprise et al. 1998) and prescribed changes in water table ("10 cm).

The spatial pattern of this sensitivity to water table variability for the region was determined by summarizing the range of carbon accumulation values determined for each peatland type from the warm/wet and warm/dry climate scenarios for each grid cell. Accumulation rates were corrected for the influence of specific-specific maximum peat depth on catotelm volumes (long-term peat decomposition losses). Hundred-year simulations were run for each peatland type for each specific, and point-model values were extrapolated to known coverages of peatland type. The range of response, or uncertainty, is greatest in the south of the region, and largely follows fen cover (Fig. 7), with lower variability occurring in the north where bogs and peat plateaus are more common. This spatial pattern of uncertainty in peat accumulation response coincides with sensitive moisture-limited climates close to the southern limit of peatlands.

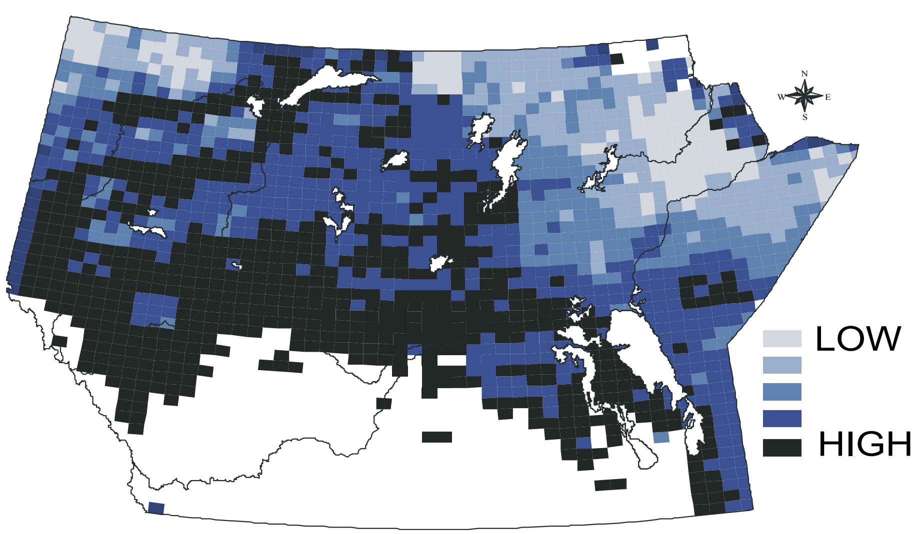

Figure 7. Variability in carbon sequestration between warm/wet and warm/dry climate change scenarios. Calculated as the difference of mean C accumulation rate per cell between the two scenario results. Values range from LOW (< 30 g C m^{-2} yr^{-1}) to HIGH (> 60 g C m^{-2} yr^{-1}).

Changes in temperature and WTD differentially affect peatland carbon sequestration behaviour in different continental peatland types in western Canada. If the simple two-layer peat accumulation model as parameterized here accurately simulates behaviour of continental peatland types, peatlands are sensitive to climate-induced changes in near-surface peatland processes, and fens are where much of the variability in carbon sequestration occurs on the landscape. Sensitivity of undisturbed carbon sequestration in peatlands across the region to climate variability, as well as uncertainty of response to future climate change, largely follows distributions of geogenous peatlands in continental western Canada. Natural disturbance in continental peatlands (e.g. fire and permafrost melt) also have a strong affect on peatland carbon accumulation (Zoltai et al. 1998; Vitt et al. 2001) that will also likely be unequal among the different peatland types. In contrast to undisturbed carbon sequestration patterns, fire and permafrost melt likely affect drier, treed peatlands, and thus will affect peat plateaus and bogs more than fens.

MANAGEMENT APLICATIONS

As peatlands of continental western Canada store a significant amount of the world's terrestrial carbon, management strategies targeted at carbon storage may be of value in the future. Calculations of annual long-term annual storage (Vitt et al. 2000) relative to current emissions (Jaques et al. 1997) at the provincial level suggest that peatlands sequester 4 % (Alberta), 8 % (Saskatchewan), and 62 % (Manitoba) of the emitted carbon from anthropogenic sources (industrial and household) on a yearly basis (Table 4) (Vitt et al. 2001). As fens have the greatest variable, and largest potential for change, our research suggests that manipulations of fen water tables or changes induced from natural or anthropogenic disturbances may allow for changes in carbon storage. Further research into this aspect is required to address model uncertainties.

TABLE 4: Yearly, long-term budgets of carbon accumulation in peatlands of continental western Canada. Long-term accumulation and decomposition rates follow those of Vitt *et al.,* (2000). Total flux has been converted to CO_2 equivalents following a greenhouse warming potential for methane of 21x that of carbon dioxide (IPCC 1996). Carbon emitted from anthropogenic sources is also reported in CO_2 equivalents (Jaques et al. 1997).

Type	**Alberta**	**Saskatchewan**	**Manitoba**	**Total**
Permafrost Bog	6.84×10^{11}	1.40×10^{11}	2.62×10^{12}	3.44×10^{12}
Nonpermafrost Bog	3.66×10^{11}	2.55×10^{11}	4.13×10^{11}	1.03×10^{12}
Wooded Fen	1.19×10^{12}	6.64×10^{11}	1.54×10^{12}	3.39×10^{12}
Shrubby Nonpatterned Fen	3.96×10^{11}	1.76×10^{11}	3.84×10^{11}	9.56×10^{11}
Open Nonpatterned Fen	6.58×10^{11}	2.68×10^{11}	1.33×10^{12}	2.25×10^{12}
Open Patterned Fen	1.56×10^{11}	2.01×10^{11}	7.59×10^{11}	1.12×10^{12}
Peatland	3.45×10^{12}	1.70×10^{12}	7.04×10^{12}	1.22×10^{13}
Carbon Emitted from Catotelm	1.85×10^{12}	9.07×10^{11}	3.85×10^{12}	7.08×10^{12}
Peatland Carbon Budget	$\mathbf{1.60 \times 10^{12}}$	$\mathbf{7.93 \times 10^{11}}$	$\mathbf{2.19 \times 10^{12}}$	$\mathbf{4.58 \times 10^{12}}$
Carbon Emitted (Anthropogenic)	4.24×10^{13}	1.03×10^{13}	3.55×10^{12}	5.63×10^{13}
% Wetland Offset	3.8	7.7	61.7	8.1

SUMMARY

Peatlands of continental western Canada began accumulating peat and hence carbon around 9000 BP. Half of the 48.0 Pg of carbon currently stored had accumulated by 4000 BP, with the annual increase in storage beginning to decrease around 3000 BP. While peatlands continue to act as a regional carbon sink, the decline in carbon storage around 3000 years BP can be related to the development of permafrost through the Subarctic and Boreal Regions of continental western Canada as well as the current southern limit of peatlands being reached.

Macrofossil and physico-chemical analyses of a high-resolution peat record from a western Alberta rich fen suggests that hydrological conditions that affect regional patterns of peatland expansion, also affect local peat accumulation. Detailed investigation of the pattern of carbon accumulation in this core based on 20 AMS ^{14}C dates reveals a convex-shaped peat accumulation pattern that is in contrast to the widely accepted concave model. Estimates of peat decomposition rates for upper and lower portions of the peat profile are made from available radiometrically dated cores and curve fitting exercises. These estimates were used together with available data from western Canada to investigate spatial patterns of peat accumulation variability in response to climate change. Geogenous peatlands (fens) show the greatest variability, and regional patterns of uncertainty in peatland response to potential changes in local hydrology follows the distribution of fens in western Canada.

As peatlands store a significant amount of the world's terrestrial carbon, and annually sequester 8% of the carbon emitted from all anthropogenic sources in continental western Canada, carbon management plans in the Boreal Forest should consider these ecosystems. As fens have the greatest variable, and largest potential for change, our research suggests that manipulations of fen water tables or changes induced from natural or anthropogenic disturbances may allow for changes in carbon storage. Further research into this aspect is required to address model uncertainties.

REFERENCES

Belland, R.J., and Vitt, D.H. 1995. Bryophyte vegetation patterns along environmental gradients in continental bogs. Ecoscience 2: 395-407.

Campbell, C., Vitt, D.H., Halsey, L.A., Campbell, I. D., Thormann, M.N. and Bayley, S.E. 2000. Net primary production and standing biomass in northern continental wetlands. Can. For. Serv. Northern For. Cent. Inf. Rep. NOR-X-369.

Clymo, R. C. 1984. The limits to peat bog growth. Phil. Trans. Royal Soc.London B 303: 605-654.

Frolking, S., Roulet, N.T., Moore, T.R., Richard, P.J.H., Lavoie, M. and Muller, S. 2001 (in press). Modeling northern peatland decomposition and peat accumulation. Ecosystems.

Gignac, L.D., Vitt, D.H., Zoltai, S.C., and Bayley, S.E. 1991. Bryophyte response surfaces along climatic, chemical, and physical gradients in peatlands of western Canada. Nova Hedw. 53: 27-71.

Gore, A.J.P. 1983. Ecosystems of the World 4B. Mire: swamp, bog, fen, and moor. Elsevier Scientific Publishing Co., Amsterdam, The Netherlands.

Gorham, E. 1991. Northern peatlands: role in the carbon cycle and probable responses to climatic warming. Ecol. Appl. 1: 182-195.

Halsey, L.A., Vitt, D.H., and Bauer, I.E. 1998. Peatland initiation during the Holocene in continental western Canada. Clim. Change 40: 315-342.

Jaques, A., F. Neitzert & P. Boileau, 1997. Trends in Canada's Greenhouse Gas Emissions (1990-1995). Environment Canada, Ottawa, Ontario.

Joiner, D.W., Lafleur, P.M., McCaughey, J.H., Bartlett, P.A. 1999. Interannual variability in carbon dioxide exchanges at a boreal wetland in the BOREAS northern study area. J. of Geophys. Res. 104: 27663-27672.

Kuhry, P., 1997. The palaeoecology of a treed bog in western boreal Canada: a study based on microfossils, macrofossils and physico-chemical properties. Rev. Palaeobot. Palynol. 96: 183-224.

Kuhry, P. and Vitt, D.H., 1996. Fossils carbon/nitrogen ratios as a measure of peat decomposition. Ecology 77: 271-275.

Lafleur, P.M., Roulet, N.T., and Admiral, S.W. 2001. Annual cycle of CO_2 exchange at a bog peatland. J. of Geophys. Res. 106: 3071-3081.

Lafleur, P. M., McGaughey, J.H., Joiner, D.W., Bartlett, P.A., and Jelinski, D.E.. 1997. Seasonal trends in energy, water and carbon dioxide fluxes at a northern boreal wetland. J. of Geophys. Res. 102: 29009-29020.

Laprise, R., Caya, D., Giguere, M., Bergeron, G., Cote, H., Blanchet, J-P., Boer, G.J., and McFarlane, N.A. 1998. Climate and climate change in western Canada as simulated by the Canadian Regional Climate Model. Atmos. Oc.36: 119-167.

Mäkilä, M. 1997. Holocene lateral expansion, peat growth and carbon accumulation on Haukkusuo, as raised bog in southeastern Finland. Boreas 26: 1-14.

Moore, T.R., Roulet, N.T., and Waddington, J.M. 1998. Uncertainty in predicting the effect of climatic change on the carbon cycling of Canadian peatlands. Clim. Change 40: 229-245.

Nicholson, B J., Gignac, L.D., Bayley, S.E., and Vitt, D.H. 1997. Vegetation response to global warming: interactions between boreal forest, wetlands, and regional hydrology. In Mackenzie Basin Impact Study Final Report. Edited by S. Cohen, Environment Canada, Ottawa.

Post, W.M., Chavez, F., Mulholland, P.J., Pastor, J., Peng, T.-H., Prentice, K., and Webb III, T. 1992. Climatic feedbacks in the global carbon cycle. In The science of global change: the impacts of human activities on the environment. Edited by D. A. Dunnette and R. J. O'Brien. American Chemical Society, Washington, D.C.

Rapalee, G., Trumbore, S.E., Davidson, E.A., Harden, J.W., and Veldhuis, H. 1998. Soil carbon stocks and their rates of accumulation and loss in a boreal forest landscape. Glob. Biogeochem. Cycles 12: 687-701.

Shurpali, N. J., J. K. Verma, and T. J. Arkebauer. 1995. Carbon dioxide exchange in a peatland ecosystem. J. of Geophys. Res. 100: 14319-14326.

Vitt, D.H. 1994. An overview of factors that influence the development of Canadian peatlands. *Mem. Ent. Soc. Can.* 169: 7-20.

Vitt, D.H., Halsey, L.A., and Zoltai, S.C. 1994. The bog landforms of continental Canada in relation to climate and permafrost patterns. Arct. Alp. Res. 26: 1-13.

Vitt, D.H., Halsey, L.A., Bauer, I.E., and Campbell, C. 2000. Spatial and temporal trends in carbon storage of peatlands of continental western Canada through the Holocene. Can. J. Earth Sci. 37: 683-693.

Vitt, D. H., Halsey, L. A., Campbell, C., Bayley, S. E., and Thormann, M., 2001. Spatial patterning of net primary production in wetlands of continental western Canada. Ecoscience (in press).

Yu, Z.C. and Campbell, I.D. 1998. Peatland dynamics simulation model: A literature review and modelling design. Working Paper 1998-17, SFM-NCE, University of Alberta, Edmonton. 54 p.

Yu, Z.C., Vitt, D.H., Campbell, C. and Campbell, I.D. 2000. Pattern and processes of peat accumulation in continental rich fens: hypothesis and preliminary results. In Proceedings of the 11th International Peat Congress, Quebec City, Quebec. Edited by Line Rochefort and J.-Y. Daigle. pp. 208-215

Zoltai, S.C. 1995. Permafrost distribution in peatlands of west-central Canada during the Holocene warm period 6000 years BP. Géog. Phys. et Quat. 49: 45-54.