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# Quantifying Long Term Changes in Organic Matter Sequestration for Carbon Management: Permafrost Dynamics and Climate Change


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# Quantifying Long Term Changes in Organic Matter Sequestration for Carbon Management: Permafrost Dynamics and Climate Change

by

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## INTRODUCTION

With the possible inclusion of terrestrial ecosystems as carbon sources or sinks for greenhouse gases, there is a heightened interest in quantifying and modeling ecosystem atmosphere carbon exchange. Peatlands in the Boreal and Subarctic regions of the northern hemisphere represent a significant sink for carbon and contain and estimated 1/3 of the world's soil carbon stored as peat (Gorham 1991). Most of this peat is sequestered as permafrost that responds dynamically to climate change (Vitt et al. 1994, Halsey et al. 1995). Since the end of the Little Ice Age, roughly 100 years ago, permafrost has been degrading across a sensitive band of the boreal forest (Vitt et al. 1994). Degradation has resulted and will continue result in a shift in peatland ecosystems from permafrost bogs to poor fens (Vitt et al. 1994). This shift in ecosystems results in an increase carbon sequestration rates (Turetsky et al. 2000).

Here we present the published preliminary results of our efforts to quantify the change in carbon sequestration rates and magnitude of carbon storage across continental western Canada (Vitt et al. 2000). While we have not requested further funding, my graduate student (Merritt Turetsky) will continue to examine additional cores from areas of permafrost degradation to more fully elucidate the variation in carbon sequestration rates.

## SUMMARY OF DATA ANALYSIS

Peatlands and peatland complexes across continental western Canada were inventoried by type from 1:40,000 to 1:60,000 aerial photographs and the data transferred to 1:250,000 base maps. The presence of permafrost as peat plateaus or permafrost lenses in continental bogs and internal lawns (degraded permafrost) was identified to the nearest 10% cover following Vitt et al. (1994). Peatland distributions were determined from the 1:250,000 maps through digitizing onto provincial base maps. Aerial extents were calculated in ARC/INFO for 0.25° latitude and 0.5° longitude grids by wetland type. Summaries have been completed for Alberta (Vitt et al. 1996) and Manitoba (Halsey et al. 1997). A zone of permafrost degradation was determined based on the extent of internal lawns. Within this zone current permafrost and the amount that has degraded (area of internal lawns) was quantified. Degradation within this zone was then subdivided into four subzones determined by percent degradation increments of 25%. The amount of permafrost currently in disequilibrium with climate was determined for each grid cell by examining the difference between the inventory and amounts predicted by a model that defines permafrost at equilibrium with climate:

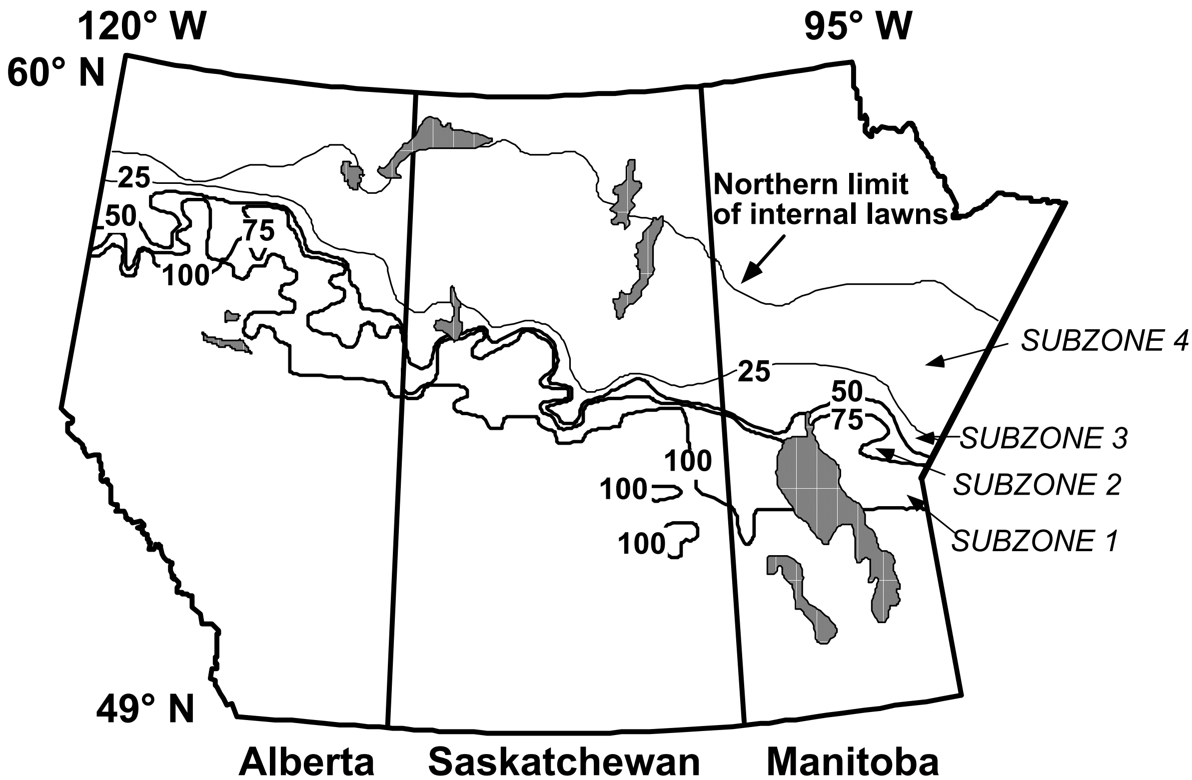
$$y_i = 0.3y_{(i-1)} - 14.6x_i - 0.1 \tag{1}$$

where $y_i$ = percent of permafrost bogs and $x_i$ = mean annual temperature (Halsey et al. 1995). Using long-term net organic matter accumulation values for permafrost bogs and internal lawns collected from single, but representative sites (Turetsky et al. 2000), change in net organic matter accumulation due to permafrost degradation is predicted.

The maximum southerly extent of permafrost during the Little Ice Age for continental Canada extended between 55°-57° N latitude in Alberta and 52°-53° N latitude in Manitoba as indicated by the presence of internal lawns (Fig. 1). Internal lawn outliers are also found in some southern boreal uplands of Saskatchewan and Manitoba. Although permafrost degradation is currently in disequilibrium with climate (Halsey et al. 1995, Camill and Clark 1998), a northerly regression of the southernmost limit of permafrost has occurred, with percent degradation becoming progressively less towards the north throughout continental Canada (Fig. 1).

Detailed mapping of peatland landforms in continental western Canada has allowed us to calculate areas of regional permafrost change. Permafrost distributions over the last millennium have fluctuated in a sensitive zone that covers about 672,000 $km^2$ of continental western Canada. Within this zone, 28,800 $km^2$ of permafrost was present during the Little Ice Age. Subsequent degradation, as interpreted from current internal lawn distribution, represents 2,627 $km^2$ , or 9% of this permafrost (Table 1), with most being found in the south (Fig. 1). Following the equilibrium model of Halsey et al. (1995) the amount of permafrost that could melt in today's climate was calculated as 8,430 $km^2$ (Table 1). As an estimated 9% of this permafrost has currently melted following internal lawn distributions, 5,813 $km^2$ remains today in disequilibrium, representing 22% of the current permafrost area (Table 1). As degradation approaches equilibrium with the climate of today, the amount of permafrost that can potentially degrade increases by an order of magnitude in the northern part of the zone (Fig. 2).

FIGURE 1: Zone of active permafrost degradation in continental western Canada, based on the presence of internal lawns. Degradation of permafrost was calculated for 0.25° latitude and 0.50° longitude grids using maximum area of Little Ice Age permafrost peatland extent relative to the present area represented by internal lawns. Areas of permafrost landforms were taken from 1:250,000 maps constructed for the provinces from 1:40,000 to 1:60,000 scale aerial photographs and digitized into ARC/INFO. The zone of permafrost degradation is subdivided into four subzones based on the percent of internal lawns that has melted:1- 1-25% melted; 2- 26-50% melted; 3- 51% melted; 4- 76-100% melted.




Melting of permafrost results in an increase in storage of organic matter, and thus carbon, in the boreal forest (Turetsky et al. 2000). Since the Little Ice Age, long-term organic matter accumulation averaged over a 100 year period has changed +5%, an increase of 2 x 1011 $gyr^{-1}$ (Table 1). In contrast, at equilibrium, the area of internal lawns will result in a 16% change in organic matter accumulation averaged over a 100 year period, increasing around 5 x 1011 $gyr^{-1}$ from Little Ice Age amounts (Table 1). This is approximately equivalent to 10% of the annual organic matter harvested by the forest industry in continental western Canada following biomass estimates for the Boreal Plains by Penner et al. (1997). If managed correctly permafrost degradation can form a substantial increased sink to Canada's annual carbon budget.

TABLE 1: Change is net organic matter accumulation based on 100 year mean accumulation from single, representative sites following Turetsky et al. (2000).

| Time | Permafrost Area ($km^2$) | Permafrost Organic Matter Accumulation ($gyr^{-1}$) | Internal Lawn Area ($km^2$) | Internal Lawn Organic Matter Accumulation ($gyr^{-1}$) | Change in Organic Matter Accumulation from Little Ice Age ($gyr^{-1}$) |
|---|---|---|---|---|---|
| Little Ice Age | 28,816 | $3.40 \times 10^{12}$ | 0 | 0 | 0 |
| Current | 26,189 | $3.09 \times 10^{12}$ | 2,627 | $4.73 \times 10^{11}$ | $1.63 \times 10^{11}$ |
| Equilibrium | 20,386 | $2.41 \times 10^{12}$ | 8,430 | $1.52 \times 10^{12}$ | $5.30 \times 10^{11}$ |

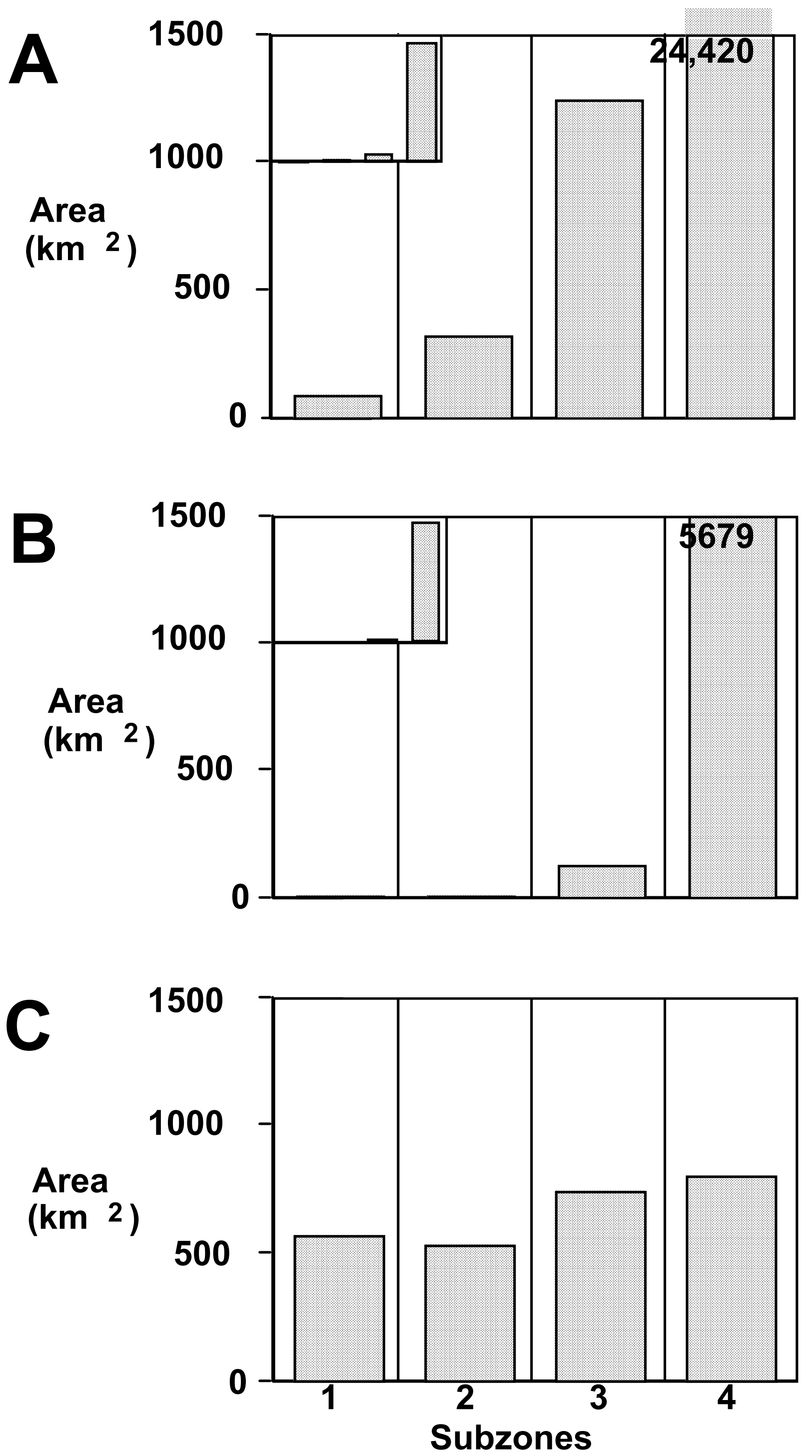
## MANAGEMENT APPLICATIONS

Continued degradation of permafrost will result in continued loss of forested lands but with an increase in carbon sequestration. Management practices examining changes in carbon storage and sequestration rates in Canada's boreal forest need to take into account the changes related to this ecosystem shift.

## CONCLUSIONS

The aggradation and degradation of permafrost during the last millennium has responded dynamically to climatic changes that have occurred since the Little Ice Age. Permafrost reached its southernmost limit at some point during the Little Ice Age and has responded to subsequent warming by shifting northwards in a disequilibrium fashion (Halsey et al. 1995). Permafrost melting results in the formation of internal lawns that occur in a broad zone spanning the boreal forest of continental western Canada. Currently 9% of permafrost within this zone has degraded, with a corresponding 5% increase in long-term net organic matter accumulation. Large tracts of permafrost are currently unstable and in disequilibrium with present climate; these represent 22% of current boreal permafrost and a corresponding 11% increase in long-term net organic matter accumulation upon degradation of this disequilibrium permafrost.

FIGURE 2: Area of A) current equilibrium permafrost, B) current disequilibrium permafrost, and C) current degraded permafrost (internal lawn) distribution present within the sensitive zone demarcated by permafrost degradation. The zone has been subdivided into four areas based on the percentage of permafrost that has melted following Figure 1.



Predicted greenhouse gas forced warming from global circulation models is in the range of 3 to 4°C for northern latitudes by the middle of the twenty-first century (Cohen 1997), roughly double the temperature rise since the Little Ice Age (cf. Grove 1988, Campbell and McAndrews 1993). Using warming since the end of the Little Ice Age as an analogue, changes in mean annual temperatures of this magnitude will have slow, but potentially dramatic impacts on the permafrost peatland environment, affecting not only the southern limit of permafrost, but also vast areas of peat plateau in the northern part of Canada's Boreal Forests, resulting in substantial loss of forested lands and increases in long-term net organic matter accumulation generated by this natural disturbance.

## REFERENCES


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

Bradshaw, C. J. A., Hebert, D. M., Rippin, A. B., and Boutin, S. 1995. Winter peatland habitat selection by woodland caribou in northeastern Alberta. Canadian Journal of Zoology 73: 1567-1574.

Brown, R. J. E. 1960. The distribution of permafrost and its reaction to air temperature in Canada and the U.S.S.R. Arctic 13: 163-177.

Brown, R. J. E. 1969. Factors influencing discontinuous permafrost in Canada. Pages 11-53 in T.L. Péwé, editor. The periglacial environment past and present. McGill-Queens University Press, Canada.

Brown, R. J. E. 1983. Effects of fire on the permafrost ground thermal regime. In The role of fire in northern circumpolar ecosystems. Edited by R.W. Wein and D.A. MacLean. John Wiley and Sons, pp. 97-110.

Brown, R. J. E., and Williams, G. P. 1972. The freezing of peatlands. Technical Paper 381, Division of Building Research, National Research Council of Canada, Ottawa.

Camill, P., and Clark, J. S. 1998. Climate change disequilibrium of boreal permafrost peatlands caused by local processes. American Naturalist 151: 207-222.

Campbell, I.D., and McAndrews, J. H. 1993. Forest disequilibrium caused by rapid Little Ice Age cooling. Nature 366: 336-338.

Cohen, S. J. 1997. Mackenzie basin impact study final report. Environment Canada, Ottawa, Canada.

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

Grove, J. M. 1988. The Little Ice Age. Meuthen, New York.

Halsey, L. A., Vitt, D. H., and Zoltai, S. C. 1995. Disequilibrium response of permafrost in boreal continental western Canada to climatic change. Climatic Change 30: 57-73.

Halsey, L. A., Vitt, D. H., and Zoltai, S. C. 1997. Climatic and physiographic controls on wetland type and distribution in Manitoba, Canada. Wetlands 17: 243-262.

Hillman, G. R. 1992. Some hydrological effects of peatland drainage in Alberta's boreal forest. Canadian Journal of Forest Research 22: 1588-1596.

Kershaw, G. P., and Gill, D. 1979. Growth and decay of palsas and peat plateaus in the Macmillan Pass-Tsichu River area Northwest Territories, Canada. Canadian Journal of Earth Sciences 16: 1362-1374.

Muller, S. W. 1945. Permafrost or perennially frozen ground and related engineering problems. United States Geological Survey Special Report, Strategic Engineering Study 62, 2nd ed, Washington, D. C.

Penner, M., Power, K., Muhairwe, C., Tellier, R., and Wang, Y. 1997. Canada's forest biomass resources: deriving estimates from Canada's Forest Inventory. Canadian Forest Service, Information Report BC-X-370, Pacific Forest Centre, Victoria, B.C., 33 pp.

Turetsky, M., Wieder, R. K., Williams, C., and Vitt, D. H. 2000. Organic matter accumulation, peat chemistry, and permafrost melting in peatlands of boreal Alberta. Ecoscience (in press).

Tyritkov, A. P. 1964. The effect of vegetation on perennially frozen soil. Pages 69-90 in National Research Council of Canada Technical Translation 1088, Ottawa, Canada.

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

Vitt, D. H., Halsey, L. A., Thormann, M. N., and Martin, T. 1996. Peatland inventory of Alberta. Phase 1: Overview of peatland resources in the natural regions and subregions of the province. Stephen C. Zoltai Peatland Resource Centre, Devonian Botanic Garden, University of Alberta, Edmonton, Alberta, Canada, 117p.

Vitt, D. H., Halsey, L. A., and Zoltai, S. C., 2000. The changing landscpe of Canada's western boreal forest: the current dynamics of permafrost. Canadian Journal of Forest Research 30: 283-287.

Williams, D. J., and Burn, C. R. 1996. Surficial characteristics associated with the occurrence of permafrost near Mayo, Central Yukon Territory, Canada. Permafrost and Periglacial Processes 7: 193-206.

Zoltai, S. C. 1971. Southern limit of permafrost features in peat landforms, Manitoba and Saskatchewan. Geological Association of Canada Special Paper 9: 305-310.

Zoltai, S. C. 1972. Palsas and peat plateaus in central Manitoba and Saskatchewan. Canadian Journal of Forest Research 2: 291-302.

Zoltai, S. C. 1993. Cyclic development of permafrost in the peatlands of northwestern Alberta, Canada. Arctic and Alpine Research 25: 240-246.

Zoltai, S. C., and Tarnocai, C. 1971. The properties of a wooded palsas in northern Manitoba. Arctic and Alpine Research 3: 115-129.