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Over-Winter Chemistry of Subarctic Fens, Eastern Canada

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Two subarctic fens (one nutrient-poor, one nutrient-rich) were sampled from October, 1984 to July, 1985 near Schefferville, northern Quebec. The changes in concentations of chemicals (pH, conductance, Ca, Mg, Na, K, Fe, dissolved organic carbon, P, NH_4^+-N and NO_3^--N) dissolved in the peat water were identified during the freeze-thaw cycle. The highest chemical concentrations were in the winter (associated with the ice formation process), followed by the spring-summer, then fall. Four main processes influenced the concentration of dissolved chemicals in subarctic fens: 1) Snowmelt diluted the peat water; 2) Freezing of the peat increased concentrations of dissolved nutrients and other chemicals, believed to originate from biological sources; 3) Further increases in concentrations over the winter were caused by the incorporation of peat water, which migrated into the frozen peat; 4) Thawing of peat influenced the water chemistry by combining the release of the above 3 processes, along with biotic utilization. The freeze-thaw cycle in the subarctic fens appeared to increase the availability of important nutrients (such as phosphorus) during the spring.

Introduction

Peatlands cover about 110×10^6 ha in Canada, most of which occur in boreal and subarctic regions (Zoltai and Pollett 1983). Peat water chemistry has a major effect on, and is affected by, vegetation growing on the peatlands and the relationships between peat water chemistry and plant distribution have been strongly established

(Sjörs 1950, Vitt, Achuff and Andrus 1975). Most studies of peatland water chemistry have been made during the summer months (*e.g.* Sparling 1966, Damman 1986). Yet little is known about the winter period, when northern peatlands can be frozen for more than 6 months each year. Freezing of water can cause chemical redistributions, which have been commonly reported on lakes (*e.g.* Adams and Lasenby 1982) and modelled for peats (Kadlec, Li and Cotton 1988). There is also evidence of increases in nutrient concentrations in streams draining wetlands during thaw (*e.g.* Schwartz and Milne-Home 1982, Edwards, Creasey and Cresser 1986).

As a peatland freezes, four different layers of ice can be produced. One is black (or clear) ice, formed by the freezing of standing water on the peat surface. Another is white (or snow) ice, formed at the base of the snowcover by the freezing of water produced by terrestrial runoff onto the peat surface or by the upwelling of groundwater. A layer of well-bonded pore ice commonly underlies these layers and may be underlain, in turn, by a layer of segregated ice with ice lenses, caused by the migration of water to the freezing front (Juusela 1967).

Lake ice studies have shown that black ice is chemically pure, through the loss of dissolved substances by exsolution, whereas white ice can be enriched by chemicals from the water column or the snowpack (*e.g.* Adams and Lasenby 1982, 1985, Barica and Armstrong 1971, Gröterud 1972, Leung and Carmichael 1984). The experimental freezing of surface peat water (presumably forming black ice) results in the exsolution of dissolved chemicals from the water into the upper peat layers (Kadlec *et al.* 1988). Freezing of water in organic soils, on the other hand, may cause increases in chemical concentrations, through the breakdown of decomposing plant cells and soil fauna (*e.g.* Edwards *et al.* 1986).

During the thaw, snowmelt and terrestrial runoff along with their chemical loads, can either flow over the frozen surface (Pierson and Taylor 1985) or be incorporated into the peat, depending on the surface hydrology. Peat thaw can occur from both above and below (Kingsbury and Moore 1987), with dissolved substances being released into the water. Once the fen is ice-free, water can migrate upwards to the biological active layer (upper 30 cm), where mire plants can utilize both the water and its dissolved chemical substances (*e.g.* nutrients) content.

Despite the importance of the freeze-thaw cycle to the evolution of northern peatlands and their vegetation, no study has attempted to examine the chemical changes associated with this cycle. In this paper, we report on the chemical changes observed in two subarctic fen sites near Schefferville, northern Quebec, from the fall through to the early summer.

Study Area and Methods

The Schefferville area (lat. 54° 48′ N, long. 66° 49′ W) is located in the low subarctic wetland zone of Canada, where peatlands cover 10-15 % of the land surface (Zoltai and Pollett 1983). The area lies in the Labrador Trough, composed mainly of sedimentary and metamorphic rocks, such as shales, slates, quartzite, iron formations and dolomite. The climate is characterised by a mean annual temperature of −4.9°C and a mean annual precipitation of 785 mm, of which half falls as snow (Barr and Wright 1981). The peatlands in the lowlands freeze to depths ranging from 50 to 100 cm (Moore 1987), though permafrost occurs beneath the adjacent ridges and upland peatlands contain palsa.

Two sites were selected for the study. One known as Aries (UTM 423732, zone 19U; NTS map 23J/15), covers an area of about 3 ha, being bounded by a spruce-moss forest to the north and east and by a lake and a stream on the south and west. The fen slopes towards the stream and has no well-defined outflow. The vegetation consists of sedges, such as *Carex rariflora,* and *Sphagnum* spp. with some shrubs and occasional *Larix laricina.* The fen has a peat depth of < 200 cm, and is partially underlain by dolomite, which imparts high calcium and magnesium concentrations, a high specific conductance and a high pH on the peat water, classifying it as a rich fen (Sjörs 1950).

The second site known as Capricorn (UTM 423723, zone 19U; NTS map 23J/15), is located in the upper section of a larger mire, covering about 4 ha, which drains to the north and the south-east. The peat profile is deep, up to 275 cm, and covered by *Carex limosa, Chamaedaphne calyculata* and *Sphagnum lindbergii.* The underlying substrate does not appear to contain dolomite and the peat water contains low calcium and magnesium concentrations and has a low specific conductance and pH. This, in effect, classifies Capricorn as a poor fen (*sensu* Sjörs 1950).

Snow samples were collected at each site with a "Standard Federal" snow tube or from snow pits (Adams and Barr 1974). The depth and character of the frozen peat was determined by drilling with a lake ice auger. When the fens were unfrozen, a peat water tube sampler was inserted vertically into the peat, sampling at 10 cm intervals to a depth of 100 cm. During winter, a hole was drilled through the frozen peat and a heated tent was set-up over the sampling area. The water samples were then taken from below the frozen peat in the same manner as above. Samples of the frozen peat were collected by drilling three holes, cutting a triangular block with a chain saw and storing the block in a freezer. The block was then profiled into 10 cm sections, rinsed with distilled water, and allowed to thaw, with the water being saved for chemical analysis.

Samples of the snow, peat water and water drained from the thawed peat were filtered through Whatman #42 paper and analyzed as follows:

- pH by pH meter;
- specific conductance at 25°C by conductivity meter;

- NH_4^+-N by the phenolhypochlorite method (Solorzano 1969);
- NO_3^--N by the brucine method (Jenkins and Medsker 1964);
- total dissolved phosphorus (P_t) by the ammonium molybdate method (Strickland and Parsons 1968);
- dissolved organic carbon (DOC) from absorbance at a wavelength of 330 nm (Moore 1985);
- free iron (Fe) by reaction with o-phenanthroline (Moore 1985);
- calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na) by atomic absorption spectrophotometry and emission spectroscopy (Environment Canada 1979).

The Mann-Whitney U test was used to establish significant differences at the 95 % level. This non-parametric statistical test was used because of the difficulty in assuming a normal distribution of the variables.

Results

Measurements were made from October, 1984 to July, 1985. This study period was characterised by a snowfall of 279 mm, 1 standard deviation below the 25 year mean of 377 mm for the July to June snow year (Barr and Wright 1981). The precipitation in spring and early summer (May to July, 1985) was also low, totalling 115 mm, 1.5 standard deviations below the 25 year mean of 195 mm. Air temperatures were close to the average for the period, reaching a monthly mean of −21.1°C in January, 1985.

The accumulation of the snowcover at the two sites is depicted in Fig. 1, reaching a maximum thickness of 68.5 cm at Aries and 57.0 cm at Capricorn in late April, based on snow pit measurements. The freezing pattern in the peat showed the development of well-bonded pore ice and segregated ice with ice lenses (Fig. 1). After the initial rapid development of the pore ice, the insulating influence of the snowcover slowed its progression into the peat. The water table fell at both sites, leaving an unsaturated zone beneath the pore ice layer, where the segregated ice formed. A maximum depth of freezing of 110 cm at both sites was reached in late April.

Snowmelt started in mid-April and was completed by the end of May. This was followed by a melting of the peat from the surface and also upward melting from the base of the peat, probably from the geothermal heat flux (Kingsbury and Moore 1987). The dry spring in 1985 created an unsaturated, thawed surface layer in the peat, which increased to a thickness of about 30 cm by early July, after which rains and upwelled peat water caused saturation to the peat surface. The dry peat layer slowed the downward melting of the frozen peat, so that the ice completely

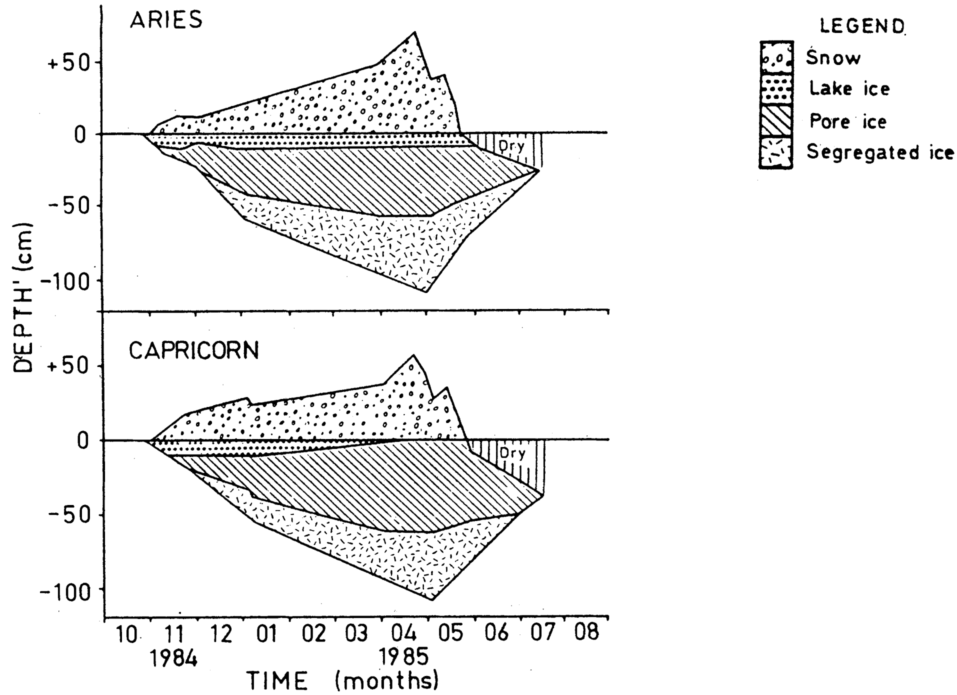

Fig. 1. The physical evolution of the snowcover and the freeze-thaw regime at Aries and Capricorn over the 1984-5 winter.

disappeared from the sites only in late July, and entirely from the fens in early August.

Concentrations of dissolved chemicals in the snowpack were low on April 23, 1985 and only minor differences in concentrations between the two sites were observed (Table 1). During the early melt, there was an elution of dissolved chemicals from the snowpack, as illustrated by the lower specific conductance of the snowpack at the Aries site (Fig. 2). Differences in specific ions were difficult to discern because of the spatial variations in the snowpack chemistry and the contamination of the lower portions of the snowpack with chemicals migrating from the upper layers of the peat.

Samples of water from the two peat sites were collected from November 21, 1984 to July 19, 1985. Once the entire peat profiles were unfrozen, the Aries site had significantly ($p<0.05$) higher concentrations of Ca, Mg and Fe and a higher specific conductance and pH than the Capricorn site, reflecting the influence of the dolomitic substrate (Table 2). However, there were no significant differences in NH_4^+-N and NO_3^--N, Na, K, P_t or DOC.

Comparison of peat water concentrations between the November and July sampling dates at the Capricorn site revealed only three significant differences: a

Table 1 – Concentrations of chemicals in the snowpack at peak condition, sampled on April 23, 1985.

Site	n	pH	Sp. Cond ($\mu S\ cm^{-1}$)	NH_4^+-N	NO_3^--N	DOC	Fe	Ca	Mg	K	Na (mg l^{-1})	P_t ($\mu g\ l^{-1}$)	Water equivalent (cm)
Aries	14	5.1	6.8	0.19	0.05	1.39	0.18	0.41	0.10	0.23	0.39	4.6	21.2
Capricorn	12	5.0	7.7	0.14	0.09	2.55	0.13	0.36	0.11	0.30	0.35	5.2	21.7

Table 2 – Concentrations of chemicals in the peat water at the date and state indicated, for the Aries and Capricorn sites.

Site	n	Date	State	pH	Sp. Cond ($\mu S\ cm^{-1}$)	NH_4^+-N	NO_3^--N	DOC	Fe	Ca	Mg	K	Na (mg l^{-1})	P_t ($\mu g\ l^{-1}$)
Aries	10	21/11/84	Unfrozen	5.4	63.6	0.42	0.06	7.44	0.24	6.09	2.99	0.42	0.79	15.7
	10	09/01/85	Frozen*	6.4	83.6	0.71	0.20	10.72	0.38	7.34	3.80	0.69	1.60	19.1
	10	29/05/85	Frozen*	6.4	66.9	0.46	0.08	8.88	0.13	7.27	3.01	1.24	2.33	34.6
	10	03/07/85	Unfrozen	6.8	57.8	1.02	0.18	9.36	0.18	5.01	2.34	0.38	1.30	24.2
	10	19/07/85	Unfrozen	7.0	85.9	0.74	0.10	12.95	0.32	9.27	3.79	0.42	1.14	28.8
Capricorn	10	21/11/84	Unfrozen	5.0	26.1	0.53	0.06	16.79	0.22	2.31	0.97	0.32	0.96	14.8
	10	09/01/85	Frozen*	6.0	38.4	0.87	0.11	17.26	0.27	3.12	1.38	1.39	1.52	32.9
	10	29/05/85	Frozen*	5.4	28.1	0.73	0.08	17.81	0.12	2.16	0.94	1.32	2.81	56.0
	10	03/07/85	Unfrozen	5.4	25.5	0.35	0.05	13.93	0.17	1.98	0.95	0.50	1.52	90.2
	10	19/07/85	Unfrozen	5.8	24.8	0.47	0.07	13.31	0.27	2.23	0.93	0.42	1.01	28.6

* Includes both frozen and unfrozen samples.

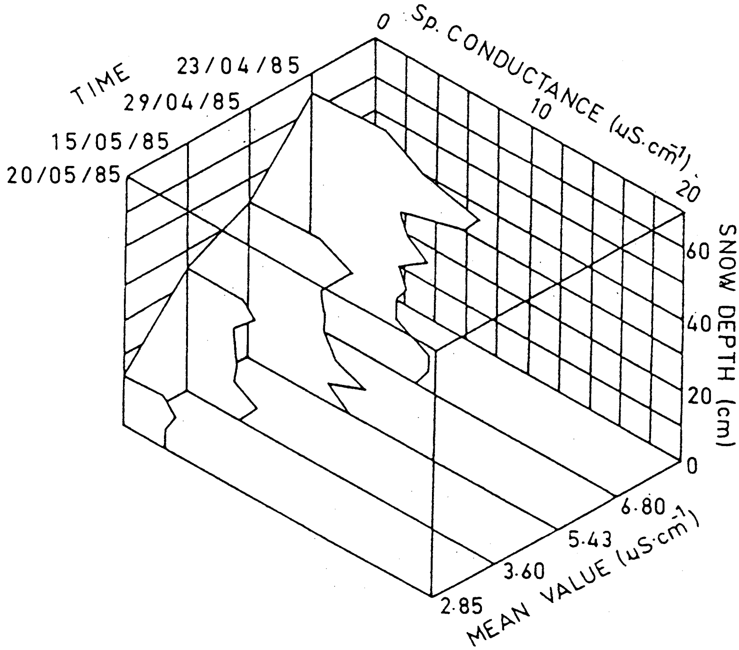

Fig. 2. Three-dimensional snowcover profile of specific conductance during the melt for Aries fen.

higher P_t concentration and pH in the early summer and a higher DOC concentration in the fall. At the Aries site, in contrast, there were significant increases in concentrations of P_t, Ca, Mg and DOC and a higher specific conductance and pH in the early summer, compared to the fall.

Comparison of the peat water drained from the thawing blocks of peat collected in the winter revealed no significant differences between the sites, except for higher concentrations of DOC and P_t at the Capricorn site. Compared to the unfrozen peat water for Capricorn, the frozen peat samples exhibited significantly higher concentrations of P_t, NH_4^+-N, Ca. Mg, Na and K and a higher specific conductance. At Aries, only P_t, NH_4^+-N, K and Fe showed significantly higher concentrations in the frozen peat water.

Seasonal changes in water chemistry of the fens are best summarized by the specific conductance profiles (Fig. 3). A similar seasonal pattern was observed for both fens, although Aries had higher values. In the fall (November 21, 1984) and early summer (July 19, 1985), the specific conductance increased with depth. During the winter-spring period (January 9 to July 3, 1985), higher values were observed in the upper layers and these were related to the presence of seasonally frozen peat.

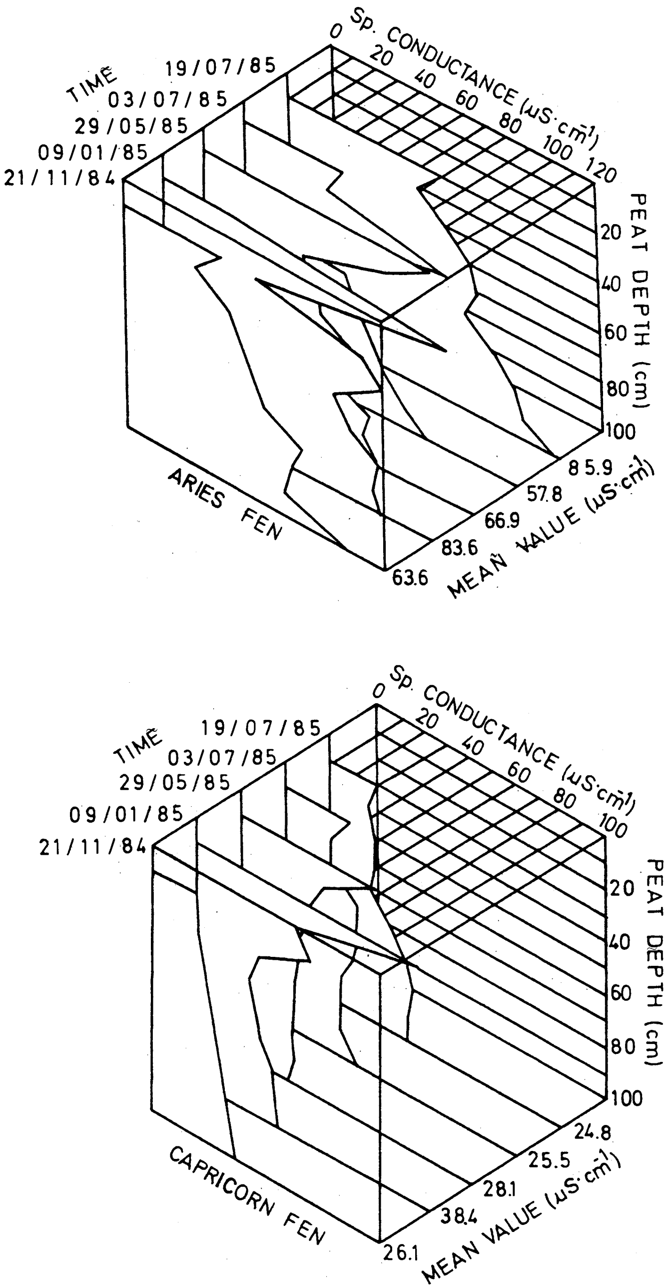

Fig. 3. Three-dimensional peat water profiles of specific conductance for Aries and Capricorn fens during the freeze-thaw cycle.

Discussion

The results of this study have shown significant changes in the concentration of dissolved nutrients and other chemicals in subarctic peatlands over the winter freeze-thaw cycle. There are four major processes contributing to these changes:

(1) The snowcover is generally low in dissolved chemicals, because of the remote location of the eastern Canadian subarctic from major sources of pollution and the absence of a tall plant cover on the peatlands, which can influence the snow chemistry via leaching. There may, however, be some contamination of the lower layers of the snowpack by upward migration of chemicals from the peat surface or from terrestrial runoff in the spring. During the snowmelt, dissolved chemicals are eluted from the snowpack early, as has been observed elsewhere (*e.g.* Johannessen and Henriksen 1978, Skartveit and Gjessing 1979) and may be washed away from the frozen surface and/or incorporated into the surface layers of the thawing peat.

(2) As peat freezes, the concentration of dissolved chemicals in the ice is generally higher than in the unfrozen water, suggesting that the breaking of cells of decomposing plant tissues and soil fauna are major sources, especially for P_t, K, Na and NH_4^+- N. This process appears to outweigh any changes in concentration that may occur through exsolution, associated with the freezing of the peat water.

(3) Where the groundwater in the lower layers is rich in chemicals (*e.g.* Aries site), the water and its chemicals can migrate upwards into the peat towards the freezing front. This can further contribute to changes in the frozen peat, by increasing the dissolved chemical concentrations over the winter.

(4) As peat thaws in the spring, the changes in nutrient concentrations reflect the balance of the diluting effect of snowmelt water, the increased concentrations caused by freezing, the release of water drawn up to the freezing front, and biotic usage (*e.g.* microorganisms and macrophytes).

This study of a rich and a poor fen has shown that the patterns of changes in chemical concentrations over the winter can be complicated and that different patterns may occur at sites at which the four processes operate with different effects. The significance of the results are two-fold. Firstly, during the spring there may be considerable changes in the composition of water draining subarctic peatlands as the different components of the peatland are released. Secondly, subarctic peatland plants grow in a harsh environment, in terms of both cool soil temperatures and limited nutrient availability. The freezing process in the peat appears to increase the availability of important nutrients such as phosphorus, nitrogen and potassium, but this can be diluted by snowmelt entering the peatland, or influenced by the incorporation of groundwater, which may be either rich or poor in nutrients.

The occurrence of a dry, insulating surface layer of peat can reduce water availability to plant roots and cause further stress on plants during spring and early summer.

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