Ecological Tolerances and Niche Structure of Sphagnum along Climate and Pollution Gradients

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A Manuscript Report Prepared for the
Canadian Environmental Assessment
Research Council
1986

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ABSTRACT

Ecological Tolerances and Niche Structure of Sphagnum along Climate and Pollution Gradients

submitted by L. Dennis Gignac

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Sphagnum mosses have proven to be good pollution monitors. In light of this fact, this study has attempted to:

1) analyse the mineral content of sphagnum species occupying different niches along noistive and nutrient gradients; and

2) relate these concentrations to a pollution source.

Copper and nitrogen concentrations in for sphagnum mosses were analysed relative to smelting activities in the Sudbury area. As well, sulphur concentrations in three sphagnum mosses were analysed relative to Kraft wood pulping mills in the Prince Rupert area.

Emissions from the smelting operations in the Sudbury area have resulted in abnormally high Cu and Ni concentrations in the four sphagnum species tested. Concentrations were higher in the peat than in the mosses, indicating that they were readily leached from the mosses to the peat.

The total amount of reduced sulphur emitted by the kraft wood pulping mill has not adversely affected the distribution of sphagnum in the area and concentrations did not decrease with increasing distance from the mill.

ECOLOGICAL TOLERANCES AND NICHE STRUCTURE OF *SPHAGNUM* ALONG CLIMATIC AND POLLUTION GRADIENTS

by

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ABSTRACT

The accumulation of Cu and Ni emanating from smelting operations near Sudbury, Ontario, decreases in four continental *Sphagnum* species with increasing distance from the smelter. At high inputs, Cu and Ni were enriched in the peat indicating passive uptake. At low inputs, active uptake was indicated by enrichment in the capitulum. Significantly more Cu was actively taken up than Ni. Concentrations of 50 ug/g of Ni indicate the limit of uptake in the capitula of all the mosses and evidence indicates that this concentration approaches toxic levels.

Concentrations of total S emanating as reduced sulphur from kraft wood pulping mills near Prince Rupert, British Columbia, were analysed in three maritime *Sphagnum* species. Concentrations do not decrease with increasing distance from the mills. The S reaches concentrations of 1500 ug/g in the capitula of the moss, however, the levels measured in the mosses are not toxic to the plants.

INTRODUCTION

Sphagnum (peat mosses) are slender plants consisting of a head or capitulum and a stem. The head is composed of a tuft of short, crowded branches surrounding the apical cell. The stems are relatively weak, of indeterminate length, and support fascicles of branches. Branches are covered with spirally arranged leaves and are of two types, spreading and pendent (Crum 1984). Decomposition is slow, particularly in hummock forming species (Clymo 1965) and the stems may remain largely undecomposed for 30 cm or more within a hummock.

Sphagnum mosses are important components of bog and poor fen communities (Moore & Bellamy 1974). The principal nutrient inputs into these mires are either from dry deposition or from precipitation (Malmer 1962, Malmer & Nihlgård 1980). Sphagnum species are well adapted to these mire conditions by having more binding sites per unit area than other plants (Clymo 1963). These numerous binding sites not only retain nutrients but also aerially deposited heavy-metal cations (Pakarinen & Tolonen 1976). In fact, Sphagnum mosses have proved to be excellent pollution monitors (Pakarinen & Tolonen 1976, Pakarinen 1977, Pakarinen & Tolnen 1977, Glooshenko & Capobianco 1978, Pakarinen 1978b, Gorham & Tilton 1978, Pakarinen 1981b, Arafat & Glooshenko 1982, Pakarinen & Gorham 1983). Although many studies have analysed metal concentrations in Sphagnum, only Arafat & Glooshenko (1982) have attempted to relate concentrations to a pollution source.

Sulphur concentrations in _Sphagnum_ mosses have been extensively examined (Malmer & Sjörs 1955, Malmer 1962, Malmer 1974, Malmer & Nihlgård 1980, Pakarinen 1981a, Pakarinen & Gorham 1983, Bayley 1986). The effects of sulphur compounds on the growth of _Sphagnum_ have been studied (Ferguson et al 1978, Ferguson & Lee 1979, Ferguson & Lee 1980, Aulio 1984). However, the sulphur compounds studied are bisulphite and sulphate forms that are associated with acid rain. The effects of reduced sulphur on _Sphagnum_ mosses have not as yet been examined. As well, concentrations of sulphur in _Sphagnum_ have never been related to a pollution source.

Sphagnum species occupy different niches along moisture and ionic gradients (Jeglum 1971, Vitt & Slack 1975, Vitt et al 1975, Slack et al 1980, Aulio 1982, Hayward & Clymo 1982, Vitt & Slack 1984, Vitt & Bayley 1985). The moisture gradient is indicated by the heights above the water table, where the hollows are wetter than the tops of the hummocks. Variations in the nutrient status of the mire waters can be indicated by pH.

The purpose of this study is to 1) analyse the mineral content of _Sphagnum_ species occupying different niches and 2) relate these concentrations to pollution sources. _Sphagnum_ niches will be analysed along moisture and pH gradients under two climatic regimes.

Copper and nickel concentrations in four _Sphagnum_ mosses are analysed relative to smelting activities in the Sudbury area. Concentrations of Cu and Ni in peatlands in the Sudbury area have already been shown to be related to smelting activities (Gignac &

Beckett 1986). However, concentrations of Cu and Ni in the peat mosses have not as yet been determined in the Sudbury area.

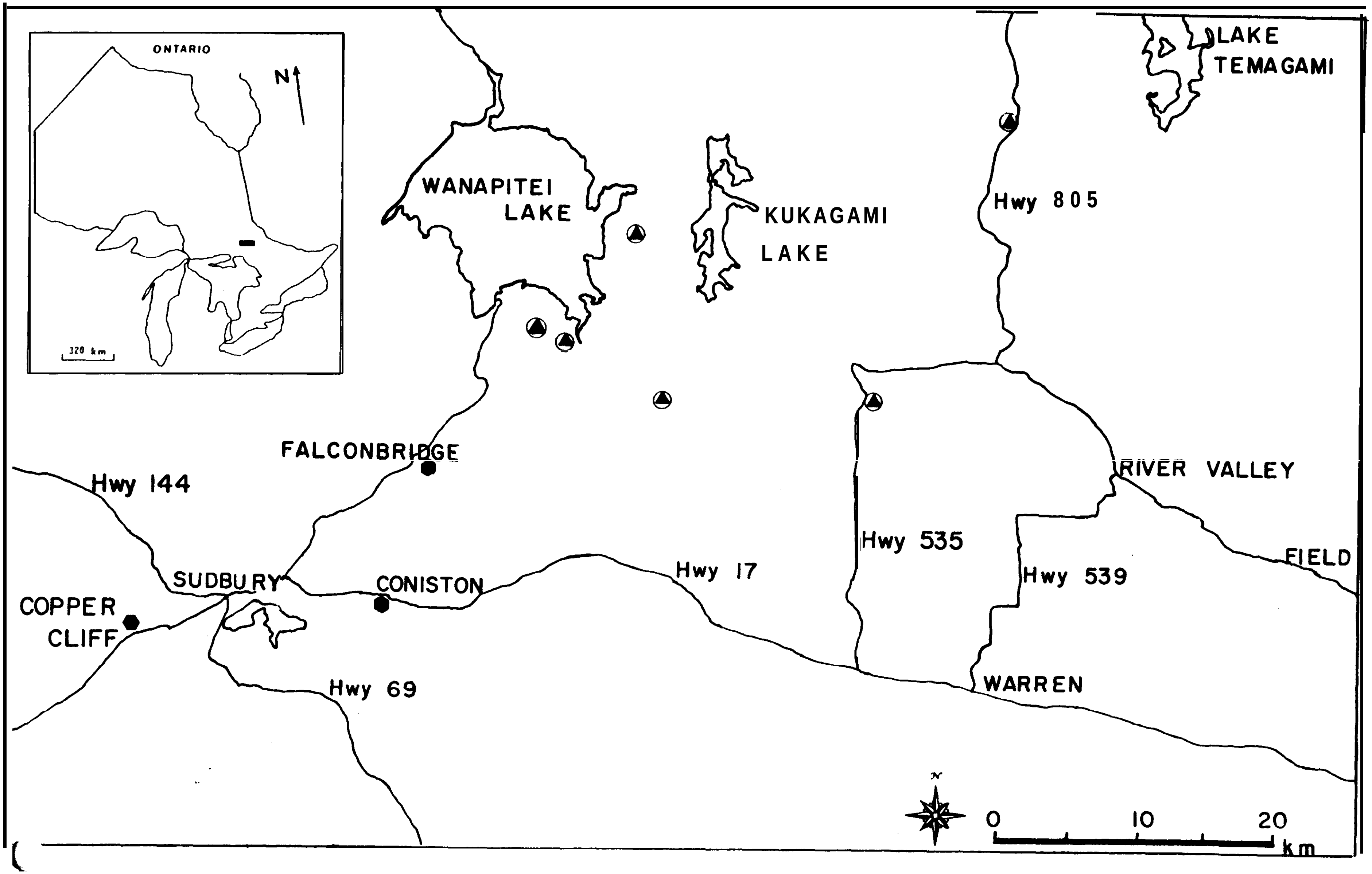
Sulphur concentrations in three Sphagnum species will be analysed in the Prince Rupert area. Kraft wood pulping mills in the area emit on average between 225 and 547 ug/g of total reduced sulphur per month (British Columbia Ministry of the Environment, unpublished data). The total reduced sulphur produced by the kraft wood pulping process consists mainly of hydrogen sulphide, methyl mercaptan, dimethyl sulphide, and dimethyl-disulphide (Benjamin 1979). Little SO_2 is produced, thus acid precipitation does not appear to be a problem in the immediate vicinity of the mills.

STUDY AREAS

The Sphagnum species studied in the Sudbury Ontario area are found on mires ENE of Falconbridge (45°35'N; 80°49'W) (Fig. 1). The Falconbridge smelter is situated approximately 8 km ENE of Sudbury. The peatlands formed in shallow basins that are a common feature of the Precambrian Shield. The granite or sedimentary rock formations of the Shield were scoured most recently during the Wisconsinan Glaciation and became ice free about 10,000 years ago (Prest 1969).

The mires can be classified as poor fens (sensu Sjörs 1952), as the water in the hollows contain between 3.5 and 5.0 ug/g of Ca^{++}. The peatlands are dominated by such Ericaceae as Chamaedaphne calyculata, Ledum groenlandicum and Kalmia angustifolia. The bryophyte layer on metal contaminated sites is dominated by Pohlia nutans, Drepanocladus fluitans and Mylia anomala. Such

Fig. 1. Map of the area ENE of Sudbury, Ontario. The hexagons represent smelters and the circled triangles indicate the study sites.



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Sphagnum species as S. riparium, S. russowii, S. rubellum, S. magellanicum, and S. fuscum are prominent on uncontaminated sites.

The climate is boreal cold-temperate (Walter & Lieth 1960) with cold winter temperatures and warm summers (Fig. 2). The mean annual temperature is 4.8°C and the growing season extends from May to September. Total yearly precipitation is 794.1 mm with the highest amount falling in September. Snowfall accounts for approximately 25% of the total precipitation.

The land surrounding Prince Rupert, British Columbia (58° 22'N; 130°22'W) is dissected by the many inlets that indent the coastline (Fig. 3). The major surface features are Mount Hays (3500 m) and Mount Oldfield (3000 m). The inlets and basins are bordered by mountains of the Coast Range. The rise from sea level is often steep with occasional areas of more subdued relief. The less precipitous mountain sides are covered by slope bogs while the occasional flatter areas feature either bogs or poor fens (Tarnocai 1982).

The mires are dominated by Sphagnum species principally S. imbricatum, S. fuscum, S. rubellum, S. nemoreum, and S. lindbergii. Vascular species include Rubus chamaemorus, Empetrum nigrum, Ledum groenlandicum, Kalmia polifolia, Pinus contorta, and Lysichitum americanurn.

The climate in the Prince Rupert area is boreal cold-temperate with oceanic tendencies (Walter & Lieth 1960). Total precipitation is high at 2334.9 mm per annum with no extended periods of drought (Fig. 4). Slightly less precipitation falls during the growing season between May and September. The mean

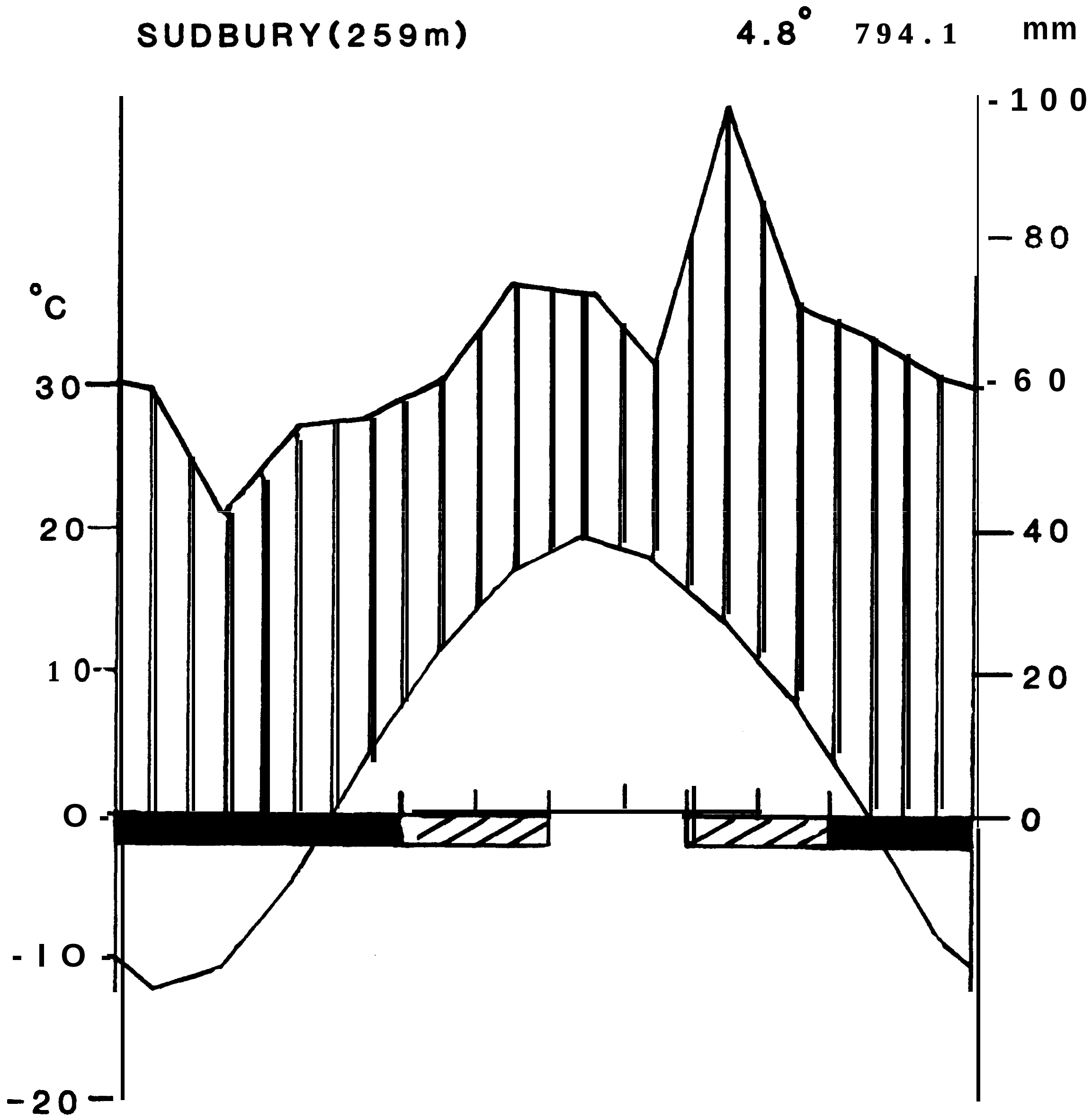
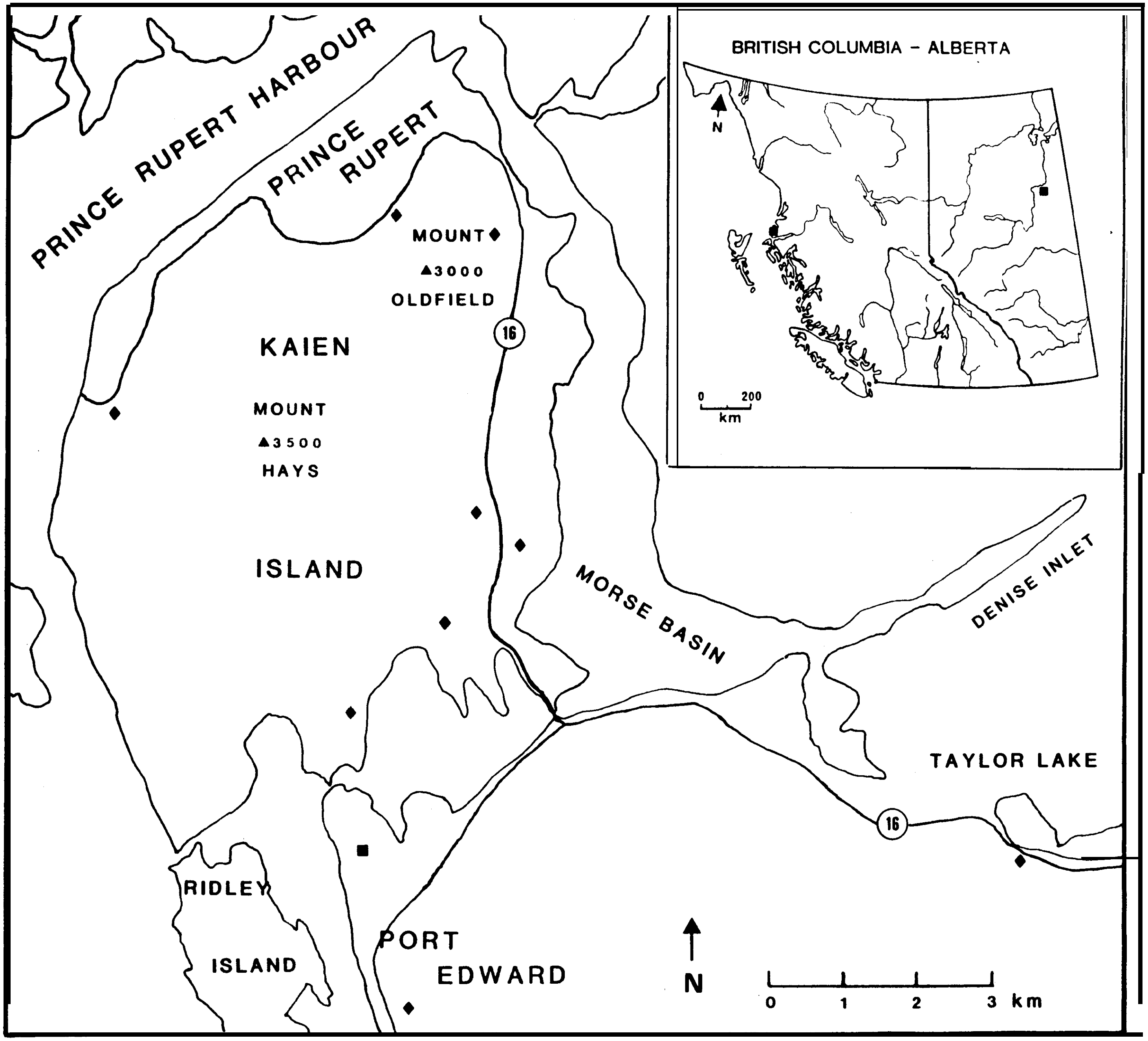


Fig. 2. Walter and Leith (1960) climate diagram for Sudbury, Ontario. The monthly temperature is indicated by the lower line and the monthly precipitation thetopline. Mean annual temperature 4.8° c; total annual precipitation 794.1 mm; solid bar is months with mean temperature below 0° C; hatched bar is months with absolute minimum temperature <0° c.

Fig. 3. Inset - study sites in the Mariana Lake of northeastern Alberta and the Prince Rupert area. Map of the Prince Rupert area showing the highly disected coast line. The solid square represents the kraft wood pulping mills. The diamonds indicate the sites.



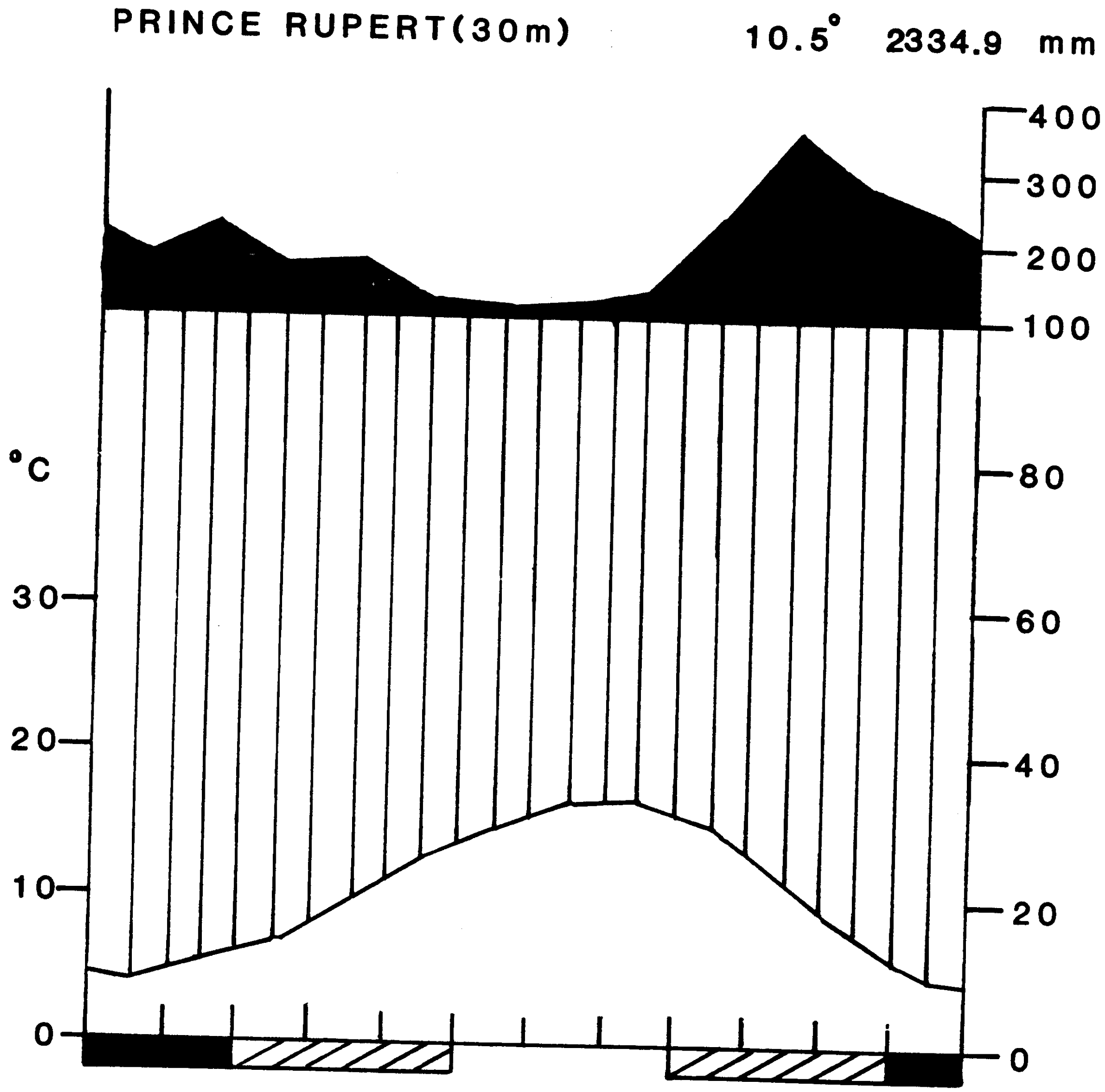


Fig. 4. Walter and Leith (1960) climate diagram for Prince Rupert, British Columbia. The mean monthly precipitation is indicated by the top line; the mean monthly temperaature is the bottom line; mean annual temperature 10.5° C; total annual precipitation 2334.9 mm; solid bar is months with mean temperatures below 0° C; hatched bar is months with absolute minimum temperature < 0° C.

annual temperature is 10.5' C with mean monthly winter temperatures of approximately 5° C and mean summer temperature of 15° C.

A control sample of S. fuscum was also taken from the Mariana Lake area of northeastern Alberta (55°54'N; 112°04'W) (Fig. 3, inset). This site was selected as it was isolated from any industrial activity. The peatland from which the samples were taken was a poor fen with ombrotrophis bog islands. The mire is dominated by Sphagnum angustifolium in the poor fen portion and by S. magellanicum and S. fuscum in the ombrotrophic portion. The principal vascular plants are Rubus chamaemorus, Ledum groenlandicum and Picea marianna.

MATERIALS AND METHODS

Four Sphagnum species were studied in the Sudbury area and three in the Prince Rupert area. The species selected grew along the hummock-hollow gradient. The Sudbury species include Sphagnum fimbriatum Wils. & Hook., S. russowii Warnst., S. riparium Aongstr. and S. magellanicum Brid. Sphagnum rubellum Wils., S. fuscum (Schimp.) Klinggr. and S. imbricatum Russ. were studied in the Prince Rupert area. Sphagnum species nomenclature follows Ireland (1982). Voucher specimens are deposited at ALTA.

Several hummocks formed by one or more of the Sphagnum species to be studied were analysed on each peatland. The pH was measured in the water in the hollows using a portable Beckman pH/EH meter. Where no surface water was found, shallow pits were dug and the pH taken in the water that accumulated therein.

The height of the capitulum above the water table was determined using a point intercept method. In Sudbury, a line was strung over a hummock and solidly braced on either side. The line was levelled to the water table and measurements were taken every 5 cm along the line. The distance of the capitulum to the line was subtracted from the distance of the line to the water table to yield the height of the capitulum above the water table. In the Prince Rupert area a plywood board supported by four posts and levelled was used instead of a string. The remainder of the methodology remained the same.

CHEMICAL ANALYSIS

A 15 cm diameter stovepipe was used to core each hummock down to the water table. Two cores were removed per species per site. Plants from the Sudbury area were sectioned into the capitulum, green and brown portions of the stem and some partially humified peat at the bottom of the core. Since the green and brown portions of the stem could not readily be distinguished on plants from the Prince Rupert area, the stems were sectioned into 5 cm increments. The length of the stem sectioned depended on the height of the capitulum above the water table. Thus stems of Sphagnum rubellum could only be cut to a depth of 10 cm while those of S. imbricatum could be cut to a minimum of 15 cm.

The Sudbury material was analysed for Cu and Ni, using a dry ashing technique. A 0.25 g sample of material was ashed at 600°C for 24 hours. The ash that remained after cooling was digested in 10 ml of aqua regia and heated to dryness. The residue was taken up in 10 ml of 2.5 N HNO_3, filtered and brought to volume with distilled-deionized water (Gignac & Beckett 1986). The filtrate was analysed for Cu and Ni by flame atomic absorption spectrophotometry, using a Perkin-Elmer Atomic Absorption Spectrophotometer Model 303.

The Prince Rupert material was analysed for total S using a wet ashing method. A 0.25 g sample was digested in acid washed Kjeldahl flasks using 15 ml of concentrated HNO_3 and 3 ml of 60% $HClO_4$. The solution was evaporated until 1 or 2 ml remained. Two ml of concentrated HCl were added and the solution was heated for 15 minutes. The warm digest was filtered into 50 ml volumetric flasks using Whatman #42 filter paper. The sides of the flasks were washed down with distilled-deionized water. Total S was determined by inductively coupled Argon plasma spectrophotometry.

RESULTS AND DISCUSSION

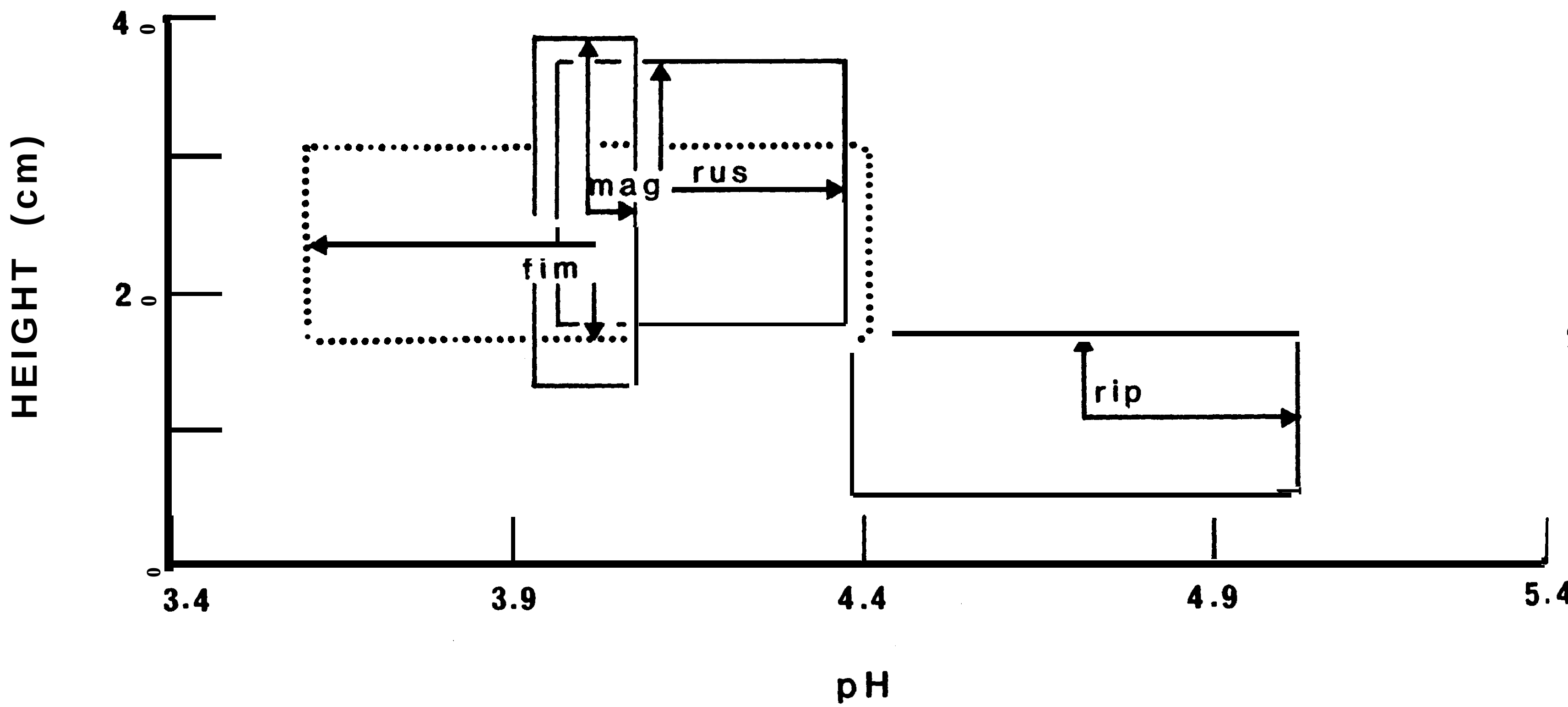
SPHAGNUM NICHES

Sudbury

Sphagnum fimbriatum, *S. magellanicum*, and *S. russowii* occupy overlapping niches relative to the height above the water table and the pH (Fig. 5). *Sphagnum fimbriatum* occupies the widest pH range and is found along the mire margins usually in shaded conditions. It forms pure hummocks growing in association with stems of *Ledum groenlandicum* and *Chamaedaphne calyculata* and is rarely in direct contact with the peat.

Sphagnum magellanicum and *S. russowii* are normally found towards the centre of poor fens, where the pH is lower than along the margins. Both species may grow on the same hummocks, with *S. magellanicum* occurring slightly lower on the hummock than *S.*

Fig. 5. Niches of four *Sphagnum* species in the Sudbury area relative to the height above the water table and pH. The rectangles represent the means + standard deviation for: rip, *S. riparium*; fim, *S. fimbriatum*; mag, *S. magellanicum*; and rus, *S. russowii*.



russowii. Sphagnum magellanicum occupies a narrow pH range and is found only in the central portions of the mires. Sphagnum russowii occupies a wider pH range and can be found on both the central portion and along the margins of the mires.

Sphagnum riparium occupies a habitat between 4 and 15 cm above the water table. It normally grows in wet carpets or in pools at the bases of hummocks. It has a relatively wide pH range, but the mean pH is significantly higher ($p < 0.05$) than the other species. It is more abundant on the more minerotrophic sites and along the margins of the more oligotrophis sites.

Prince Rupert

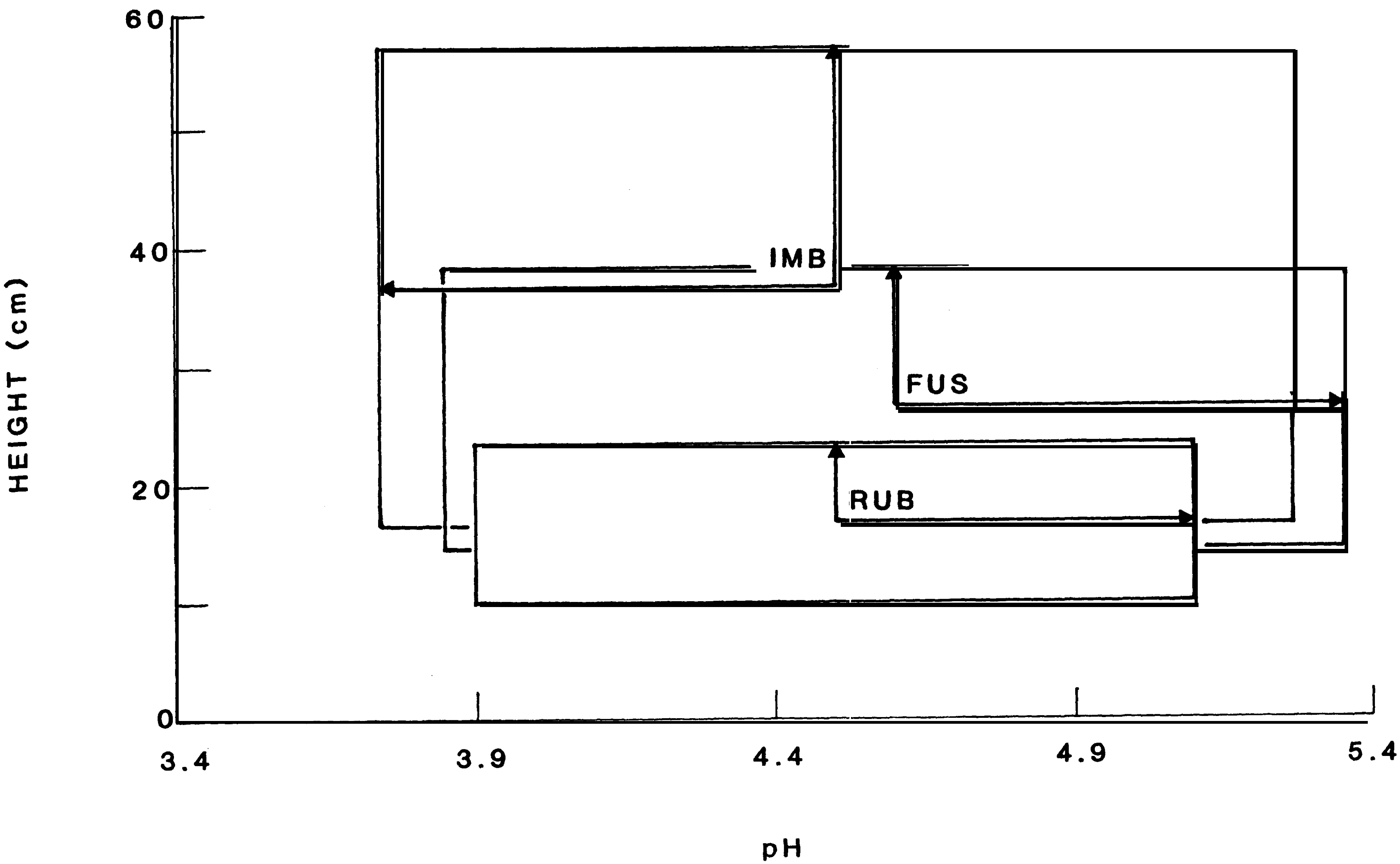
The three Sphagnum species growing in the Prince Rupert area occupy overlapping niches along the pH and height gradients (Fig. 6). Although they grow together on the same hummocks, generally S. rubellum occurs closer to the water table than either S. fuscum or S. imbricatum. Sphagnum fuscum grows on hummocks where the pH is slightly higher than the other two species. Sphagnum imbricatum occupies the widest height range and also forms the highest hummocks on the oligotrophic peatlands.

SPHAGNUM DISTRIBUTION

Sudbury

Sphagnum fimbriatum and S. russowii occur on mires 12.2 km from the Falconbridge smelter. This was the closest poor fen to the smelter on which either species grows (Gignac & Beckett 1986). Both species are found exclusively along the margin of this mire, although S. russowii can also grow in the centre on sites farther from the pollution source. Sphagnum fimbriatum was

Fig. 6. Niches of three *Sphagnum* species in the Prince Rupert area relative to the height above the water table and the pH. The rectangles represent the means ± standard deviation for: rub, *S. rubellum*; fus, *S. fuscum*; and imb, *S. imbricatum*.



not found on the farthest sites from the smelter, since the sides of these peatlands are very abrupt and the margins are poorly developed.

Sphagnum riparium and S. magellanicum are found at 16.0 km from the smelter. Sphagnum riparium is an important component of the margin on this site (Gignac & Beckett 1986). An extensive search of the area, however, revealed only one small hummock of S. magellanicum. It is only at 20.3 km from the smelter that S. magellanicum becomes an important component of the vegetation.

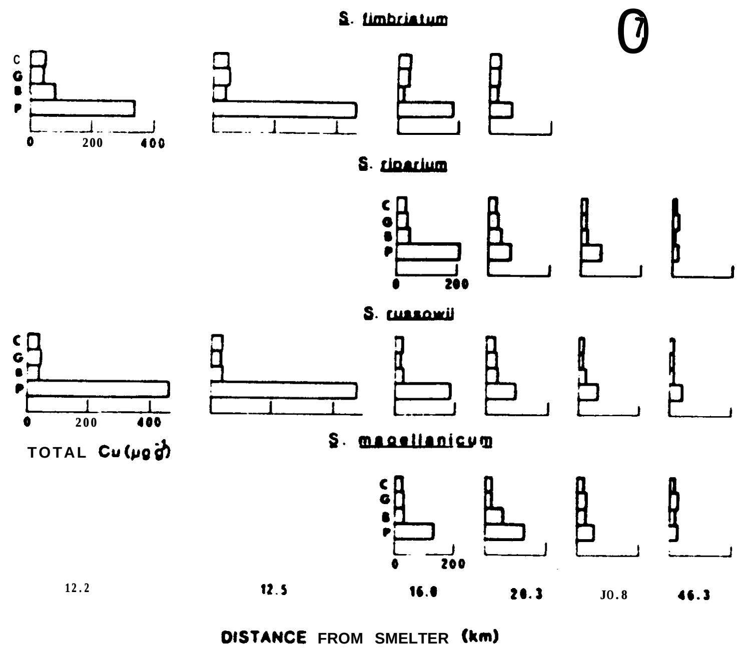
Prince Rupert

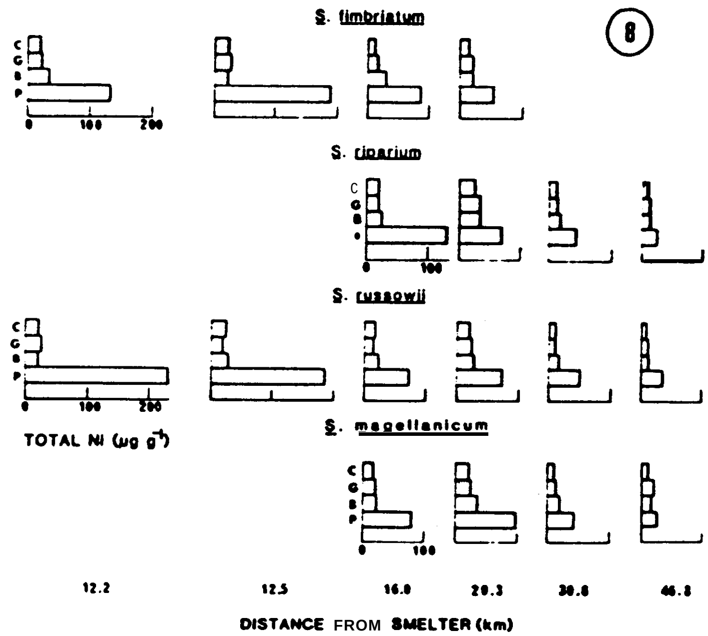
The distribution of S. rubellum, S. fuscum, and S. imbricatum does not appear to be affected by the emissions of the mills at Port Edward. All species are an important part of the vegetation on all the mires, although the abundance of S. fuscum varied from site to site. The distribution of S. fuscum, however is not significantly correlated with distance from the mills, and cannot be attributed to emissions from the mills.

VERTICAL DISTRIBUTION OF THE ELEMENTS

Sudbury

There is a general increase in the Cu and Ni with increasing depth in the core for all species (Fig. 7 & 8). The concentrations in the capitulum and green and brown portions of the stem are not significantly different. Both Cu and Ni, however, seem to concentrate in the partially humified peat at the base of the hummocks. The vertical distribution of Cu through cores of S. girgenshonii (Pakarinen & Rinne 1979) and S. fuscum (Pakarinen





Figs. 7 & 8. The vertical distribution of heavy-metals in surface cores taken fran Sphagnun hummocks in the Sudbury area. Figure 7 gives total Cu concentrations and Figure 8 total Ni concentrations. Cores were cut fran hummocks and hollows at increasing distances from the Falconbridge smelter. Missing values represent sites where a species is not present.

C = capitulum

G = green portion of stem

B = brown portion of stem

P = partially humified peat at base of hummocks

1978a) on uncontaminated sitesindicate a decrease in Cu concentration through the profile. Pakarinen and Gorham (1983 for S. fuscum) and Malmer and Nihlgård (1980 for S. fuscum and S. balticum) reported that concentrations of Cu remain the same with depth. This profile is what seems to be occurring on the farthest sites from the smelter where Cu concentrations in S. riparium and S. magellanicum remain constant or decrease with depth. Although there is no data available for Ni concentrations, the same phenomenon seems to be occurring.

The increase in Cu and Ni concentrations with depth on contaminated sites is used as an indicator of passive uptake by the moss plants (Malmer 1962, Pakarinen 1977). The metals are only loosely bound to the plants by cation exchange sites in the dead hyaline cells and are not incorporated into the living tissue (Pakarinen 1977). Therefore most of the Cu and Ni can be leached into the peat.

However, where Cu concentrations are low, the concentrations no longer increase with depth but remain constant or decrease (Pakarinen 1978b, Pakarinen & Rinne 1979). This enrichment of Cu in the living or upper portions of the moss would suggests that at least small quantities are retained inside the living tissue. At 46.3 km from the smelter, the enrichment factor for Cu (concentration in the capitulum/concentration in the peat) for all species is 0.57 ± 0.04. The enrichment factor for Ni for the same species on the same site is 0.34 ± 0.01. A t-test revealed that these enrichment factors were significantly different ($p < 0.01$). This may indicate that more Cu than Ni is actively taken into the cells of the moss plants.

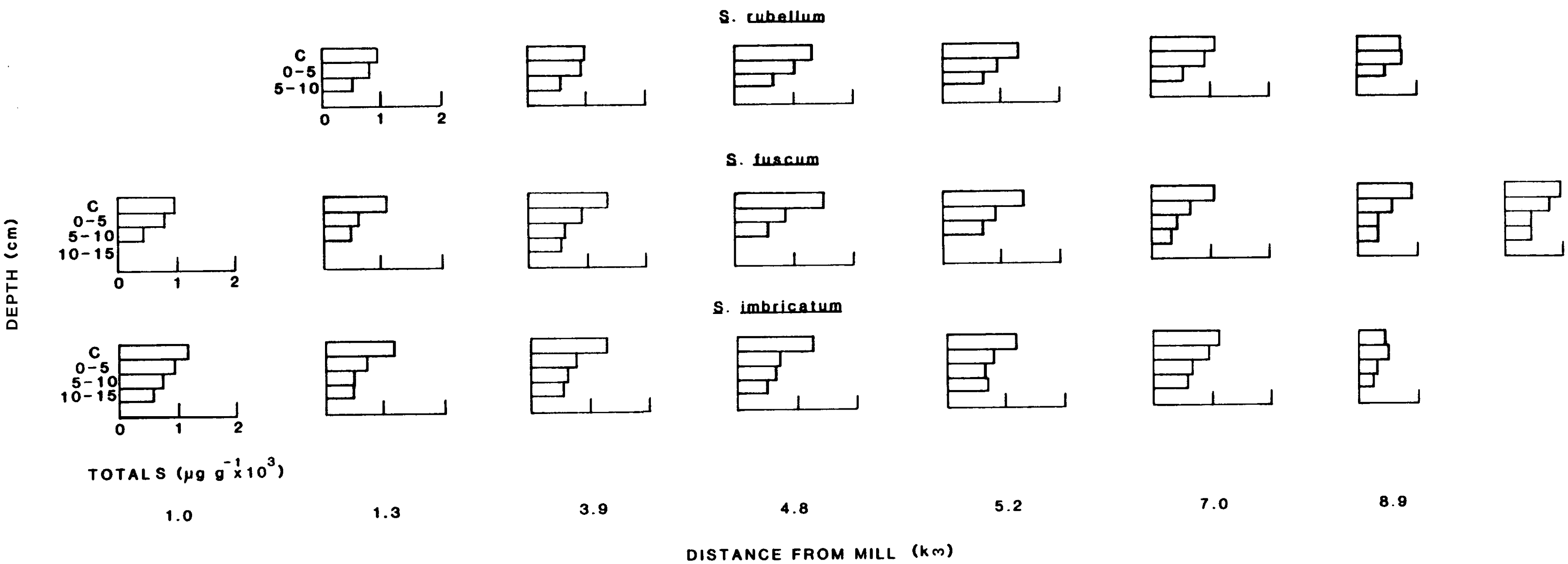
Prince Rupert

Contrary to the results obtained for Cu and Ni, S concentrations for all species decrease with depth in the cores taken from the Prince Rupert area (Fig. 9). This concurs with S profiles in Sphagnum from other sites (Malmer & Nihlgard 1980, Pakarinen 1981b, Pakarinen & Gorham 1983, Bayley 1986).

The sulphur that is not retained by the mosses may 1) accumulate in the underlying peat (Pakarinen & Gorham 1983, Bayley 1986), or 2) be leached from the ecosystem by water running off the surface of the peatland (Hermond 1980, Pakarinen 1981b). Accumulations of S in the peat occur below the water table. Sulphur contained in peatland waters is readily retained as reduced sulphur by the peat under anaerobic conditions (Brown & McQueen 1982). When the water table is lowered, as a result of a long period of drought for example, the reduced sulphur can be oxidized to SO (Bayley 1986). This oxydized form becomes very mobile and is leached from the system by subsequent rains. However, Hemond (1980) calculated that approximately 77% of the SO was retained in the peat.

The amount of S retained in the peat relative to the quantities leached from the peatland appears to be related to the amount of precipitation falling on the ecosystem (Bayley 1986). There is a minimum amount of time required for the aerially deposited S to be incorporated into the anaerobic zone. When large and frequent amounts of precipitation fall on the mire, the S does not have time to be incorporated into the peat but is flushed from the system. In the Prince Rupert area, where pre-

Fig. 9. The vertical distribution of total S in the capitulum and 5 cm stem increments of surface cores taken from three species in the Prince Rupert area. The cores were cut from hummocks at increasing distances from the kraft wood pulping mill at Port Edward. The depth of each core depends on the height of the moss above the water table.



cipitation exceeds 2334.9 mm per annum with no long periods of drought (Fig. 4), most of the S would appear to be washed into the ourflow from the peatlands. Sulphur concentrations in the water taken from the moat that drains the bog are four to seven times higher than levels in water taken from pools on the mire expanse. The relatively pronounced slopes of these bogs as well as the large amounts of precipitation may also reduce the time necessary for the sulphur to accumulate in the peat. On relatively uncontaminated sites, however, the quantity of S in the moat water is not excessively high when compared to water taken from the mire expanse. Thus, it would appear that most of the sulphur inputs are retained by the living moss or the peat at relatively low S deposition rates and it is only when inputs become excessive that S will be leached from the soil.

INTERSPECIFIC VARIATION

Sudbury

There is a significant correlation ($p < 0.05$) between the log of the Cu and Ni concentrations in the peat and the concentrations in the capitulum for Sphagnum riparium, S. magellanicum, and S. russowii (Fig. 10 & 11). This log relationship indicates that at lower concentrations the quantity of Cu and Ni retained in the capitulum is relatively high when compared to concentrations in the peat. As the quantities of Cu and Ni increase, proportionally less is retained by the capitulum and more is leached into the peat. When concentrations in the capitulum reach approximately 50 ug/g, the capitulum retains very little additional Cu and Ni and most if not all of the excess is leached

Fig. 10. The relationship between the total Cu in the capitula of four Sphagnum species in the Sudbury area and the log of the total Cu in the partially humified peat at the base of the hummocks. There are significant correlations ($p < 0.05$) for S. russowii, S. magellanicum, and S. riparium. The log relationship is not significant for S. fimbriatun, therefore no line has been drawn.

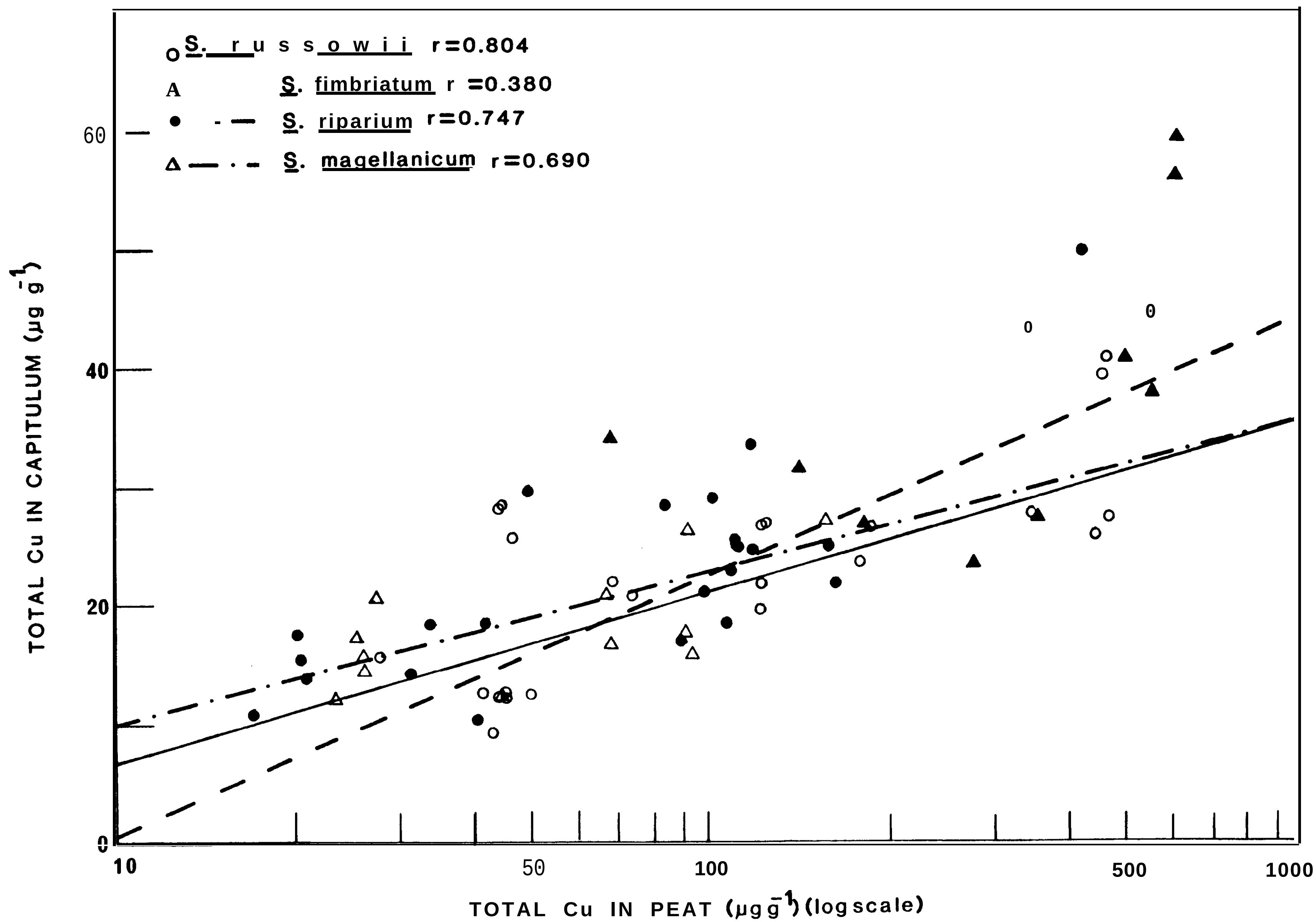
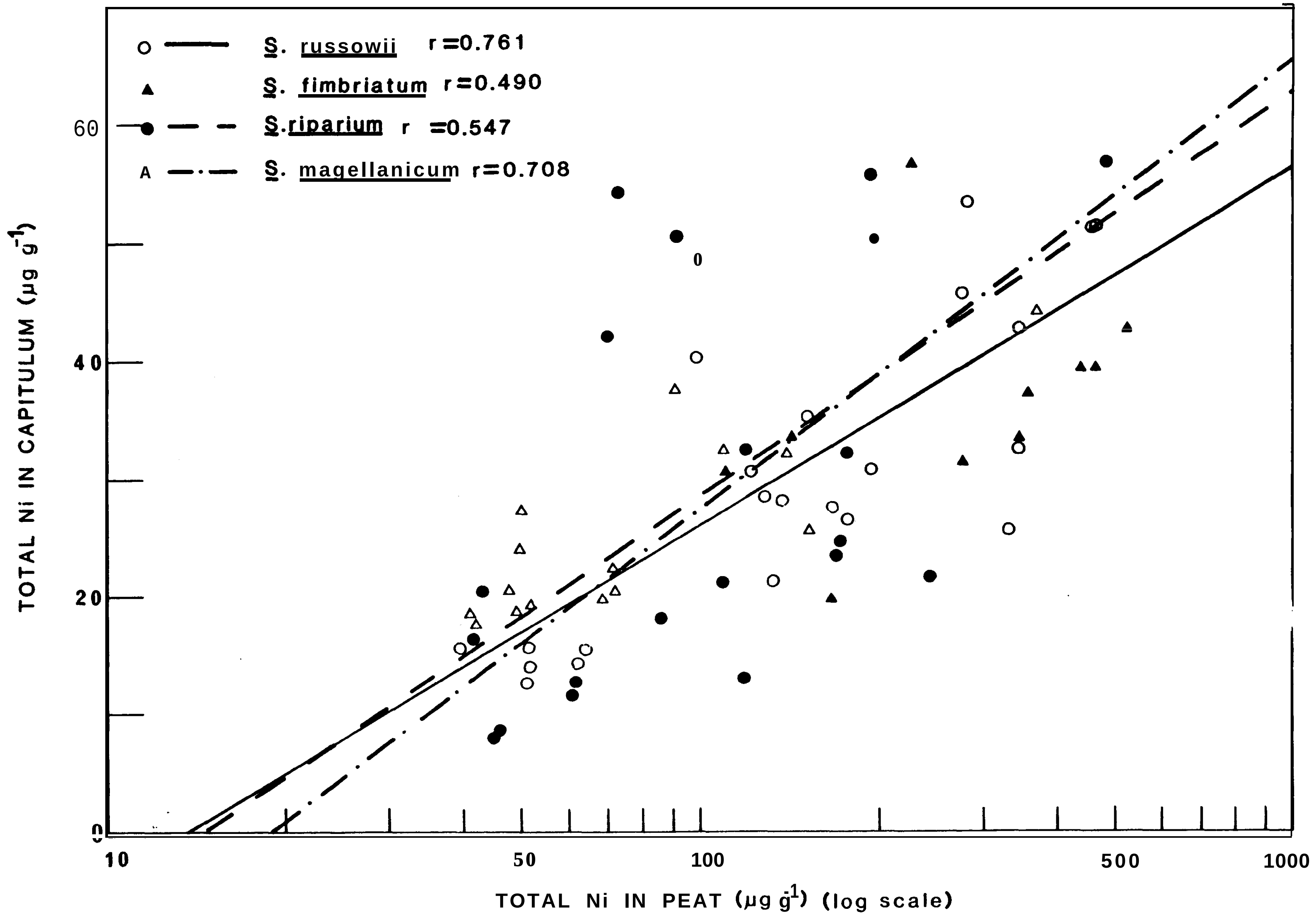


Fig. 11. The relationship between the total Ni in the capitula of four Sphagnum species in the Sudbury area and the log of the total Ni in the partially hunified peat at the base of the hummocks. There are significant correlations ($p < 0.05$) for S. russowii, S. magellanicum, and S. riparium. The log relationship is not significant for S. fimbriatun, thereforeno line has been drawn.



into the peat. It would appear that concentrations of 50 ug/g in the capitulum may be very close to being toxic as the species do not grow closer to the smelter where inputs exceed those recorded here.

At the lowest concentrations the quantity of Cu retained by the different species is lowest in the hollow species Sphagnum riparium and highest in the hummock formers S. magellanicum and S. russowii. These results agree with those of Pakarinen (1978a). Species growing on hummocks have more binding sites per gram dry weight than species growing in the hollows (Clymo 1963), thus, hummock forming Sphagnum should retain more Cu and Ni. At the highest concentrations however, S. riparium retains more in the capitulum than either S. russowii or S. magellanicum (Fig. 10).

The pattern of Ni accumulations in the capitulum at lowest concentrations does not seem to follow the hummock-hollow gradient (Fig. 11). The order of species according to Ni concentrations in the capitulum is as follows: S.magellanicum < S. riparium < S. russowii. This order is reversed at the highest concentrations and seems to follow the distribution of each species relative to the distance from the smelter. Sphagnum magellanicum, which contains the highest concentrations in the capitulum, is found farthest from the smelter, while S. russowii is found on the closer sites. This pattern may indicate that Ni rather than Cu is the more toxic of the two elements.

Sphagnum fimbriatum does not follow the same patterns as the other mosses, as it often grows on the stems and branches of Eriaceae and may not be in contact with the peat surface. Thus there is no significant correlation between the amount of Cu and Ni in the capitulum and the concentration in the peat.

Prince Rupert

The same log relationship exists for Sphagnum species in the Prince Rupert area. The quantity of S in the capitulum is significantly correlated with the concentrations at the base of the hummock for all three species (Fig. 12). As was the case for Cu at lower concentrations, the lowest species along the hummock, S. rubellum, contains the smaller quantities of S. At higher concentrations the order is reversed, with S.rubellum containing the most S in the capitulum. The maximum S contained in the capitulum is approximately 1500 ug/g.

VARIATIONS WITH DISTANCE FROM THE POLLUTION SOURCE

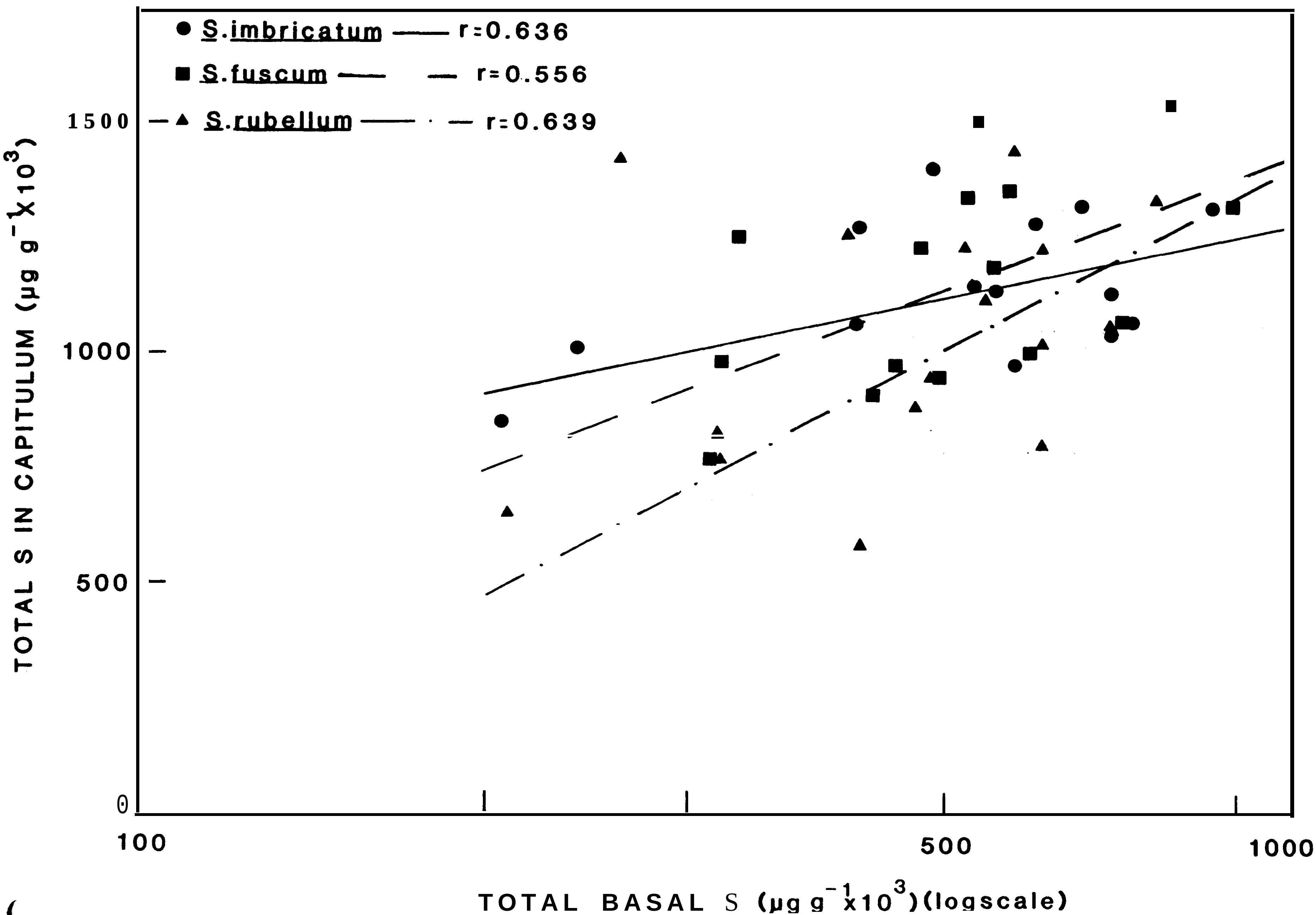
Sudbury

The concentrations of Cu and Ni decrease in the different portions of the mosses with increasing distance from the smelter (Fig. 7 & 8). Since much of the input is leached from the moss plants into the peat, concentrations in the peat are probably the best indicator of the total Cu and Ni inputs on a site.

Prince Rupert

Sulphur concentrations in the capitula of the three moss species are highest at 4.8 km from the pollution source although there are severeal sites closer to the mills. It would appear that this site is in the direct path of the plume unlike other sites that are closer. Some of these sites may also be partially

Fig. 12. The relationship between the total S in the capitula of three Sphagnum species in the Prince Rupert area and the total S in the 5 cm stem increments at the base of the hummocks. There are significant correlations for S. rubellum, S. fuscun, and S. imbricatum.



sheltered from the pollution effects by ridges. Beyond 4.8 km, concentrations decrease with increasing distance from the mills.

At 8.9 km from the mills, S concentrations in the capitula of S. fuscum are approximately the same as the levels measured in Alberta (Fig. 9). Concentrations in the capitula of S. rubellum at this site are also similar to results obtained by Malmer & Sjörs (1955) in uncontaminated areas of Sweden. Thus S concentrations would appear to be at background levels at 8.9 km. However, the study area should be expanded to ascertain if this holds true for British Columbia.

SUMMARY AND CONCLUSIONS

Emissions of metal particles from smelting operations in the Sudbury area resulted in abnormally high Cu and Ni concentrations in four Sphagnum species commonly found on peatlands in the area. Concentrations of these metals decrease in the capitula, green, and brown portions of the stems of S. riparium, S. magellanicum and S. russowii with increasing distance from the smelting operations. Concentrations of both Cu and Ni in the peat are substantially higher than accumulations in the mosses and provide a rough measurement of the total input into the peatland.

The increase of Cu and Ni with depth indicates that most of the particles are only loosely bound to the moss and are readily leached into the peat. However, small quantities of Cu and Ni are taken into the plants, with Cu being taken up in greater quantities than Ni.

The total reduced sulphur emitted by the kraft wood pulping mills at Port Edward has not adversely affected the distribution of Sphagnum in the area. Accumulations of S in the plants have not reached toxic levels even though some mosses contain higher levels in the capitula.

To establish a significant correlation between the S content of the mosses and the distance from the wood pulping mills, the study area should be expanded approximately 50 km. Although S levels in S. fuscum at 8.9 km from the mills, approximate those encountered in unpolluted sites in Alberta, it would be important to determine background levels in British Columbia. By expanding the study area, background levels for such maritime species as S. rubellum and S. imbricatum that are not found in Alberta, could also be quantified.

Suitable sites within that area are not accessible by road. Alternate and ultimately more expensive methods of transportation must be used within this expanded study area. However, this would be a worthwhile effort in order to determine the extent of S accumulations.

Sphagnum species growing close to the water table contain more Cu and S than species growing higher up the hummocks, when inputs are relatively low. However, at higher levels, this pattern is reversed, and species growing in the hollows contain more Cu and S than hummock species. At relatively high inputs of Ni, S. magellanicum accumulates more Ni in the capitulum than S. russowii. The latter species is found closest to the smelter. Concentrations of 50 ug/g of Ni in the capitulum are probably toxic to the mosses and is the most toxic of the three elements analysed.

Concentrations of Cu and Ni deposited on sites within 12 km ENE of the Falconbridge smelter exceed the tolerance limits of poor fen *Sphagnum* species. As a result, *Sphagnum* is completely absent from these mires, thus the mire ecosystem is disrupted and peat accumulation is greatly reduced.

The use of living *Sphagnum* species as bio-monitors of mineral deposition is very effective at low deposition rates. Hummock forming species are the best monitors as they retain more of the aerially deposited elements than species occurring in hollows. Several species may be used to detect low levels of atmospheric inputs including *Sphagnum imbricatum* in oceanic regions and such species as *S. fuscum*, *S. magellanicum*, and *S. russowii* that are found in both continental and maritime climates. An important consideration is to choose the most abundant species in the study area.

When pollutant inputs are relatively high, the use of *Sphagnum* species as environmental monitors becomes more complex. Under these conditions species growing closer to the water table retain more of the pollutants than do hummock forming species. Therefore, both a hummock species and a species growing closer to the water table should be included in a study of high mineral depositions.

At very high inputs of potentially toxic pollutants, living *Sphagnum* plants are not useful bio-monitors. When deposition surpasses certain levels, for example 50 ug/g of Cu and Ni or 1500 ug/g of S in the capitulum, the moss will retain very little additional influx. When using concentrations of pollutants in

Sphagnum to monitor excessive levels of minerals emanating from a pollution source, deposition close to the source appears to remain constant when it actually increases. In this case the partially humified peat below the hummocks gives more accurate data regarding mineral deposition close to a pollution source.

The presence or absence of Sphagnum on poor fens and bogs in the immediate vicinity of a pollution source, can provide an easily verifiable and economic means of monitoring pollution stresses. This method is especially useful for monitoring aerial deposition of pollutants. Sphagnum, particularly hummock forming species, are very sensitive to aerially deposited pollutants. Sphagnum growth is affected at lower pollutant concentratons than vascular plants. Although mires may appear to be unaffected by pollutants, the absence of hummock forming species provide the first indications that inputs are reaching toxic levels.

The absence of Sphagnum species in close proximity to a pollution source indicates that toxic concentrations of pollutants are being emitted by the source. Their sensitivity to aerially distributed pollutants make then an excellent indicator of toxic pollutant levels not only in peatlands but also in terrestrial and aquatic ecosystems. Their absence can provide the first indications of pollutant stresses on the environment before effects of these stresses become visible in other ecosystems. Their absence can also provide further justification for more in-depth studies of the impact of an industry on the environment.

ACKNOWLEDGEMENTS

I wish to thank Lyse Martel and Sandra Vitt for their help with the sample preparation and Elaine Gignac for the field studies. I also wish to thank Professors D.H. Vitt (University of Alberta) and P.J. Beckett (Laurentian University) for their suggestions. I am particularly grateful to Steve Zoltai of the Canadian Forestry Service, Edmonton, for analysis of the samples on the Inductively Coupled Argon Plasma Spectrophotometer. The Prince Rupert portion of this study was funded by a grant from the Canadian Environmental Assessment Research Council, for which I am grateful.

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