ASPECTS OF THE VEGETATION, HYDROLOGY, WATER CHEMISTRY AND MICROCLIMATE OF BARCLAY'S BOG, NORTHWESTERN ONTARIO

BY

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DECLARATION

The research presented in this thesis was carried out by the author, and has not been previously submitted for credit toward any degree or diploma.

Where the work of others has been included, it has been appropriately cited.

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SUMMARY

Aspects of the microclimate, peat depth, surface topography, stratigraphy, hydrology, water chemistry, and vegetation were measured at Barclay's Bog, a small kettle bog in northwestern Ontario.

Shading from the forest surrounding the bog results in cool, humid conditions at edge areas. Significantly lower temperatures, both above and below the peat surface, and higher relative humidity were recorded by instruments near the edge than at the centre. The only exceptions were mean maximum temperature at the peat surface (which was higher at the edge) and mean temperature at 1 cm below the surface (no significant difference between centre and edge), probably as a result of restricted air movement caused by the trees near the edge. Snow persists longer in the spring at the edges of the bog (especially the south edge) as a result of greater accumulation due to drifting and slower melting associated with lower insolation.

The highest surface elevations are found in a narrow band along the north, west and south edges of the bog, as well as at several tall hummocks. The lowest elevations are found at northeastern edge of the bog and extend to the floating mat at the centre. Difference between the highest and lowest point is approximately 65 cm.

The position of the bog on the Dog Lake Moraine indicates that it is situated in a glacial kettle hole and is approximately 10,000 years old. Peat depth measurements indicate that the bog basin is a relatively uniform bowl shape with depths of over 5 m near the centre. Stratigraphy shows a thin layer of *Sphagnum* peat overlying sedge peat at some stations and suggests that the present *S. angustifolium* lawn is the result of a relatively recent invasion. The boundary between layers of mat peat (formed at the surface on a framework of woody stems) and debris peat (which drops from the mat and settles on the bottom of the basin) is identified in some cores.

Loss - on - ignition of peat samples indicate ombrotrophic conditions at most cores, but slightly elevated values in the surface peat suggest that atmospheric deposition of dust has recently increased.

The hydrology of the bog appears to be relatively simple compared to other peatlands. The concentric pattern of pH isopleths originating at the northern tip suggests that this point is the major source of groundwater inflow to the bog. Surface runoff from the surrounding hills has a smaller influence on water chemistry, but has created a small minerotrophic lagg zone at the western and southern edges of the bog. Fluctuations in the water table caused the surface of the floating mat section to move up and down by as much as 14 cm, but in other areas, little or no movement was observed. Water table depth is greatest where the surface elevation is greatest, typically at *Sphagnum* hummocks and on the *S. angustifolium* lawn.

Bog water pH data show that conditions on the bog range from minerotrophic at the northern tip where there is inflow of groundwater, to ombrotrophic at the north, west and south edges where the *S. angustifolium* lawn occurs. A large drop in pH was observed between July 28 and August 04 1988, when a period of dry weather was followed by heavy rains. This was believed to be a result of organic acids being concentrated in the upper layers of peat through evapotranspiration followed by flushing of the acids into the water table. Concentrations of major ions are generally in the range expected for ombrotrophic to mildly minerotrophic peatlands, but spatial variation is difficult to interpret and requires more intensive sampling.

The vegetation of Barclay's Bog shows an edge to centre gradient which is probably due to a combination of microclimate and factors associated with successional age, especially depth to the water table. The presence of *S. angustifolium* appears to be controlled by microclimate and groundwater inflow. It is a shade-loving species and is found primarily in edge areas where shading from the surrounding forest is greatest, except at the northern tip of the bog where groundwater inflow occurs. The presence of this lawn-forming species has many implications for the ecology of the bog.

ACKNOWLEDGEMENTS

I want to thank Dr. Paul Barclay, my advisor, for suggesting this project and providing guidance throughout. The bog is named in his honour.

Financial support was provided by the Centre for Northern Studies at Lakehead University and the Thunder Bay Field Naturalists.

Robert Ireland identified *Sphagnum* samples. My father, David Harris, helped in the collection of peat cores.

I owe a special thanks to my wife Cathy, who supported me throughout the project, helped with field work, and provided encouragement and moral support.

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INTRODUCTION

Peatlands are an integral part of the Canadian landscape. Approximately 14 % of Canada's land area is covered by peatland, concentrated in a belt through the boreal forest region extending from western Quebec to the Northwest Territories (Canadian Committee on Ecological Land Classification 1986). In Ontario, peatlands cover approximately 40 to 50 % of the land area; mostly in the northern part of the province. This area includes the largest continuous tract of peatland in the world in the James Bay / Hudson Bay lowland (Sjors 1963).

Peatland development is highly dependant on the pattern of groundwater flow and water chemistry conditions. Bogs, or ombrotrophic peatlands receive water and nutrients only from atmospheric sources because the surface of the peat is isolated from contact with groundwater (water that has been in contact with mineral soil) and as a consequence are nutrient-poor (Gorham 1957, Sjors 1963). Fens, or minerotrophic peatlands receive nutrients from groundwater runoff as well as from the atmosphere and have higher nutrient levels. pH is highly correlated with nutrient level and is frequently used to distinguish bogs (pH less than 4.0) from fens (pH greater than 4.0) (Jeglum 1971, Moore and Bellamy 1974).

Peatlands are important to the Canadian economy because they support commercially valuable forests and contain a potential source of fuel in the form of peat that is widely used in Europe and Asia, but has yet to be exploited to any extent in Canada (Canadian Committee on Ecological Land Classification 1986). They act in regulating the waters of our rivers and streams and moderating flood peaks and provide habitat for fish and wildlife (Carter 1986). Recently, there has been considerable interest on the impacts of acid precipitation on peatlands. Some peatlands are probably vulnerable to acidification, but little research is being done on the effects of acid deposition on these systems (Gorham _et al_. 1984). There is also concern regarding the effects of "the greenhouse effect" on boreal peatlands since they store huge amounts of carbon and probably play an important role in the global carbon cycle (Bramryd 1980, Harriss _et al_. 1985).

Despite their significance, Canadian peatlands have not been extensively studied and relatively little is known about their biological, chemical, and hydrological processes.

Literature Review

Dansereau and Segadas-Vianna (1952) give an overview of the vegetation of peatlands of eastern North America, concentrating on the Laurentian region of Canada. Moss (1953) describes various wetland communities in northwestern Alberta and describes community succession from open water to bog forest. The significance of fire and permafrost in peatland development are discussed. Sjors (1959, 1963), in some of the most important Canadian research to date, worked on the Attawapiskat River in the Hudson Bay lowlands in northern Ontario. The extensive peatlands of this area were little known until the 1950's when air transportation became widely available. The various peatland types, including patterned fens and bog islands, are described and the relationships between elevation and drainage patterns and peatland development are discussed. Sims et al. (1982) examined fens on the Hudson Bay lowlands near southern James Bay in an attempt to classify them on the basis of vegetational physiognomy and identify important environmental factors. Three types of fen were identified (graminoid, low shrub, and treed) which were arranged along a minerotrophic-ombrotrophic gradient. Peat thickness, pH, sulphate and potassium concentrations were the factors that best discriminated the vegetation types. Peat depth was found to increase as distance from the coast increased, probably as a result of the gradual reemergence of the coast from beneath James Bay.

Jeglum (1971) determined that pH and depth to water table were important environmental factors influencing the distribution of plant communities in peatlands at Candle Lake, Saskatchewan. Indicator species of pH and water level were listed.

There have been few studies of the peatlands of the

Canadian Shield region of northwestern Ontario. Vitt and Bayley (1984) analyzed the relationships between water chemistry and vegetation patterns in four small kettle bogs in the Experimental Lakes area of northwestern Ontario. Glaser (1983) described the vegetation, physiognomy, and water chemistry of a patterned fen near Grand Marais, Minnesota, approximately 80 km south of the northwestern Ontario border.

Most of the of peatland studies noted above examine the relationships between vegetation and environmental factors in large peatland areas. Fewer studies have examined the vegetation and environmental conditions within small kettle bogs. Vitt and Slack (1975) examined the zonation of plant communities in Michigan kettle bogs. Vitt and Bayley (1984) (described above) did similar studies in northern Ontario kettle bogs.

Purposes

The purposes of this study are:

1) To describe the microclimate, physical parameters, stratigraphy, hydrology, water chemistry, and vegetation of a small, northwestern Ontario kettle bog. Spatial and seasonal variation in microclimate factors and water chemistry will be described.

2) To provide baseline data for future studies. Emphasis is placed on aspects of peatland biogeochemistry

that could serve in acid precipitation monitoring as suggested by Gorham *et al*. (1984).

3) To interpret the vegetation patterns of Barclay's Bog using microclimate, hydrology and water chemistry data.

In order to accomplish these aims, a series of studies were carried out at Barclay's Bog in 1987 and 1988.

Site description

Barclay's Bog (latitude 48 degrees 42 minutes N; longitude 89 degrees 28 minutes W) is located approximately 40 km north of the city of Thunder Bay in northwestern Ontario (Fig. 1). The term "bog" in this case is used in the sense of "... *Sphagnum* dominated habitats including potentially ombrotrophic and minerotrophic conditions..." (Vitt and Slack 1975). It borders the Hawkeye Lake Watershed Study Site of the Acidic Precipitation in Ontario Study near the west end of Hawkeye Lake where a forested watershed has been intensively studied and monitored since 1982 (Barclay 1984, Barclay *et al.* 1985). The bog is in an area near the southern edge of the Superior section of the boreal forest region (Rowe 1972). Balsam fir (*Abies balsamea* (L.) Mill), white birch (*Betula papyrifera* Marsh.), and trembling aspen (*Populus tremuloides* Michx.) are the dominant tree species. The area is in the Low Boreal Wetland Region where "characteristic wetlands are bowl bogs that are treed and often surrounded by peat margin swamps..." (Canadian Committee on Ecological Land Classification 1986).

The climate is characterized by long, cold winters and short, warm summers. Normal monthly temperatures and precipitation (30 year mean from 1951 to 1980) from Thunder Bay airport are shown in Fig. 2 a and b (Anon. 1951-1980). Mean annual temperature is 2.3 degrees C. Mean January temperature is -15.4 degrees C and mean July temperature is 17.6 degrees C. Mean annual precipitation is 711.8 mm of which 213.0 mm is snowfall. Mean temperatures at Thunder Bay during the study period (1987 and 1988) were several degrees above the normal for most months of both years, particularly between January and May in 1987 and between May and August in 1988. Precipitation was below normal in both years (156 mm below normal in 1987 and 21.7 mm in 1988) (Fig. 2 a, b). August 1988 had over twice the normal rainfall. Conditions at Kakabeka Falls, approximately 25 km south of Hawkeye Lake (latitude 48 degrees 24 minutes N; longitude 89 degrees 37 minutes W) are probably closer to those of the study site because it is inland from Lake Superior. Mean temperatures are approximately 0.4 degrees warmer in July and approximately 0.5 degrees colder in January than Thunder Bay and precipitation, particularly snowfall is slightly lower (Anon. 1951-1980). However, data from Kakabeka Falls was not available for 1987 and 1988.

The bog is situated on the Dog Lake Moraine which was formed approximately 9900 years ago during the Marquette advance of the Wisconsin stage of glaciation (Sado and Carswell 1987). The moraine is composed of sand and gravel with scattered boulders and rises to a maximum height of approximately 50 m above its surroundings (Zoltai 1963). The predominant soil of the moraine is an orthic humo-ferric podzol overlying granitic bedrock (Reino Viitala, personal communication). Total surface area of the bog is approximately 1.3 ha (Harris 1987). Steep banks rise from the edge of the Barclay's Bog along most of its perimeter except at the northeast corner where the terrain flattens out. There is no stream flow entering or leaving the bog.

The shape and surrounding topography suggest that it was formed in a glacial kettle hole (Fig. 3 a, b). Kettle holes are formed when blocks of ice break from the main body of the retreating glacier and are buried in outwash. The ice block melts and forms a small lake (Florin and Wright 1968). The absence of an inflow stream and lack of wave action due to small surface area create stagnant conditions and promote peatland development.

Kettle, or basin bogs are formed in poorly-drained depressions, usually deepest at the centre and often a central floating mat of vegetation (Gorham 1957, Canadian Committee on Ecological Land Classification 1987). Kettle bogs are of particular interest in the study of relationships among vegetation, chemical and physical conditions because they are small, usually with discrete boundaries and sources of groundwater inflow and patterns of water movement can be more easily determined than in larger peatland complexes. They often exhibit a wide range of degrees of minerotrophy within a small area. A number of other small kettle bogs are found in the area, particularly along the upper Kaministiquia River between Little Dog Lake and the Mattawin River (personal observation). The following vegetation zones were identified on Barclay's Bog by Harris (1987) based on aerial photographs and distribution maps of plant species (Fig. 4.) and are supplemented by data collected in the present study:

i) Floating mat zone. A small pool of open water near the centre of the bog is surrounded by a wet floating mat area. Utricularia cornuta Michx., Rhynchospora alba (L.) Vahl, and Drosera rotundifolia L. reach their peak abundance in this area and are found only rarely elsewhere on the bog. Sphagnum cuspidatum Ehrh. ex Hoffm. and Scheuchzeria palustris L. are also common. Small Sphagnum fuscum (Scrimp.) Klinggr. hummocks with Andromeda glaucophylla Link, Kalmia polifolia Wang., Sarracenia purpurea L., and Oxycoccus microcarpus Turcz. are found throughout the zone, but make up only a small proportion of the area.

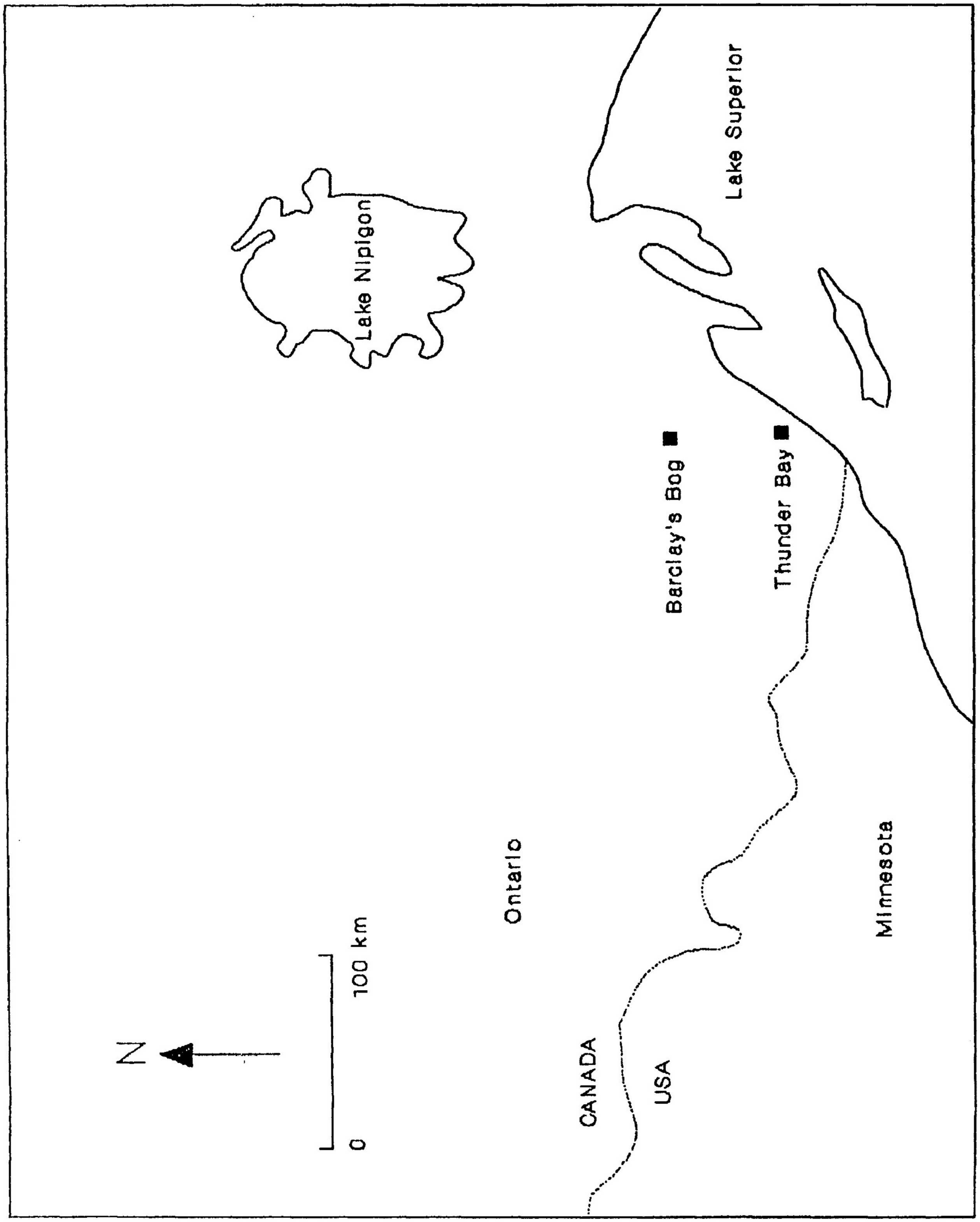
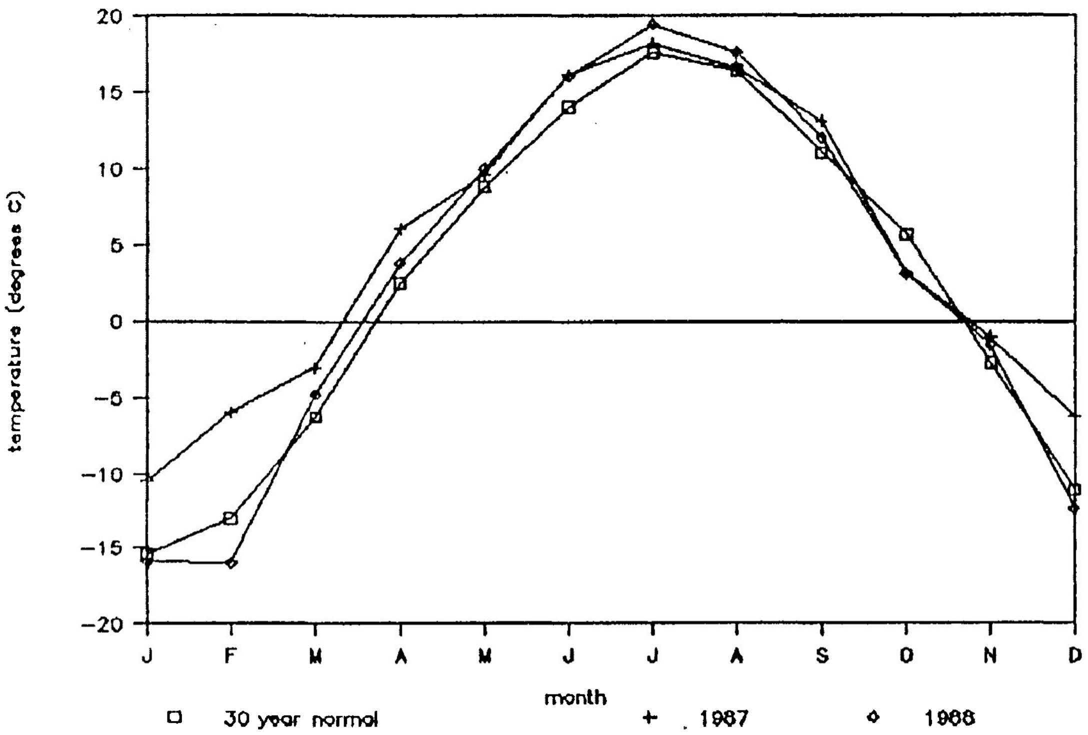


Fig. 1. Map of northwestern Ontario showing location of Barclay's Bog.

a) mean monthly temperatures



b) mean monthly precipitation

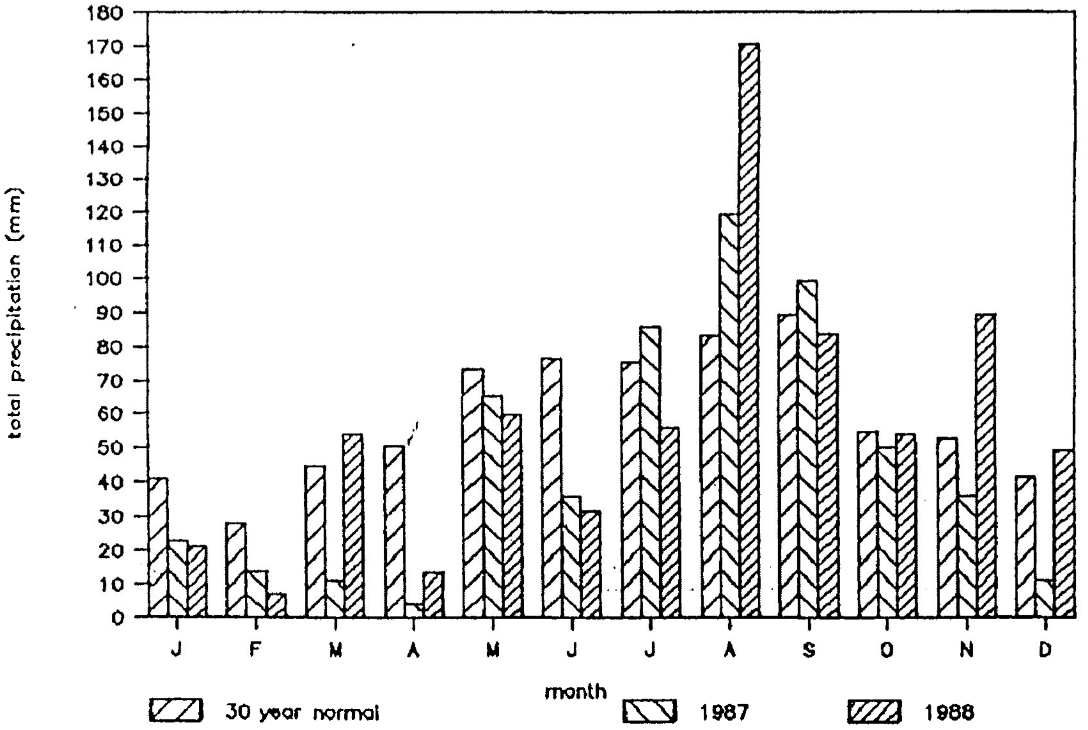


Fig. 2. Climate data from Thunder Bay airport, including 1951 - 1980 mean and data from 1987 and 1988.
a) Mean monthly temperatures
b) Mean monthly precipitation

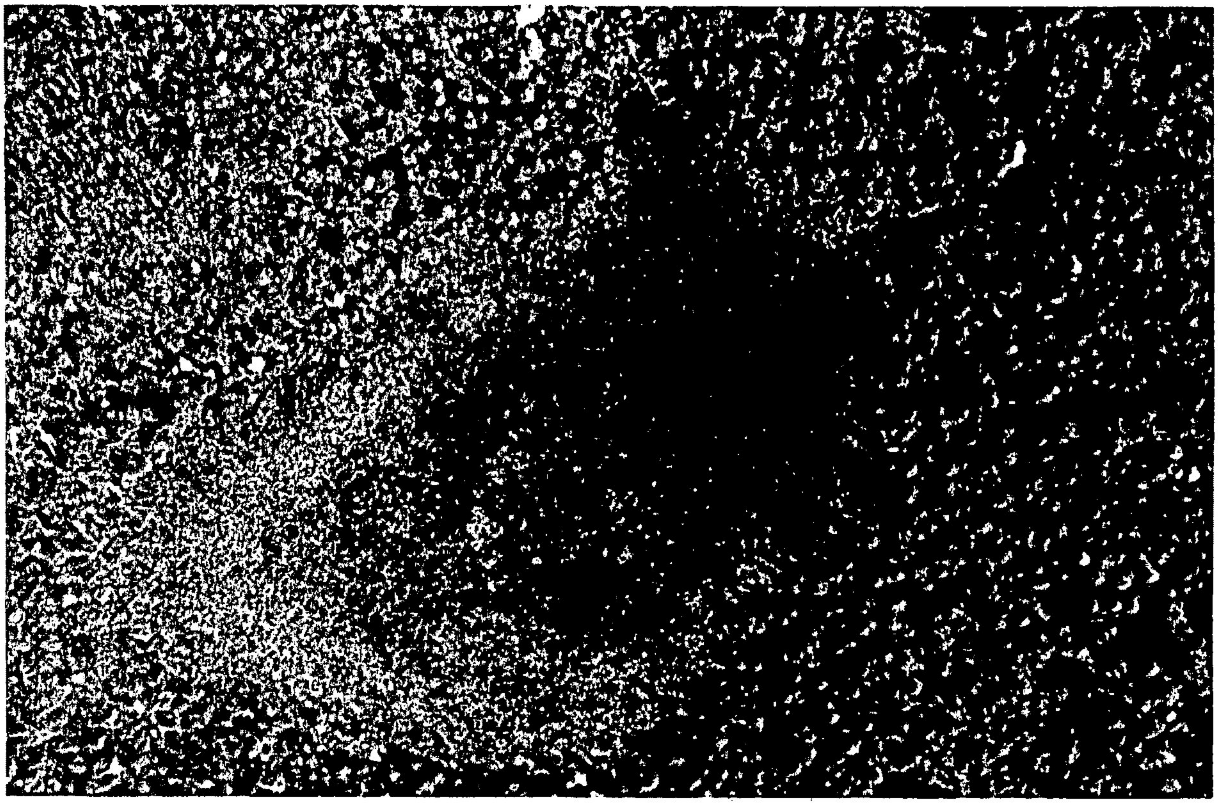


Fig. 3 a. Aerial photo of Barclay's Bog, June 1983, scale 1:2250.

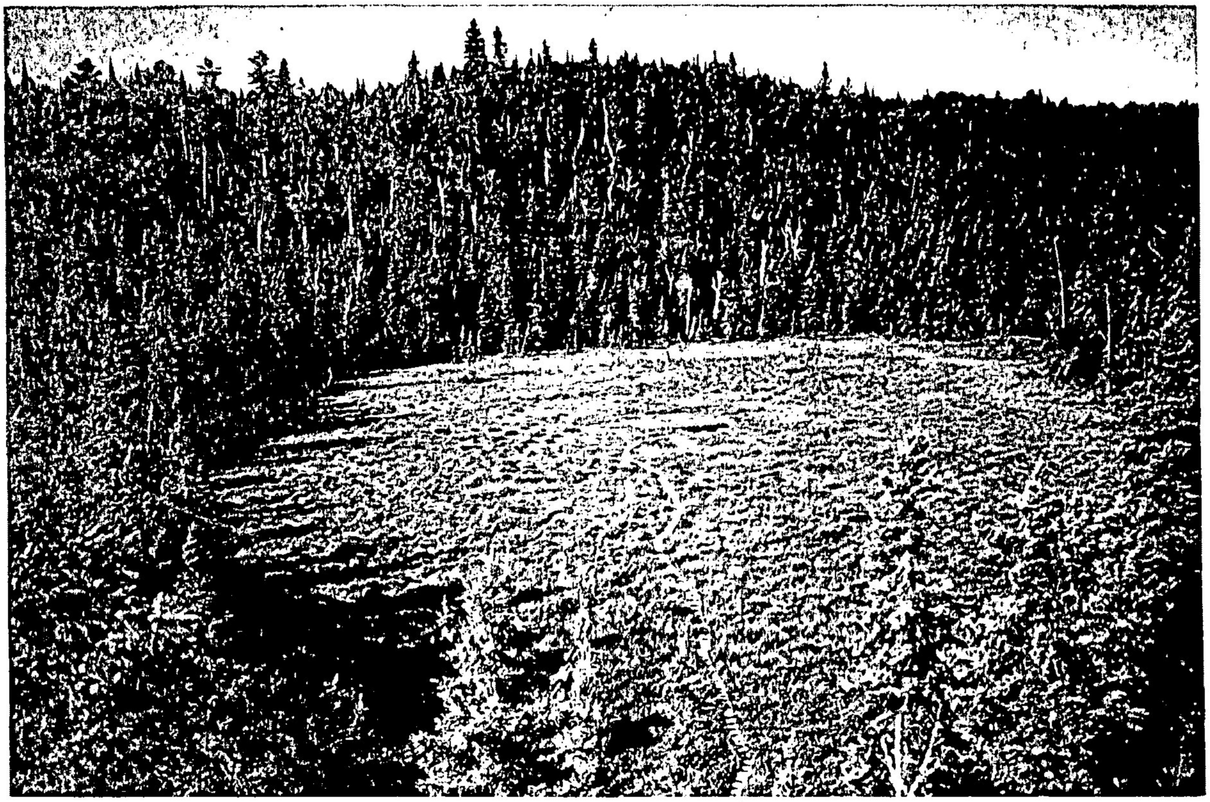


Fig. 3 b. Photograph of Barclay's Bog taken from east edge.

ii) *Hummocks and hollows zone* An area of hummocks and wet hollows forms a ring around the floating mat and extends to the northeast edge of the bog. The physiognomy of this zone is similar to the floating mat zone, but hummocks are more abundant and hollows are generally not as wet. *Sphagnum magellanicum* Brid. is the primary hummock-forming species in this zone, but the vegetation of the hummocks is similar to that of the floating mat zone. *Carex limosa* L. becomes the most important hollow species with *S. palustris*, and *S. cuspidatum* also present.

iii) *Sphagnum angustifolium lawn zone*. At the west end of the bog and extending along the north and south edges of the basin, but absent at the northeast edge, is a continuous, uniform lawn of *Sphagnum angustifolium* (C. Jens. *ex* Russ) C. Jens. This zone is characterized by abundant *S. angustifolium*, *Carex oligosperma* Michx., *Ledum groenlandicum* Oeder, and *Carex trisperma* Dewey (*C. oligosperma* and *C. trisperma* were not distinguished in Harris 1987). *Chamaedaphne calyculata* (L.) Moench reaches its greatest cover in this zone, but is also present in the other zones. *A. balsamea*, *B. papyrifera*, *Pleurozium schreberi* (Brid.) Mitt, *Gaultheria hispidula* (L.) Muhl. and several other species are present near the edges of the bog and reach their peak cover in this zone.

Additional details on the vegetation of Barclay's Bog can be found in Harris (1987).

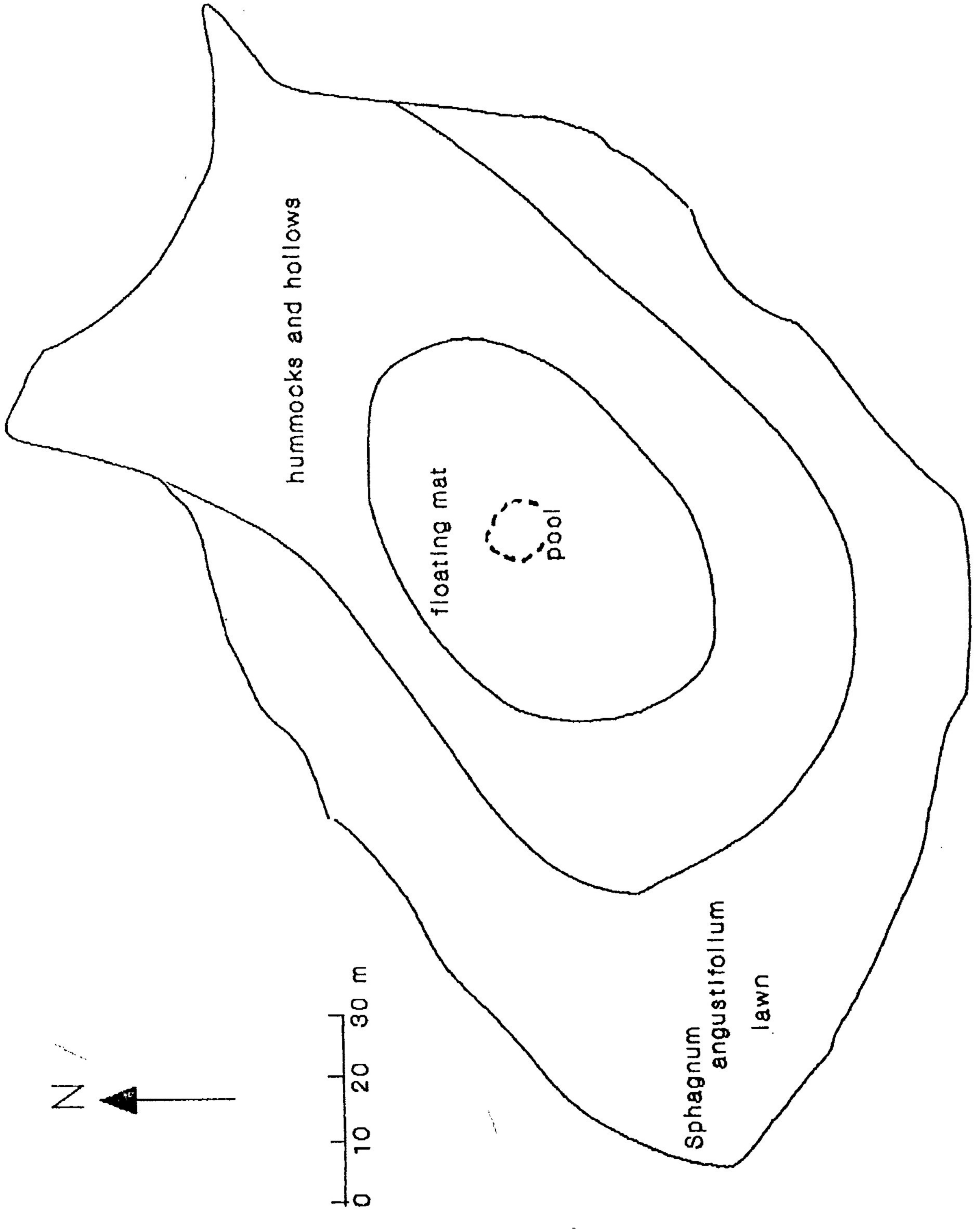


Fig. 4. Map of Barclay's Bog showing vegetation zones. Location of the centre pool indicated by dashed line.

METHODS

1) General

Various aspects of the ecology of Barclay's Bog were measured in a series of separate studies. The methods are arranged first with topics that relate to climate followed by soil topics, water factor topics, vegetation topics and finally by a section dealing with data analysis.

In order to systematically locate sampling and monitoring locations, the grid system established by Harris (1987) was used to divide the surface of the bog into 133 - 10 m x 10 m sections (Fig. 5). The intersections of west-east and north-south transects were numbered and marked with white plastic tags inserted into the peat. Many of the vegetation, surface elevation and other measurements were taken at these stations. Standpipes were installed at 28 of these stations for collecting water samples (Fig. 5). In addition, two stations were established to measure climate and microclimate factors (indicated "c" and "e" in Fig. 5).

A wooden boardwalk was constructed from the west edge of the bog to the centre pool to reduce trampling of the vegetation.

2) Climate and Microclimate

By measuring aspects of the temperature, light, and relative humidity at a station near the centre of the bog and at a station near the shady south edge of the bog, it will be possible to compare the microclimate of the two areas and determine the effects on plant communities. Two sites were chosen to represent the edge and central portions of the bog. The edge station was placed in the zone receiving the lowest amount of direct sunlight (Fig. 5) located 7 m from the south edge of the bog in the *S. angustifolium* lawn. The centre station was placed in the zone receiving the greatest amount of sunlight, approximately 30 m east of the centre pool in a large, flat, relatively dry hollow (it was necessary to avoid the floating mat area at the centre of the bog in order to find peat solid enough to support the instruments) (Fig. 5). The vegetation consists of *Drosera rotundifolia*, *Rhynchospora alba*, and *Utricularia cornuta*. There are several large hummocks of *Sphagnum fuscum* and *S. magellanicum* surrounding the hollow. Depth of the peat to the underlying mineral soil at the edge and centre stations is 237 cm and 238 cm respectively.

a) Temperature

i) Air temperature (Sixes Maximum-Minimum Thermometer)

Weekly maximum and minimum temperatures were measured with a Sixes maximum-minimum thermometer (Daubenmire 1974). The thermometer was mounted on a birdhouse shelter mounted on posts at a height of 1.5 m above the surface of the peat. The birdhouse is designed to protect the instruments from direct sunlight, but permit air to circulate freely (Fraser

1961). Temperatures were recorded weekly from May 29 1987 to November 23 1988. Mean temperature was calculated from maximum and minimum values.

ii) Air temperatures at 1.5 m above the surface (bimetallic strip thermometers)

Daily temperatures were recorded from May 06 to Aug 31 1989 at the centre and edge stations using Casella hygrothermographs. The hygrothermographs were housed in birdhouse shelters. The temperature-sensitive element in this hygrothermograph is a deformation thermometer made of a laminated strip of two different steels. The two metals have different coefficients of expansion, and a change in temperature causes one to expand or contract more than the other and causes the strip to bend. The bend is transmitted through a magnifying link and is recorded on a chart on a rotating drum (Painter 1976).

Daily maximum and minimum temperatures were read from the charts and the mean was calculated. Maximum and minimum temperatures at centre and edge stations were tested for significant difference using a paired *t*-test (Kreyszig 1970).

Occasional failure of the timing mechanism of both hygrothermographs, resulted in gaps in the data set. Only those dates where data is available for both stations were used in the analysis.

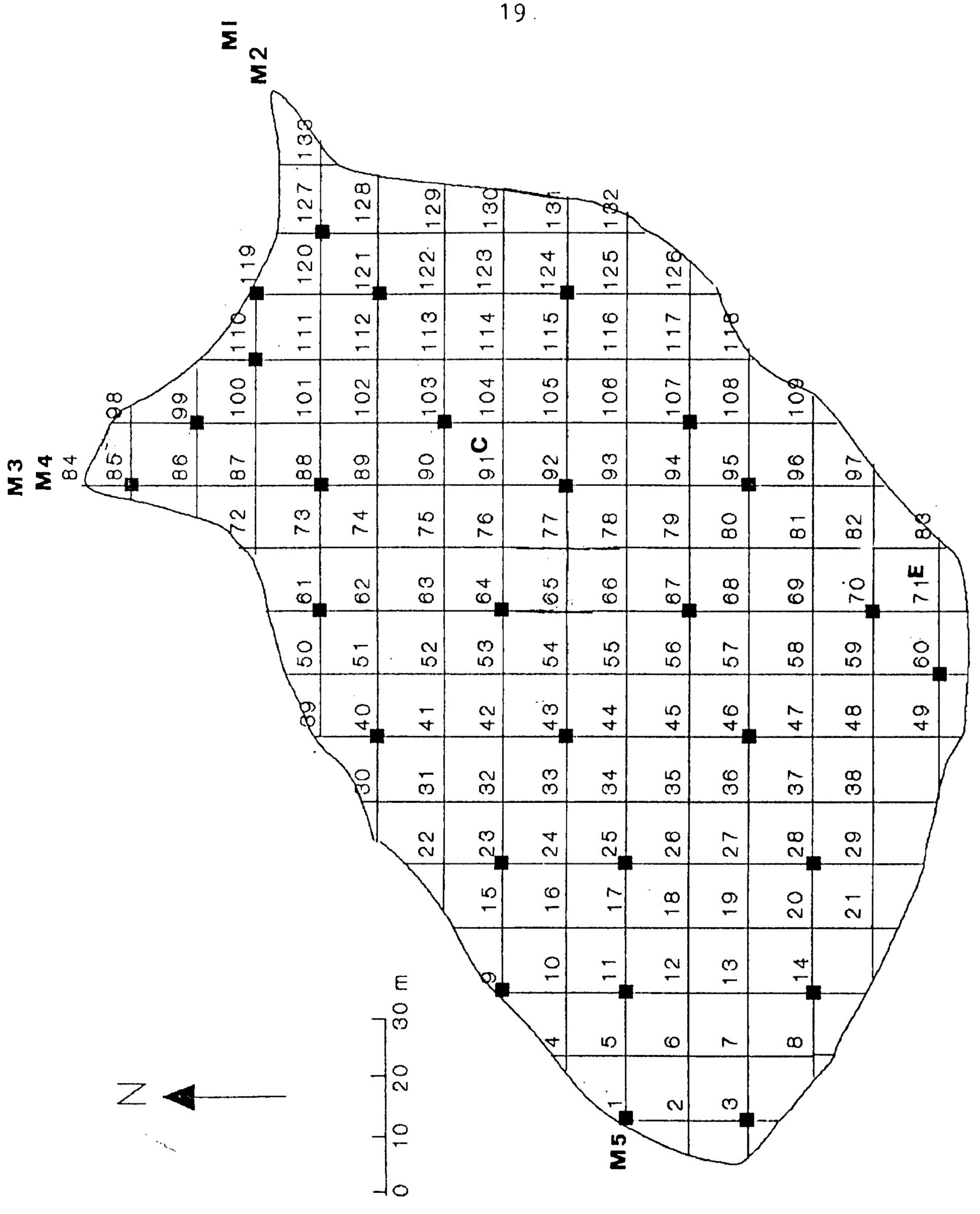


Fig. 5. Map of Barclay's Bog showing grid system and station numbers. Locations of centre ("c") and edge ("e") microclimate stations are also shown. Standpipes are indicated with a solid square. M1 to M5 are mineral soil standpipes.

Temperatures were standardized every week using a mercury thermometer. Measurements were taken inside the birdhouse within 1 cm of the bimetallic strip thermometer, and recorded on the hygrothermograph chart. Comparison of the temperature readings are shown in Appendix I. Temperatures recorded by the hygrothermograph at the centre station were consistently similar to standardthermometer readings and no correction factor was applied. At the edge station, a correction factor of 2 degrees C was added to deformation thermometer readings taken between June 14 and August 16 and a correction factor of 3 degrees C was added to readings taken from August 23 to August 31.

iii) Air temperatures at the peat surface (grass thermometers)

Maximum and minimum recording grass thermometers were installed at the centre and edge stations. These thermometers are placed at the surface of the ground where temperatures tend to be higher during critically hot periods and lower during critically cold periods than temperatures at 1.5 m above the surface (Daubenmire 1974). The thermometers were calibrated using a standard mercury thermometer at 0 degrees C, 24 degrees C, and approximately 45 degrees C before being installed and at the end of the study period. In all cases, the thermometers were within 0.5 degrees C of the standard thermometer.

In order to protect the thermometers from direct sunlight while permitting air circulation, a shelter consisting of a piece of 23 cm x 38 cm x 0.5 cm plywood, painted white and raised 8 cm above the surface of the peat was placed over the thermometers. The thermometers were supported by pieces of wood so that they were parallel with the surface of the peat, with the bulb 2 cm above the surface. Temperature readings were taken weekly between May 17 and November 1 1988. Maximum and minimum temperatures at centre and edge stations were tested for significant difference using a paired *t*-test (Kreyszig 1970).

iv) Soil Thermometers

Soil thermometers were installed at centre and edge stations at depths of 0.5 m and 1.0 m. These thermometers consist of a mercury - in - glass thermometer fused in a glass shield. The bulbs are embedded in wax to slow the response to temperature change and permit accurate readings after they are pulled from the soil (Platt and Griffiths 1964). Steel pipes approximately 150 cm long and sealed at the bottom end were driven into the peat so that 15 cm of the pipe was left protruding above the surface. The thermometers were suspended on string and lowered into the pipe so that the bulbs were at the desired depth and the open ends of the pipes were covered with a plastic bottle to prevent rain from entering. Readings were taken weekly between May 10 and November 23 1988.

The thermometers were calibrated using a standard mercury thermometer at 0 degrees C, 24 degrees C, and approximately 45 degrees C before being installed and at the end of the study period. In all cases, soil thermometers were within 0.5 C of the standard thermometer. Mean temperatures at centre and edge stations were tested for significant difference using a paired *t*-test (Kreyszig 1970).

v) Thermocouples

Temperature measurements of the peat profile were taken using thermocouples and a Digimite potentiometer. The thermocouples are those used by Wilson (1970), but were modified for the requirements of this study. Thermocouples consist of a junction between dissimilar metals which produces a voltage that varies with temperature (Unwin 1980). Number 26 copper - constantan, polyvinylchloride covered wire was used. The ends of the wires were bared for a length of approximately 2 cm, cleaned, twisted together, and soldered. The elements were then sealed with flexible plastic cement to prevent corrosion (Wilson 1970). The thermocouple elements were calibrated using a standard mercury thermometer at 0 degrees C, 24 degrees C, and approximately 45 degrees C before being installed. Readings were consistently within 0.5 degrees C of the standard thermometer. The thermocouples were mounted on a post made from a 2.5 m length of 5.1 cm outside diameter heavy plastic laboratory tubing, light blue in colour. Elements were insulated from the pipe with a 1 cm x 1 cm x 1 cm styrofoam chip and fastened down with black electrical tape. The leads were taped together to form a single cable leading to the top of the standard (Wilson 1970). Two standards were constructed and were installed at the centre and edge stations so that the elements were positioned at depths of 1, 20, 40, 60, 80, 100, 120, 140, 160, 180, and 200 cm in the peat. The top of the standard was level with the surface of the peat with the leads protruding approximately 1.5 m above the surface (Fig. 6a).

The Digimite potentiometer contains an temperature-sensitive silicon diode sensor that serves as an internal reference junction and automatically compensates for ambient air temperatures; there is no need to place a separate reference junction in an ice bath (Roger Heslington, personal communication). It is necessary, however, to shelter the potentiometer from rapid changes in temperature. This was accomplished by placing it in a white styrofoam bucket which served as shade from direct sunlight and as protection from wind. Voltage generated by the thermocouple is converted directly to a temperature value.

The instrument was checked for error every week by means of an internal check circuit, and by comparing air temperature measured by a thermocouple inside the birdhouse with a standard mercury thermometer. Thermocouple temperatures rarely differed by more than 1 degrees C from standard thermometer readings and were usually within 0.5 degrees C. No correction factor was applied to the data.

vi) Standpipe water temperatures

Standpipes were constructed from 60 cm lengths of 2 cm outside diameter polyvinyl chloride pipe, perforated with 3 mm holes drilled at 2 cm intervals. The standpipes were installed at 28 locations on the bog surface in late fall 1987 (Fig. 5). A piece of pipe of the same dimensions as the standpipes, closed at the bottom end, was first inserted into the peat to create a hole and prevent the standpipe from becoming filled with peat as it was inserted. Standpipes were inserted to a depth of 40 cm, leaving 20 cm of pipe above the surface.

Temperature readings were taken at all standpipes at weekly intervals from June 16 to September 01 1988. A standard mercury thermometer was lowered to the bottom of the pipe and left for approximately 2 minutes. It was then quickly withdrawn from the pipe and the temperature read immediately. Temperature of the centre pool was measured at 5 cm below the surface. Occasionally, the water table was below 40 cm and no reading was taken. This method is potentially open to error since the reading begins to change immediately after it is exposed to the air, but a standard method was used and the data is acceptable for comparing temperatures measured in identical fashion at the various stations. Temperature isopleths were mapped. In order to determine if *Sphagnum* cover influenced subsurface temperatures, mean temperatures of: a) *Sphagnum angustifolium* lawn stations and b) the other stations (including floating mat and hummock and hollow stations) were calculated and tested for significant difference using a paired *t*-test (Kreyszig 1970).

b) Solar radiation

An index of the amount of solar insolation received by the different areas of the bog was accomplished by mapping the areas in shade throughout the course of the day. Previous studies (e.g. Vitt and Slack 1975) have used total importance values of trees and tall shrubs as an index of shading but this method would not give an accurate estimate of shade on Barclay's Bog because there are few trees on the bog itself and most of the shade comes from the surrounding forest.

Data were collected on and around the summer solstice (June 20 to 23 1988), the day receiving the greatest amount of sunlight in the year. The proportion of each grid square in shade was recorded at 2 hour intervals beginning at 10:00 EDT and ending at 18:00 EDT. Measurements were taken only

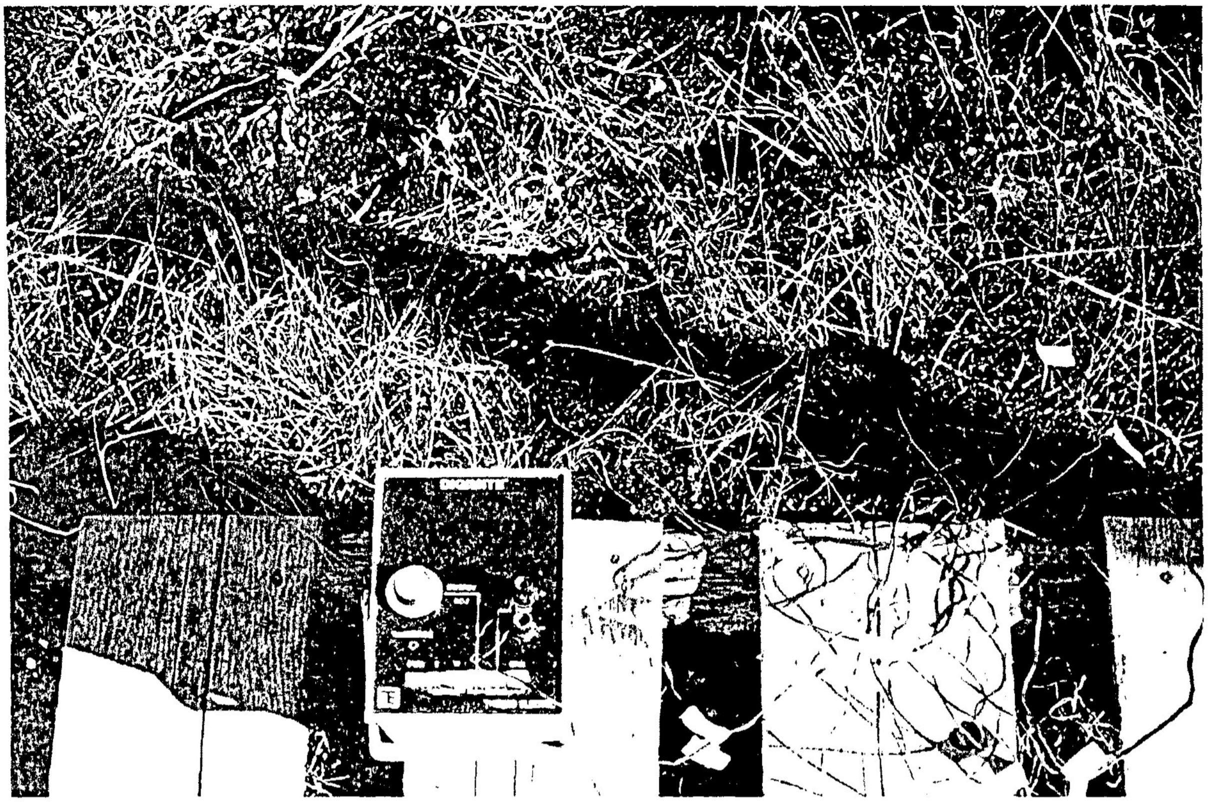


Fig. 6 a. Digimite potentiometer used in measuring peat temperatures.

Fig. 6 b. Snow course.

when there was no overcast. June 21 was mostly sunny, but due to some intermittent cloud, some data were collected on June 20 and 22. An attempt was made to collect data at 20:00, but the sun had descended to the level of the tree tops by this time and the shade line was advancing rapidly across the bog (moved approximately 20 m between the start and end of the session) and this data was rejected. The sky was at least partly overcast on all three days at 0800 and it was not possible to complete this set of readings.

The following codes were used:

code	% shaded
5	75 - 100 %
4	50 - 75 %
3	25 - 50 %
2	1 - 25 %
1	no shade

Total shade code was determined for each station by calculating the sum of the hourly readings between 10:00 and 18:00. A map showing total shade codes was drawn.

c) Water Factor

i) Precipitation

A standard British rain gauge was installed near the centre of the bog at ground level at a location where there were no obstacles to interfere with air movement. The volume of precipitation collected was measured weekly using a standard 1000 ml graduated cylinder. In order to convert the rain gauge volume to mm of precipitation, the following formula was applied:

$$\text{amount of precipitation (mm)} = \frac{\text{rain gauge volume (ml)}}{\text{pi} \times r2}$$

where r = radius of opening of rain gauge = 6.25 cm

ii) Snow Course

A snow course consists of a series of evenly spaced fixed markers that measure changes in snow depth. It is a simple method of measuring changes in snow depth and more accurate than some more complicated methods such as snow pillows (Goodison et al. 1981, Bernier 1986).

Wooden metre sticks were installed on December 01 1987. By this date there was sufficient snow to hold the sticks upright. They were placed at 10 m intervals along a transect crossing the bog from north to south at its widest point and left in place for the duration of the winter (Fig. 6 b). An additional marker was placed in the woods approximately 30 m east of the edge of the bog. Snow depth readings were taken by walking along the transect at a distance of approximately 3 m from the metre sticks so as to minimize the influence on snow movement caused by the presence of a deep trail (Goodison et al. 1981). Readings were taken weekly from December 01 1987 to April 26 1988.

iii) Relative humidity

Relative humidity was measured using the hygrothermographs described above. The humidity-sensitive element of the hygrothermograph consists of a bundle of human hair which changes length in response to changes in humidity due to the absorption of moisture. The change in length is translated to a movement of a pen on a rotating drum by means of a mechanical link (Painter 1976).

Daily maximum and minimum relative humidity readings were taken from May 06 to August 31 1988. The hygrothermograph at the edge station was replaced on Jun 07 when it was noticed that some of the hairs of the hair hygrometer element were broken. Mean relative humidity was calculated from daily maximum and minimum readings. Maximum and minimum hair hygrometer readings were corrected for ambient temperature using the following formula:

corrected RH = RH + (temperature - 20 degrees C)/2.5

(Anonymous, no date).

Maximum relative humidity almost invariably occurred at minimum temperatures, and minimum relative humidity occurred at maximum temperature, therefore, minimum temperature was used to correct maximum relative humidity and maximum temperature was used to correct minimum relative humidity (Appendix II).

The hair hygrometer was calibrated weekly using an Assman hygrometer. Readings were taken in the birdhouse with the thermometer bulbs of the Assman hygrometer within 1 cm of the element of the hair hygrometer. Temperature - corrected hair hygrometer readings were subtracted from corresponding Assman hygrometer readings and the mean difference used as a correction factor. Correction factors of 3.5 and 7.2 % for the centre and edge stations respectively were added to the mean temperature - corrected relative humidity. An exception was made for the edge hygrothermograph for the period from May 06 to June 07 1988 during which period hair hygrometer readings were very close to Assman readings and no correction factor was applied.

Mean daily relative humidity at centre and edge stations were tested for significant difference using a paired *t*-test (Kreyszig 1970).

3) Surface topography

Surface elevation measurements were taken on Nov. 7 1987 using a Geotec 12 inch dumpy level with 22 times magnification. On this date, the surface of the bog was sufficiently frozen to support the weight of the observer. This eliminated the problem of peat compaction and sinking of the floating mat. A platform to support the level was constructed on the south side of the bog at a location which offered an unobstructed view of most of the bog surface (Fig. 7). Wooden stakes were driven through the peat into the mineral soil (the peat was less than 1 m deep at this location) and a platform measuring 1 m on each side was nailed to the top of the posts. A similar platform was constructed to support the observer. A reference point was marked on a nearby tree and was checked approximately every 15 minutes to detect any error due to movement of the platform. No movement was detected and no correction factors were necessary.

Elevation readings were taken at all 133 stations. Two observers were involved: one walked between grid points and placed the rod at the markers and the other took the elevation readings with the level. On two occasions, the sight line between the level and the rod was obscured by trees. In these cases, the rod was placed at a nearby unobscured point of approximately the same height (estimated by eye). Elevation measurements were taken to the nearest centimetre.

A surface topography map was drawn using elevation data. The station with the lowest elevation was set as the "zero" point and other elevations were expressed relative to that point.

4) Peat depth

Measurements were taken on October 8 and October 13 1987 at a point 30 cm east of each station. A 3 m length of 12 mm diameter copper pipe was hammered shut at one end (to prevent it from clogging with peat) and pushed into the peat until downward movement was stopped by contact with mineral soil or until a depth of greater than 2.0 m was reached. The pipe was then raised approximately 20 cm and vigorously pushed down again to ensure that the pipe had not been obstructed by friction with the peat. This method could be used to a maximum depth of 2.0 m; at greater depths friction resistance prevented insertion and withdrawal of the pipe. At stations 12, 54, and 103, where peat was deeper than 2.0 m, depth was remeasured using a Russian peat corer which measured to a maximum depth of 5 m.

5) Peat Stratigraphy

Low oxygen levels in peatlands cause vegetation remains to decompose very slowly and since the peat is stratified in the sequence it is laid down, it is possible to reconstruct the history of the bog by examining peat cores (Moore and Bellamy 1974).

Cores were collected at stations 2, 12, 54, 70, 86, 103, 122, and 129 forming a west-east transect across the bog (Fig. 5). A Russian peat corer with a 50 cm long barrel and inside cross-sectional area of 5 cm was used to collect peat samples (Fig. 8 a). Depths of the layers were measured and the peat making up the layer was placed into one of the following categories: (i) sedge peat: consisting mainly of sedge remains, (ii) *Sphagnum* peat: consisting mainly of *Sphagnum* leaves and stems, (iii) woody peat: with a high

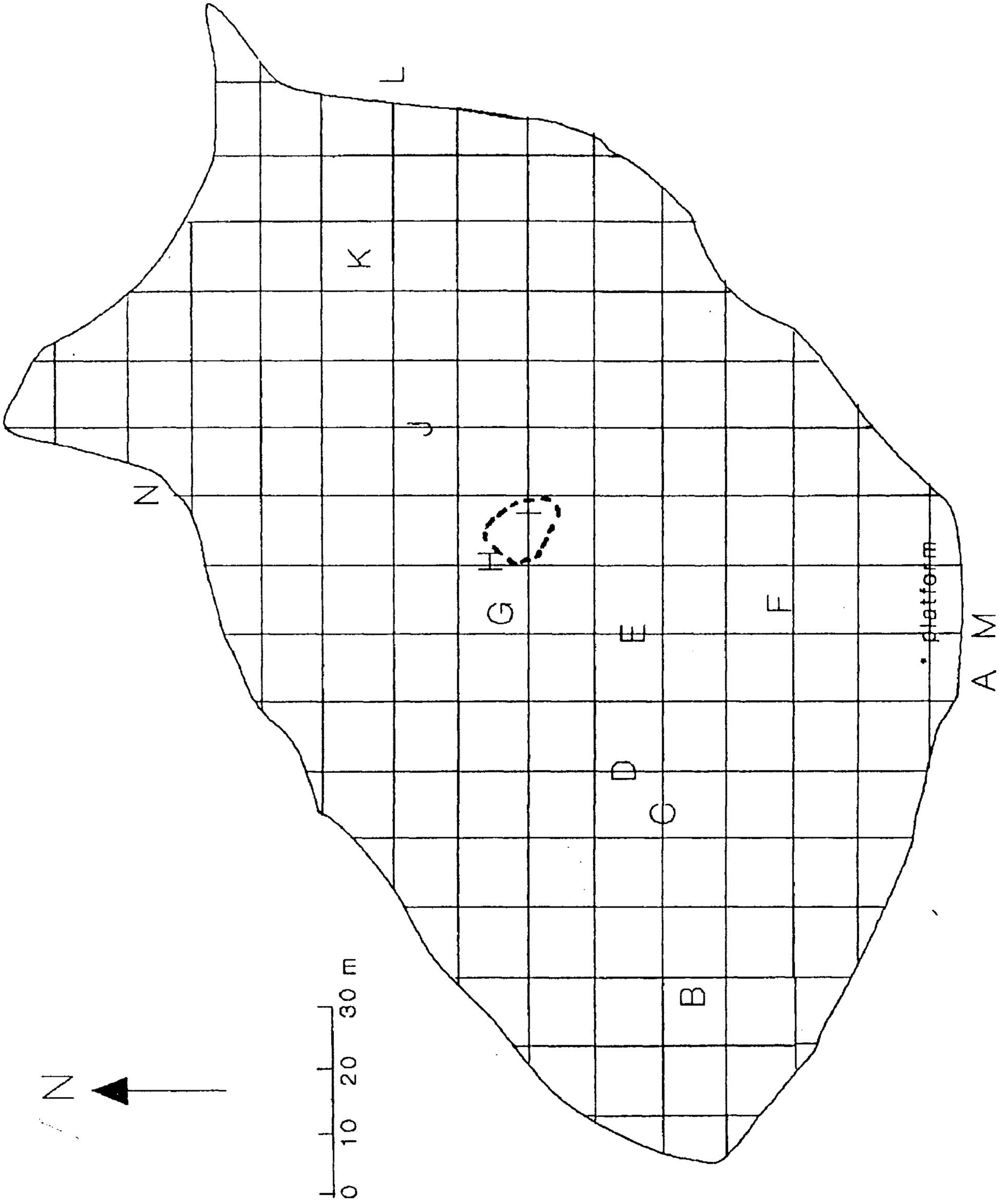


Fig. 7. Map showing locations of surface elevation fluctuation markers and observation platform. Location of the centre pool indicated by dashed line.

proportion of wood chips or twigs (iv) amorphous peat: well-decomposed peat with little or no recognizable plant material and (v) gyttja: fine, clay-like peat originating from lake sediments (Fig. 8 b) (Moore and Bellamy 1974). The presence of charcoal, sand, and gravel in the peat was also noted. Degree of decomposition was recorded using the method of von Post (Canadian Soil Survey Committee 1978).

6) Soil loss - on - ignition

Loss - on - ignition measures the proportion of organic material in a soil sample and can be used to identify areas of groundwater inflow and periods of increased deposition of airborne inorganic material (Zoltai and Johnson 1985). Peat cores were collected using the Russian peat corer. In most cases, the core was divided into 10 cm sections and placed into plastic bags. Some cores (stations 70 and 103) were divided into sections on the basis of peat composition rather than into 10 cm sections. Loss - on - ignition measurements were done on alternate sections of the core and pH measurements on the remaining sections. The samples were placed in a freezer within 12 hours of collection and kept frozen for up to three months. Prior to analysis, samples were removed from the freezer, placed in open plastic dishes, and allowed to dry for seven to 10 days. Air dried peat samples were placed in pre-weighed porcelain crucibles. If the peat sample was too large to fit into a single crucible, the sample was carefully broken up and mixed by hand until a relatively homogeneous mixture of dried peat was obtained, and divided into replicate samples. The crucibles and contents were placed in a drying oven at 105 degrees C for 22 to 28 hours, then removed and weighed immediately to the nearest milligram using an electronic balance. The crucibles were then put in a muffle furnace and fired at 450 degrees C for 23 to 25 hours, removed, and allowed to cool in a dessicator for approximately 30 minutes. The cooled samples were removed from the dessicator and weighed immediately to the nearest milligram. Loss - on - ignition was calculated using the following formula (Atkinson *et al.* 1958):

$$LOI = \frac{OD - BW}{OD - CW} \times 100$$

where:
OD = oven dry weight (g)
BW = burnt weight (g)
CW = crucible weight (g)
LOI = loss - on - ignition (%)

7) Hydrology

a) Water table depth

Depth to the water table below the surface of the peat was measured at all stations at approximately biweekly intervals between June 16 and August 18 1987. A 60 cm length of 2 cm (outside diameter) polyvinyl chloride pipe with 3 mm holes drilled at 2 cm intervals was sealed and

Fig. 8 a. Russian peat corer.

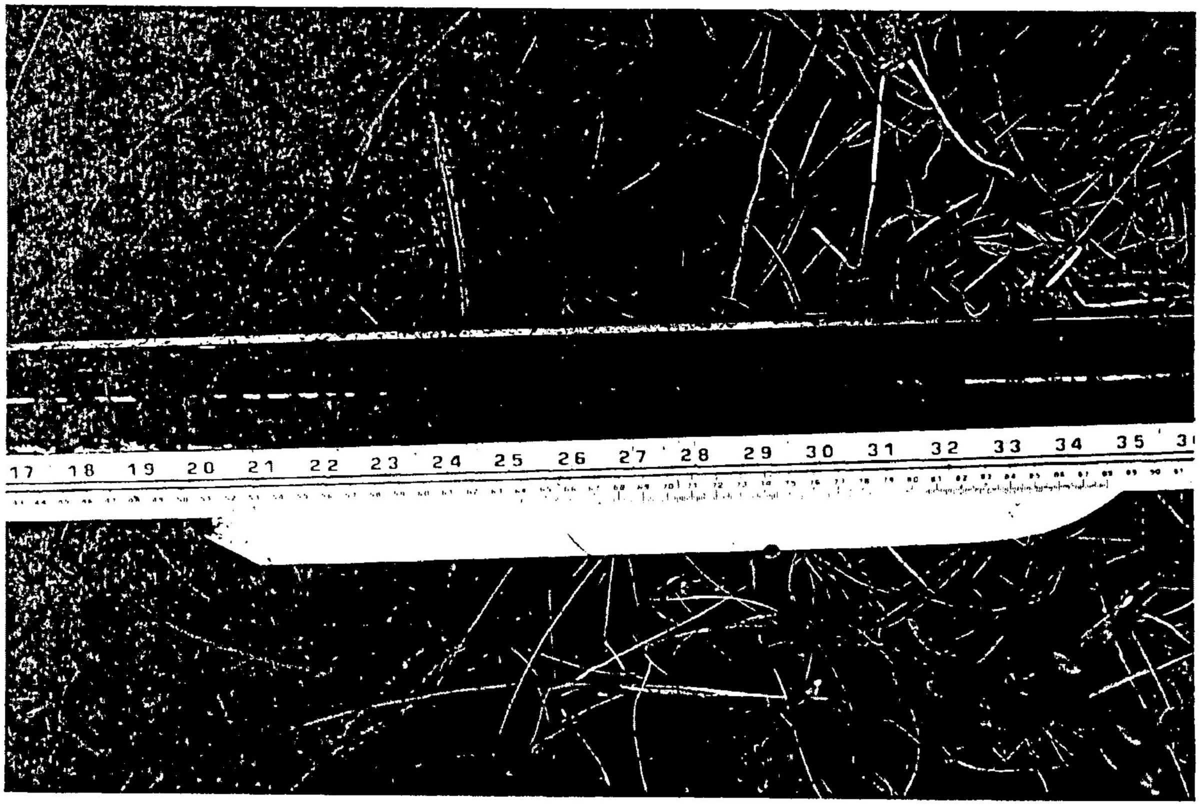


Fig. 8 b. Russian corer with peat core.

formed to a point at one end. This diameter of pipe was chosen because it is small enough to rapidly fill with water and small enough to minimize disturbance resulting from insertion. The sealed end was inserted in the peat to a depth of 40 cm and allowed to fill to the level of the water table for approximately 2 minutes. Depth to the water level was determined by lowering a plastic float on a string into the pipe until it reached the surface of the water. The length of the string from the top of the pipe to the waterline on the float was measured and the height of the pipe above the peat surface subtracted. No depth was determined when the water table was greater than 40 cm below thesurface. It is important to note that the weight of the observer compresses the peat and forces water up the standpipe resulting in artificially shallow water table depths. An attempt was made to minimize this effect by maintaining an arm's length distance from the standpipe at all times. Other factors including the "piezometer effect" of the narrow pipe and the displacement of water by the float must also be considered before interpreting the data. However, measurements were taken using identical methods from week to week and these data can be used to compare different stations and to measure changes between sampling periods.

The minimum depth to the water table (ie closest to the surface) was used in analyses because the maximum depth was often greater than the depth of the pipe. Water table depths were mapped.

b) Surface elevation fluctuation

A series of elevation marker posts was set up along a west to east transect to measure fluctuations of the surface elevation of the bog (Fig. 7). Markers B and H, I, J and K consist of 2.2 m length of 5 cm X 5 cm lumber sunk into the peat to a depth of 50 cm and supported at the base with wooden struts (Fig. 9). A metre stick was attached to the surface of the post facing the observation platform. Other elevation markers (C to G) consist of metre sticks nailed to trees rooted on the bog. The distance between the bottom of the metre stick and the surface of the peat was measured at the time of installation. This length was remeasured at the end of the study period and was found to have deviated from the original reading by less than 0.5 cm in all cases.

Height readings were taken to the nearest centimetre at weekly intervals between June 07 and November 01 1988 using the surveyor's level and platform described above. Readings were corrected for the height of the metre stick above the surface of the peat and then converted to a height relative to reference point A.

In order to check for instrument error and possible movement of the viewing platform, measurements were taken on four reference points situated at various locations around

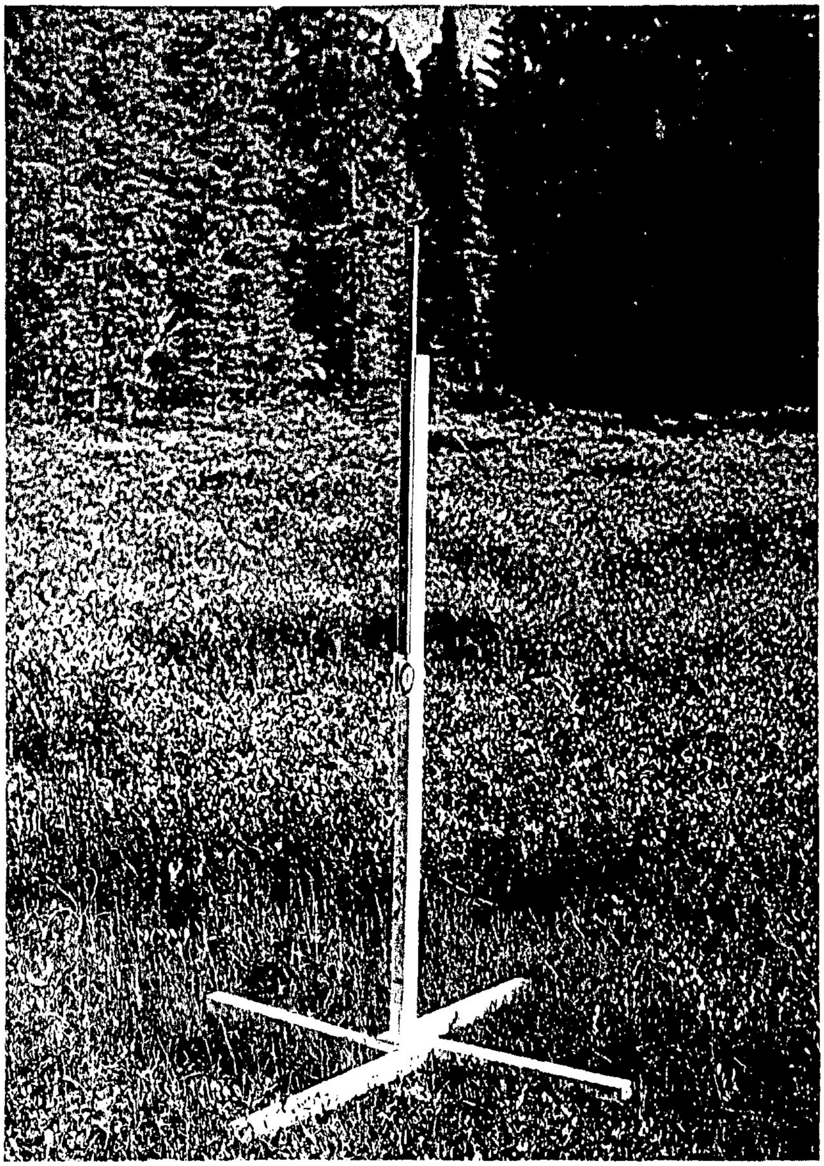


Fig. 9. Marker used to measure surface elevation fluctuation.

the margin of the bog (markers A and L to M). These points consisted of metre sticks nailed to trees rooted in mineral soil. It was assumed that these points were immovable and that any variation in the height readings is due to error. With the exception of station L, the reference points deviated less than 1 cm from their mean elevation and exhibited no consistent trends. The elevation readings at station L decreased by approximately 2 cm after July 26 and remained at approximately that level until the end of the study, possibly due to wind moving the tree. For this reason, station L was disregarded as a reference point. Since the deviations at the reference points was small, no correction factor was applied to the data (Appendix I).

8) Water chemistry

a) Bog water pH

Measurements of pH are frequently taken in peatland studies because pH is often highly correlated with nutrient level and can be used to distinguish ombrotrophic from minerotrophic conditions (Jeglum 1971, Moore and Bellamy 1974).

pH readings were taken weekly between June 16 and September 20 1988 from 28 points on the bog. Water samples were collected from the standpipes described above (Fig. 5). Five additional standpipes were set up in mineral soil at various locations around the perimeter of the bog. These standpipes were made of a similar material as the bog standpipes, but were of a larger diameter (5 cm) to hold a larger volume of water because of the slower percolation rate in mineral soil. The perforated end of each standpipe was covered with 1 mm diameter mesh plastic screen (to prevent the pipe from filling with soil) and the pipes were sunk to depths from 50 cm to 200 cm below the ground. No water was present in the mineral soil standpipes until after the period of heavy rain between July 28 and August 04 1988 and no data is available for these standpipes until August 04. Samples were collected and analyzed using the same methods as were used for bog water samples.

Water samples were collected using a pump consisting of a 60 ml plastic syringe and section of plastic tubing. The end of the tubing was inserted into the standpipe and a water sample was drawn up into the syringe. Two samples of approximately 60 ml were drawn up and then pumped out and discarded in order to rinse out the pump apparatus and sample collection bottle. A third water sample was drawn up and pumped into a 100 ml polythene bottle. Occasionally, when the water table was low and the rate of seepage was insufficient to fill the standpipe within a few minutes, the bottles were only partially filled during the rinsing process and a smaller sample (at least 20 ml) was collected. Bottles were sealed and placed in a cooler. No pH measurements were taken when the water table level was below the bottom of the standpipe (below 40 cm). This occurred more frequently early in the summer and more frequently at edge stations than centre stations.

Between sampling periods, the bottles were rinsed three times in distilled water and then soaked for 12 to 24 hours in distilled water. The pump was rinsed thoroughly with distilled water and then soaked for 12 to 24 hours in a beaker of distilled water.

The samples were usually tested for pH within 12 hours after collection, but in some cases the samples were refrigerated at 4 degrees C for 24 to 36 hours before being analyzed. A Fisher Accumet Model 805 pH meter with a combination electrode was standardized using pH 4.00 potassium biphthalate buffer and pH 7.00 potassium phosphate monobasic - sodium hydroxide buffer at the beginning and end of each set of samples. The water samples were allowed to warm to room temperature and the probe was placed in the water sample so that the glass bulb was suspended at approximately the centre of the sample, then swirled briefly, and left until a constant reading was obtained.

In order to calculate mean pH, pH values were converted to hydrogen ion concentration using the following formula:

$$\text{hydrogen ion concentration} = \text{antilog}(\text{pH} \times -1).$$

The mean hydrogen ion concentration was calculated and the mean value converted back to a pH. The difference between the two methods of calculating pH is greatest at low pH and least at higher pH. Mean pH was calculated for each station and for all stations collectively on each sampling day.

Mean pH and mean hydrogen ion concentrations were plotted on maps of the bog and isopleths were drawn to delimit areas with similar conditions. Maps showing pH isopleths were also drawn for the sets of readings taken on July 15 and August 04 1988. These dates were chosen because July 15 falls in a dry period (July 22 and 28 were in the same dry period but many stations had dried up on these dates and a complete data set was not available) and August 04 falls after a period of heavy rain. Maximum and minimum pH values were also mapped.

Mean pH was calculated for the 14 stations with at least 50 % *Sphagnum angustifolium* cover (Braun Blanquet values of 4 or 5) and for the 14 stations with less than 50 % cover (Braun-Blanquet values less than 4). Student's *t* - test was used to test for significant difference between the means (Kreyszig 1970).

b) *Peat pH*

Peat samples were collected, frozen and air-dried as described for soil loss - on - ignition. Cores were divided into 10 cm sections (stations 2, 12, and 54) or were divided into sections on the basis of peat composition (stations 70 and 103). Peat pH measurements were done on alternate sections of the core and loss - on - ignition measurements on the remaining sections. Air-dried samples were placed in wax-covered paper cups and 40 ml of 0.01 M $CaCl_2$ was added. The $CaCl_2$ method is widely used and has several advantages over using a water-based solution (McKeague 1978). The mixture was stirred with a glass rod every 10 minutes for the next 30 minutes. If all of the $CaCl_2$ was absorbed by the peat by the end of the 30 minute period, an additional 20 ml of solution was added and the mixture allowed to settle for an additional 30 minutes. The pH was measured using the pH meter described above by immersing the tip of the electrode into the supernatant liquid without disturbing the settled peat and allowing the reading to stabilize.

c) Analysis for major ions

Water samples were collected on October 15 1988 using the methods described for the collection of samples for pH analysis. Before sampling, polyethylene sample bottles (100 ml) were washed with a 10 % solution of hydrochloric acid, left to soak in the acid for one hour, drained and triple-rinsed with distilled water and left to soak in distilled water for approximately five days. Two sample bottles were filled at each station. One sample was acidified to approximately pH 2.5 using 10 drops of a 5% solution of HNO3. This prevents metal ions from adhering to the walls of the bottle and inhibits growth of algae and bacteria (Golterman 1970).

Samples were filtered through 47 mm diameter Metricel membrane filters (0.45 um pore size) using a suction pump and a polythene filtration unit consisting of a funnel, filter holder, and holding vessel. The filter unit was acid-washed before use (using the procedure described for bottles) and rinsed with distilled water between samples. Samples were poured from the collection bottles into the filtration unit, filtered, and the filtrate was poured into acid-washed 140 ml glass beakers and covered with Parafilm to avoid recontaminating the filtrate with the residue in the bottom of the collecting bottle.

Water samples were analyzed for S, Pb, P, Na, Mn, Mg, K, Fe, Al, Ca, Zn, and Cd on the inductively coupled plasma atomic emission spectroscopy (ICP) unit at Lakehead University. Minimum detection limits are shown in Table 1. In order to correct for contamination during the filtering and acidifying process, four "blanks" were subjected to the same analysis. The blanks consisted of i) unfiltered distilled water, ii) filtered distilled water, iii) acidified, unfiltered distilled water, and iv) acidified, filtered distilled water. Both of the filtered blanks had elevated concentrations of phosphorus compared to the unfiltered blanks and a factor of 1.70 mg/l (the mean of the concentration in the two distilled filtered samples) was subtracted from sample phosphorus concentrations. All four blanks had calcium and sodium concentrations above the detectible limit due to trace amounts present in the distilled water. No correction factor was applied for these elements.

A paired *t*-test was applied to determine if there were significant differences between acidified and non-acidified samples. Where no significant difference was detected ($p = 0.005$), the samples were treated as duplicates and the mean concentration of the two samples was used in analysis (sulphur, phosphorus, iron, aluminum, and cadmium). When concentrations of elements were significantly lower in non-acidified samples, it was assumed that some binding of elements to the surface of the bottle had occurred, and the value of the acidified samples was used (sodium, manganese, magnesium, potassium, calcium and zinc).

d) Calcium:magnesium ratio of bog waters

Groundwater from a given point source will have a characteristic ratio of Ca:Mg concentration determined by the nature of the bedrock and soil that it moves through. The ratio is normally not affected by dilution with rain water and surface runoff and can be used to ascertain whether a peatland has more than one distinct sources of groundwater. If the bog is fed by a single source of groundwater, the Ca:Mg ratio will be similar at all points on the bog. Changes in absolute concentrations of the

Table 1. Minimum detection limits of the inductively coupled plasma atomic emission spectroscopy (I.C.P.) unit used in chemical analysis of bog waters.

element	Minimum detection limit (mg/l)
Al	0.05
Ca	0.001
Cd	0.002
Fe	0.005
K	0.300
Mg	0.001
Mn	0.001
Na	0.01
P	0.08
Pb	0.025
Zn	0.004
S	0.100

elements are caused primarily by dilution with cation-poor water (Siegal and Glaser 1987).

e) Comparison of bog waters with precipitation

Concentrations of some elements were compared to precipitation values collected at the Forbes Township site of the Acidic Precipitation in Ontario Study (approximately 10 km west of Barclay's Bog). Data from 1986 (the most recent available data) was used.

9) Vegetation

Vegetation data were recorded at each of the 133 stations. Field work was carried out between August 4 and August 20 1987. A 1 m x 1 m quadrat was used in order to sample 1% of the bog surface area (Barbour *et al.* 1980). The quadrat frame was placed on the ground at each grid point, with one edge oriented along the north-south transect and the other oriented along the east-west transect. Braun-Blanquet cover values (Barbour *et al.* 1980) were assigned for each plant species:

Braun-Blanquet Cover Value	Percent Cover
trace	less than 1%
1	1-5%
2	6-25%
3	26-50%
4	51-75%
5	greater than 75%

Specimens of plants that were not recognizable in the field were collected and identified in the laboratory. Only those plants rooted inside the quadrat were recorded; overstorey vegetation was not recorded to avoid including in the analysis plants that are not rooted on the bog, but overhang its edges. Authority names and nomenclature follow Scoggan (1979) for vascular plants and Ireland (1982) for bryophytes.

i) Polar ordination

Vegetation data were analyzed using Bray and Curtis polar ordination (Bray and Curtis 1957). This method constructs a two-dimensional scattergram of the vegetation plots based on species composition and cover which can be interpreted in terms of various environmental factors. Polar ordination is a widely used and reliable method for showing the relationships of the vegetation and is at least as successful as more complex methods (Beals 1984, Causton 1988).

Index of difference (ID) between pairs of quadrats was calculated using Sorensen's coefficient with Braun-Blanquet cover values (Barbour et al. 1980). The two quadrats with the greatest index of difference (A and B) are used as endpoints of the x-axis and each of the remaining quadrats is positioned on the x-axis relative to A and B. Poorness - of - fit (e) is calculated for each quadrat and the quadrat with the greatest e value (C) is used as one endpoint of the

Y axis. The other endpoint of the y-axis is the quadrat with the greatest index of difference with C, but within 0.1 L of C on the x-axis (where L is the length of the x-axis) (Bray and Curtis 1957). Calculations were performed using a microcomputer.

Only those species occurring in at least 5 % of the quadrats were included in the analysis. Eliminating rare species reduces the computing time by eliminating rows from the data matrix containing mostly zeros. Furthermore, the presence of rare species is often a matter of chance rather than an indication of environmental conditions (Gauch 1982). Quadrats whose vegetation consists largely of atypical species should also be excluded from the data set because they tend to compress the spread of the remaining points in the ordination and "...their relationship with the other quadrats is not expressed in the data anyway..." (Gaugh 1982). Quadrat 60 was deleted from the analysis because it had an index of difference of 1.0 (no shared species) with 13 other quadrats. There were no other pairs of stands with an index of difference of 1.0.

A form of indirect gradient analysis was accomplished by superimposing various environmental factors on the polar ordination. It is possible in this way to interpret some relationships among bog vegetation and environmental factors (Vitt and Slack 1975).

10) Data analysis

i) Pearson correlation

Pearson correlation coefficients (r) were calculated using the PEARSON CORR subprogram of the Statistical Package for the Social Sciences (SPSS) (Nie *et al.* 1970) on the MicroVAX computer at Lakehead University. This program determines the correlation coefficient for a linear relationship between two variables and tests for significance using Student's *t* -test (Nie *et al.* 1970). Correlation coefficients were determined between various microclimate, water chemistry, and vegetation factors.

RESULTS

The following results of the study at Barclay's Bog are presented in the same order as are the "Methods". Figures and tables are incorporated into the text.

1) Climate and Microclimate

a) Temperature

i) Air temperatures (Sixes Max - Min thermometer)

Maximum temperature recorded at Barclay's Bog during the study period was 37 degrees C recorded in the week ending July 12 1988. Minimum temperature was -37 degrees C recorded in the week ending February 09 1987. The latest frost in spring of 1988 was recorded in the week ending June 21. First frost was recorded in the week ending September 28 1988 (Fig. 10, Appendix VI).

ii) Air temperatures at 1.5 m above the peat surface

Maximum and minimum temperatures recorded by bimetallic bar thermometers at 1.5 m above the bog surface are significantly higher at the centre station than the edge station (Table 2, Fig. 11, Appendix VIII).

iii) Air temperatures at peat surface (grass thermometers)

Mean minimum temperature recorded by grass thermometers is significantly lower at the edge station than at the centre station (Table 2, Fig. 12, Appendix IX). Mean maximum temperature is significantly higher at the edge

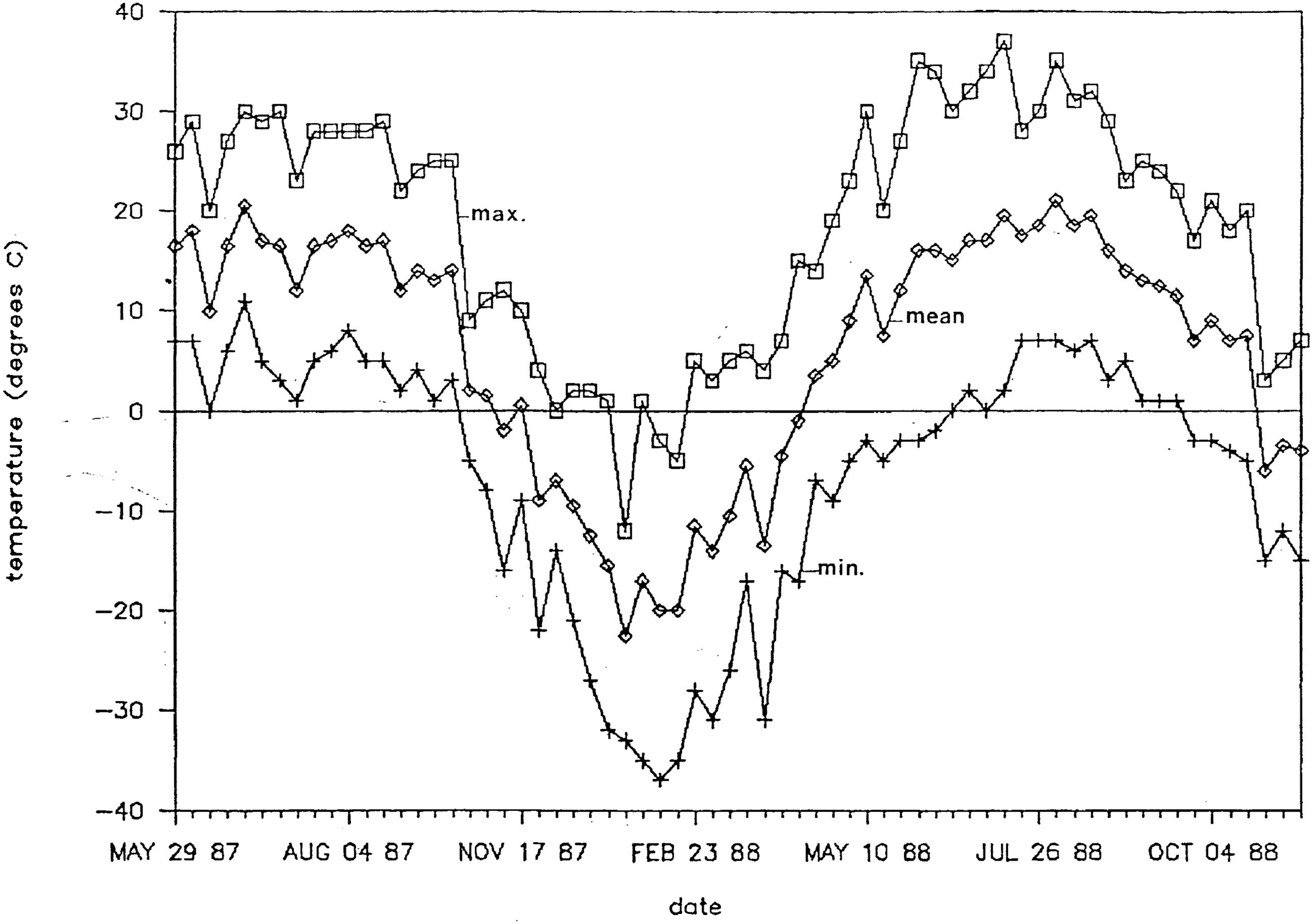


Fig. 10. Weekly maximum, minimum, and mean temperatures recorded by Sixes Max-Min thermometer at centre station, May 27 1987 to November 08 1988.

station, but maximum temperatures were consistently higher at the centre station after September 13. Minimum temperatures increased gradually from the week ending May 24 until early August and then began to decline slowly. Maximum temperatures declined throughout the study period. The widest range of temperatures is experienced in early to mid-June when minimum temperatures frequently dip below freezing at night and rise to over 30 degrees C during the day. The edge station experiences a wider range of temperatures than the centre station with maximum temperatures occasionally exceeding 40 degrees C and minimum temperatures dropping to as low as -6.5 degrees C in June.

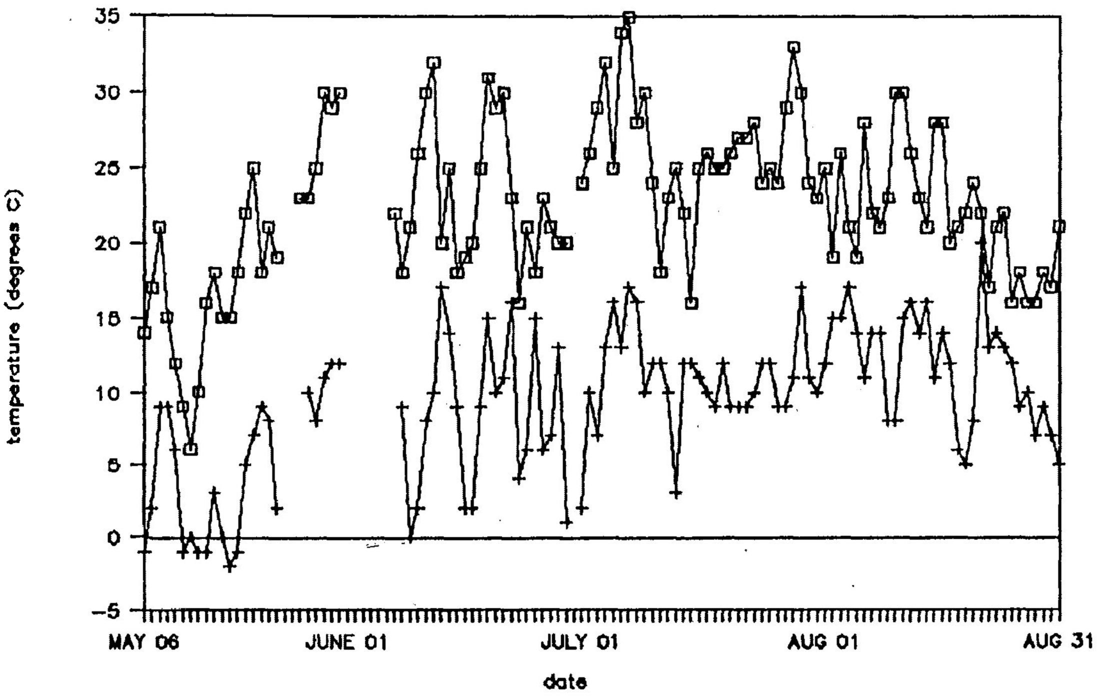
The centre station has a longer frost free period than the edge station. Minimum temperatures at the edge station were above freezing for only 5 weeks between mid-July and mid-August while the frost free period at the centre station extended from early July to mid-September.

Higher extreme maximum temperatures and lower extreme minimum temperatures were recorded at the peat surface than at 1.5 m above the peat surface during the same period (Fig. 11, 12).

iv) Soil thermometers

Mean peat temperature recorded by soil thermometers is approximately 2 degrees C lower at the edge station than at the centre station at both 0.5 m and at 1.0 m (Table 2, Fig.

a) centre station



b) edge station

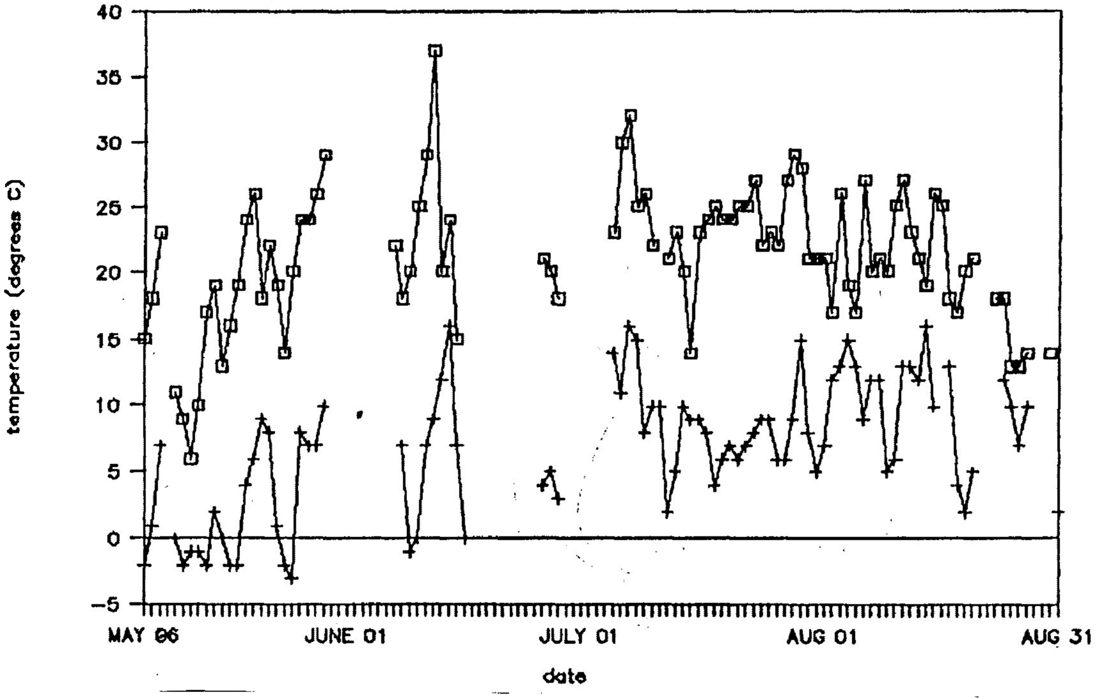


Fig. 11. Daily maximum (upper line) and minimum (lower line) temperatures recorded at 1.5 m above the surface of the peat by bimetallic strip thermometers at (a) centre and (b) edge stations May 06 to August 30 1988. Refer to Fig. 5 for locations of stations.

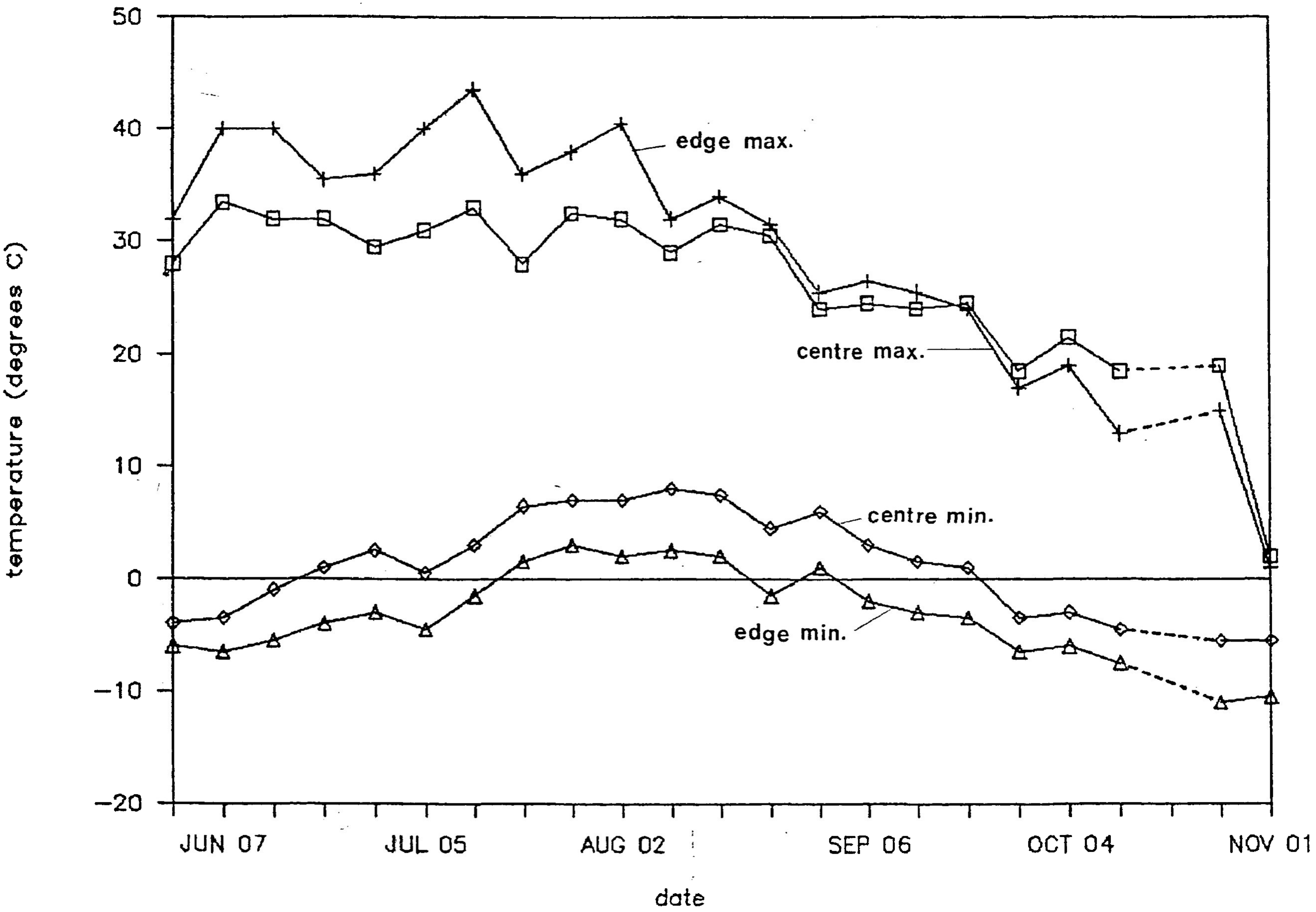


Fig. 12. Weekly maximum and minimum temperatures recorded at the surface of the peat by grass thermometers at centre and edge stations May 24 to November 01 1988. Refer to Fig. 5 for locations of stations.

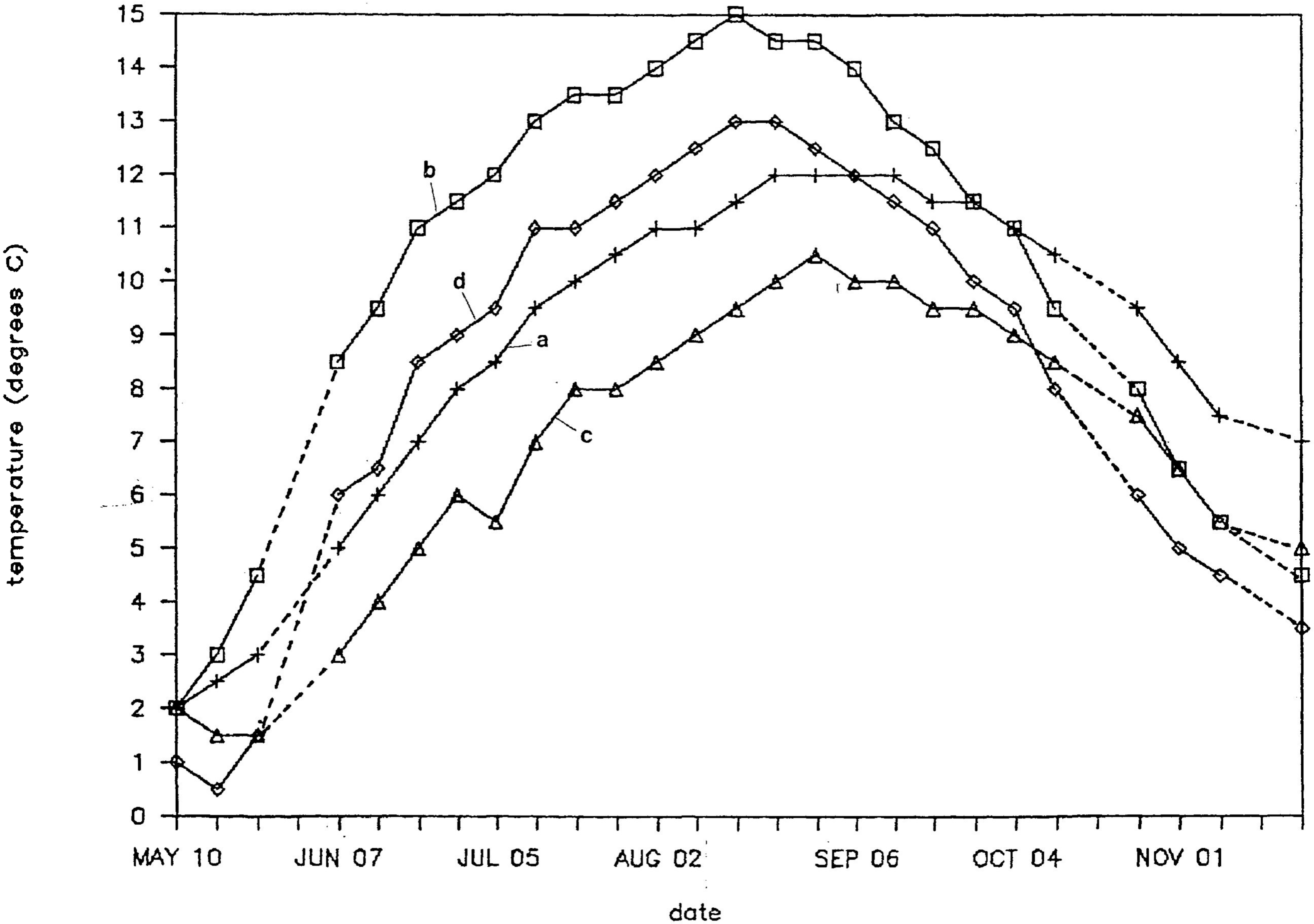


Fig. 13. Temperatures recorded by soil thermometers at 0.5 m and 1.0 m depths at centre and edge stations May 10 to November 23 1988. "a" is centre station 1.0 m depth, "b" is centre station 0.5 m depth, "c" is edge station 1.0 m depth, and "d" is edge station 0.5 m depth. Refer to Fig. 5 for locations of stations.

Table 2. Comparison of aspects of the microclimate of centre and edge stations. Values are mean ± standard deviation and number of readings (n). Level of significance of paired *t* -test is indicated "p", where < 0.001 indicates significant difference at p = 0.001 level, < 0.01 indicates significant difference at p = 0.01 level, and "ns" indicates no significant difference at p = 0.05 level.

	centre	edge	n	p
1) Bimetallic strip thermometers: (degrees C)				
maximum	22.68 ± 5.61	21.29 ± 5.37	79	< 0.001
minimum	9.13 ± 5.04	7.20 ± 4.90	79	< 0.001
2) Grass thermometers: (degrees C)				
maximum	26.32 ± 7.33	29.34 ± 10.93	22	< 0.01
minimum	1.30 ± 4.58	-3.20 ± 4.08	22	< 0.001
3) Soil thermometers: (degrees C)				
0.5 m	10.40 ± 3.93	8.46 ± 3.89	26	< 0.001
1.0 m	8.87 ± 3.07	6.92 ± 2.81	26	< 0.001
4) Thermocouples: (degrees C)				
1 cm	13.13 ± 6.81	12.43 ± 10.20	14	ns
20 cm	12.82 ± 4.88	10.76 ± 5.30	14	< 0.001
40 cm	12.40 ± 3.81	10.34 ± 3.93	14	< 0.001
60 cm	11.69 ± 2.85	9.67 ± 2.84	14	< 0.001
80 cm	10.99 ± 2.18	8.93 ± 2.19	14	< 0.001
100 cm	10.27 ± 1.62	8.20 ± 1.64	14	< 0.001
120 cm	9.59 ± 1.12	7.49 ± 1.24	14	< 0.001
140 cm	8.81 ± 0.90	6.74 ± 1.03	14	< 0.001
160 cm	8.12 ± 0.63	6.18 ± 0.87	14	< 0.001
180 cm	7.48 ± 0.59	5.60 ± 0.80	14	< 0.001
200 cm	6.86 ± 0.54	5.14 ± 0.78	14	< 0.001
5) Relative humidity: (%)	67.55 ± 10.58	71.65 ± 6.09	70	< 0.001

13, Appendix X). Temperatures at the 0.5 m depth at the two stations followed similar trends with steadily rising temperatures from mid-May to mid-August followed by a steady decline. Temperatures at the 1.0 m depth followed similar trends, but lagged behind the 0.5 m temperatures by one to two weeks. Higher temperatures were recorded at the 0.5 m depth at both stations until early October when they dropped below the temperatures at the 1.0 m depth. The range of temperatures was smaller at the 1.0 m depth at centre and edge stations, and smaller at the edge station than the centre station.

v) Thermocouples

Mean temperatures recorded at the edge station are significantly lower at all depths except at 1 cm where there is no significant difference between the centre and edge stations (Table 2, Fig. 14, Appendix XI). Difference in mean temperature between the stations is approximately 2 degrees C at all depths. During the period from July 29 to September 20, temperatures were highest at both stations at the 1 cm depth and decreased linearly with depth. Between September 20 and November 01, the depth of maximum temperature moved progressively deeper in the peat profile.

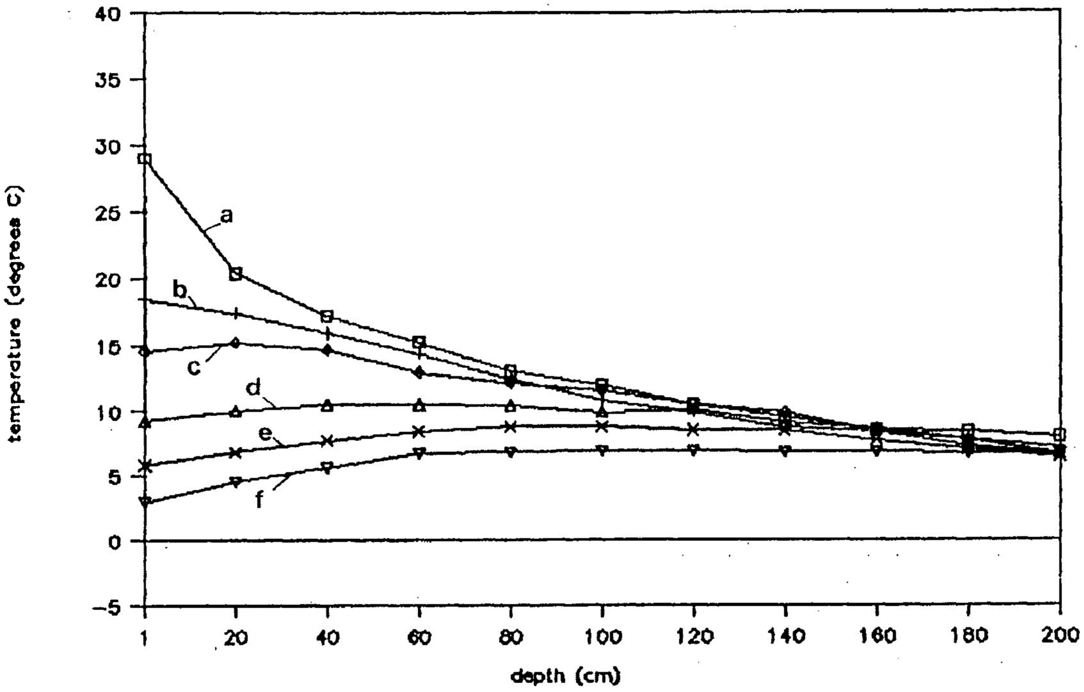
Range of temperature fluctuation is greatest at the 1 cm depth at both stations and decreases steadily with depth as is shown in the decrease in standard deviation of the temperatures at progressively greater depths (Table 2).

vi) Standpipe water temperatures

The map showing mean standpipe water temperatures (Fig. 15, Appendix XII) also shows a roughly concentric pattern of isopleths with increasing temperatures from the edge of the bog to the centre. Highest temperatures are found at two adjacent stations south of the centre of the bog. Mean temperature at these stations is approximately 3 to 5 degrees C higher than at the majority of the stations within 20 m of the edge. Temperatures are somewhat lower in a band along the west and southwest edge of the bog than at the northern and eastern edges. Stations 9 and 110, at the northwest and northeast edges respectively, have mean temperatures 3 to 4 degrees lower than nearby stations. Temperatures of the centre pool are more variable and generally higher than temperatures measured in peat (Table 3).

Mean water temperature is significantly lower at the standpipes on the Sphagnum angustifolium lawn (mean = 11.50 degrees C) than at the remaining standpipes (mean = 13.56 degrees C) ($t = -7.50$, $n = 200$, $p < 0.001$). Relationships between water temperatures and various environmental factors are summarized in Table 4. Maximum and minimum water temperatures show a negative correlation with degree of

a) centre station



b) edge station

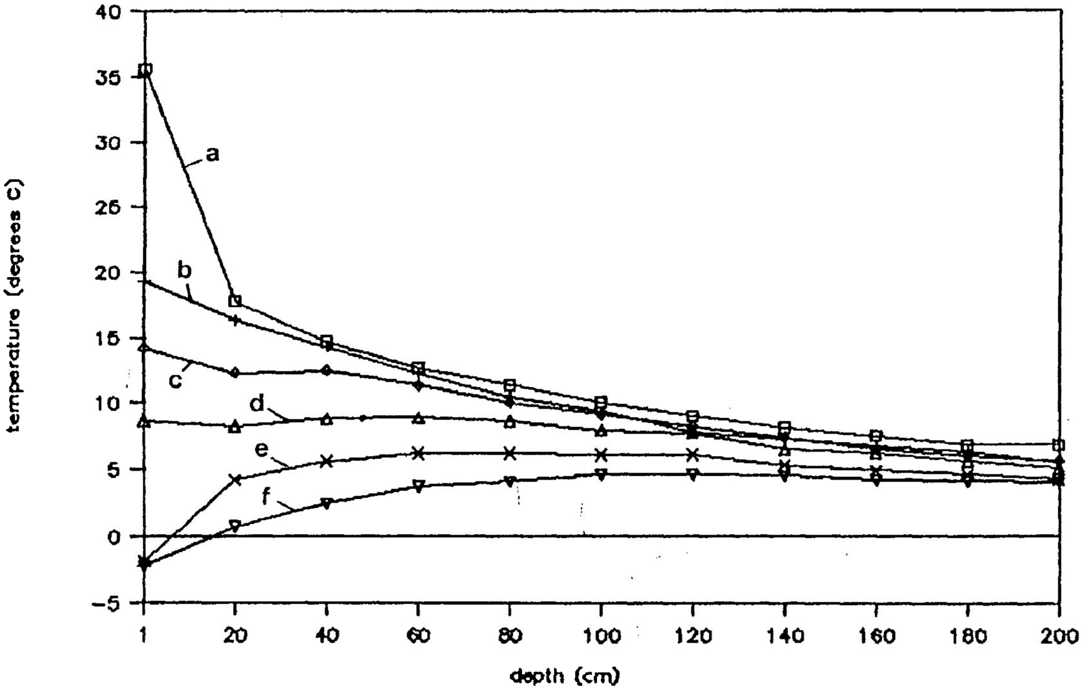


Fig. 14. Variation in peat temperatures with depth as measured by thermocouples on selected dates at centre and edge stations. "a" is July 29, "b" is August 16, "c" is September 06, "d" is September 28, "e" is October 12, and "f" is November 01. Refer to Fig. 5 for locations of stations.

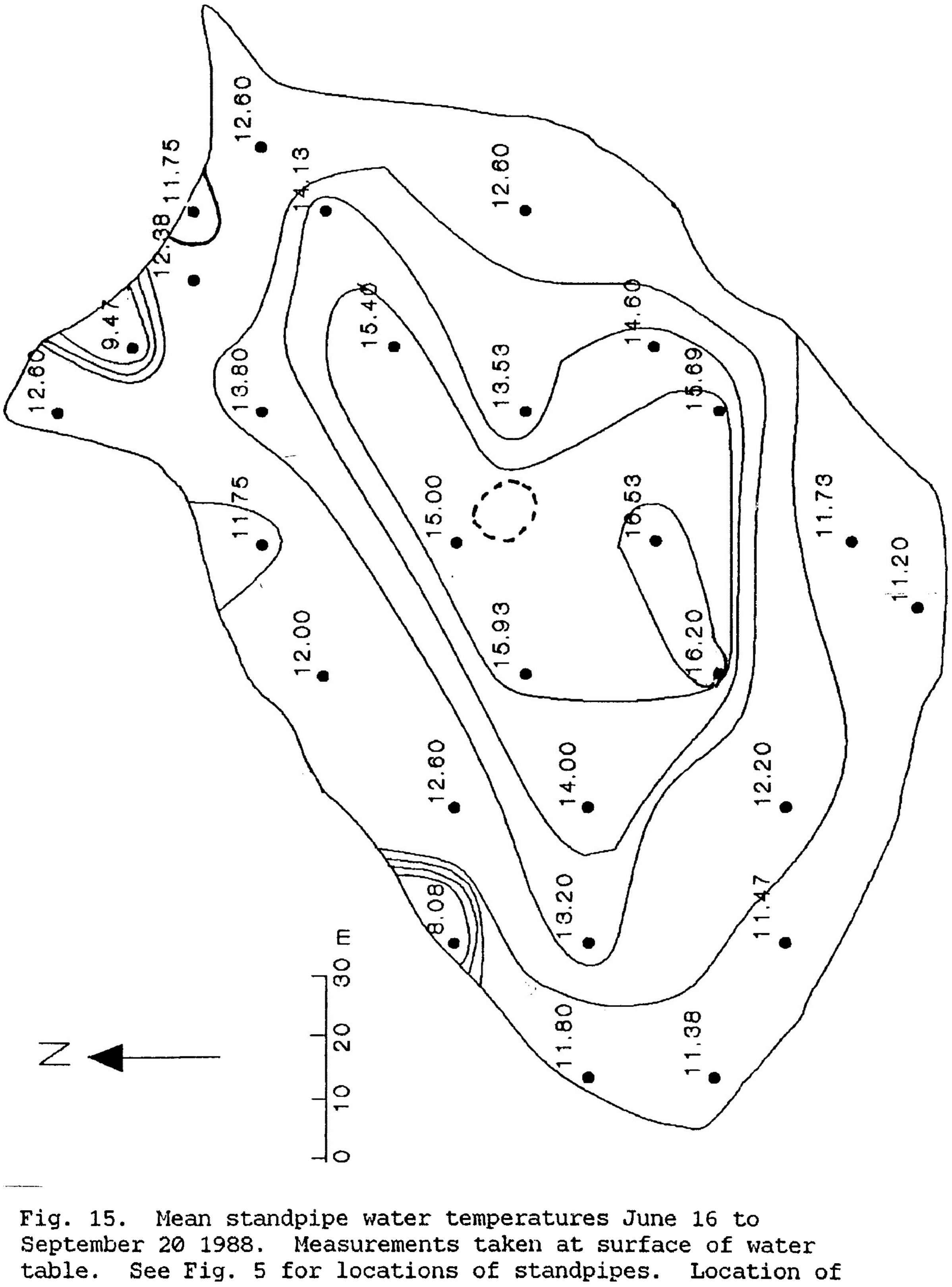


Fig. 15. Mean standpipe water temperatures June 16 to September 20 1988. Measurements taken at surface of water table. See Fig. 5 for locations of standpipes. Location of the centre pool is indicated by dashed line.

Table 3. Mean, maximum, and minimum standpipe temperatures arranged by vegetation zone. Refer to Fig. 5 for locations of stations.

i) S. angustifolium lawn zone

Station no.	mean	max	min	n	std. dev.
1	11.80	14	9	15	1.37
3	11.38	12	10	13	0.87
9	8.08	11	3	13	2.60
11	13.20	15	11	15	1.26
14	11.47	13	9	15	1.36
23	12.60	14	10	15	1.30
40	12.00	15	10	14	1.41
60	11.20	13	8	15	1.42
61	11.75	14	8	12	1.96
70	11.73	14	9	15	1.58
85	12.60	14	11	10	1.17
88	13.80	16	11	15	1.47
mean	11.80				

ii) floating mat zone

Station no.	mean	max	min	n	std. dev.
43	15.93	20	14	15	1.67
64	15.00	17	13	15	1.41
67	16.53	18	15	15	1.19
92	13.52	15	10	15	1.64
mean	15.25				

iii) hummocks and hollows zone

Station no.	mean	max	min	n	std. dev.
25	14.00	15	11	15	1.20
28	12.20	14	10	15	1.15
46	16.20	18	14	15	1.47
95	15.69	18	13	13	1.55
99	9.47	11	7	15	1.55
103	15.40	17	13	15	1.30
107	14.60	17	12	15	1.45
110	12.38	14	10	13	1.12
119	11.75	13	10	12	1.14
121	14.13	16	13	15	1.06
124	12.60	15	10	15	1.30
127	12.60	15	11	15	1.24
mean	13.42				

Table 4. Correlations between maximum and minimum standpipe temperatures and various environmental factors where "r" indicates Pearson correlation coefficient and "n" indicates number of readings. Level of significance of paired *t* -test is indicated "p", where < 0.001 indicates significant difference at p = 0.001 level, < 0.05 indicates significant difference at p = 0.05 level, and "ns" indicates no significant difference at p = 0.05 level.

	maximum temperatures			minimum temperatures		
	r	n	p	r	n	p
shade	-0.66	28	<0.001	-0.69	28	<0.001
SPAN	-0.38	28	<0.05	-0.42	28	<0.05
Shrub	-0.23	28	ns	-0.36	28	<0.05
Edge	0.74	28	<0.001	0.68	28	<0.001

"Shade" is shade code (refer to Fig. 16 for explanation), "SPAN" is *Sphagnum angustifolium* cover, "Shrub" is total shrub cover, "Edge" is distance from the edge.

shading and a positive correlation with distance from the edge. A weaker negative correlation is shown between maximum and minimum temperatures and *S. angustifolium* cover and minimum temperatures with total shrub cover.

b) Solar radiation

Sunrise on June 20 was at 05:55 EST, but the bog was completely shaded until approximately 07:30. Parts of the bog were exposed to direct sunlight between 07:30 and 20:45. A large portion of the centre of the bog was in full sunlight between 10:00 and 18:00 (Fig. 16, Appendix VII). The boundaries of this area are roughly equidistant with the outline of the bog, but come closer to the edge at the southwest. The amount of shading increases toward the edge of the bog in any direction. Stations receiving the least sunlight are those directly beneath trees at the perimeter of the bog.

c) Water factor

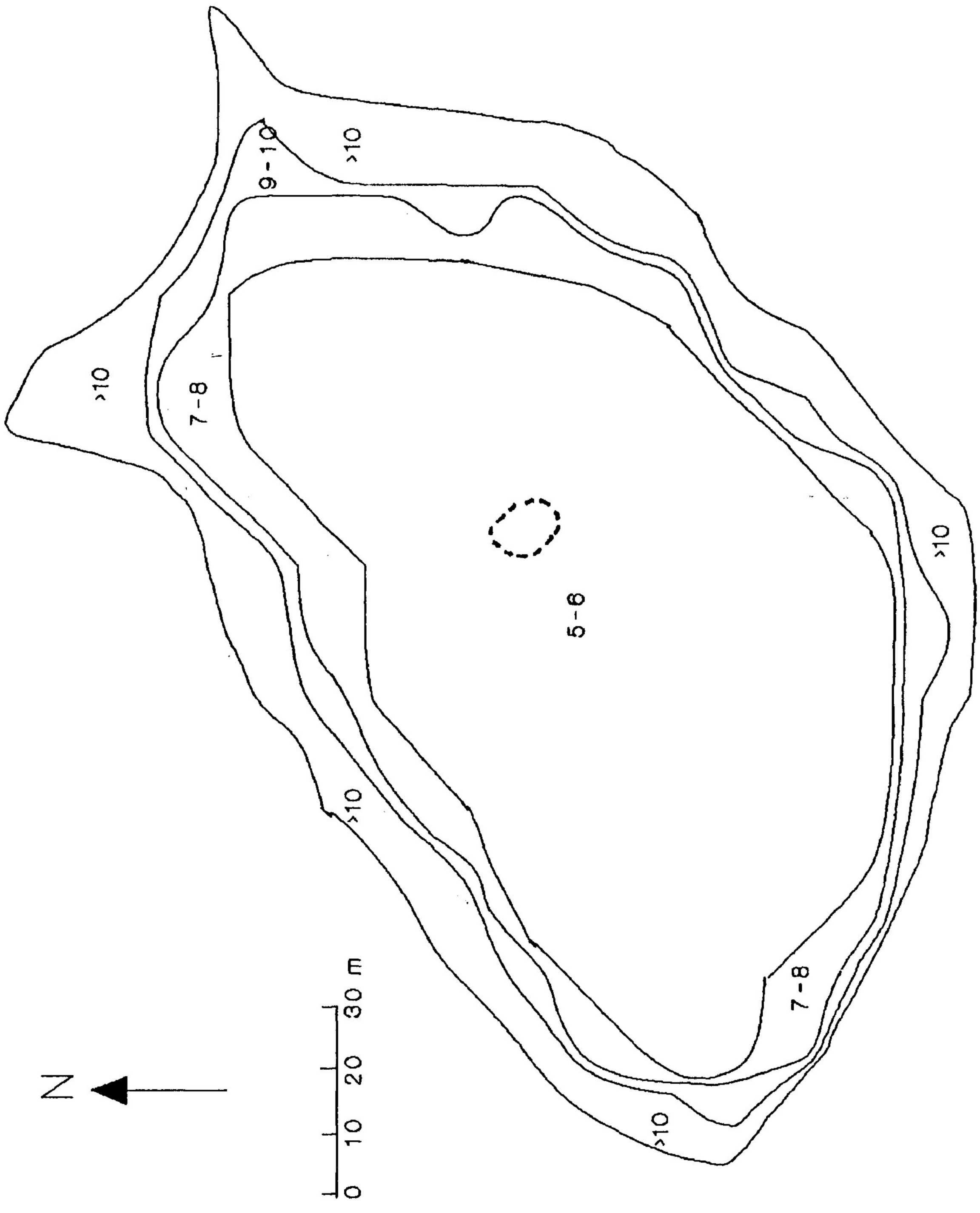
i) Precipitation

Weekly rain measurements are shown in Fig. 17. Both 1987 and 1988 experienced relatively dry conditions in May and June, with rainfall increasing in late July and August. In 1988 May, June, and July, weekly precipitation was consistently less than 25 mm and less than 2 mm on two occasions. August was much wetter; the first two weeks

Fig. 16. Shade code isopleths, June 20 to 23 1988. Numbers shown are the sums of shade codes recorded at 2 hour intervals between 10:00 EDT and 18:00 EDT for each grid square. The following codes were used:

code	% shaded
5	75 - 100 %
4	50 - 75 %
3	25 - 50 %
2	1 - 25 %
1	no shade

Higher numbers indicate greater shading. Location of the centre pool is indicated by dashed line.


>10
9-10
>10
7-8
5-6
>10
>10
7-8
>10
0
10
20
30 m
N

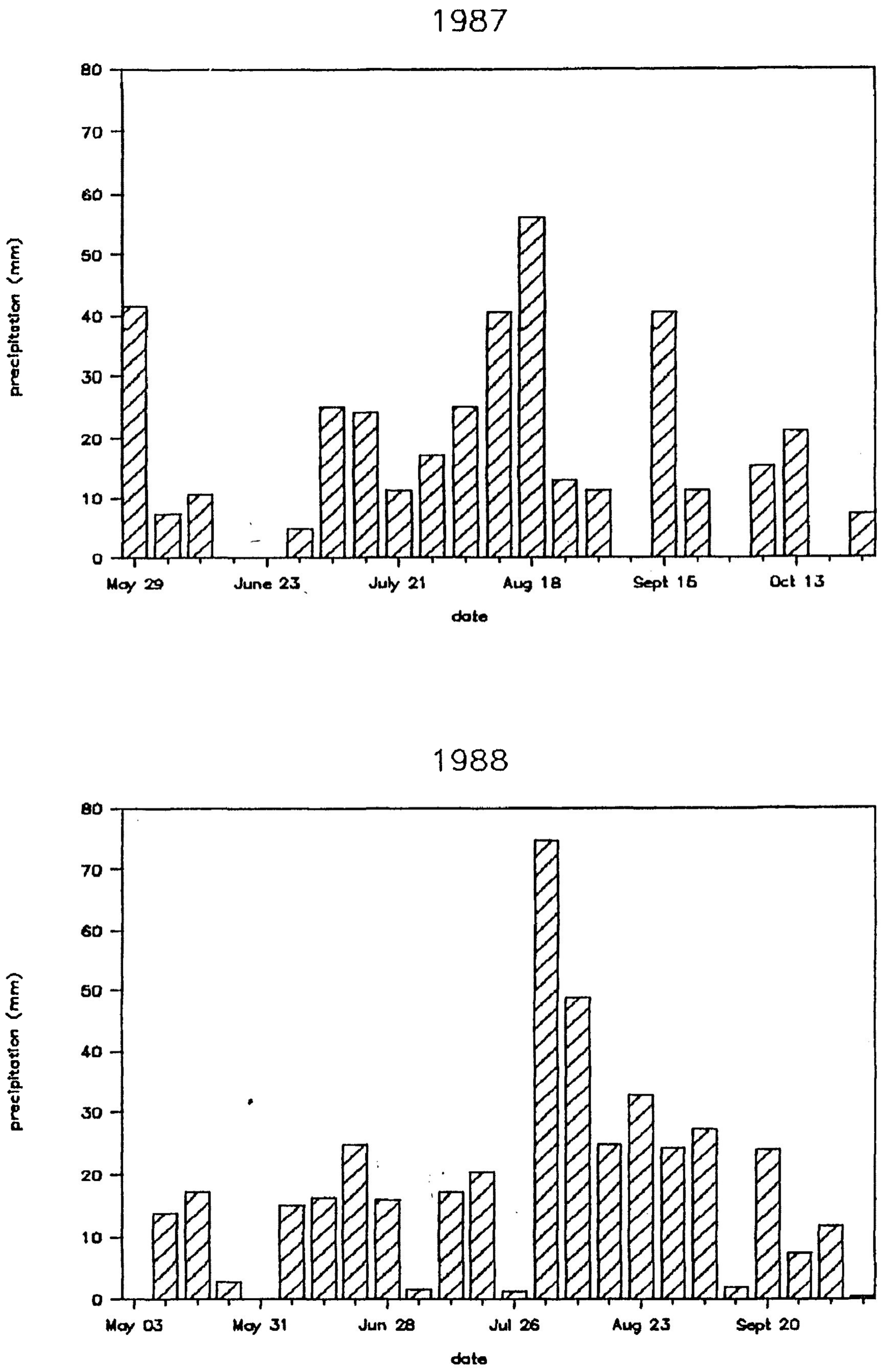


Fig. 17. Weekly precipitation collected in standard British rain gauge, summer 1987 and 1988.

received 74.57 and 48.7 mm. A similar pattern of precipitation was recorded at Thunder Bay airport in 1988, with below-average precipitation in May, June, and July and above average precipitation in August (Fig. 2).

ii) Snow Course

Snow depths increased from December 01 to March 17 then decreased rapidly until April 26 when snow had completely melted from all stations (Fig. 18, Appendix XIII). The bog vegetation was almost entirely covered with snow by approximately mid February. Stations near the north and south ends of the course (85 and 97) had consistently greater snow accumulation than stations closer to the centre of the bog (stations 91 and 95) although there is some variation in the middle section of the transect associated with the distribution of hummocks and hollows (Fig. 19). Snow accumulation was greatest at station 97 at the south end of the course. A maximum depth of 76 cm was recorded at this station on March 15. Snow cover persisted longer at the stations near the edge of the bog than at the centre. By April 12, snow had disappeared from all stations except those located near the north and south edges of the bog where it persisted for approximately another week. Snow depths at the station located in the woods east of the bog showed a similar pattern of accumulation, but were consistently lower. Snow persisted at this station until

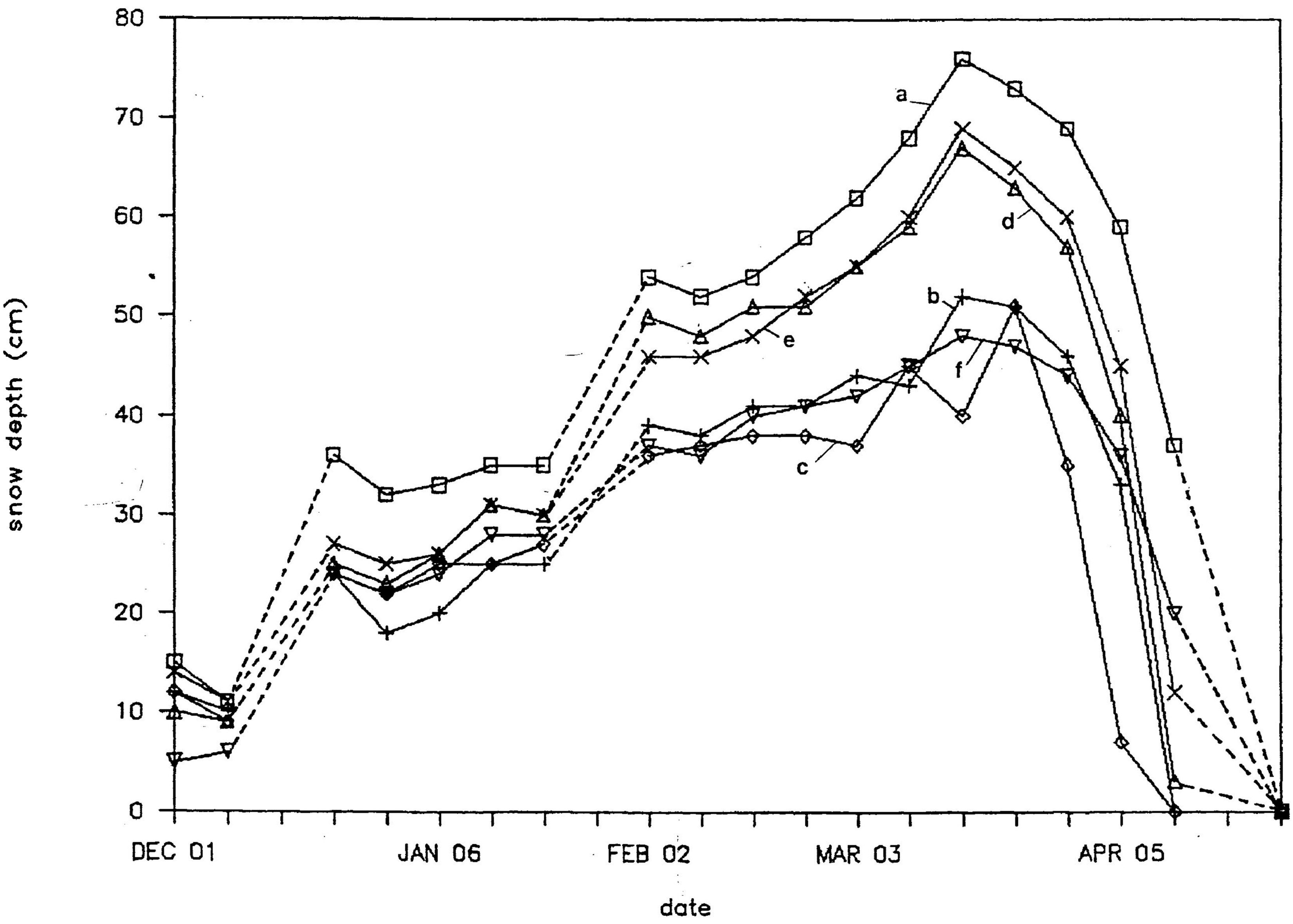


Fig. 18. Changes in snow depth at selected snow course stations, December 1 1987 to April 26 1988. "a" is station 97, "b" is station 95, "c" is station 91, "d" is 87, "e" is station 85, and "f" is the station in the woods. Refer to Fig. 5 for locations of stations.

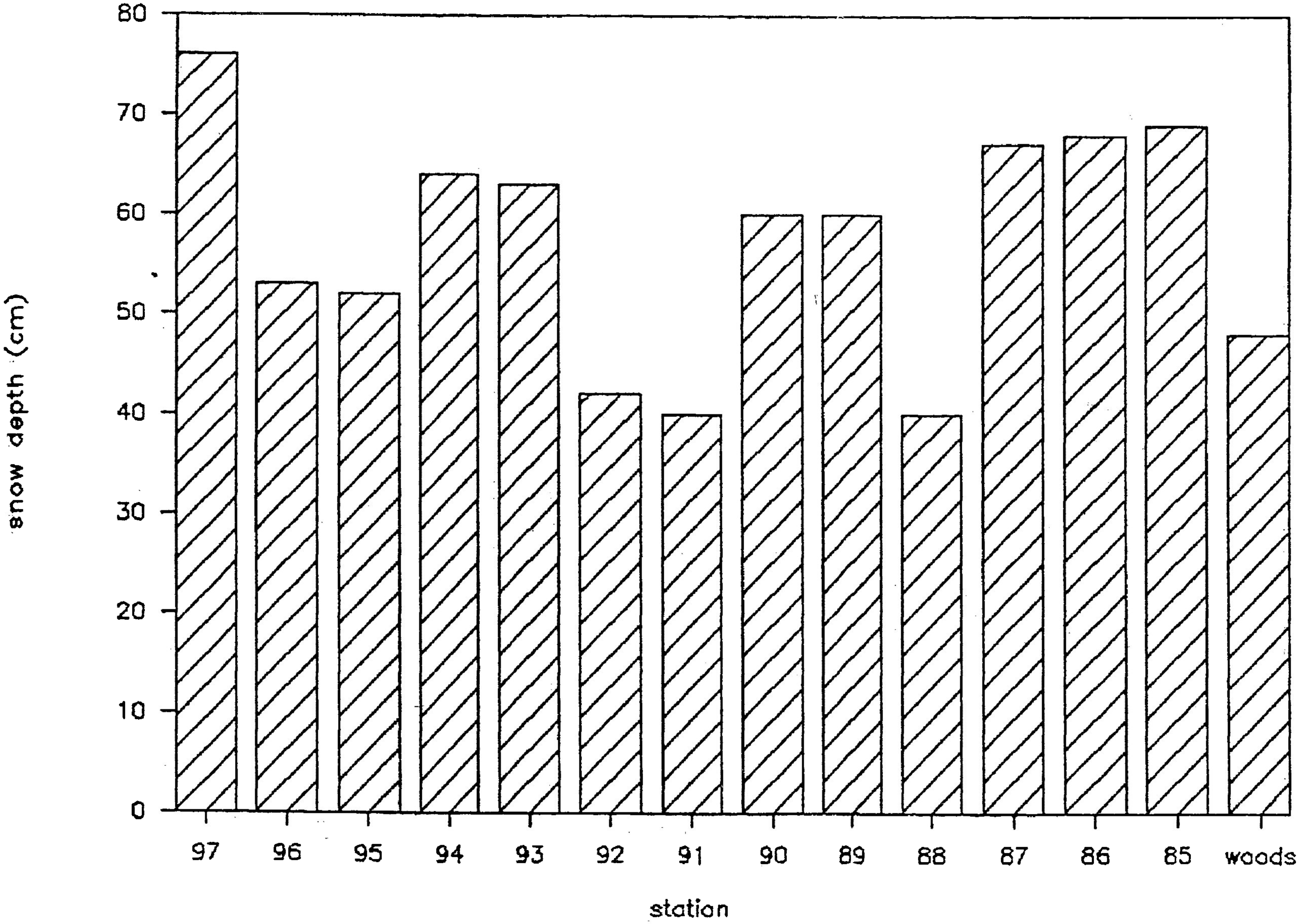


Fig. 19. Snow depths, March 15 1988. Refer to Fig. 5 for locations of stations.

between April 12 and 26.

iii) Relative Humidity

Mean relative humidity is significantly higher at the edge station than the centre station (Table 3, Fig. 20, Appendix XIV). Daily maximum relative humidity usually occurred at night and often reached 80 to 100 %. During the day, relative humidity decreased to 30 to 60 %.

2) Surface Topography

The elevation contour map (Fig. 21, Appendix III) shows a low lying area (height less than 10 cm) originating at the northeast corner and extending approximately 40 m towards the centre of the bog. A second low area is found at the extreme northern tip of the bog separated by a narrow band of higher elevation. Most of the centre portion of the bog has a surface elevation of 10 to 19 cm, but higher hummocks are present. A band of higher elevation, 10 to 30 m wide, is found on the north and south edges of the bog and expands to fill the west end of the basin. The areas of highest elevation are found at the outermost edges of this band and on occasional high *Sphagnum fuscum* hummocks. The surface generally slopes downward from west to east and the height of the surface of the centre pool (frozen at the time of measurement) is approximately 14 cm higher than station 121 near the north east edge of the bog (the lowest point on the bog). The raised edges and low, flat centre are also

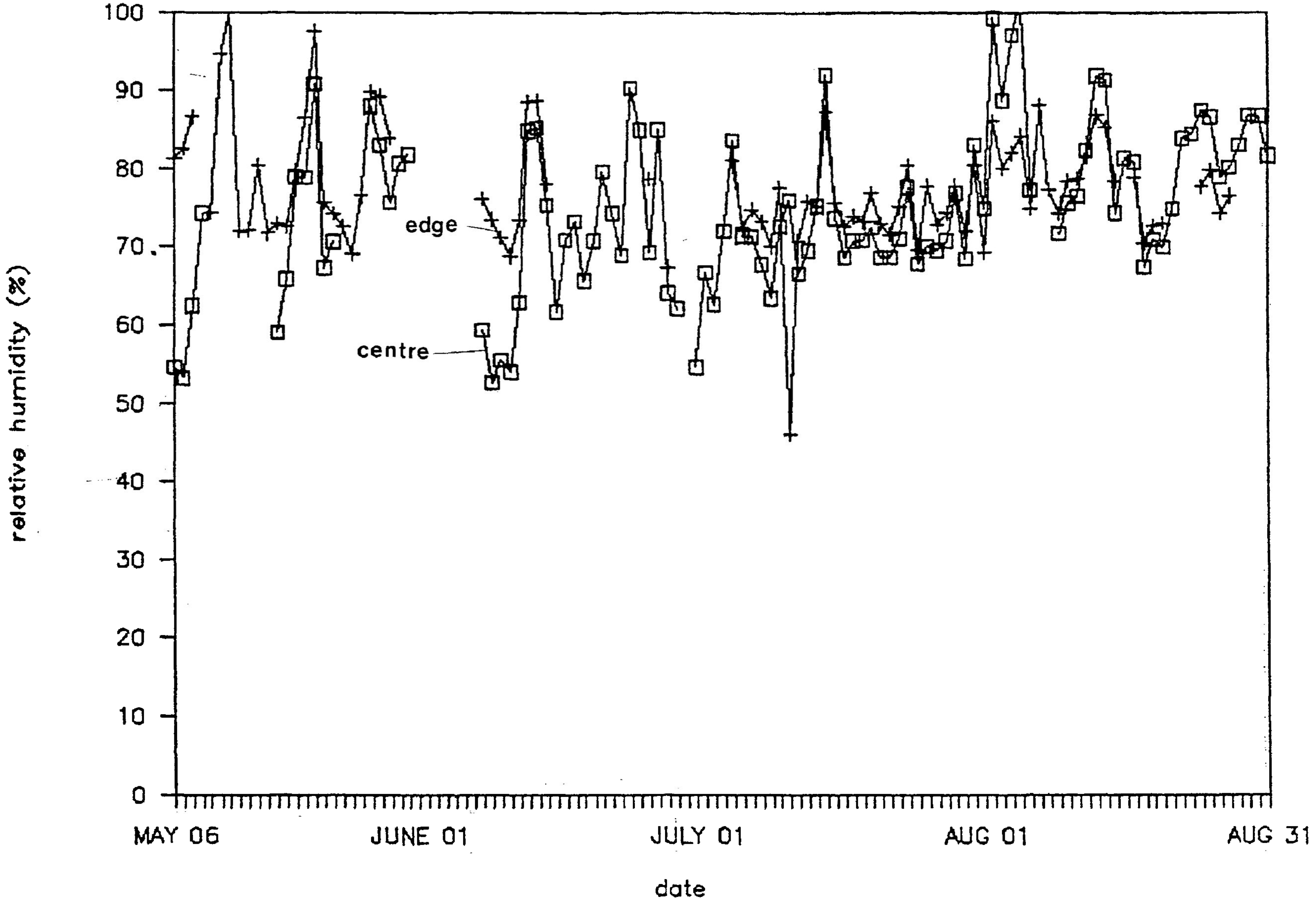


Fig. 20. Mean daily relative humidity at centre and edge stations. Refer to Fig. 5 for locations of stations.

evident in north-south cross-sections across the central portion of the bog (Fig. 21, 22). These sections have a dish-shaped profile with the north and south ends of the line approximately 20 to 30 cm higher than the mid-section. A transect across the west end of the bog does not have the lower central portion. The contour map shows a narrow band of higher elevation (stations 54 to 57, 64, 66) extending from near the south edge of the bog through the central low-lying area toward the centre of the bog. This is not, in fact a continuous raised area, but consists of several distinct hummocks separated by hollows.

The only indication of the presence of a "lagg" zone - a low, wet, minerotrophic zone surrounding the perimeter of many ombrotrophic peatlands (Moore and Bellamy 1974) - is two, small, somewhat depressed areas at the extreme western and southern edges. With the relatively large 10 m sampling interval, it is possible that a narrow, continuous lagg zone was present, but missed because few sampling points happened to fall there.

Surface elevation is positively correlated with *S. angustifolium* cover (r= 0.4899; p=0.004) and total *Sphagnum* cover (r= 0.3496; p=0.034). Elevation shows a weak negative correlation with distance from the edge of the bog (higher elevations near the edge)
(r=-0.3300; p= 0.043).

3) Peat Depths

Peat depth for most of the centre part of the bog is greater than 2.0 m (Fig. 23, 24, Appendix III). This isopleth is roughly equidistant with the perimeter of the bog basin with peat becoming shallower near the edges. At station 54, near the centre of the bog, the peat depth is greater than 5.0 m (measured using Russian corer). Although the maximum depth was greater than the length of the corer, it is probably not much deeper than 5 m, judging from the slope of the bottom of the basin shown in the west-east cross-section. The underlying mineral soil slopes down gradually at the northeast part of the bog, but abruptly at the west edge (Fig. 23, 24).

4) Peat Stratigraphy

The following section describes the peat stratigraphy of Barclay's Bog, beginning with the surface layer and moving downward to the underlying mineral soil. The data is summarized in Table 5 and Fig. 25.

A layer of *Sphagnum* peat of variable depth makes up the surface peat at most stations. At stations 2, 12, and 70 in the *S. angustifolium* lawn, the *Sphagnum* peat is relatively thin (less than 50 cm). Station 86, is outside of the main part of the lawn, but also has a relatively high *S. angustifolium* cover in the present vegetation and has a similar thin layer of *Sphagnum* peat. At station 54, uniform

Fig. 21. Surface elevation contours. Heights are relative to the lowest point on the bog surface (= station 121; indicated by solid dot). Numbers are the upper limit of the contour interval where;

"10" indicates 0 to 10 cm above the lowest point
"20" indicates 11 to 20 cm above the lowest point
"30" indicates 21 to 30 cm above the lowest point
"40" indicates 31 to 40 cm above the lowest point
"40+" indicates more than 40 cm above the lowest point

Location of the centre pool is indicated by dashed line. North - south lines are locations of the profiles shown in Fig. 22. Station numbers at the ends of the north - south lines are indicated.

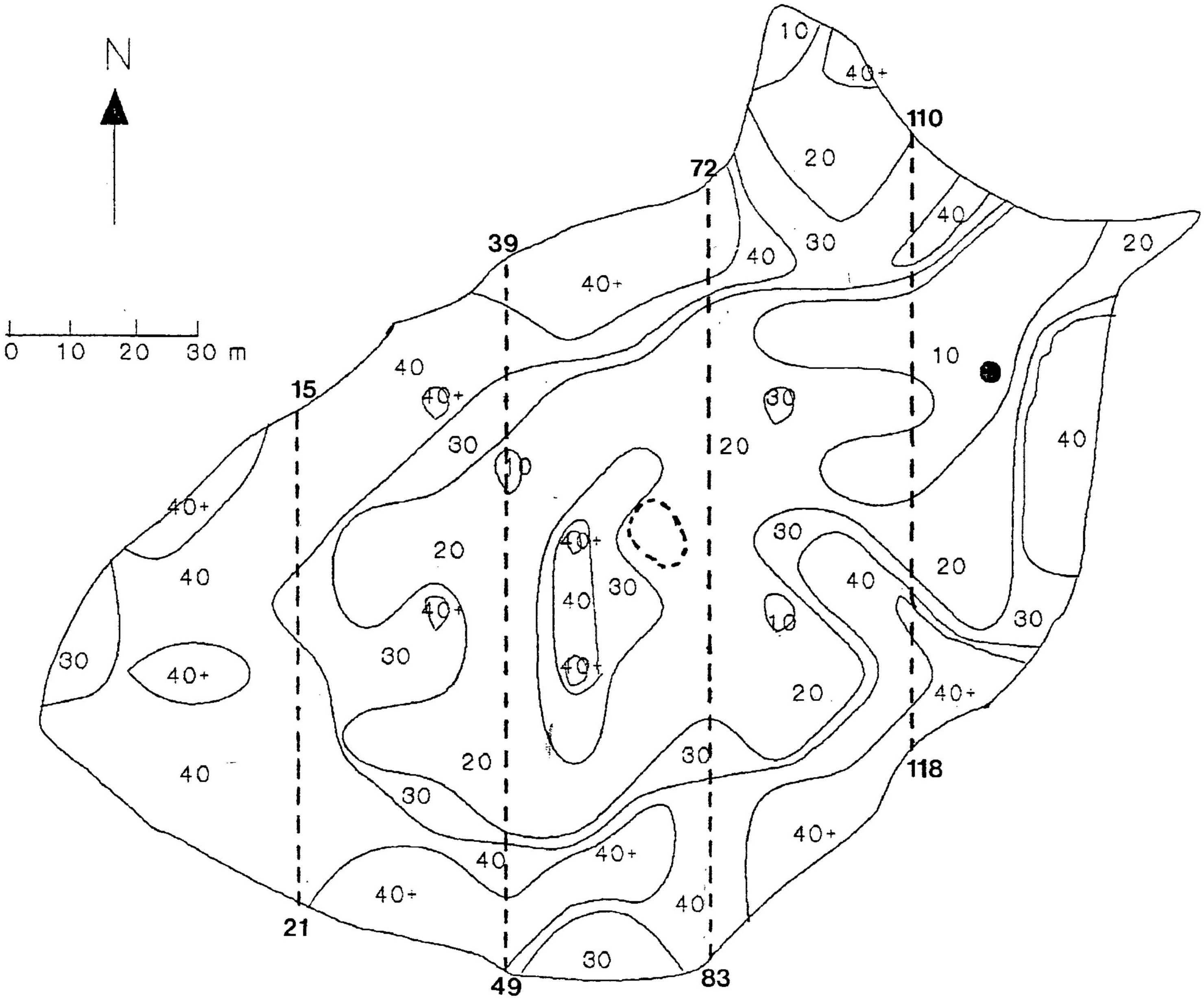
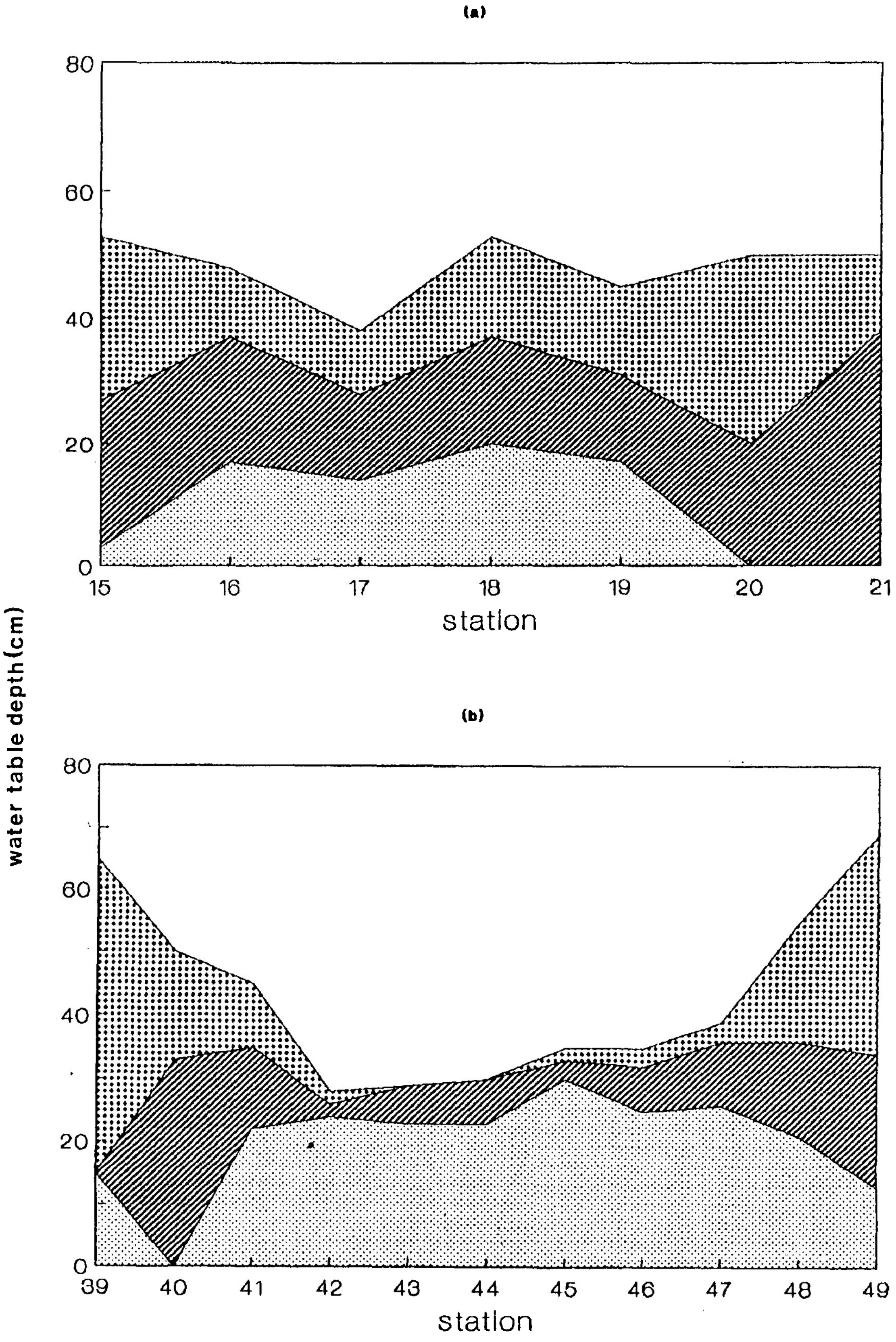
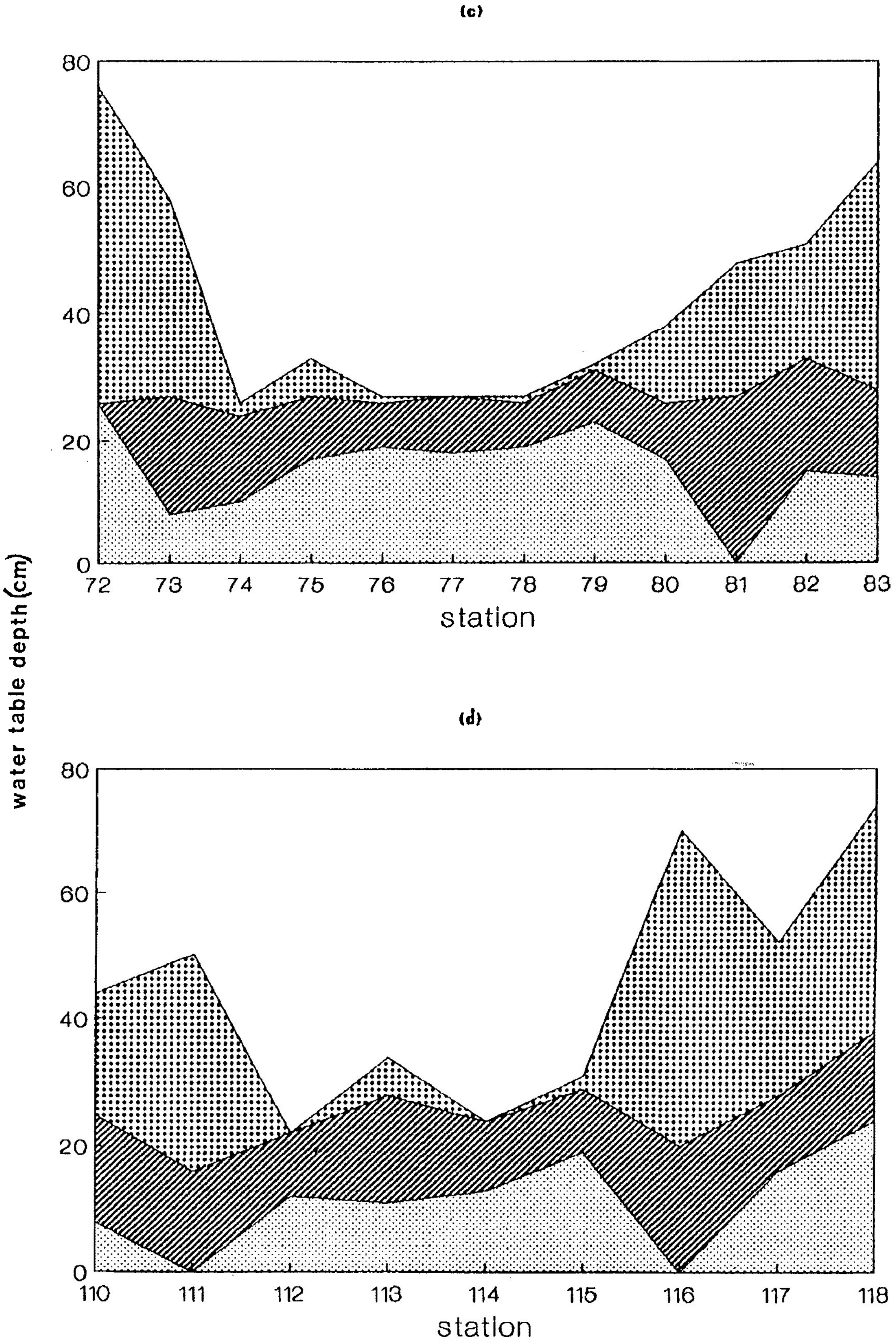

N
0 10 20 30 m
10
40+
110
20
72
40
30
39
40+
40
20
10
15
40+
30
30
10
20
40
40+
40
30
40+
40
40+
40
20
40+
30
40+
30
10
40+
40
20
30
30
40+
30
40+
20
30
118
40
40+
40+
40
40
21
40+
30
49
83

Fig. 22 a - d. North - south cross-sectional profiles of Barclay's Bog showing surface elevation (top line), maximum table depth (middle line), and minimum water table depth (lower line). Also indicated are saturated peat (light stipple), peat above water table (coarse stipple) and zone of water table fluctuation (diagonal hatching). Locations of profiles are shown in Fig. 21. Horizontal axes not to the same scale.


(a)
80
60
40
20
0
15
16
17
18
19
20
21
station
water table depth (cm)
(b)
80
60
40
20
0
39
40
41
42
43
44
45
46
47
48
49
station


(c)
80
60
40
20
0
72
73
74
75
76
77
78
79
80
81
82
83
station
water table depth (cm)
(d)
80
60
40
20
0
110
111
112
113
114
115
116
117
118
station

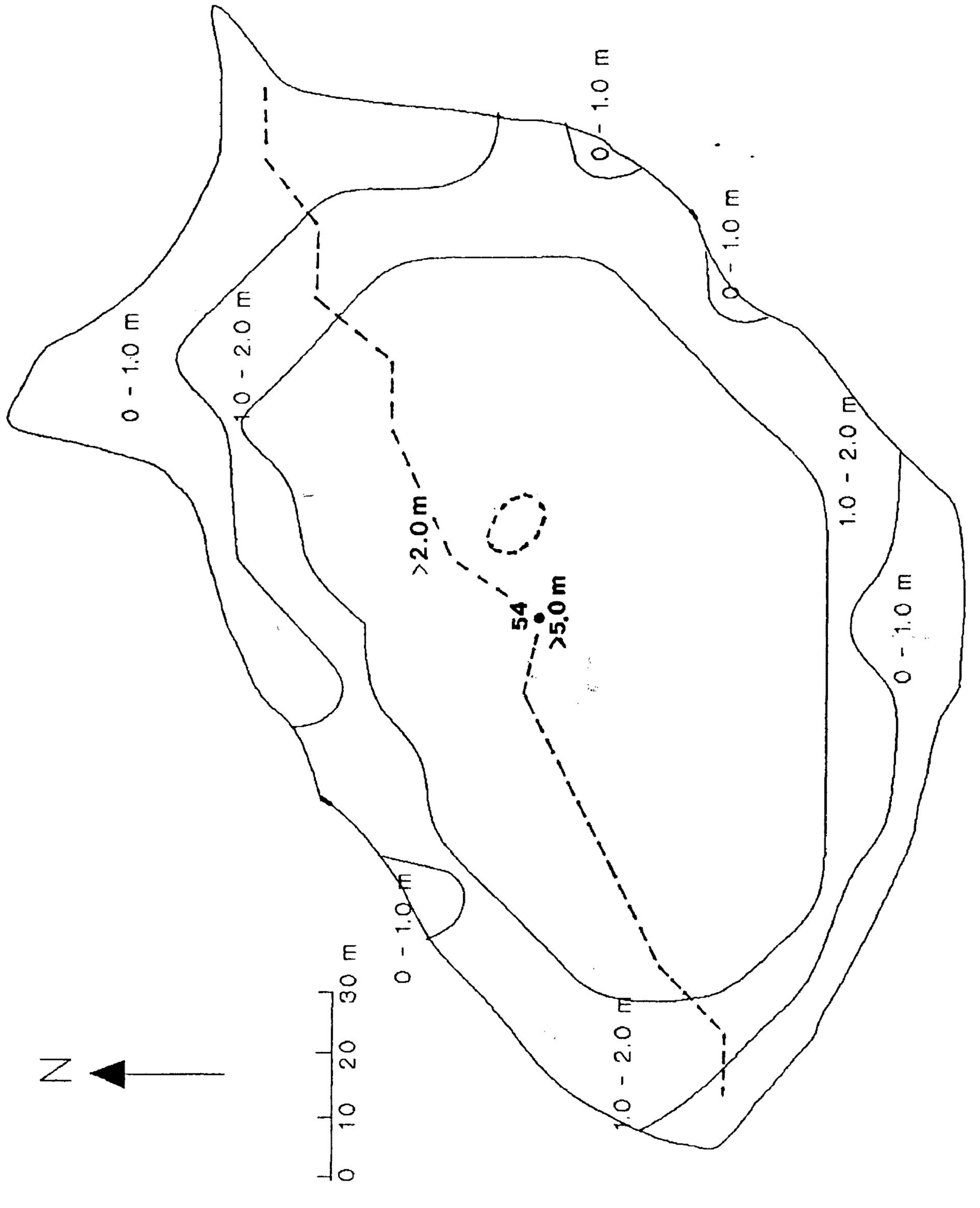


Fig. 23. Peat depth contour map. Station 54 has a depth of greater than 5 m (indicated with a solid dot). Location of the centre pool is indicated by dashed line. The diagonal line is the approximate location of the profile shown in Fig. 24.

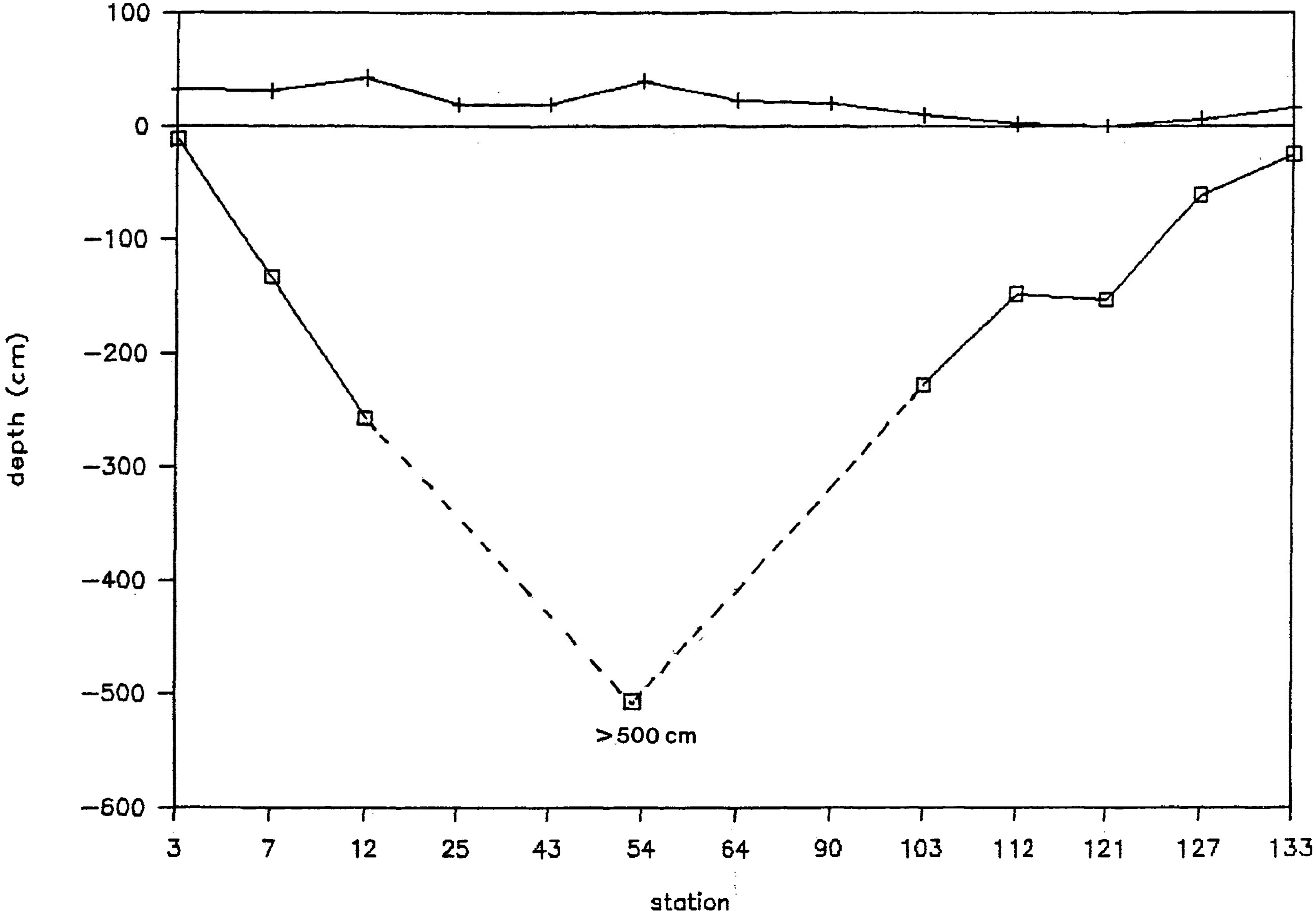


Fig. 24. West - east cross-section of Barclay's Bog showing surface topography and peat depths. See Fig. 23 for approximate location of profile. Depth at station 54 is greater than 5.0 m.

S. fuscum / *S. magellanicum* peat extends to a depth of 269 cm. The present vegetation at this station consists of a *S. fuscum* hummock.

A layer of sedge peat is present at most stations below the *Sphagnum* peat layer and extends to depths of 200cm to 350 cm. At stations 103 and 122, where the present vegetation consists mainly of *Carex limosa*, *Rhynchospora alba*, and other hollow-inhabiting species, the layer of sedge peat begins at the surface and extends to depths of 167 cm and 56 cm respectively before grading into a well-decomposed peat.

A thin, well-decomposed layer of peat within the sedge peat layer was recorded in cores at stations 12, 70, 86, and 103 and a similar layer was found in *Sphagnum* peat at station 54. Although this layer occurs at depths ranging from 8 cm to 269 cm, this peat may have been a continuous layer at the surface if subsequent rates of peat accumulation were variable and therefore may represent a single event in the bog's history.

Stations 2 and 70 at the west and south edges of the bog have a basal layer of woody peat. Twigs and wood chips are occasionally present at various depths in many of the other cores, but do not form a uniform woody layer. Layers containing charcoal were found at station 2 near the west end of the bog (at depths of 70, 75, and 79 cm), station 70 near the south end of the bog (237 cm) and station 122 near

Table 5. Description of peat strata.

Station 2

Surface vegetation: *Sphagnum angustifolium* lawn

Depth	Description
0 - 11 cm	Surface layer of living *Sphagnum* turning into a light brown *Sphagnum* peat at approximately 4 cm. Von Post decomposition 4. Transition to next layer abrupt.
11 - 62 cm	Loose, dark brown sedge peat. Twigs and wood chips present, increasing with depth. Von Post decomposition 3 at 10 to 20 cm , increasing to 6 at 50 to 60 cm. Transition to next layer abrupt.
62 - 89 cm	More compacted, well decomposed peat with twigs throughout. Dark bands containing charcoal at 70 cm, 75 cm and 79 cm. Von Post decomposition 7. Transition to next layer abrupt.
89 - 94 cm	Blackish band consisting of well decomposed peat mixed with coarse sand. Von Post decomposition 7. Transition to next layer abrupt.
94 - 115 cm	Dark brown amorphous peat, similar to the 62 - 89 cm layer, but somewhat more well-decomposed. Von Post decomposition 7 to 8. No sand present. Transition to next layer abrupt.
115 - 117 cm	Dark band of well-decomposed peat mixed with sand. Von Post decomposition 7. Transition to next layer abrupt.
117 - 125 cm	Dark brown amorphous peat with occasional wood chips. Woody remains increasing at 125 cm. Transition to next layer abrupt.
125 cm +	Coarse sand.

Table 5. continued

Station 12

Surface Vegetation: *S. angustifolium* lawn.

Depth	Description
0 - 50 cm	Living *Sphagnum* turning into a light brown *Sphagnum* peat at 4 cm. Woody (ericaceous?) stems present, increasing below 15 cm. Von Post decomposition 1 at 0 to 10 cm, increasing to 3 at 40 to 50 cm. Transition to next layer gradual.
50 - 215 cm	Uniform dark brown sedge peat with occasional woody stem. Von Post decomposition increasing with depth (4 to 7). Transition to next layer abrupt.
215 - 217 cm	Blackish band of well-decomposed amorphous peat. Von Post decomposition 7. Transition to next layer abrupt.
217 - 233 cm	Dark brown sedge peat, similar to 50 - 215 layer. Von Post decomposition 6. Transition to next layer abrupt.
233 - 237 cm	Woody peat with sections of twigs and larger chips. Transition to next layer abrupt.
237 - 262 cm	Loose sedge peat. Von Post decomposition 6 to 7. Transition to next layer abrupt.
262 - 270 cm	Compact, amorphous, dark brown peat. Von Post decomposition 7. Transition to next layer abrupt.
270 - 280 cm	Loose woody peat. Von Post decomposition 7. Transition to next layer gradual.
280 - 291 cm	Compact, well-decomposed sedge peat. Von Post decomposition 9. Transition to next layer gradual.
291 - 300 cm	Amorphous peat mixed with coarse sand and gravel. Transition to next layer gradual.
300 cm +	Coarse sand and gravel.

Table 5. continued

Station 54

Surface vegetation: Large *Sphagnum fuscum* hummock surrounded by hollows.

Depth	Description
0 - 269 cm	Reddish brown *Sphagnum* peat (mostly *S. fuscum*, with some *S. magellanicum*). Woody stems and occasional sedge remains throughout. Almost undecomposed at the surface (Von Post decomposition 2); the degree of decomposition increasing with depth to weakly decomposed at 269 cm (Von Post 4). Layer containing fibrous peat, perhaps *Oxycoccos microcarpus*, at 262 to 268 cm. Transition to next layer abrupt.
269 - 273 cm	Dark brown, well decomposed amorphous peat. Von Post decomposition approximately 7 (sample was lumped with peat from above and below). Transition to next layer abrupt.
273 - 286 cm	Poorly decomposed *Sphagnum* peat with occasional sedge remains and *O. microcarpus* stem. Von Post decomposition 3 to 4. Transition to next layer gradual.
286 - 350 cm	Well-decomposed dark brown sedge peat. Degree of decomposition increasing with depth (von Post decomposition 5 at 290 - 300 cm and 7 to 8 at 340 - 350 cm). Transition to next layer gradual.
350 - 500 cm	Completely decomposed amorphous peat. Von Post decomposition 10. Birch or alder twig at 400 - 410 cm.

Table 5. continued.

Station 70

Surface Vegetation: *S. angustifolium* lawn with *Carex calyculata* and *Carex oligosperma*.

Depth	Description
0 - 15 cm	Living *S. angustifolium* and barely decomposed *Sphagnum* peat mixed with twigs. Von Post decomposition 1 to 2. Transition to next layer gradual.
15 - 146 cm	Dark brown sedge peat with occasional twigs and wood chips, especially at 15 to 100 cm. Von Post decomposition 3 to 5. Reddish-brown sedge layers at 75 - 79 cm and 119 - 122 cm. Transition to next layer abrupt.
146 - 170 cm	Black, mushy, amorphous peat. Von Post decomposition 5. Large chunks of wood at 135 - 139 cm, 155 cm, and 161 - 163 cm. Transition to next layer abrupt.
170 - 173 cm	Reddish-brown fibrous sedge peat. Von Post decomposition 4. Transition to next layer abrupt.
173 - 190 cm	Dark brown amorphous peat, similar to 146 - 170 cm layer. Von Post decomposition 6. Transition to next layer gradual.
190 - 229 cm	Dark brown amorphous peat mixed with sand and gravel; the amount of sand and gravel increasing with depth and becoming finer and grittier at 227 cm. Occasional twigs and wood chips between 200 and 227 cm. Transition to next layer abrupt.
229 - 237 cm	Wood peat with birch (?) bark at 229 cm and a narrow charcoal band at 234 cm. Occasional gravel throughout.
237 cm +	Coarse sand and gravel.

Table 5. continued.

Station 86

Surface Vegetation: *S. angustifolium* and *C. limosa*

Depth	Description
0 - 8 cm	Living *Sphagnum* with almost undecomposed *Sphagnum* peat beginning at 4 cm. Von Post decomposition 2. Transition to next layer gradual.
8 - 16 cm	Light grey amorphous peat mixed with light grey clay. Von Post decomposition 6. Transition to next layer gradual.
16 - 43 cm	Sedge peat. Von Post decomposition 4. Transition to next layer gradual.
43 - 60 cm	Well-decomposed peat mixed with fine sand and clay; the proportion of inorganic material increasing with depth. Von Post decomposition 4 to 6. Transition to next layer gradual.
60 cm +	Fine sand and clay.

Station 103

Surface vegetation: Hollow with *Rhynchspora alba*, *Drosera rotundifolia*, and *Scheuchzeria palustris*.

Depth	Description
0 - 167 cm	Loose sedge peat. Poorly decomposed at the surface (Von Post decomposition 3) becoming more so with depth (Von Post decomposition 5 at 150 -167 cm). Occasional twigs at 100 - 136 cm. Band of reddish-brown fibrous peat at 136 - 144 cm; less well-decomposed than above or below. Transition to next layer abrupt.
167 - 180 cm	Amorphous peat. Von Post decomposition 6. Transition to next layer abrupt.
180 - 183 cm	Fibrous sedge peat. Transition to next layer abrupt.

Table 5. continued.

183 - 200 cm	Amorphous peat, similar to 167 - 180 cm. Wood chip at 190 cm. Von Post decomposition 6. Transition to next layer gradual.
200 - 238 cm	Uniform dark brown mushy peat mixed with sand and gravel. Single wood chips at 202 - 204 cm and 217 - 223 cm. Transition to next layer abrupt.
238 cm +	Sand.

Station 122

Surface Vegetation: Hollow with *C. limosa* and *S. palustris*

Depth	Description
0 - 56 cm	Dark brown sedge peat. Von Post decomposition 3 at surface, increasing to 4 at 50 - 56 cm. Transition to next layer abrupt.
56 - 64 cm	Amorphous peat with black bands containing charcoal at 61 cm and 62.5 cm. Von Post decomposition 6. Transition to next layer abrupt.
64 - 73 cm	Reddish-brown woody peat. Transition to next layer abrupt.
73 - 91 cm	Dark brown sedge peat. Von Post decomposition 4. Transition to next layer abrupt.
91 cm +	Sand.

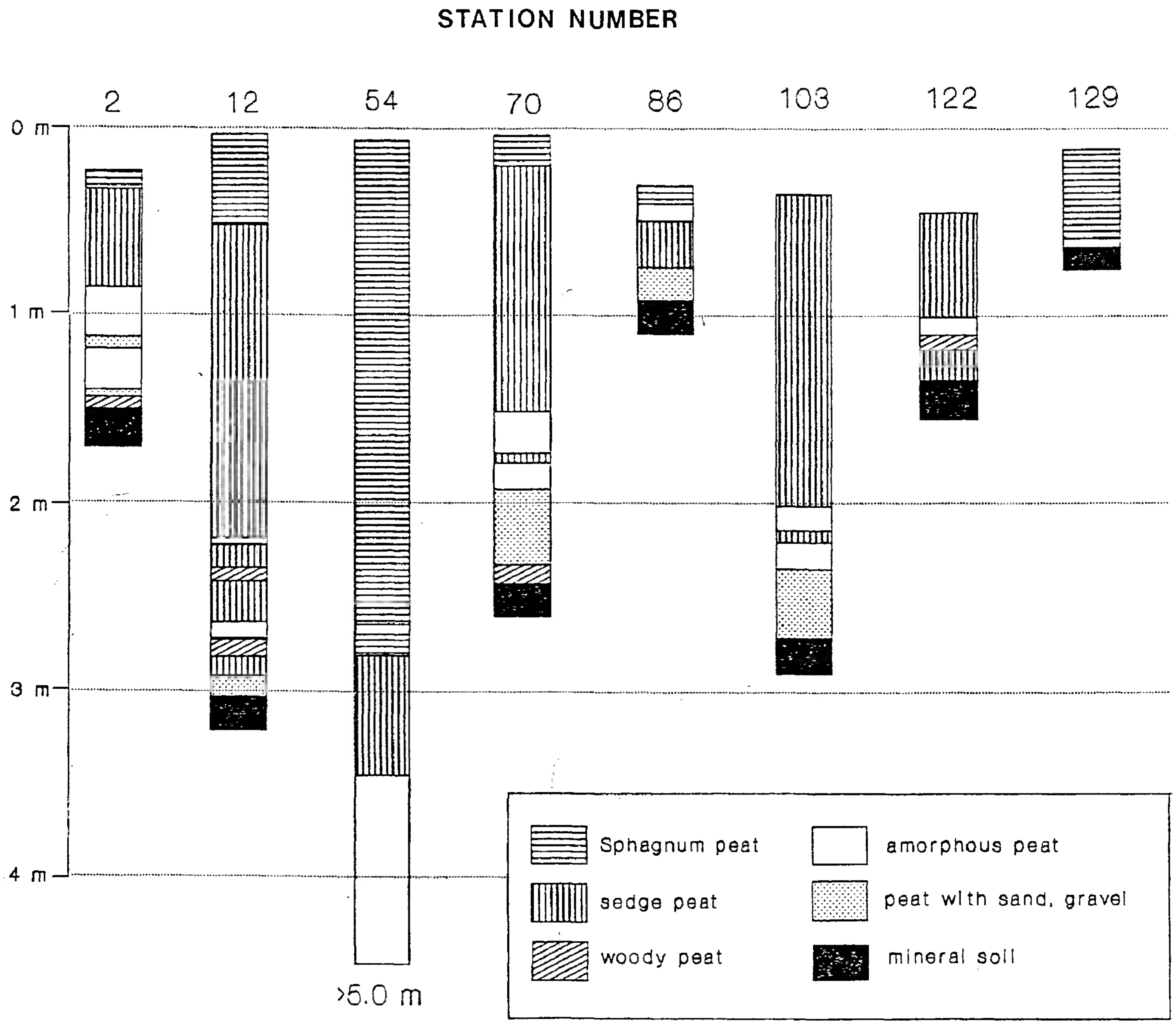
Station 129

Surface Vegetation: *S. angustifolium* lawn.

Depth	Description
0 - 46 cm	Yellowish-brown *Sphagnum* peat, gradually turning into a darker brown *Sphagnum* peat with depth. Von Post decomposition 2 at 0 - 10 cm, increasing to 4 at 40 - 46 cm. Occasional twigs in the lower part of this layer.

	Transition to next layer abrupt.
46 - 50 cm	Fine dark brown gyttja with numerous black bands. Transition to next layer abrupt.
50 cm +	Clay and fine sand.

Fig. 25. Stratigraphy diagrams for peat cores. Positions of tops of cores represent surface elevation with 0 m at the surface elevation of the highest core. See Fig. 5 for locations of cores.


STATION NUMBER
2
12
54
70
86
103
122
129
0 m
1 m
2 m
3 m
4 m
>5.0 m
Sphagnum peat
sedge peat
woody peat
amorphous peat
peat with sand, gravel
mineral soil

the east end of the bog (61 and 62.5 cm). Peat mixed with sand was found below the charcoal at station 2 (89 - 94 cm and 115 - 117 cm). The peat immediately above and below these layers does not contain sand suggesting that periods of sand deposition were separated by a period with no sand deposition.

Gyttja was not noted at the base of most of the cores with the exception of station 129 where 4 cm of gyttja consisting of alternating dark brown and black bands was found at the bottom of the core.

The mineral soil below the peat is a coarse sand mixed with gravel with the exception of stations 86 and 129 where a mixture of fine sand and clay is found. Peat mixed with sand and/or gravel was recorded at the bottom of cores at stations 12, 70, 86, and 103.

5) Soil loss - on - ignition

Maximum loss - on - ignition (LOI) values are approximately 90% in most cores (Table 6). The highest LOI is generally found at a depth ranging from 30 to 200 cm below the surface with lower values above and below. Near the bottom of the cores, LOI decreases as the peat becomes mixed with sand and gravel and the lowest values are usually in the basal layer of peat. Station 122 has a different pattern, with LOI increasing uniformly with depth to a maximum of 91.5% at the bottom (80 - 90 cm). Stations 2,

Table 6. Loss - on - ignition of peat samples collected at various depths.

	Station							
Depth	2	12	54	70	103	122	129	mean
0-10			85.9			76.2	82.0	81.4 (3)
10-20	88.5	87.5	95.9	86.6		79.0	79.5	86.2 (6)
20-30					80.7	75.4	73.7	76.6 (3)
30-40	89.6	93.3				78.3	63.1	81.1 (4)
40-50						83.7	36.2	60.0 (2)
50-60	90.0	90.4	94.5			84.8		89.9 (4)
60-70						86.0		86.0 (1)
70-80	67.0	90.0		92.4	85.2	85.9		84.1 (5)
80-90						91.5		91.5 (1)
90-100	26.3	91.9						59.1 (2)
100-110			96.1	89.2				92.7 (2)
110-120	74.5	86.4			90.1			83.7 (3)
120-130				91.1				91.1 (1)
130-140		89.4		93.3	93.0			91.9 (3)
140-150				73.7	86.0			79.9 (2)
150-160		92.0	93.2					92.6 (2)
160-170				78.3	70.8			74.6 (2)
170-180		93.7		90.3				92.0 (2)
180-190				54.3				54.3 (1)
190-200		84.2			33.5			58.9 (2)
200-210			96.6	43.3				70.0 (2)
210-220		52.4			20.8			36.6 (2)
220-230								-
230-240		90.5		25.9				58.2 (2)
240-250								-
250-260		85.0						85.0 (1)
260-270								-
270-280		91.8						91.8 (1)
280-290								-
290-300		3.9						3.9 (1)
300-310			81.0					81.0 (1)
310-320								-
320-330								-
330-340								-
340-350								-
350-360			69.8					69.8 (1)
.								
.								
.								
450-460			61.1					61.1 (1)
460-470								-
470-480								-
480-490								-
490-500			71.9					71.9 (1)
mean	72.7	81.5	84.6	74.4	70.0	82.3	66.9	74.6
n	6	15	10	11	8	9	5	64

12, and 70, have relatively constant LOI values in the upper layers, followed by a layer with anomolously high LOI values ranging in depth from 210 - 220 cm at station 12 to 146 - 150 cm at station 70. This layer corresponds to a well-decomposed layer of peat (described above). At station 2, the layer of low LOI corresponds to a layer of peat mixed with sand.

LOI tends to be higher in the surface peat in cores collected at the west end of the bog (2, 12, 70, 54) than those near the northeast edge of the bog (103, 122, 129) (see Fig. 5 for locations of stations). The highest values were found in a *S. fuscum* hummock at station 54.

6) Hydrology

a) Water table depths

Water table depth isopleths closely follow the surface topography (Fig. 21, 26, Appendix IV). The water table tends to be deepest near the north and south edges where the surface elevation is the greatest and shallowest at the central floating mat where the surface elevation is low. A shallow water table at several points at the extreme western and southern edges of the bog suggest that a lagg zone is present. North-south transects show that the water table is relatively flat when corrected for variation in surface elevation and does not follow the contours of hummocks (Fig. 22). Fluctuation of the water table relative

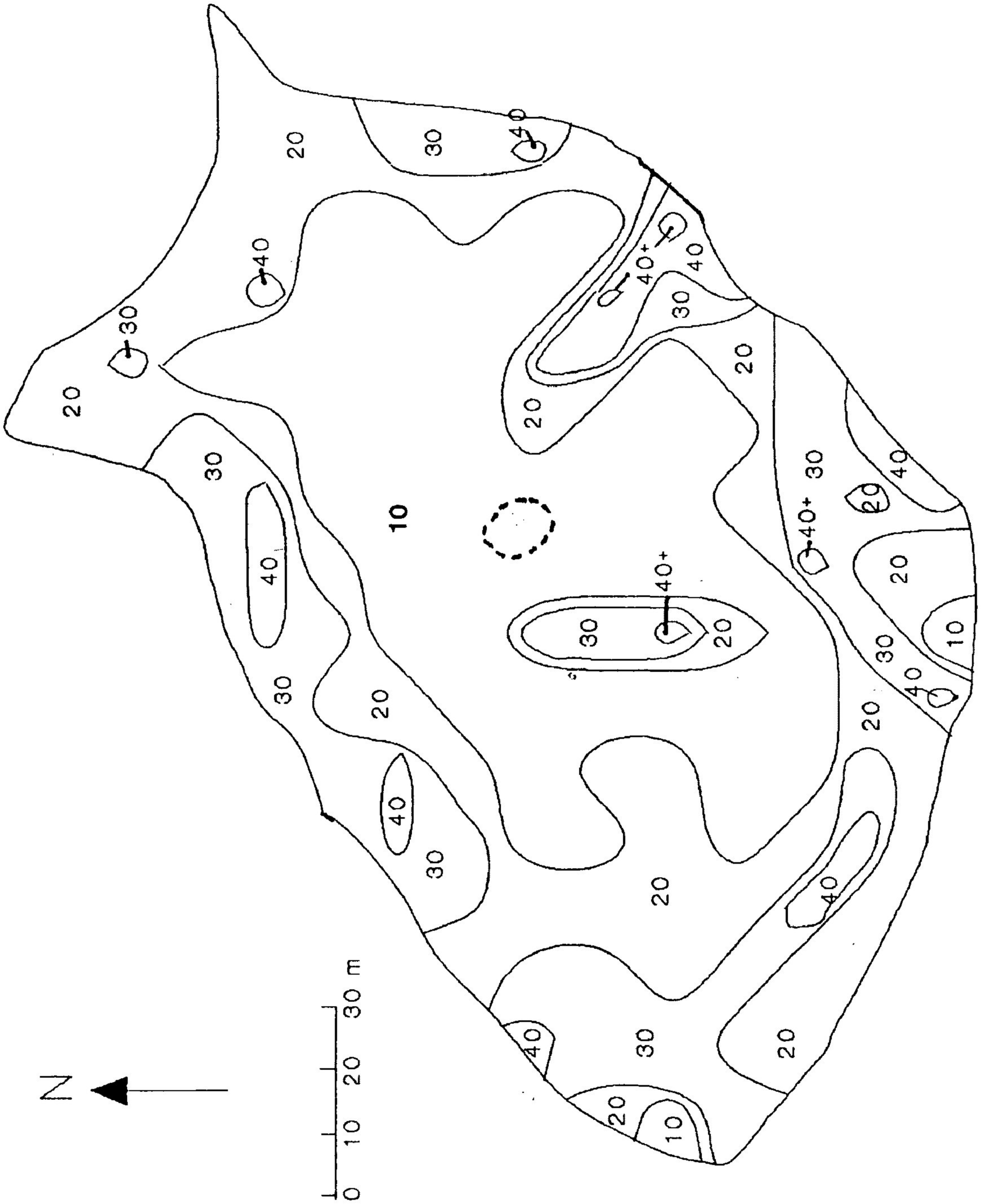


Fig. 26. Minimum water table depth, June 16 to August 18 1987. Numbers are the upper limit of the contour interval where; 10 indicates 0 to 10 cm below the surface

20 indicates 11 to 20 cm below the surface
30 indicates 21 to 30 cm below the surface
40 indicates 31 to 40 cm below the surface
40+ indicates greater than 40 cm below the surface

Location of the centre pool is indicated by dashed line.

to the surface of the peat is smaller at stations near the centre of the bog than at stations near the edges (Fig. 22).

Water table was closest to the surface at most stations on August 18 1987. A total of 122.23 mm of rain fell in the three weeks following the previous reading on July 28 1987 which raised the mean water table by 10.1 cm.

b) Surface elevation fluctuation

The stations can be separated into two broad groups: those showing a relatively large degree of surface elevation fluctuation and those showing little or no fluctuation. The stations falling in the first category include stations H,I,J, and to a lesser extent, K (Fig. 8, 27, Appendix V). These stations are referred to as "floating mat stations". Stations B to G are in the second category. These stations are situated on hummocks and in the case of station B, at the *S. angustifolium* lawn at the west end of the bog and are referred to as "hummock and lawn stations".

A prolonged dry period during the spring and early summer of 1988 resulted in a drop in the elevation of the floating mat in the period between June 9 and July 26 during which only 97.4 mm of rain fell. The elevation of floating mat stations dropped between 2 cm (stations J and K) and 8 cm (station I). Hummock and lawn stations dropped by only 1 cm (stations C,D and G), showed no change (stations B and E), or showed an increase in elevation of 1 cm (station F).

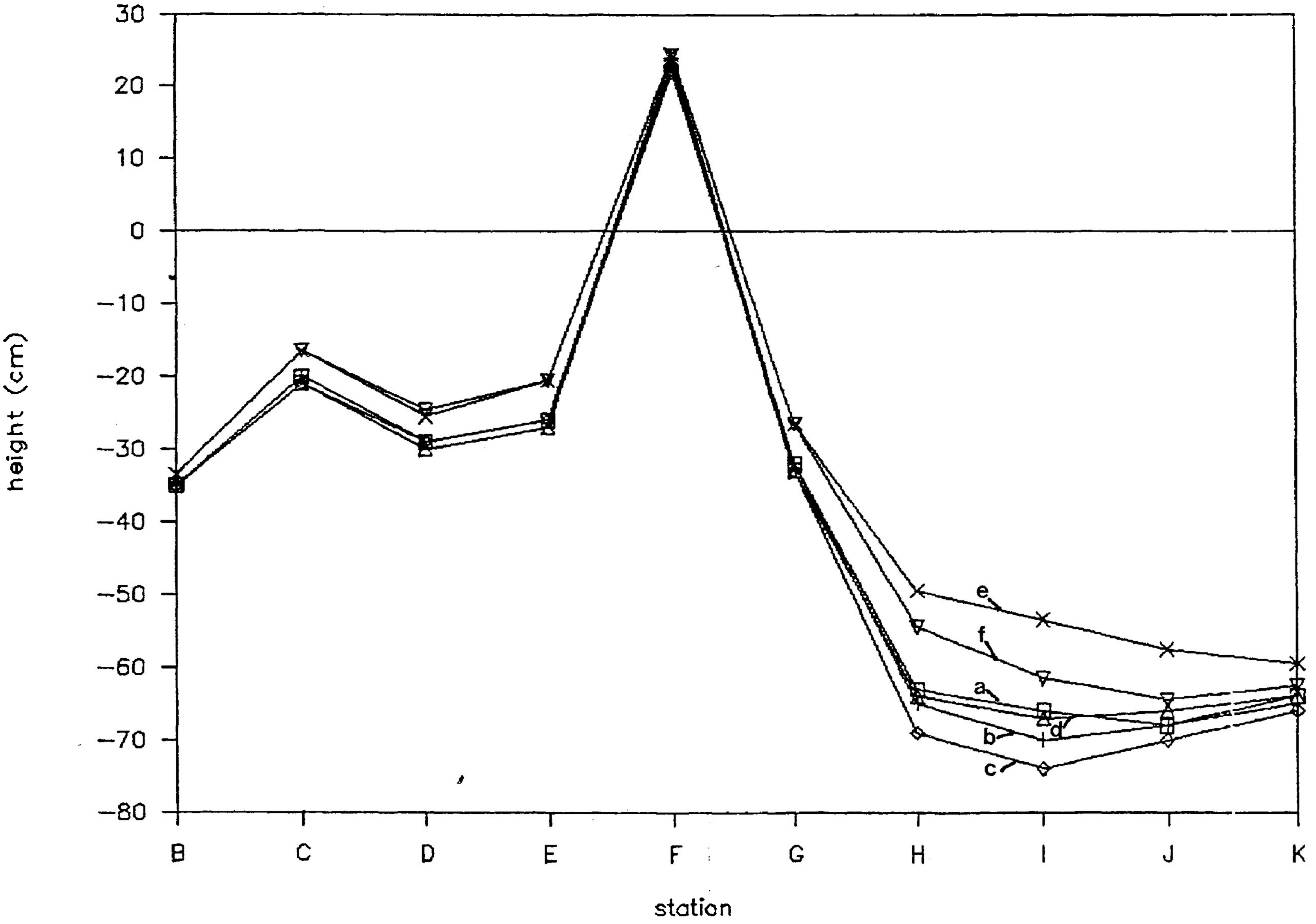


Fig. 27. Fluctuations in surface elevation at various positions on the bog at selected dates, 1988, where "a" is June 09, "b" is July 05, "c" is July 26, "d" is August 02, "e" is September 06 and "f" is November 01. See Fig. 7 for locations of stations.

A total of 123.5 mm of rain fell in the next 24 days between July 26 and August 09 1988 and the surface of the floating mat rose 9 cm at station J and 14 cm at station H. Hummock and lawn stations increased only by an average of 1 cm. Surface elevations remained high after August 09. The maximum elevations for the study period at the floating mat stations were recorded on August 30 or September 06 1988.

7) Water chemistry

a) Bog water pH

i) Spatial variation

Mean pH is highest at stations near the extreme northern tip of the bog and becomes progressively lower toward the centre (Fig. 28 a, Appendix XV). The lowest pH values (pH 3.90 to 4.09) are found in a narrow, C-shaped band that is equidistant with the edge of the bog along the north, south and west margins, but is separated from the edge by stations with slightly higher pH. The map of mean hydrogen ion isopleths (Fig. 28 b) shows a similar pattern as the pH map, but has a greater number of intervals in the more acidic areas and fewer in the less acidic areas. This difference is to be expected given the logarithmic nature of the pH scale. It follows that hydrogen ion concentration is a better indicator of the chemical gradient that is present in the bog waters than is pH. Nonetheless, pH values are more widely reported in the literature, and for the sake of comparison will be used in this discussion. The pH isopleths serve equally well as hydrogen ion concentrations to identify points of groundwater inflow.

The map showing minimum pH values (Fig. 29 b) has a similar pattern of isopleths as the mean pH map (Fig. 28 a), but with most stations in lower pH intervals. The map of maximum pH (Fig. 29 a) is also similar to the mean pH map, with highest values recorded at the northern tip and progressively lower values towards the centre, but the c-shaped band of low pH values does not appear. Maximum and minimum pH data and dates that these values were recorded are presented in Table 7.

Significantly lower mean pH is found at the stations situated in the *S. angustifolium* lawn than at the other stations ($p < 0.001$; $t = -7.34$) (Table 8). pH shows a negative correlation with *S. angustifolium* cover as well as total *Sphagnum* cover (Table 9).

Mineral soil stations (m1 to m5) have generally higher pH values than bog water stations, although only a few weeks data was available for these stations (Table 7).

ii) Seasonal variation

Relatively high mean pH values (4.33 to 4.51) were recorded between June 16 and July 28. Low water levels up to and including July 28 resulted in no readings being taken at some of the stations where the water table is deep. A

Table 7. Mean, maximum, and minimum water pH values recorded at standpipes and at centre pool, June 16 to September 20 1988. Date of occurrence of maximum and minimum pH are indicated. Locations of stations are shown in Fig. 5.

Stn	Mean (n)	Maximum	Minimum
1	4.11 (13)	4.58 (Jul 07)	3.93 (Sep 01)
3	4.14 (10)	4.39 (Jul 15)	3.98 (Aug 04)
9	4.25 (13)	4.58 (Jul 28)	4.02 (Sep 01)
11	3.96 (15)	4.25 (Jul 22)	3.73 (Aug 04)
14	3.91 (11)	4.02 (Sep 13)	3.76 (Aug 04)
23	4.01 (15)	4.34 (Jul 07)	3.76 (Sep 01)
25	4.23 (15)	4.34 (Sep 13)	4.10 (Aug 04,Sep 01)
28	4.04 (15)	4.24 (Jul 22)	3.88 (Sep 01)
40	4.02 (11)	4.41 (Jun 16)	3.81 (Sep 01)
43	4.29 (15)	4.44 (Jun 16,Jul 07)	4.15 (Aug 11)
46	4.18 (15)	4.29 (Jul 07,Jul 28)	4.02 (Sep 01)
60	4.24 (15)	4.68 (Jul 07)	4.07 (Aug 04)
61	3.94 (8)	4.09 (Sep 20)	3.83 (Aug 11)
64	4.14 (15)	4.31 (Jul 28)	4.02 (Aug 04)
67	4.32 (15)	4.51 (Jun 16,Jul 22)	4.14 (Aug 11)
70	3.96 (15)	4.36 (Jun 16)	3.71 (Aug 11)
85	5.15 (8)	5.38 (Sep 01)	4.90 (Aug 11)
88	4.92 (15)	5.11 (Jul 15)	4.75 (Jun 30)
92	4.39 (14)	4.69 (Sep 13)	4.19 (Aug 04)
95	4.06 (13)	4.32 (Jul 07)	3.88 (Sep 01)
99	4.80 (15)	5.82 (Jul 28)	4.54 (Aug 04)
103	4.73 (15)	4.85 (Aug 11)	4.64 (Sep 01)
107	4.28 (15)	4.41 (Jul 07,Jul 22)	4.10 (Aug 04)
110	4.61 (11)	4.89 (Jul 07)	4.46 (Aug 11)
119	4.31 (11)	5.09 (Jul 15)	4.14 (Aug 11)
121	4.83 (15)	5.04 (Jun 16)	4.66 (Aug 11)
124	4.41 (15)	4.58 (Jul 15)	4.30 (Aug 04)
127	4.71 (15)	4.94 (Sep 13)	4.53 (Aug 11)
pool	4.39 (15)	4.48 (Aug 18)	4.24 (Jul 07)
m1	4.51 (5)	4.95 (Sep 20)	4.37 (Aug 25)
m2	4.88 (8)	5.16 (Aug 11)	4.59 (Aug 04)
m3	5.73 (4)	5.76 (Aug 18,Sep 01)	5.67 (Aug 25)
m4	5.31 (8)	5.62 (Sep 01)	5.11 (Aug 11)
m5	5.21 (4)	5.82 (Sep 09)	5.03 (Sep 01)

Fig. 28 a. Map showing mean pH isopleths of water samples collected June 16 to September 20 1988. Contour intervals (in pH units) are:

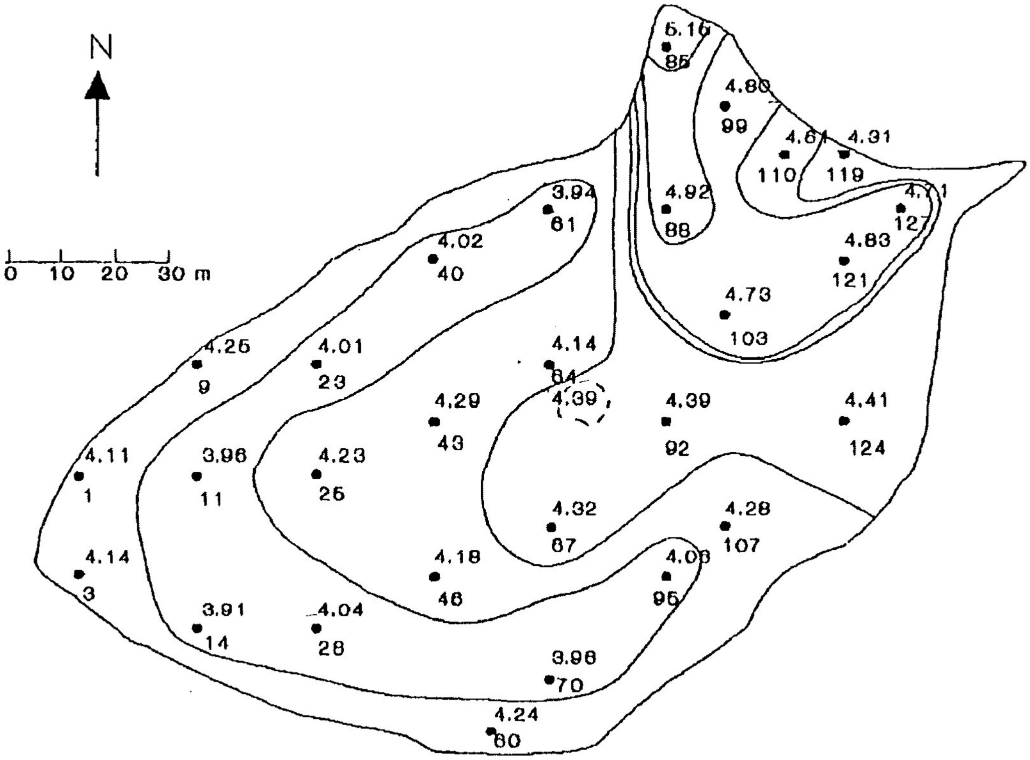
3.91 - 4.10
4.11 - 4.30
4.31 - 4.50
4.51 - 4.70
4.71 - 4.90
4.91 - 5.10
5.11 - 5.30

Fig. 28 b. Map showing mean hydrogen ion concentration isopleths of water samples collected June 16 to September 20 1988 expressed in moles/litre x 10000. Contour intervals (x 10^5 moles/litre) are:

0.00 - 0.20
0.21 - 0.40
0.41 - 0.60
0.61 - 0.80
0.81 - 1.00
1.01 - 1.20
1.21 - 1.40

Location of centre pool indicated by dashed line, station numbers are given beneath pH or hydrogen ion concentration.

a) pH



b) hydrogen ion concentration x 10000

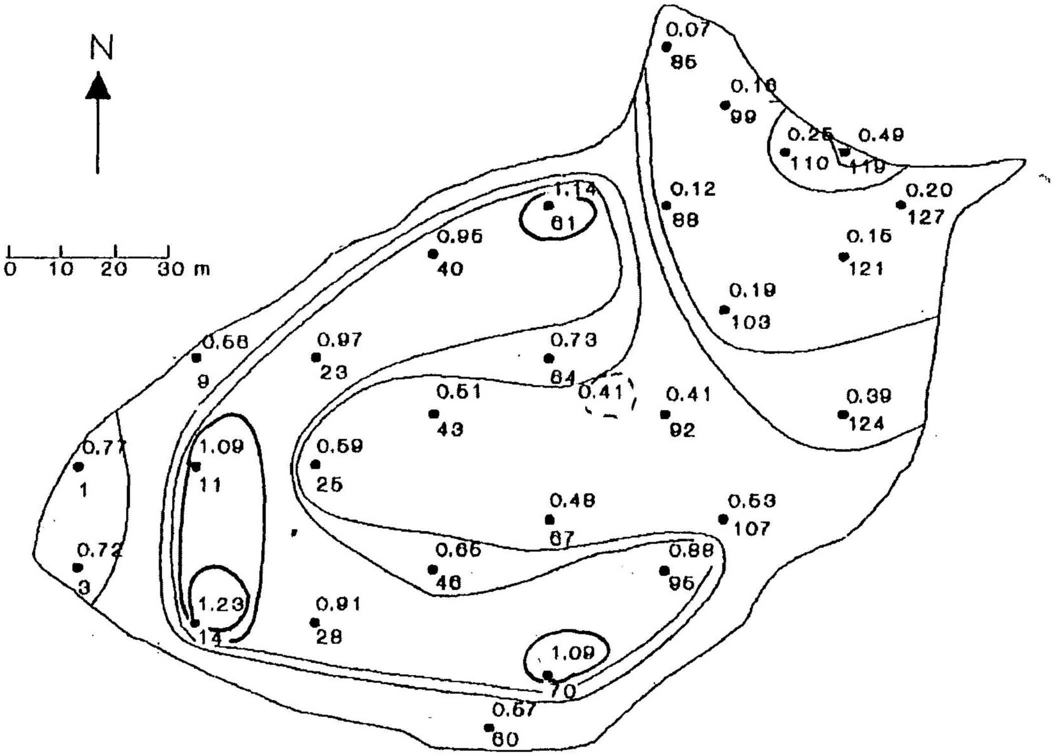
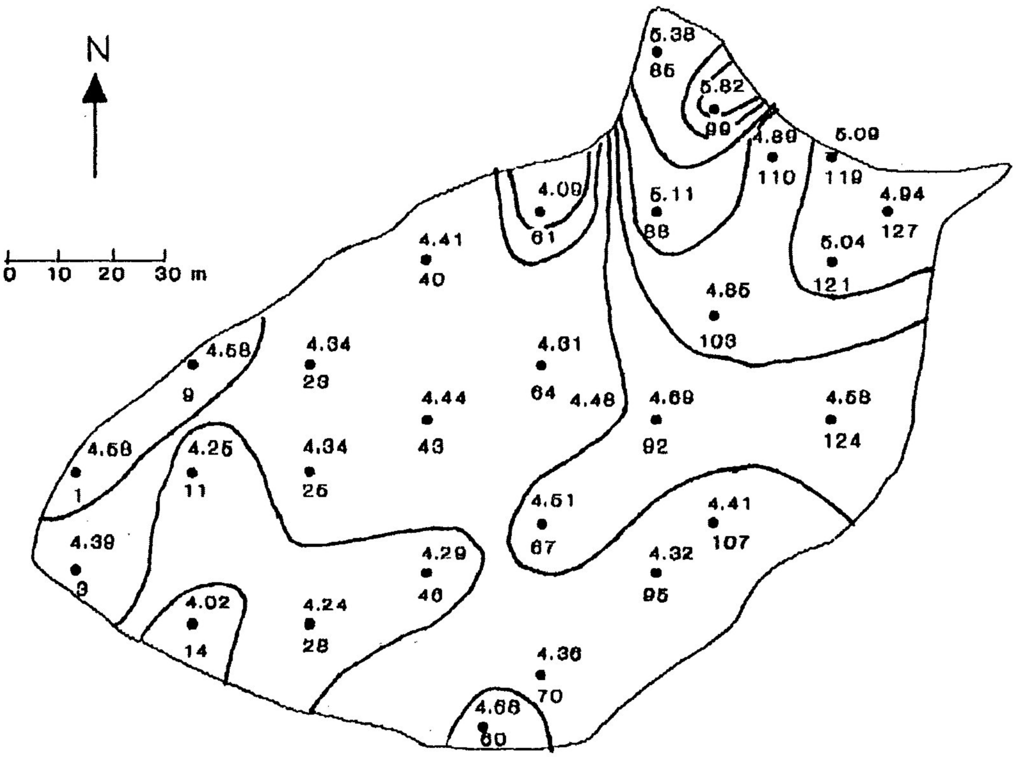


Fig. 29. Maps showing a) maximum and b) minimum water pH isopleths from the period June 16 to September 20 1988. Contour intervals (in pH units) are:

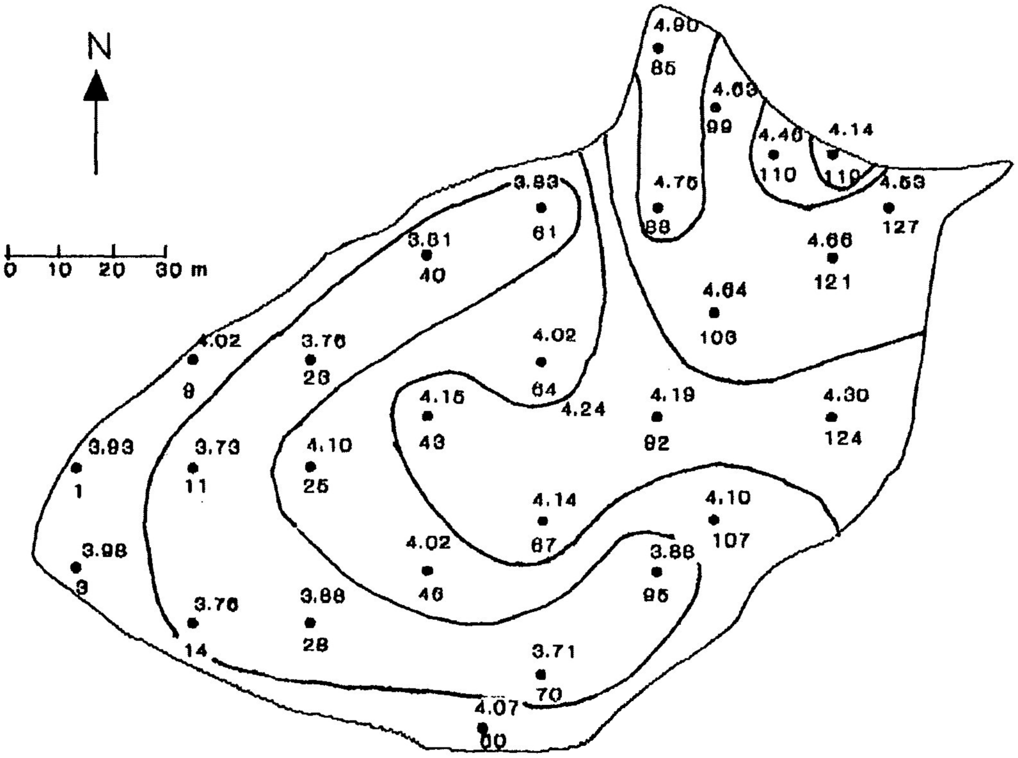
3.91 - 4.10
4.11 - 4.30
4.31 - 4.50
4.51 - 4.70
4.71 - 4.90
4.91 - 5.10
5.11 - 5.30
5.31 - 5.50
5.51 - 5.70
5.71 - 5.90

Location of centre pool is indicated by dashed line. Station numbers are given beneath pH values. See Table 7 for dates that maximum and minimum pH values were observed.

a) maximum pH readings



b) minimum pH readings



paired t-test showed that mean pH dropped significantly between July 28 and August 04 from 4.49 to 4.21 ($p = 0.001$ level) (Fig. 30). The drop in pH was concurrent with a period of heavy precipitation after a prolonged dry period. Approximately 75 mm was recorded during the week of July 28 to August 04 compared to only approximately 81 mm in the entire previous six week period. Mean pH remained relatively low after August 04, but began to increase somewhat after September 01. The pH of the centre pool did not show the same pattern of variation as the standpipes. Pool pH showed almost no change between July 28 and August 04 at the same time as the mean standpipe pH dropped significantly. Pool pH was lowest on July 7 and rose to relatively constant values (approximately pH 4.4) thereafter.

Comparison of the pH isopleth maps (Fig. 31) shows that pH decreased at most stations between July 15 and August 04, but that the overall pattern of isopleths is similar. The pH 4.11 - 4.30 interval, which filled most of the west end of the bog on July 15 is largely superceded by the pH 3.90 - 4.10 interval on August 04. In addition, three stations with pH values of less than 3.90 were recorded on the later date. The relatively small change in the pool pH between the two dates caused some distortion in the isopleths at the north east corner of the bog. On both dates however, a concentric pattern of isopleths originating

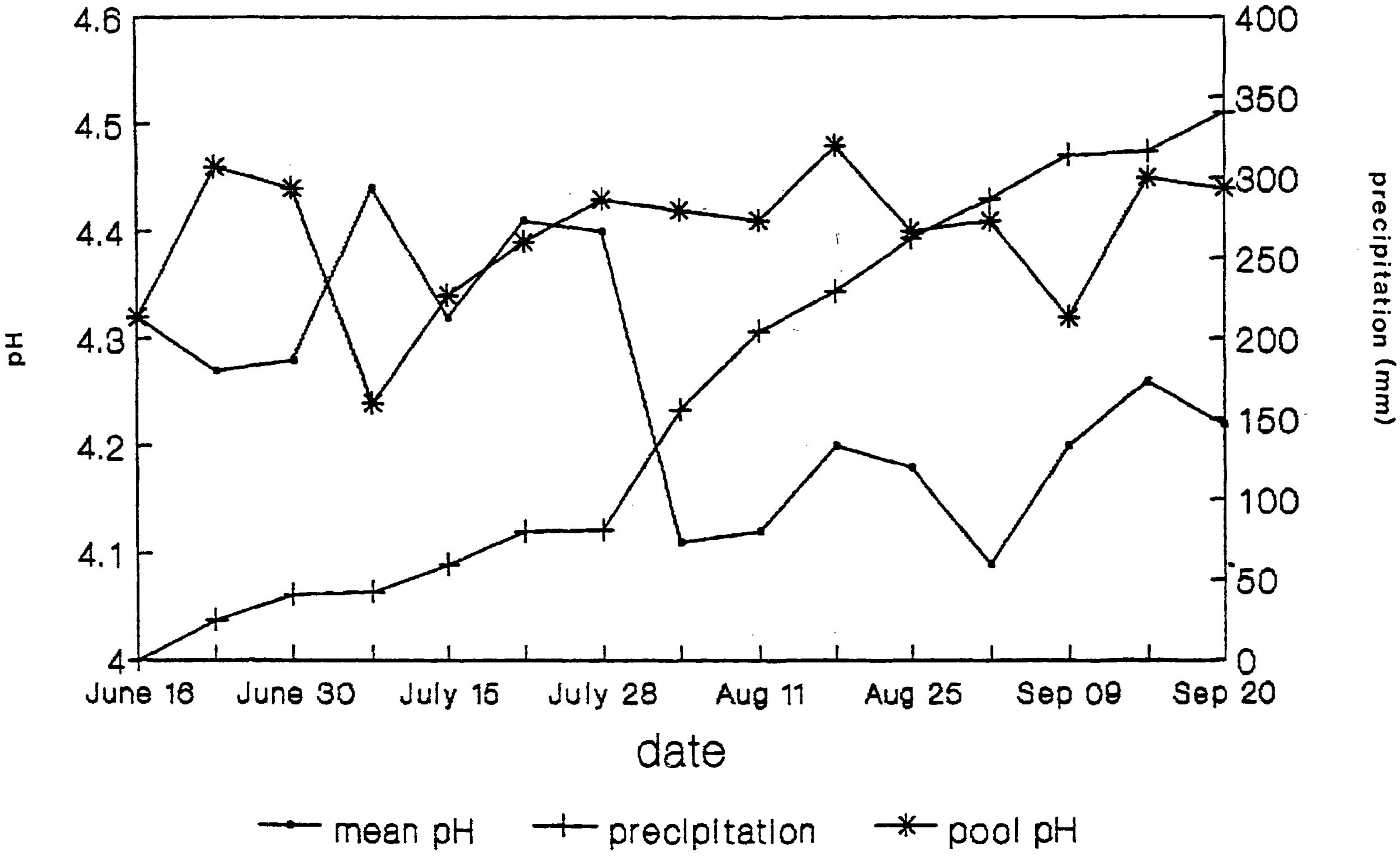
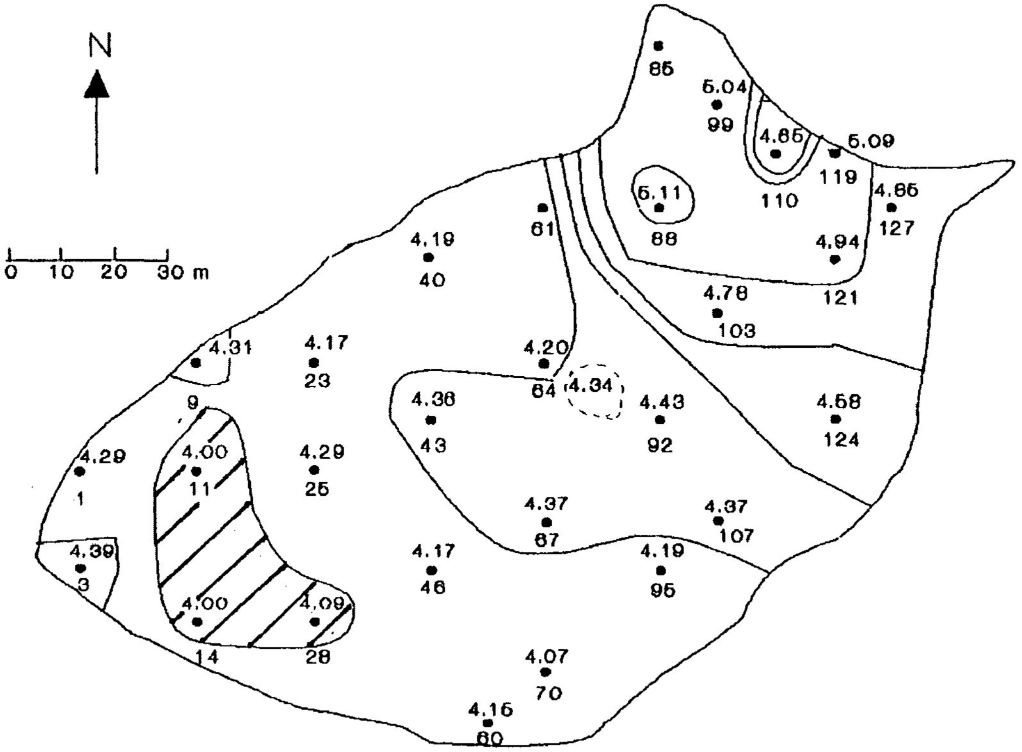


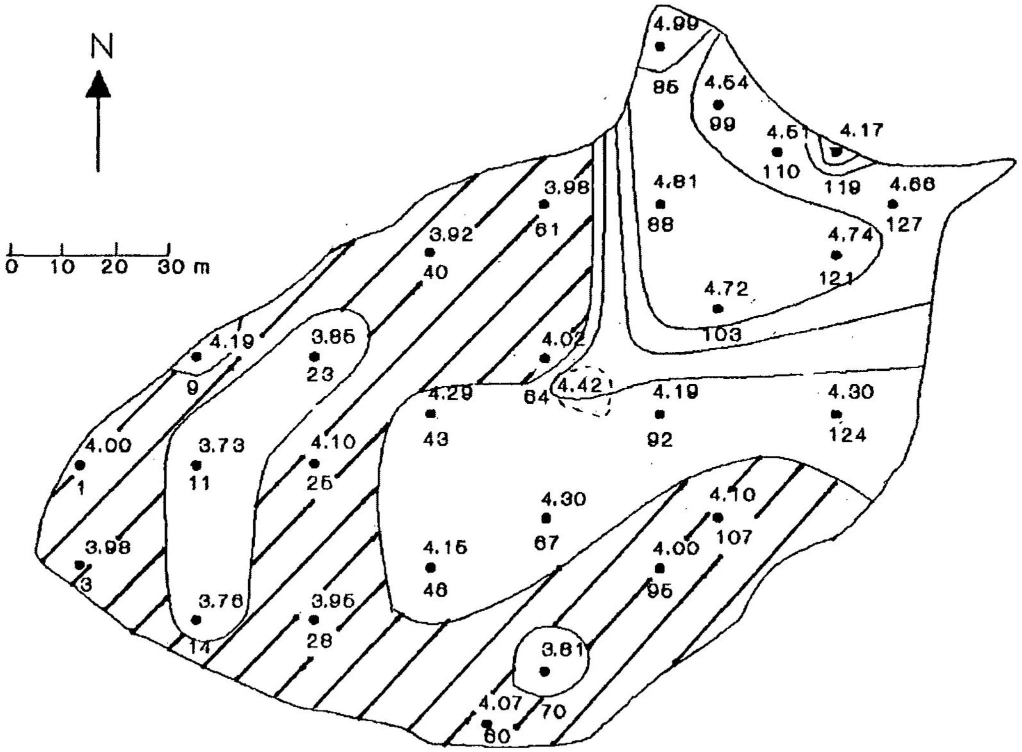
Fig. 30. Mean pH of water samples collected from standpipes between June 16 and September 20 1988. Pool pH is plotted separately. Cumulative precipitation recorded at the bog in the same period is also shown.

Fig. 31. Maps showing water pH isopleths on (a) July 15 1988 and (b) August 04 1988. Missing values are from stations too dry to sample. Contour interval is 0.2 pH units. The pH 3.90 - 4.10 interval is cross-hatched in both figures. Location of centre pool is indicated by dashed line. Station numbers are given beneath pH values.

a) July 16 1988



b) August 04 1988



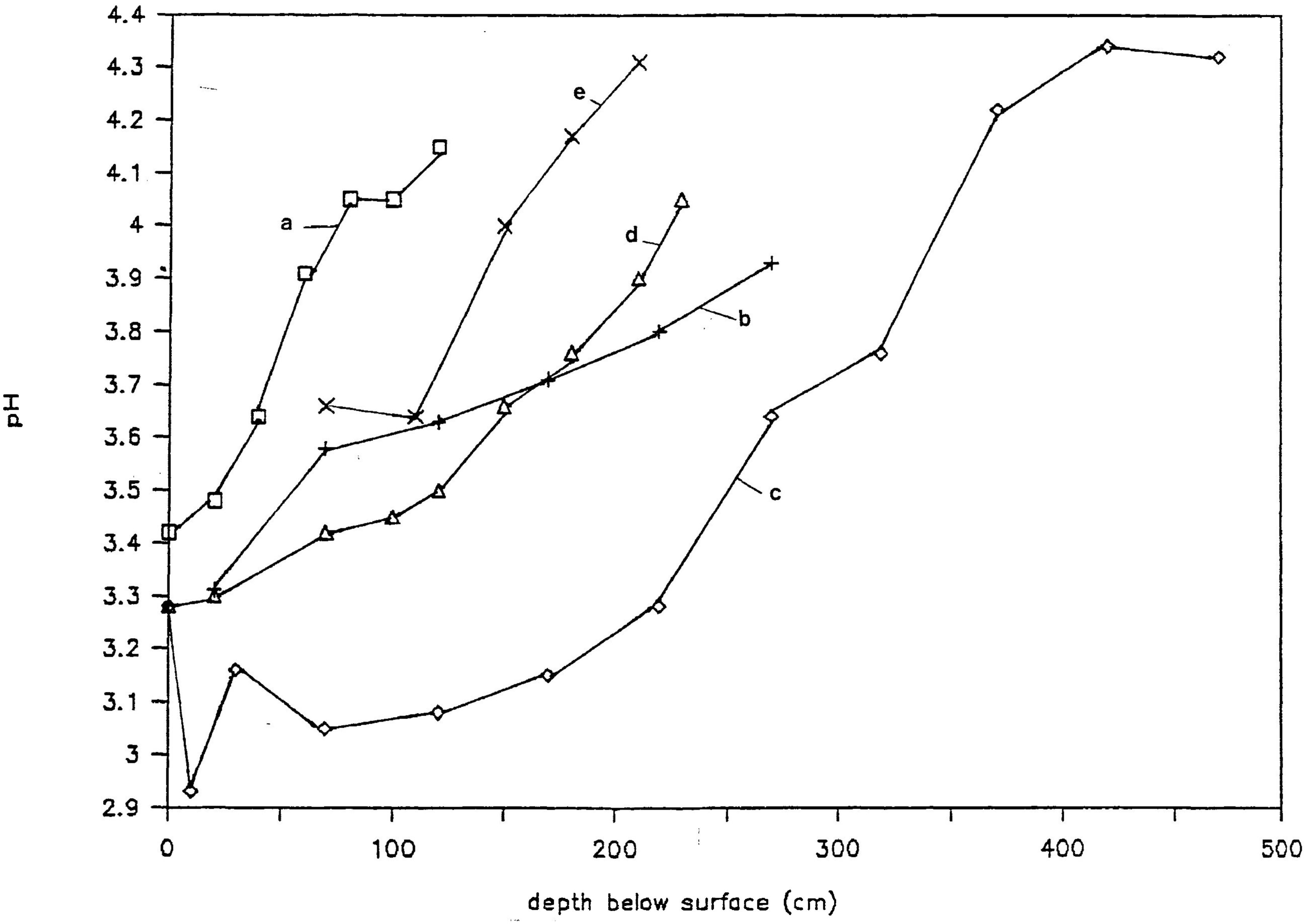


Fig. 32. Peat pH ($CaCl_2$) at various depths below the surface. See Fig. 5 for locations of stations: "a" (station 2), "b" (station 12), "c" (station 54), "d" (station 70), and "e" (station 103).

at the northern tip of the bog and extending toward the middle of the bog is seen. Stations 99 and 119 at the north east edge of the bog show a wide range of pH fluctuation between the two dates, whereas station 110, located in close proximity, show very little change.

b) Peat pH

Peat pH is generally lowest in the top 10 to 15 cm below the surface and increases at a relatively consistent rate with depth (Fig. 32, Appendix XVI). Values are lower than those obtained for water samples, but this might be in part a result of the two different method used to measure pH. Station 54 is an exception, with the lowest pH at a depth of 10 cm and less acid peat at 0 cm. The lowest overall pH values are found at this station where the vegetation consists of a *S. fuscum* hummock. Peat pH increases with depth between 30 and 420 cm and then becomes constant, with similar pH readings at 420 cm and 470 cm.

A comparison of the five cores shows that pH is relatively similar in the surface layers, but differs with increasing depth. This appears to be related to the depth of the core to the underlying mineral soil; the pH of shallower cores increases more rapidly with depth than deeper cores.

c) Concentrations of major ions

This section presents results of chemical analyses of bog water samples. Elements with similar distribution patterns are discussed together. Data is presented in Table 8 and Appendix XVII.

Sulphur

Mean sulphur concentration is significantly higher at the *S. angustifolium* stations than at other stations ($p < 0.01$) (Table 8, Fig. 33a). Sulphur shows a positive correlation with *S. angustifolium* cover and a negative correlation with distance from the edge of the bog (Table 9). Weak positive correlations are shown with the concentrations of manganese, magnesium, zinc and potassium.

Phosphorus

Phosphorus concentration shows strong positive correlation with many of the metal cations, especially magnesium, iron and aluminum and to a lesser degree with sodium and manganese (Table 9). Like many of the cations, maximum phosphorus concentration was found at the north tip of the bog, but no clear distribution pattern is apparent. Concentrations are below detectable limits at six stations (Table 8, Fig. 33b).

Table 8. Mean concentrations of major ions in bog waters and precipitation where: "total" is the mean of all stations, "lawn" is the mean of *S. angustifolium* lawn stations, "other" is the mean of stations other than the lawn, "pool" is the mean of the centre pool, and "ppt" is the mean of precipitation values. Bog water samples were collected October 15 1988. Samples for pH analysis were collected between June 16 and September 20 1988. Precipitation data is from the Ontario Ministry of Environment, Air Resources Branch (data for Forbes Township 1986). Ion concentrations are expressed as mean concentrations in mg/l. Standard deviation (in parentheses) and sample sizes are given.

"nd" indicates concentration below detection limit
"na" indicates data not available
* as sulphate

	total	lawn	other	pool	ppt
pH	4.23 (0.36) n=378	4.21 (0.31) n=182	4.46 (0.34) n=196	4.35 (0.06) n=15	5.2 (0.7)
S	0.372 (0.145) n=15	0.465 (0.118) n=8	0.284 (0.114) n=7	0.248 n=1	1.25* (0.95)
P	0.365 (0.819) n=10	0.398 (0.556) n=5	0.767 (1.404) n=5	1.642 n=1	na
Na	0.743 (0.480) n=15	0.526 (0.422) n=8	0.985 (0.487) n=7	0.795 n=1	0.048 (0.036)
K	0.574 (0.645) n=10	1.207 (0.943) n=4	0.661 (0.221) n=6	0.389 n=1	0.022 (0.016)
Mg	0.584 (0.309) n=15	0.695 (0.196) n=8	0.505 (0.390) n=7	0.248 n=1	0.031 (0.033)
Mn	0.102 (0.067) n=15	0.118 (0.064) n=8	0.091 (0.076) n=7	0.056 n=1	na
Al	0.280 (0.476) n=15	0.206 (0.052) n=8	0.393 (0.731) n=7	0.074 n=1	na
Fe	0.578 (0.528) n=15	0.565 (0.110) n=8	0.638 (0.813) n=7	0.259 n=1	na
Ca	2.684 (1.838) n=15	3.711 (1.712) n=8	1.785 (1.436) n=7	0.754 n=1	0.306 (0.291)
Zn	0.026 (0.018) n=15	0.039 (0.015) n=8	0.014 (0.010) n=7	0.010 n=1	na
Cd	0.002 (na) n=1	nd	0.002 (na) n=1	nd	na
Pb	nd	nd	nd	nd	na

Table 9. Pearson correlations coefficients between water chemistry parameters and other factors. EDGE is distance from the edge of the bog, SPAN is *Sphagnum angustifolium* cover, SPHG is total *Sphagnum* cover, pH indicates mean bog water pH, and HT indicates surface elevation.

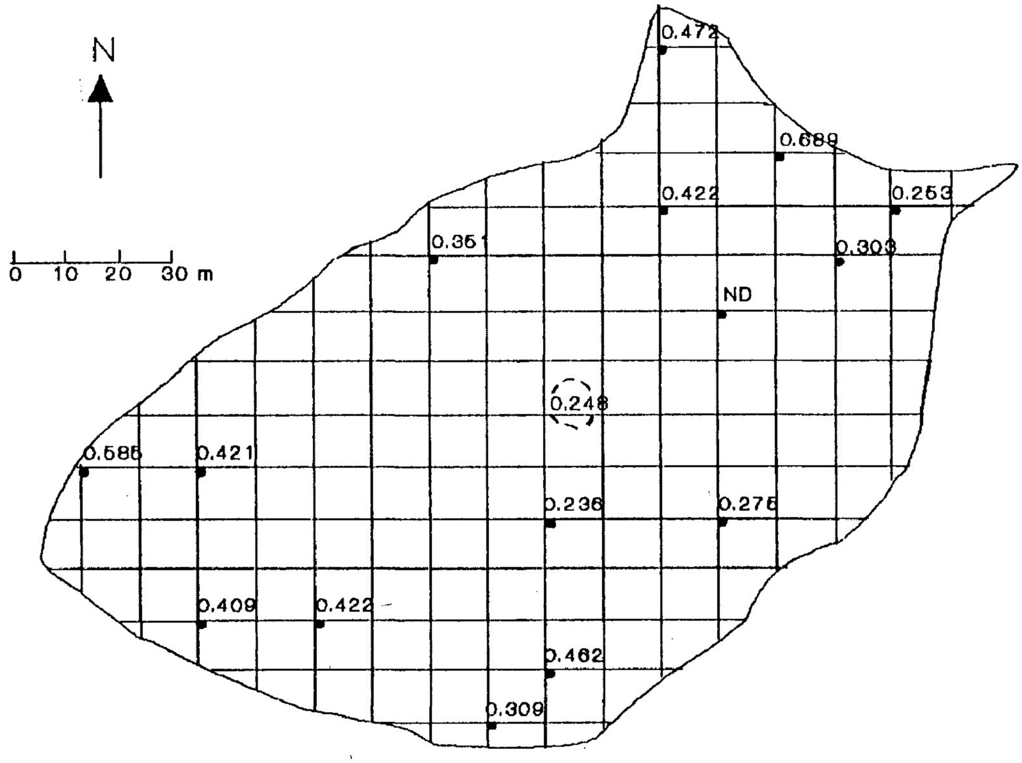
ns	indicates no significant relationship at 0.05 level
*	indicates significant relationship at 0.05 level
**	indicates significant relationship at 0.01 level
***	indicates significant relationship at 0.001 level.

	EDGE	SPHG	SPAN	HT	pH	S	P	Na	Mn	Mg	Fe	Ca	Zn	K	Al
SPHG	ns	-													
SPAN	-0.41*	0.58***	-												
HT	-0.33*	0.35*	0.49**	-											
pH	ns	-0.37*	-0.50**	-0.63***	-										
S	-0.64**	0.45*	0.55*	ns	ns	-									
P	ns	-0.47*	ns	ns	ns	ns	-								
Na	ns	-0.49*	-0.65**	-0.57*	0.79***	ns	0.54*	-							
Mn	-0.44*	ns	ns	ns	ns	0.56*	0.54*	ns	-						
Mg	-0.65**	ns	ns	ns	ns	0.59*	0.66***	ns	0.86***	-					
Fe	ns	ns	ns	ns	0.46*	ns	0.89***	0.53*	0.63*	0.76***	-				
Ca	-0.60*	ns	0.46*	ns	ns	ns	ns	ns	0.66**	0.85***	ns	-			
Zn	-0.58*	ns	0.57*	0.46*	0.49*	0.54*	ns	ns	0.62*	ns	ns	0.91***	-		
K	ns	ns	ns	ns	ns	0.49*	ns	0.63*	ns	ns	ns	ns	0.46*	-	
Al	ns	ns	ns	ns	0.52*	ns	0.91***	0.59*	0.59*	0.71**	0.98***	ns	ns	ns	

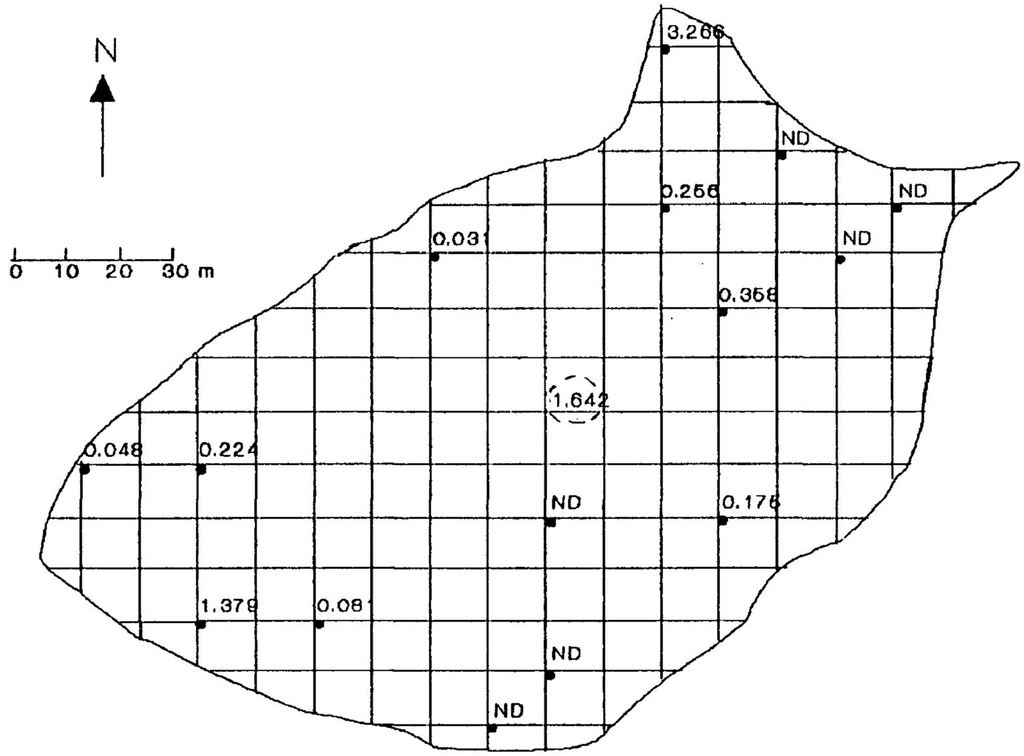
Fig. 33 a - j. Concentrations of major ions (mg/l) in bog water samples collected October 15 1988. Concentrations of elements indicated below by "*" are mean values of two duplicate samples. Others are single samples. "ND" indicates concentration below detectable limits. Position of the centre pool is indicated by dashed line.

a) sulphur *
b) phosphorus *
c) sodium
d) potassium
e) magnesium
f) manganese
g) aluminum *
h) iron *
i) calcium
j) zinc

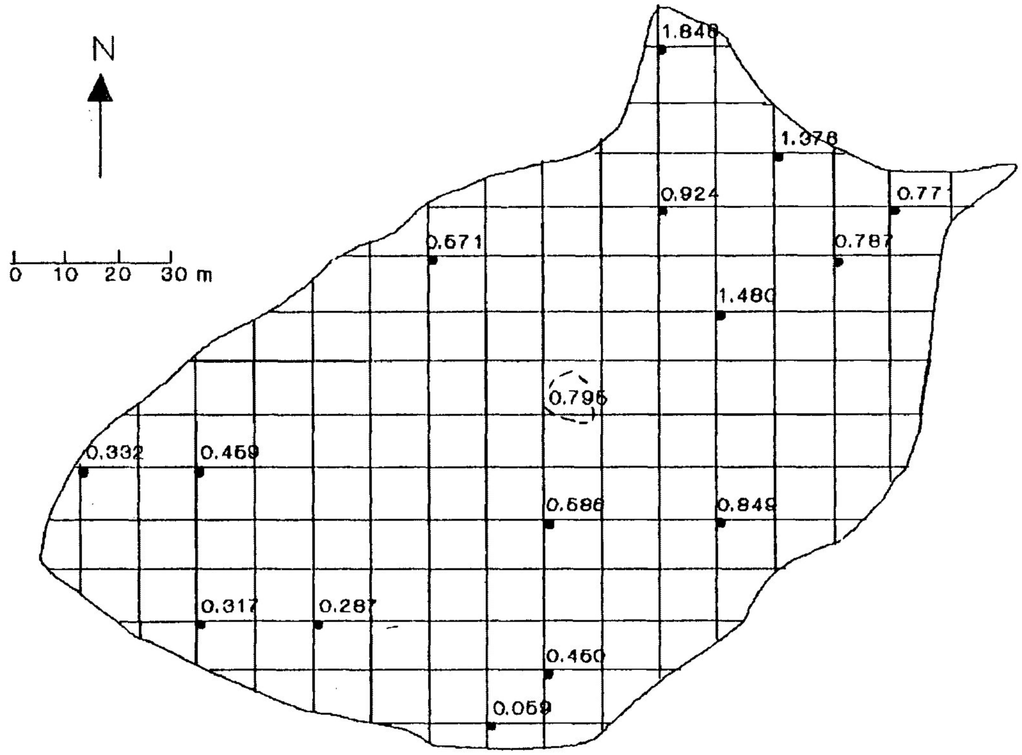
a) Sulphur



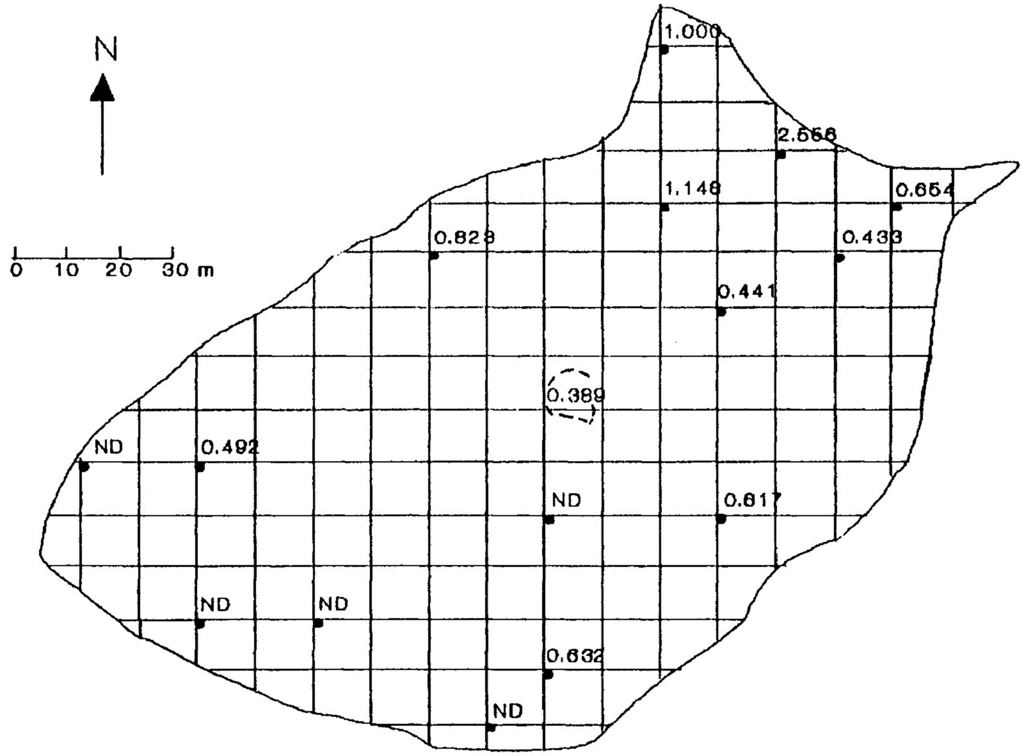
b) Phosphorus



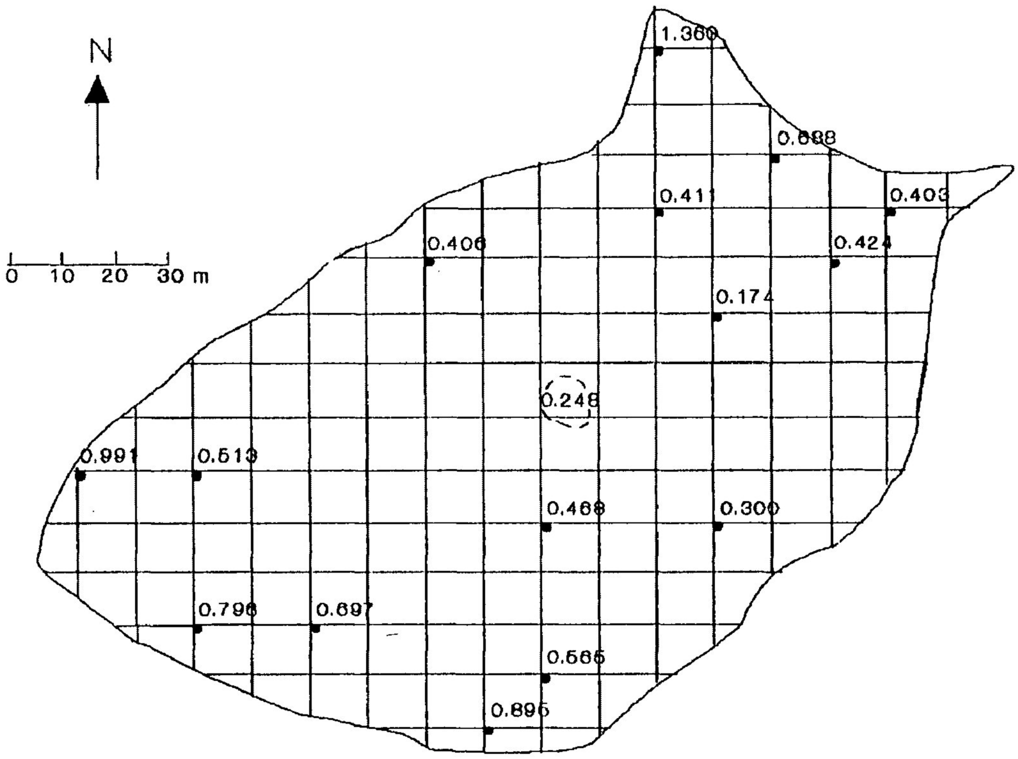
c) Sodium



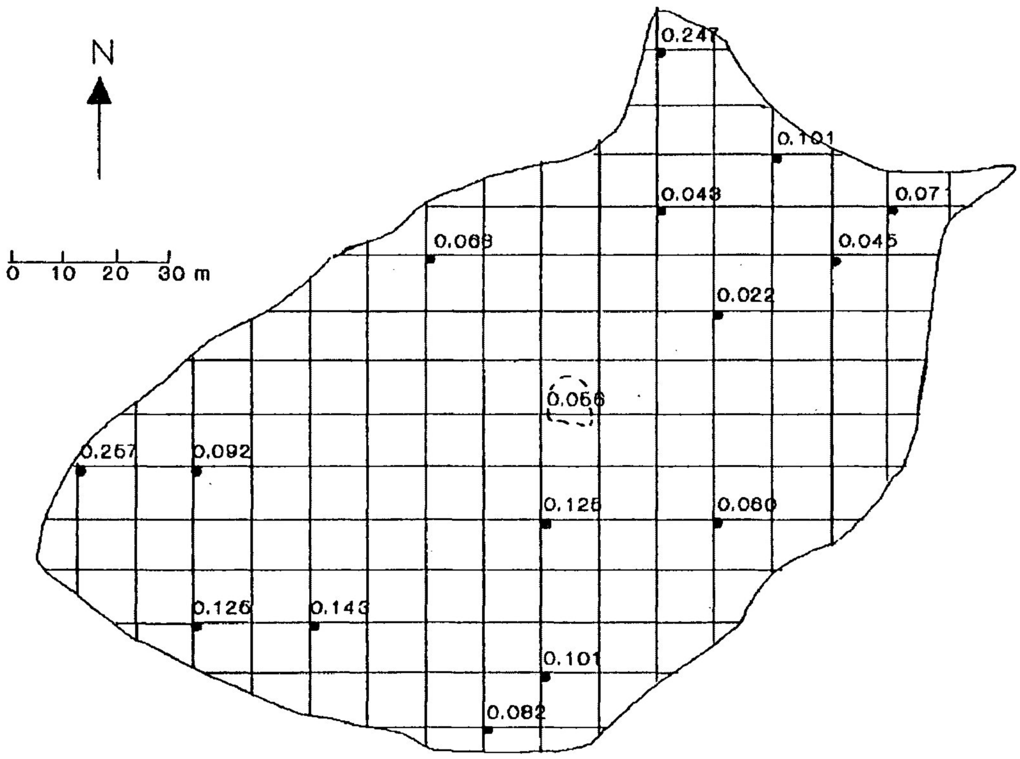
d) Potassium



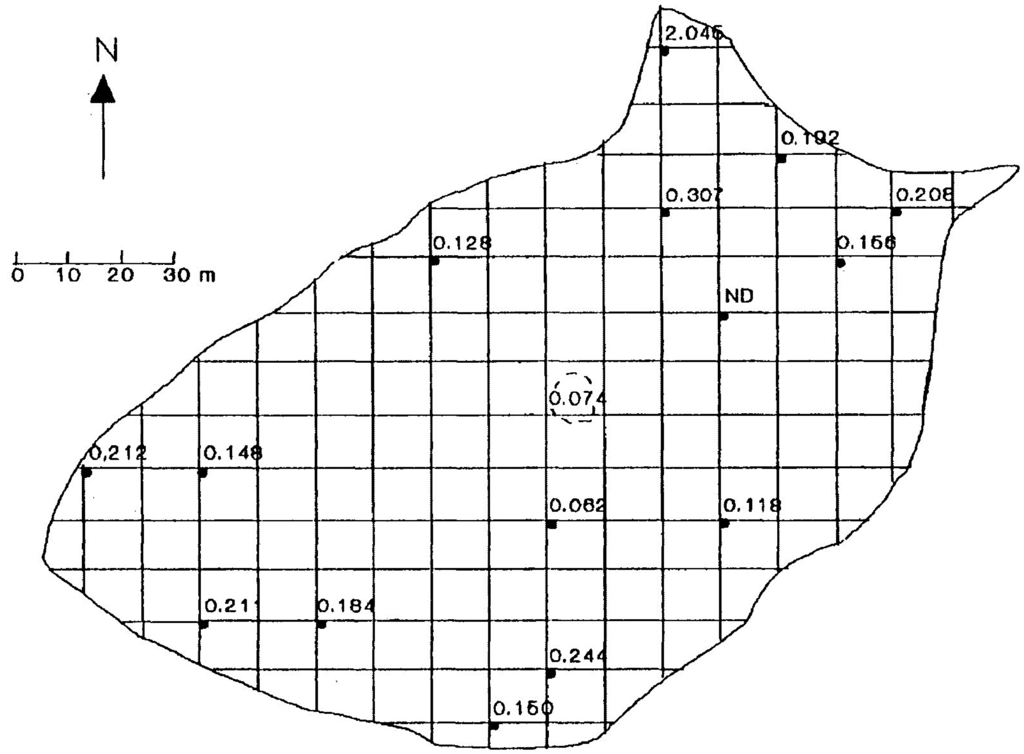
e) Magnesium



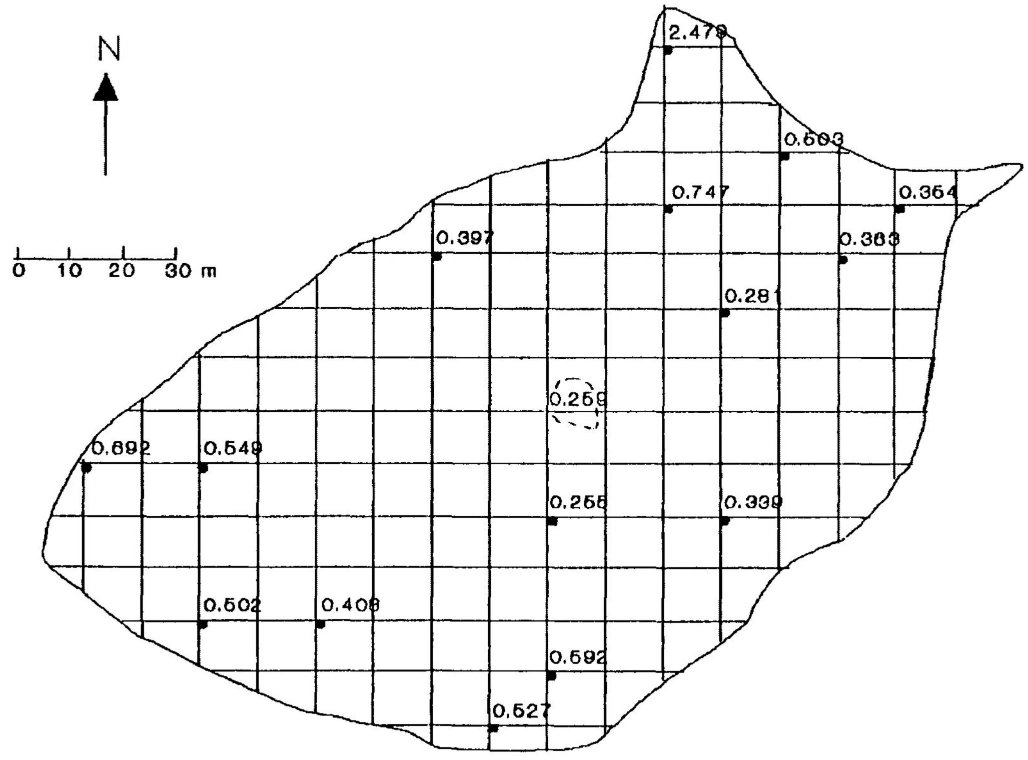
f) Manganese



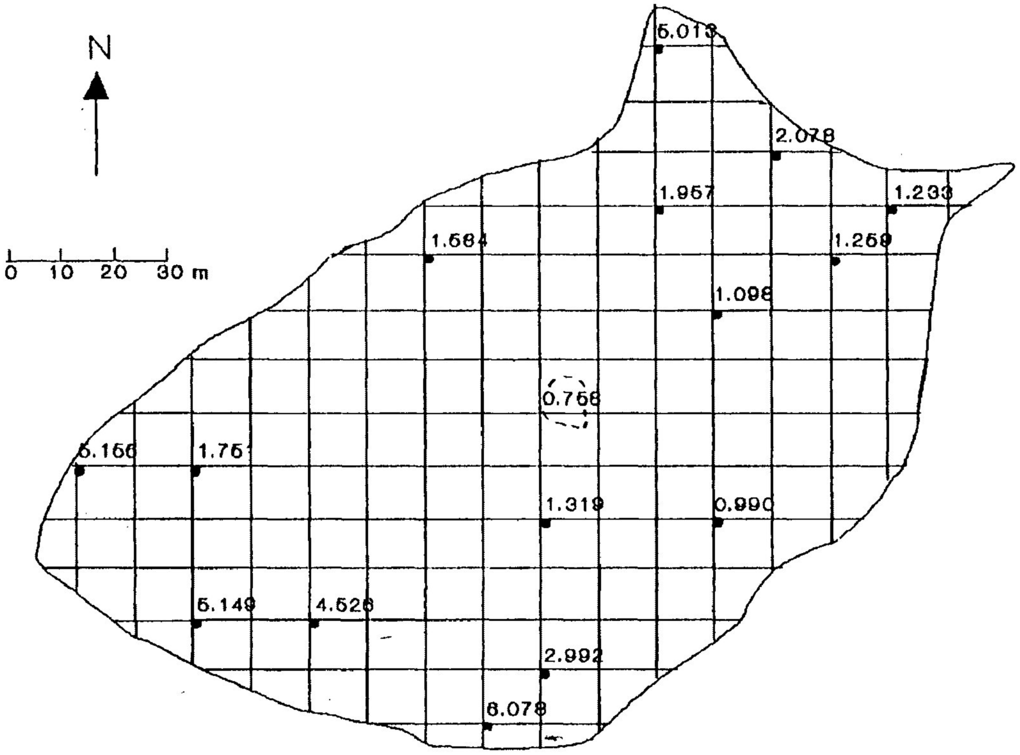
g) Aluminum



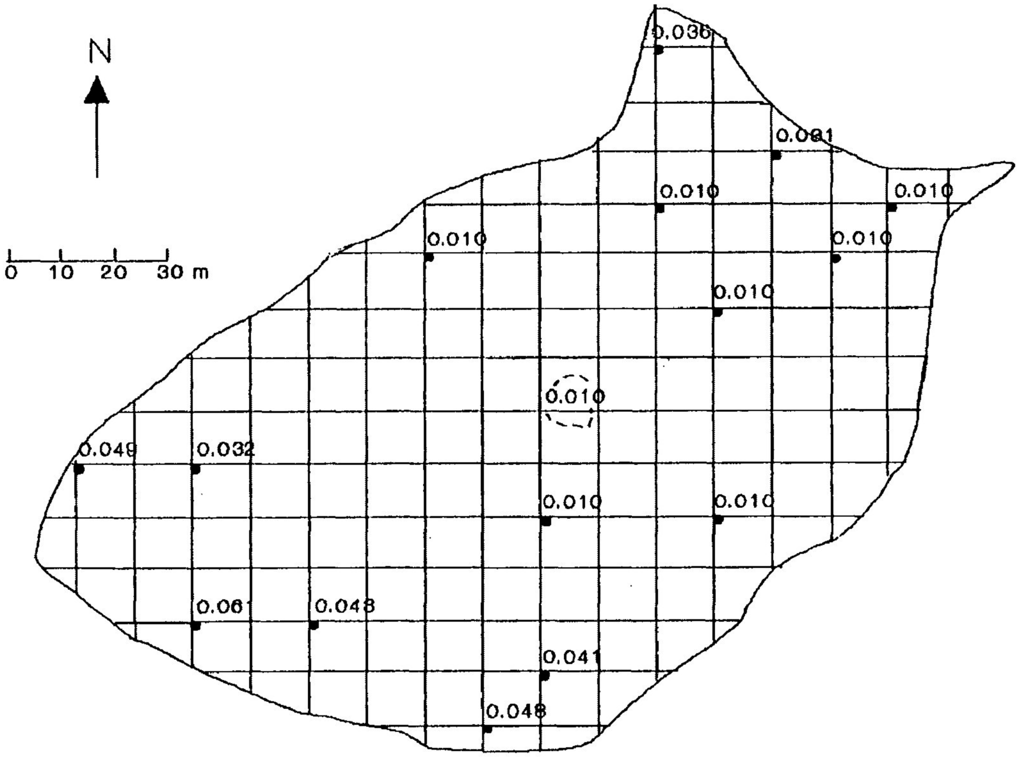
h) Iron



i) Calcium



j) Zinc



Sodium and potassium

Sodium and potassium concentrations are positively correlated with one another (Table 9) and tend to decrease from the stations near the northwest corner of the bog in a southwest direction (Fig. 33 c, d). Potassium concentrations range from 2.56 mg/l at the northeast edge of the bog to below detectable limits at five stations at the west end of the bog. Sodium concentrations occur at similar levels, with a maximum of 1.85 mg/l at station 85 and minimum of 0.06 mg/l at the south edge. Mean sodium concentration is significantly lower in the stations situated in the *S. angustifolium* lawn than at the other stations ($p < 0.01$; $t= -3.67$) (Table 8). Sodium is a negatively correlated with factors that may represent ombrotrophic conditions, namely *S. angustifolium* cover, surface elevation and pH (Table 9).

Magnesium and manganese

Concentrations of magnesium and manganese are highest at the north and west edges and are negatively correlated with distance from the edge of the bog (concentrations decrease from edge areas towards the centre) (Table 9, Fig. 33 e, f). Both elements show positive correlations with sulphur, iron, calcium and aluminum concentrations (Table 9) and both occur in significantly higher concentrations at *S. angustifolium* lawn stations than at other stations ($p<0.05$).

Aluminum and Iron

Aluminum and iron concentrations have a strong positive correlation and occur at similar levels (Table 8, Table 9). Although not negatively correlated with distance from the edge, concentrations of both elements are lowest near the centre of the bog (stations 67, 103 and pool), and, in the case of aluminum, drop to below detectable limits in this area (Fig. 33 g, h). Concentrations are approximately an order of magnitude higher at station 85 at the north tip of the bog than at other stations.

Calcium

Highest calcium concentrations (5 to 6 mg/l) are at stations within 10 m of the edge of the bog and tend to be lower near the centre. Calcium concentrations show a negative correlation with distance from the edge of the bog and a positive correlation with *S. angustifolium* cover and surface height (Table 8, 9, Fig. 33 i). Zinc and calcium have a strong positive correlation.

Zinc

Highest zinc concentrations are found at two stations at the north edge and the six stations at the southwest edge with somewhat lower concentrations at the stations between. Zinc shows a positive correlation with *S. angustifolium*

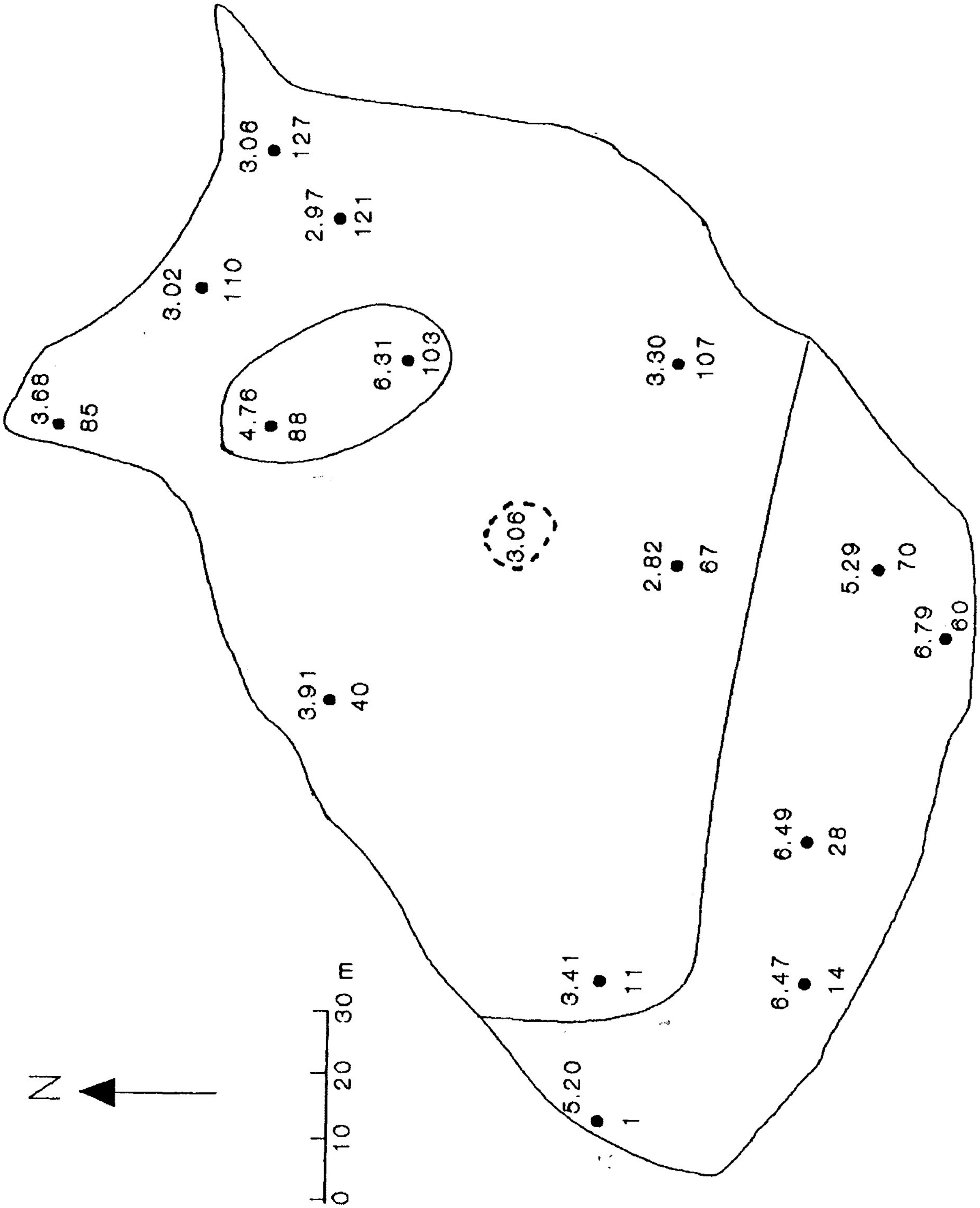


Fig. 34. Ratios of calcium and magnesium concentrations (in mg/l) in bog water samples collected October 15 1988. Concentrations are from single samples collected at each station. Position of centre pool indicated by dashed line.

cover and negative correlation with distance from the edge and pH (Table 8, 9, Fig. 33 j).

Cadmium and lead

Cadmium and lead are present at levels below detection limits (0.002 mg/l and 0.025 mg/l respectively) in all cases except at station 103 where cadmium concentration is 0.002 mg/l (Table 8).

d) Calcium:magnesium ratio of bog waters

With the exception of stations 88 and 103, the bog can be divided into two zones based on the Ca:Mg ratio of the surface waters (calcium and magnesium concentrations are positively correlated: $r=0.8517$; $p=<0.001$). The five stations closest to the southwest margin of the bog have Ca:Mg ratios ranging from 5.20 to 6.79. These stations are all within approximately 15 m of the edge of the bog. The other nine stations (including the centre pool, but excluding stations 88 and 103) have Ca:Mg ratios ranging from 2.82 to 3.91. Stations 88 and 103, within the larger area of lower Ca:Mg ratios have anomalous higher ratios of 6.31 and 4.76 respectively (Fig. 34).

e) Comparison of bog water data with precipitation data

Mean calcium, magnesium, and sodium concentrations are approximately an order-of-magnitude higher in bog waters than in precipitation. Potassium concentrations are also approximately an order-of-magnitude higher in bog waters except at a cluster of five stations along the south west edge where concentrations are below the detection limit. Sulphur concentrations are approximately 2 to 7 times higher in precipitation than in bog waters (Table 9).

8) Vegetation

The following section describes the results of the polar ordination of vegetation data and shows the relationship between the ordination scattergram and several environmental factors. The distributions of stations in each of the vegetation zones (Fig. 4) are indicated on all figures. Raw data is presented in Appendix XVIII.

a) Polar ordination

The polar ordination scattergram shows a large, centrally-placed cluster of stations that is slightly elongated in the horizontal direction (Fig. 35 a). Vertical spread of the quadrats is most pronounced at the right side of the scattergram. No group of quadrats was distinctly separated from the rest.

Stations from the hummocks and hollows zone are found at the lower part of the scattergram and spread for most of the length of the x - axis. The floating mat stations are found in a fairly tight cluster at the left side of the ordination but intergrade with the hummocks and hollows. *S. angustifolium* lawn stations are found at the upper right and also intergrade with the hummocks and hollows stations at the centre.

Distance to the edge of the bog is the factor that perhaps best accounts for the separation of the stations along the X-axis. Most stations situated less than 10 m from the edge are concentrated near the upper right of the scattergram while stations nearest the centre of the bog are clustered at the left (Fig. 35 b). Both extremes intergrade into the centre and stations at intermediate locations are mostly close to the centre of the scattergram. There is a wide range of vertical scatter within stations close to the edge of the bog. Stations in this category comprise the top, bottom, and right endpoints of the ordination. Centre stations show less spread along the Y-axis.

Variation in surface elevation accounts for some of the vertical spread especially among those stations close to the edge. Stations in the highest elevation category are clustered near the upper right of the scattergram and elevation tends to decrease from the upper right to the lower left (Fig. 35 c).

The scattergram overlaying water table depth shows most stations with water table depths of less than 10 cm at the left side, but intergrading into the centre (Fig. 35 d). The remainder of the stations show no apparent trends.

Fig. 35 a - f. Polar ordination of vegetation data showing various environmental factors.

Fig. 35 a. Vegetation zones where "M" indicates floating mat stations, "L" indicates *S. angustifolium* lawn stations, and "H" indicates hummocks and hollows stations (see Fig. 4 for locations of the zones).

Fig. 35 b. Distance to the edge of the bog where:
1 indicates less than 10 m from the edge
2 indicates 10 to 20 m from the edge
3 indicates 21 to 30 m from the edge
4 indicates greater than 30 m from the edge

Fig. 35 c. Surface elevation where:
1 indicates 0 to 10 cm above minimum elevation
2 indicates 11 to 20 cm above minimum elevation
3 indicates 21 to 30 cm above minimum elevation
4 indicates 31 to 40 cm above minimum elevation
5 indicates greater than 40 cm above minimum elevation

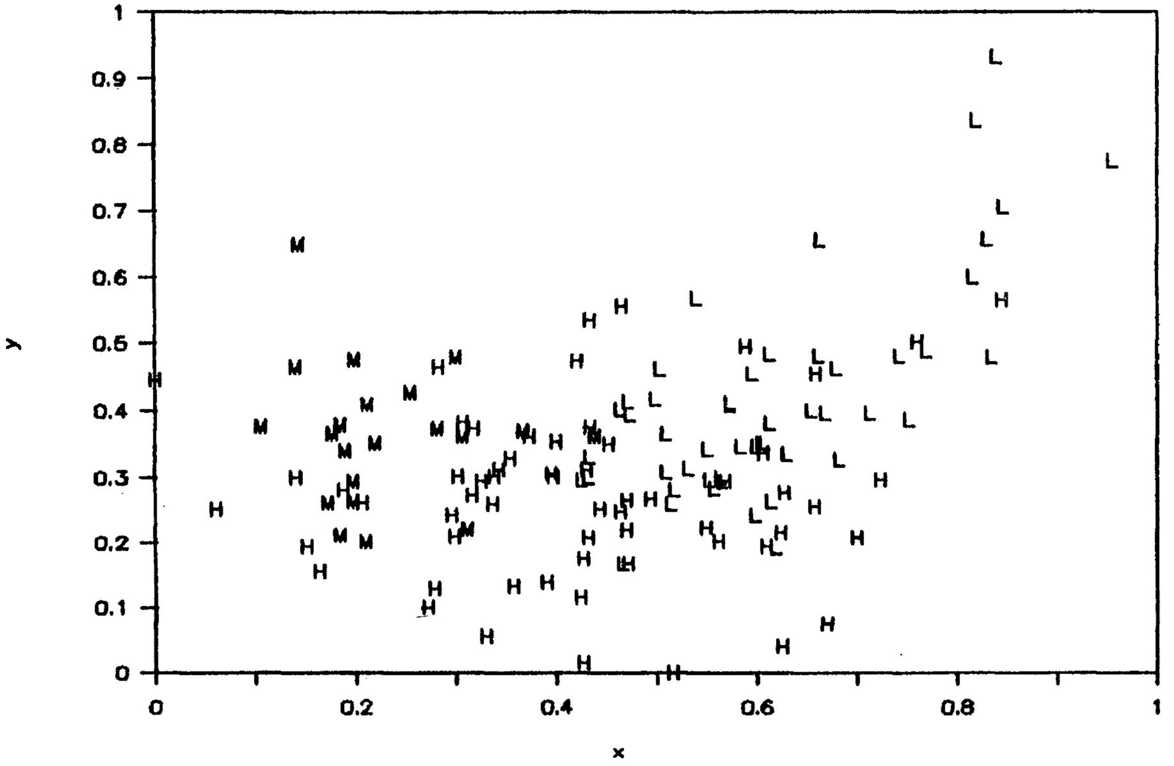
Fig. 35 d. Minimum water table depth where:
1 indicates 0 to 10 cm below the surface
2 indicates 11 to 20 cm below the surface
3 indicates 21 to 30 cm below the surface
4 indicates 31 to 40 cm below the surface
5 indicates greater than 40 cm below the surface

Fig. 35 e. Shade codes recorded June 20 to 23 1988. Numbers indicate the of shade codes. Higher numbers indicate greater shading. See Methods section for further details.

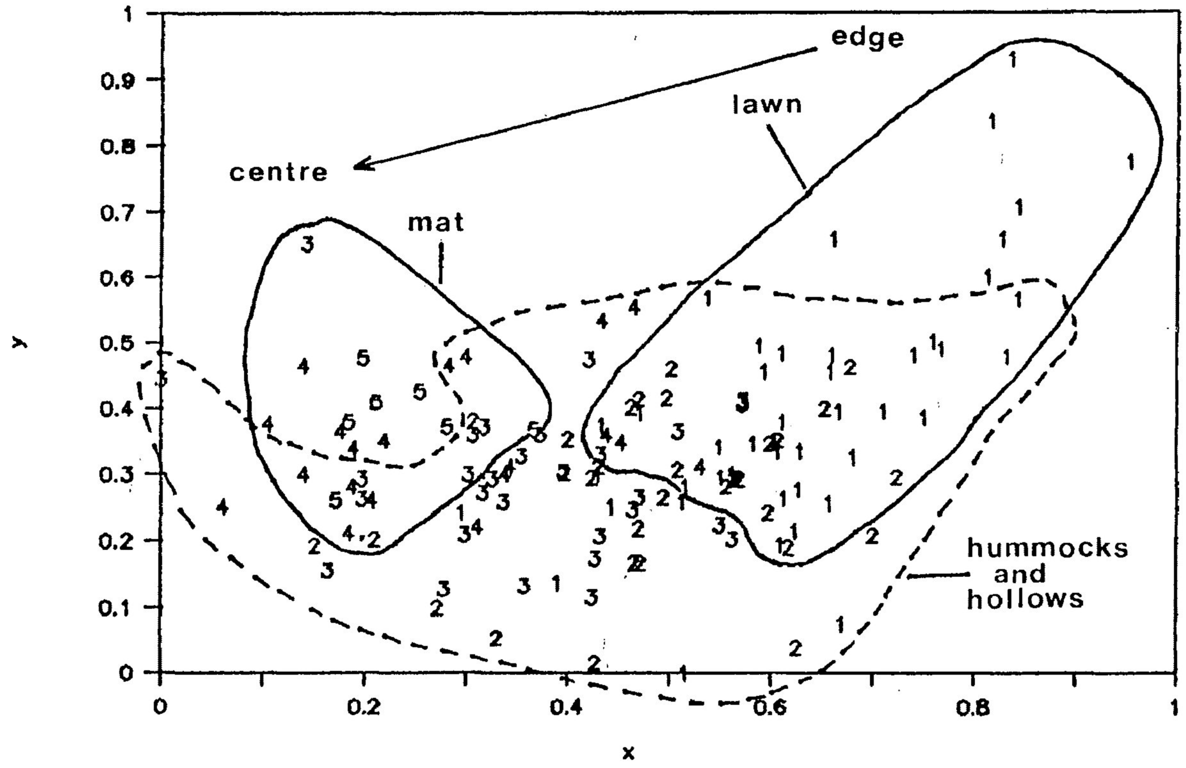
Fig. 35 f. Mean pH of bog water samples collected between June 16 and September 20 1988 from stations for which data is available.

Fig. 35 g - j. Concentrations of elements (mg/l) in bog water samples collected at selected stations: (g) sodium, (h) potassium, (i) magnesium and (j) calcium. Values of "0.0" are below detectable limits.

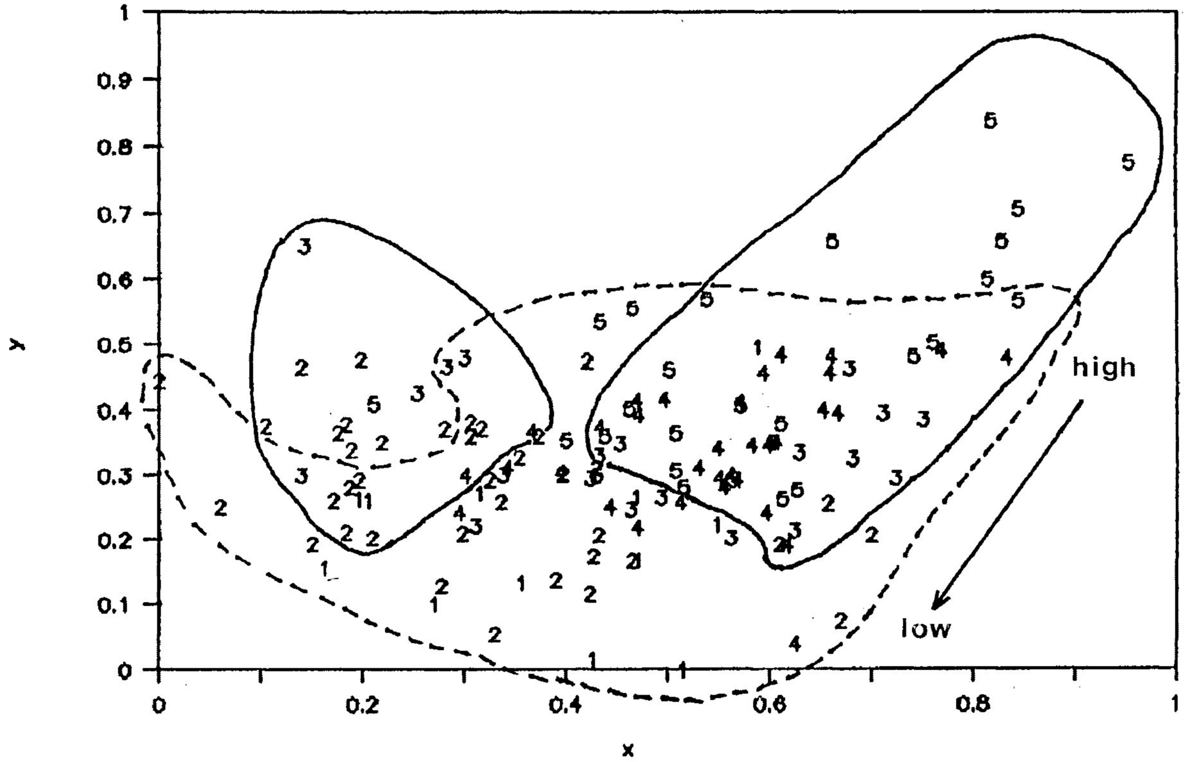
a) polar ordination scattergram



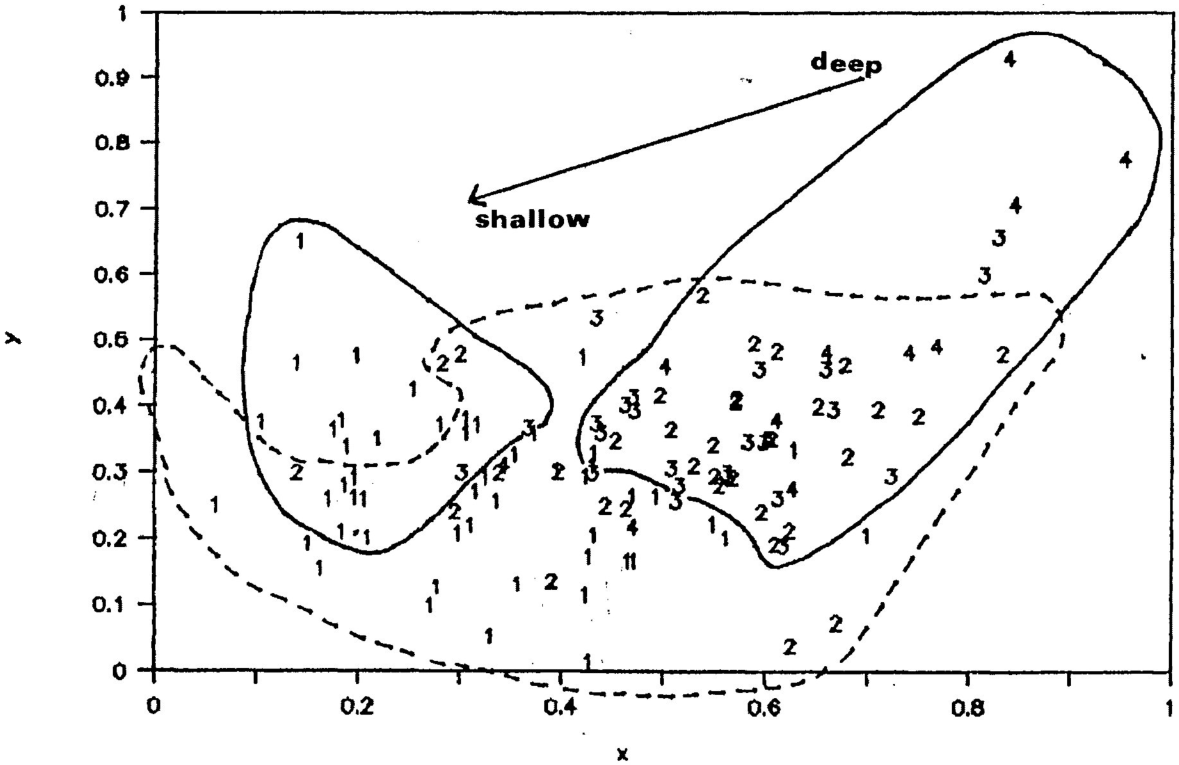
b) distance to the edge



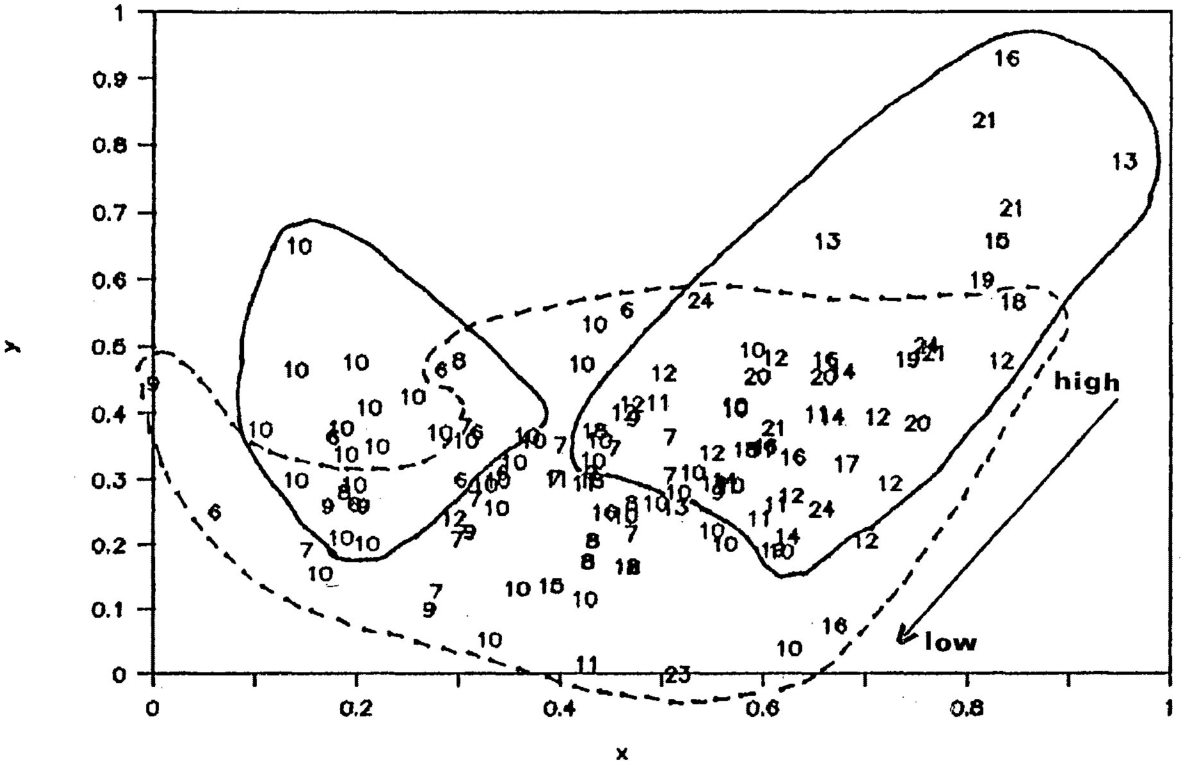
c) surface elevation



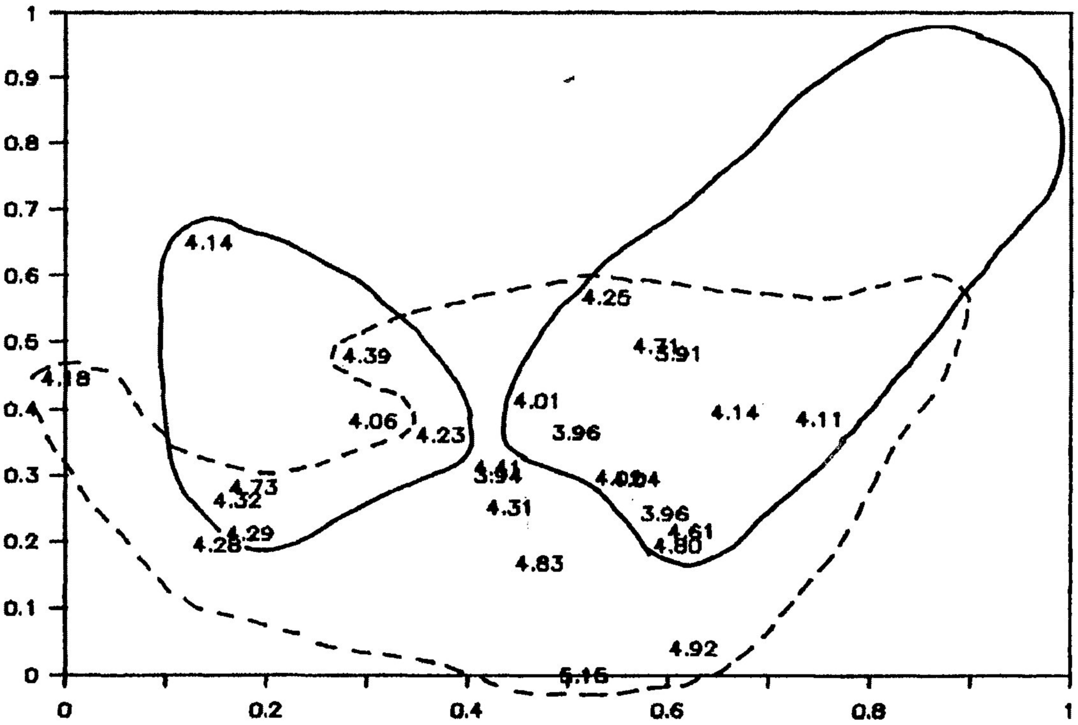
d) minimum water table depth



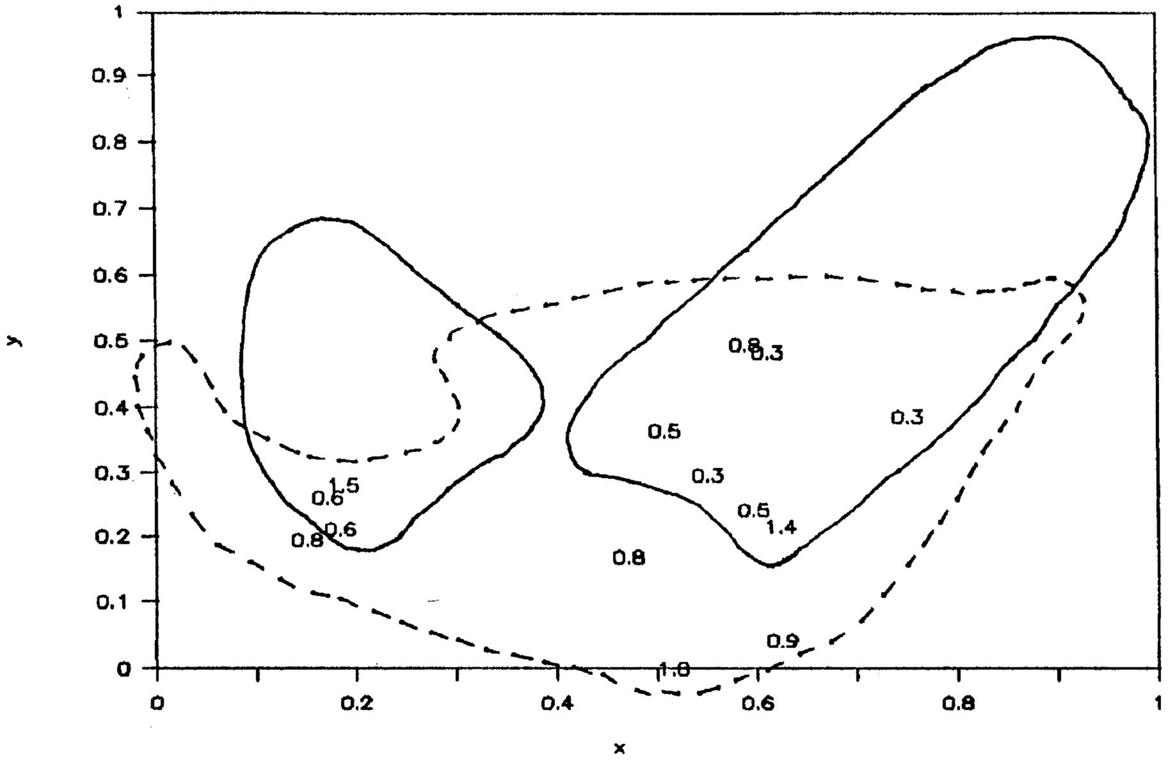
e) shade code



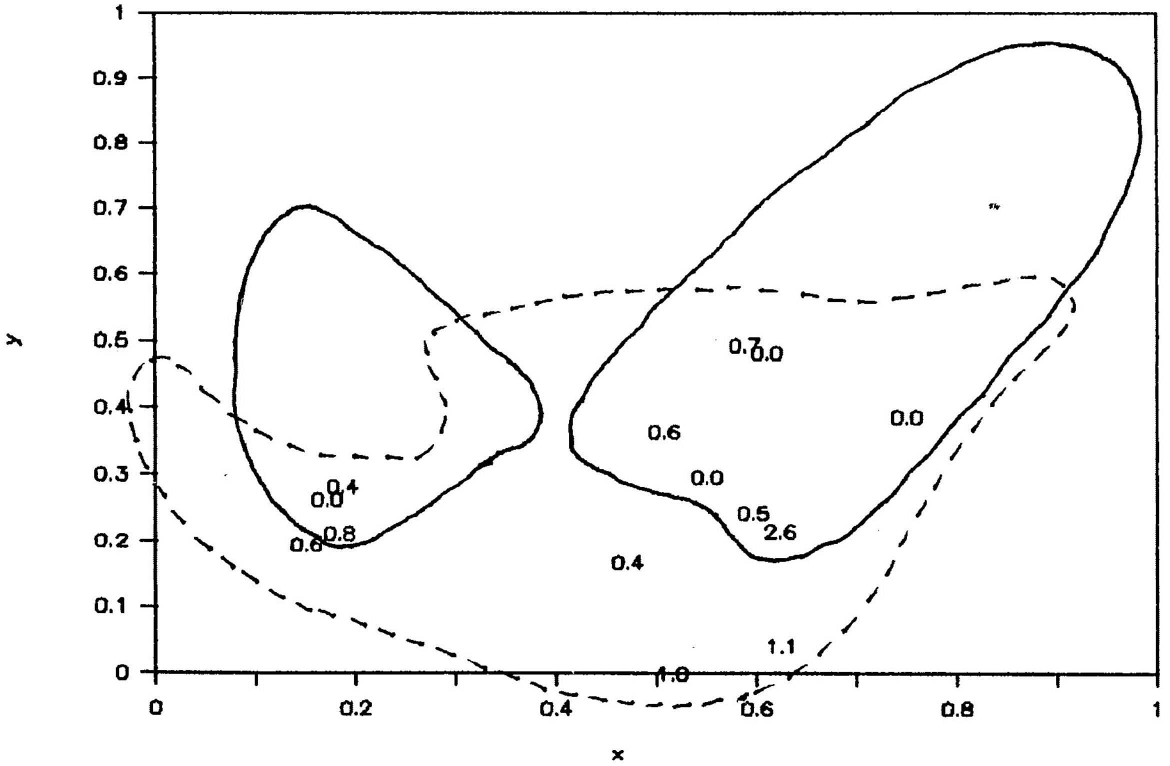
f) mean bog water pH



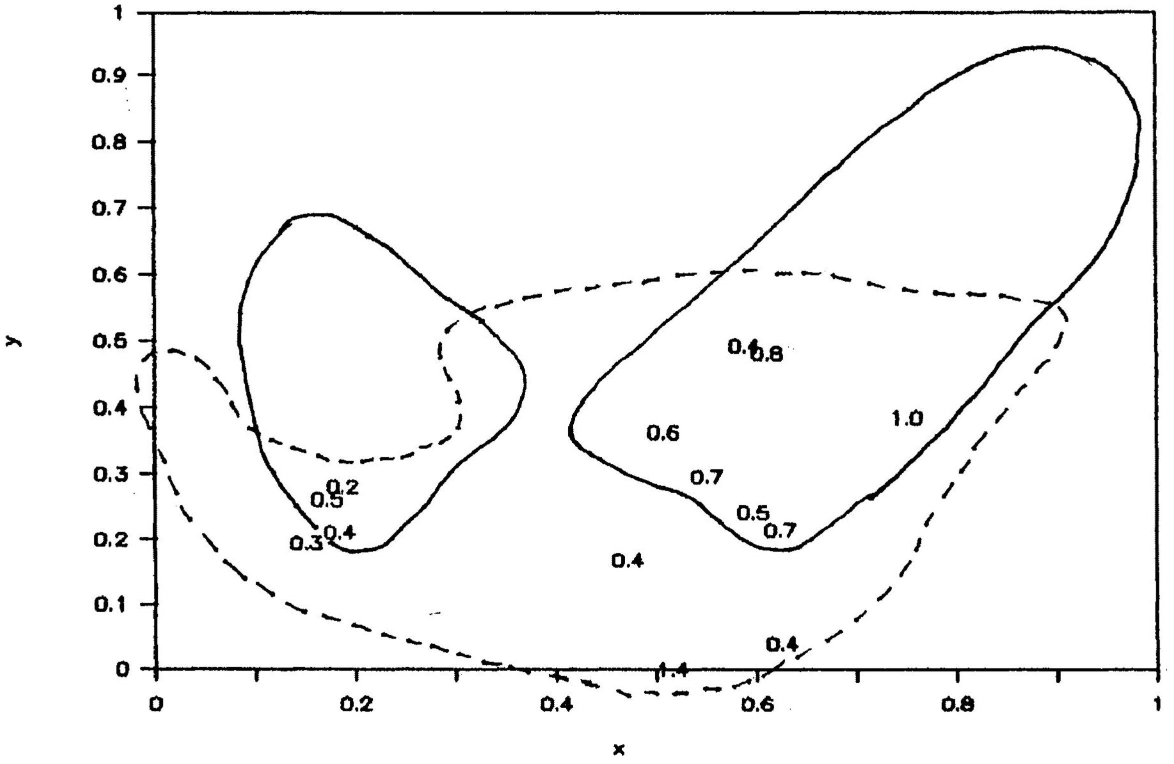
g) sodium concentrations



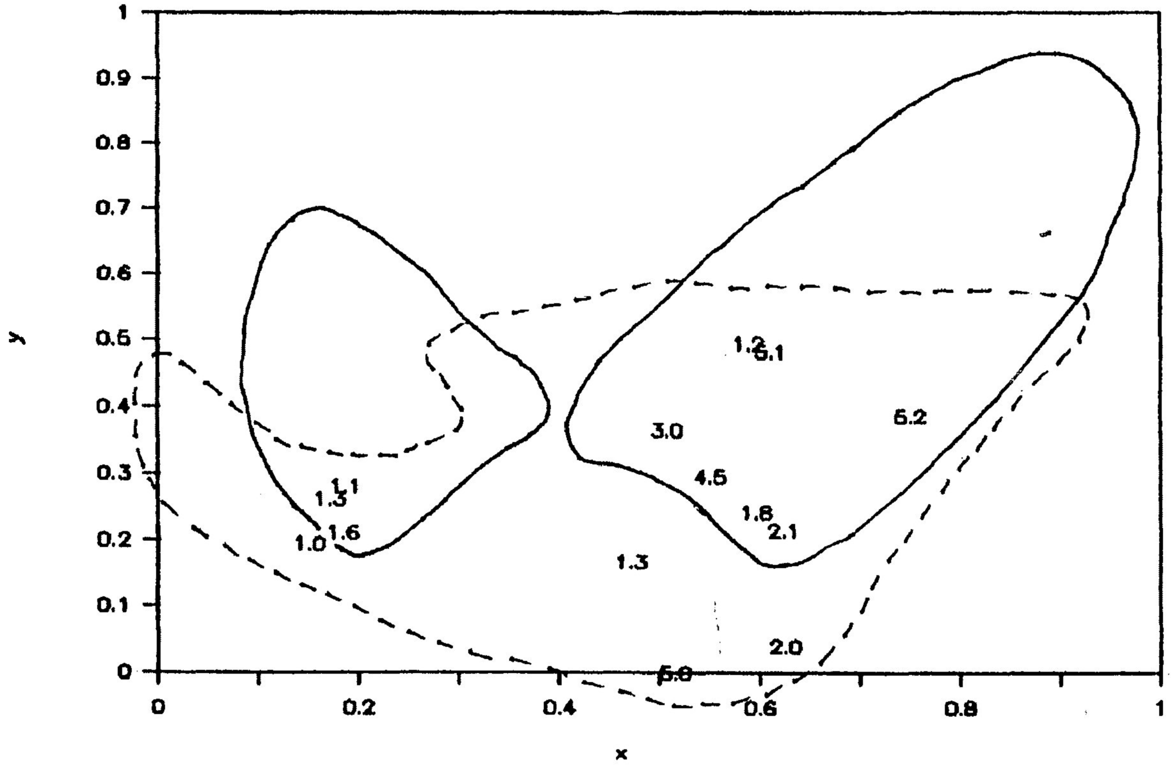
h) potassium concentrations



i) magnesium concentrations



j) calcium concentrations



Degree of shading, which is positively correlated with distance from the edge, demonstrates a similar, but less well-defined pattern, with the stations receiving more sunlight concentrated at the left end of the scattergram and degree of shading increasing to the right (Fig. 35 e).

There is no strbng relationship between distribution of stations in the ordination and pH. Some stations with higher pH (4.61 to 5.15) are clustered at the bottom centre, but others show no obvious pattern (Fig. 35 f). Similarly, no relationships are apparent when concentrations of sodium, potassium, magnesium, and calcium are superimposed on the scattergram (Fig. 35 g - j).

DISCUSSION

1) Climate and Microclimate

a) Temperature

i) Air temperatures

The lower air temperatures that were observed at the edge compared to the centre station (Fig. 11, 12) are probably due largely to differences in solar insolation, but variation in vegetation cover and air movement might also be important. Sunlight striking the peat surface is transformed to heat which is reradiated to the air. The centre station receives direct sunlight for a longer period during the day and therefore absorbs more heat and has higher diurnal temperatures than the edge station. At night, heat stored in the peat continues to be reradiated, resulting in higher minimum temperatures at the centre station. Peat is a poor heat conductor, but is efficient at reradiating heat from the surface at night (Mills *et al.* 1987). This results in lower subsurface temperatures than occur in mineral soil exposed to the same climatic conditions and therefore a shorter frost free period than would be observed in the surrounding forest.

The higher mean maximum temperature of the peat surface at the edge station (Fig. 12) was unexpected, but might be due to protection from southerly winds by the surrounding forest. Vaartaja (1949) found that highest soil surface temperatures occurred where the canopy was open and allowed more radiation to reach the soil surface but high temperatures were also observed where trees blocked the wind and reduced conduction of heat from the soil. In Barclay's Bog, this effect appears to be limited to the layer of air close to the peat surface because maximum temperatures are significantly higher at the centre station at 1.5 m above the surface where mixing of the air occurs (Fig. 12). At night, temperatures are lower at the edge station because the actual net radiation absorbed is less than that at the centre station.

The lower minimum temperatures recorded at the edge station at the peat surface and at 1.5 m above the surface might be a result of cold air drainage from the hillside beyond the edge of the bog basin. As the air at the top of a slope cools, it becomes more dense and drains downward (Daubenmire 1974). Cold air drainage might have some influence on air temperatures, but water temperature data (discussed below) show that subsurface temperatures are lower even at the northeast edge, where the ground surface flat and presumably air drainage is negligible. It is also unlikely that movement of cool air onto the bog at night is sufficient to influence temperatures at 2 m below the surface (as was observed with thermocouple data). It is therefore reasonable to conclude that differences in air temperature are primarily due to variation in solar insolation.

Variation in surface temperature has been attributed to differences in vegetation cover in other peatlands. Brown (1972) found that differences in surface albedo (light reflecting ability) of vegetation resulted in variable amounts of solar radiation being converted to heat in different parts of a Minnesota peatland. Unusually dry conditions, as were experienced in the early summer of 1988, cause the dense capitula of Sphagnum plants to dry out and turn white, resulting in higher albedo and therefore less heat absorption than occur with wet conditions (Ingram 1983). The higher Sphagnum cover at the edge station than the centre station might have contributed to the lower air temperatures there if less heat adsorption, and therefore less reradiation resulted.

Shrub cover is another potential source of variation in surface temperatures. Barclay-Estrup (1971) found that microclimate is strongly influenced by Calluna cover in a Scottish heath. Temperature varies widely at the soil surface during pioneer and degenerate phases of the cycle when Calluna cover is low, and moderately during building and mature phases when cover is higher. However, in the present study, shrub cover at both stations is low and it is unlikely that this is the major factor causing differences in observed temperatures at edge and centre areas, although it may be a contributing factor. Furthermore, standpipe water temperatures show only a weak correlation with total shrub cover, but strong relationships with shade and distance from the edge (Table 4).

ii) Subsurface temperatures

The concentric pattern of surface water temperature isopleths show highest temperatures near the centre of the bog (Fig. 15) and a strong correlation between temperature and distance from the edge (Table 4). The pattern suggests that variation in water temperature is due to the influence of the edge, either directly as a result of shading or indirectly from runoff of cool groundwater from the surrounding forest. The groundwater hypothesis, however, is inconsistent with water chemistry data. If variation in water temperature were mainly due to groundwater inflow, temperature isopleths (Fig. 15) should closely resemble pH isopleths (Fig. 28a) since pH is strongly influenced by groundwater, and this is clearly not the case. Furthermore, if water movement from the surrounding forest were responsible for the differences in temperature, the difference would be more pronounced in the uppermost layer of peat where most water movement occurs (Ingram 1983); observed subsurface temperatures are in fact lower throughout the peat profile. Peat depth is similar at the two stations (Fig. 23), and reradiation of heat from the underlying mineral soil probably occurs at a similar rate (Wilson 1939). It is therefore reasonable to conclude that the differences in temperatures are mostly a result of variation in solar radiation. Stations 9 and 99, however, have markedly lower temperatures than their surrounding stations (Fig. 15) which can most readily be explained by groundwater inflow.

The somewhat irregular pattern of the isopleths, with the highest temperatures south of the centre, suggest that other factors, of which surface albedo is probably the most significant, also contribute to temperature variation. Brown (1972) concludes that temperature differences in a Minnesota peatland were largely due to differences in heat absorption as a result of surface albedo of the vegetation.

The lower subsurface temperatures at edge compared to central areas observed in this study are similar to observations by Mills et al. (1987) who found that shading from trees resulted in lower subsurface temperatures and promoted the formation of permafrost in northern Manitoba peatlands. Conflicting observations were reported by Brown (1976) who found no significant difference in temperatures at depths up to 1 m between forested and clearcut strips in a Minnesota bog (assuming that the forested and clearcut strips are analogous to the shaded edges and unshaded centre of Barclay's Bog in terms of insolation). Brown (1972) concludes that subsurface temperatures are not directly related to solar radiation and that removal of the trees has little or no effect. Radiation of heat from the mineral soil and inflow of groundwater in Brown's study were thought to contribute to variability in temperatures.

Differences in subsurface temperatures between edge and centre stations (Fig. 13, 14, Table 2) suggest that there is little horizontal movement or mixing of water and/or that mixing is slow enough to allow relatively stable temperatures to persist. This is consistent with the concept of "acrotelm" and "catotelm" developed by Ingram (1983). The acrotelm is the top layer of peat, approximately 50 cm deep, that is porous enough to permit water flow. Below the acrotelm is the catotelm, which consists of compacted peat and permits only very slow water movement. In the peatland studied by Brown (1976), subsurface water movement perhaps occurred to a greater degree, causing more uniform temperatures.

Diurnal heating and cooling of the air cause temperatures to fluctuate in the surface peat, which is evident in the higher variance of temperatures at 1 cm below the surface compared to other depths (Fig. 14). The centre pool has higher and more variable temperatures than the surrounding peat pore water because water has a greater heat conductivity than peat, resulting in greater heating during the day and more rapid loss of heat at night. Relatively high temperatures measured at the 1 cm depth (35.6 degrees C on July 29 at the edge station) were also noted by Vaartaja (1949) in southern Finland where surface temperatures regularly exceeded 50 degrees C and occasionally reached 60 degrees C. Less extreme temperatures were recorded in the present study, in part because the thermocouple was placed approximately 1 cm deeper below the surface.

As was the case with air temperatures near the peat surface, temperatures at the 1 cm depth are not significantly lower at the edge station. Probably greater air movement at the centre cause heat to be carried away from the surface peat, whereas at the edge, trees block and redirect air movement.

Temperatures below approximately 1 m were essentially constant for the duration of this study (Fig. 13, 14). This is the approximate maximum depth for diurnal variation in soil temperature (Daubenmire 1974). Seasonal fluctuations in temperature in mineral soil penetrate as deep as 3 m with a lag time of approximately 5 months behind changes in air temperature (Daubenmire 1974). Peat has lower heat conductivity than mineral soil and it is likely that the lag in temperature variation in peatlands is longer than in mineral soils. Brown (1976) found that peat below 2 m in depth exhibited a marked temperature inversion, with higher temperatures in winter than in summer. Therefore, higher temperatures than were observed during the study period (July to November) might therefore be expected during the winter and spring.

The decrease in temperature with depth in the peat profile noted in this study was also observed by Wilson

(1939) in a Wisconsin peat bog. The temperature profile in the Wisconsin bog however, showed an increase at the bottom of the bog basin. This was attributed to heat conduction in the underlying sand from the periphery of the bog, to the bottom of the basin, infiltrating upwards into the peat. That this phenomenon was not observed in Barclay's Bog might be attributed to the fact that the lowest thermocouple element was at least 30 cm above the bottom of the basin at both stations.

The difference between temperatures recorded by soil thermometers and thermocouples at the same depth is probably due to heat conduction by the metal soil thermometer pipe (Fig. 13, 14). Platt and Griffiths (1964) note that "appreciable error due to conduction down the metal" is frequently a problem with soil thermometers. This was evident in the fact that soil thermometer data was approximately 1 C higher than thermocouple data taken at the same location. Sunlight striking the part of the pipe above the surface of the peat was converted to heat and transferred down the pipe to the thermometer. Shading the pipe would probably have resulted in a smaller temperature difference, but some heat transfer is inevitable. The use of plastic pipe for the thermocouple standard and the fact that the top of the pipe was level with the surface of the peat, rather than protruding above it, undoubtedly resulted in less heat transfer and more accurate readings.

Sphagnum is an efficient thermal insulator. A layer of ice was present at a depth of approximately 30 cm under thick *S. angustifolium* cover until mid June in Barclay's Bog, although small patches might have persisted undetected. Ice was present until at least early August 1988 in bogs at Crooked Rapids, approximately 10 km west of Barclay's Bog, and at a bog at Thunder Bay (personal observation). The persistance of ice might have been prolonged by the unusually dry spring and summer of 1988 if melting is hastened by the penetration of warm rain water. The consequences of the persistent frozen layer include increased pooling of water on the bog surface due to decreased water penetration during the spring runoff period, decreasing the potential for water storage and flooding plant communities.

The potential implications of the lower subsurface temperatures of shaded edge areas compared with unshaded central parts of the bog include lower microbial activity and other biological processes and therefore increased peat accumulation rates, longer persistence of subsurface ice in the spring, and quality of receiving waters in terms of temperature and chemical parameters (Brown 1976).

b) Solar radiation

Since no quantitative measurements of light intensity were taken, it is difficult to evaluate the influence of light on the development of plant communities in edge and central areas, except in terms of its influence on temperatures (discussed above).

Insolation is higher near the centre than edges of the bog (Fig. 16), but seasonal variation in the position of the sun will influence the amount of the surface area that is shaded. The study period was near the summer solstice when the sun is at its farthest point north and day length is at its maximum. At other times of the year a greater portion of the bog will be shaded for most of the day. This effect will be more pronounced at the western edge where hills will cast more shade.

c) Water Factor

i) Snow course

Lower insolation resulting in slower snow melt, in combination with greater accumulation due to drifting, cause snow to persist at the edges for a week or more later in the spring than it does in central areas (Fig. 18, 19). The surface of the bog at the centre is exposed to sunlight earlier in the spring than are edge areas or the floor of the forest surrounding the bog. Plant growth, activity of decomposer organisms, and other light- and temperature-dependant biological processes at the centre can benefit from mild temperatures a week or more earlier than edge areas in late April and early May. Persistence of snow therefore could strongly influence the development of plant communities and peat accumulation rates.

Most of the bog vegetation is covered with snow for the greater part of the winter. This was true even during the winter of 1987/1988 when snowfall was well below the 30 year normal (Fig. 2). The plants are therefore less vulnerable to damage caused by extreme low temperatures, water loss, and snow abrasion that is often observed in plants above the level of the snow (Daubenmire 1974). It is possible that this factor operates as a selection pressure on the vegetation of open peatland areas since taller shrubs would be subjected to greater stresses than low sprawling species.

ii) Relative humidity

The higher average relative humidity at the edge station might be a result of moist air moving from the surrounding forest (Fig. 20). The canopy tends to prevent moist air generated by evapotranspiration from dissipating (Daubenmire 1974). At the centre of the bog where there is no tree cover, moist air is free to be carried away by air currents. Alternately, the observed difference in relative humidity might be an artefact of cooler temperatures at the edge station. Warm air can hold more water than cooler air and therefore, relative humidity increases as a body of air is cooled, even though the absolute amount of water contained in the air remains the same (Daubenmire 1974).

2) Surface topography

Barclay's Bog shows only relatively small variation in surface elevation and lacks the convex surface of a "domed bog" (Fig. 21, 24) (Canadian Committee on Ecological Land Classification 1987). The hummocks and hollows zone has some of the characteristics of a "mound bog", with isolated raised mounds occurring on a flatter, more minerotrophic area (Canadian Committee on Land Classification 1987).

Variability in surface elevation is probably a result of a combination of factors including relief of the substratum, presence of *S. angustifolium* lawn and *Sphagnum* hummocks, and water chemistry factors. Successional age of the plant communities in Barclay's Bog is influenced by the relief of the underlying mineral soil. Vitt and Slack (1975) noted that the build up of peat increased from the central open pool, outward in Michigan kettle bogs. A similar situation is present at Barclay's Bog where the shallow edge areas are the first to be filled in with accumulated peat and are the first to undergo succession towards ombrotrophic conditions. This in turn influences the rate of peat accumulation and therefore the surface elevation.

The presence of the S. angustifolium lawn and Sphagnum hummocks are other factors contributing to variability in surface elevation. The S. angustifolium lawn roughly corresponds to the band of higher elevations along the north, west, and south edges of the bog. The presence of S. angustifolium appears to be influenced by microclimate factors (see discussion below). S. fuscum and S. magellanicum hummocks are more or less randomly scattered in the hummock and hollow zone, but probably arise at points initially elevated slightly above the water table. Once hummock development is initiated, it is subject to positive feedback - increased hummock height results in more rapid accumulation of peat as the degree of ombrotrophy increases.

The lower relief at the northeastern edge of the bog is probably in part a result of increased decomposition rate related to water chemistry factors. Peat accumulation tends to be greater at infertile than fertile sites, because of less favorable conditions for decomposer organisms, which results in more rapid peat accumulation, and ultimately greater surface elevations (Heinselman 1970, Malmer 1986). Water chemistry data indicate that the northern tip of the bog is a point of groundwater inflow where concentrations of oxygen and certain nutrients are elevated and therefore conditions for decomposers are more favorable than at other points on the bog.

3) Peat depths

The shape of the basin of Barclay's Bog, with the greatest depths near the centre (Fig. 23, 24), classifies it as a "basin bog" according to the Canadian Wetland Classification System (Canadian Committee on Land Classification 1987) and is consistent with its origin as a glacial kettle hole. No anomalous depths were recorded indicating that the basin is a relatively uniform bowl shape.

4) Peat stratigraphy

Barclay's Bog probably began development soon after deglaciation, approximately 10,000 years B.P. (Sado and Carswell 1987, Terasmae 1977). A thick basal layer of gyttja, typical of peatlands that have gone through a phase as an open water body (Moore and Bellamy 1974), is absent at most cores (Fig. 25), suggesting that Barclay's Bog did not go through a prolonged period as an open pond or lake but began to fill in immediately after the ice block forming the kettle basin had melted. The block may have persisted for several hundred to as much as a thousand years following deglaciation if air temperatures remained sufficiently cold (Florin and Wright 1968). In contrast to Barclay's Bog, thick layers of gyttja recorded at the bottom of bogs in Wisconsin (Winkler 1988) and Maine (Gajewski 1987) are thought to indicate that bog development did not begin for 3000 to 6000 years after deglaciation.

The stratigraphy of Barclay's Bog is more or less consistent with Kratz and DeWitt's (1986) model of autogenic kettle bog development. External factors, however, particularly climate, also appear to be important. The model recognizes two vertical zones of peat accumulation: i) mat peat which is formed on a framework of *C. calyculata* stems and roots and consists of poorly-decomposed *Sphagnum*, graminoid, and ericaceous remains and ii) debris peat which drops from the mat and settles on the bottom of the basin. Debris peat consists of moderately decomposed, unstructured plant remains. As the mat thickens and debris peat accumulates, the two layers meet and form a continuous layer. At stations 2, 54, 70 and 103 at Barclay's Bog, the sharp transition between poorly-decomposed surface peat and amorphous peat probably marks the boundary between mat and debris peat (Fig. 25). In other cores however, mat peat with recognizable macrofossils of sedge and *Sphagnum* remains are found at the bottom of the basin.

Some changes in mat peat composition in a given core are probably due to climatic factors. The thin layer of *Sphagnum* peat overlying sedge peat at stations 2, 12, 70, and 86 suggests that the present *S. angustifolium* lawn is the result of a relatively recent invasion. Heinselman (1970) and Winkler (1988) have interpreted a transition from sedge peat to *Sphagnum* - Ericaceae peat at approximately 3000 years B.P. as a result of changes toward a cooler, wetter climate. The relatively shallow depth to sedge peat below the *S. angustifolium* layer suggests that the invasion is more recent, but without radiocarbon dated samples it is impossible to date precisely. Alternately, the presence of *S. angustifolium* might indicate succession from minerotrophic to ombrotrophic conditions as a result of peat accumulation (Heinselman 1970). In contrast, the relatively consistent sedge peat composition of stations 103 and 122 suggests that these stations have seen little change in the vegetation for much of the bog's history.

The thin layer of well-decomposed peat found at various depths in most of the cores might represent a warm, dry period when that layer (assuming that it is a continuous layer) was at the surface. Svensson (1988) interpreted several thin, highly humified bands through hummocks in a Swedish bog as representing periods of very slow peat accumulation, possibly due to a warming of the climate. A return to cooler, moister conditions caused peat accumulation to resume. A similar layer noted in Wisconsin bogs (Winkler 1988) has been interpreted as resulting from opening of a drainage channel, resulting in lower sedimentation rates and increased decomposition. In either case this layer, although fairly thick in some cores, might represent a relatively short period where the decomposition rate exceeded the deposition rate.

The *S. fuscum* hummock at station 54 has apparently remained with little change for much of the bog's history. The position of hummocks often tend to remain constant during peatland evolution while the pools in between expand and contract. Development of ombrotrophic hummocks is sometimes initiated on the highest points on the underlying mineral soil (Moore and Bellamy 1974; Zoltai and Johnson 1985), but this is not true in this case. Svensson (1988) found that hummock communities often survive for centuries and are less susceptible to changes in climate and variation in water table than are other bog communities. Hollows develop secondarily and are more vulnerable to change.

The presence of a woody layer at the base of cores taken at stations near the edge of the bog (2 and 70) (Fig. 25) suggests that rising water levels resulting from climate or hydrological changes have caused the bog to expand and encroach upon the edges of the surrounding forest (Moore and Bellamy 1974). The "paludification" process has been described in peatlands in Michigan (Futyma and Miller 1986) and Labrador (Foster et al. 1983). The presence of scattered wood chips and twigs that are found at varying depths in many of the cores, on the other hand, are probably a result of tree branches falling onto the bog surface rather than transitions in the bog vegetation.

Fire does not appear to have been an important factor in the development of Barclay's Bog. There is not a continuous layer of charcoal which would be present if the surface of the bog had been burned. Charcoal is present only at edge stations which is probably from fire in the surrounding forest. When fire does occur, it can influence peatland development by causing changes in species abundance and altering the hydrology. Sphagnum is usually killed, causing a decrease in moisture at the surface and allowing more xerophytic species to invade (Foster and Glaser 1986, Jasieniuk and Johnson 1982). The presence of several layers of charcoal at depths of 70 cm to 79 cm at station 2 and 61 cm to 62.5 cm at station 122 indicates the occurrence of several successive fires in the forest during a relatively brief period. The layer of sand in the peat below the charcoal-containing layer at station 2 might be a result of increased erosion on slopes surrounding the bog.

The presence of sand mixed with the peat at the base of some of the cores is puzzling. The pieces are probably too large to have been deposited by wind and may be a result of erosion from the surrounding banks, or mixing of the underlying mineral soil by waves or animals during the early stages of the bogs development.

5) Soil Loss-on-ignition

The maximum LOI values of most cores (90 to 96%) (Table 6) is similar to the surface peat in ombrotrophic conditions recorded by Zoltai and Johnson (1985) in an Alberta peatland. The decrease in LOI in the surface peat compared to the peat immediately beneath it that was observed in the present study was not observed in the Alberta bog and might be a result of a relatively recent increase in atmospheric deposition of dust associated with nearby road construction or gravel extraction.

The highest LOI values (lowest mineral content) are at station 54, a _S. fuscum_ hummock. The surface of this hummock is ombrotrophic and receives all minerals from the atmosphere. Lower LOI values were recorded at other stations where contact with groundwater is greater as sand and clay particles, as well as dissolved minerals are carried into the bog and accumulate in the peat. The general decrease in LOI with depth that is seen at most stations is a result of the gradual decomposition of peat and resulting increase in the mineral component. The more abrupt decrease in LOI at the bases of cores at stations 12 and 103 is due to mixing of the peat with the underlying sand. The well decomposed layer of peat that was described in the stratigraphy section has lower LOI than the peat above or below. This might be a result of an influx of mineral rich groundwater during bog development, deposition of sand or dust from the atmosphere (either of which could increase the rate of decomposition) or simply a period of rapid decomposition resulting in loss of the organic portion of the peat and increased concentration of the inorganic portion.

6) Hydrology

The absence of inlet and outlet streams and difficulty of measuring seepage and evapotranspiration make it difficult to construct a precise water budget for Barclay's Bog. However, it is possible to identify important components of the hydrologic cycle.

Low calcium concentrations (0.8 to 6.1 mg/l) (Table 8, Fig. 33) suggest that the bog is either perched above, or sealed to a large extent from the local water table by a layer of compact, impermeable peat. Groundwater in areas with similar soil and bedrock in northern Minnesota has calcium concentrations greater than 10 mg/l, surface runoff concentrations of 2.0 to 10 mg/l, and precipitation concentrations of 0.3 to 2.0 ml/l (Boelter and Verry 1977). The depth of the bog basin (greater than 5 m) (Fig. 23), presence of a relatively shallow water table in the mineral soil at the edges of the bog, and similar elevation to nearby Hawkeye Lake suggest that the bog is sealed rather than perched above the local water table.

Barclay's Bog appears to be a "dead end" section of a larger watershed that drains into Hawkeye Lake to the north. Water chemistry data (see discussion below) indicate that some flow from this watershed enters the bog basin at the northern tip. The volume of water inflow has created minerotrophic conditions at the northern-most tip, but is insufficient to appreciably influence the entire bog. The lack of an outlet stream means that incoming groundwater, as well as precipitation are stored until lost through evapotranspiration or seepage. Surface runoff from hillsides at other points on the bog margin has a smaller, but measurable effect on the bog water chemistry. This perhaps explains the apparent conflict between surface topography and water chemistry data which indicates that water inflow, instead of outflow, occurs at the lowest point in the bog basin. During years with greater snow accumulations than were recorded during the study period, water levels will be higher during spring snow melt and some surface runoff from the bog may occur at this time. Water would probably escape from the northern tip of the bog where the topography of the basin is lowest and would lead to a reversal of the direction of flow.

Evapotranspiration is difficult to measure in peatlands due to fluctuations in the water table, variation in albedo with different plant cover, and seasonal differences in transpiration rate (Boelter and Verry 1977, Ingram 1983). Few studies have examined this aspect of peatland hydrology, but Boelter and Verry (1977) conclude that evapotranspiration is more important than seepage and streamflow as a water output from Minnesota peatlands. The same is probably true for Barclay's Bog since it occurs on similar soils and is exposed to similar climatic conditions as the Minnesota bogs. The absence of tree cover over most of Barclay's Bog causes higher surface temperatures and allows greater air movement, suggesting that evaporation might be more important here than in treed bogs.

a) Water table depth

Spatial variation in water table depth is mostly due to surface elevation. Factors influencing these parameters are discussed below in the surface elevation section.

Water table depths and surface elevations were not recorded during the spring runoff period, but might not be as high as during the late fall despite the fact that there is generally more water present in the spring. During 1987 and 1988, the bog remained frozen until most of the snow melt and runoff had occurred, preventing water from penetrating the surface. As a result, much of the low-lying central part of the bog was covered by pools of surface water during this period. At least in some years, perhaps spring snow melt is not as important a source of water to the bog as it is to some other ecosystems, because much of this water undoubtedly evaporates or runs off without penetrating the frozen surface. The presence of surface pools influences the vegetation (little or no *Sphagnum* is present in most of the hollows) and also appears to increase the rate of decomposition of underlying peat, and hummocks where they contact the pools. Many of the *S. fuscum* hummocks that are surrounded by pools during the spring snow melt show evidence of erosion at the point of contact with the pools (personal observation). This is probably a result of increased decomposition where the oxygen-rich pool water comes in contact with hummock peat (atmospheric oxygen penetration is much greater in pools than in peat resulting in more rapid decomposition [Sikora and Keeny 1983]). A similar mechanism has been described for the development of "string" patterns in large boreal peatland complexes (Foster *et al.* 1983). Whether rates of peat production by hummocks in Barclay's Bog are sufficient to counterbalance rates of decomposition, or whether the hummocks are experiencing a net loss of peat require further study.

The zone of water table fluctuation (layer of peat between the maximum and minimum water table) is significant because redox-sensitive cations (iron, aluminum and lead) accumulate here in the form of sulphides (Damman 1978). Metal cations are deposited from the atmosphere and accumulate in the acrotelm where they increase in concentration as the peat decomposes. As this layer is moved below the water table and encounters anaerobic conditions, metal ions are converted to water-soluble, reduced states and combine with hydrogen sulphide to form metal sulphides. Fluctuation of the water table causes sulphides to be exposed to oxygen and reoxidized to insoluble metal sulphates which accumulate near the surface of the water table. During the study period, the zone of water table fluctuation in Barclay's Bog ranged from approximately 20 cm thick in edge areas to less than 10 cm thick near the centre (Fig. 22). The layer is closer to the surface in centre areas than in edge areas.

b) Surface elevation fluctuation

Larger surface elevation fluctuations at the centre compared to the edges of Barclay's Bog are a result of the shape of the bog basin. Near edges of the bog, accumulation of peat has filled the basin to the bottom ("grounded mat"). Near the centre, the floating mat is advancing faster than it is filling with debris peat below (Kratz and DeWitt 1986). Where the mat is grounded, a precipitation increase causes a rise in water table, but only small changes in surface elevation (Fig. 26, 27). On the floating mat, a precipitation increase causes a small change in water table relative to the peat surface, but causes the surface to rise. Buell and Buell (1941) observed similar conditions in a Minnesota kettle bog where surface fluctuation was small on parts of the bog underlain by solid peat, but increased closer to the centre pool where fluctuations of up to 70 cm were observed. The floating mat areas provide a constant environment in terms of water conditions for the plant communities because the surface is neither flooded nor desiccated as the water table moves up and down.

Almendinger _et al._ (1986) found that surface elevation of a Minnesota raised bog fluctuated by as much as 10.7 cm in a season and that the greatest rise in surface elevation occurs in deeper peat. They conclude that the change in elevation is a result of swelling of the sub-surface peat caused by increased artesian pressure. Greater fluctuations are observed in deeper peat because there is a greater volume of "expandable medium" available. Although a superficially similar pattern is seen in Barclay's Bog, (greater fluctuations in elevation occurring where the peat is deepest) it is likely that different forces are involved. Barclay's Bog is much smaller than the large peatland complex studied by Almendinger _et al._ (1986); the smaller watershed that it serves is probably insufficient to generate the hydraulic gradient required to produce enough artesian pressure. Instead, fluctuations are due merely to variations in amount of water stored in the bog.

Water chemistry data (discussed below) indicates that heavy rains in late July and early August of 1988 did not result in a large influx of groundwater. Consequently, the rise in water table during this period is primarily from precipitation rather than runoff. Had these rains not been preceded by a prolonged dry period, runoff would probably have been greater (i.e. less water would be absorbed by soil, litter, etc) and the same amount of rain would produce a larger rise in surface elevation.

7) Water chemistry

a) Bog water pH

Spatial variation

Differences between pH and hydrogen ion concentration data are obvious (Fig. 28 a and b). The logarithmic nature of the pH scale results in more contour intervals in less acidic areas, and fewer intervals in more acidic areas, when compared to hydrogen ion concentration data. Due to the method of calculating mean pH (pH values were first converted to hydrogen ion concentrations before performing calculations and then converted back to pH), the map showing mean pH values (Fig. 28 a) more closely resembles the minimum pH map (Fig. 29 b) than it does the maximum pH map (Fig. 29 a). This leads to the conclusion that hydrogen ion concentration is a more suitable indicator of chemical gradient that is present in the bog waters than are pH values. Nonetheless, pH values are more widely reported in the literature, and for the sake of comparison will be used in this discussion. The pH isopleths can serve to indicate broad patterns of water movement and changes in water chemistry over time, even if they are less accurate than hydrogen ion concentration isopleths.

Gorham *et al.* (1985) states that the transition from fens receiving groundwater to bogs receiving only atmospheric deposition is marked by a decline in pH from about 6.0 to 4.0. Glaser *et al.* (1981) found that water samples from ombrotrophic plant communities at Red Lake in northern Minnesota had pH values of less than 4.2. Rich fens samples had pH values between 5.1 and 7.0 and poor fen samples ranged from 3.8 to 5.1. On this basis, a small area at the northern tip of Barclay's Bog is classified as rich fen (the size of which varies seasonally), poor fen conditions are present at much of the central part of the bog, and ombrotrophic conditions are present at the *S. angustifolium* lawn.

The concentric pattern of pH isopleths originating at the northern tip suggests that this point is the primary source of groundwater (Fig. 29, 30, 31). The pH of groundwater with a relatively high concentration of bicarbonate ion (which buffers in the range of pH 6.0 to 8.0) decreases as a result of dilution with rainwater and cation exchange by *Sphagnum* as the water flows out into the bog basin (Boelter and Verry 1977, Vitt and Bayley 1984). Slightly higher pH readings at standpipes near the western and southern edges of the bog compared to those closer to the centre suggests that a minor minerotrophic lagg zone is present there. Mineral rich surface runoff from steep hillsides at the western and southern edges of the bog result in elevated pH compared to nearby *S. angustifolium* lawn stations.

Temporal variation

The drop in bog water pH observed between July 28 and August 04 was concurrent with a period of heavy precipitation (Fig. 17, 28, 29, 30). Evaporative concentration of organic or inorganic acids in the upper peat layers during the dry, early summer was followed by flushing of accumulated acids into the water table during heavy rain in early August, thus causing the bog water pH to drop. At the centre pool, pH fluctuations were smaller than at standpipes. Evaporative concentration of acids is less pronounced due to the large volume of stored water in the pool and therefore no acid flush was observed (Fig. 30).

LaZerte and Dillon (1985) observed a drop in pH in the outflow stream from a conifer swamp in southern Ontario (where atmospheric sulphur deposition is high) when heavy precipitation followed a dry summer period. Sulphur output was near zero during the summer, but increased dramatically following autumn rains. Sulphur entering the swamp during summer in the form of atmospheric deposition or inflow is retained and oxidized to sulphate, which is flushed out with subsequent rains, causing pH to drop. Alternatively, organic acids (fulvic and hydrophilic acids) might be regulating the bog water pH. Hemond (1980) and McKnight *et al.* (1985) conclude that these acids are primarily responsible for maintaining bog acidity. Organic acids are produced by decomposition of plant material primarily in surface *Sphagnum* layer and moderately humified peat. They can become concentrated as a result of evapotranspiration (McKnight *et al.* 1985). In Barclay's Bog, where atmospheric sulphur deposition is relatively low (Barclay *et al.* 1985), organic acids are probably more important than sulphate.

Contrary to expectations, heavy rains in late July and early August did not result in an influx of cation-rich groundwater and consequent rise in pH near the northern tip of the bog. This might be because soil and humus layers of the forest floor were dry and absorbed most of the rainfall before it reached the water table, resulting in very little runoff.

b) Peat pH

Gradual reduction in peat pH with increasing depth suggests that subsurface peat is not in contact with groundwater (Fig. 32), unlike conditions observed in an Alberta peatland by Zoltai and Johnson (1985). Had the subsurface peat been fed by groundwater, pH would increase markedly at the level where groundwater was present (Zoltai and Johnson 1985). Gradual increase in peat pH with depth is probably due to increased concentration of cations (and therefore increased buffering capacity) associated with the gradual increase in the degree of peat humification.

c) Concentrations of major ions

Verry and Timmons (1982) and Hemond (1980) have described peatlands as "sinks" where annual inputs of many nutrients exceed the outputs, with the remainder accumulating in the peat. In Barclay's Bog, elevated levels of minerals that would be expected where there is no outlet stream and evapotranspiration is the major output of water, were not observed because the annual accumulation of minerals are buried in peat.

Nutrient loss in the form of herbivory is probably small. The most important herbivores appear to be grasshoppers (Orthoptera: Acrididae) which are present in high numbers in mid to late summer. Sedges are their preferred food, but *S. angustifolium*, and probably other plants, are also occasionally used (personal observation). Gray jays (*Perisoreus canadensis*) and blue jays (*Cyanocitta cristata*) were observed feeding on grasshoppers on numerous occasions, particularly in early autumn when cool weather slowed the insects. This might represent a minor loss of nutrients from the bog system as birds may remove more nutrients from the bog than they contribute (Sturges *et al*. 1974).

Unlike the large peatland complex studied by Heinselman (1970), there is little correlation between surface topography and water chemistry parameters (except weak relationships between elevation and pH and sodium concentrations) (Table 9). Similarly, most elements show only weak relationships with *S. angustifolium* cover. This could indicate that water samples were drawn from more mineral-rich groundwater beneath the thin layer of ombrotrophic surface peat and that the surface peat does not greatly influence the chemistry of underlying waters. Siegal and Glaser (1987) found that calcium concentrations at a depth of 1 m in a large Minnesota peatland were similar to concentrations in the groundwater of surrounding uplands. Decreases in calcium concentration in surface peats are due to dilution with rain water and uptake and absorption by *Sphagnum* and other plants. In the case of Barclay's Bog however, peat pH values do not indicate pronounced minerotrophic conditions in the subsurface peat. The relationship between surface topography and water chemistry requires further study.

It is also important to note that these conclusions are based on a single set of readings and concentrations are probably variable through the season. The water samples were collected in October when water table level is close to its maximum during the study period (Fig. 27) and after relatively heavy precipitation in August and September (Fig. 2). Higher concentrations of elements might have been observed during drier periods when the rate of evaporation is greater (Urban *et al.* 1987).

Sulphur

The decrease in sulphur concentration in bog waters compared to precipitation is probably a result of sulphate reduction in the low oxygen conditions of the subsurface peat (Table 8). Bayley *et al.* (1987) found that sulphate concentrations in surface waters of an experimentally acidified peatland increased immediately after irrigation events, but then decreased rapidly. The concentration of reduced sulphur in the form of H_2S was found to increase in some cases after application of acid; the sulphate was exposed to the low oxygen conditions of the subsurface peat and reduced to sulphide. Absorption by *Sphagnum* and/or peat are offered as other possible explanations for the loss of sulphate from surface waters. Gorham *et al.* (1985) also noted lower sulphate concentrations in bog waters than in precipitation and concluded that plant uptake and microbial reduction are factors responsible for such concentrations.

Phosphorus

Phosphorus concentrations in Barclay's Bog are strongly correlated with concentrations of magnesium, iron and aluminum (Table 9). Phosphorus enters peatlands in the form of dustfall and groundwater runoff and tends to form insoluble chemical complexes with metal cations under low pH conditions (Damman 1978). Waughman (1980) found that total phosphorus was higher in fen peat, but extractable phosphorus was higher in bog peat, probably as a result of binding with iron and aluminum in more minerotrophic conditions. Lower mean phosphorus concentrations at *S. angustifolium* stations (Table 8) might be a result of increased isolation from groundwater.

Sodium and potassium

Vitt and Bayley (1984) found that cations in inflow water were depleted when the water moved through the peatland from edge to central areas. Uptake of nutrients by vegetation and cation exchange with peat were thought to be responsible. Similarly, Boelter and Verry (1977) note that cation exchange causes concentrations of sodium, potassium, and other cations in groundwater to decrease as the water moves through or across organic soils.

Distribution patterns of sodium and potassium concentrations in Barclay's Bog indicate that these elements enter the bog basin primarily in groundwater flow originating at the northern tip, similar to the pattern that was observed for pH data (Fig. 28a, 33c, d). Concentrations decrease as water moves towards the centre of the bog and are lowest at the southwest edge. Sodium concentrations in bog approach those of precipitation at station 60 at the south edge of the bog. It appears that depletion of cations due to cation exchange is occurring as groundwater moves outward from the northern tip.

Manganese and magnesium

Manganese and magnesium enter peatlands primarily in groundwater, and in Barclay's Bog remain approximately an order of magnitude above precipitation levels at all stations (Table 8). Concentrations of both elements are somewhat higher than those measured by Vitt and Bayley (1984) in northwestern Ontario kettle bogs, probably as a result of regional variation in the mineral composition of bedrock or overburden (Fig. 33e, f).

Iron and aluminum

Iron and aluminum concentrations in the present study are similar to those recorded by Urban _et al._ (1987) and Vitt and Bayley (1984) in peatlands in the central part of the continent (western Ontario, Minnesota, Manitoba) (Fig. 33g, h). Urban _et al._ (1987) concludes that concentrations of these elements depend on atmospheric deposition of soil particles. Variation in pH or the binding of iron and aluminum with organic matter are not important as has been suggested in past studies.

Within Barclay's Bog there is apparently little variation in atmospheric deposition. A paved road passes within approximately 60 m of the north edge, separated from the bog by a strip of forest approximately 50 m wide, and is a possible factor contributing to higher concentrations of elements at the northern tip of the bog. Santelmann and Gorham (1988) found that concentrations of aluminum and iron among other elements are strongly correlated with distance from a gravel road in Sphagnum samples from a raised bog in New Brunswick. However since the road is presently paved, the amount of dust raised is probably minimal. Before being paved the road might have been a more significant source of atmospheric dust, but the strip of forest between the road and the bog would act as a filter, removing dust before it reached the bog surface. The configuration of the basin surrounding the bog would also cause the air currents to swirl around and deposit the dust evenly over the surface. There is also an inactive sand/gravel pit approximately 150 m from the north edge of the bog which could have contributed dust fall to the bog, but this is close to the 200 m limit beyond which Santelmann and Gorham (1988) found concentrations fell to levels similar to uncontaminated areas.

Concentrations of iron and aluminum therefore depend on other factors including the influence of groundwater. The high concentrations of aluminum and iron at station 85 at the northern tip of the bog is consistent with the hypothesis that this is a point of groundwater inflow. However, the higher aluminum and iron concentrations at the ombrotrophic stations (ie 11, 14, 28, 70) compared to those near the centre (where pH indicates more minerotrophic conditions) is contrary to expectations unless the lower pH has resulted in chemical reduction of these elements and therefore increased solubility. Concentrations of aluminum and iron however, show only a rather weak negative correlation with pH. More intensive sampling over a longer period of time would help to establish the relationship between cation concentrations, ground water movement and pH.

Calcium

High calcium concentrations are frequently used as indicators of minerotrophic conditions in peatlands. Conditions in Barclay's Bog are similar to the "semi-ombrotrophic bogs" (1.5 to 3.5 mg/l) described by Heinselman (1970) with the exception of several stations close to the edge of the bog (5 to 6 mg/l) where concentrations indicate weakly minerotrophic conditions (Fig. 33 i). The term "semi-ombrotrophic" is used in the sense of peatlands receiving groundwater runoff only occasionally through the year or receiving groundwater that has percolated through peat and is consequently low in nutrients. Gorham *et al.* (1985) states that the transition from fens receiving groundwater to bogs receiving only atmospheric deposition is marked by a decrease in calcium concentration below about 7 mg/l. Strongly ombrotrophic bogs have as low as 0.7 mg/l. Concentrations in Barclay's Bog vary from close to the upper end of this range at stations along the southwest edge to the low end at the centre pool. Glaser *et al.* (1981) found calcium concentrations ranging from 0.8 to 2.1 mg/l in ombrotrophic bog communities and from 3.0 to 13.5 mg/l in rich fens. Calcium concentrations indicating poor fen conditions overlapped bog vegetation and rich fen vegetation.

The trend of declining concentrations from the presumed point of inflow at the northern tip of the bog toward the centre that was observed for potassium and sodium and also noted by Vitt and Slack (1975) was not observed for calcium although high concentrations were recorded at station 85. This might be due to a second source of calcium ions in the form of dustfall or animal activity, or variable rates of evaporative concentration and/or plant uptake. Calcium concentrations are lowest at the centre pool station where they approach mean precipitation levels and are as low as the lowest concentration in ombrotrophic bogs studied by Heinselman (1970). Evaporative concentration of calcium at the standpipe stations and the dilution effect of the large body of water in the pool might be responsible for lower concentrations observed there.

Relatively high concentrations of calcium, along with sulphur, magnesium, manganese, and iron are found at station 1 in comparison with surrounding stations, suggesting that this might be a minor source of groundwater inflow. The topography (a shallow valley between two hills descends to the edge of the bog at this point) and presence of fen vegetation including _Iris versicolor_ and _Potentilla_ *palustris* (Heinselman 1970) support the hypothesis that this is a point of inflow of mineral-rich groundwater. Calcium concentrations at stations near the southwest edge of the bog are similar to values reported for surface flow (2 to 10 mg/l) in similar soil and bedrock conditions in northern Minnesota (Boelter and Verry 1977).

Zinc

Zinc concentrations in Barclay's Bog are higher than those recorded by Urban *et al.* (1987) at most stations (Fig. 33j). These authors calculated enrichment factors in bog waters compared to precipitation values using aluminum as a normal (aluminum was assumed to be supplied primarily by soil dust) and concluded that zinc originates primarily from anthropogenic sources. In the present study, the fact that zinc concentrations are elevated while concentrations of lead and cadmium remain relatively low suggests that zinc concentrations in the local groundwater or dustfall are abnormally high. Possibly samples were contaminated.

Cadmium and lead

Cadmium and lead in bogs originate primarily from air pollution (Santelmann and Gorham 1988, Urban *et al*. 1987). These elements tend to occur at lower concentrations in bog waters than in precipitation, probably due to adsorption to peat. In Barclay's Bog, cadmium and lead occur at very low levels, mostly below detection limits. Lead concentrations measured by Urban *et al.* (1987) were (with only three exceptions) below the detection limit of 0.025 mg/l used in the present study, even in the most polluted areas. The results presented here are therefore of little value in assessing pollution levels in this part of northwestern Ontario.

d) *Calcium : Magnesium ratio of bog waters*

Calcium : magnesium ratios in the surface waters of Barclay's Bog are similar to those recorded by Waughman (1980) in peat samples from German peatlands. Ratios of 1:1 or less have been considered to be indicators of ombrotrophic conditions by some earlier authors because this is similar to the ratio in precipitation (see Waughman 1980). This is not the case in Barclay's Bog where higher ratios are found in the less minerotrophic parts of the bog (ie *S. angustifolium* lawn) than in other areas (Fig. 34). Higher ratios in ombrotrophic rather than minerotrophic areas have also been recorded in Minnesota (Heinselman 1970) and Germany (Waughman 1980) perhaps due to selective adsorption of magnesium ions by *Sphagnum* (Waughman 1980).

8) Vegetation

The ordination scattergram indicates that the three vegetation zones on Barclay's Bog (*S. angustifolium* lawn, hummocks and hollows zone, and floating mat) intergrade with one another, rather than exist as discrete units (Fig. 35a). Similar patterns were observed by Vitt and Bayley (1984) using data from northwestern Ontario kettle bogs. They conclude that "...the vegetation exists as a series of gradients with individual plant species occupying overlapping habitat ranges." In Barclay's Bog, the hummock and hollow zone is a transition area with hummocks similar to the *S. angustifolium* lawn zone and hollows similar to the floating mat zone in terms of vegetation and water table conditions. This accounts for the wide horizontal scatter of the hummock and hollow quadrats in the ordination.

The vegetation of Barclay's Bog appears to be responding to a combination of environmental gradients. The factor that best accounts for the horizontal spread of points in the polar ordination scattergram is distance from edge of the bog (Fig. 35b). Distance from edge actually represents the sum of numerous factors including successional age (and associated changes in surface elevation and water table), hydrology, and microclimate. The wide vertical spread among edge quadrats in the scattergram (Fig. 35b) is probably due to invasion of non-peatland species from the surrounding forest. Species such as *Abies balsamea* and *Cornus canadensis* were recorded only in quadrats close to the edge of the bog.

A successional gradient of plant communities is present with the oldest stages of vegetation around the outer perimeter, followed by progressively younger stages, and a primary bare area of open water at the centre (Vitt and Slack 1975, Harris 1987). This pattern of development results from the shape of the basin as more shallow edge areas are infilled earlier during bog development and consequently begin succession sooner (Kratz and DeWitt 1986). The sequence of plant communities surrounding the centre pool at Barclay's Bog is similar to that described by Vitt and Slack (1975) for Michigan kettle bogs. These authors conclude that the distribution of communities is strongly influenced by successional age as a result of changes in water table depth and surface elevation which tend to increase as peat accumulation increases.

In Barclay's Bog, surface elevation and water table depth generally increase from the centre to the edges as peat accumulation increases (Fig. 21, 26), creating drier conditions. The shallow water table over most of the bog is probably responsible for the lack of trees on the bog. The only trees present are on drier *S. fuscum* hummocks. Heinselman (1970) also found that trees were excluded from wetter sites, even where nutrient levels are high. The ombrotrophic-minerotrophic gradient is also associated with successional age when conditions become suitable for

Sphagnum to invade and create acid, nutrient-poor conditions, but as discussed below, there is no obvious relationship between water chemistry factors and distribution of plant communities.

The microclimatological factors associated with shading from the surrounding forest act independently of successional factors, but because they are also correlated with distance from the edge, the influences are difficult to distinguish (Fig 35e). However the presence of significantly lower light conditions and temperatures, greater snow accumulation, and higher relative humidity at the edge suggest that microclimate has strong potential to influence plant communities. Shade is an important environmental factor in the Michigan bogs described by Vitt and Slack (1975). Trees (Picea mariana and Larix laricina) and tall shrubs are absent in the central, wettest parts of the bog, but increase in abundance from the centre, outward. Where trees are abundant and the surface of the bog is well-shaded, S. angustifolium (sensu lato) forms continuous lawns. S. magellanicum hummocks are more abundant in open areas dominated by ericaceous shrubs. Similar lawns have been described in bogs in northwestern Ontario (Vitt and Bayley 1984) and northern Minnesota (Glaser et al. 1981) but are usually found in shaded, Picea mariana-dominated areas. In Barclay's Bog, where trees are virtually absent, the cooler, more humid conditions caused by increased shading on edges of the bog permit S. angustifolium to outcompete other species of Sphagnum and form dense, ombrotrophic lawns. In the central areas that receive more solar radiation, S. angustifolium grows more slowly, and is outcompeted by shade-intolerant species of Sphagnum. Luken (1985) found that S. angustifolium had higher growth rates than S. fuscum and S. magellanicum and was likely to outcompete them in cool, wet conditions, but not in drier conditions.

Unlike the peatlands studied by Heinselman (1970) and Vitt and Bayley (1984), the minerotrophic - ombrotrophic gradient in relation to groundwater inflow does not appear to have a major influence on the vegetation as is observed in the superimposition of mean pH and concentrations of calcium, magnesium, sodium and potassium on the ordination (Fig. 35 f-j). Karlin and Bliss (1984) concluded that the vegetation of weakly minerotrophic peatlands (such as Barclay's Bog) unlike strongly minerotrophic peatlands, responds primarily to gradients of substrate moisture and biotic interaction rather than substrate chemistry. This generalization seems to apply to the present study.

The suggestion by Harris (1987) that S. angustifolium is virtually excluded from the northern tip of the bog by inflow of cation-rich groundwater is not strongly supported by the water chemistry data in the current study. Concentrations of most elements were at most only marginally higher in this area than at other points on the bog (Fig.

33) and *S. angustifolium* cover shows at best weak relationships with the concentrations of most elements (Table 9). Probably during periods of greater runoff, the influx of ions at the northern tip is higher and conditions over the longer term are unsuitable for *S. angustifolium*.

As for future successional changes in the vegetation of Barclay's Bog, peat will continue to accumulate. Eventually higher surface elevations and drier conditions will exist in the wet central areas as the floating mat becomes grounded on debris peat (Kratz and DeWitt 1986). The drier conditions will permit trees (especially *P. mariana*) to invade. Tree cover will maintain shady, cooler conditions and encourage further spread of *S. angustifolium*, resulting in ombrotrophic conditions and exclusion of plant species that require wet hollows or minerotrophic conditions. An exception might occur at the northern tip of the bog; if the influx of mineral-rich groundwater remains sufficient to exclude *Sphagnum* and retard peat accumulation, wet fen conditions will persist. The degree to which this influence will extend toward the centre of the bog is unknown. The conversion to an ombrotrophic treed bog will occur over a long period, probably thousands of years. Conditions on the floating mat are extremely wet and will remain so until accumulated peat has raised the surface above the water table.

CONCLUSIONS

This study has fulfilled the purposes outlined in the Introduction. A description of the microclimate, physical parameters, stratigraphy, hydrology, water chemistry, and vegetation of Barclay's Bog has been completed and provides one of the few baseline studies of a peatland area in this part of Canada.

The data presented in this study has potential to be used for monitoring environmental changes and natural successional processes. Vegetation data and maps of the distribution of plant species that are provided in the present study and in Harris (1987) can easily be repeated at a future date to monitor successional changes. Surface elevations can be remeasured to detect changes in the topography. These kinds of studies are facilitated by the small size of the bog, it's easy accessibility, and relatively undisturbed condition.

Concentrations of pollutants including zinc, lead, and cadmium are generally low and can be compared against future increases in atmospheric pollution or with more heavily polluted areas. Similarly, a detailed picture of the seasonal and spatial variation in pH is provided; this has the potential to be used in acid deposition studies. The variation in water chemistry conditions within Barclay's Bog spans the range of minerotrophic to ombrotrophic and highlights the importance of intensive sampling when classifying peatlands. Seasonal variation in bog water pH may be particularly significant. The relationship between water chemistry, particularly concentrations of nutrients, and water movement requires more study and is a possible area for future research.

Microclimatic factors associated with shading appear to strongly influence the vegetation of Barclay's Bog. Assuming that differences in air temperatures, subsurface temperatures, relative humidity and snow accumulation would be observed between forested and clearcut peatlands, forestry activities could influence all of these factors and in turn affect the quality of receiving waters.

Effect of global warming on boreal peatlands is also of concern. Peatlands store huge amounts of carbon and play an important role in the global carbon cycle. The present study illustrates that even small changes in climate conditions have the potential to alter many peatland processes.

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APPENDICES

Appendix I. Data used to calibrate bimetallic strip thermometers. Temperatures in degrees C where STAND and HTG are temperatures recorded by standard mercury - in - glass thermometer and bimetallic strip respectively, and DIFF is STAND - HTG.

DATE	CENTRE STAND	HTG	DIFF	EDGE STAND	HTG	DIFF
MAY 3	23	22	1	16	17	-1
MAY 10	9	9	0	11	11	0
MAY 10	9	10	-1	11	11	0
MAY 17	12	12	0	13	13	0
MAY 17	13	13	0	13	13	0
MAY 24	9	9	0	10	10	0
MAY 24	9	10	-1	10		
JUN 07	22	21	1	22	22	0
JUN 07	22	22	0	22	22	0
JUN 14	16	16	0	16	14	2
JUN 14	16	16	0	16	15	1
JUN 21	13	13	0	13	10	3
JUN 21	13	13	0	13	11	2
JUN 28	14	13	1	13	12	1
JUN 28	14	14	0	13		
JUL 05	21	21	0	22	20	2
JUL 05	21	22	-1	22	21	1
JUL 12	18	18	0	18	17	1
JUL 12	18	18	0	18	18	0
JUL 19	20	20	0	20	19	1
JUL 19	20	20	0	20	18	2
JUL 26	16	16	0	17	15	2
JUL 26	16	16	0	17	15	2
AUG 02	17	17	0	17	15	2
AUG 02	17	17	0	17	15	2
AUG 09	19	20	-1	19	18	1
AUG 09	19	20	-1	19	17	2
AUG 16	20	19	1	22	21	1
AUG 16	20	20	0	22	20	2
AUG 23	15	15	0	16	13	3
AUG 23	15	15	0	16	13	3
AUG 30	17	16	1	15	12	3
AUG 30	17	17	0	15	13	2
SEP 06	15	16	-1	15	12	3

Appendix II. Data used to calibrate hair hygrometers. ASSMAN and HAIR are relative humidity (%) measured by Assman and hair hygrometers respectively and DIFF is ASSMAN -HAIR.

	CENTRE			EDGE		
DATE	ASSMAN	HAIR	DIFF	ASSMAN	HAIR	DIFF
MAY 3				76	66.4	9.6
MAY 10						0.0
MAY 10	80	53.6	26.4	48	51.4	-3.4
MAY 17	39	30.8	8.2	38	39.2	-1.2
MAY 17	39	35.2	3.8	38	39.2	-1.2
MAY 24	42	53.6	-11.6	44	46	-2.0
MAY 24	42	49.6	-7.6	44	42	2.0
JUN 07	66	75.8	-9.8	66	74.8	-8.8
JUN 07	66	75.8	-9.8	66	64.8	1.2
JUN 14	100	82.4	17.6	100	87.4	12.6
JUN 14	100	86.4	13.6	100	84.4	15.6
JUN 21	95	75.2	19.8	90	87.2	2.8
JUN 21	95	97.2	-2.2	90	79.2	10.8
JUN 28	64	67.6	-3.6	68	63.2	4.8
JUN 28	64	65.6	-1.6	68	53.2	14.8
JUL 05	100	88.4	11.6	90	80.8	9.2
JUL 05	100	90.4	9.6	90	75.8	14.2
JUL 12	56	57.2	-1.2	64	57.2	6.8
JUL 12	56	45.2	10.8	64	47.2	16.8
JUL 19	74	76	-2.0	74	66	8.0
JUL 19	74	75	-1.0	74	70	4.0
JUL 26	98	88.4	9.6	96	81.8	14.2
JUL 26	98	88.4	9.6	96	78.8	17.2
AUG 02	100	88.8	11.2	100	82.8	17.2
AUG 02	100	96.8	3.2	100	78.8	21.2
AUG 09	65	71.6	-6.6	65	76.6	-11.6
AUG 09	65	71.6	-6.6	65	64.6	0.4
AUG 16	96	91	5.0	79	78.8	0.2
AUG 16	96	92	4.0	79	72.8	6.2
AUG 23	95	88	7.0	95	79.4	15.6
AUG 23	95	92	3.0	95	75.4	19.6
AUG 30	70	74.8	-4.8	75	70	5.0
AUG 30	70	74.8	-4.8	75	71	4.0
SEP 06	66	56	10.0	75	56	19.0
MEAN			3.5			7.2

station	HEIGHT	DEPTH
1	26	158
2	22	122
3	33	44
4	46	143
5	30	193
6	42	181
7	31	164
8	26	70
9	44	159
10	32	190
11	33	>250
12	43	>250
13	37	212
14	34	147
15	39	75
16	34	>250
17	24	>250
18	39	>250
19	31	212
20	36	>250
21	36	84
22	36	198
23	33	>250
24	17	>250
25	19	>250
26	28	>250
27	15	>250
28	31	>250
29	45	170
30	33	158
31	40	163
32	27	>250
33	16	>250
34	44	>250
35	27	>250
36	18	>250
37	21	>250
38	40	148
39	45	81
40	30	74
41	25	>250
42	8	>250
43	9	>250
44	10	>250
45	15	>250
46	15	>250
47	19	>250
48	35	175
49	49	70
50	44	76
51	43	111
52	12	>250
53	13	>250
54	40	>500
55	34	>250
56	50	>250
57	22	>250
58	18	>250
59	43	68
60	23	92
61	43	135
62	34	>250
63	17	>250
64	23	>250
65	14	>250
66	28	>250
67	18	>250
68	18	>250
69	60	>250
70	41	177
71	23	79
72	61	61
73	43	134
74	11	>250
75	18	>250
76	12	>250
77	12	>250
78	12	>250
79	17	>250
80	23	>250
81	35	>250
82	36	143
83	49	85
84		0
85	4	28
86	17	44
87	29	83
88	30	210
89	8	>250
90	20	>250
91	13	>250
92	27	>250
93	9	>250
94	13	>250
95	14	>250
96	43	173
97	52	118
98	41	12
99	16	92
100	14	107
101	24	143
102	6	210
103	10	223
104	5	>250
105	39	>250
106	36	>250

station	HEIGHT	DEPTH
107	15	>250
108	38	110
109	42	138
110	24	75
111	30	156
112	2	150
113	14	224
114	4	242
115	11	>250
116	50	>250
117	32	153
118	54	86
119	38	95
120	7	64
121	0	153
122	1	110
123	12	193
124	11	146
125	12	120
126	65	141
127	6	67
128	16	61
129	34	79
130	35	71
131	38	115
132	20	80
133	16	41

Appendix III. Surface elevation (HEIGHT) and peat depth (DEPTH) readings (cm).

station	HEIGHT	DEPTH
1	26	158
2	22	122
3	33	44
4	46	143
5	30	193
6	42	181
7	31	164
8	26	70
9	44	159
10	32	190
11	33	>250
12	43	>250
13	37	212
14	34	147
15	39	75
16	34	>250
17	24	>250
18	39	>250
19	31	212
20	36	>250
21	36	84
22	36	198
23	33	>250
24	17	>250
25	19	>250
26	28	>250
27	15	>250
28	31	>250
29	45	170
30	33	158
31	40	163
32	27	>250
33	16	>250
34	44	>250
35	27	>250
36	18	>250
37	21	>250
38	40	148
39	45	81
40	30	74
41	25	>250
42	8	>250
43	9	>250
44	10	>250
45	15	>250
46	15	>250
47	19	>250
48	35	175
49	49	70
50	44	76
51	43	111
52	12	>250
53	13	>250
54	40	>500
55	34	>250
56	50	>250
57	22	>250
58	18	>250
59	43	68
60	23	92
61	43	135
62	34	>250
63	17	>250
64	23	>250
65	14	>250
66	28	>250
67	18	>250
68	18	>250
69	60	>250
70	41	177
71	23	79
72	61	61
73	43	134
74	11	>250
75	18	>250
76	12	>250
77	12	>250
78	12	>250
79	17	>250
80	23	>250
81	35	>250
82	36	143
83	49	85
84		0
85	4	28
86	17	44
87	29	83
88	30	210
89	8	>250
90	20	>250
91	13	>250
92	27	>250
93	9	>250
94	13	>250
95	14	>250
96	43	173
97	52	118
98	41	12
99	16	92
100	14	107
101	24	143
102	6	210
103	10	223
104	5	>250
105	39	>250
106	36	>250

station	HEIGHT	DEPTH
107	15	>250
108	38	110
109	42	138
110	24	75
111	30	156
112	2	150
113	14	224
114	4	242
115	11	>250
116	50	>250
117	32	153
118	54	86
119	38	95
120	7	64
121	0	153
122	1	110
123	12	193
124	11	146
125	12	120
126	65	141
127	6	67
128	16	61
129	34	79
130	35	71
131	38	115
132	20	80
133	16	41

Appendix IV. Water table depth data (cm) June 16 to August 18 1987.

Depth to water table (cm) 1987

station	Jun 16	Jun 30	Jul 14	Jul 28	Aug 18
1	-20	-36	-26	-33	-12
2	-20	-35	-27	-29	-6
3	-25		-27	-37	-26
4					-31
5	-28		-30	-35	-22
6	-36		-33		-27
7	-27	-37	-29	-33	-15
8		-38	-20	-32	-13
9					-13
10	-29		-27		-24
11	-29	-35	-29		-20
12	-22	-30	-21	-28	-14
13	-34	-37	-30	-34	-22
14	-31	-35	-24	-34	-17
15	-40	-40	-40	-40	-26
16	-25	-31	-21	-30	-11
17	-19	-24	-13	-19	-10
18	-18	-26	-28	-33	-16
19	-21	-28	-20	-23	-14
20	-33		-33		-30
21	-17		-31		-12
22					-32
23	-28		-29	-30	-22
24	-6	-15	-8	-10	-6
25	-6	-4	-7	-8	-1
26	-25	-28	-24	-25	-16
27	-3	-7	-5	-11	-3
28	-22	-33	-24	-32	-19
29					-30
30					-24
31					-34
32	-27	-28	-20	-33	-15
33	-6	-7	-11	-11	-4
34	-37		-36		-29
35	-20	-22	-20	-33	-16
36	-3	-13	-6	-14	-3
37	-11	-18	-15	-20	-8
38	-35		-36		-25
39					
40	-28		-28	-34	-17
41	-10	-17	-18	-23	-10
42	-4	-4	-4	-4	-2
43	-1	-6	-4	-4	0
44	-1	-4	-5	-7	0
45	-3	-4	-4	-5	-2
46	-3	-5	-5	-10	-7
47	-13	-9	-8	-11	-3
48	-33	-34	-29	-33	-19
49					-35
50					-36
51	-27				-32
52	-1	-4	-3	-8	-6
53	-6	-6	-7	-7	-4

Depth to water table (cm) 1987

station	Jun 16	Jun 30	Jul 14	Jul 28	Aug 18
54	-33		-36		-27
55	-25	-30	-28	-29	-21
56					
57	-23	-33	-26	-30	-19
58	-12	-20	-16	-11	-4
59	-33		-34		-25
60	-12	-18	-8	-20	-5
61	-39		-37		-30
62	-19	-18	-18	-22	-13
63	-6	-6	-9	-10	-7
64	-3	-2	-6	-10	-3
65	-2	-1	-10	-8	-9
66	-11	-12	-14	-21	-8
67	-1	-5	-2	-5	0
68	-2	-5	-4	-5	-3
69					
70	-27	-30	-27	-30	-12
71	-16	-28	-17	-24	-11
72					
73	-38		-37		-31
74	-12	-10	-9	-16	-2
75	-9	-11	-9	-16	-6
76	-1	-1	-7	-8	-7
77	0	0	0	-7	-9
78	-1	-2	-4	-8	-2
79	-1	-6	-8	-9	-3
80	-12	-17	-18	-21	-18
81	-33		-37	0	-27
82	-32	-36	-27	-36	-18
83					-36
84					
85					
86	-37		-35		-18
87	-32		-30		-26
88	-29	-37	-19		-14
89	-6	-13	-5	-12	-2
90	-9	-9	-11	-20	-8
91	-7	-8	-7	-16	-7
92	-31	-33	-34	-31	-15
93	-2	-5	-8	-13	-3
94	-4	-10	-5	-10	-5
95	-5	-10	-9	-9	-7
96	-32		-33		-21
97	-38				-30
98					
99	-28	-30	-27	-35	-20
100	-16	-16	-17	-26	-9
101	-30	-6	-13	-32	-22
102	-8	-7	-7	-10	-7
103	-11	-4	-5	-6	-8
104	-5	-5	-2	-7	-4
105			-35		-35
106			-35	-36	-30

Depth to water table (cm) 1987

station	Jun 16	Jun 30	Jul 14	Jul 28	Aug 18
107	-8	-8	-8	-10	-4
108	-30	-32	-24	-25	-14
109			-37		-26
110	-29	-36	-28	-27	-19
111	-39				-34
112	-10	-6	-9	-9	0
113	-6	-10	-23	-14	-7
114	-2	-11	-10	-8	0
115	-7	-5	-10	-12	-2
116					
117	-33	-34	-25	-36	-24
118					-36
119			-28		-13
120	-13	-20	-16	-22	-9
121	-4	-17	-5	-10	0
122	-8	-9	-4	-16	0
123	-19	-29	-22	-27	-17
124	-11	-16	-11	-22	-6
125	-9	-14	-12	-21	-10
126					
127	-24	-37	-25	-32	-14
128	-35		-31	-38	-19
129					-25
130	-36		-28	-36	-24
131					-34
132	-25	-29	-22	-35	-19
133					

Appendix V. Surface elevation fluctuation data (cm) June 09 to November 01 1988.

	STATION							
DATE	A	B	C	D	E	F	G	H
09-Jun	0.0	-35.0	-20.0	-29.0	-26.0	22.0	-32.0	-63.0
14-Jun	0.0	-34.0	-19.0	-28.0	-25.0	23.0	-31.0	-62.0
21-Jun	0.0	-35.0	-19.0	-28.0	-24.0	24.0	-30.0	-60.0
28-Jun	0.0	-35.0	-20.0	-29.0	-25.0	24.0	-31.0	-62.0
05-Jul	0.0	-35.0	-20.0	-29.0	-26.0	24.0	-32.0	-65.0
12-Jul	0.0	-34.0	-19.0	-29.0	-25.0	24.0	-31.0	-66.0
19-Jul	0.0	-35.0	-20.0	-29.0	-25.0	24.0	-32.0	-66.0
26-Jul	0.0	-35.0	-21.0	-29.0	-26.0	23.0	-33.0	-69.0
02-Aug	0.0	-35.0	-21.0	-30.0	-27.0	23.0	-33.0	-64.0
09-Aug	0.0	-34.0	-19.0	-28.0	-28.0	24.0	-30.0	-55.0
16-Aug	0.0	-33.5	-18.5	-26.5	-22.5	24.1	-28.5	-53.5
23-Aug	0.0	-33.5	-17.5	-26.5	-22.5	24.4	-27.5	-51.5
30-Aug	-0.1	-33.5	-17.5	-25.5	-21.5	24.4	-26.5	-50.5
06-Sep	0.0	-33.5	-16.5	-25.5	-20.5	24.5	-26.5	-49.5
13-Sep	-0.1	-33.5	-16.5	-24.5	-20.5	24.9	-25.5	-51.5
20-Sep	0.0	-33.5	-16.5	-25.5	-20.5	24.5	-26.5	-51.5
28-Sep	0.0	-33.5	-16.5	-25.5	-20.5	24.3	-26.5	-52.5
04-Oct	-0.1	-32.5	-15.5	-24.5	-19.5	24.5	-25.5	-51.5
12-Oct	0.0	-34.5	-17.5	-25.5	-20.5	24.3	-26.5	-54.5
25-Oct	-0.1		-15.5	-23.5	-19.5	24.6	-25.5	-51.5
01-Nov	-0.1		-16.5	-24.5	-20.5	24.3	-26.5	-54.5

DATE	I	J	K	L	M	N
09-Jun	-66.0	-68.0	-64.0	-21.0	2.0	-32.0
14-Jun	-65.0	-66.0	-63.0	-21.0	2.0	-31.0
21-Jun	-63.0	-64.0	-61.0	-20.0	3.0	-30.0
28-Jun	-65.0	-66.0	-64.0	-19.0	3.0	-32.0
05-Jul	-70.0	-68.0	-65.0	-20.0	3.0	-32.0
12-Jul	-70.0	-68.0	-65.0	-20.0	3.0	-31.0
19-Jul	-70.0	-68.0	-65.0	-22.0	3.0	-31.0
26-Jul	-74.0	-70.0	-66.0	-23.0	3.0	-31.0
02-Aug	-67.0	-66.0	-64.0	-25.0	2.0	-31.0
09-Aug	-58.0	-61.0	-62.0	-25.0		-31.0
16-Aug	-56.5	-60.5	-60.5	-25.5	2.1	-30.5
23-Aug	-54.5	-58.5	-59.5	-24.5	2.2	-30.5
30-Aug	-53.5	-57.5	-59.5	-24.5	2.1	-30.5
06-Sep	-53.5	-57.5	-59.5	-24.5	2.2	-31.5
13-Sep	-55.5	-58.5	-59.5	-23.5	2.3	-30.5
20-Sep	-54.5	-58.5	-60.5	-23.5	2.2	-32.5
28-Sep	-56.5	-59.5	-60.5	-25.5	2.2	-31.5
04-Oct	-55.5	-58.5	-60.5	-25.5	2.2	-30.5
12-Oct	-58.5	-61.5	-62.5	-25.5	2.3	-31.5
25-Oct	-55.5	-61.5	-60.5	-25.5	2.1	-31.5
01-Nov	-61.5	-64.5	-62.5	-25.5	1.9	-32.5

Appendix VI. Temperatures recorded by Sixes maximum - minimum thermometer (degrees C) at centre station May 29 1987 to November 23 1988. MAX and MIN are maximum and minimum weekly temperatures respectively and MEAN is the mean of MAX and MIN.

DATE	MAX	MIN	MEAN
MAY 29 87	26	7	16.5
JUN 02	29	7	18.0
JUN 09	20	0	10.0
JUN 16	27	6	16.5
JUN 23	30	11	20.5
JUN 30	29	5	17.0
JUL 08	30	3	16.5
JUL 14	23	1	12.0
JUL 21	28	5	16.5
JUL 28	28	6	17.0
AUG 04 87	28	8	18.0
AUG 12	28	5	16.5
AUG 18	29	5	17.0
AUG 25	22	2	12.0
SEP 02	24	4	14.0
SEP 15	25	1	13.0
SEP 22	25	3	14.0
OCT 27	9	-5	2.0
NOV 03	11	-8	1.5
NOV 10	12	-16	-2.0
NOV 17 87	10	-9	0.5
NOV 24	4	-22	-9.0
DEC 01	0	-14	-7.0
DEC 08	2	-21	-9.5
DEC 22	2	-27	-12.5
DEC 29	1	-32	-15.5
JAN 12	-12	-33	-22.5
JAN 19	1	-35	-17.0
FEB 09	-3	-37	-20.0
FEB 16	-5	-35	-20.0
FEB 23 88	5	-28	-11.5
MAR 03	3	-31	-14.0
MAR 10	5	-26	-10.5
MAR 15	6	-17	-5.5
MAR 22	4	-31	-13.5
MAR 29	7	-16	-4.5
APR 05	15	-17	-1.0
APR 12	14	-7	3.5
APR 26	19	-9	5.0
MAY 03	23	-5	9.0
MAY 10 88	30	-3	13.5
MAY 17	20	-5	7.5
MAY 24	27	-3	12.0
JUN 07	35	-3	16.0
JUN 14	34	-2	16.0
JUN 21	30	0	15.0
JUN 28	32	2	17.0
JUL 05	34	0	17.0
JUL 12	37	2	19.5
JUL 19	28	7	17.5
JUL 26 88	30	7	18.5
AUG 02	35	7	21.0
AUG 09	31	6	18.5

DATE	MAX	MIN	MEAN
AUG 16	32	7	19.5
AUG 23	29	3	16.0
AUG 30	23	5	14.0
SEP 06	25	1	13.0
SEP 13	24	1	12.5
SEP 20	22	1	11.5
SEP 28	17	-3	7.0
OCT 04 88	21	-3	9.0
OCT 12	18	-4	7.0
OCT 25	20	-5	7.5
NOV 01	3	-15	-6.0
NOV 08	5	-12	-3.5
NOV 23	7	-15	-4.0

Appendix VII. Shade code readings June 20 to 23 1988. Numbers indicate the sum of shade codes recorded at 2 hour intervals between 10:00 and 18:00 for each grid square. Higher numbers indicate greater shading. The following codes were used:

code	% shaded
5	75 - 100 %
4	50 - 75 %
3	25 - 50 %
2	1 - 25 %
1	no shade

STATION	CODE	STATION	CODE	STATION	CODE
1	15	54	5	108	11
2	11	55	5	109	16
3	9	56	5	110	10
4	14	57	5	111	5
5	8	58	5	112	5
6	6	59	5	113	6
7	6	60	10	114	6
8	7	61	13	115	6
9	19	62	7	116	6
10	9	63	5	117	8
11	6	64	5	118	18
12	5	65	5	119	12
13	5	66	5	120	8
14	7	67	5	121	7
15	13	68	5	122	8
16	6	69	5	123	10
17	5	70	6	124	8
18	5	71	12	125	11
19	5	72	13	126	12
20	6	73	7	127	9
21	7	74	5	128	13
22	16	75	5	129	16
23	7	76	5	130	18
24	5	77	5	131	14
25	5	78	5	132	16
26	5	79	5	133	19
27	5	80	5		
28	5	81	6		
29	6	82	8		
30	15	83	14		
31	7	85	18		
32	5	86	11		
33	5	87	7		
34	5	88	5		
35	5	89	5		
36	5	90	5		
37	5	91	5		
38	5	92	5		
39	16	93	5		
40	9	94	5		
41	6	95	6		
42	5	96	10		
43	5	97	13		
44	5	98	19		
45	5	99	14		
46	5	100	7		
47	5	101	5		
48	5	102	5		
49	11	103	5		
50	16	104	5		
51	7	105	5		
52	5	106	5		
53	5	107	6		

Appendix VIII. Temperatures recorded by bimetallic strip thermometers (degrees C) at centre and edge stations May 06 to August 31 1988.

	CENTRE STATION			EDGE STATION		
DATE	MAX	MIN	MEAN	MAX	MIN	MEAN
MAY 06	14	-1	6.5	15	-2	6.5
7	17	2	9.5	18	1	9.5
8	21	9	15.0	23	7	15.0
9	15	9	12.0			
10	12	6	9.0	11	0	5.5
11	9	-1	4.0	9	-2	3.5
12	6	0	3.0	6	-1	2.5
13	10	-1	4.5	10	-1	4.5
14	16	-1	7.5	17	-2	7.5
15	18	3	10.5	19	2	10.5
16	15	0	7.5	13	0	6.5
17	15	-2	6.5	16	-2	7.0
18	18	-1	8.5	19	-2	8.5
19	22	5	13.5	24	4	14.0
20	25	7	16.0	26	6	16.0
21	18	9	13.5	18	9	13.5
22	21	8	14.5	22	8	15.0
23	19	2	10.5	19	1	10.0
24				14	-2	6.0
25				20	-3	8.5
26	23			24	8	16.0
27	23	10	16.5	24	7	15.5
28	25	8	16.5	26	7	16.5
29	30	11	20.5	29	10	19.5
30	29	12	20.5			
31	30	12	21.0			
JUNE 1						
2						
3						
4						
5						
6						
7	22			22		
8	18	9	13.5	18	7	12.5
9	21	0	10.5	20	-1	9.5
10	26	2	14.0	25	0	12.5
11	30	8	19.0	29	7	18.0
12	32	10	21.0	37	9	23.0
13	20	17	18.5	20	12	16.0
14	25	14	19.5	24	16	22.0
15	18	9	13.5	15	7	13.0
16	19	2	10.5		0	
17	20	2	11.0			
18	25	9	17.0			
19	31	15	23.0			
20	29	10	19.5			
21	30	11	20.5			
22	23	16	19.5			
23	16	4	10.0			
24	21	6	13.5			
25	18	15	16.5			
26	23	6	14.5	21	4	14.5

DATE	CENTRE STATION MAX	MIN	MEAN	EDGE STATION MAX	MIN	MEAN
27	21	7	14.0	20	5	14.5
28	20	13	16.5	18	3	12.5
29	20	1	10.5			
30						
JUL 01	24	2	13.0			
2	26	10	18.0			
3	29	7	18.0			
4	32	13	22.5			
5	25	16	20.5	23	14	20.5
6	34	13	23.5	30	11	22.5
7	35	17	26.0	32	16	26.0
8	28	16	22.0	25	15	22.0
9	30	10	20.0	26	8	19.0
10	24	12	18.0	22	10	18.0
11	18	12	15.0		10	
12	23	10	16.5	21	2	13.5
13	25	3	14.0	23	5	16.0
14	22	12	17.0	20	10	17.0
15	16	12	14.0	14	9	13.5
16	25	11	18.0	23	9	18.0
17	26	10	18.0	24	8	18.0
18	25	9	17.0	25	4	16.5
19	25	12	18.5	24	6	17.0
20	26	9	17.5	24	7	17.5
21	27	9	18.0	25	6	17.5
22	27	9	18.0	25	7	18.0
23	28	10	19.0	27	8	19.5
24	24	12	18.0	22	9	17.5
25	25	12	18.5	23	9	18.0
26	24	9	16.5	22	6	16.0
27	29	9	19.0	27	6	18.5
28	33	11	22.0	29	9	21.0
29	30	17	23.5	28	15	23.5
30	24	11	17.5	21	8	16.5
31	23	10	16.5	21	5	15.0
AUG 01	25	12	18.5	21	7	16.0
2	19	15	17.0	17	12	16.5
3	26	15	20.5	26	13	21.5
4	21	17	19.0	19	15	19.0
5	19	14	16.5	17	13	17.0
6	28	11	19.5	27	9	20.0
7	22	14	18.0	20	12	18.0
8	21	14	17.5	21	12	18.5
9	23	8	15.5	20	5	14.5
10	30	8	19.0	25	6	17.5
11	30	15	22.5	27	13	22.0
12	26	16	21.0	23	13	20.0
13	23	14	18.5	21	12	18.5
14	21	16	18.5	19	16	19.5
15	28	11	19.5	26	10	20.0
16	28	14	21.0	25		14.5
17	20	12	16.0	18	13	17.5

	CENTRE STATION			EDGE STATION		
DATE	MAX	MIN	MEAN	MAX	MIN	MEAN
18	21	6	13.5	17	4	12.5
19	22	5	13.5	20	2	13.0
20	24	8	16.0	21	5	15.0
21	22	20	21.0			
22	17	13	15.0			
23	21	14	17.5	18		
24	22	13	17.5	18	12	18.0
25	16	12	14.0	13	10	14.5
26	18	9	13.5	13	7	13.0
27	16	10	13.0	14	10	15.0
28	16	7	11.5			
29	18	9	13.5			
30	17	7	12.0	14		
31	21	5	13.0		2	

Appendix IX. Weekly maximum (MAX) and minimum (MIN) temperatures recorded by grass thermometers (degrees C) at centre and edge stations May 24 to November 01 1988.

	CENTRE				EDGE		
	MAX	MIN	MEAN		MAX	MIN	MEAN
MAY 24	28.0	-4.0	12.0		32.0	-6.0	13.0
JUN 07	33.5	-3.5	15.0		40.0	-6.5	16.8
JUN 14	32.0	-1.0	15.5		40.0	-5.5	17.3
JUN 21	32.0	1.0	16.5		35.5	-4.0	15.8
JUN 28	29.5	2.5	16.0		36.0	-3.0	16.5
JUL 05	31.0	0.5	15.8		40.0	-4.5	17.8
JUL 12	33.0	3.0	18.0		43.5	-1.5	21.0
JUL 19	28.0	6.5	17.3		36.0	1.5	18.8
JUL 26	32.5	7.0	19.8		38.0	3.0	20.5
AUG 02	32.0	7.0	19.5		40.5	2.0	21.3
AUG 09	29.0	8.0	18.5		32.0	2.5	17.3
AUG 16	31.5	7.5	19.5		34.0	2.0	18.0
AUG 23	30.5	4.5	17.5		31.5	-1.5	15.0
AUG 30	24.0	6.0	15.0		25.5	1.0	13.3
SEP 06	24.5	3.0	13.8		26.5	-2.0	12.3
SEP 13	24.0	1.5	12.8		25.5	-3.0	11.3
SEP 20	24.5	1.0	12.8		24.0	-3.5	10.3
SEP 28	18.5	-3.5	7.5		17.0	-6.5	5.3
OCT 04	21.5	-3.0	9.3		19.0	-6.0	6.5
OCT 12	18.5	-4.5	7.0		13.0	-7.5	2.8
OCT 25	19.0	15.0	4.0	-11.0	5.5	6.8	2.0
NOV 01	2.0	1.0	1.0	-10.5	5.0	-1.8	-4.8

Appendix X. Temperatures recorded by soil thermometers (degrees C) at 0.5 and 1.0 m depths at centre and edge stations May 10 to November 23 1988.

	CENTRE		EDGE	
DATE	0.5 M	1.0 M	0.5 M	1.0 M
MAY 10	2.0	2.0	1.0	2.0
MAY 17	3.0	2.5	0.5	1.5
MAY 24	4.5	3.0	1.5	1.5
JUN 07	8.5	5.0	6.0	3.0
JUN 14	9.5	6.0	6.5	4.0
JUN 21	11.0	7.0	8.5	5.0
JUN 28	11.5	8.0	9.0	6.0
JUL 05	12.0	8.5	9.5	5.5
JUL 12	13.0	9.5	11.0	7.0
JUL 19	13.5	10.0	11.0	8.0
JUL 26	13.5	10.5	11.5	8.0
AUG 02	14.0	11.0	12.0	8.5
AUG 09	14.5	11.0	12.5	9.0
AUG 16	15.0	11.5	13.0	9.5
AUG 23	14.5	12.0	13.0	10.0
AUG 30	14.5	12.0	12.5	10.5
SEP 06	14.0	12.0	12.0	10.0
SEP 13	13.0	12.0	11.5	10.0
SEP 20	12.5	11.5	11.0	9.5
SEP 28	11.5	11.5	10.0	9.5
OCT 04	11.0	11.0	9.5	9.0
OCT 12	9.5	10.5	8.0	8.5
OCT 25	8.0	9.5	6.0	7.5
NOV 01	6.5	8.5	5.0	6.5
NOV 11	5.5	7.5	4.5	5.5
NOV 23	4.5	7.0	3.5	5.0

Appendix XI. Temperatures recorded by thermocouples (degrees C) at various depths at centre and edge stations July 29 to November 01 1988.

CENTRE STATION
DEPTH (CM)

DATE	1	20	40	60	80	100	120	140	160	180	200
JUL 29	29.0	20.4	17.2	15.2	13.1	12.1	10.6	9.6	8.6	8.5	8.1
AUG 03	17.4	17.0	15.8	13.4	12.0	10.4	9.5	8.4	7.9	7.0	6.4
AUG 09	16.7	16.3	14.7	13.5	11.7	10.6	9.2	8.3	7.2	6.6	6.4
AUG 16	18.4	17.4	15.9	14.4	12.5	10.9	10.0	8.8	8.5	7.9	7.2
AUG 23	16.2	16.3	15.4	13.7	12.7	11.2	10.1	8.7	7.9	7.2	6.9
AUG 30	16.0	15.8	15.3	14.6	13.5	12.6	11.2	10.3	9.3	8.5	7.9
SEP 06	14.6	15.2	14.7	13.0	12.2	11.6	10.6	10.0	8.5	7.4	6.7
SEP 13	12.5	12.9	13.2	12.7	12.5	11.3	10.6	9.6	8.5	7.9	6.8
SEP 20	12.6	11.9	11.5	11.2	10.9	10.2	9.4	8.5	7.8	7.1	6.4
SEP 28	9.3	10.1	10.6	10.6	10.5	10.0	10.2	9.2	8.7	7.9	6.7
OCT 04	7.4	8.8	9.1	9.2	9.6	9.5	9.0	8.7	7.9	7.3	6.4
OCT 12	5.9	6.9	7.8	8.5	8.9	8.9	8.6	8.6	7.8	7.1	6.5
OCT 19											
OCT 25	4.8	5.9	6.7	6.9	6.8	7.5	8.3	7.7	8.2	7.5	6.9
NOV 01	3.0	4.6	5.7	6.8	6.9	7.0	7.0	6.9	6.9	6.8	6.8

EDGE STATION
DEPTH (CM)

DATE	1	20	40	60	80	100	120	140	160	180	200
JUL 29	35.6	17.7	14.7	12.7	11.4	10.1	9.1	8.2	7.6	6.9	6.9
AUG 03	19.2	15.3	13.2	11.2	9.5	8.4	7.3	6.2	5.8	4.8	4.6
AUG 09	16.4	15.1	13.2	11.0	10.1	8.0	7.3	6.4	5.8	4.7	4.6
AUG 16	19.3	16.3	14.3	12.3	10.5	9.4	7.9	7.3	6.8	6.4	5.6
AUG 23	19.4	15.3	13.8	12.5	11.3	10.1	8.8	8.0	7.1	6.3	5.8
AUG 30	16.9	13.5	13.0	11.9	10.7	9.9	8.9	7.7	6.8	6.3	5.7
SEP 06	14.2	12.3	12.5	11.4	10.1	9.2	8.3	7.5	6.6	6.1	5.7
SEP 13	10.1	10.6	10.7	10.4	9.5	8.9	7.9	7.2	6.4	5.8	5.4
SEP 20	12.1	10.9	9.5	9.0	8.9	8.0	7.4	6.7	6.2	5.7	4.7
SEP 28	8.7	8.3	8.9	9.0	8.7	8.0	7.8	6.6	6.3	5.7	5.1
OCT 04	6.5	7.0	8.4	8.8	8.3	8.0	7.5	6.9	6.4	5.8	5.3
OCT 12	-1.8	4.3	5.7	6.3	6.3	6.2	6.2	5.4	5.0	4.7	4.3
OCT 19											
OCT 25	-0.4	3.3	4.3	5.1	5.5	5.9	5.7	5.6	5.4	5.0	4.2
NOV 01	-2.2	0.8	2.5	3.8	4.2	4.7	4.7	4.6	4.3	4.2	4.1

Appendix XII. Temperatures measured in standpipes using mercury - in - glass thermometer (degrees C) June 16 to September 20 1988.

Standpipe temperatures 1988 (degrees C)

	STATION												
DATE	1	3	9	11	14	23	25	28	40	43	46	60	61
Jun 16	9			11	9	10	11	10	10	14	14	8	8
Jun 23	10			11	9	11	13	10	10	15	16	10	8
Jun 30	10	12	3	12	10	11	13	11	10	14	15	10	
Jul 07	11	11	5	13	11	12	13	12	12	15	14	11	11
Jul 15	11	10	5	13	12	12	14	12	11	16	16	11	
Jul 22	12	12	6	14	12	12	15	13	12	16	18	12	
Jul 28	12	12	7	14	12	13	15	13		17	17	12	14
Aug 04	13	12	8	14	13	14	15	13	13	16	18	13	13
Aug 11	13	12	10	15	13	14	15	14	13	17	18	13	13
Aug 18	14	12	10	15	13	14	15	13	15	20	18	13	13
Aug 25	13	12	10	14	13	14	15	13	13	17	17	12	13
Sep 01	13	12	11	14	12	14	15	13	13	18	17	12	13
Sep 09	12	10	10	13	11	13	14	12	12	15	15	11	12
Sep 13	12	10	10	13	11	13	14	12	12	15	15	10	12
Sep 20	12	11	10	12	11	12	13	12	12	14	15	10	11

DATE	64	67	70	85	88	92	95	99	103	107	110	119	121
Jun 16	13	15	9	11	11	11		7	13	12			13
Jun 23	13	16	9	11	12	10		7	14	13			13
Jun 30	13	15	10		12	12	14	8	14	13	10	10	13
Jul 07	14	18	11		15	12	16	9	16	14	12	11	14
Jul 15	15	16	11		14	13	16	8	15	15	12	11	14
Jul 22	15	18	12		14	15	17	8	15	15	11	10	15
Jul 28	15	17	12		14	14	17	9	16	16	13		15
Aug 04	17	17	13	14	14	15	17	11	17	16	13	12	15
Aug 11	17	18	14	14	16	15	17	11	17	16	14	13	16
Aug 18	17	18	13	14	16	15	18	11	17	17	14	13	15
Aug 25	16	17	13	13	15	15	16	11	17	16	13	13	15
Sep 01	16	17	14	13	15	14	15	11	16	15	13	13	15
Sep 09	15	16	12	12	13	14	14	10	15	14	12	12	13
Sep 13	15	15	12	12	13	15	14	11	15	14	12	12	13
Sep 20	14	15	11	12	13	13	13	10	14	13	12	11	13

DATE	124	127	pool
Jun 16	11	11	23
Jun 23	10	11	22
Jun 30	11	12	21
Jul 07	12	11	30
Jul 15	12	12	17
Jul 22	13	12	22
Jul 28	13	13	24
Aug 04	14	13	21
Aug 11	13	14	23
Aug 18	15	14	23
Aug 25	14	15	17
Sep 01	13	14	21
Sep 09	13	13	18
Sep 13	13	12	20
Sep 20	12	12	16

Appendix XIII. Snow depths (cm) measured at selected stations December 01 1987 to April 26 1988.

DATE	STATION												
	97	96	95	94	93	92	91	90	89	88	87	86	85	wood
DEC 01	15	15	12	12	10	12	12	12	13	15	10	15	14	5
DEC 08	11	13	10	10	10	10	9	11	8	9	9	12	11	6
DEC 22	36	26	24	25	24	23	24	26	23	21	25	29	27	24
DEC 29	32	24	18	23	23	21	22	22	22	17	23	25	25	22
JAN 06	33	26	20	25	25	23	25	25	25	17	26	30	26	24
JAN 12	35	26	25	29	31	22	25	32	30	24	31	35	31	28
JAN 19	35	28	25	30	31	24	27	32	30	23	30	36	30	28
FEB 02	54	38	39	46	45	35	36	46	46	34	50	53	46	37
FEB 09	52	36	38	44	43	33	37	45	45	32	48	53	46	36
FEB 16	54	37	41	49	48	35	38	48	46	32	51	55	48	40
FEB 23	58	38	41	49	50	33	38	48	47	28	51	56	52	41
MAR 03	62	42	44	53	52	36	37	51	51	32	55	59	55	42
MAR 10	68	49	43	59	58	43	45	58	55	35	59	62	60	45
MAR 15	76	53	52	64	63	42	40	60	60	40	67	68	69	48
MAR 22	73	52	51	61	61	42	51	58	57	38	63	65	65	47
MAR 29	69	46	46	56	53	35	35	49	51	31	57	58	60	44
APR 05	59	35	33	42	37	23	7	35	37	17	40	44	45	36
APR 12	37	0	0	0	0	0	0	0	0	0	3	4	12	20
APR 26	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix XIV. Maximum (MAX) and minimum (MIN) daily temperature-corrected relative humidity (%) measured by hair hygrometer at centre and edge stations May 06 to August 31 1988. MEAN is mean of MAX and MIN. CORR is MEAN relative humidity corrected for instrument error.

	CENTRE STATION				EDGE STATION			
DATE	MAX	MIN	MEAN	CORR	MAX	MIN	MEAN	CORR
MAY 06	65.6	36.6	51.1	54.6	91.2	57	74.1	81.3
7	66.8	32.8	49.8	53.3	92.4	58.2	75.3	82.5
8	69.6	48.4	59.0	62.5	94.8	64.2	79.5	86.7
9	69.6	72	70.8	74.3				
10					92	42.4	67.2	74.4
11					91.2	83.6	87.4	94.6
12					91.6	94.4	93.0	100.2
13					91.6	38	64.8	72.0
14					91.2	38.8	65.0	72.2
15					92.8	53.6	73.2	80.4
16					92	37.2	64.6	71.8
17	75.2	36	55.6	59.1	91.2	40.4	65.8	73.0
18	75.6	49.2	62.4	65.9	91.2	39.6	65.4	72.6
19	92	58.8	75.4	78.9	93.6	51.6	72.6	79.8
20	84.8	66	75.4	78.9	94.4	64.4	79.4	86.6
21	85.6	89.2	87.4	90.9	95.6	85.2	90.4	97.6
22	85.2	42.4	63.8	67.3	95.2	41.8	68.5	75.7
23	82.8	51.6	67.2	70.7	92.4	41.6	67.0	74.2
24					91.2	39.6	65.4	72.6
25					90.8	33	61.9	69.1
26		31.2			95.2	43.6	69.4	76.6
27	96	73.2	84.6	88.1	94.8	70.6	82.7	89.9
28	87.2	72	79.6	83.1	94.8	69.4	82.1	89.3
29	88.4	56	72.2	75.7	96	57.6	76.8	84.0
30	96.8	57.6	77.2	80.7				
31	88.8	68	78.4	81.9				
JUNE 1								
2								
3								
4								
5								
6								
7		82.8				48.8		
8	78.6	33.2	55.9	59.4	94.8	43.2	69.0	76.2
9	74	24.4	49.2	52.7	91.6	41	66.3	73.5
10	74.8	29.4	52.1	55.6	92	36	64.0	71.2
11	77.2	24	50.6	54.1	92.8	30.6	61.7	68.9
12	78	40.8	59.4	62.9	89.6	42.8	66.2	73.4
13	80.8	82	81.4	84.9	89.8	73	81.4	88.6
14	85.6	78	81.8	85.3	89.4	73.6	81.5	88.7
15	82.6	61.2	71.9	75.4	80.8	61	70.9	78.1
16	78.8	37.6	58.2	61.7	86			
17	77.8	57	67.4	70.9				
18	81.6	58	69.8	73.3				
19	84	40.4	62.2	65.7				
20	81	53.6	67.3	70.8				
21	96.4	56	76.2	79.7				
22	98.4	43.2	70.8	74.3				
23	87.6	43.4	65.5	69.0				
24	87.4	86.4	86.9	90.4				
25	90	73.2	81.6	85.1				
26	86.4	45.2	65.8	69.3	80.6	62.4	71.5	78.7

	CENTRE STATION				EDGE STATION			
DATE	MAX	MIN	MEAN	CORR	MAX	MIN	MEAN	CORR
27	86.8	76.4	81.6	85.1	78			
28	89.2	32	60.6	64.1	83.2	37.2	60.2	67.4
29	80.4	37	58.7	62.2				
30		20						
JUL 01	78.8	23.6	51.2	54.7				
2	82	44.4	63.2	66.7				
3	80.8	37.6	59.2	62.7				
4	83.2	53.8	68.5	72.0				
5	88.4	72	80.2	83.7	80.6	67.2	73.9	81.1
6	89.2	46.6	67.9	71.4	80.4	50	65.2	72.4
7	88.8	47	67.9	71.4	85.4	49.8	67.6	74.8
8	88.4	40.2	64.3	67.8	88	44	66.0	73.2
9	84	36	60.0	63.5	85.2	40.4	62.8	70.0
10	84.8	53.6	69.2	72.7	86	54.8	70.4	77.6
11	85.8	59.2	72.5	76.0	78		39.0	46.2
12	85	41.2	63.1	66.6	78.8	48.4	63.6	70.8
13	85.2	47	66.1	69.6	84	53.2	68.6	75.8
14	88.8	54.8	71.8	75.3	80	56	68.0	75.2
15	88.8	88.4	88.6	92.1	80.6	79.6	80.1	87.3
16	88.4	52	70.2	73.7	80.6	56.2	68.4	75.6
17	87	43.4	65.2	68.7	80.2	50.6	65.4	72.6
18	86.6	48	67.3	70.8	79.6	54	66.8	74.0
19	86.8	48	67.4	70.9	84.4	47.6	66.0	73.2
20	86.6	51.4	69.0	72.5	86.8	52.6	69.7	76.9
21	85.6	44.8	65.2	68.7	85.4	46	65.7	72.9
22	85.6	44.8	65.2	68.7	84.8	44	64.4	71.6
23	86	49.2	67.6	71.1	85.2	50.8	68.0	75.2
24	86.8	61.6	74.2	77.7	85.6	60.8	73.2	80.4
25	86.8	42	64.4	67.9	79.6	45.2	62.4	69.6
26	85.6	47.6	66.6	70.1	86.4	54.8	70.6	77.8
27	86.6	45.6	66.1	69.6	78.4	52.8	65.6	72.8
28	87.4	47.2	67.3	70.8	79.6	54.6	67.1	74.3
29	88.8	58	73.4	76.9	81	60.2	70.6	77.8
30	86.4	43.6	65.0	68.5	79.2	50.4	64.8	72.0
31	86	73.2	79.6	83.1	78	68.4	73.2	80.4
AUG 01	86.8	56	71.4	74.9	75.8	48.4	62.1	69.3
2	96	95.6	95.8	99.3	80.8	76.8	78.8	86.0
3	94	76.4	85.2	88.7	75.2	70.4	72.8	80.0
4	98.8	88.4	93.6	97.1	76	73.6	74.8	82.0
5	97.6	99.6	98.6	102.1	76.2	77.8	77.0	84.2
6	96.4	51.2	73.8	77.3	75.6	59.8	67.7	74.9
7	91.6				85.8	76	80.9	88.1
8					81.8	58.4	70.1	77.3
9	87.2	49.2	68.2	71.7	80	54	67.0	74.2
10	87.2	57	72.1	75.6	80.4	62	71.2	78.4
11	90	56	73.0	76.5	82.2	60.8	71.5	78.7
12	89.4	68.4	78.9	82.4	81.2	67.2	74.2	81.4
13	87.6	89.2	88.4	91.9	80.8	78.4	79.6	86.8
14	89.4	86.4	87.9	91.4	80.4	75.6	78.0	85.2
15	88.4	53.2	70.8	74.3	80	62.4	71.2	78.4
16	88.6	67.2	77.9	81.4		65		
17	88.8	66	77.4	80.9	80.2	63.2	71.7	78.9

	CENTRE STATION				EDGE STATION			
DATE	MAX	MIN	MEAN	CORR	MAX	MIN	MEAN	CORR
18	85.4	42.4	63.9	67.4	77.6	48.8	63.2	70.4
19	84	50.8	67.4	70.9	76.8	54	65.4	72.6
20	85.2	47.6	66.4	69.9	79	52.4	65.7	72.9
21	90	52.8	71.4	74.9				
22	88.2	72.8	80.5	84.0				
23	93.6	68.4	81.0	84.5		62.2		
24	97.2	70.8	84.0	87.5	77.8	63.2	70.5	77.7
25	93.8	72.4	83.1	86.6	78	67.2	72.6	79.8
26	91.6	59.2	75.4	78.9	76.8	57.2	67.0	74.2
27	91	62.4	76.7	80.2	79	59.6	69.3	76.5
28	88.8	70.4	79.6	83.1				
29	91.6	75.2	83.4	86.9				
30	90.8	75.8	83.3	86.8		67.6		
31	94	62.4	78.2	81.7	76.8			

Appendix XV. Bog water pH readings at selected stations June 16 to September 20 1988.

STATION	16-Jun	23-Jun	30-Jun	07-Jul	15-Jul	22-Jul	28-Jul	04-Aug
1	4.12	4.19	4.20	4.58	4.29			4.00
3			4.17		4.39			3.98
9			4.27	4.51	4.31	4.56	4.58	4.19
11	4.10	3.97	4.05	4.20	4.00	4.25	4.14	3.73
14		3.95	4.00		4.00			3.76
23	4.10	4.17	4.22	4.34	4.17	4.22	4.19	3.85
25	4.26	4.24	4.24	4.31	4.29	4.32	4.26	4.10
28	4.02	4.15	4.10	4.19	4.09	4.24	4.17	3.95
40	4.41	4.15	4.15		4.19			3.92
43	4.44	4.29	4.36	4.44	4.36	4.29	4.39	4.29
46	4.24	4.17	4.19	4.29	4.17	4.27	4.29	4.15
60	4.19	4.27	4.29	4.68	4.15	4.41	4.49	4.07
61								3.98
64	4.10	4.10	4.27	4.29	4.20	4.19	4.31	4.02
67	4.51	4.31	4.31	4.41	4.37	4.51	4.43	4.30
70	4.36	4.14	4.05	4.19	4.07	4.22	4.29	3.81
85								4.99
88	4.84	4.92	4.75	4.82	5.11	4.97	4.89	4.81
92	4.32	4.29	4.39	4.48	4.43	4.49	4.43	4.19
95			4.09	4.32	4.19	4.20	4.22	4.00
99	4.63	4.79	4.70	5.24	5.04	5.73	5.82	4.54
103	4.74	4.75	4.68	4.80	4.78	4.80	4.73	4.72
107	4.32	4.26	4.34	4.41	4.37	4.41	4.34	4.10
110			4.49	4.89	4.65			4.51
119			4.31	4.56	5.09			4.17
121	5.04	4.84	4.82	4.77	4.94	4.97	4.85	4.74
124	4.36	4.39	4.43	4.49	4.58	4.47	4.44	4.30
127	4.84	4.67	4.68	4.73	4.85	4.66	4.63	4.66
pool	4.32	4.46	4.44	4.24	4.34	4.39	4.43	4.42
M1								
M2								4.59
M3								
M4								5.21
M5								

STATIO	11-Aug	18-Aug	25-Aug	01-Sep	09-Sep	13-Sep	20-Sep
1	3.95	4.12	4.19	3.93	4.07	4.09	4.05
3	4.12	4.19	4.12	4.07	4.12	4.21	4.15
9	4.27	4.19	4.17	4.02	4.17	4.21	4.20
11	3.86	3.98	3.87	3.76	3.93	4.02	3.91
14	3.81	3.97	3.90	3.84	3.95	4.02	3.90
23	3.91	3.98	3.92	3.76	3.91	4.00	3.90
25	4.14	4.31	4.25	4.10	4.22	4.34	4.20
28	3.98	4.09	3.95	3.88	3.97	4.03	4.00
40	3.91	3.97	4.00	3.81		4.00	4.00
43	4.15	4.29	4.24	4.19	4.20	4.31	4.26
46	4.14	4.26	4.17	4.02	4.20	4.15	4.14
60	4.17	4.22	4.08	4.12	4.31	4.31	4.24
61	3.83	3.90	3.93	3.84	4.02	4.02	4.09
64	4.03	4.15	4.12	4.05	4.03	4.17	4.14
67	4.14	4.26	4.24	4.22	4.36	4.26	4.36
70	3.71	3.81	3.81	3.74	3.90	4.02	3.95
85	4.90	5.14	5.16	5.38	5.28	5.27	5.26
88	4.99	4.94	5.01	5.03	4.99	4.93	4.99
92	4.26	4.41	4.49	4.31		4.69	4.51
95	3.97	3.97	4.02	3.88	3.95	4.02	4.12
99	4.70	4.70	4.74	4.66	4.66	4.77	4.89
103	4.85	4.73	4.72	4.64	4.65	4.74	4.68
107	4.19	4.17	4.37	4.21	4.27	4.29	4.26
110	4.46	4.53	4.61	4.69	4.68	4.60	4.75
119	4.14	4.17	4.22	4.33	4.24	4.39	4.34
121	4.66	4.78	4.78	4.84	4.78	4.91	4.84
124	4.32	4.32	4.39	4.33	4.48	4.45	4.51
127	4.53	4.70	4.78	4.76	4.66	4.94	4.72
pool	4.41	4.48	4.40	4.41	4.32	4.45	4.44
M1		4.41	4.37	4.59	4.43		4.95
M2	5.16	4.82	4.93	4.93	5.02	4.93	4.90
M3		5.76	5.67	5.76	5.72		
M4	5.11	5.36	5.31	5.62	5.40	5.29	5.31
M5			5.08	5.03	5.82		5.24

Appendix XVI. Peat pH readings at various depths at selected stations.

DEPTH(CM)	2	12	54	70	103
0	3.42		3.28	3.28	
10			2.93		
20	3.48	3.31		3.30	
30			3.16		
40	3.64				
50					
60	3.91				
70		3.58	3.05	3.42	3.66
80	4.05				
90					
100	4.05			3.45	
110					3.64
120	4.15	3.63	3.08	3.50	
130					
140					
150				3.66	4.00
160					
170		3.71	3.15		
180				3.76	4.17
190					
200					
210				3.90	4.31
220		3.80	3.28		
230				4.05	
240					
250					
260					
270		3.93	3.64		
280					
290					
300					
310					
320			3.76		
330					
340					
350					
360					
370			4.22		
380					
390					
400					
410					
420			4.34		
430					
440					
450					
460					
470			4.32		

Appendix XVII. Concentrations (mg/l) of various elements in bog water samples collected October 15 1988 at selected stations. Column indicated "acid" is concentration of element in acidified water sample. "dH2O" and "dH2O(fil)" are concentrations in unfiltered and filtered distilled water samples respectively.

station	S	S (acid)	Pb	Pb (acid)	P
1	0.6028	0.5675	nd	nd	1.7060
11	0.3808	0.4615	nd	nd	1.7750
14	0.4489	0.3682	nd	nd	3.3340
40	0.4439	0.4010	nd	nd	1.8570
43	0.3758	0.3253	nd	nd	1.7580
60	0.3329	0.2850	nd	nd	0.8576
67	0.2068	0.2648	nd	nd	0.8225
70	0.4994	0.4237	nd	nd	0.9294
85	0.5876	0.3556	nd	nd	7.3310
88	0.5044	0.3405	nd	nd	2.0060
103	nd	0.1942	nd	nd	2.1850
107	0.2724	0.2774	nd	nd	2.0450
110	0.9332	0.4439	nd	nd	1.3820
121	0.2875	0.3178	nd	nd	1.0510
127	0.2673	0.2396	nd	nd	1.2890
pool	0.3077	0.1891	nd	nd	1.7140
dH2O(fil)	nd	0.1059	nd	nd	1.6560
dH20	nd	nd	nd	nd	nd

station	P (acid)	Na	Na (acid)	Mn	Mn (acid)
1	1.7820	0.3080	0.3316	0.2272	0.2571
11	2.0630	0.4081	0.4593	0.0855	0.0916
14	2.8150	0.3004	0.3174	0.0742	0.1251
40	1.4700	0.2673	0.2871	0.1148	0.1434
43	1.5340	0.5164	0.5709	0.0563	0.0679
60	0.9527	0.0427	0.0594	0.0428	0.0817
67	0.8096	0.5347	0.5856	0.1120	0.1247
70	0.8317	0.3913	0.4501	0.0838	0.1010
85	2.5920	1.9260	1.8480	0.0739	0.2466
88	1.8970	0.8886	0.9241	0.0365	0.0434
103	1.9210	1.3290	1.4800	0.0180	0.0219
107	1.3110	0.7822	0.8487	0.0533	0.0598
110	1.4220	1.3010	1.3760	0.0830	0.1010
121	1.2710	0.6908	0.7871	0.0357	0.0445
127	1.7080	0.7033	0.7713	0.0447	0.0709
pool	1.5690	0.7363	0.7945	0.0482	0.0563
dH2O(fil)	1.7350	0.0192	0.0287	nd	0.0013
dH20	nd	0.0268	0.0168	0.0013	0.0013

station	Mg	Mg (acid)	K	K (acid)	Fe
1	0.8974	0.9909	nd	nd	0.6265
11	0.4797	0.5133	nd	0.4922	0.5326
14	0.4920	0.7959	nd	nd	0.3852
40	0.5943	0.6969	nd	nd	0.3517
43	0.3422	0.4060	0.5069	0.8227	0.3410
60	0.5673	0.8946	nd	nd	0.4265
67	0.4245	0.4684	nd	nd	0.2289
70	0.4817	0.5653	nd	0.6317	0.5575
85	0.8169	1.3600	0.7566	1.0000	0.7390
88	0.3606	0.4111	1.1900	1.1480	0.6429
103	0.1448	0.1740	0.4701	0.4408	0.2182
107	0.2711	0.3003	0.7272	0.6171	0.3044
110	0.6087	0.6877	2.1450	2.5560	0.4318
121	0.3644	0.4240	0.6758	0.4334	0.3172
127	0.2972	0.4028	0.3379	0.6538	0.2720
pool	0.2152	0.2481	nd	0.3893	0.2090
dH2O(fil)	nd	0.0086	nd	nd	nd
dH20	nd	nd	0.3673	nd	nd

station	Fe (acid)	Al	Al (acid)	Ca	Ca (acid)
1	0.7575	0.1932	0.2303	4.3060	5.1560
11	0.5646	0.1467	0.1496	1.5330	1.7510
14	0.6191	0.1535	0.2677	2.6290	5.1490
40	0.4635	0.1586	0.2087	3.3660	4.5260
43	0.4532	0.1102	0.1463	1.1980	1.5840
60	0.6276	0.1144	0.1855	2.7860	6.0780
67	0.2805	0.0630	0.0613	1.0970	1.3190
70	0.6272	0.2250	0.2624	1.9740	2.9920
85	4.2180	0.3331	3.7570	2.6170	5.0130
88	0.8508	0.2851	0.3288	1.4500	1.9570
103	0.3442	nd	0.0705	0.7315	1.0980
107	0.3741	0.1102	0.1261	0.8463	0.9898
110	0.5742	0.1819	0.2027	1.5740	2.0780
121	0.4097	0.1365	0.1764	0.9013	1.2590
127	0.4357	0.1414	0.2751	0.7433	1.2330
pool	0.3079	0.0641	0.0843	0.6384	0.7583
dH2O(fil)	nd	nd	nd	0.0178	0.0399
dH20	nd	nd	nd	0.0219	0.0393

station	Zn	Zn (acid)	Cd	Cd (acid)
1	0.0402	0.0492	nd	nd
11	0.0282	0.0321	nd	nd
14	0.0184	0.0612	nd	nd
40	0.0237	0.0430	nd	nd
43	0.0101	0.0101	nd	nd
60	0.0101	0.0478	nd	nd
67	0.0101	0.0101	nd	nd
70	0.0285	0.0405	0.0026	nd
85	0.0101	0.0363	0.0028	nd
88	0.0101	0.0101	0.0021	0.0026
103	0.0053	0.0101	nd	nd
107	0.0101	0.0101	nd	nd
110	0.0101	0.0307	0.0021	nd
121	0.0098	0.0101	nd	nd
127	0.0101	0.0101	nd	nd
pool	0.0067	0.0095	nd	nd
dH2O(fil)	nd	0.0045	nd	nd
dH20	nd	nd	nd	nd

Appendix XVIII. Braun - Blanquet cover values of plant species at all stations. Where CHAM is *C. calyculata*, VOXY is *O. microcarpus*, KALM is *K. polifolia*, SARR is *S. purpurea*, SCHE is *S. palustris*, ANDR is *A. glaucophylla*, CXTR is *C. trisperma*, CXLI is *C. limosa*, RHYN is *R. alba*, DROS is *D. rotundifolia*, UTRI is *U. cornuta*, LEDM is *L. groenlandicum*, MENY is *Menyanthes trifoliata* L., ABIE is *A. balsamea*, CALA is *Calamagrostis canadensis* (Michx.) Nutt., GAUL is *G. hispidula*, CXPA is *Carex paupercula* Michx., SMIL is *Smilacina trifoliata* (L.) Desf., BETU is *B. papyrifera*, LARX is *Larix laricina* (DuRoi) Koch, ERIO is *Eriophorum spissum* Fern., CXOL is *Carex oligosperma* Michx., CXPF is *Carex pauciflora* Lightf., VMYR is *Vaccinium myrtilloides* Michx., POTE is *Potentilla palustris* (L.) Scop., CXCA is *Carex canescens* L., IRIS is *Iris versicolor* L., PINU is *Pinus strobus* L., EQUI is *Equisetum sylvaticum* L., SASP is *Salix* spp., SPMA is *S. magellanicum*, SPAN is *S. angustifolium*, SPCU is *S. cuspidatum*, SPRU is *Sphagnum russowii* Warnst., PLEU is *Pleurozium schreberi* (Brid.) Mitt, DIPO is *Dicranium polysetum* SW., DISP is *Dicranium* spp., PIMA is *Picea mariana* (Mill.) BSP., SPFU is *S. fuscum*, POLY is *Polytrichum juniperinum*, PIGL is *Picea glauca* (Moench) Voss., and AGRO is *Agrostis* sp.

	CHAM	VOXY	KALM	SARR	SCHE	ANDR	CXTR	CXLI	RHYN	DROS	UTRI
54	3	1	2	1	1						
55	4	3	3	1	1						
56	2	0.1	1	0.1	3	1			3	2	
57	4	2	3	3	0.1	0.1		1	0.1	0.1	
58	4	2	2	3	0.1	1		4		0.1	
59	5	1	3	1	1			1			
60											
61	5	2	3	2							
62	2	1	2	1	2	2		3			
63	5		1	0.1	2	1		1	2		1
64	1	4	2	5	1	1			3	1	
65	1	4	1	4	1	1		0.1	5	1	
66	2	2	3	2	2				0.1		
67	3		1		2				5	1	
68	2	4	1	3	2	2		3	4	2	
69	2	1	1	2						0.1	
70	4	2	3		1						
71	2		1					0.1			
72	3	0.1	0.1								
73	5		1								
74	2				2	2		4			
75	3	2	1	1	2	2			3	0.1	
76	2	2	2	3		0.1			3	1	2
77	4	4	3	3		1			3	1	
78	2	2	2	3	2	1			4	2	
79	2	1	2	0.1	2	0.1			4	3	
80	2	0.1	1	1		2			4	1	
81	3	2	1	2		1					
82	5	0.1		2	0.1						
83	1		0.1								
84	1										
85	3							4			
86	5		0.1					4			
87	5							2			
88	3				1			4			
89	4	1	0.1		1	0.1		3		0.1	
90	4				3	3		2		2	1
91	3	2	2	2	1	0.1		1	4	1	1
92	2	3	3	4	1	1			2		
93	3	0.1	0.1		1	1			5	2	
94	4	2	3	2	2	1			2	0.1	
95	2	1	0.1	3	2	3			3		
96	4	0.1	0.1	1							
97	5	1					2				
98	3										
99	5		2					4		0.1	
100	3		2		0.1			4			
101	5			1		2		5			
102	5				3	2		4			
103	2			0.1	2	1		1	4	3	1
104	3		3	2	1	1				2	
105	3	2	1	0.1	2	2		2	3		2
106	2	2	3	1	1	1		3	1	3	

	CHAM	VOXY	KALM	SARR	SCHE	ANDR	CXTR	CXLI	RHYN	DROS	UTRI
1	4										
2	4	3									
3	4	2						2			
4	5	1									
5	5	2	0.1	1							
6	5	2		0.1							
7	5	1									
8	3										
9	3	3	2				2				
10	5	1		1	0.1						
11	5	1	1					2			
12	5	1	2	1	0.1					0.1	
13	5	1						2			
14	4	2	2					0.1			
15	5	1	1	1			1				
16	4	2	1	3	0.1						
17	5	3	3	2	1	0.1		2		0.1	
18	4	2	2	1	0.1			2		0.1	
19	4	2	2	0.1	0.1						
20	5	2									
21	3						3				
22	5	2					1				
23	4	2	2	2							
24	2	3	0.1	4	1	1				0.1	
25	3	2	2	2	1	2		1	1	0.1	
26	3	1	1	1	1			2	3	0.1	
27	4	3	3	2	2	1		2	1	0.1	
28	5	1			1						
29	4	1	2								
30	5	3	2				2				
31	5	2	2	2							
32	4	3	0.1	4	1			4		0.1	
33	2	1	1	0.1	2	1		4			
34	4	3	2	2	0.1					1	
35	4	1	1	1	3	2			3	0.1	
36	4	1	0.1	1	2	1		0.1	2		
37	4	3	0.1	1	1	0.1		3			
38	4	1	2	1				0.1			
39	1	1					3				
40	5	2	1					1			
41	3	3	0.1	4	0.1			2			
42	1		0.1		1	0.1		4	3	2	1
43	2		1		3	3		2		1	1
44	3	2	2	2	3	3			3	1	1
45	2	1	1	1	2	1		1	3	0.1	
46	1	4	1	2	3	1			3	1	
47	3	1	3	2	1			3		1	
48	3	1	1	1	0.1		2				
49	2						2				
50	5	3									
51	5	2	1	1	1	1		0.1			
52	4	1	2	1	2	1		1	1	3	
53	3	3	2	1	1	2			2		

	CHAM	VOXY	KALM	SARR	SCHE	ANDR	CXTR	CXLI	RHYN	DROS	UTRI
107	2	0.1		1	1	1		3	3	3	
108	4	0.1	1	2			0.1				
109	4		2				2				
110	4	2						4			
111	3		2	2	1	2		4			
112	2			1	2	2		3			
113	3	1			2	3		3	2	3	
114	3				2	2		2	2	3	0.1
115	3			3		2		3	2	2	1
116	2	1	2	2	2	1		2	1		
117	5	1	1	2				0.1			
118	5		1				0.1				
119	3										
120	4	1		0.1	0.1	0.1		4			
121	3				3			4		0.1	
122	2		1		2	1		3	0.1	0.1	
123	3	2	3	3	0.1			2		1	
124	3	3	2	3	1	0.1		2			
125	4		3	0.1	3	1		4			
126	4	3	3				1				
127	3		4	1						0.1	
128	3				0.1			2			
129	4	3	3	3	0.1						
130	3	2	2								
131	3			1	1						
132	5	0.1	2					1			
133	2			1				3			

	LEDM	MENY	ABIE	CALA	GAUL	CXPA	SMIL	BETU	LARX	ERIO	CXOL
1	1	2				1					1
2			0.1	1		2		3			3
3		3		2			2				
4	3										
5											4
6											4
7		1				1	2				3
8		4		2			0.1				
9			5								
10											5
11											3
12											3
13											5
14	2						2				1
15											
16											4
17											2
18		0.1									4
19											5
20											4
21	2						2				
22	2							3			
23											4
24											2
25											
26											
27											2
28											4
29						2	1				3
30	2		1								1
31			1						5		3
32											3
33											
34					3						0.1
35											
36											
37											3
38											2
39	5		2	0.1	3						
40		2									1
41											
42		1									
43											
44											
45											
46											
47											
48											2
49	5				2		1	3			
50	3										
51										1	1
52		0.1									
53											

	LEDM	MENY	ABIE	CALA	GAUL	CXPA	SMIL	BETU	LARX	ERIO	CXOL
54											3
55											1
56											
57											
58											
59											2
60	1	5									4
61										1	
62											0.1
63											
64											1
65											
66											2
67											
68											
69	2				1						
70											4
71	1	5					1				3
72	5		2					5			
73											2
74											
75											
76											
77											
78											
79											
80											
81											4
82											3
83	4		4		3		2				
84				5				3			
85											
86											2
87		4									1
88											
89		1									
90											
91											
92		1									1
93											
94		0.1									
95											
96											2
97	3		2		2		0.1				
98	2		1	2							
99		0.1									2
100		2									
101											
102		1									
103		1									
104											
105											
106											

	LEDM	MENY	ABIE	CALA	GAUL	CXPA	SMIL	BETU	LARX	ERIO	CXOL
107		1									
108											2
109	4				4			0.1			
110		2									2
111		2									0.1
112		0.1									
113		2									
114		0.1									
115											
116											
117											1
118	4				3						
119	0.1										4
120											
121											
122		0.1									
123											0.1
124											1
125											
126	3				3						
127		3									2
128		2									2
129	0.1										2
130	2										3
131											3
132	1										
133	2			1							2

	CXPF	VMYR	POTE	CXCA	IRIS	PINU	EQUI	SASP	SPMA	SPAN	SPCU
1									0.1	5	
2								5	1	5	
3			1		1			4	1	4	
4										5	
5								3		5	
6									0.1	5	
7									0.1	5	
8				1						5	
9									4	2	
10									0.1	5	
11									1	5	
12									2	5	
13									0.1	5	
14										5	
15									1	4	
16									3	5	
17									3	5	
18									2	5	
19									2	5	
20									1	5	
21										4	
22									2	5	
23									4	3	
24									2	5	0.1
25									2	5	1
26									2	3	3
27									2	4	
28									0.1	5	
29									0.1	5	
30										5	
31									3	5	
32									3	4	
33										4	
34	3								2	2	
35										1	1
36										5	1
37									2	5	
38										5	
39									3	2	
40									1	5	
41									3	3	1
42											1
43											1
44									1	2	1
45									1	2	2
46											2
47									1	5	
48									1	5	
49									2	4	
50								1		5	
51									3	4	
52										4	
53									1	3	

	CXPF	VMYR	POTE	CXCA	IRIS	PINU	EQUI	SASP	SPMA	SPAN	SPCU
54	4								1	2	
55	3								1	2	
56									1	1	
57	1					1			3	3	
58									1	4	
59									1	5	
60										5	
61										5	
62									1	2	2
63											
64									3	1	2
65									2	1	4
66									1	0.1	
67											
68											4
69											
70									1	5	
71										5	
72		2								3	
73									0.1	5	
74											
75										2	
76											4
77									0.1	3	2
78									3	1	1
79										1	1
80									2	1	1
81										5	
82										5	
83		0.1							2		
84			1				2	3			
85			2					1			
86										4	
87									3	5	
88										4	
89									3	2	
90									1		
91									3	3	2
92									2	2	
93											0.1
94									1	5	
95									0.1	5	
96										5	
97										5	
98			1					3		3	
99									2	2	
100									3	4	
101									4	2	
102									1	0.1	
103											
104											
105									2	3	
106									2	1	

	CXPF	VMYR	POTE	CXCA	IRIS	PINU	EQUI	SASP	SPMA	SPAN	SPCU
107											4
108									1	5	
109										5	
110									3	4	
111									2	3	
112									3	2	
113									1	1	
114									2		
115										1	
116									3	3	
117									5	2	
118									1	5	
119											3
120											
121									3	1	
122										0.1	
123									4	2	
124									3	4	
125									1	4	
126										3	
127									3	2	
128											4
129									1	5	
130									1	5	
131									2	4	
132									1	5	
133										3	

	SPRU	PLEU	PTIL	DIPO	DISP	PIMA	SPFU	POLY	PIGL	AGRO
1	1									
2					1					
3	1	1			1					
4	1				1					
5										
6										
7										
8	2									
9					1					
10										
11										
12										
13										
14					0.1					
15					2					
16										
17										
18										
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20										
21		0.1								
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23										
24								0.1		
25										
26										
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28										
29										
30										
31					1					
32										
33										
34						4	5			
35										
36										
37										
38					0.1					
39		0.1	0.1							
40										
41										
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43										
44										
45										
46										
47										
48					1					
49	1	2							2	
50					0.1					
51										
52										
53							1			

	SPRU	PLEU	PTIL	DIPO	DISP	PIMA	SPFU	POLY	PIGL	AGRO
54							5			
55							5			
56										
57						0.1				
58										
59										
60										
61										
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64							2			
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66							5			
67										
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69		1				5	5			
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83	2	3				3				
84										1
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91										
92						1	5			
93										
94										
95										
96										
97		2		0.1						
98		4								
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100									1	
101										
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103										
104										
105										
106										

	SPRU	PLEU	PTIL	DIPO	DISP	PIMA	SPFU	POLY	PIGL	AGRO
107										
108										
109										
110										
111										
112										
113										
114										
115										
116									1	
117										
118	1	2								
119									1	
120										
121										
122										
123										
124										
125										
126		4			0.1				0.1	
127	3									
128										
129										
130									3	
131	2									
132										
133										