MINNESOTA PEAT PROGRAM

Ecological and Floristic Studies of the Red Lake Peatland

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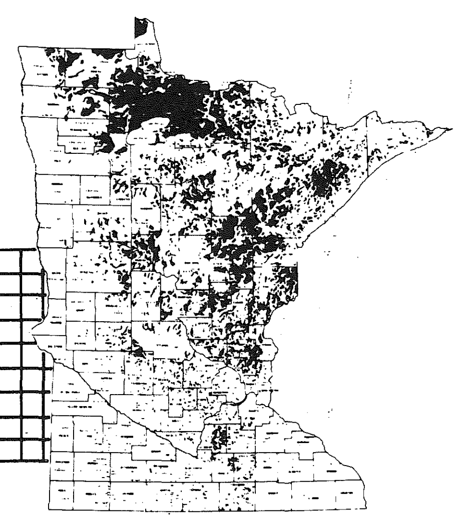

·ta Department
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ECOLOGICAL AND FLORISTIC STUDIES
OF THE RED LAKE PEATLAND

Final Report

to

Peat Program, Minnesota Department of Natural Resources

Eville Gorham and H.E. Wright, Jr.

Part 1. The Patterned Mires of the Red Lake Peatland, Northern Minnesota: Vegetation, Water Chemistry, and Landforms. P.H. Glaser, G.A. Wheeler, E. Gorham, and H.E. Wright, Jr.

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PART I

THE PATTERNED MIRES OF THE RED LAKE PEATLAND, NORTHERN MINNESOTA: VEGETATION, WATER CHEMISTRY, AND LANDFORMS[1]

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SUMMARY

1. Red Lake Peatland on the bed of Glacial Lake Agassiz in northwestern Minnesota covers an area almost 80 km long and 15 km broad uninterrupted by streams or uplands -- a vast complex of raised bogs and water tracks that are intricately related to water chemistry and surface-water movements, as revealed on infrared photography and LANDSAT imagery.

2. To the west a large water track up to 5 km broad carries minerotrophic water from uplands adjacent to the peatland. This western water track is marked not only by the usual pattern of transverse strings and linear pools (flarks) but also by teardrop-shaped islands consisting of a forested head and a long tail of dwarf birch leading downslope.

3. Raised bogs with radiating lines of spruce trees and bog drains cap the watershed divides to the east. The bogs are fringed downslope by aprons of patternless _Sphagnum_ lawns on which incipient water tracks arise. The incipient tracks lead downslope into well-defined water tracks that flow between other raised bogs, apparently shaping these bogs into ovoid islands several kilometers long.

4. The major types of vegetation as delineated by the relevé method are characterized by generally distinctive water chemistry. Two types of bog vegetation occur on the raised bogs and ovoid islands. They have waters of low pH (range 3.8 - 4.1), low Ca^{2+} concentration (range 0.5 - 2.1 mg/l), and low conductivity (range 12 - 50 μmho minus the conductivity owing to H+ ions).

5. Three types of fen vegetation occur respectively on strings, flarks, and teardrop islands in the water tracks, which are characterized by high pH (range 5.2 - 7.0), high Ca^{2+} concentration (range 3.0 - 19.6 mg/l), and

high conductivity (range 23 - 128 μmho minus the conductivity owing to H+ ions).

6. Poor fens closely resemble the bog or fen vegetation but may be distinguished by their location, water chemistry, and the presence/absence of certain indicator species. Poor fens occur on the broad Sphagnum lawns, within ovoid islands that have been altered by fire, and wherever minerotrophic water tracks border ombrotrophic landforms. The poor fens have intermediate ranges in pH (4.0 - 5.1), Ca^{2+} concentration (2.2 - 4.3 mg/l), and conductivity (22-50 μmho, minus the conductivity owing to H+ ions).

7. The importance of surficial drainage in the maintenance of mire patterns is suggested by the localized effects of drainage ditches on the vegetation and landforms.

8. Infrared aerial photographs and LANDSAT imagery indicate that water flow is channeled across broad surfaces of peat to initiate the development of water tracks, bog drains, and islands that have an ovoid, horseshoe, or teardrop shape.

INTRODUCTION

Patterned mires were first discovered in northern Minnesota by Heinselman (1963), who called attention to the distinctive patterns of the Red Lake Peatland. The most striking landforms in this mire complex are water tracks that contain alternating strings and flarks and islands of various shapes and sizes. The patterned water tracks are typical of circumboreal Strangmoor or Aapamoor (Hamelin & Cook 1967, Mali 1958, Tricart 1969, Washburn 1973), but the island patterns are unique to North America. Similar islands with an ovoid, teardrop, or circular shape have been described from the Alaskan interior (Drury 1956), Hudson Bay Lowlands (Sjörs 1963), and northern Saskatchewan and Manitoba (Zoltai 1971, Zoltai & Tarnocai 1971).

The origin of these mire patterns is still enigmatic despite extensive speculation. Several different hypotheses have been presented that are based on geomorphic, biologic, and climatic criteria, but each of these explanations is open to criticism (Washburn 1973). An integrated approach is clearly needed to elucidate the pattern-forming process, but such an approach is precluded in North America by insufficient information.

In the Glacial Lake Agassiz region of Minnesota conditions are especially favorable for studying the development of mire patterns. Stratigraphic analyses (Heinselman 1963, Janssen 1968, Griffin 1977) indicate that permafrost is not present in these mires even though many patterned landforms in this area are associated with permafrost farther north. Recent advances in remote sensing such as infrared aerial photography and multispectral imaging from LANDSAT satellites have greatly facilitated the interpretation of surface drainage and vegetational patterns in the Red Lake area. In addition the importance of hydrology in the development of mire patterns may be inferred from the localized effects of drainage ditches on the vegetation and landforms.

The present study was conducted with a helicopter that provided comprehensive access to the mire complex, which covers an area about 80 x 15 km. The major objectives of this study were to 1) classify the major vegetation types of Red Lake Peatland, 2) determine the relationships of the vegetation to the major landforms and to their water chemistry, and 3) seek evidence for the present vegetation dynamics in the diverse landforms. This information should form the basis for reconstructing the origin and history of the mire complex from the stratigraphic analysis of peat cores. A thorough understanding of mire patterns and the factors controlling their development should be of great value in either preserving representative mires or rehabilitating those that are damaged by human disturbance.

STUDY AREA

The Red Lake Peatland (Fig. 1) is situated in the Beltrami Arm of Glacial Lake Agassiz in northwestern Minnesota at approximately 48° N. Lat. and 95° W. Long. (Wright 1972). This mire complex of 1200 km^2 is uninterrupted by streams or uplands (Plate 1), making it one of the largest continuous mires in the conterminous United States. At its southern edge the mire straddles a major drainage divide that separates the Rainy River basin to the north from the Red River basin to the south. Peat slopes average less than 1 m/km, giving the entire area little relief.

The study area is largely underlain by 1.5 to 3 m of peat, with peat depths generally greater than 3 m in the central portion of the peatland (Soper 1919, Farnham & Grubich 1966, Griffin 1977). Radiocarbon dates of basal peat suggest that the Red Lake Peatland arose in the east and developed westward. Basal peat has been dated by C-14 at 3950 ± 80 years BP (Wis-1037) in the eastern portion and 1950 ± 65 years BP (Wis-1037) in the western portion. Farther east in the Glacial Lake Agassiz basin Heinselman (1963) reported a date of 4360 ± 160 years BP (W-562) at Lindford Bog.

The mineral substrate of the study area consists of calcareous silty till locally with a thin veneer of lake sediments (Wright 1972). A soil horizon a few centimeters thick may occur immediately beneath the peat, but the origin of this horizon may be the result of down-leaching of humics from the peat.

The regional climate is humid continental, with short warm summers, long cold winters, and a warm-season precipitation maximum (Baker 1963, 1965; Baker, Haines, & Strub 1967). The mean annual temperature for the Red Lake

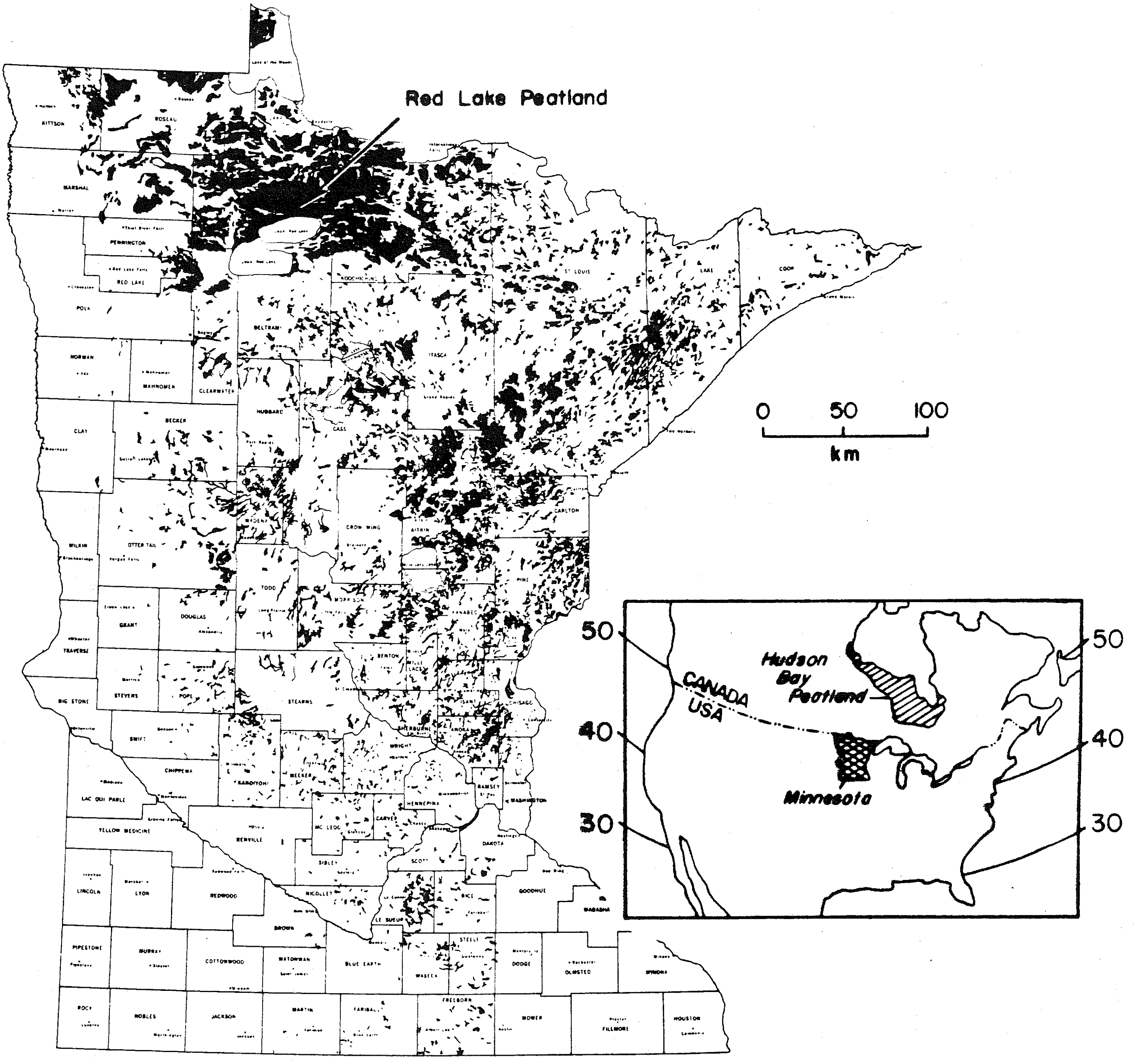


Figure 1. Map of Minnesota showing location of the Red Lake Peatland with respect to other peatlands.

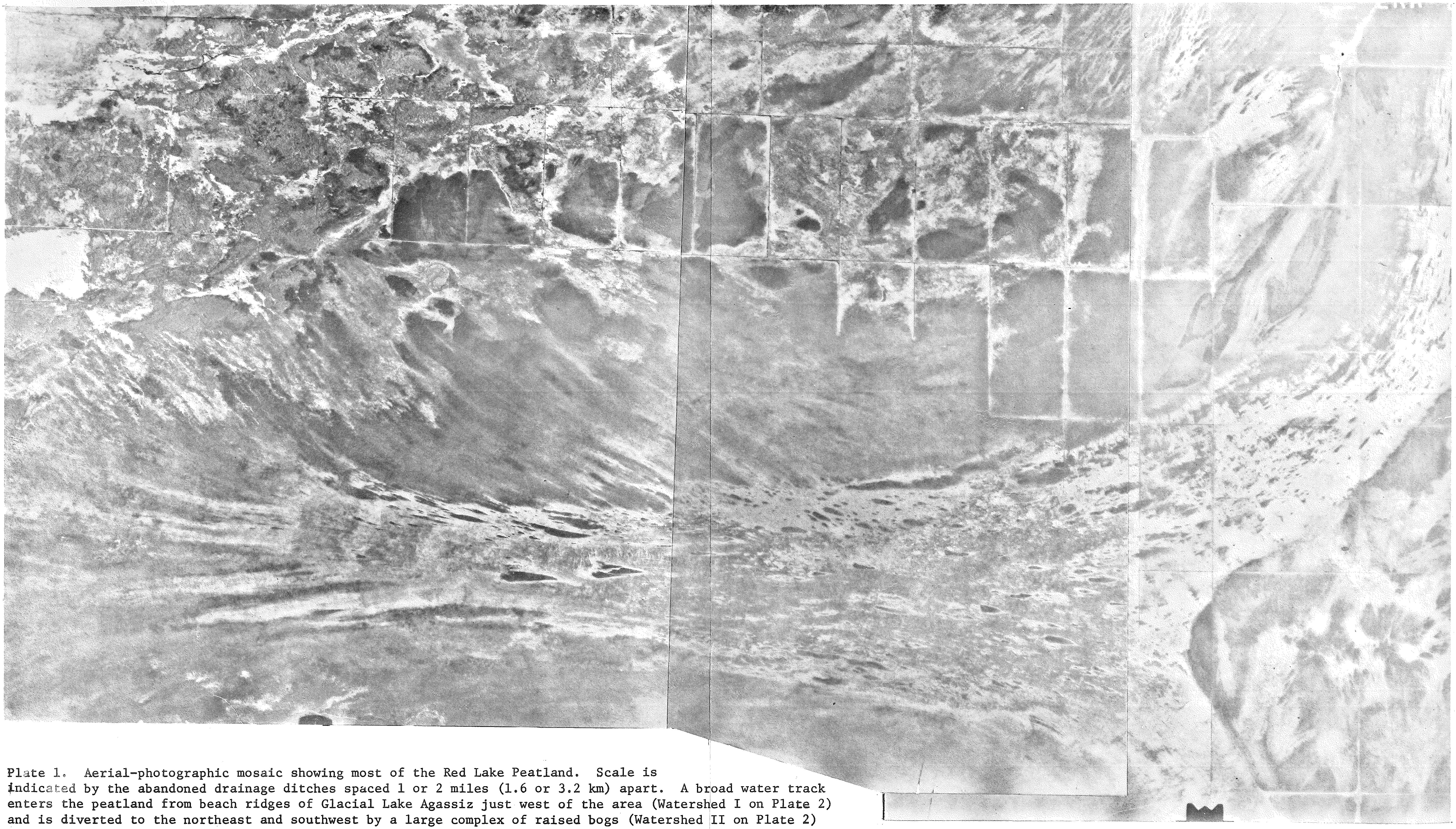
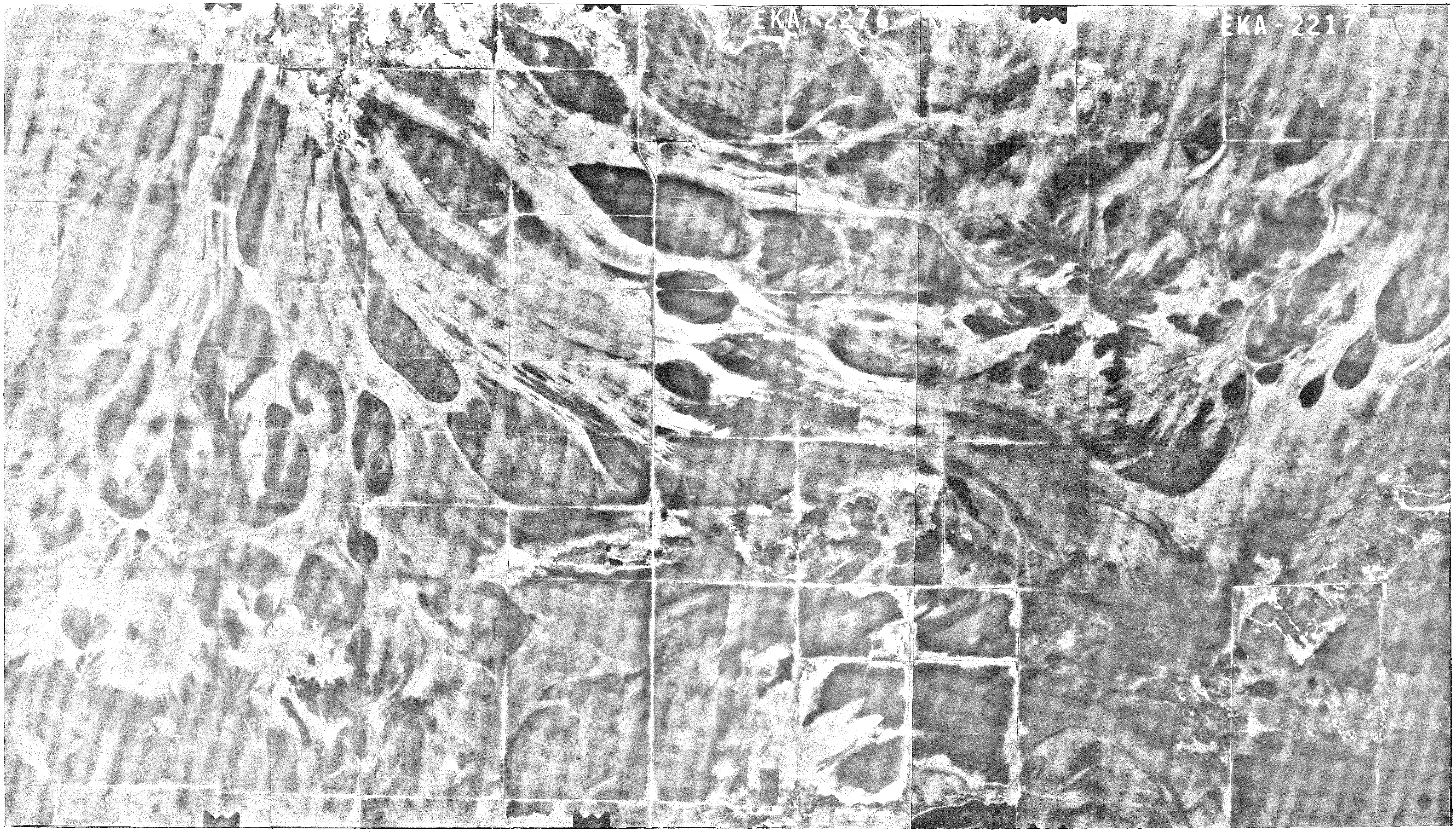


Plate 1. Aerial-photographic mosaic showing most of the Red Lake Peatland. Scale is indicated by the abandoned drainage ditches spaced 1 or 2 miles (1.6 or 3.2 km) apart. A broad water track enters the peatland from beach ridges of Glacial Lake Agassiz just west of the area (Watershed I on Plate 2) and is diverted to the northeast and southwest by a large complex of raised bogs (Watershed II on Plate 2) many of which have been converted to ovoid islands by the development of internal water tracks streaming to the north (see Plate 3 for labels). Another major water track originates from raised bogs in the east and southeast and flows northwestward (Watershed III on Plate 2). In the northeast is another complex of raised bogs, ovoid islands, and internal water tracks (Watershed IV on Plate 2).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area is 3°C. The average temperature is -13 to -14°C in winter, 3°C in spring, 13°C in summer, and 6°C in fall (Hofstetter 1969). Extremes in both temperature and precipitation increase westward across the ecotone from peatland to prairie (Heinselman 1963).

Red Lake Peatland is located at the northwestern edge of the mixed conifer-hardwood forest of the Great Lakes region (Cushing 1965). The upland vegetation is transitional between the boreal forest of Canada and the deciduous forest of northeastern United States and is distinguished by extensive stands of Pinus strobus, P. resinosa, and P. banksiana. Westward the peatland grades directly into prairie or is separated from the prairie by a narrow zone of "brush prairie", which contains small trees of Populus tremuloides and P. balsamifera (McAndrews 1966, Marschner 1974).

PHYSIOGRAPHIC SUBDIVISIONS

The Red Lake Peatland may be divided into four major watersheds on the basis of landscape and vegetation patterns. These four systems all contain water tracks (sensu Sjörs 1948) of the Strangmoor type but differ in the distribution of other landscape features. Raised bogs (sensu Heinselman 1963, 1970) and ovoid islands (Hofstetter 1969), for example, are absent from the western watershed, whereas teardrop islands (Heinselman 1963) are absent from the central and eastern watersheds. The four watersheds of the study area are shown on LANDSAT imagery taken during spring break-up of 1978 (Plate 2).

The western watershed (area I on Plate 2) contains a large water track approximately 4 km wide and 40 km long, extending eastward for 25 km and then bifurcating into north- and south-flowing branches (Plate 1). Patterned landforms are absent from the head of the water track but become apparent

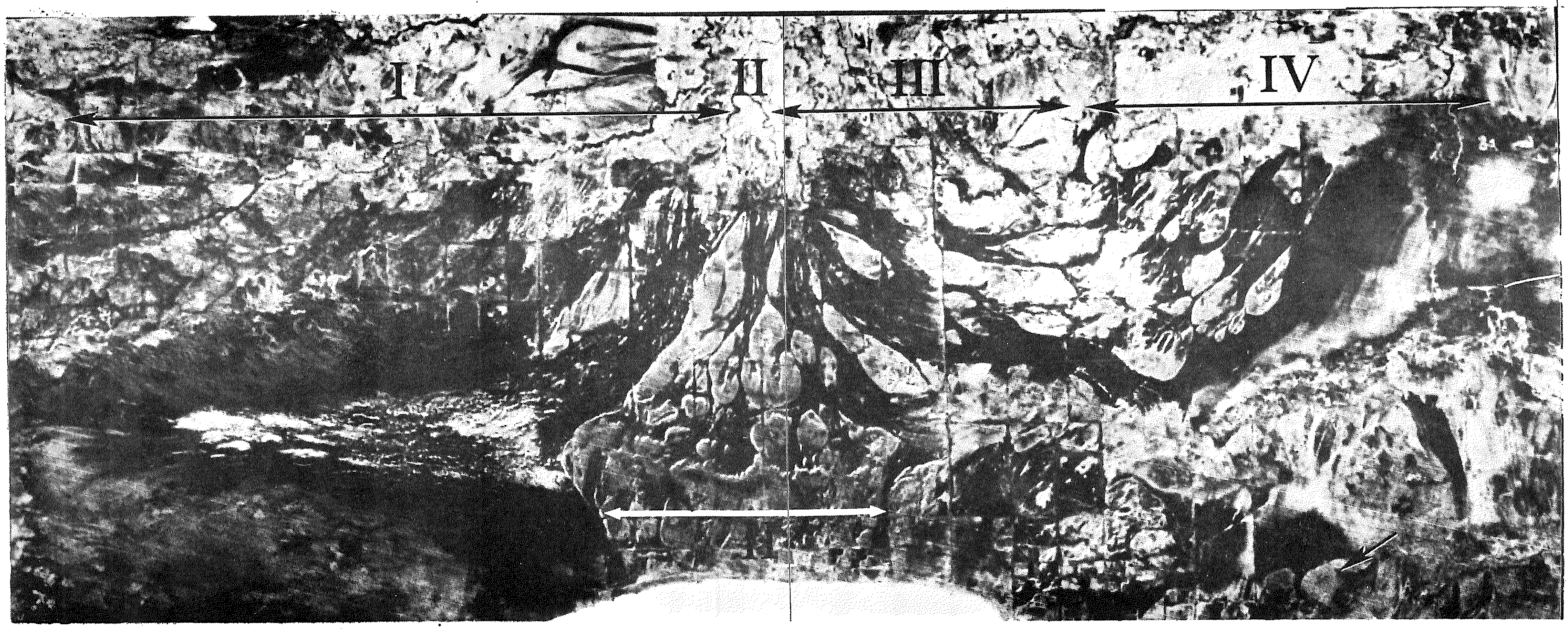


Plate 2. LANDSAT imagery (bands 5 & 7) of the Red Lake Peatland and adjacent areas in northwestern Minnesota. The black areas represent wet surfaces that are typical of water tracks or peripheral areas of swamp forests and wet thickets during spring break-up. The white areas represent either snow or ice. The western (I), west-central (II), east-central (III), and eastern (IV) watersheds are marked. The white arrow marks the southern drainage divide of the west-central watershed. Drainage ditches cut the down-slope portions of the peatland and appear as straight lines or squares 1 or 2 miles (1.6 or 3.2 km) apart. The image was recorded on April 16, 1978.

several kilometers downslope. There the track contains sinuous strings and flarks oriented transverse to the slope and interrupted by teardrop-shaped tree islands. The islands range in length from 30 to 800 m and generally have a small rounded head with trees and a long tapering tail of brush. The densest concentration of islands is found along the north-central margin of the track, where numerous lines of water flow enter obliquely from the edge. The strings, flarks, and tree islands are prominent throughout the downstream portion of the water track and disappear abruptly at the edge of the mire, where the surface water enters tributaries of the Rapid River (north branch) or Upper Red Lake (south branch).

The west-central watershed (area II on Plate 2; Plate 1) contains a mire complex of raised bogs dissected by smaller water tracks. Starting from an east-west drainage divide near the south edge of the area, water flows northward to tributaries of the Rapid River (Plate 3). The head of the watershed is occupied by a linear raised-bog that has centrifugal drainage. Fingers of stunted trees extend down the flank of the raised bog and define tongue-shaped openings called bog drains (Hofstetter 1969). Immediately downslope from the drains is a broad and relatively flat _Sphagnum_ lawn with abundant _Carex oligosperma_. Farther downslope water tracks arise and flow northward between clusters of ovoid-shaped islands. These islands, which measure as much as 2 x 4 km, have forested margins and more open interiors. They resemble the horseshoe-shaped islands described by Sjörs (1963) in the Hudson Bay Lowlands. At the source of several of the main water tracks is an area of small circular islands that resemble the wooded palsas described by Zoltai (1971) and Zoltai and Tarnocai (1971) in Manitoba and Saskatchewan. These islands measure less than 50 m in diameter

Plate 3. Aerial photograph of the west-central watershed of the Red Lake Peatland. Small portions of water tracks from the west and east-central watersheds are also visible in the uppermost left and right hand corner respectively. The drainage ditches are 1 or 2 miles (1.6 - 3.2 km) apart. The following landscape units are labeled: I - western watershed, II - west-central watershed, III - east-central watershed; 1 - patterned fen, 1a - teardrop island, 1b - linear island, 1c - circular island , 2 - ovoid islands (with horseshoe ring of spruce forest), 3 - <u>Sphagnum</u> lawn, 3a - incipient water track, 3b - incipient ovoid island, 4 - raised bog forest, 4a - bog drain, 5 - fire scar, 6 - drainage ditch. The inferred direction of water flow is from the lower portion of the photograph toward the upper portion.

and are interspersed among smaller circular hummocks. Downslope from this zone the water tracks consist of alternating strings and flarks. At the extreme downslope portion of the watershed small linear islands are present that resemble the teardrop islands of the western watershed. These islands, however, have no pronounced head of trees but instead have a narrowly elliptical streamline shape.

In the east-central system (area III on Plate 2; Plate 1) the water tracks originate from several raised bogs and flow westward for 13 km before turning northwestward to merge and flow an additional 6 km before draining into tributaries of the Rapid River. These water tracks contain alternating strings and flarks except for the extreme upslope portions and areas affected by roadbuilding. Zones of ovoid islands are present throughout the tracks, but linear islands are restricted to the extreme downslope portions.

The eastern watershed (area IV on Plate 2; Plate 1) contains a complex of raised bogs at the source, as well as *Sphagnum* lawns, water tracks, and ovoid islands downslope. It also contains unique features such as deep pools in the water tracks and upland ridges that cut across the mire patterns.

Fire scars are present in each watershed but are difficult to detect in the upstream portion of the western watershed. Drainage ditches are also present in the downstream portion of each watershed, but the western and eastern systems have very large areas that have never been ditched. The east-central watershed has been most altered by ditching, roadbuilding, and wildfire.

METHODS

The entire study area was first examined on infrared aerial photography (scale 1:15,840) and orthophotomaps published by the United States Geological Survey. A preliminary overflight of the study area was then taken in June of 1978. Vegetation and water sampling was conducted in late June and early July, usually by helicopter. Certain plots were rechecked in late August to record late-maturing species. In October additional bryophytes were collected, as well as more water samples. At certain sites of particular interest a camp was set up where a number of different vegetation-landform types could be examined in detail.

Vegetation Sampling

The vegetation within the study area was classified by the relevé method of the Braun-Blanquet school of phytosociology (Shimwell 1971, Westhoff and van der Maarel 1973). This method permits a rapid yet precise means of describing vegetation over a broad area when time constraints preclude a quantitative approach. Within each homogeneous stand selected for study a plot was laid out, and all species occurring in the plot were recorded by stratum. The standard plot size was 400 m^2 in forested stands and 100 m^2 for nonforested areas. Occasionally, the size of a plot had to be changed to accommodate irregularly shaped stands such as strings. Visual estimates of cover (abundance) and sociability (dispersion) were made for each species that occurred within the plot. A total of 195 taxa of vascular plants and 72 taxa of bryophytes were collected in the study area. A complete set of vouchers is to be deposited in the University of Minnesota Herbarium. Nomenclature follows Fernald (1970) for most vascular plants, and Gleason and Cronquist (1963) in a few cases. Stotler & Crandell-Stotler (1977) is followed for hepatics, and Crum, Steere, & Anderson (1973) for mosses, except that Sphagnum spp. and Polytrichum juniperinum var. affine follow Crum (1976). Each plot was permanently marked at the corners with meter lengths of metallic conduit. Short cores were taken from certain plots to determine the composition of the uppermost 20 cm of peat. Fifteen longer cores were also taken down to mineral soil for future study.

Vegetation Analysis

A phytosociological table was compiled by methods outlined in Shimwell (1971) and Westhoff and van der Maarel (1973). A raw table of relevés was first compiled with rows of species and columns of relevés. The table was then rearranged to provide the optimum grouping of species with similar distributions as well as relevés with similar species composition. The relevés were divided into Tables 1 and 2 because of an obvious dichotomy between releves from bogs and those from rich fens. These tables include several poor-fen relevés that are not sufficiently defined floristically to be treated as a separate type. These two tables clearly represent patterns obvious within these data sets, and numerical methods of analysis were therefore considered to be unnecessary.

Water Chemistry

Water samples were taken during the summer and fall from the full range of landscape features in addition to each relevé plot. Samples were usually collected by gently depressing the peat, but in a few cases it was necessary to dig shallow pits and allow them to fill in with water. Water was collected in 500 ml polyethylene bottles that were first washed in hydrochloric acid, then several times in distilled water, and finally rinsed three times with water from the site. Water color -- an index of stagnation -- was measured with a Beckman DU Spectrophotometer, as light extinction at 320 nanometers in a 1-cm cell with a corex filter. Specific conductivity -- an index of total ionic concentration -- was measured with a platinum electrode. The conductivity data were standardized to 20°C, and the conductivity owing to hydrogen ions was subtracted in order to eliminate the effect of varying acidity (Sjörs 1950b). Acidity was measured as pH with separate glass and calomel electrodes. The concentration of Ca^{2+} was determined with an atomic absorption spectrophotometer.

Relationships among the data are shown both as regressions and as reduced major axes (Imbrie 1956, Till 1974), where neither variable is dependent (Fig. 2, 3, and 4).

RESULTS AND DISCUSSION

The vegetation of the Red Lake Peatland may be separated into bog and fen associations on the basis of species composition and floristic diversity. This basic dichotomy in the vegetation classification is strongly related to differences in water chemistry (Figs. 2 & 4). The ombrotrophic bog surfaces receive water only from atmospheric precipitation, whereas the minerotrophic fens are fed also by water that has percolated through mineral soil (Sjörs 1948, 1950a, 1963). The bogs are characterized by a relatively poor flora and a nearly continuous mat of *Sphagnum* moss. They are found in the eastern and central portions of the peatland on the raised-bog divides and ovoid islands.

Rich fens, in contrast, are distinguished by 1) a much richer flora, 2) a sparse or discontinuous moss mat rich in Bryales, and 3) minerotrophic indicators such as *Triglochin maritima*, *Carex leptalea*, or *Carex chordorrhiza*. Minerotrophic communities occur on the strings, flarks, and teardrop and linear islands in all the water tracks of the study area.

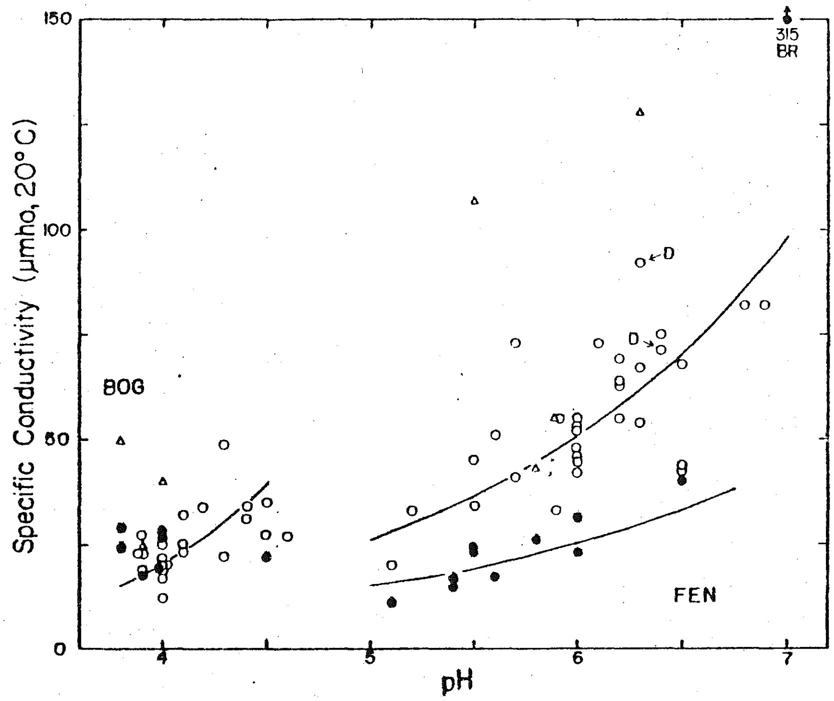


Fig. 2. Relationship of specific conductivity (minus the conductivity of H^+ ions) to pH of surface waters from the Red Lake Peatland. Open symbols represent summer, and dots October samples; triangles represent samples from shallow pits dug in the peat. D marks samples collected in a fen water track immediately upslope (east) of Highway 72, BR marks a sample collected in a fen water track immediately downslope of an intersecting beach ridge. Reduced major axes exclude pits and samples marked D and BR.

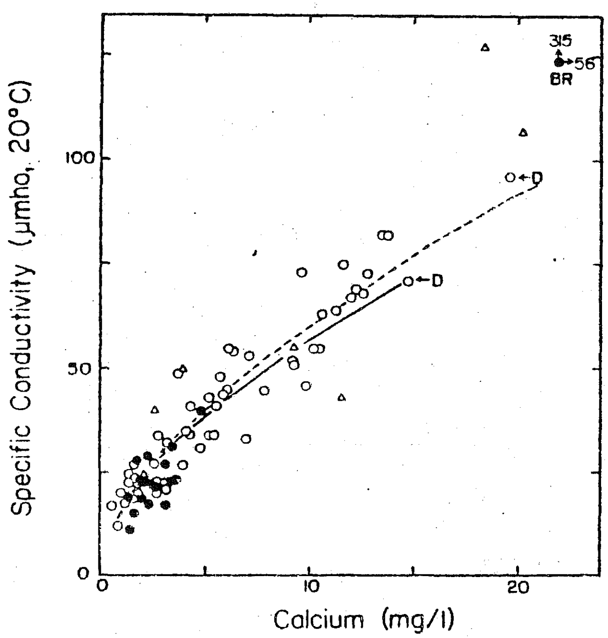


Fig. 3. Relationship between specific conductivity and calcium in surface waters of the Red Lake Peatland. Symbols are as in Figure 2. Solid line excludes pits and samples marked D and BR; dashed line includes all samples.

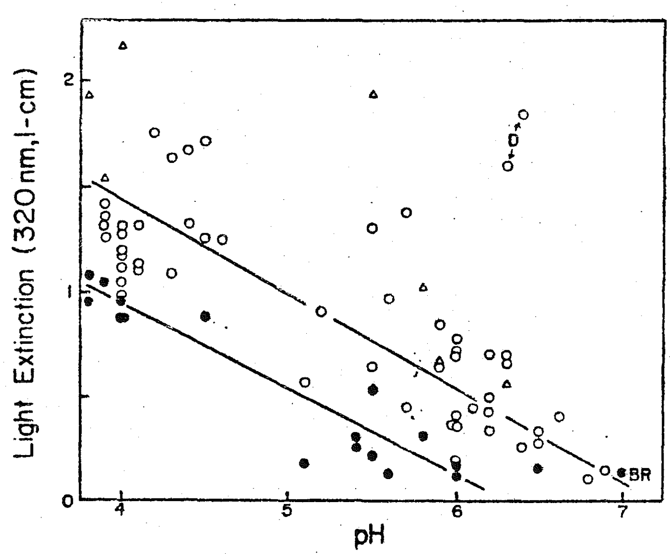


Fig. 4. The relationship between light extinction and pH in surface waters from Red Lake Peatland. Symbols and exclusions are as in Figure 2.

A group of intermediate poor fens may also be distinguished, primarily on the basis of water chemistry, location, and plant indicators. Their vegetation closely resembles that of either bogs or fens, but one or more minerotrophic indicators are present in all cases. Poor fens are found on the broad *Sphagnum* lawns and along the margins of ombrotrophic landforms next to minerotrophic water tracks. Certain ovoid islands in heavily burned areas also have waters with poor-fen properties, as do the smaller circular islands.

Bog Vegetation

Two types of bog may be distinguished on the basis of floristic data (Table 1). The *Carex oligosperma* association occurs in unforested openings wherever the water table is near the surface, whereas the *Carex trisperma* association is typically found under forests of *Picea mariana*. These two associations occur on both ovoid islands and raised bogs.

Carex oligosperma Association

This association is distinguished by the dominance of *Carex oligosperma* and the absence of *C. trisperma*. *C. pauciflora* is occasionally present and is more common near the forested margins. Also present are *Sarracenia purpurea*, *Kalmia polifolia*, *Andromeda glaucophylla*, *Eriophorum spissum*, *Ledum groenlandicum*, and *Chamaedaphne calyculata*. Clumps of stunted *Picea mariana* trees are scattered throughout the stand but seldom reach heights of 5 to 6 m. The trees are conspicuously layered and contain numerous strata of adventitious roots beneath the surface peat. The ground layer

Table 1. Phytosociological Table for Bog and Poor-Fen Relevés from the Red Lake Peatland. Relevés marked with * have characteristics of poor-fens.

	Carex oligosperma Association								*Carex trisperma*/ *Vaccinium vitis-idaea* Association							
Relevé No.	1	8	9	14	15	32	23	*33	*31	22	2	*6	13	16	24	*29
pH	4.0	4.1	3.9	4.0	4.0	4.0	3.9	4.1	4.4	3.9	4.0	4.0	4.0	4.0	3.8	4.1
Conductivity (μmho)	17.	25.	23.	25.	22.	20.	27.	31.	34.	25.	18.	40.	20.	12.	50.	23.
Ca^{2+} (mg/1)	0.5	1.4	1.4	1.7	1.8	1.9	1.6	3.2	2.8	2.1	1.2	2.6	1.0	0.8	2.0	2.7
Light extinction at 320 nm	1.2	1.1	1.3	1.3	1.3	1.1	1.4	1.3	1.7	1.5	1.2	2.2	1.1	1.0	1.9	1.1
No. of species	11	11	11	11	12	9	11	12	11	10	11	10	10	9	13	12
Carex oligosperma	3·4	4·3	2·3	4·3	3·3	3·3	3·3	3·3								
Carex pauciflora	+·2			+·2	+·2		+·2									
Sarracenia purpurea	+·1	+·1	+·1	+·1	+·1	+·1	+·1	1·1	+·1							+·1
Larix laricina		+·1	+·1	+·1	+·1	+·1			+·1	+·1		+·1				
Eriophorum spissum	3·3	+·2	2·3	2·3	+·3	3·3	1·3	3·3	1·2	+·3	1·3	+·2	1·2	3·2	+·2	1·1
Ledum groenlandicum	1·2	+·1	3·3	+·1	+·1	+·1	1·2		+·2	3·3	2·2	3·3	2·1	3·2	3·3	3·3
Chamaedaphne calyculata	1·2	2·3	3·3	2·3	+·3	+·2	1·2	2·3	2·3	2·2	+·2	+·1	1·2		+·2	1·3
Kalmia polifolia	1·2	1·2	2·2	2·3	1·2	1·3	2·2	1·2	2·2	2·2	1·2		1·2	1·2	+·1	1·2
Vaccinium oxycoccos	1·2	+·2	1·2	1·2	1·2	1·2	1·2	1·2	1·3	1·2	1·2	+·1	1·2	1·1	+·1	1·1
Picea mariana	+·1	1·2	2·2	+·3	1·3	1·3	2·3		1·1	+·1	2·2	4·2	3·2	2·3	4·1	2·3
Drosera rotundifolia	+·1	+·1	1·1		+·1		+·2	1·1	+·1		+·1			+·1	+·2	
Andromeda glaucophylla	+·2	1·2	1·2	1·2	1·2		2·2	1·2	3·3		+·1		+·2			1·3
Carex livida var. *grayana*								1·2								
Scheuchzeria palustris								+·2								
Carex limosa								1·1								
Smilacina trifolia										+·2	2·2	+·2	1·2		2·3	1·1
Vaccinium vitis-idaea										+·2	+·2	+·2	+·2	+·2	1·3	+·2
Carex trisperma											3·4	2·3	3·3	3·2	2·3	2·3
ADDITIONAL SPECIES:																
Eriophorum virginicum								+·1								+·2
Betula pumila var. *glandulifera*									1·2							
Vaccinium myrtilloides										+·1					+·1	
Salix pyrifolia												r·1				
Gaultheria hispidula														1.2	1.3	
Listera cordata															+.2	
Monotropa uniflora															+·2	

KEY: The two symbols after each species are indices of cover and sociability.

Cover

+ sparsely present
1 plentiful but small cover value
2 V. numerous, or covering 1/20 or area
3 any number of individuals covering 1/2 - 1/2 area
4 any number of individuals covering 1/2 - 3/4 area
5 covering more than 3/4 area

Sociability

Soc. 1 growing singly, isolated individuals
Soc. 2 grouped or tufted
Soc. 3 in small patches cushions
Soc. 4 in small colonies, in extensive patches, or forming carpets
Soc. 5 in pure populations

is dominated by Sphagnum recurvum, S. capillifolium, and S. papillosum in the hollows and S. warnstorfii, S. capillifolium, and Polytrichum juniperinum var. affine on the hummocks. The water table is close to the surface, and a pool of water appears with each footstep.

Similar communities that are dominated by Carex oligosperma have been described from northeastern Minnesota (Conway 1949, Glaser and Wheeler 1977) and northern Michigan (Vitt and Slack 1975). Carex oligosperma has also been reported as a minor component of poor swamp forests in the Glacial Lake Agassiz region of Minnesota (Janssen 1967, Heinselman 1970). These reports seem at variance with the pronounced heliophilous distribution of Carex oligosperma in the Red Lake area. Carex oligosperma has also been reported by Sjörs (1963) as fairly frequent in wet hollows on certain open bogs in the Hudson Bay Lowlands.

Carex trisperma -- Vaccinium vitis-idaea Association

This association is distinguished by Carex trisperma, Vaccinium vitis-idaea, and Smilacina trifolia. Also present are most of the species that occur in the unforested openings except for Carex oligosperma. Typical species of the ground layer are Sphagnum fuscum, S. recurvum, S. magellanicum, and Dicranum undulatum. Usually restricted to this association are Dicranum polysetum and Pleurozium schreberi. Stunted trees of Picea mariana and occasional small trees of Larix laricina are present. Larger trees are found along the margins of the ovoid islands and in the interior of the linear raised bog of the west-central watershed. Communities similar to the Carex trisperma association have been elsewhere reported in Minnesota (Heinselman 1970, Janssen 1967, Glaser and Wheeler 1977) and in Michigan (Cooper 1913) and Canada (Moss 1953; Sjörs 1961, 1963).

Rich-fen Vegetation

The minerotrophic water tracks contain three distinct landforms, namely flarks, strings, and teardrop islands, which generally exhibit a rich-fen vegetation (*sensu* Sjörs 1963). This vegetation displays a continuous variation over these landforms, although discrete types may be recognized in the teardrop islands and flarks and less distinctly on the strings (Table 2). The variable microrelief of all these landforms with respect to water levels accounts for much of the variability of the vegetation. To facilitate discussion the rich-fen vegetation is examined in relation to the three landscape features.

Flarks (*Triglochin maritima* - *Drosera intermedia* Association)

The distinctly minerotrophic flarks are dominated by *Carex lasiocarpa* var. *americana*, *C. livida* var. *grayana*, *C. limosa*, *Menyanthes trifoliata*, and *Rhynchospora alba*. These species, however, have a wide distribution in the water tracks and also occur on one or more of the other landforms. As a result the flark association may best be delimited by *Triglochin maritima* and to a lesser degree by *Drosera intermedia* and *Utricularia intermedia*. These species never reach dominance in the flarks, but *Triglochin* in particular is confined to this landform. The characteristic mosses of the flarks are *Campylium stellatum*, *Scorpidium scorpioides*, and *Sphagnum subsecundum*. Two minor but significant associations within the flarks are formed by clones of *Rhynchospora fusca* and occasionally *Carex*

Table 2. Phytosociological Table for Fen Releves from the Red Lake Peatland. Releves marked with * have characteristics of poor fens.

	Flarks					*Rhynchospora fusca* clones/*Carex exilis* clones								Strings					Teardrop islands							
Relevé number	4	5	11	30	35	44	42	17	34	*19	38	47	41	10	12	21	27	*7	*3	20	36	37	39	40	43	45
pH	6.5	6.0	6.2	6.2	6.9	6.8	6.1	5.9	5.7	4.6		6.5	6.0	6.0	6.2		5.9	4.3	4.4	6.0	6.4	5.5	6.0	5.2	6.3	6.2
Conductivity (μmho)	44.	42.	67.	55.	82.	82.	73.	33.	41.	27.		68.	52.	55.	69.		55.	22.	31.	46.	75.	34.	45.	34.	128.	63.
Ca (mg/l)	5.9	5.8	12.0	10.1	13.8	13.5	12.8	7.0	4.3	4.0		12.6	9.2	10.2	12.2		6.1	3.2	4.8	9.9	11.6	5.5	7.9	5.3	18.4	10.6
Light extinction at 320 nm	0.3	0.4	0.7	0.3	0.2	0.1	0.5	0.6	0.5	1.3		0.4	0.7	0.8	0.7		0.9	1.1	1.3	0.8	0.3	0.7	0.4	0.9	0.6	0.5
No. of species	13	12	18	23	18	18	14	24	22	21	22	32	28	27	18	22	24	20	23	26	58	34	44	25	51	41
Triglochin maritima	+·2	+·2	1·2	1·2	+·2	1·1	1·1	+·1	+·1	-	+·2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Scheuchzeria palustris	+·1	-	+·1	1·2	+·2	+·1	-	+·1	+·1	-	+·1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Drosera intermedia	+·2	+·2	1·2	1·2	1·2	+·2	1·2	1·2	+·1	+·1	+·1	-	-	-	+·1	-	-	-	-	-	-	-	-	-	-	-
Utricularia intermedia	2·3	1·2	+·2	1·2	1·2	1·1	+·1	+·1	+·1	+ 1	1·2	+·2	-	+·1	-	-	-	-	-	-	-	-	-	-	-	-
Eleocharis compressa	-	-	+·2	+·2	+·1	+·2	+·1	+·1	+·1	+·2	+·1	-	-	-	-	-	-	-	-	-	-	-	+·1	-	-	-
Utricularia minor	-	-	-	-	1·2	1·2	1·2	+·1	-	-	1·2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rhynchospora fusca	-	-	-	-	-	-	3·3	2·3	1·2	2·3	2·2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Carex exilis	-	-	-	-	-	-	-	-	-	2·3	2·3	3·2	3·3	-	-	-	-	-	-	-	-	-	-	-	-	-
Scirpus cespitosus var. callosus	-	-	-	-	-	-	-	-	-	-	1·2	3·2	4·3	-	-	-	-	-	-	-	-	-	-	-	-	-
Rhynchospora alba	2·3	-	1·2	1·2	1·2	+·1	2·3	1·3	2·2	2·3	2·2	+·1	1·1	1·2	-	-	-	-	-	-	-	-	-	-	-	-
Carex livida var. grayana	+·1	-	2·2	1·2	2·3	1·2	1·3	2·3	1·2	+·1	2·1	1·1	+·1	+·2	+·2	-	1·2	-	-	-	-	-	-	-	-	-
Carex lasiocarpa var. americana	2·3	3·2	3·2	3·1	3·3	4·3	3·3	1·3	3·2	1·2	3·2	2·2	+·1	2·2	2·3	1·2	+·2	+·1	-	+·2	-	-	-	-	-	-
Carex limosa	3·2	2·2	1·1	2·2	1·2	1·2	1·1	1·2	1·1	1·2	1·2	1·1	-	-	1·1	-	-	-	+·1	-	-	-	+·1	+·1	-	-
Carex chordorrhiza	+·2	-	1·2	+·2	1·2	+·1	1·2	+·1	+·2	-	-	-	-	+·2	-	-	+·2	+·2	4·4	1·2	-	-	-	1·3	-	-
Menyanthes trifoliata	2·3	2·2	1·1	2·2	+·1	2·1	2·1	+·1	+·1	1·1	+·1	+·2	+·1	+·1	-	-	1·2	-	-	1·1	+·1	1·3	1·2	2·3	-	+·1
Sarracenia purpurea	-	+·1	+·1	1·1	-	+·1	+·1	+·1	+·1	-	+·1	+·1	+·1	+·1	+·1	+·1	+·2	+·1	+·1	+·1	-	+·1	+·1	+·1	-	+·1
Carex leptalea	-	-	+·1	-	-	-	-	+·1	+·1	-	-	-	+·1	+·2	+·1	+·2	1·2	-	-	+·2	+·1	+·2	-	-	-	+·2
Salix pedicellaris var. hypoglauca	-	-	+·1	+·2	+·2	-	-	-	-	-	-	-	-	+·2	+·1	+·2	1·2	-	-	+·1	+·1	+·2	1·1	+·1	+·1	-
Andromeda glaucophylla	+·1	+·2	+·1	-	-	-	-	+·1	+·1	+·1	+·2	1·2	+·1	2·3	2·3	1·2	1·2	2·1	+·2	1·1	-	+·1	+·1	+·1	-	1 1
Vaccinium oxycoccos	-	+·1	-	-	-	-	-	+·1	+·1	+·1	+·1	+·1	+·1	+·2	1·2	1·2	1·2	1·2	1·2	1·1	+·1	+·1	+·1	1·2	1·2	1·2
Chamaedaphne calyculata	-	+·1	-	-	-	-	-	+·1	+·1	+·1	+·1	2·3	1·2	2·3	-	1·2	1·2	3·3	+·1	2·3	1·3	1·2	1·2	-	1·3	3·3
Betula pumila var. glandulifera	-	-	-	-	-	+·2	-	+·1	+·1	-	-	-	-	1·2	2·3	3·3	3·2	1·2	1·2	3·1	-	1·2	1·2	1·2	2·1	1·2
Drosera rotundifolia	-	-	-	-	-	-	-	+·1	+·1	+·1	-	+·1	+·1	+·1	+·1	+·1	+·2	+·1	-	+·1	-	-	-	+·1	-	-
Campanula aparinoides	-	-	-	-	-	-	-	-	-	-	-	+·1	+·1	-	+·2	-	+·2	-	-	+·1	+·1	+·1	+·1	-	+·1	+·1
Thelypteris palustris var. pubescens	-	-	-	-	-	-	-	-	-	-	-	1·2	1·2	+·2	-	1·2	1·2	-	-	+·2	1·2	1·2	1·2	-	+·1	1·2
Potentilla fruticosa	-	-	-	-	-	-	-	-	-	-		2·3	+·1	+·1	-	2·3	+·2	-	-		-	-	-	-	-	-
Carex cephalantha	-	-	-	-	-	-	-	-	-	-	-	-	-	1·2	1·2	+·1	+·2	-	-	-	-	-	-	-	-	-
Larix laricina	-	-	-	-	-	-	-	-	-	-	-	-	+·1	+·1	+·1	+·1	-	2·1	3·1	2·3	3·1	3·1	2·1	2·1	3·1	3·1
Potentilla palustris	-	-	-	-	-	-	-	-	-	-	-	-	-	+·1	+·2	-	+·1	+·1	+·1	+·1	1·2	1·2	1·2	1·2	+·1	1·1
Carex tenuiflora	-	-	-	-	-	-	-	-	-	-	-	-	-	+·1	+·2	-	-	+·1	1·2	1·2	1·2	+·2	+·1	1·2	+·1	1·2
Lysimachia thyrsiflora	-	-	-	-	-	-	-	-	-	-	-	+·1	+·1	-	-	-	-	-	-	+·1	+·1	+·1	+·1	-	+·1	-
Carex paupercula var. pallens	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+·1	+·2	-	+·2	1·2	1·1	1·2	1·2	1·2
Carex canescens	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1·3	+·2	-	+·1	1·2	1·2	1·2	-	+·2
Ledum groenlandicum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+·2	1·2	-	1·3	1·2	1·2	2·2	2·3	3·1
Carex trisperma	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+·2	1·1	-	-	-	-	3·3	3·3	2·3
Picea mariana	-	-	-	-	-	-	-	-	-	-	-	+·1	-	-	-	-	-	-	+·1	-	+·1	+·1	+·1	1·1	+·1	+·1
Cypripedium acaule	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+·2	-	-	+·1	+·1	+·1	-	+·2
Carex interior	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+·1	+·1	+·1	2·3	+·1	-	-
Calla palustris	-	-	-	-	-	-	-	-	-	-	-	-	-	1·2	-	-	-	-	-	+·1	1·2	+·2	1·2	1·2	+·1	2·1
Lonicera villosa var. solonis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+·2	+·1	+·2	+·1	-	+·1	1·1
Smilacina trifolia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+·2	+·1	-	+·1	+·1	+·1	+·1
Aronia melanocarpa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+·1	+·1	+·1	-	+·1	+·1
Carex disperma	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2·3	1·3	1·1	-	1·3	2·3
Carex pseudo-cyperus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+·1	+·1	+·1	-	+·1	1·1
Rubus pubescens	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1·3	+·1	-	-	+·1	+·2
Calamagrostis inexpansa var. brevior	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+·2	1·1	+·1	-	1·2	1·1
Vaccinium myrtilloides	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2·3	1·2	1·1	+·1	-	-

Table 2 (cont.)

	Flarks					*Rhynchospora fusca* clones					*/Carex exilis* clones			Strings					Teardrop islands							
	4	5	11	30	35	44	42	17	34	19	38	47	41	10	12	21	27	7	3	20	36	37	39	40	43	45
ADDITIONAL SPECIES:																										
Eriophorum chamissonis	+·2	+·2	-	-	-	-	-	-	1·2	-	-	1·1	-	-	-	-	-	+·3	-	-	-	-	-	-	-	-
Eriophorum angustifolium	-	-	+·1	-	-	-	-	-	-	-	-	-	-	+·2	-	-	-	-	+·2	-	-	-	-	-	-	-
Viola mackloskeyi var. pallens	-	-	-	+·2	-	-	-	-	-	-	-	+·1	+·1	-	-	-	-	-	-	-	+·2	+·2	+·1	-	-	+·2
Bidens connata	-	-	-	-	-	-	-	-	-	-	-	-	+·1	-	-	-	-	-	-	-	+·1	-	-	-	-	+·1
Phragmites communis	-	-	-	-	+·2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1·1	2·1	2·2	-	cf.+·1	+·2
Iris versicolor	-	-	-	-	+·2	-	-	-	-	-	-	-	+·1	-	-	-	+·2	-	-	+·2	2·2	-	+·1	-	+·1	-
Solidago uliginosa	-	-	-	+·2	-	-	-	-	-	-	-	-	-	-	-	+·2	+·2	-	-	-	-	-	-	-	+·1	-
Habenaria lacera	-	-	-	+·1	-	-	-	-	+·1	-	-	-	-	-	-	-	-	-	-	-	-	+·1	-	-	-	-
Drosera anglica	-	-	-	+·1	1·2	-	-	1·1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Eriophorum tenellum	-	-	-	+·1	-	-	-	+·1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Utricularia cornuta	-	-	-	-	3·3	-	-	-	-	+·2	1·2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Myrica gale	-	-	-	-	-	+·1	-	-	-	-	-	1·2	-	-	-	-	-	-	-	-	-	-	+·1	-	-	-
Scirpus hudsonianus	-	-	-	-	-	-	-	+·3	-	-	-	2·3	-	+·2	-	+·2	-	-	-	-	-	-	-	-	-	-
Muhlenbergia glomerata	-	-	-	-	-	-	-	-	-	-	cf.+·1	-	+·1	-	-	+·1	-	-	-	-	-	-	-	-	-	-
Rubus acaulis	-	-	-	-	-	-	-	-	-	-	-	+·1	+·1	-	-	+·1	+·2	-	-	1·2	+·1	-	-	-	-	-
Trientalis borealis	-	-	-	-	-	-	-	-	-	-	-	+·1	-	-	-	-	-	-	-	-	-	-	+·1	-	+·1	+·2
Aster umbellatus var. pubens	-	-	-	-	-	-	-	-	-	-	-	+·1	+·1	-	-	-	-	-	-	-	-	-	-	-	-	-
Rhamnus alnifolia	-	-	-	-	-	-	-	-	-	-	-	+·1	-	-	-	-	-	-	-	-	-	-	-	-	+·1	-
Aster junciformis	-	-	-	-	-	-	-	-	-	-	-	+·1	+·1	-	-	+·1	+·1	-	-	-	-	-	-	-	-	-
Agrostis scabra	-	-	-	-	-	-	-	-	-	-	-	+·1	-	-	-	-	-	-	-	-	-	-	+·1	-	+·2	-
Epilobium leptophyllum	-	-	-	-	-	-	-	-	-	-	-	+·1	-	-	-	-	-	-	-	-	-	-	-	+·1	+·1	-
Kalmia polifolia	-	-	-	-	-	-	-	-	-	-	-	-	-	+·2	-	-	-	1·2	+·1	-	-	-	-	+·1	-	-
Arethusa bulbosa	-	-	-	-	-	-	-	-	-	-	-	-	-	r·1	+·1	-	-	-	-	-	-	-	-	-	-	-
Bromus ciliatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+·1	+·2	-	-	-	-	-	-	-	+·2	-
Lycopus uniflorus	-	-	-	-	-	-	-	-	-	-	-	-	+·1	-	-	-	-	-	-	-	+·1	-	-	-	+·1	+·2
Vaccinium angustifolium	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+·1	-	-	-	-	-	-	+·1
Carex brunnescens var. sphaerostachya	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1·2	r·1	+·1	-	-	-	-	-
Salix discolor	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+·1	-	-	-	+·1	-
Carex diandra	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1·3	-	1·1	-	-	-
Polygonum sagittatum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+·2	-	+·1	-	-	-
Circuta bulbifera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+·1	-	+·1	-	-	-
Osmunda cinnamomea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1·2	-	+·2	-	-	+·1
Rubus strigosus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+·1	-	-	-	+·1	-
Dryopteris spinulosa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+ 1	-	-	-	+·1	-
Dryopteris cristata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+·2	-	-	-	+·1	-
Salix bebbiana	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+·1	+·1	-	+·1	-
Salix serissima	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+·1	+·1	-	-	-
Pyrola secunda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+·2	+·1

Pedicularis lanceolata (30, +·2), Malaxis unifolia (30, r·1), Drosera linearis (35, 1·2), Parnassia palustris (35, r·1), Potamogeton gramineus (42, +·1), Xyris montana (19, +·1), Juncus stygius var. americanus (19, +·2), Cladium mariscoides (34, 1·3), Lonicera oblongifolia (47, +·2), Eriophorum spissum (7, +·2), Eriophorum viridi-carinatum (10, +·2) Viola sp. (20, +·1), Solidago sp. (20, +·1), Caltha palustris (36, +·2), Pyrola secunda (36, +·1), Carex stricta (36, +·1) Viola incognita (36, +·1), Stellaria longifolia (36, +·1), Ranunculus gmelini var. hookeri (36, +·2), Cornus stolonifera (36, +·2), Maianthemum canadense (36, +·2), Thuja occidentalis (43, 1·1), Monotropa uniflora (43, +·2), Aster puniceus (43, +·1), Pyrola asarifolia var. purpurea (43, +·1), Cornus rugosa (43, +·1), Athyrium filix-femina var. michauxii (43, +·1), Gymnocarpium dryopteris (43, +·2), Viola incognita (43, +·1), Salix lucida (43, +·1), Salix planifolia (43, 1·2), Calamagrostis neglecta (43, +·2), Pyrola secunda var. obtusata (43, +·1), Potamogeton gramineus (45, +·1).

exilis. C. exilis is much more typical of the poor-fen margins, where it forms hummocks with Scirpus cespitosus var. callosus.

Even the wettest flarks have microrelief that favors the establishment of such string species as Andromeda glaucophylla, Salix pedicellaris var. hypoglauca, Sarracenia purpurea, and Thelypteris palustris var. pubescens. These species grow on fallen clumps of sedges that form microhummocks close to the water level.

The easternmost water tracks contain flarks that are floristically distinctive within the study area. Xyris montana and Juncus stygius var. americanus are occasional to frequent in these flarks, although they are virtually absent elsewhere in the peatland. The deep fen pools of this watershed are also the sole habitat of Juncus pelocarpus and Scirpus validus within the peatland.

The flark vegetation of the Red Lake Peatland is strikingly similar to that of the flarks of the Hudson Bay Lowlands described by Sjörs (1963). Less similarity exists with the vegetation of the patterned fens of the Swan Hills, Alberta (Vitt, Achuff, & Andrus 1975) and the Kuskokwim Lowlands of Alaska (Drury 1956).

Strings (Carex cephalantha - Potentilla fruticosa Association)

The strings are dominated by Betula pumila var. glandulifera, Andromeda glaucophylla, Vaccinium oxycoccos, and Chamaedaphne calyculata. These species occasionally occur on the microhummocks of the flarks but are more typical of the teardrop islands. Species typical of the flarks, such as Carex lasiocarpa, Menyanthes trifoliata, and Carex livida, are also found along the edges of the strings or in water-filled depressions. The strings are best distinguished floristically by Carex cephalantha and

Potentilla fruticosa, which are largely restricted to this landform. The better developed strings usually contain small stunted trees of Larix laricina. Other vascular plant species include Sarracenia purpurea, Thelypteris palustris var. pubescens, Drosera rotundifolia, and Salix pedicellaris var. hypoglauca. Within the ground layer Sphagnum fuscum, S. papillosum, Campylium stellatum, Aulacomnium palustre, and Polytrichum juniperinum var. affine are the most characteristic bryophytes.

The strings vary considerably in size, shape, and height above the water level. In the driest tracks the strings are about 50 to 60 cm above the surface of the adjacent pools. In the wettest situations the strings are barely perceptible above the water surface.

Teardrop Islands (Carex pseudo-cyperus - Aronia melanocarpa Association)

Teardrop islands vary in size and floristic composition but display the greatest number of species of any landform in the peatland. Despite this variability, islands with well-developed stands of Larix laricina and Picea mariana have a distinctive assemblage of species that are largely restricted to this landform, including Carex pseudo-cyperus, Aronia melanocarpa, Rumex orbiculatus, Lonicera villosa var. solonis, Carex disperma, and Rubus pubescens. Species common to the strings that also occur on these islands are Carex tenuiflora, Chamaedaphne calyculata, Betula pumila var. glandulifera, and Vaccinium oxyccocos. Characteristic bryophytes are Sphagnum papillosum, S. recurvum, Aulacomnium palustre, Calliergon stramineum, and Mnium punctatum.

The teardrop islands usually contain a mosaic of hummocks around the bases of trees, alternating with water-filled hollows. Species restricted to the hollows are Calla palustris, Iris versicolor, Carex pseudo-cyperus, and Typha latifolia, with the mosses Scorpidium scorpioides and Campylium stellatum. The hummocks appear to be composed of fallen trees covered by sedges such as Carex disperma, C. brunnescens var. sphaerestachya, and C. trisperma, and a variety of mosses, including several Sphagna, Pleurozium schreberi, Polytrichum juniperinum var. affine, and Aulacomnium palustre.

Poor-fen Vegetation

Poor fens occur wherever minerotrophic water tracks border ombrotrophic landforms such as ovoid islands or raised bogs. The margins of these landforms either consist of a mosaic of open pools and hummocks or are forested with uniform stands of Larix laricina. Poor fens are also found on the broad Sphagnum lawns and within ovoid islands that have been heavily burned.

These areas almost always contain one or more species that Sjörs (1963) considers to be indicative of poor fens in the Hudson Bay Lowlands. However, the poor-fen relevés at Red Lake closely resemble either the bog or rich-fen vegetation. Relevés 29, 31, and 33, for example, contain minerotrophic indicators such as Carex livida var. grayana, Betula pumila var. glandulifera, and Salix pyrifolia but otherwise closely resemble the ombrotrophic bog vegetation. Similarly, relevés 3, 7, and 19 are nearly indistinguishable from the rich-fen vegetation except for the absence of such rich-fen indicators as Carex leptalea and Salix pedicellaris. Moreover, all the poor-fen relevés lack bryophyte species such as Sphagnum riparium, S. jensenii, and S. pulchrum, which Sjörs (1963) considers to be poor-fen indicators. However, these species are rare or unknown from Minnesota.

The lack of definition of the poor fens may be the result of either insufficient sampling or the relative instability of this vegetation type.

Further sampling of the poor fens may fill in the gap that separates the bog-like relevés from those that resemble rich fens. Alternatively, the poor-fen relevés may indicate unstable vegetation that is changing from bog to fen or the reverse. Such changes appear to be taking place along the margins of the water tracks and on the broad Sphagnum lawns. Poor fens are also found within the interiors of certain ovoid islands that have been conspicuously altered by fire.

The poor fens of the Red Lake Peatland are strikingly similar to those of the Hudson Bay Lowlands (Sjörs 1963) but are less similar to those of the Swan Hills, Alberta (Vitt, Achuff, and Andrus 1975). The Sphagnum lawns at Red Lake have species assemblages that are similar to Carex oligosperma lawns in northeastern Minnesota (Glaser & Wheeler 1977) and northern Michigan (Vitt & Slack 1975).

Water Chemistry

The major vegetational differences within the Red Lake Peatland are clearly related to the chemical properties of surface waters, which exhibit wide ranges of pH, specific conductivity, calcium concentration, and color. The various chemical properties are also clearly interrelated, as shown in Figures 2 - 5 and Table 3.

The relationship between the salt content of the peatland waters (measured as specific conductivity, minus that owing to H+ ions) and their acidity (measured as pH) is shown in Figure 2. The curves in the figure are all reduced major axes (Imbrie 1956, Till 1964) instead of regressions, for neither variable is dependent on the other. It is evident that conductivity rises with increasing pH both in the bog/poor-fen waters and in the rich-fen waters, with the latter less rich in salts during October.

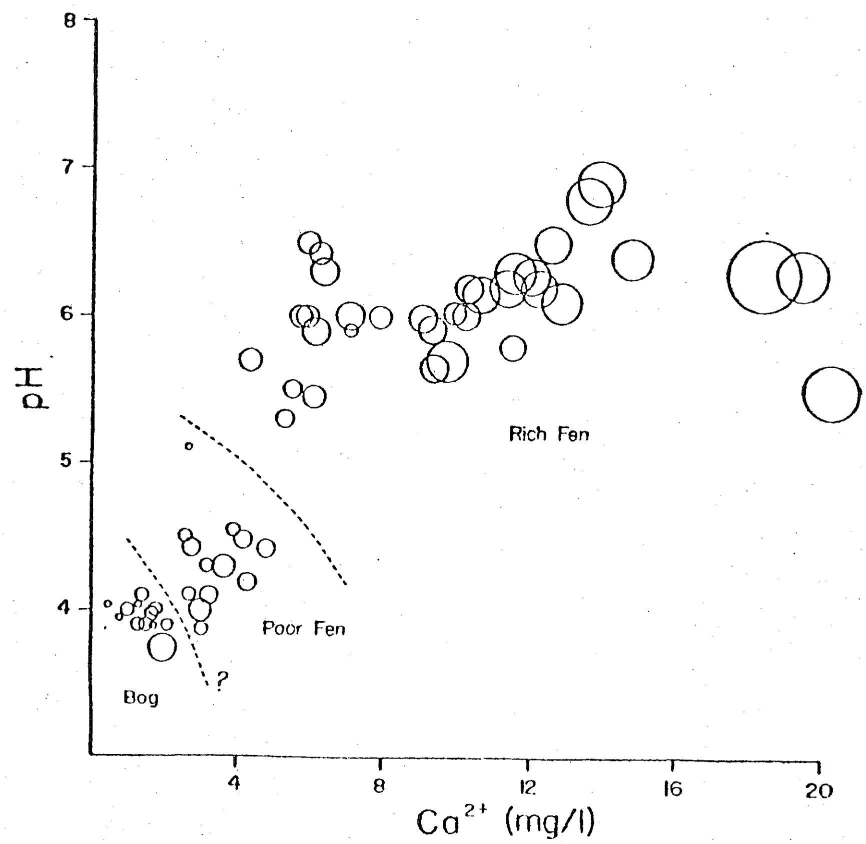


Fig. 5. The relationship between pH, Ca $^{2+}$ concentration (ppm), and specific conductivity (μmho, minus the conductivity owing to H^+ ions) in surface waters of the Red Lake Peatland. The diameter of the circles is proportional to increasing conductivity. Samples taken during October are excluded.

Table 3. Relationships among chemical properties of surface waters from the Red Lake Peatland. Acidity is measured in pH units, specific conductivity in μmhos at 20°C (minus the conductivity owing to H^+ ions), calcium in mg/l, and light extinction at 320 nm in 1-cm cells. Except for one of the two regressions of conductivity on calcium, samples from pits are omitted, as are two samples from a stagnant fen water track just upstream (east) of Highway 72, and another sample collected in a water track immediately downslope from an intersecting beach ridge.

A. Specific conductivity (y) and pH (x): reduced major axes, with neither variable dependent.

1. Summer bog waters ($n = 22$, $\underline{r} = 0.564$, $p < 0.01$)

   $\log y = 0.589x - 1.05$

2. Summer fen waters ($n = 29$, $\underline{r} = 0.712$, $p < 0.001$)

   $\log y = 0.284x$

3. October fen waters ($n = 10$, $\underline{r} = 0.89$, $p < 0.001$)

   $\log y = 0.234x$

B. Specific conductivity (y) and calcium (x): regression of conductivity upon calcium, a major contributor to it.

1. Normal bog and fen waters, summer and October ($n = 68$, $\underline{r} = 0.909$, $p < 0.001$)

   $\log y = 1.18 + 0.557 \log x$

2. All bog and fen waters ($n = 78$, $\underline{r} = 0.911$, $p < 0.001$)

   $\log y = 1.17 + 0.606 \log x$

Table 3 -- continued

C. Light extinction (y) and pH (*x*): reduced major axes, with neither variable dependent.

1. Summer bog and fen waters (n = 51, $\underline{r}$ = −0.839, $p < 0.001$)

   $y = 3.25 - 0.452x$

2. October bog and fen waters (n = 17, $\underline{r}$ = −0.933, $p < 0.001$)

   $y = 2.60 - 0.414x$

There is a notable gap in Figure 2, with no samples in the pH range between 4.6 and 5.1, despite a marked overlap in the conductivities of bog/poor-fen and rich-fen waters. The more acid samples are from bogs or poor-fens that have one or more indicators of minerotrophy. The less acid samples are from rich fens, except for one (at pH 5.1) from poor fen. Within the fen waters the concurrent rise in conductivity and pH betokens strongly increasing minerotrophy.

At a given pH, the highest conductivities come from shallow pits dug in the peat (shown as triangles in Fig. 3). The reason is not as yet understood. The highest single conductivity and pH values come from a sample (marked BR in Fig. 2) taken from a water track immediately downstream from an intersecting beach ridge that obviously provides a very strong minerotrophic input.

Figure 3 shows the close relationship between conductivity and calcium that comes about because the dominant contributor to the salt content of minerotrophic waters is calcium bicarbonate. The lowest calcium and conductivity values among the rich-fen samples are from the narrow water-tracks of the west-central and eastern watershed that are surrounded by ombrotrophic peat. The sample from just downstream from a beach ridge (marked BR in Fig. 4) is unusually rich in calcium, at 56 mg/l.

Light extinction is related to the concentration of dissolved organic matter (Gorham 1957a), which in turn is greatest where waters are stagnant and the products of organic decay accumulate. Bog waters in the Red Lake Peatland are rather stagnant, with flow rates estimated at about 1 cm/min or less, whereas the less highly colored fen waters generally come from water tracks where flow wates are often as much as 1 m/min or more (Hofstetter 1969).

Figure 4 shows the inverse relationship between light extinction and pH, and three points are worth noting. First, the highest values come from samples taken in pits (triangles in Fig. 5), where water flow might be expected to be slow. Second, light extinction is also unusually high in the two fen waters (marked D in Fig. 4) collected just east of Highway 72 where it intersects a westward-flowing water track and stagnates its drainage. More generally, extinction values are higher in the ditched portions of the mire than in the relatively pristine areas where waters are presumably more mobile. Third, all the October samples exhibit low values, unlike the case for conductivity, in which only the fen waters are low. The reason for these seasonal differences is as yet unknown, but it may be noted that the autumn — and the peat -- was relatively dry so that dilution by high rainfall was unlikely.

Chemical properties also serve to differentiate the major types of vegetation at Red Lake (Fig. 5). Ombrotrophic bog waters exhibit pH values below 4.2, whereas the rich-fen waters are above 5.1 and range up to 7.0. Poor-fen samples generally have a pH of 4.0 to 4.6, but certain samples with a pH as low as 3.8 or as high as 5.1 seem to indicate poor fens on the basis of Ca^{2+} concentrations and specific conductivity. These extreme values suggest that the chemical properties of poor fens at Red Lake overlap with those of the rich fens and ombrotrophic bogs. The conspicuous gap between pH 4.6 and 5.1 (Fig. 5) may therefore be a result of insufficient sampling.

The ombrotrophic bog waters are generally low in salts (conductivity range 12-27 μmhos, and to 50 μmhos in pits), whereas the rich fens exhibit a higher range of concentration (usually 23-82 μmhos, to 92 μmhos where drainage is stagnated by Highway 72, 128 μmhos in pits, and 315 μmhos downstream from a beach ridge). Calcium is also low in the bog waters (0.8 - 2.1 mg/l) and is generally much higher in the rich fens (usually 3.0 - 13.5 mg/l, to 19.6 mg/l upstream of Highway 72, 18.4 mg/l in pits, and 55.7 mg/l downslope from a beach ridge). In contrast, the stagnant bog waters are highly colored (extinction 0.9 - 1.4, to 1.9 in pits), whereas the more rapidly flowing fen waters are less so (extinction usually 0.1 - 1.4, to 1.9 upstream from Highway 72, and 0.6 in pits). These ranges are all based on samples taken from June through August. The October samples are excluded because of their unexpectedly low Ca^{2+} concentration and specific conductivity.

Poor fens are generally distinguished by a pH range of 4.0 to 5.1 and calcium concentrations greater than 2 mg/l (cf. Sjörs 1950b, 1961, 1963, Heinselman 1970, Vitt, Achuff, and Andrus 1975). A number of water samples from the Red Lake area fall within this range.

These water-chemistry data support the major division of the vegetation into bog and rich fen. However, samples within the poor fen range correspond closely to either bog or fen vegetation. A few samples taken from pits are also difficult to classify on the basis of water properties alone. They resemble bogs in terms of their low pH (3.8 - 3.9) and poor fens in regard to Ca^{2+} concentration (2.0 - 2.1 mg/l) and specific conductivity (25 - 50 μmho). The relevés from which these samples were taken lacked minerotrophic indicators and therefore seem to be best described as bogs.

The different types of bog and fen communities are also not related to differences in water chemistry. These communities seem to be differentiated more by differences in light intensity and water levels. Certain species display a high fidelity to narrow ranges in pH. *Carex oligosperma*, *Eriophorum spissum*, and *Vaccinium vitis-idaea* are restricted to sites with a pH less than 4.2, whereas *Carex leptalea*, *Carex pseudo-cyperus*, and *Triglochin maritima* are only found in minerotrophic sites with a pH above 5.1. Species that reach their greatest abundance in the poor fens between these two pH values are *Carex exilis*, *Scirpus cespitosus* var. *callosus*, and *Carex pauciflora*. The relationship between the principal species of *Carex* in the peatland with the water chemistry is more thoroughly discussed in another paper (in preparation).

The Effects of Drainage Ditches

The most distinctive feature of patterned mires is the alignment of the major landforms relative to the prevailing slope. This condition suggests that surface drainage plays an important role in the development of these mire patterns. In the Red Lake area broad-scale surface drainage amounting to a major perturbation was carried out during the early twentieth century (Soper 1919). Ditches were cut through the downslope portions of the peatland to drain the land for agriculture, leaving the upslope portions intact. The ditches failed to drain the peatland, but they did produce local changes in hydrology. Significant local alterations in the vegetation and landforms associated with these ditches provide a marked contrast with conditions in the pristine areas upslope.

Drainage ditches are most effective in lowering the water table in the active layer of a peatland (Boelter 1972), through which most water moves as lateral subsurface flow (Gorham and Hofstetter 1971, Rycroft, Williams,

& Ingram 1975). The active layer consists of the uppermost layers of peat that are relatively undecomposed and exhibit a relatively high hydraulic conductivity (Boelter 1972, Goode, Marson, & Michaud 1973, Romanov 1961). Boelter (1972) shows that a deep ditch in northeastern Minnesota was ineffective in lowering the water table below the active layer at horizontal distances greater than 5 m from the ditch. Similar results were obtained by Rutter (1955) in a mire in southeastern England.

The minerotrophic water tracks in the Red Lake Peatland have been most affected by ditching. Flarks are noticeably drier on the downslope sides of the ditches, although a narrow zone of wet pools may still persist along the edges of the track. This effect is most conspicuous on the infrared aerial photography that depicts wetter conditions by darker tones. Plate 4 illustrates the abrupt change from the wetter flarks of the pristine portions of the western water track to drier conditions immediately downslope from the first drainage ditch. _Carex lasiocarpa_ becomes progressively more dominant in these drier flarks, as species more susceptible to drying such as _Drosera_ spp., _Utricularia_ spp., _Equisetum fluviatile_, and _Scheuchzeria palustris_ drop out.

Wherever the drainage ditches create drier flarks, changes also take place in the strings. Strings are both higher and wider in the ditched portions of the water tracks, in contrast to the wetter pristine areas. Small trees of _Larix laricina_ and more rarely _Picea mariana_ are frequently present on strings within ditched portions of the peatland. Strings are typically closer together in the driest portions of a track but are usually spaced much farther apart where the wetter pools occur near the edge of a track. As the water tracks become progressively drier across a series of

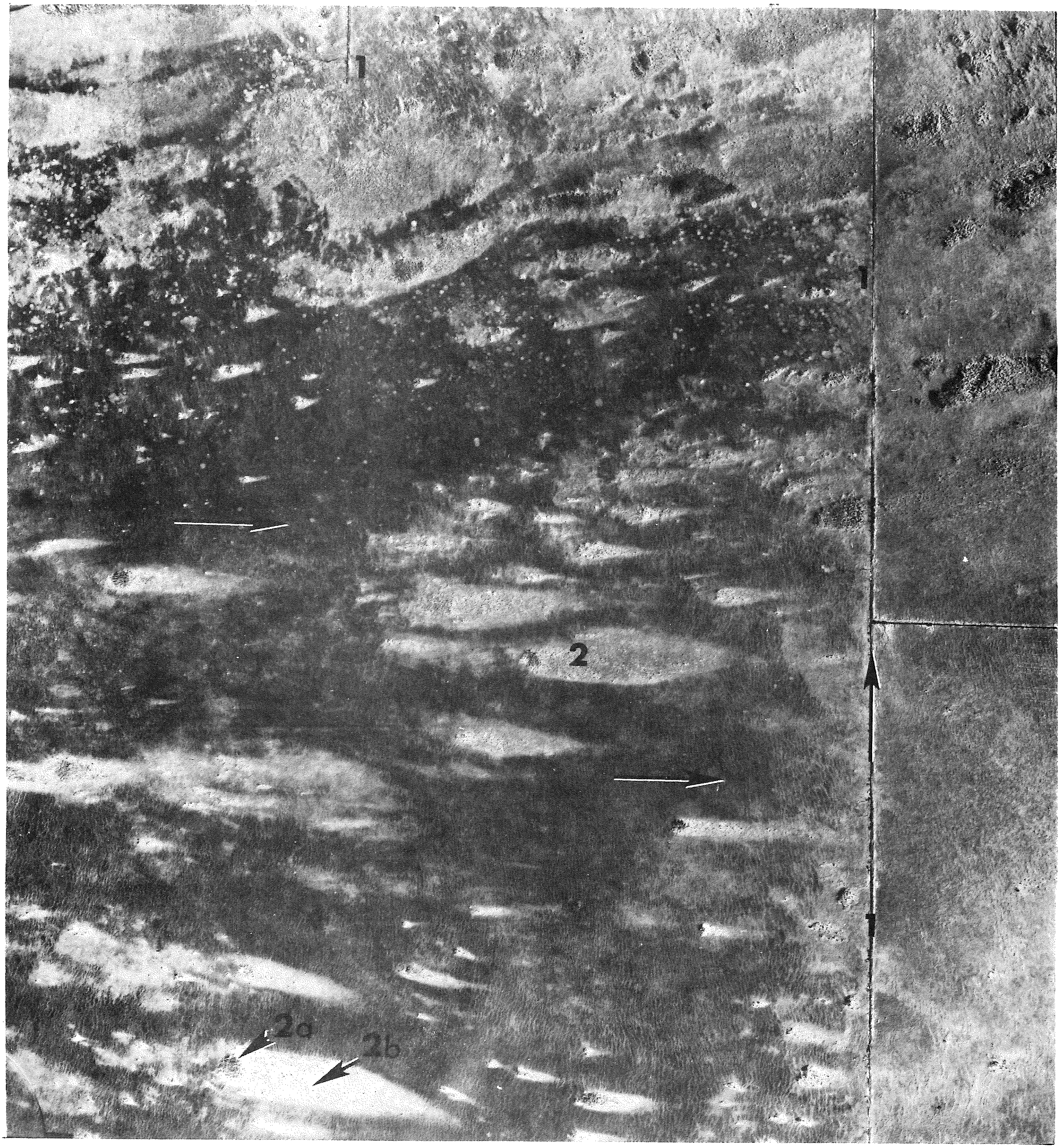


Plate 4.
Infrared aerial photograph (scale 1:15, 840) of the western water track. The water flows from left to right (see unlabeled arrows) and is partially diverted by the north-south drainage ditch (1) at the right-hand side of the photograph. The dark shade of the water track west of the ditch indicates very wet surfaces, whereas the lighter tones to the east represent drier surfaces. Note the fine pattern of strings and flarks between the tear-drop islands (2). Most of the islands have a small area of trees at the head (2a), and a long tapering tail of brush (2b) downslope.

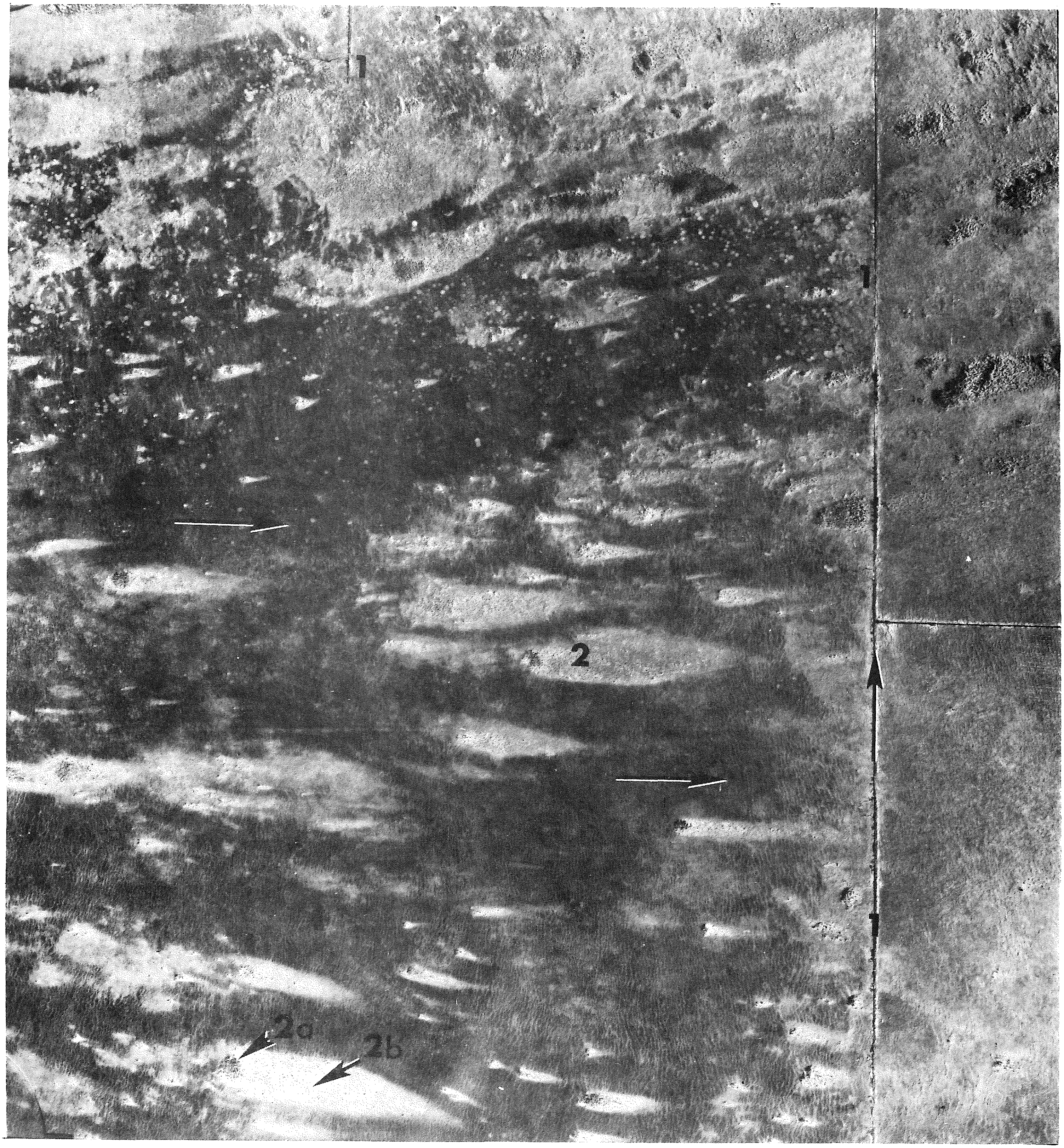
drainage ditches the strings expand and may coalesce in the driest locations to form extensive shrublands. The shrub tails of the teardrop islands also enlarge under these conditions, especially where an island is bisected by a ditch.

The most striking change in the patterned water tracks occurs where Minnesota Highway 72 traverses the east-central water tracks. Water flow is diverted into the drainage ditch on the eastern upslope side of the road, and as a result the downslope portions have partially dried out. After a heavy rainstorm in July of 1978 water flowed over the spoil bank on the upslope side of the road, and the water level within the adjacent ditch rose several centimeters from the previous day. At the same time the water table was 20 cm below the surface about 100 m downslope from the road. The characteristic string-flark pattern has almost completely disappeared from this area, and exotic species such as Spiraea alba, Populus tremeloides, Asclepias incarnata, and Cirsium arvense have invaded the water track.

The drainage ditches and roadways have produced less noticeable changes in the ombrotrophic areas. The margins of the ovoid islands have maintained their integrity, although the water table may have fallen as much as 30 cm below the surface. In such cases Carex oligosperma and Carex pauciflora are conspicuously absent from the open areas, in which the common bog ericads predominate.

Origin of the Mire Patterns

The development of the patterned landforms in Red Lake Peatland can only be reconstructed from the stratigraphic analysis of peat cores.



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However, the present-day landscape contains evidence of dynamic processes that may account for the origin of these features. Infrared aerial photography and LANDSAT imagery furnish important clues to the influence of lateral surface and subsurface flow upon the origin of these mire patterns, and they provide the basis for hypotheses that may be tested later by stratigraphic analysis.

Formation and Development of Islands

The formation of island patterns in the Red Lake Peatland seems to be intimately associated with the origin of patterned water tracks. Near the source of these water tracks incipient islands occur that grade into discrete, well-developed islands farther downslope. The type of island formed appears to be a function of the vegetation-landform unit from which a water track arises. Large ovoid islands, for example, are all found in watersheds that arise from *Sphagnum* lawns and raised bogs. The smaller teardrop islands, however, are restricted to the western water track, which originates from a peripheral zone of minerotrophic swamp forests and wet thickets. In either case horizontal water movements become progressively channeled into water tracks that delineate island patterns. Channeled flow off the raised bogs and ovoid islands also seems to favor the growth of unforested openings producing bog drains and horseshoe-shaped islands, respectively. But channeled flow does not seem to be responsible for the origin of circular or linear islands. Thus the various types of islands are not all created by the same processes, nor do they seem to represent different stages of the same developmental sequence.

Ovoid Islands

The formation of ovoid islands seems to be associated with the channeling of water flow across the *Sphagnum* lawns. The channeling process is evident on aerial photographs by the alignment of the bog drains at the head of the watershed, with the incipient water tracks farther downslope (Plates 1, 3, and 5). Channeling of water movements is apparently favored by irregularities in the active layer of peat that produce gradients in hydraulic potential.

Incipient ovoid islands appear on the *Sphagnum* lawns at places where horizontal water movements are diverted by obstructions (Plates 3, 5). The incipient islands have diffuse margins and are covered by relatively open stands of *Picea mariana*. The concentration of subsurface wood under these islands may obstruct surface drainage (Anderson 1964, Rycroft, Williams, & Ingram 1975) and divert water flow around the margins of the islands. This hypothesis is supported by LANDSAT imagery (Plate 2), in which the light shades of the incipient islands indicate relatively dry surfaces in contrast to the dark and presumably wet surfaces of the *Sphagnum* lawns.

Downslope the incipient islands grade into well-developed ovoid islands, whose margins are sharply defined by water tracks (Plates 3, 6). This transition suggests a developmental sequence, because the incipient islands have sizes, shapes, and arrangements similar to those of the mature islands farther downslope. Upslope the incipient islands also grade into isolated segments of the wooded portions of raised bogs that extend out onto the *Sphagnum* lawns (Plates 3, 5). Incipient islands may arise as the bog drains grow headward and progressively isolate segments of forest from the

Plate 5.
Infrared aerial photograph (scale 1:15, 840) of the eastern watershed showing: patterned fen (1), ovoid island (2), Sphagnum lawns (3), incipient water tracks (3a), incipient ovoid islands (3b), raised bogs (4), bog drains (4a), and fire scars (5). The incipient water tracks in the lower part of the photograph are aligned with bog drains below the photograph off the field of view. The shapes of the raised bogs have been altered by fire. This area is directly west of that shown in Plate 6.

Plate 6.

Infrared aerial photograph (scale 1:15,840) **of ovoid islands in the eastern watershed.** The central island has a drain (1) on its downslope side. An unforested opening (2) surrounds the drain and is superimposed over the pattern of spruce forest (3) that radiates from the crest of the island. The position of this drain is similar to that of the broad downslope openings of the horseshoe-shaped ovoid islands of the west-central watershed (compare with Plate 3). The darkness of the tone in the water tracks is proportional to the wetness of the surface. The direction of water flow in the tracks is indicated by unlabeled arrows.

main forested bog-divide. The diversion of water around the margins of these segments may produce incipient islands.

The sequence of vegetation-landform types across the eastern and central watersheds therefore appears to represent a chronosequence. According to this hypothesis, which should be tested by stratigraphic analysis, the direction of mire development in these watersheds is as follows: raised bogs → bog drains → *Sphagnum* lawns → incipient water tracks and ovoid islands → mature water tracks and ovoid islands. Although the channeling of water flow appears to be the overriding factor that determines the direction of these changes, the mechanisms by which physical and biological changes are brought about by channeled flow remain obscure.

Horseshoe - Shaped Islands and Bog Drains

The development of bog drains (Plates 3, 5) appears to be similar to that of the unforested interiors of the horseshoe-shaped islands (Plate 3). Both landforms have essentially the same vegetation and exhibit several features indicative of paludification. There is a marked decline in the density, height, vigor, and growth rates of *Picea mariana* trees from the forested margins toward the open interiors of these landforms. The *Picea* trees are strongly layered in the open interiors and show numerous strata of adventitious roots. Several authors have considered these processes to be a response to the rapid growth of *Sphagnum* moss (LeBarron 1945, Capps 1931, Horton & Lees 1961). In addition field observations and LANDSAT imagery suggest that the open interiors are wetter than the surrounding forest.

These open interiors appear to be advancing headward into the forests of the raised bogs and ovoid islands. The best evidence for such an advance is found on an ovoid island in the eastern watershed. This island has a wet drain-like structure (Plate 6, feature 1) near its downslope margin in a position that is similar to that of the broad downslope openings of the horseshoe-shaped islands in the west-central watershed (Plate 3, feature 2). An unforested opening surrounds this drain (Plate 6, feature 2) and is superimposed over the pattern of spruce that radiates from the crest of the island (Plate 6, feature 3). This drain could therefore represent the initial development of a much wider tongue-shaped opening that is developing down the center of the island.

The headward growth of these unforested openings may be produced by the channeling of surface drainage across the raised bogs and ovoid islands. The wetter channels would favor the growth of Sphagnum at the expense of forest. An increase in the accumulation of Sphagnum would in turn promote horizontal water flow as less buried wood is present to obstruct flow. Thus channeled flow and increased growth of Sphagnum would mutually reinforce each other to favor the headward advance of the unforested openings.

Teardrop and Linear Islands

Teardrop islands do not appear to be related to the ovoid islands in regard to either vegetation or developmental processes. Teardrop islands are restricted to the western water track, where ovoid islands are absent (Plate 1). On the northern edge of the water track a transition of patterns is present (Plate 7). Fingers of forest protrude out into the water track and closely resemble the teardrop islands in size, shape, and

Plate 7.

Infrared aerial photograph (scale 1:15,840) showing the north-central edge of the western water track. Broad lines of water flow (1) converge on the northern edge of the track and delimit fingers of forest (2). Farther downslope teardrop islands (3) appear with the same general size, shape, and orientation; they may be remnants of such fingers. The inferred direction of water flow is marked by arrows. The wetness of the surface is indicated by the darkness of tone.

orientation. These forested fingers are defined by numerous flow lines that originate from the periphery of the peatland and converge on the western water track. The margin of the track appears to be in a state of flux at this point, but only stratigraphic studies can confirm whether the track is advancing upslope into the edge and actively forming new islands.

Similar transitions occur along the southern and western margins of the western water track. These margins are also marked by converging lines of flow and forested fingers that are strikingly aligned with zones of teardrop islands farther downslope (Plate 1). In the central zone of teardrop islands the islands are aligned with the wide channels and long tapering tails of trees that extend out from the western edge of the track. Narrower zones of islands flare out to the northwest on the north side of the track and to the southwest on the south side. All of these islands seem to represent remnants of forest that were isolated as the water track grew headward into the margin. Support for this hypothesis comes from stratigraphic cores that indicate younger and shallower peat in the upslope portions of the track. A 155 cm core down to mineral soil was recovered from the center of the upslope portion of the track with basal peat dated (by radiocarbon) at 1950 ± 65 years BP (Wis-1037). In contrast basal peat in a teardrop island farther downslope was dated at 3170 ± 100 years BP (Y-1777) (Griffin 1977). The pollen and macrofossil stratigraphy of this core, however, indicates that the island is not a forest remnant but originated from a _Carex aquatilis_ - _C. diandra_ sedge meadow about 2,000 years ago (Griffin 1977).

The central and eastern water tracks also contain a few linear islands (Plate 3, feature 1b) that resemble the teardrop islands of the western water track. The linear islands, however, arise from long tapering tails of brush that trail downslope from ovoid islands. Brushlands of this type are frequently encountered in the water tracks wherever islands, ditches, mineral uplands, or other obstructions to water flow are present. The drainage ditches that cut through the zones of linear islands may also promote reduced flow rates and drier surfaces that favor the growth of trees on these brush tails.

Circular Islands

The circular islands of the Red Lake Peatland (Plate 3, feature 1c) are similar in size and shape to the wooded palsas of Manitoba and Saskatchewan (Zoltai 1971, Zoltai & Tarnocai 1971). One of the Red Lake islands also has an unforested interior that from the air resembles the collapse scars described by Zoltai (1971). However, the circular islands at Red Lake do not have cores of permafrost and rise less than a meter from the surrounding water track. A field check of the island with the open interior also established that this opening was caused by an infection of dwarf mistletoe (*Arceuthobium pusillum*) rather than the collapse of a frozen core. Thus despite apparent similarities with wooded palsas, the circular islands of the Red Lake region must have an origin quite different from that proposed for palsas (Lundqvist 1969, Mackay 1965).

Two hypotheses regarding the origin of circular islands may be formulated from the analysis of aerial photographs and ground reconnaissance. In the west-central watershed the circular islands are interspersed in the water track among smaller circular hummocks and dense clones of Rhynchospora fusca. The islands are generally forested with Picea mariana and occasionally Larix laricina, and even the largest hummocks contain a few small trees. The apparently continuous range of variation between islands and hummocks suggests a developmental link. Hummocks may originate from clones of Rhynchospora fusca. Clumps of dead shoots at the base of the clones typically support the growth of Sphagnum and other vascular plants more typical of hummocks. These clumps may form the nucleus of a hummock as separate growth centers of Sphagnum coalesce. The appearance of trees on the larger hummocks and islands may also be related to the drainage ditches that surround the area of circular islands. Just downslope from the islands the water tracks that lead northward between the ovoid islands contain well-developed strings with a denser growth of Larix laricina than is found in any unditched water track. In contrast a zone of circular hummocks and Rhynchospora fusca clones is found in the unditched eastern watershed, where trees are generally absent from strings and hummocks.

Alternatively, the circular islands and hummocks may be remnants of a previously flooded surface of peat, for they are typically found near the heads of water tracks where the tracks may be actively spreading. At this point the margins of the water tracks are composed of circular hummocks that extend out from the edge and grade into discrete islands in the adjacent pools. It appears as if the northward drainage off the main linear raised bog at the south edge of the west-central area (Plate 3) is dammed up behind the cluster of large ovoid islands, escaping northward with difficulty in narrow water tracks between the islands. The lack of strong gradient here may result in the circular rather than streamlined shape of the small islands and hummocks.

Patterned Water Tracks

The water tracks within the Red Lake Peatland appear to originate from the channeling of water flow across two types of source areas. The large western water track (Plate 1) arises from an extensive area of swamp forests and wet thickets that covers the periphery of the peatland. Surface drainage is channeled into parallel lines of flow that dissect this edge area and converge eastward into the western core of the track. These flow lines are particularly conspicuous on the LANDSAT imagery taken during spring break-up of 1978 (Plate 2).

Water tracks of the Red Lake area also arise from the surface of the *Sphagnum* lawns. Incipient water tracks there are marked by a striking rise in pH. The raised bogs and bog drains at the heads of these watersheds have strongly acidic water, with pH below 4.0. Farther downslope the pH rises from 4.1 to 4.5 on the *Sphagnum* lawns. However, a sample from an incipient water track within the west-central lawn had a pH of 5.5, even though it was surrounded by more ombrotrophic peat. The incipient water tracks lead downslope into distinct water tracks between ovoid islands, which in places exhibit pH values of 6 or more. Similar water tracks with seemingly minerotrophic water set within ombrotrophic mires have been described by Heinselman (1970), Kulczynski (1949), Malmer (1962), Osvald (1949), and Sjörs (1963).

There are two possible explanations for the origin of these seemingly minerotrophic zones. Rutter (1955) has demonstrated that artesian pressure in an English mire caused the upwelling of groundwater from the underlying mineral substrate. Artesian flow seems unlikely in the Red Lake area, however, because 1) the incipient tracks are not associated with unusually high conductivity and calcium concentration such as characterize the fen samples downslope from the beach ridge, 2) the path of the incipient tracks can be traced to bog drains at the head of the watersheds, and 3) pools in the incipient tracks are highly colored (extinction 1.3 - 1.4) thus suggesting relatively stagnant water.

Ingram (1967) proposed an alternative hypothesis (*cf*. Heinselman 1970) that horizontal water movements gather ombrogenous ions from the mire expanse into water tracks. As water seeps across the raised bogs and *Sphagnum* lawns it becomes channeled into drains because of irregularities in the active layer of peat. The drains widen downslope and become water tracks, where the higher levels of oxygen picked up by surface aeration of the moving water may promote corrosive oxidation of the peat (*sensu* Sjörs 1963) and the consequent release of ions to enrich the mire water. Presumably, corrosive oxidation decomposes the organic matter dissolved in the bog waters at the same time. This hypothesis of the conversion of an ombrotrophic bog water into apparently minerotrophic fen water has unfortunately not been tested. Whether there are biological and physical mechanisms that can account for the origin of such seemingly minerotrophic waters within the incipient water tracks remains to be established. A thorough investigation of the hydrology of the peatland would do much to elucidate the origin of these waters.

String-Flark Pattern

A great deal has been written about the origin of strings and flarks and critiques of existing theories can be found in Auer (1920), Drury (1956), Heinselman (1963), Hofstetter (1969), Moore & Bellamy (1974), Thom

(1972), and Washburn (1973). In the Red Lake Peatland several independent factors may be responsible for the development of patterned water tracks.

In certain locations the string-flark pattern appears to be associated with the origin of water tracks. Zones of narrow, sinuous pools elongated parallel to the contours are visible on the upslope portions of the *Sphagnum* lawns, and these zones gradually merge downslope to form incipient water tracks. The pools in these incipient tracks become further elongated and spaced much more closely together downslope until a typical string-flark pattern forms. The initial development of these pools seems to be related to the surface pattern of the *Sphagnum* lawns which consists of sinuous, elongate tussocks of *Carex oligosperma* and hollows of *Sphagnum*.

Such elongate pools on the *Sphagnum* lawns and incipient water tracks resemble the elongate pools on certain raised bogs in Scotland (Boatman & Armstrong 1968, Boatman & Tomlinson 1973, 1977). In both areas the pools contain peninsulas and many small hummocks that suggest flooding. Boatman & Armstrong (1968) propose that the elongate pools are initiated by the lateral flooding of adjacent pools on the same contour, whereas the overflow of a pool to a downslope pool would result in erosion and thus drainage downslope (*cf.* Gorham 1957b). In the Red Lake area, initial random pools may be favored on the *Sphagnum* lawns because of the presence of hummocks and hollows. Lateral flooding of those pools along the same contour could cause elongation and could lead ultimately to development of the string-flark pattern.

Strings may also be formed by the clonal growth of *Carex exilis* and *Scirpus cespitosus*, which grow out from the margins of the western and west-central water tracks. Lundqvist (1962) also noted the tendency of Scirpus cespitosus to form strings in Scandinavia. In the Red Lake Peatland circular clones of Rhynchospora fusca also seem to form nuclei of circular hummocks in various water tracks.

The development of strings may also be related to the microhummocks that occur in all the water tracks within the study area. These microhummocks consist of dead shoots of Carex lasiocarpa and are generally oriented obliquely downslope. The dead shoots have a clumped appearance that suggests the influence of water flow, for instance during spring break-up. Even the wettest pools contain these microhummocks, which are colonized by species characteristic of the strings. The microhummocks may develop into larger hummocks or strings depending on variations in the water level.

The presence of patterned landforms in boreal mires adds another level of complexity to a poorly understood ecosystem. The development of mire patterns must involve vegetational changes, but the direction and stages of plant succession have seldom been established for even patternless mires in North America. Unlike upland sites, little is known about the factors that control the direction of mire development. Mire ecologists have noted that gross changes in vegetation are often associated with corresponding changes in water chemistry. However, mutual interactions between lateral movements of water and the uppermost centimeters of peat through which it passes may promote unexpected changes in the mire expanse. In the Red Lake Peatland seemingly minerotrophic water tracks arise from within largely ombrotrophic expanses of peat where the influence of mineral soil is minimal. Moreover, the origin of ovoid and circular islands and of linear arrangements of strings and flarks seems to be intimately related to the developmnet of water tracks. Important steps toward understanding the origin of mire patterns are most likely to result from studies of present-day differences in vegetation combined with hydrologic investigations and the stratigraphic analysis of peat cores.

Mire patterns also seem to be products of differential growth of peat, because these landforms are generally composed of peat accumulations several meters thick. The rate of peat accumulation in the Red Lake Peatland appears to be very rapid, as demonstrated by the numerous strata of adventitious roots on trees. Even individuals of *Sarracenia purpurea* may extend down into the peat for almost a meter. Estimates for peat accumulation in this and other mires of North America may provide information on the relationship between mire patterns and rates of peat growth.

CONCLUSIONS

The patterned mires of the Red Lake Peatland are similar in large part to other mire complexes in North America. The mire patterns of the Hudson Bay Lowlands described by Sjörs (1963) seem to bear the closest resemblance to the landforms of the Red Lake area. Both areas contain patterned water tracks that have ovoid, teardrop, and horseshoe-shaped islands. The vegetation and flora, particularly of the minerotrophic areas, are also strikingly similar in these two regions (Hofstetter 1969; Wheeler *et al.*, in prep.). However, the distinctive bog pools and string bogs of the Hudson Bay Lowlands are absent from the Red Lake area.

The circular spruce islands in the Red Lake area superficially resemble the wooded palsas described by Zoltai (1971) and Zoltai & Tanocai (1971) in Manitoba and Saskatchewan. One of these islands from the Red Lake area also has an open center that superficially resembles the collapse-scar features described by Zoltai (1971). However, the circular islands in the Red Lake area do not have cores of permafrost, and the open-centered island was created by a dwarf mistletoe infection.

The vegetation and flora of Red Lake Peatland are less similar to those of the patterned mires of the Swan Hills, Alberta (Vitt et al. 1975) and the Kuskokwim Lowlands, Alaska (Drury 1956). Unfortunately, published reports of patterned mires from elsewhere in North America (Allington 1961, Hamelin 1957, Henoch 1960, Knollenberg 1964, Mills et al. 1977, Radforth 1962, Schenk 1966, and Thom 1972) do not contain sufficient information to permit a satisfactory comparison with the Red Lake Peatland.

Several authors have considered permafrost to be an important factor in the development of either the string-flark pattern (Schenk 1966, Hamelin 1957, Tricart 1970 p. 111) or of tree islands (Sjörs 1963, Zoltai 1971, Zoltai & Tarnocai 1971). However, very similar landforms occur in the Red Lake Peatland where permafrost is absent. Apparently the formation of these landforms is not solely dependent on the presence of permafrost, which may instead become secondarily associated with these features farther north.

The origin of the patterned landforms of the Red Lake Peatland seems to be closely associated with the dynamics of surficial drainage. Channeling of water flow across broad surfaces of peat may initiate the development of water tracks, bog drains, and islands that have an ovoid, teardrop, or horseshoe shape. The importance of lateral water flow in maintaining these landforms is demonstrated by the local effects of drainage ditches or roadways on the vegetation and landforms of the Red Lake area. The striking resemblance that exists between peatland patterns in the Red Lake area and other mires in North America suggests that surficial flow may play a similar role in the formation of patterned peatlands farther north. Such peatlands may, indeed, represent at least as delicate an adjustment of vegetation to hydrology as that in the much better known coastal salt marshes.

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APPENDIX: Common names of plants referred to in the text

Scientific Name	Common Name
Andromeda glaucophylla	bog rosemary
Arceuthobium pussillum	dwarf mistletoe
Aronia melanocarpa	black chokeberry
Ascelepias incarnata	swamp milkweed
Betula pumila	bog birch
Calla palustris	water arum
Carex spp.	sedge
Chamaedaphne calyculata	leatherleaf
Cirsium arvense	Canada thistle
Drosera spp.	sundew
Eriophorum spissum	cotton grass
Equisetum fluviatile	horsetail
Iris versicolor	blue flag
Juncus spp.	rush
Kalmia polifolia	swamp laurel
Larix laricina	tamarack
Ledum groenlandicum	Labrador tea
Lonicera villosa	honeysuckle
Menyanthes trifoliata	buckbean
Picea mariana	black spruce
Pinus banksiana	jack pine
Pinus resinosa	red pine
Pinus strobus	white pine
Populus balsamifera	balsam poplar
Populus tremuloides	trembling aspen

Potentilla fruticosa .... shrubby cinquefoil

Rhynchospora spp .... beak rush

Rubus pubescens .... dwarf raspberry

Rumex orbiculatus .... great water-dock

Salix spp .... willow

Sarracenia purpurea .... pitcher plant

Scheuchzeria palustris ....

Scirpus spp. .... bulrush

Smilacina trifolia .... three-leaved false Solomon's sea

Spiraea alba .... meadow sweet

Thelypteris palustris .... marsh fern

Triglochin maritima .... arrow grass

Typha latifolia .... cattail

Utricularia intermedia .... bladderwort

Vaccinium oxycoccos .... small cranberry

Vaccinium vitis-idaea .... mountain cranberry

Xyris montana .... yellow-eyed grass

MOSSES

Aulacomnium palustre

Calliergon stramineum

Campylium stellatum

Dicranum spp.

Mnium punctatum

Polytrichum juniperinum

Pleurozium schreberi

Scorpidium scorpioides

Sphagnum spp.

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PART II

CONTRIBUTIONS TO THE FLORA OF THE RED LAKE PEATLAND, NORTHERN MINNESOTA[1]

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Introduction

The Red Lake Peatland, situated just north of Upper Red Lake in northern Minnesota, is the largest area of continuous peatland in the northern portion of the contiguous United States. Owing to its immense size and general inaccessibility, most of the peatland remained botanically unexplored prior to the present study, which covered the 1978 field season. The major purpose of this investigation was to establish a classification of plant communities that could be used as a basis for mapping the peatland vegetation. The peatland patterns are described in more detail in a separate paper (Glaser *et al*. 1979).

The studies of Heinselman (1963, 1970), Hofstetter (1969), and Griffin (1975, 1977) supplied most of the botanical knowledge of the area prior to 1978, with Hofstetter's the most important floristically. However, owing to the small fraction of the total peatland covered by these studies, the floristic checklists given by these workers are far from complete. The 1978 study differs greatly from previous studies in covering a large portion of the interior rather than small areas near the periphery. This was made possible by the availability of a helicopter during the field season. In all, 89 sites scattered throughout the major landscape features of the peatland were visited during the study.

Although information is included to acquaint the reader with the physiography and vegetation of the study area, the primary objectives of this paper are to provide a record of plant collections made in the peatland and to discuss the floristic similarities that exist between the Red Lake Peatland and other peatlands in North America and northern Europe.

The classification of peatland vegetation used in this paper makes use of two major types, bog and fen, that were first defined in their present sense by Du Rietz (1949, 1954) and have since been used by Sjörs (1948, 1950a, 1950b, 1959, 1963), Malmer (1962), and many others. Bog plant communities are ombrotrophic, i.e. dependent solely upon atmospheric deposition for their mineral supply, whereas fen communities are minerotrophic, i.e. dependent largely upon water that has percolated through mineral soil. In addition, a differentiation is made between poor fen and rich fen, also proposed by Du Rietz and based on acidity and other chemical properties of the minerotrophic peat and water.

Physiography

The Red Lake Peatland is situated in northeastern Beltrami County and adjacent parts of Koochiching and Lake of the Woods counties (Fig. 1). It occupies a large area of gentle slope that was formerly the eastern arm of Glacial Lake Agassiz. The peatland extends about 80 km east to west and 15 km north to south, thus having an area of about 1200 km^2. It is bounded on the south, north, and west by sandy beach ridges of Glacial Lake Agassiz or by low moraines. To the east it is bounded by several smaller peatlands, which were apparently once continuous with the Red Lake Peatland but which have been detached by headward erosion of the Big Fork River and its tributaries.

The uplands surrounding the peatland are covered by the mixed conifer-deciduous forest characteristic of the Great Lake region, but the prairie is only 20 km to the west. The climate is continental, with short, warm summers and with winters that are long, cold, and dry. Precipitation decreases westward across the area.

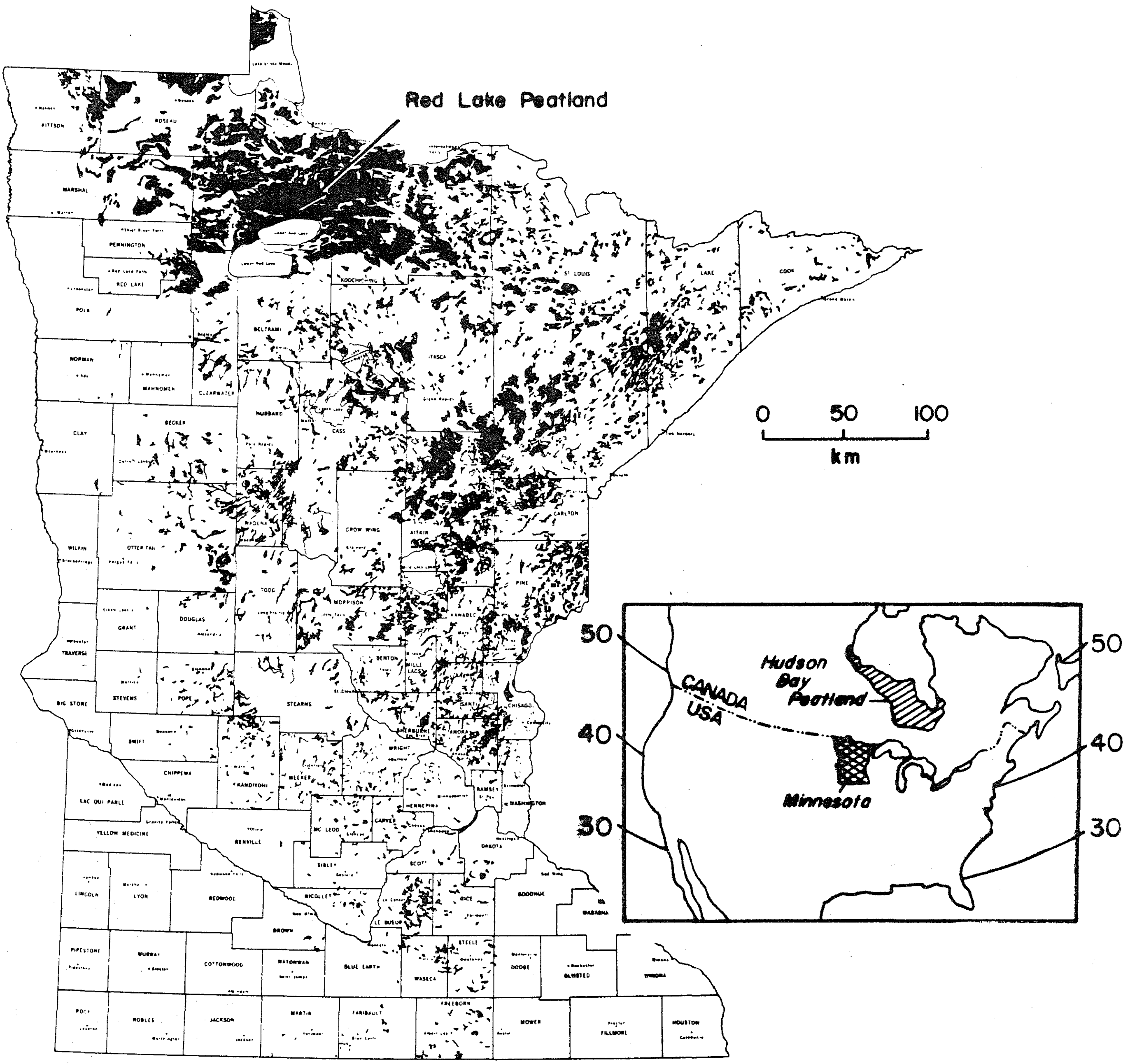

Figure 1. Map of Minnesota showing location of the Red Lake Peatland with respect to other peatlands.

The peatland consists of a complex of ombrotrophic bogs and minerotrophic fens. These can be assigned to four main areas or watersheds, from west to east: (I) Western area, consisting of a broad patterned water track, (II) West-central area, a complex of raised bogs, ovoid islands, and water tracks, (III) East-central area, a broad patterned water track leading to the northwest, and (IV) Eastern area, a complex of raised bogs and water tracks. In a previous publication (Wheeler and Glaser 1979) these areas were termed (I) Great Western Water Track, (II) Divide, (III) Ludlow Patterned Fen, and (IV) Koochiching Raised Bog Area.

The western water track (I), which is approximately 4 km wide, carries mineral-rich water eastward and then northward for a distance of about 40 km to tributaries of the Rapid River. A smaller branch leads south to Upper Red Lake. The minerotrophic water is derived mainly from the mineral soil upland to the west, but along the northern edge some additional nutrient-rich water enters from the northwest. The water track is for the most part a "ribbed fen" composed of watery linear depressions or "flarks" alternating with low, sinuous ridges or "strings" (Sjörs 1950a, 1963), all oriented at right angles to the water flow. The distance between strings is thought to be related to the degree of slope (Sjörs 1963). The western water track is studded with small forested islands, which are elongated and somewhat "raindrop-shaped" (Sjörs 1963) or "teardrop-shaped" (Heinselman 1963), being widest at the blunt, upstream end and narrowing to a prolonged tail downstream. Hofstetter (1969) believes that each island had its origin when some biomorphic obstruction impeded water flow in the fen and was enlarged by subsequent continuous diversion of minerotrophic water around the original obstruction. Paleoecological information (Griffin 1977) indicates that the ribbed fen started as a wet meadow about

3,000 years ago as the climate became wetter and that island growth started later. The teardrop islands are, like the ribbed fen in which they are found, minerotrophic in nature.

Watershed II is predominantly an ombrotrophic complex consisting of a large, linear raised bog and several ovoid "islands", which contain both open and forested bog vegetation (Fig. 2). The linear raised bog is centered about 3 km north of Upper Red Lake and extends some 6 km west to east. It displays both radiating "tongues" of forested bogs and intervening "bog drains", which are predominantly open bogs. Similar raised bogs are known elsewhere in Minnesota (Finney 1966) and from the Hudson Bay Lowlands (Sjörs 1963). The several ovoid islands to the north, like the linear raised bog, are not influenced by water from mineral soil. These differ from the elongate teardrop islands of the minerotrophic fen in being much larger and more bulbous, as well as definitely ombrotrophic. The ovoid islands are 1-4 km long and 1-2 km wide. In contrast, most if not all of the teardrop islands are much narrower and less than 500-800 m long. Some of the ovoid islands have the radiating tongues of forested bog and the intervening bog drains characteristic of raised bogs, although others have well-developed trees only along the margins of the islands, the centers being predominantly treeless. They are believed to have originated as raised bogs (Glaser _et al_. 1979).

The ovoid islands are sharply bounded by fen water tracks, which are extremely narrow but still display the ribbed fen pattern. Occasionally unvegetated areas of open water or "fen pools" can be found in these water tracks. The narrow water tracks appear to run north from the ombrotrophic area of the linear raised bog, but they become minerotrophic in their northward course by some means as yet not understood. The ovoid islands

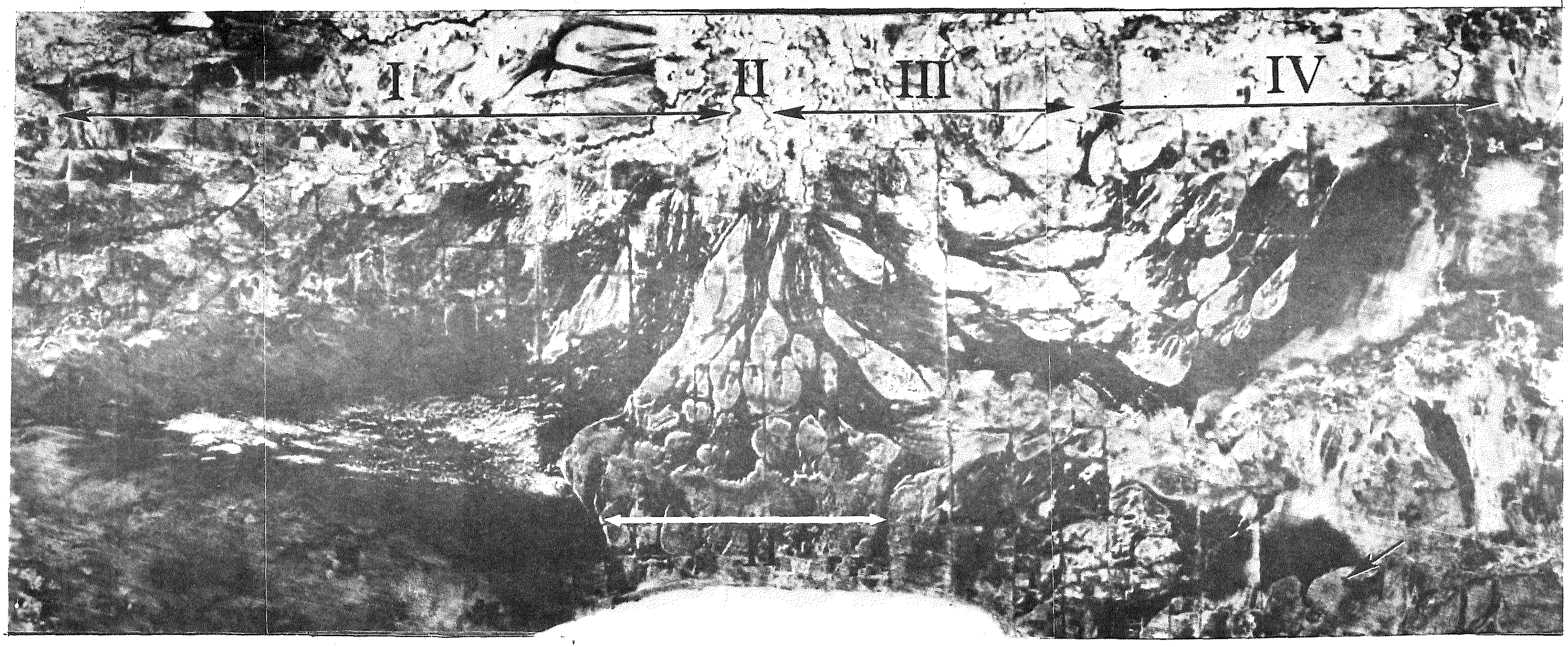

Figure 2. LANDSAT imagery (band 5 & 7) of the Red Lake Peatland and adjacent areas in north-central Minnesota. The black areas represent wet surfaces that are typical of water tracks or peripheral areas of swamp forests and wet thickets during spring break-up. The white areas represent either snow or ice. The western (I), west-central (II), east-central (III), and eastern (IV) watersheds are marked. The arrows indicate semicircular shaped bogs that have patterned water tracks diverging around their convex margins. Drainage ditches cut the downslope portions of the peatland and appear as straight lines or squares 1 or 2 miles apart. The image was recorded on April 16, 1978.

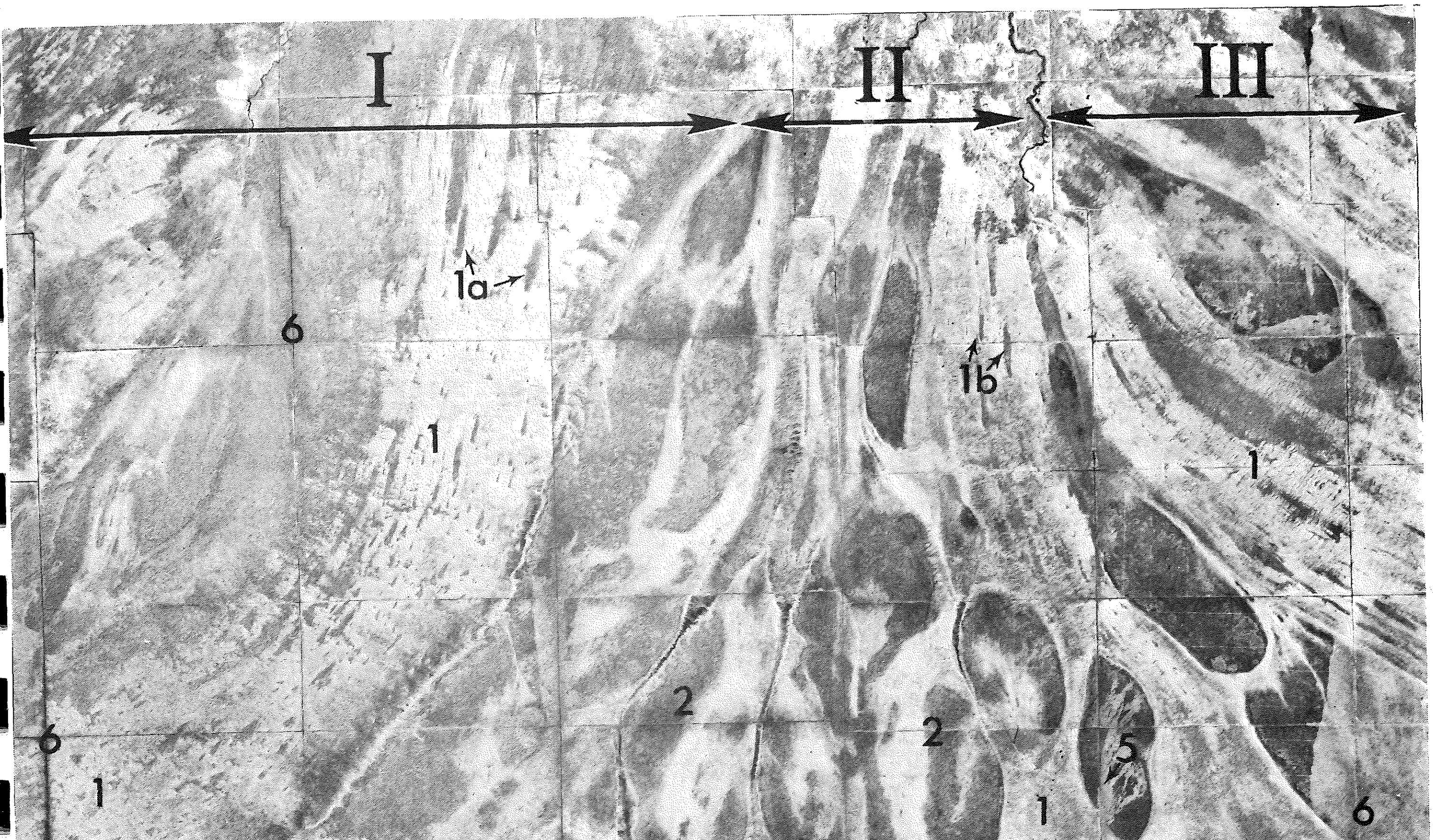

Fig. 3 Aerial pnotograph of the west-central watershed of the Red Lake Peatland. Small portions of water tracks from the west and east-central watersheds are also visible in the uppermost left and right hand corner respectively. The drainage ditches are 1 or 2 miles (1.6 - 3.2 km) apart. The following landscape units are labeled: I - western watershed, II - west-central watershed, III - east-central watershed; 1 - patterned fen, 1a - teardrop island, 1b - linear island, 1c - circular island , 2 - ovoid islands (with horseshoe ring of spruce forest), 3 - Sphagnum lawn, 3a - incipient water track, 3b - incipient ovoid island, 4 - raised bog forest, 4a - bog drain, 5 - fire scar, 6 - drainage ditch. The inferred direction of water flow is from the lower portion of the photograph toward the upper portion.

tend to be somewhat attenuated downslope to the north.

Lying between the large, linear raised bog and the group of ovoid islands is a large open, meadow-like area that appears where bog drains from the raised bog coalesce northward. This area extends about 3 km south to north and 10 km west to east. Within it are several small forested islands, most of which are circular in shape. Although situated in a portion of the peatland that is predominantly ombrotrophic in nature, surface waters taken from the meadow-like area and the small wooded islands reveal them to be weakly minerotrophic.

Watershed III lies just east of II and is somewhat curved. The flow of water in the fen is at first from east to west, but as it approaches area II it curves northward to the Rapid River. Like the western water track, area III is marked by alternating flarks and strings. The forested islands it contains are narrow and elongate rather than teardrop-shaped. The area is traversed by a major north-south highway, the only one that has been constructed through the Red Lake Peatland. Several miles of drainage ditches were dug in the peatland area between 1900 and 1918 (Hofstetter 1969) along north-south and east-west section lines, 1 or 2 miles apart, in preparation for agriculture. After the project failed,ditching was halted. Drainage ditches are common in areas II and III, less so in I and IV.

Watershed IV forms the northeastern portion of the peatland. Like area II, it is predominantly an area of ombrotrophic bogs. It contains a variety of raised bogs as well as a few ovoid islands sharply bounded by narrow fen water tracks. These water tracks locally contain large fen pools and do not display the ribbed pattern as well as do most of the other fens in the peatland.

Taxonomy

Under the "Catalogue of Species" that follows as the Appendix, the collection numbers for all vascular plants are those of two of the authors (Wheeler and Glaser); Wheeler claims full responsibility for these identifications. All vascular specimens cited are deposited in the University of Minnesota Herbarium (MIN). The lichens were collected and identified by Wetmore and are on deposit at the University of Minnesota Herbarium. All lichen records have been computerized for future retrieval if desired. Most of the bryophytes were collected by Bowers and Wheeler. However, critical collections were also made by Gorham and Glaser. All bryophytes were identified by Bowers, and a set will eventually be housed in the University of Minnesota Herbarium.

Unfortunately, the considerable amount of time spent collecting vascular plants was greater than that given to the collection of nonvascular plants. Therefore, while the writers believe that the list given for the vascular plants is nearly complete, the lists for bryophytes and lichens are not. We do believe, however, that all lists are complete as regards those plants that are of major importance to the development of the peatland.

In the vascular plant list after the name of each taxon a short description of the plant's status in the peatland is given, i.e. location and habitat. However, for many of the nonvascular plants their exact status in the peatland is still not clear. Therefore, only the binomial name is given for all nonvascular plants.

Authorities and nomenclature for the vascular plants follow in large part Fernald (1970). However, in some instances Gleason and Cronquist (1963) have been followed. Crum _et al_. (1973) were followed for the mosses, except that _Sphagnum_ spp. and _Polytrichum juniperinum_ var. _affine_ follow Crum (1976). Stotler _et al_. (1977) were used for the hepatics, and Hale and Culberson (1970) for the majority of the lichens.

Chemistry of Surface Waters

Data on water chemistry are presented in Table 1. The surface waters of the peatland range from very acid bog waters (minimum pH 3.9) to circumneutral fen waters (maximum pH 6.9). Specific conductivity (minus that ascribable to hydrogen ions, see Sjörs 1950) is a measure of salt content, and is low in all the peatland waters. The bog waters are the most dilute, with a minimum conductivity of 12 μmho. The fen waters are more concentrated, and exhibit a maximum conductivity of 92 μmho. Figure 4 shows that conductivity changes little between pH 4 and 6 but rises sharply between pH 6 and 7.

The major factor increasing the salt content of minerotrophic fen water over that of ombrotrophic bog water is calcium bicarbonate leached from the mineral soil. Figure 5 demonstrates the expected close correlation between calcium concentration and specific conductivity. Bog waters are low in calcium (minimum Ca 0.5 mg/1), and fen waters are high (maximum Ca 19.6 mg/1).

Light extinction in general reflects the degree of stagnation of the peatland waters, because where water moves slowly it tends to accumulate large amounts of dissolved organic matter that absorbs strongly in the ultraviolet. The acid bog waters are generally highly colored and slowly moving, especially in those sites where they do not reach the peat surface and must be sampled from pits dug in the peat. (Conductivity and calcium are also high in the bog pits.) In such sites light extinction may exceed

TABLE 1

Chemical characteristics of surface waters collected in summer from the Red Lake Peatland.

Watershed	Relevé	Bog	pH	Specific Conductivity[2]	Calcium[3]	Absorbance[4]
II	14	Ovoid island, open center	4.0	25	1.7	1.28
II	15	Ovoid island, open center	4.0	22	1.8	1.31
II	8	Ovoid island, open center	4.1	25	1.4	1.14
II	23	Linear bog, open drain	3.9	27	1.6	1.36
II		Linear bog, open drain	4.0	20	1.9	1.12
III	57	Spruce island, fire scar	3.9	25	2.1	1.54 P[5]
III	1	Spruce island, fire scar	4.0	17	0.5	1.20
II	9	Ovoid island, marginal forest	3.9	23	1.4	1.26
II	16	Ovoid island, marginal forest	4.0	12	0.8	0.99
II	13	Ovoid island, marginal forest	4.0	20	1.0	1.05
II	24	Linear bog, forest	3.9	50	2.0	1.94 P
III	2	Spruce island, forest	4.0	18	1.2	1.19
		Poor Fen				
II	33	Meadow-like area (open)	4.1	32	3.2	1.32
II	19	Narrow ecotone (open)	4.6	27	4.0	1.25
II	18	Narrow ecotone (open)	5.1	20	2.7	0.57
II	6	Meadow-like area (wooded island)	4.0	40	2.6	2.19 P
III	29	Spruce island, forest	4.1	23	2.7	1.13
III	3	Tamarack island, forest	4.4	31	4.8	1.33
III	31a	Spruce island, forest	4.4	34	2.8	1.68

Table 1 -- continued

Watershed	Relevé	Rich Fen	pH	Specific Conductivity[2]	Calcium[3]	Absorbance[4]
I	40	Elongate island, hollow	5.2	34	5.3	0.91
I	37	Elongate island, hollow	5.5	34	5.5	0.65
II	17	Flark between two ovoid islands	5.9	33	7.0	0.64
I	46	Elongate island, hollow	5.9	55	9.3	0.66 P
II	5	Water track just south of ovoid islands	6.0	42	5.8	0.41
I	39	Elongate island, hollow	6.0	45	7.9	0.36
I	20	Elongate island, hollow	6.0	46	9.9	0.75
I	45	Elongate island, hollow	6.2	63	10.6	0.50
I	42	Flark	6.1	73	12.8	0.45
III	30a	Flark	6.2	64	11.3	0.43
II	11	Flark between two ovoid islands	6.3	67	12.0	0.70
III	25	Flark	6.3	92	19.6	1.62D
III	26	Flark	6.4	71	14.8	1.85D
I	36a	Elongate island, hollow	6.4	75	11.6	0.26
II	4	Water track just south of ovoid islands	6.5	44	5.9	0.34
I	47	Water track at northern edge of peatland	6.5	68	12.6	0.41
I	44	Flark	6.8	82	13.5	0.11
I	35	Flark	6.9	82	13.8	0.15

[1]by glass electrode soon after return to laboratory

[2]micromhos at 20°C, with the conductivity of hydrogen ions subtracted (Sjörs 1950)

[3]mg/l, determined by atomic absorption

[4]extinction at 320nm, 1 cm cell, Beckman DU spectrophotometer; values labelled P were from shallow pits dug in the peat, values labelled D were from sites just east of highway where water flow is dammed back.

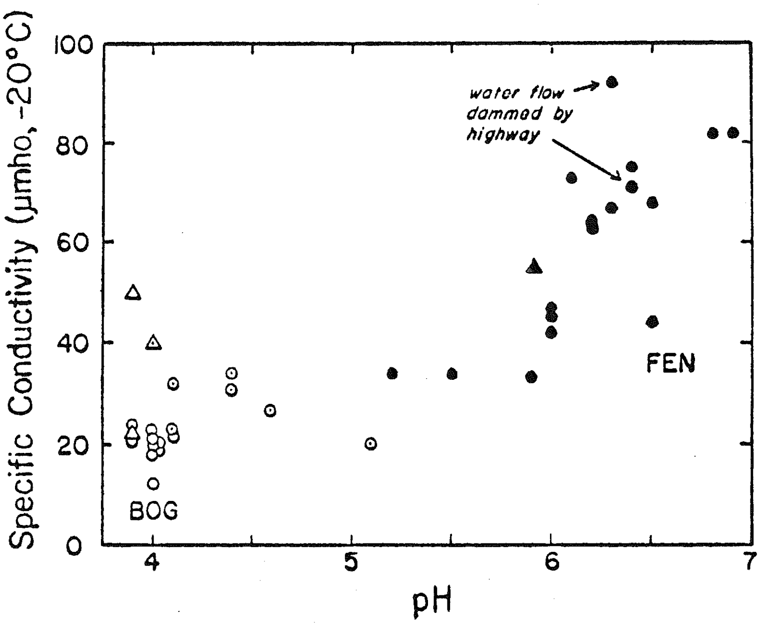

Fig. 4. The relationship between specific conductivity (μmhos at 20°C, minus μmhos attributable to H^+ ions) and pH in surface waters of the Red Lake Peatland. Open circles represent bog, dotted circles poor fen, and solid circles rich fen. Triangles represent samples collected from pits dug in the peat.

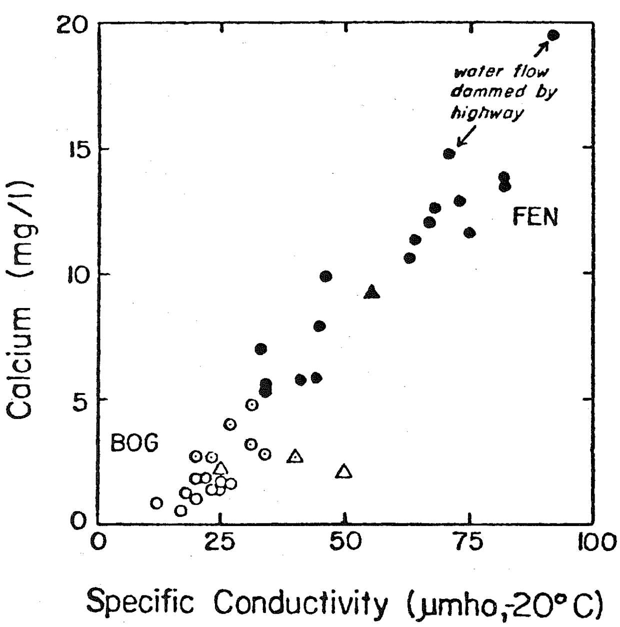

Fig. 5. The relationship between calcium (mg/l) and specific conductivity (μmhos at 20°C, minus μmhos attributable to H^+ ions) in surface waters of the Red Lake Peatland. Symbols as in Figure 4.

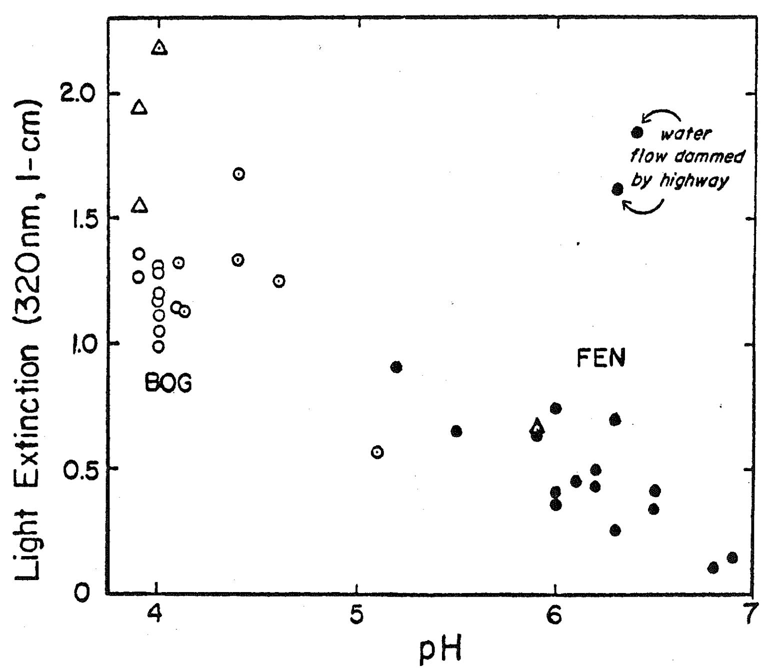

Fig. 6. The relationship between light extinction (at 320 nm, l-cm cells) and pH in surface waters of the Red Lake Peatland. Symbols as in Figure 4.

2 units. The fen waters move more swiftly in their water tracks and are sometimes very clear indeed, with extinction values as low as 0.1 unit. The usual inverse relation between extinction and pH is shown in Figure 6. Two fen waters in Figure 5 are clearly exceptions to the normal relationship, and both come from sites just east of Highway 72, where the road dams a westward-flowing fen water track and leads to local water stagnation.

Vegetation in Relation to Landscape Features and Water Chemistry

Characteristics of Species Richness and Water Chemistry

The vegetation of the Red Lake Peatland can be separated floristically into five major types (Glaser *et al*. 1979), which can be grouped in the two major categories of bog and fen, based on species richness and surface-water chemistry.

The communities of the ombrotrophic bogs, which characterize areas II and IV, are distinguished by low species richness. These communities occupy sites whose surface waters are acid and poor in mineral salts (resulting in low specific conductivity). But because of the relatively stagnant nature of the bog waters, they are rich in dissolved organic matter, which imparts a brown color (resulting in high light extinction).

Only 23 vascular taxa are known from the ombrotrophic sites. They are listed in Table 2 as occurring in either open or wooded bogs, or in both.

The pH in open bogs ranges from 3.9 to 4.1, and calcium from 0.4 to 1.8 ppm (Table 1), thus comparing well with values for ombrotrophic bogs cited by other workers (Sjörs 1950a, 1963; Gorham 1967; Witt and Slack 1975; Heinselman 1970). In addition, the following determinations were made

TABLE 2

Vascular species from ombrotrophic bogs. The taxa in this table can also be found on other landscape features in the peatland.

Open and Wooded Bogs

Andromeda glaucophylla
Carex pauciflora
Chamaedaphna calyculata
Drosera rotundifolia
Eriophorum spissum
Eriophorum virginicum
Kalmia polifolia
Larix laricina
Ledum groenlandicum
Picea mariana
Sarracenia purpurea
Vaccinium oxycoccos

Open Bogs (strongly preferential)

Carex oligosperma

Wooded Bogs (strongly preferential)

Arceuthobium pusillum
Carex paupercula
Carex trisperma
Cypripedium acaule
Gaultheria hispidula
Listera cordata
Monotropa uniflora
Smilacina trifolia
Vaccinium myrtilloides
Vaccinium vitis-idaea var. *minus*

from water samples collected in open bogs: specific conductivity 17 to 27 µmhos (Table 1); extinction 1.14 to 1.36 units (Table 1).

The pH values found in wooded bogs range from 3.9 to 4.4 (Table 1). These values fit closely those reported by Sjörs (1963) for wooded bogs of the Attawapiskat area in the Hudson Bay Lowlands. The calcium values found in wooded bogs of the Red Lake Peatland, which range from 0.8 to 2.0 mg/l (Table 1), correspond well with those of Vitt and Slack (1975), who use values of 2 mg/l or less to differentiate ombrotrophic bogs from poor fens. For wooded bogs of the Red Lake Peatland, the values for specific conductivity range from 12 to 50 µmho and the extinction values from 0.99 to 1.94 units (Table 1).

The communities of the rich minerotrophic fens, which are so characteristic of the broad water tracks of areas I and III and the narrow water tracks that separate the ovoid islands in areas II and IV, are distinguished from those of the ombrotrophic bogs by higher species richness and specific conductivity and by lower acidity, but because the waters are generally moving instead of stagnant they are poor in dissolved organic matter (resulting in low light extinction).

The pH in rich minerotrophic fens ranges from 5.2 to 7.0, and calcium from 5.2 to 20.2 mg/l (Table 1). Both ranges fit values for rich fens given by other workers; Sjörs (1963) uses a pH value of above 5.2 for rich fens, and Sjörs (1963) and Gorham and Pearsall (1956) use calcium values of greater than 5 mg/l to characterize rich fens. Specific conductivity and extinction values for rich fens of the Red Lake Peatland range from 33 to 128 µmho and 0.11 to 1.85 units, respectively (Table 1).

In addition to the distinct ombrotrophic bog and rich minerotrophic fen areas, there exist areas of fen in the peatland where minerotrophy is very weak. Such weak minerotrophy is found in the meadow-like extensions of bog drains and the narrow ecotones that lie between the ombrotrophic bogs and the minerotrophic fens. Some wooded islands in areas II and III are also best included here. Similar areas of weak minerotrophy are called poor fens by Sjörs (1963) in the Hudson Bay Lowlands of Canada. Poor-fen areas contain several bog species as well as some indicators of minerotrophy.

The pH in poor fens in the Red Lake Peatland ranges from 4.0 to 5.2, and calcium from 2 to 5 ppm (Table 1). These values fit very closely the ranges for poor fens used by Sjörs (1963) in the Attawapiskat area, Ontario, and by Vitt, Achuff, and Andrus (1975) for poor fens in the Swan Hills, Alberta. The conductivity and extinction values for the poor fens of the Red Lake Peatland tend to be intermediate to those found in ombrotrophic bogs and rich minerotrophic fens (Table 1).

Of the vascular taxa recorded in the minerotrophic rich and poor fens, 126 are not found in the ombrotrophic bogs. Of these, 78 (Table 3) are found either on strings or in flarks (and/or on the edge of fen pools). Table 4 lists 48 taxa found on minerotrophic islands but not on either ombrotrophic bogs or in the open portions of minerotrophic fens. It should be noted in the tables, however, that many of the taxa found in ombrotrophic bogs also frequent minerotrophic open fens and wooded islands. Similarly, many taxa found in open fens are also found on the wooded islands.

Species Associated with Landscape Features

The vegetation of the various physiographic features of the Red Lake Peatland is each quite distinctive in its floristic composition. There

TABLE 3

Vascular species from minerotrophic fens. The taxa in this table are not found in ombrotrophic bogs. Many of them, however, can also be found on teardrop-shaped minerotrophic islands, in partially dried-up fens, and along the margins of drainage ditches.

Flarks and Fen Pools

Calla palustris
Carex buxbaumii
Carex chordorrhiza
Carex lasiocarpa var. americana
Carex leptalea
Carex limosa
Carex livida var. grayana
Carex rostrata var. utriculata
Cladium mariscoides
Drosera anglica
Drosera intermedia
Drosera linearis
Dulichium arundinaceum
Eleocharis compressa
Equisetum fluviatile
Eriophorum angustifolium
Eriophorum gracile
Eriophorum tenellum
Eriophorum viridi-carinatum
Juncus canadensis
Juncus pelocarpus
Juncus stygius var. americanus
Menyanthes trifoliata
Phragmites communis var. berlandieri
Pogonia ophioglossoides
Pogonia ophioglossoides forma albiflora

TABLE 3 (cont.)

Potamogeton gramineus
Potentilla palustris
Rhynchospora alba
Rhynchospora fusca
Scheuchzeria palustris var. *americana*
Scirpus hudsonianus
Scirpus validus
Triglochin maritima
Typha latifolia
Utricularia cornuta
Utricularia intermedia
Utricularia minor
Xyris montana

Strings

Agrostis scabra
Arethusa bulbosa
Aster junciformis
Aster umbellatus var. *pubens*
Betula pumila var. *glandulifera*
Bromus ciliatus
Campanula aparinoides
Carex cephalantha
Carex exilis
Carex tenuiflora
Cirsium muticum
Cornus stolonifera
Dryopteris cristata
Epilobium leptophyllum
Eriophorum chamissonis
Galium labradoricum
Habenaria lacera
Hypericum virginicum var. *fraseri*

TABLE 3 (cont.)

Iris versicolor
Liparis loeselii
Lobelia kalmii
Lycopus uniflorus
Malaxis unifolia
Muhlenbergia glomerata
Parnassia palustris var. _neogaea_
Pedicularis lanceolata
Potentilla fruticosa
Rhamnus alnifolia
Rubus acaulis
Rubus pubescens
Salix pedicellaris var. _hypoglauca_
Scirpus cespitosus var. _callosus_
Scutellaria epilobiifolia
Senecio pauperculus
Solidago canadensis
Solidago uliginosa
Thelypteris palustris var. _pubescens_
Trientalis borealis
Viola mackloskeyi ssp. _pallens_

TABLE 4

Vascular species from wooded islands. The taxa in this table are not found in ombrotrophic bogs nor in open portions of minerotrophic fens. Some of them, however, are occasionally found in partially dried-up fens and along the margins of drainage ditches.

Hummocks

Amelanchier humilis var. *compacta*
Aronia melanocarpa
Aster puniceus
Athyrium filix-femina
Carex brunnescens var. *sphaerostachya*
Carex disperma
Cinna latifolia
Cornus canadensis
Cornus rugosa
Dryopteris spinulosa
Eupatorium maculatum
Eupatorium perfoliatum
Geum aleppicum var. *strictum*
Gymnocarpium dryopteris
Lonicera oblongifolia
Lonicera villosa var. *solonis*
Maianthemum canadense
Osmunda cinnamomea
Petasites sagittatus
Polygonum sagittatum
Populus tremuloides
Pyrola asarifolia var. *purpurea*
Pyrola secunda var. *obtusata*
Rubus strigosus
Salix bebbiana

TABLE 4 (cont.)

Salix candida
Salix discolor
Salix pyrifolia
Solidago graminifolia
Sonchus arvensis var. _glabrescens_
Stellaria longifolia
Thuja occidentalis
Vaccinium angustifolium
Viburnum trilobum
Viola incognita

Hollows

Calamagrostis canadensis
Calamagrostis neglecta
Caltha palustris
Carex canescens var. _disjuncta_
Carex diandra
Carex pseudo-cyperus
Cicuta bulbifera
Lysimachia thyrsiflora
Myrica gale
Potamogeton natans
Ranunculus gmelini var. _hookeri_
Rumex orbiculatus
Sparganium minimum

exists in the peatland such a delicate relationship between plants and their moisture and chemical tolerances that only slight variation in these parameters results in a different vegetation pattern.

The ombrotrophic areas of the peatland can be divided into linear raised bogs and ovoid islands. As pointed out earlier, most ovoid islands have trees only along their margins, whereas the centers are predominantly open. The floristic composition of the marginal forested areas differs significantly from that of the central open areas. The higher plants of the open bogs are almost invariably dominated by *Carex oligosperma*. This species plays a very conspicuous and important role in the vegetation of open bogs, bog drains, and some poor fen areas in the Red Lake Peatland. Several bogs investigated in Itasca County, Minnesota, also have *C. oligosperma* as the dominant vascular plant (Glaser 1977), although other investigators of Minnesota peatlands (Conway 1949, Finney 1966, Heinselman 1963, 1970, Janssen 1967, Hofstetter 1969, Griffin 1975, 1977) have not reported *C. oligosperma* as of more than minor significance. Outside Minnesota, *C. oligosperma* has been described as a dominant in poor fen and as frequent in ombrotrophic bogs of the Hudson Bay Lowlands (Sjörs 1963), as having a high importance value in kettle-hole bogs in northern Michigan (Vitt and Slack 1975), and as common in bogs in northern Wisconsin (Zimmerman 1976).

Along with *C. oligosperma*, other species consistently present in open bogs of the Red Lake Peatland include *Chamaedaphne calyculata*, *Eriophorum spissum*, *Kalmia polifolia*, *Sarracenia purpurea*, *Ledum groenlandicum*, *Andromeda glaucophylla*, and less commonly *Drosera rotundifolia*, *Eriophorum virginicum*, and *Carex pauciflora*. A few trees of *Picea mariana* and *Larix laricina* are usually found in the open bogs, but they tend to be widely scattered and stunted, seldom reaching 6 m in height.

In the open ombrotrophic bogs Sphagnum communities play a most conspicuous role, with hummocks usually displaying a vertical zonation of species. Several workers (Ratcliffe and Walker 1958, Rose 1953, Vitt, Crum, and Snider 1975) discuss the vertical distribution of mosses on hummocks. In the Red Lake Peatland, a common arrangement is -- from top to bottom -- Sphagnum fuscum, S. capillifolium, S. magellanicum, and S. recurvum. However, several variations can be observed. In some cases S. warnstorfii, and in others Polytrichum juniperinum var. affine, are found on top of the hummocks instead of S. fuscum. In yet other instances lichens, especially Cladonia spp., invade the Sphagnum fuscum communities. According to Osvald (1970), if the surrounding hummocks continue to grow in height, the lichen-dominated hummocks eventually become hollows because of retarded growth. He states that although lichen invasion is one way that hummock-hollow regeneration takes place in bogs, Polytrichum invasion also gives the same result and is presumably more common. Hummock-hollow regeneration in bogs is also discussed by Tansley (1939), Moss (1953), and Vitt, Crum, and Snider (1975). In the wetter portions of open bogs in the Red Lake Peatland, Sphagnum recurvum var. amblyphyllum and S. papillosum are often found. The moss Dicranum undulatum and the hepatic Mylia anomala also commonly frequent open bogs.

Lichen communities are scattered throughout open bogs but are usually most abundant on the sides of hollows, especially those that harbor island-like clumps of trees. Cladonia mitis and C. rangiferina are most common, but other species such as C. cristatella and C. verticillata are locally abundant.

The marginal forested bogs are dominated by Picea mariana, with scattered trees of Larix laricina. Many trees are infected by Arceuthobium pusillum and display large witches' brooms. Most species of open bogs also frequent forested bogs, but Carex oligosperma is conspicuously absent. Further, Carex trisperma, Vaccinium vitis-idaea var. minus, Gaultheria hispidula, Cypripedium acaule, Monotropa uniflora, and Smilacina trifolia are commonly found in forested bogs but are rare or absent from open bogs.

The mosses on hummocks of the marginal forested bogs are generally the same as those in open bogs. However, the hummock tops in forested bogs are often dominated by *Dicranum polysetum*, *D. undulatum*, and *Pleurozium schreberi*, which is rarely the case in open bogs.

Lichen communities on the floors of the marginal forested bogs are similar to those of open bogs, with *Cladonia* spp. being the most common. As in open bogs, the best developed lichen communities are usually associated with depressions. However, fallen trees, stumps, and newly exposed peat also provide excellent sites for lichen development. Most trees in the marginal forested bogs are at least partially covered with lichens, most common being *Parmelia caperata*, *P. flaventior*, *P. subaurifera*, *P. sulcata*, *P. ulophyllodes*, *Evernia mesomorpha*, *Hypogymnia physodes*, *Lecanora coilocarpa*, *Cetraria halei*, and *Bryoria furcellata*. In addition, *Usnea hirta* and *U. subfloridana* commonly hang from the trees but are not so abundant or so well grown as on trees in the minerotrophic islands, perhaps because of lower humidity in bogs as compared to islands. Lower humidity in bogs may also explain why other large fruticose lichens, such as *Usnea cavernosa*, are absent from the forested bogs although present in the minerotrophic islands. Although lichens are abundant in wooded bogs, the number of species is small. This is also true for the open bogs where, however, lichens are not abundant.

Raised bogs, exemplified by the large linear bog at the southern edge of area II, are dominated by *Picea mariana*. Trees on these bogs are normally taller and better grown than those of the marginal forests on the ovoid islands. The raised bogs display radiating tongues of wooded bog covered with *Picea mariana*. In general the species are the same as those in the marginal forested bogs of the ovoid islands. However, *Listera cordata* and *Polytrichum commune* were observed on raised bogs but never on the ovoid islands. The bog drains that lie between the radiating tongues of wooded bog are dominated by *Carex oligosperma* and closely resemble the central open areas of the ovoid islands both floristically and in surface-water chemistry. They are definitely ombrotrophic in nature.

Lying between the ombrotrophic bogs and the strongly minerotrophic patterned fens are poor fens that have pH values lower than rich fens but higher than bogs. Ranging in size from narrow strips to open areas of several hectares, they typically support both bog species and a few indicators of minerotrophy. Some species, such as *Scirpus cespitosus* var. *callosus*, *Carex exilis*, *C. pauciflora*, *Eriophorum chamissonis*, and *Habenaria lacera*, are found in greater abundance in these areas than in any other peatland habitat. In some places, *Scirpus cespitosus* var. *callosus* and *Carex exilis* thrive so well that they extend for some distance into the fen, actually forming a floristically unique type of string. This is especially well developed where the north branch of the bifurcated western water track borders the ovoid islands of area II.

One of the largest areas of weak minerotrophy in the peatland is found within area II, lying between the linear raised bog and the ovoid islands to the north. It is an open, meadow-like area formed by coalescence of the numerous bog drains from the large, linear bog. Although dominated by a lawn of *Carex oligosperma* set in carpets of sphagna (*S. papillosum* is especially characteristic), this area differs floristically from the open bogs of the ovoid islands in that species such as *Carex chordorrhiza*, *C. livida* var. *grayana*, *C. limosa*, *Scheuchzeria palustris*, and *Rhynchospora alba* are present. Significantly, *Carex chordorrhiza* has been recognized by Sjörs (1963) as indicative of poor fens. The only lake (Hilman Lake) within the Red Lake Peatland is situated on the extreme western edge of this meadow-like area. It is extremely oligotrophic, and its origin is still unknown. No taxa were found in or around the lake that are not represented elsewhere in the peatlands.

As mentioned previously, many wooded islands in areas II and III are best considered as poor fens. Although the undervegetation on these islands strongly resembles that of the wooded ombrotrophic bogs, they contain clearly minerotrophic species such as Carex chordorrhiza, C. brunescens var. sphaerostachya, and Potentilla palustris. Sphagnum subsecundum is also found on several islands. As Sjörs (1963) points out, the poor fen is usually best characterized by its bryophytes, and he gives Sphagnum subsecundum as a minerotrophic indicator.

The small, elongate teardrop islands, so numerous in the western water track (area I), are normally forested on the blunt, upstream end and occupied by shrubs on the long downslope tail. Most islands display a pronounced hummock-and-hollow topography, with the hollows often containing standing water. The trees forming the canopy on the islands heads are Larix laricina (dominant), Picea mariana, and rarely Thuja occidentalis. The trees are replaced by Betula pumila var. glandulifera on the tapered downstream tails. The understory flora on the islands is unusually rich and includes many species seldom found elsewhere in the peatland. Hummock species include Aronia melanocarpa, Lonicera villosa var. solonis, L. oblongifolia, Rubus pubescens, Rumex orbiculatus, Osmunda cinnamomea, Polygonum sagittatum, Viola incognita, and Carex disperma. In the hollows are Ranunculus gmelini var. hookeri, Sparganium minimum, and Carex pseudo-cyperus. On the other hand, the islands also harbor many species common elsewhere in the peatland. Chamaedaphne calyculata, Ledum groenlandicum, Vaccinium oxycoccos, Carex canescens var.

disjuncta, C. paupercula, Bromus ciliatus, Agrostis scabra, Cirsium muticum, Cypripedium acaule, and Drosera rotundifolia are found on hummocks, and Calla palustris, Menyanthes trifoliata, and Typha latifolia in hollows.

As with the vascular plants, the moss flora is exceptionally rich on the minerotrophic teardrop islands and includes species uncommon or absent elsewhere in the peatland, notably Climacium dendroides and Amblystegium serpens. The higher hummocks commonly bear a moss cover of Sphagnum warnstorfii, S. centrale, Pleurozium schreberi, and Polytrichum juniperinum var. affine. The lower hummocks are mostly covered with Sphagnum teres, S. centrale, S. recurvum, and Aulacomnium palustre. Mosses commonly found in the hollows include Scorpidium scorpioides and Campylium stellatum. Other mosses frequently present include Calliergon stramineum, Calliergonella cuspidata, Leptodictyum trichopodium, Mnium punctatum, Plagiothecium denticulatum, and Pohlia nutans. Although some hummocks on the islands display a vertical zonation of mosses, very often the species of Sphagnum grow in pure colonies, not in the well-defined mosaic of species so commonly found in the open bogs.

The hepatics are also floristically richer on teardrop islands than elsewhere in the peatland. When hummocks have been disturbed by fallen trees or by animals (the moose, Alces alces, is known to visit the islands), their sides often become colonized by Mylia anomala, Cephalozia pleniceps, and Cladopodiella fluitans. Other hepatics include Scapania irrigua, Ptilidium ciliare, Fossombronia foveolata, Frullania aboracensis, Lophocolea heterophylla, and Plagiochila asplenioides. In addition, Marchantia polymorpha and Aneura pinguis are often present along the edges of hollows, and on tree branches that are almost submerged in them.

The teardrop islands provide a diversity of habitats for lichens, especially on trees, logs, old stumps, bases and lower branches of bushes, and areas with thin or slow-growing mosses. Species consistently present on tree bark include Parmelia caperata, P. flaventior, Evernia mesomorpha, Hypogymnia physodes, Lecanora coilocarpa, Bryoria furcellata, and Cetraria halei. In addition, Bacidia chlorococca is often present, but it is primarily confined to dead twigs at the end of small branches. Cetraria pinastri and Parmeliopsis capitata are commonly associated with tree bases. Usnea hirta and U. subfloridana commonly hang from the trees, sometimes in large festoons. The hummocky surfaces of the islands also harbor several lichen species, most notably Cladonia mitis and C. rangiferina. High humidity may play an important role in the abundance and large growth of lichens on the islands, especially those of the fruticose type.

The strings of patterned fens are dominated by Betula pumila var. glandulosa, Chamaedaphne calyculata, Andromeda glaucophylla, and Vaccinium oxycoccos. Other taxa commonly found on string hummocks include Salix pedicellaris var. hypoglauca, Sarracenia purpurea, Thelypteris palustris var. pubescens, Carex tenuiflora, C. cephalantha, Arethusa bulbosa, and Drosera rotundifolia. In addition, stunted trees of Larix laricina are usually present on the better-developed strings.

The moss flora of the strings is much richer and more abundant than that in the flarks. Although hummocks vary greatly in height, nearly all display the usual vertical zonation of species. The taller hummocks of the strings have, from top to bottom, Sphagnum fuscum, S. capillifolium, S. magellanicum, S. recurvum, and S. cuspidatum. However, in many cases Polytrichum juniperinum var. affine is found on top of the hummocks instead of Sphagnum fuscum. Also, quite often S. capillifolium, or more rarely S. magellanicum, dominates the tops of the lower hummocks. Other mosses commonly associated with the strings include Aulacomnium palustre, Pleurozium schreberi, and Sphagnum teres.

Lichens are not abundant on the string hummocks, but sometimes small communities are found, most containing one or more species of Cladonia. Trees on the strings, however, will usually be at least partially covered with lichens, Parmelia spp. being the most common.

While species such as Carex chordorrhiza, C. limosa, and Pogonia ophioglossoides grow both on string hummocks and in flarks, most plants that frequent the flarks do not grow on the strings. The species dominating the flarks are Carex lasiocarpa var. americana, C. livida var. grayana, and Menyanthes trifoliata. Many other species are consistently present, among them C. leptalea, Rhynchospora alba, Utricularia intermedia, U. minor, Drosera intermedia, Triglochin maritima, and Scheuchzeria palustris. Also present in the flarks, though less commonly, are Utricularia cornuta, Rhynchospora fusca, Cladium mariscoides, and Drosera anglica. Drosera linearis is occasionally found in flarks in the western water track, but not in the central and eastern portions of the peatland. According to Sjörs (1963), rich fen can be divided into moderately rich fen and extremely rich fen. In the Red Lake Peatland, Drosera linearis appears to be an indicator of extremely rich fen.

In general, the bryophyte flora in flarks is impoverished. The common moss species are Scorpidium scorpioides, Campylium stellatum, Drepanocladus revolvens, and Sphagnum subsecundum. Where low moss cushions have developed, however, Aulacomnium palustre, Sphagnum recurvum var. amblyphyllum, and S. magellanicum are also often present.

As mentioned above, unvegetated areas of open water sometimes occur in flarks. Although flark species dominate in the borders of these fen pools, the edges sometimes harbor plants that are otherwise extremely uncommon or absent from the flarks themselves, notably *Xyris montana*, *Juncus stygius* var. *americana*, *J. pelocarpus*, *J. canadensis*, and *Scirpus validus*.

Ditching and roadbuilding in the peatland have had distinct effects upon the vegetation. Drainage ditches cut through large portions of the peatland, especially prominent in area II and the western portion of area III. The margins of the ditches often harbor taxa unknown from undisturbed portions of the peatland, for example *Alnus rugosa*, *Spiraea alba*, *Mimulus ringens*, *Carex viridula*, and several species of *Salix*. Also, flooding upstream and drying out downstream have marked effects upon the fen water tracks. Especially noticeable is the extensive growth of *Betula pumila* var. *glandulifera* on the drier, downslope side of the ditches. The north-south highway that transects area III has caused such severe drying west of the road that the ribbed pattern is obliterated for over 0.4 km inland. Species such as *Asclepias incarnata* and *Cirsium arvense*, which now grow in abundance in these partially dried-up fens, are unknown from the undisturbed portions of the peatland. Table 5 lists 46 vascular taxa, found either in partially dried-up fens or along the edges of drainage ditches, that are otherwise unknown from the undisturbed portions of the peatland. However, these areas are commonly dominated by many of the same species that dominate the peatland interior.

TABLE 5

Vascular species from partially dried-up fens and drainage ditches. The taxa in this table are confined to disturbed, partially dried-up fens and the environs of drainage ditches.

Partially Dried-up Fens

Asclepias incarnata
Bidens cernua
Bidens connata var. petiolata
Carex interior
Cirsium arvense
Gentiana rubricaulis
Gerardia paupercula var. borealis
Juncus alpinus var. rariflorus
Lycopus americanus
Lysimachia terrestris
Parnassia glauca
Scirpus atrocinctus
Viola nephrophylla

Drainage Ditches (including the edges)

Alnus rugosa
Apocynum cannabinum
Betula papyrifera
Betula X sandbergi
Calamagrostis inexpansa var. brevior
Carex aquatilis var. altior
Carex aurea
Carex bebbii
Carex lacustris
Carex lanuginosa
Carex projecta

TABLE 5 (cont.)

<u>Carex tenera</u>
<u>Carex vaginata</u>
<u>Carex viridula</u>
<u>Epilobium angustifolium</u>
<u>Glyceria borealis</u>
<u>Glyceria striata</u>
<u>Hippuris vulgaris</u>
<u>Juncus brevicaudatus</u>
<u>Juncus dudleyi</u>
<u>Juncus nodosus</u>
<u>Mimulus ringens</u>
<u>Nuphar variegatum</u>
<u>Pinus banksiana</u>
<u>Populus balsamifera</u>
<u>Salix gracilis</u>
<u>Salix interior</u>
<u>Salix lucida</u>
<u>Salix planifolia</u>
<u>Salix serissima</u>
<u>Sium suave</u>
<u>Spiraea alba</u>
<u>Utricularia vulgaris</u>

Flora

Red Lake Peatland

Within the peatland 195 vascular plant taxa were found, representing 104 genera in 50 families. Among the nonvascular plants, 69 lichen taxa and 72 bryophyte taxa (58 mosses and 14 hepatics) were observed. In all, 336 taxa were recorded from the Red Lake Peatland during the 1978 study. This includes not only the taxa found in the peatland proper, but also taxa observed along the margins of the drainage ditches in the peatland interior and in the partially dried-up fens adjacent to the north-south highway. Not included are plants growing in marginal communities, on upland sites on mineral soil, on wooded spoil banks near the highway, and along roadsides and embankments. Hofstetter (1969) reported 11 bryophyte taxa from the peatland that were not found during the 1978 study, and these are included in the Catalogue of Species (Appendix). Thus, a total of 347 taxa are presently known from the Red Lake Peatland, in contrast to the 171 taxa previously reported (Hofstetter 1969).

Of the vascular plants collected during the 1978 study, members of the Cyperaceae make up 23% of the taxa; Carex alone makes up 15%. The next largest family, the Asteraceae, makes up 8%. The Asteraceae with 8 genera and the Cyperaceae, Poaceae, and Orchidaceae with 7 genera each are the families with the largest representation. The largest genus is Carex, with 29 taxa represented. The 195 vascular taxa are broken down into major groups in Table 6.

Eight of the taxa found in the peatland are considered rare in Minnesota: Carex exilis, Cladium mariscoides, Drosera anglica, D. linearis, Juncus stygius var. americanus, Rhynchospora fusca, Pogonia ophioglossoides forma albiflora, and Xyris montana (Wheeler and Glaser 1979). Each of these

TABLE 6

Major groups of vascular plants in the Red Lake Peatland.

Vascular Plant Group	Taxa			Genera	Families
	Native	Intro-duced	Total		
Pteridophytes	7	0	7	6	3
Gymnosperms	4	0	4	4	2
Monocotyledons	81	0	81	32	12
Dicotyledons	101	2	103	62	33
Total	193	2	195	104	50

plants attains greater abundance in the peatland than in any of their other known locations in the state.

Comparisons with Floras Elsewhere

When the vascular flora of the peatland is compared with vascular floras from other areas in Minnesota of similar size and under approximately the same climatic conditions, the depauperate nature of the peatland vascular flora is quickly realized. Most areas in northern and eastern Minnesota approximating the size of the peatland are ecologically complex, with a diverse topography and a complicated soil catena; this normally results in a rich flora. The Red Lake Peatland, however, covers a very large area of gentle slope and poor drainage, resulting in a flora that is relatively impoverished.

The vascular plant data from the Red Lake Peatland can be compared with vascular data from a study (Wheeler 1977) done about 160 km southeast of the peatland near Grand Rapids (Itasca County, Minnesota), and another (Moore, 1973) done at the Cedar Creek Natural History Area of the University of Minnesota (Anoka and Isanti counties), approximately 350 km south-southeast of the peatland. Whereas the vascular floras of both the Grand Rapids and Cedar Creek areas number over 700 species in more than 300 genera, the vascular flora of the peatland is less than 200 species in slightly over 100 genera. Further, although the cyperaceous plants constitute less than 10% of the taxa in both the Grand Rapids and Cedar Creek areas, in the Red Lake Peatland they make up nearly 25% of the taxa.

The quotient of similarity is an excellent measure of the floristic affinity between two areas or two types of vegetation (Sjörs 1963). This is defined as the number of species shared by the two areas times 100, divided by the mean of the numbers of species for the two areas or vegetation types. The quotients of similarity show striking differences when the Red Lake, Grand Rapids, and Cedar Creek vascular floras are compared. The quotient between the Grand Rapids and Cedar Creek floras is 66, thus indicating a high degree of floristic similarity. On the other hand, the quotient between the Red Lake Peatland flora and the Grand Rapids and Cedar Creek floras are only 35 and 31, respectively. In contrast, the quotient between the vascular floras of the Red Lake Peatland and the Hudson Bay Lowlands is 53 (see Table 7). Thus the quotients of similarity indicate that the vascular flora of the Red Lake Peatland has a much closer affinity with the vascular flora of the Hudson Bay Lowlands, about 1100 km to the north, than with the vascular floras of the Grand Rapids and Cedar Creek areas, only 160 km and 350 km to the southeast, respectively.

That the similarity between regions is greater for plant species found in peatlands than for those found on mineral soil has been discussed by Sjörs (1959). Further, it is generally recognized that when peatlands are compared the similarity in the cryptogamous floras is greater than that of the vascular floras (Sjörs 1959, 1963). However, several problems arise when the vegetation and floristic data from one peatland are compared with those of others: variation in size of area, inclusion or exclusion of marginal communities, inland bogs versus coastal plateau bogs, difference in the time devoted to the study of various groups of plants (e.g. most studies do not give detailed lichen data), taxonomic problems (lumping or splitting of species and synonymy), confusion in peatland terminology and in definitions of bog and fen. Some of these problems have been discussed by Dansereau and Segadas-Vianna (1952), Damman (1977), Drury (1956), Persson and Sjörs (1960), and Sjörs (1963). Because of these and other problems,

TABLE 7

Floristic similarities between the Red Lake Peatland and other peatlands in North America and northern Europe. Q.S. = similarity quotient.

	Vascular Plants			Bryophytes		
North America	Gen.	Spp.	Q.S.	Gen.	Spp.	Q.S.
Hudson Bay Lowlands, Canada						
Persson and Sjörs (1960); Sjörs (1963)	62%	49%	53	84%	68%	56
Saskatchewan, Canada						
Jeglum (1971)	60%	45%	52	30%	24%	38
Michigan, U.S.A.						
Vitt and Slack (1975)	58%	33%	43	51%	42%	52
Gates (1942)	85%	50%	43	-	-	-
Alaska, U.S.A.						
Drury (1956)	50%	27%	33	49%	45%	47
Alberta, Canada						
Moss (1953)	32%	23%	34	16%	17%	29
Vitt, Achuff, and Andrus (1975)	23%	13%	23	40%	20%	30
Northern Europe						
Finland						
Eurola and Kaakinen (1978)	62%	26%	21	63%	61%	49
Western Soviet Union (Polesie)						
Kulczynski (1949)	53%	16%	17	33%	30%	41

Table 7 -- continued

Northern Europe -- continued	Vascular Plants Gen.	Vascular Plants Spp.	Vascular Plants Q.S.	Bryophytes Gen.	Bryophytes Spp.	Bryophytes Q.S.
Sweden, southern						
Mörnsjö (1969)	36%	12%	17	37%	24%	35
Malmer (1962)	28%	11%	17	42%	36%	42
Sweden, northern						
Sonesson (1970)	30%	12%	16	49%	43%	41
Britain and Ireland						
Osvald (1949)	39%	13%	17	58%	33%	31
Scotland						
Ratcliffe (1964)	34%	10%	12	56%	37%	36

some of them very subtle, the results achieved from the comparative study of peatlands may not be entirely satisfactory. Nevertheless, some of the results of comparative studies are indeed enlightening, especially those that reveal floristic differences. In Table 7, the floras of several peatlands from North America and northern Europe have been compared with the flora of the Red Lake Peatland. For each comparison, the numbers of genera and species of both vascular plants and bryophytes that the two peatlands have in common are expressed as a percentage of the total number of each category recorded for the Red Lake Peatland. Quotients of similarity for species of vascular plants and bryophytes found in each selected peatland and in the Red Lake Peatland are also given in the table. It appears that both the vascular and bryophyte floras of other North American peatlands exhibit about the same degree of floristic similarity to those of the Red Lake Peatland, the mean quotients for six different areas being 40 and 42, respectively. In contrast, it can be seen that the bryophyte floras of northern Europe and the Red Lake area are more similar than the vascular floras of the two areas, the mean quotients for seven areas being 17 and 39, respectively. Although there is not much difference in the quotients for the bryophyte floras of peatlands in North America and northern Europe when compared to the Red Lake Peatland, there is a substantial difference in the quotients for the vascular floras of the two regions when compared to the Red Lake area, with the North American floras much more similar to that of Red Lake. It can also be seen that the Red Lake Peatland has a closer floristic affinity, for both bryophytes and vascular plants, with the Hudson Bay Lowlands than with any other area compared, even though some other areas are geographically closer.

Another interesting comparison is that between the ombrotrophic flora of the Red Lake Peatland and those of the Hudson Bay Lowlands and northern Fennoscandia. As pointed out above, 23 vascular taxa are known to occur within the Red Lake Peatland in the ombrotrophic bogs (see Table 1). In comparison, 34 vascular species are known from the ombrotrophic bogs of the Attawapiskat River area, Ontario, and 23 species from the bogs of northern Fennoscandia (Sjörs 1963). According to Sjörs (1963), in most cases a species that is common to ombrotrophic sites in eastern North America and northern Europe is very similar as regards its vegetative morphology and ecology in the two areas. However, Sjörs (1963) states that a few taxa that frequent ombrotrophic bogs in North America have vicariads in northern Europe, with the distinction being not only morphological but ecological as well. For taxa found in the ombrotrophic bogs of the Red Lake Peatland, the plants included in this category are *Eriophorum spissum*, *Ledum groenlandicum*, and *Vaccinium vitis-idaea* var. *minus*; the vicariads to these in northern Europe are *Eriophorum vaginatum*, *Ledum palustre*, and *Vaccinium vitis-idaea*, respectively (Sjörs, 1963).

Not counting vicarious taxa, 5 vascular species are common to ombrotrophic sites in the Red Lake, Attawapiskat, and Fennoscandian areas; these are given in Table 8. Table 8 also lists 19 vascular species that are common to the ombrotrophic bogs of the Red Lake Peatland and the Attawapiskat area. Sjörs (1963) reported 15 vascular taxa as being common to the ombrotrophic bogs of the Attawapiskat area and northern Fennoscandia. Besides the 5 taxa that are known from ombrotrophic bogs in all three areas, an additional 5 species out of the 15 taxa common to bogs in the Attawapiskat and northern Fennoscandian areas are also found in the Red Lake Peatland

TABLE 8

Plants common to ombrotrophic bogs of the Red Lake Peatland and the Attawapiskat area, Ontario; taxa marked with an asterisk are also known from bogs in northern Fennoscandia.

Vascular Plants

Carex oligosperma
Carex pauciflora*
Carex paupercula
Carex trisperma
Chamaedaphne calyculata*
Drosera rotundifolia*
Eriophorum spissum
Eriophorum virginicum
Gaultheria hispidula
Kalmia polifolia
Larix laricina
Ledum groenlandicum
Picea mariana
Sarracenia purpurea
Scirpus cespitosus var. callosus*
Smilacina trifolia
Vaccinium myrtilloides
Vaccinium oxycoccos*
Vaccinium vitis-idaea var. minus

Mosses

Aulacomnium palustre*
Calliergon stramineum*
Dicranum undulatum*
Dicranum drummondii
Dicranum polysetum*
Drepanocladus fluitans*

TABLE 8 (cont.)

Hylocomium _splendens_*
Pleurozium _schreberi_*
Pohlia _nutans_*
Polytrichum _juniperinum_ var. _affine_*
Sphagnum _capillifolium_*
Sphagnum _capillifolium_ var. _tenellum_*
Sphagnum _cuspidatum_*
Sphagnum _fuscum_*
Sphagnum _papillosum_
Sphagnum _recurvum_ var. _tenellum_*
Sphagnum _recurvum_ var. _tenue_*
Sphagnum _russowii_*

Hepatics

Cephaloziella _elachista_*
Cladopodiella _fluitans_*
Mylia _anomala_*
Ptilidium _ciliare_*

but are known there only from minerotrophic sites. These species are *Carex limosa*, *Drosera anglica*, *Rhynchospora alba*, *Scheuchzeria palustris*, and *Scirpus cespitosus* var. *callosus*. Further, Sjörs (1963) reports that *Eriophorum chamissonis* and *Nuphar variegatum* are found in ombrotrophic sites in the Attawapiskat area. Again, although these two species are found in the Red Lake Peatland, they occur only in minerotrophic sites. When the landforms of the three areas are compared, it is clear that the large, open bog-pools found within the ombrotrophic bogs of the Attawapiskat River area and northern Fennoscandia are absent from the Red Lake Peatland. This may well account for the restriction to minerotrophic sites in the Red Lake Peatland of some vascular species that are reported from ombrotrophic sites in other areas.

The quotients of similarity for the vascular floras of the ombrotrophic bogs of the Red Lake Peatland and those of the Attawapiskat River area and northern Fennoscandia are 68 and 22, respectively. The absence of large, open bog pools from ombrotrophic sites in the Red Lake Peatland no doubt impoverishes its vascular flora. The quotients of similarity between the Red Lake bog flora and both the Attawapiskat and Fennoscandian bog floras would be much greater if it were not for the absence of this particular habitat. According to Sjörs (1963), the quotient for the vascular floras of the ombrotrophic bogs of the Attawapiskat River area and those of northern Fennoscandia is 53.

As regards the cryptogamous vegetation of ombrotrophic sites, several bryophytes found in ombrotrophic bogs of the Red Lake Peatland are also known from bogs in the Hudson Bay Lowlands (Persson and Sjörs 1960, Sjörs 1963) and northern Fennoscandia (Sjörs 1963). Of the 31 bryophyte taxa reported from ombrotrophic sites in the Hudson Bay Lowlands (Sjörs 1963), 22 are known from bogs in the Red Lake Peatland (Table 8). Remarkably, 20 bryophyte taxa are common to ombrotrophic sites in the Red Lake Peatland and northern Fennoscandia (see Table 8). Indeed, for ombrotrophic bogs of all three areas, the similarity in the cryptogamic floras is greater than that of the vascular floras.

Although there is a great deal of floristic similarity between the ombrotrophic bogs of the Red Lake Peatland and the Hudson Bay Lowlands, certain floristic differences are worthy of note. Andromeda polifolia, Rubus chamaemorus, Vaccinium uliginosum, and V. microcarpum are reported by Sjörs (1963) as very common in bogs in the Attawapiskat area, but have not been found in the Red Lake Peatland. Empetrum hermaphroditum, Geocaulon lividum, Kalmia angustifolia, and Pinguicula villosa are also reported from bogs in the Hudson Bay Lowlands (Sjörs 1963), but appear to be absent from the Red Lake area. On the other hand, whereas Andromeda glaucophylla is frequent in ombrotrophic bogs of the Red Lake Peatland, it is not reported by Sjörs (1963) for the Attawapiskat area. It would appear that Andromeda polifolia replaces A. glaucophylla in bogs as one proceeds from south to north in eastern North America, much as the south to north change from Ledum groenlandicum to Ledum palustre var. decumbens, as reported for bogs in western North America (Moss 1953, Osvald 1970).

Some differences in the bryophyte flora between the two areas should also be mentioned. Sphagnum balticum, S. jensenii, and S. lindbergii are common cryptogams in the Hudson Bay Lowlands (Persson and Sjörs 1960, Sjörs 1963) but have not been found in the Red Lake Peatland. Floristic changes in species of Sphagnum from south to north, such as from S. magellanicum to S. capillaceum, in Alberta bogs have been discussed briefly by Moss (1953).

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APPENDIX: CATALOGUE OF SPECIES

Mosses marked by asterisk were not found in the Red Lake Peatland during the 1978 study but were reported from there by Hofstetter (1969).

Great Western Patterned Fen = Area I; Divide = Area II; Ludlow Patterned Fen = Area III; Koochiching Raised Bog Area = Area IV

FERNS AND FERN ALLIES

EQUISETACEAE

Equisetum fluviatile L. Common throughout peatland in flarks and drainage ditches. Divide --- flark, 3018. Ludlow Patterned Fen --- drainage ditch, 2880.

OSMUNDACEAE

Osmunda cinnamomea L. Occasional on Larix islands. Divide --- uncommon in linear raised bog, 3115.

POLYPODIACEAE

Athyrium filix-femina (L.) Roth. var. michauxii (Spreng.) Farw. Great Western Patterned Fen --- north branch, rare on Larix island, 3279.

Dryopteris cristata (L.) Gray. Occasional throughout peatland in minerotrophic sites. Ludlow Patterned Fen --- poor fen ecotone, 2996; partially dried-up fen, 2864.

Dryopteris spinulosa (Mueller) Watt. Great Western Patterned Fen --- main water track, rare on Larix island, 3214.

Gymnocarpium dryopteris (L.) Newm. Great Western Patterned Fen --- north branch, rare on Larix island, 3282.

Thelypteris palustris Schott var. *pubescens* (Lawson) Fern. Frequent throughout peatland in minerotrophic sites. Ludlow Patterned Fen --- poor fen ecotone, 2997; partially dried-up fen, 2860.

GYMNOSPERMS

CUPRESSACEAE

Thuja occidentalis L. Great Western Patterned Fen --- main water track, uncommon on *Larix* islands, 3197; north branch, infrequent on *Larix* islands, 3232.

PINACEAE

Larix laricina (Du Roi) K. Koch. Common on minerotrophic islands and occasional in forested bogs and on strings throughout peatland. Divide --- ovoid-shaped island, forested bog, 3047. Ludlow Patterned Fen --- forested bog, 2876.

Picea mariana (Mill.) BSP. Very common on forested ombrotrophic sites throughout peatland. Divide --- ovoid-shaped island, forested bog, 3046. Ludlow Patterned Fen --- forested bog, 2875.

Pinus banksiana Lamb. Ludlow Patterned Fen --- rare along drainage ditch, 3437.

ANGIOSPERMS (MONOCOTS AND DICOTS)

APIACEAE

Cicuta bulbifera L. Infrequent on *Larix* islands. Divide --- linear raised bog, occasional along drainage ditch, 3112.

Sium suave Walt. Ludlow Patterned Fen --- infrequent along drainage ditch, 2933.

APOCYNACEAE

Apocynum cannabinum L. Great Western Patterned Fen --- north branch, rare along drainage ditch, 3277.

ARACEAE

Calla palustris L. Occasional on Larix islands and in string hollows. Divide --- margin of Hilman Lake, 2975; string, 3021.

ASCLEPIADACEAE

Asclepias incarnata L. Ludlow Patterned Fen --- occasional in partially dried-up fen, 3175 and 3323.

ASTERACEAE

Aster junciformis Rydb. Frequent throughout peatland on strings. Great Western Patterned Fen --- main water track, string, 3187; north branch, string, 3254. Koochiching Raised Bog Area --- string, 3369.

Aster puniceus L. Great Western Patterned Fen --- north branch, infrequent on Larix island, 3266. Ludlow Patterned Fen --- uncommon on Larix island, 3336.

Aster umbellatus Mill. var. pubens Gray. Great Western Patterned Fen --- north branch, rare on string, 3285. Ludlow Patterned Fen --- frequent in partially dried-up fen.

Bidens cernua L. Ludlow Patterned Fen --- uncommon in partially dried-up fen, 3316.

Bidens connata Muhl. var. petiolata (Nutt.) Farw. Ludlow Patterned Fen --- rare in partially dried-up fen, 3315.

Cirsium arvense (L.) Scop. Ludlow Patterned Fen --- infrequent in partially dried-up fen, 3176.

Cirsium _muticum_ Michx. Uncommon throughout peatland in minerotrophic sites. Great Western Patterned Fen --- north branch, string, 3256; _Larix_ island, 3230. Ludlow Patterned Fen --- partially dried-up fen, 3174.

Eupatorium _maculatum_ L. Ludlow Patterned Fen --- infrequent in partially dried-up fen, 3172.

Eupatorium _perfoliatum_ L. Ludlow Patterned Fen --- rare in partially dried-up fen, 3438.

Petasites _sagittatus_ (Pursh) Gray. Ludlow Patterned Fen --- occasional in partially dried-up fen, 2862.

Senecio _pauperculus_ Michx. Uncommon throughout peatland in minerotrophic sites. Great Western Patterned Fen --- north branch, string, 3243. Ludlow Patterned Fen --- partially dried-up fen, 3078.

Solidago _canadensis_ L. Occasional throughout peatland in minerotrophic sites. Great Western Patterned Fen --- north branch, string, 3286. Ludlow Patterned Fen --- partially dried-up fen, 3322.

Solidago _graminifolia_ (L.) Salisb. Great Western Patterned Fen --- north branch, uncommon on _Larix_ island, 3283. Ludlow Patterned Fen --- infrequent in partially dried-up fen, 3319.

Solidago uliginosa Nutt. Frequent throughout peatland in minerotrophic sites. Great Western Patterned Fen --- main water track, _Larix_ island, 3194; north branch, string, 3257. Ludlow Patterned --- partially fried-up fen, 3318. Koochiching Raised Bog Area --- string, 3368.

Sonchus arvensis L. var. _glabrescens_ Guenth., Grab. and Wimm. Great Western Patterned Fen --- main water track, rare on _Larix_ island, 3192.

BETULACEAE

Alnus rugosa (Du Roi) Spreng. Great Western Patterned Fen --- north branch, rare on edge of drainage ditch, 3278. Ludlow Patterned Fen --- rare on edge of drainage ditch, 3097.

Betula papyrifera Marsh. Great Western Patterned Fen --- north branch, rare on edge of drainage ditch, 3289.

Betula pumila L. var. _glandulifera_ Regel. Common throughout peatland, especially on the drier, open sites. Great Western Patterned Fen --- main water track, tail of _Larix_ island, 3187. Divide --- edge of _Larix_ island, 3006. Ludlow Patterned Fen --- partially dried-up fen, 2802. Koochiching Raised Bog Area --- string, 3374.

Betula X _sandbergi_ Britt. Great Western Patterned Fen --- rare on edge of drainage ditch, 3291.

CAMPANULACEAE

Campanula aparinoides Pursh. Frequent throughout peatland on strings. Ludlow Patterned Fen --- string, 3088.

CAPRIFOLIACEAE

Lonicera oblongifolia (Goldie) Hook. Occasional on Larix islands. Ludlow Patterned Fen --- uncommon in partially dried-up fen, 2861.

Lonicera villosa (Michx.) R. & S. var. solonis (Eaton) Fern. Frequent on Larix islands. Ludlow Patterned Fen --- Larix island, 2995; occasional in partially dried-up fen, 2809 and 2930.

Viburnum trilobum Marsh. Great Western Patterned Fen --- north branch, rare on Larix island, 3276.

CARYOPHYLLACEAE

Stellaria longifolia Muhl. Great Western Patterned Fen --- main water track, infrequent on Larix island, 3217. Ludlow Patterned Fen --- occasional on edge of drainage ditch, 3098.

CORNACEAE

Cornus canadensis L. Infrequent on Larix islands. Ludlow Patterned Fen --- rare in partially dried-up fen, 2828.

Cornus rugosa Lam. Great Western Patterned Fen --- north branch, uncommon on Larix island, 3235.

Cornus stolonifera Michx. Great Western Patterned Fen --- main water track, rare on string, 3222; north branch, infrequent on Larix island, 3264. Ludlow Patterned Fen --- infrequent in partially dried-up fen, 2883.

CYPERACEAE

Carex aquatilis Wahlenb. var. altior (Rydb.) Fern. Ludlow Patterned Fen --- infrequent on edge of drainage ditch, 3059 and 3069.

Carex aurea Nutt. Ludlow Patterned Fen --- uncommon along edge of drainage ditch, 2912.

Carex bebbii Olney. Ludlow Patterned Fen --- uncommon in partially dried-up fen, 3079; infrequent on edge of drainage ditch, 3096.

Carex brunnescens (Pers.) Poir. var. *sphaerostachya* (Tuckerm.) Kukenth. Great Western Patterned Fen --- main water track, occasional on *Larix* island, 3196.

Carex buxbaumii Wahlenb. Infrequent throughout peatland in flarks. Great Western Patterned Fen --- north branch, flark, 3274. Ludlow Patterned Fen --- flark, 2943; partially dried-up fen, 2867.

Carex canescens L. var. *disjuncta* Fern. Occasional throughout peatland in minerotrophic sites. Divide --- margin of Hilman Lake, 2980. Ludlow Patterned Fen --- partially dried-up fen, 2858.

Carex cephalantha (Bailey) Bickn. Frequent throughout peatland on strings. Divide --- string, 3011 and 3019. Ludlow Patterned Fen --- string, 3133 and 3149.

Carex chordorrhiza L. f. Frequent throughout peatland in minerotrophic sites. Great Western Patterned Fen --- main water track, *Larix* island, 3199. Divide --- margin of Hilman Lake, 2983; edge of fen pool, 3042. Ludlow Patterned Fen --- flark, 2926; partially dried-up fen, 2871. Koochiching Raised Bog Area --- bog drain, 3383.

Carex _diandra_ Schrank. Great Western Patterned Fen --- main water track, frequent on _Larix_ island, 3200. Divide --- occasional along edge of drainage ditch, 3114. Ludlow Patterned Fen --- frequent in partially dried-up fen, 2873.

Carex _disperma_ Dew. Occasional on _Larix_ islands. Great Western Patterned Fen --- main water track, _Larix_ island, 3216.

Carex _exilis_ Dew. Occasional throughout peatland in poor fen ecotones and uncommon on strings. Great Western Patterned Fen --- main water track, string, 3209; north branch, string, 3259. Divide --- poor fen ecotone, 3037 and 3300. Ludlow Patterned Fen --- poor fen ecotone, 2986 and 3054.

Carex _interior_ Bailey. Ludlow Patterned Fen --- frequent in partially dried-up fen, 3063.

Carex _lacustris_ Willd. Ludlow Patterned Fen --- infrequent on edge of drainage ditch, 2852 and 3056.

Carex _lanuginosa_ Michx. Ludlow Patterned Fen --- uncommon on edge of drainage ditch, 3156.

Carex _lasiocarpa_ Ehrh. var. _americana_ Fern. Very common throughout peatland in flarks. Great Western Patterned Fen --- main water track, flark, 3226. Ludlow Patterned Fen --- flark, 3093; partially dried-up fen, 2865.

Carex _leptalea_ Wahlenb. Occasional throughout peatland in flarks. Ludlow Patterned Fen --- string hollow, 2938.

Carex limosa L. Frequent throughout peatland in flarks. Divide --- margin of Hilman Lake, 2981. Ludlow Patterned Fen --- flark, 2927; partially dried-up fen, 2990.

Carex livida (Wahlenb.) Willd. var. *grayana* (Dewey) Fern. Common throughout peatland in flarks. Great Western Patterned Fen --- main water track, flark, 3225. Divide --- flark, 3017. Ludlow Patterned Fen --- flark, 2850 and 2925; partially dried-up fen, 2803 and 2869. Koochiching Raised Bog Area --- flark, 3347 and 3393; edge of fen pool, 3358.

Carex oligosperma Michx. Very common throughout peatland in open bog ombrotrophic sites. Divide --- margin of Hilman Lake, 2984; edge of drainage ditch, 3036. Ludlow Patterned Fen --- partially dried-up fen, 3066.

Carex pauciflora Lightf. Divide --- ovoid-shaped island, occasional in open bog, 3045; infrequent on margin of Hilman Lake, 2982; linear raised bog, occasional in forested bog, 3109. Koochiching Raised Bog Area --- frequent in poor fen ecotone, 3342.

Carex paupercula Michx. Frequent on *Larix* islands and occasional in poor fen ecotones and in forested bogs throughout peatland. Great Western Patterned Fen --- main water track, *Larix* island, 3219. Ludlow Patterned Fen --- *Larix* island, 3004. Koochiching Raised Bog Area --- poor fen ecotone, 3340.

Carex projecta Mackenz. Ludlow Patterned Fen --- infrequent along drainage ditch, 3158.

<u>Carex pseudo-cyperus</u> L. Frequent on <u>Larix</u> islands. Great Western Patterned Fen --- main water track, <u>Larix</u> island, 3221. Ludlow Patterned Fen --- infrequent along drainage ditch, 3067.

<u>Carex rostrata</u> Stokes var. <u>utriculata</u> (Boott) Bailey. Infrequent throughout peatland in flarks. Great Western Patterned Fen --- north branch, flark, 3245. Divide --- margin of Hilman Lake, 2974; flark, 3309.

<u>Carex tenera</u> Dew. Ludlow Patterned Fen --- rare near edge of drainage ditch, 2968.

<u>Carex tenuiflora</u> Wahlenb. Frequent on <u>Larix</u> islands and on strings throughout peatland. Great Western Patterned Fen --- main water track, <u>Larix</u> island, 3186. Ludlow Patterned Fen --- <u>Larix</u> island, 3003 and 3055; string, 2937 and 3148. Koochiching Raised Bog Area --- string, 3377.

<u>Carex trisperma</u> Dew. Common throughout peatland in forested bog ombrotrophic sites. Divide --- ovoid-shaped island, forested bog, 3033.

<u>Carex vaginata</u> Tausch. Divide --- adjacent to a drainage ditch in the linear raised bog, rare, 3111.

<u>Carex viridula</u> Michx. Ludlow Patterned Fen --- occasional on edge of drainage ditch, 3068, 3145, and 3159.

<u>Cladium mariscoides</u> (Muhl.) Torr. Great Western Patterned Fen --- main water track, occasional in flark, 3184 and 3212; north branch, infrequent in flark, 3247.

<u>Dulichium</u> <u>arundinaceum</u> (L.) Britton. Great Western Patterned Fen --- north branch, infrequent on edge of drainage ditch, 3275. Divide --- margin of Hilman Lake, uncommon, 2973.

<u>Eleocharis</u> <u>compressa</u> Sulliv. Frequent throughout peatland in flarks. Great Western Patterned Fen --- main water track, flark, 3305. Divide --- flark, 3024.

<u>Eriophorum</u> <u>angustifolium</u> Honckeny. Occasional throughout peatland in minerotrophic sites. Ludlow Patterned Fen --- partially dried-up, 2811.

<u>Eriophorum</u> <u>chamissonis</u> C. A. Meyer. Frequent throughout peatland in poor fen ecotones. Divide --- poor fen ecotone, 3007. Ludlow Patterned Fen --- partially dried-up fen, 2810.

<u>Eriophorum</u> <u>gracile</u> Koch. Occasional throughout peatland in flarks. Ludlow Patterned Fen --- flark, 3091; partially dried-up fen, 3062.

<u>Eriophorum</u> <u>spissum</u> Fern. Common throughout peatland in open bog and forested bog ombrotrophic sites. Divide --- ovoid-shaped island, open bog, 3044; linear raised bog, 3101. Ludlow Patterned Fen --- forested bog, 2841 and 2877.

<u>Eriophorum</u> <u>tenellum</u> Nutt. Occasional throughout peatland in flarks. Great Western Patterned Fen --- main water track, flark, 3211. Divide --- flark, 3032. Ludlow Patterned Fen --- flark, 3139.

<u>Eriophorum</u> <u>virginicum</u> L. Divide --- ovoid-shaped island, rare in forested bog, 3271. Koochiching Raised Bog Area --- frequent in poor fen ecotone, 3341.

Eriophorum viridi-carinatum (Engelm.) Fern. Divide --- uncommon in linear raised bog, seepage drain, 3110.

Rhynchospora alba (L.) Vahl. Common throughout peatland in flarks. Great Western Patterned Fen --- main water track, flark, 3182; north branch, flark, 3251. Divide --- flark, 3306. Ludlow Patterned Fen --- flark, 3092 and 3153. Koochiching Raised Bog Area --- flark, 3345 and 3394.

Rhynchospora fusca (L.) Ait. f. Locally abundant in flarks and on the edge of fen pools. Great Western Patterned Fen --- main water track, flark, 3183 and 3210; north branch, flark, 3250. Divide --- flark, 3015; edge of fen pool, 3040 and 3334. Koochiching Raised Bog Area --- edge of fen pool, 3354 and 3364.

Scirpus atrocinctus Fern. Ludlow Patterned Fen --- infrequent in partially dried-up fen, 3324.

Scirpus cespitosus L. var. *callosus* Bigel. Occasional throughout peatland in poor fen ecotones and uncommon on strings. Great Western Patterned Fen --- main water track, string, 3208; north branch, string, 3239 and 3258. Divide --- poor fen ecotone, 3038. Ludlow Patterned Fen --- poor fen ecotone, 2988 and 3053.

Scirpus hudsonianus (Michx.) Fern. Occasional throughout peatland in minerotrophic sites. Ludlow Patterned Fen --- flark, 2848; poor fen ecotone, 3052; partially dried-up fen, 2805.

Scirpus validus Vahl. Koochiching Raised Bog Area --- rare on edge of fen pool, 3367.

DROSERACEAE

Drosera anglica Huds. Occasional throughout peatland in flarks. Great Western Patterned Fen --- main water track, flark, 3181, 3223, and 3301; north branch, flark, 3229 and 3248. Divide --- flark, 3023 and 3028. Ludlow Patterned Fen --- flark, 3142 and 3151. Koochiching Raised Bog Area --- flark, 3344 and 3385.

Drosera intermedia Hayne. Frequent throughout peatland in flarks. Great Western Patterned Fen --- north branch, flark, 3244. Divide --- flark, 3014, 3031, and 3307. Ludlow Patterned Fen --- flark, 2923, 3138, and 3154; edge of fen pool, 2991. Koochiching Raised Bog Area --- flark, 3343 and 3380.

Drosera linearis Goldie. Infrequent in flarks of the Great Western Patterned Fen --- main water track, flark, 3179, 3224, and 3302; north branch, flark, 3228 and 3249.

Drosera rotundifolia L. Frequent throughout peatland on ombrotrophic sites and occasional on strings and on Larix islands. Divide --- string, 3020 and 3026; margin of Hilman Lake, 2977; linear raised bog, 3102. Ludlow Patterned Fen --- string, 2847, 2919, and 3137.

ERICACEAE

Andromeda glaucophylla Link. Frequent throughout peatland in minerotrophic sites and occasional on ombrotrophic sites. Divide --- ovoid-shaped island, open bog, 3048. Ludlow Patterned Fen --- partially dried-up fen, 2808. Koochiching Raised Bog Area --- string, 3375.

Chamaedaphne calyculata (L.) Moench. Common throughout peatland on ombrotrophic sites and frequent in minerotrophic sites. Divide --- ovoid-shaped island, open bog, 3050. Ludlow Patterned Fen --- forested bog, 2843; partially dried-up fen, 2804. Koochiching Raised Bog Area --- string, 3370.

Gaultheria hispidula (L.) Bigel. Occasional throughout peatland on ombrotrophic sites and on *Larix* islands. Great Western Patterned Fen --- main water track, *Larix* island, 3205. Divide --- ovoid-shaped island, forested bog, 3034 and 3261; ovoid-shaped island, open bog, 3060; linear raised bog, 3103. Ludlow Patterned Fen --- *Larix* island, 2994.

Kalmia polifolia Wang. Frequent throughout peatland on ombrotrophic sites and occasional in minerotrophic sites. Divide --- ovoid-shaped island, open bog, 3051. Ludlow Patterned Fen --- partially dried-up fen, 2806.

Ledum groenlandicum Oeder. Common throughout peatland on ombrotrophic sites and occasional on *Larix* islands. Ludlow Patterned Fen --- forested bog, 2842 and 2878.

Vaccinium angustifolium Ait. Ludlow Patterned Fen --- occasional on *Larix* island, 2998.

Vaccinium myrtilloides Michx. Divide --- frequent in linear raised bog, 3107; ovoid-shaped island, infrequent in open bog, 3061.

Vaccinium oxycoccos L. Common throughout peatland on ombrotrophic sites and frequent in minerotrophic sites. Great Western Patterned Fen --- main water track, *Larix* island, 3188. Divide --- ovoid-shaped island, open bog, 3049; linear raised bog, 3100; margin of Hilman Lake, 2985. Ludlow Patterned Fen --- string, 2917; poor fen ecotone, 2989.

Vaccinium vitis-idaea L. var. *minus* Lodd. Occasional throughout peatland on ombrotrophic sites and infrequent on *Larix* islands. Great Western Patterned Fen --- main water track, *Larix* island, 3204. Divide --- linear raised bog, 3105. Ludlow Patterned Fen --- forested bog, 2946.

GENTIANACEAE

Gentiana rubricaulis Schwein. Ludlow Patterned Fen --- rare in partially dried-up fen, 3321.

Menyanthes trifoliata L. Common throughout peatland in flarks. Divide --- flark, 2849. Ludlow Patterned Fen --- flark, 2849 and 2924. Koochiching Raised Bog Area --- flark, 3382.

HIPPURIDACEAE

Hippuris vulgaris L. Divide --- uncommon on edge of drainage ditch, 3116.

HYPERICACEAE

Hypericum virginicum L. var. *fraseri* (Spach) Fern. Frequent throughout peatland in minerotrophic sites. Ludlow Patterned Fen --- string, 3090; partially dried-up fen, 3312.

IRIDACEAE

<u>Iris versicolor</u> L. Occasional throughout peatland in minerotrophic sites. Ludlow Patterned Fen --- string, 2941.

JUNCACEAE

<u>Juncus alpinus</u> Vill. var. <u>rariflorus</u> Hartm. Ludlow Patterned Fen --- uncommon in partially dried-up fen, 3439.

<u>Juncus brevicaudatus</u> (Engelm.) Fern. Ludlow Patterned Fen --- uncommon on edge of drainage ditch, 3330.

<u>Juncus canadensis</u> J. Gay. Occasional throughout peatland on edge of fen pools and infrequent in flarks. Divide --- flark, 3310. Ludlow Patterned Fen --- seepage drain, 3329. Koochiching Raised Bog Area --- edge of fen pool, 3356 and 3365; flark, 3346 and 3379.

<u>Juncus dudleyi</u> Wieg. Ludlow Patterned Fen --- rare on edge of drainage ditch, 3170.

<u>Juncus nodosus</u> L. Ludlow Patterned Fen --- uncommon on edge of drainage ditch, 3440.

<u>Juncus pelocarpus</u> Mey. Koochiching Raised Bog Area --- rare on edge of fen pool, 3351 and 3363.

<u>Juncus stygius</u> L. var. <u>americanus</u> Buchenau. Uncommon throughout peatland on edge of fen pools and rare in flarks. Divide --- edge of fen pool, 3295 and 3333; flark, 3308. Koochiching Raised Bog Area --- edge of fen pool, 3355 and 3360.

JUNCAGINACEAE

Scheuchzeria palustris L. var. americana Fern. Occasional throughout peatland in flarks. Divide --- flark, 3013; margin of Hilman Lake, 2978. Ludlow Patterned Fen --- flark, 2921. Koochiching Raised Bog Area --- flark, 3348.

Triglochin maritima L. Frequent throughout peatland in flarks. Divide --- flark, 3012. Ludlow Patterned Fen --- flark, 2922 and 2944; poor fen ecotone, 2987; partially dried-up fen, 3064. Koochiching Raised Bog Area --- flark, 3350.

LAMIACEAE

Lycopus americanus Muhl. Ludlow Patterned Fen --- uncommon in partially dried-up fen, 3080 and 3320.

Lycopus uniflorus Michx. Occasional on Larix islands and infrequent on strings. Great Western Patterned Fen --- main water track, Larix island, 3203.

Scutellaria epilobiifolia Hamilt. Occasional on Larix islands and uncommon on strings. Great Western Patterned Fen --- north branch, string, 3273. Divide --- edge of drainage ditch, 3113.

LENTIBULARIACEAE

Utricularia cornuta Michx. Locally abundant in flarks and on the edge of fen pools. Great Western Patterned Fen --- main water track, flark, 3180; north branch, flark, 3246. Divide --- edge of fen pool, 3298. Koochiching Raised Bog Area --- edge of fen pool, 3357 and 3361.

<u>Utricularia</u> <u>intermedia</u> Hayne. Common throughout peatland in flarks and on edge of fen pools. Great Western Patterned Fen --- main water track, flark, 3303. Divide --- flark, 3016; margin of Hilman Lake, 2979. Ludlow Patterned Fen --- flark, 2942; edge of drainage ditch, 2879. Koochiching Raised Bog Area --- flark, 3349; edge of fen pool, 3359 and 3366.

<u>Utricularia</u> <u>minor</u> L. Frequent throughout peatland in flraks and on edge of fen pools. Great Western Patterned Fen --- main water track, flark, 3227 and 3304. Divide --- flark, 3025.

<u>Utricularia</u> <u>vulgaris</u> L. Divide --- occasional in drainage ditch, 3117.

LILIACEAE

<u>Maianthemum</u> <u>canadense</u> Desf. Great Western Patterned Fen --- main water track, rare on <u>Larix</u> island, 3191.

<u>Smilacina</u> <u>trifolia</u> (L.) Desf. Occasional on <u>Larix</u> islands. Ludlow Patterned Fen --- infrequent in forested bog, 2945.

LOBELIACEAE

<u>Lobelia</u> <u>kalmii</u> L. Occasional throughout peatland in minerotrophic sites. Great Western Patterned Fen --- north branch, string, 3240. Ludlow Patterned Fen --- partially dried-up fen, 3326.

LORANTHACEAE

<u>Arceuthobium</u> <u>pusillum</u> Peck. Occasional throughout peatland on conifers, especially black spruce. Divide --- ovoid-shaped island, forested bog (on black spruce), 3260.

MYRICACEAE

<u>Myrica</u> <u>gale</u> L. Frequent on <u>Larix</u> islands. Great Western Patterned Fen --- main water track, <u>Larix</u> island, 3189; north branch, <u>Larix</u> island, 3284. Ludlow Patterned Fen --- partially dried-up fen, 2807 and 3065.

NYMPHAEACEAE

<u>Nuphar</u> <u>variegatum</u> Engelm. Ludlow Patterned Fen --- infrequent in drainage ditch, 2934.

ONAGRACEAE

<u>Epilobium</u> <u>angustifolium</u> L. Great Western Patterned Fen --- north branch, rare on edge of drainage ditch, 3288.

<u>Epilobium</u> <u>leptophyllum</u> Raf. Occasional throughout peatland in minerotrophic sites. Great Western Patterned Fen --- north branch, string, 3272.

ORCHIDACEAE

<u>Arethusa</u> <u>bulbosa</u> L. Occasional throughout peatland on strings. Divide --- string, 3010 and 3022. Ludlow Patterned Fen --- string, 2915, 2939, and 3027.

<u>Cypripedium</u> <u>acaule</u> Ait. Infrequent throughout peatland in forested bog ombrotrophic sites and on <u>Larix</u> islands. Great Western Patterned Fen --- main water track, <u>Larix</u> island, 3215. Divide --- ovoid-shaped island, forested bog, 3270; linear raised bog, 3104. Ludlow Patterned Fen --- <u>Larix</u> island, 3002.

<u>Habenaria lacera</u> (Michx.) Lodd. Infrequent throughout peatland in minerotrophic sites. Great Western Patterned Fen --- main water track, string, 3207; north branch, string, 3242 and 3252. Divide --- edge of fen pool, 3043 and 3299. Ludlow Patterned Fen --- string, 3134 and 3146.

<u>Liparis loeselii</u> (L.) Rich. Great Western Patterned Fen --- north branch, rare on string, 3255.

<u>Listera cordata</u> (L.) R. Br. Divide --- occasional in linear raised bog, 3108.

<u>Malaxis unifolia</u> Michx. Ludlow Patterned Fen --- rare on string, 3136.

<u>Pogonia ophioglossoides</u> (L.) Ker. Occasional throughout peatland in flarks and infrequent on strings. Divide --- flark, 3029; string, 3009. Ludlow Patterned Fen --- flark, 3141. Koochiching Raised Bog Area --- flark, 3381; edge of fen pool, 3352.

<u>Pogonia ophioglossoides</u> (L.) Ker. forma <u>albiflora</u> Rand & Redfield. Divide --- rare on edge of fen pool, 3296. Ludlow Patterned Fen --- uncommon in flark, 3140.

POACEAE

<u>Agrostis scabra</u> Willd. Frequent throughout peatland in minerotrophic sites. Great Western Patterned Fen --- main water track, <u>Larix</u> island, 3193; north branch, <u>Larix</u> island, 3236; north branch, on edge of drainage ditch, 3290.

Bromus ciliatus L. Frequent throughout peatland in minerotrophic sites. Great Western Patterned Fen --- north branch, *Larix* island, 3231. Ludlow Patterned Fen --- partially dried-up fen, 3317.

Calamagrostis canadensis (Michx.) Beauv. Frequent throughout peatland along drainage ditches and occasional on *Larix* islands. Great Western Patterned Fen --- main water track, *Larix* island, 3220; north branch, *Larix* island, 3280. Divide --- on edge of drainage ditch, 3035. Ludlow Patterned Fen --- on edge of drainage ditch, 3058.

Calamagrostis inexpansa Gray var. *brevior* (Vasey) Stebbins. Ludlow Patterned Fen --- occasional on edge of drainage ditch, 3157.

Calamagrostis neglecta (Ehrh.) Gaertn. Frequent on *Larix* islands. Great Western Patterned Fen --- main water track, *Larix* island, 3190; north branch, *Larix* island, 3237 and 3281.

Cinna latifolia (Trin.) Griseb. Ludlow Patterned Fen --- rare on *Larix* island, 3337.

Glyceria borealis (Nash) Batchelder. Ludlow Patterned Fen --- uncommon on edge of drainage ditch, 2954.

Glyceria striata (Lam.) Hitchc. Ludlow Patterned Fen --- uncommon on edge of drainage ditch, 2961.

Muhlenbergia glomerata (Willd.) Trin. Frequent throughout peatland on strings and occasional on *Larix* islands. Great Western Patterned Fen --- main water track, *Larix* island, 3206. Koochiching Raised Bog Area --- string, 3376 and 3389.

Phragmites communis Trin. var. *berlandieri* (Fourn.) Fern. Occasional throughout peatland in minerotrophic sites. Ludlow Patterned Fen --- flark, 3094; partially dried-up fen, 3311.

POLYGONACEAE

Polygonum sagittatum L. Great Western Patterned Fen --- main water track, uncommon on *Larix* island, 3198.

Rumex orbiculatus Gray. Occasional on *Larix* islands. Great Western Patterned Fen --- main water track, *Larix* island, 3202. Ludlow Patterned Fen --- partially dried-up fen, 3313.

PRIMULACEAE

Lysimachia terrestris (L.) BSP. Ludlow Patterned Fen --- infrequent in partially dried-up fen, 3173.

Lysimachia thyrsiflora L. Occasional throughout peatland in minerotrophic sites. Ludlow Patterned Fen --- partially dried-up fen, 2863 and 2931.

Trientalis borealis Raf. Infrequent on *Larix* islands. Ludlow Patterned Fen --- uncommon on string, 2940.

PYROLACEAE

Monotropa uniflora L. Occasional throughout peatland in forested bog ombrotrophic sites and infrequent on *Larix* islands. Divide --- ovoid-shaped island, forested bog, 3269; linear raised bog, 3106.

Pyrola asarifolia Michx. var. *purpurea* (Bunge) Fern. Great Western Patterned Fen --- north branch, rare on *Larix* island, 3233.

Pyrola secunda L. var. *obtusata* Turcz. Great Western Patterned Fen --- north branch, uncommon on *Larix* island, 3234.

RANUNCULACEAE

Caltha palustris L. Infrequent on *Larix* islands. Ludlow Patterned Fen --- infrequent in partially dried-up fen, 2866.

Ranunculus gmelini DC. var. *hookeri* (D. Don) Benson. Great Western Patterned Fen --- main water track, uncommon on *Larix* island, 3201. Ludlow Patterned Fen --- infrequent on edge of drainage ditch, 2851.

RHAMNACEAE

Rhamnus alnifolia L'Her. Occasional throughout peatland in minerotrophic sites. Great Western Patterned Fen --- north branch, string, 3238. Ludlow Patterned Fen --- partially dried-up fen, 2928; string, 3147.

ROSACEAE

Amelanchier humilis Wieg. var. *compacta* Niels. Great Western Patterned Fen --- north branch, rare on *Larix* island, 3268.

Aronia melanocarpa (Michx.) Spach. Occasional on *Larix* islands. Great Western Patterned Fen --- main water track, *Larix* island, 3213; north branch, *Larix* island, 3263.

Geum aleppicum Jacq. var. *strictum* (Ait.) Fern. Infrequent on *Larix* islands. Ludlow Patterned Fen --- uncommon in partially dried-up fen, 2952.

<u>Potentilla</u> <u>fruticosa</u> L. Occasional throughout peatland in minerotrophic sites. Ludlow Patterned Fen --- poor fen ecotone, 2992; common in partially dried-up fen, 2812 and 2874.

<u>Potentilla</u> <u>palustris</u> (L.) Scop. Occasional throughout peatland in minerotrophic sites. Divide --- margin of Hilman Lake, 2972. Ludlow Patterned Fen --- edge of drainage ditch, 2932.

<u>Rubus</u> <u>acaulis</u> Michx. Occasional throughout peatland in minerotrophic sites. Ludlow Patterned Fen --- string, 2845 and 2916; partially dried-up fen, 2801. Koochiching Raised Bog Area --- string, 3378.

<u>Rubus</u> <u>pubescens</u> Raf. Occasional on <u>Larix</u> islands and infrequent on strings. Ludlow Patterned Fen --- string, 3135.

<u>Rubus</u> <u>strigosus</u> Michx. Uncommon on <u>Larix</u> islands. Ludlow Patterned Fen --- uncommon in partially dried-up fen, 2886.

<u>Spiraea</u> <u>alba</u> Du Roi. Frequent throughout peatland along edges of drainage ditches. Ludlow Patterned Fen --- edge of drainage ditch, 2815, 2853, and 3001.

RUBIACEAE

<u>Galium</u> <u>labradoricum</u> Wieg. Frequent throughout peatland in minerotrophic sites. Ludlow Patterned Fen --- string, 2918 and 3089; partially dried-up fen, 2870.

SALICACEAE

Populus balsamifera L. Great Western Patterned Fen --- north branch, rare on edge of drainage ditch, 3287. Ludlow Patterned Fen --- uncommon on edge of drainage ditch, 2899.

Populus tremuloides Michx. Great Western Patterned Fen --- north branch, rare on edge of drainage ditch, 3265. Ludlow Patterned Fen --- rare on edge of drainage ditch, 2857.

Salix bebbiana Sarg. Infrequent on *Larix* islands. Ludlow Patterned Fen --- occasional in partially dried-up fen, 2884; uncommon on edge of drainage ditch, 2900.

Salix candida Fluegge. Infrequent on *Larix* islands. Great Western Patterned Fen --- main water track, *Larix* island, 3195; north branch, *Larix* island, 3267. Ludlow Patterned Fen --- partially dried-up fen, 2868, 2929, and 3314.

Salix discolor Muhl. Infrequent on *Larix* islands. Ludlow Patterned Fen --- infrequent in partially dried-up fen, 2859.

Salix gracilis Anderss. Ludlow Patterned Fen --- occasional on edge of drainage ditch, 2818 and 2897.

Salix interior Rowles. Ludlow Patterned Fen --- uncommon on edge of drainage ditch, 2834.

Salix lucida Muhl. Ludlow Patterned Fen --- Infrequent on edge of drainage ditch, 2898.

<u>Salix</u> <u>pedicellaris</u> Pursh var. <u>hypoglauca</u> Fern. Frequent throughout peatland in minerotrophic sites. Ludlow Patterned Fen --- string, 2846; partially dried-up fen, 2814; edge of drainage ditch, 3000.

<u>Salix</u> <u>planifolia</u> Pursh. Ludlow Patterned Fen --- rare on edge of drainage ditch, 2817.

<u>Salix</u> <u>pyrifolia</u> Anderss. Infrequent on <u>Larix</u> islands. Divide --- <u>Larix</u> island, 3005. Ludlow Patterned Fen --- frequent on edge of drainage ditch, 2999.

<u>Salix</u> <u>serissima</u> (Bailey) Fern. Ludlow Patterned Fen --- infrequent on edge of drainage ditch, 3155.

SARRACENIACEAE

<u>Sarracenia</u> <u>purpurea</u> L. Occasional throughout peatland. Divide --- string, 3338; poor fen ecotone, 3008. Ludlow Patterned Fen --- string, 2920. Koochiching Raised Bog Area --- string, 3371.

SAXIFRAGACEAE

<u>Parnassia</u> <u>glauca</u> Raf. Ludlow Patterned Fen --- uncommon in partially dried-up fen, 3441.

<u>Parnassia</u> <u>palustris</u> L. var. <u>neogaea</u> Fern. Occasional throughout peatland in minerotrophic sites. Great Western Patterned Fen --- north branch, string, 3241 and 3253. Ludlow Patterned Fen --- flark, 3144. Koochiching Raised Bog Area --- string, 3372.

SCROPHULARIACEAE

Gerardia paupercula (Gray) Britt. var. *borealis* (Pennell) Deam. Ludlow Patterned Fen --- infrequent in partially dried-up fen, 3327.

Mimulus ringens L. Ludlow Patterned Fen --- rare on edge of drainage ditch, 3442.

Pedicularis lanceolata Michx. Occasional throughout peatland in minerotrophic sites. Ludlow Patterned Fen --- flark, 3152. Koochiching Raised Bog Area --- string, 3373.

SPARGANIACEAE

Sparganium minimum (Hartm.) Fries. Great Western Patterned Fen --- main water track, uncommon on *Larix* island, 3443.

TYPHACEAE

Typha latifolia L. Occasional throughout peatland in minerotrophic sites. Ludlow Patterned Fen --- flark, 3095.

VIOLACEAE

Viola incognita Brain. Infrequent on *Larix* islands. Great Western Patterned Fen --- main water track, *Larix* island, 3218.

Viola mackloskeyi Lloyd ssp. *pallens* (Banks) Baker. Occasional throughout peatland in minerotrophic sites. Ludlow Patterned Fen --- partially dried-up fen, 2813 and 2872.

Viola nephrophylla Greene. Ludlow Patterned Fen --- uncommon in partially dried-up fen, 2816.

XYRIDACEAE

Xyris montana Ries. Divide --- rare on edge of fen pool, 3041, 3297, and 3335. Koochiching Raised Bog Area --- frequent on edge of fen pool, 3353 and 3362; occasional in flark, 3339.

ZOSTERACEAE

Potamogeton natans L. Great Western Patterned Fen --- main water track, rare in moat surrounding *Larix* island, 3444.

Potamogeton gramineus L. Occasional throughout peatland in flarks and in drainage ditches. Great Western Patterned Fen --- main water track, flark, 3143 and 3185. Ludlow Patterned Fen --- edge of drainage ditch, 3099.

MOSSES - SPHAGNALES

SPHAGNACEAE

Sphagnum capillifolium (Weiss) Schrank.

Sphagnum capillifolium (Weiss) Schrank var. tenellum (Schimp.) Crum.

Sphagnum capillifolium (Weiss) Schrank var. tenerrum (Sull. & Lesq. ex Sull.) Crum.

Sphagnum centrale C. Jens. ex Arnell & C. Jens.

Sphagnum cuspidatum Ehrh. ex Hoffm.

Sphagnum fimbriatum Wils. ex J. Hook.*

Sphagnum fuscum (Schimp.) Klinggr.

Sphagnum magellanicum Brid.

Sphagnum majus (Russ.) C. Jens.

Sphagnum obtusum Warnst. *

Sphagnum palustre L. *

Sphagnum papillosum Lindb. *

Sphagnum recurvum P.-Beauv.

Sphagnum recurvum P.-Beauv. var. amblyphyllum (Russ.) Warnst.

Sphagnum recurvum P.-Beauv. var. tenellum (Schimp.) Crum.

Sphagnum recurvum P.-Beauv. var. tenue Klinggr.

Sphagnum russowii Warnst. *

Sphagnum squarrosum Crome. *

Sphagnum subnitens Russ. & Warnst. ex Warnst. *

Sphagnum subsecundum Nees ex Sturm.

Sphagnum subsecundum Nees ex Sturm var. contortum (Schultz) Hueb. *

Sphagnum subsecundum Nees ex Sturm var. platyphyllum (Lindb. ex Braithw.) Car

Sphagnum subsecundum Nees ex Sturm var. rufescens (Nees, Hornsch. & Sturm) Hueb.

Sphagnum teres (Schimp.) Angstr. ex C. Hartm.

Sphagnum warnstorfii Russ.

MOSSES - BRYALES

AMBLYSTEGIACEAE

Amblystegium serpens (Hedw.) B.S.G.

Calliergon giganteum (Schimp.) Kindb.*

Calliergon stramineum (Brid.) Kindb.

Calliergon trifarium (Web. & Mohr) Kindb.*

Calliergonella cuspidata (Hedw.) Loeske.

Campylium stellatum (Hedw.) C. Jens.

Drepanocladus aduncus (Hedw.) Warnst.

Drepanocladus fluitans (Hedw.) Warnst.

Drepanocladus revolvens (Sw.) Warnst.

Drepanocladus vernicosus (Lindb. ex C. Hartm.) Warnst.

Leptodictyum trichopodium (Schultz) Warnst.

Scorpidium scorpioides (Hedw.) Limpr.

AULACOMNIACEAE

Aulacomnium palustre (Hedw.) Schwaegr.

BRACHYTHECIACEAE

Brachythecium salebrosum (Web. & Mohr) B.S.G.

Tomenthypnum nitens (Hedw.) Loeske.

BRYACEAE

Leptobryum pyriforme (Hedw.) Wils.

Pohlia nutans (Hedw.) Lindb.

Pohlia wahlenbergii (Web. & Mohr) Andr.

CLIMACIACEAE

Climacium dendroides (Hedw.) Web. & Mohr.

DICRANACEAE

Dicranella varia (Hedw.) Schimp.

Dicranum drummondii C. Muell.

Dicranum flagellare Hedw.

Dicranum montanum Hedw.

Dicranum polysetum Sw.

Dicranum undulatum Brid.

DITRICHACEAE

Ceratodon purpureus (Hedw.) Brid.

ENTODONTACEAE

Pleurozium schreberi (Brid.) Mitt.

FISSIDENTACEAE

Fissidens adiantoides Hedw.

HYLOCOMIACEAE

Hylocomium splendens (Hedw.) B.S.G.*

HYPNACEAE

Callicladium haldanianum (Grev.) Crum.

Hypnum lindbergii Mitt.

Hypnum pallescens (Hedw.) P.-Beauv.

Hypnum pratense Koch ex Brid.

Platygrium repens (Brid.) B.S.G.

Pylasiella selwynii (Kindb.) Crum, Steere & Anderson.

MEESIACEAE

Meesia triquetra (Richt.) Angstr.*

MNIACEAE

Mnium cuspidatum Hedw.

Mnium punctatum Hedw.

PLAGIOTHECIACEAE

Plagiothecium denticulatum (Hedw.) B.S.G.

POLYTRICHACEAE

Polytrichum commune Hedw.

Polytrichum juniperinum Hedw. var. affine (Funck) Brid.

TETRAPHIDACEAE

Tetraphis pellucida Hedw.

THUIDIACEAE

Helodium blandowii (Web. & Mohr) Warnst.

Thuidium delicatulum (Hedw.) B.S.G.

HEPATICS

CEPHALOZIACEAE

Cephalozia connivens (Dicks) Spruce.

Cephalozia pleniceps (Aust.) Lindb.

Cladopodiella fluitans (Nees) Buch.

CEPHALOZIELLACEAE

Cephaloziella elasticka (Jack) Schiffn.

FOSSOMBRONIACEAE

Fossombronia _foveolata_ Lindb.

FRULLANIACEAE

Frullania _aboracensis_ Gott.

HARPANTHACEAE

Lophocolea _heterophylla_ (Schrad.) Durn.

JUNGERMANNIACEAE

Lophozia sp.

Mylia _anomala_ (Hook.) S. Gray.

MARCHANTIACEAE

Marchantia _polymorpha_ L.

PLAGIOCHILACEAE

Plagiochila _asplenioides_ (L.) Dum.

PTILIDIACEAE

Ptilidium _ciliare_ (L.) Hampe.

SCAPANIACEAE

Scapania _irrigua_ (Nees) Dum.

RICCARDIACEAE

Aneura _pinguis_ (L.) Dum.

LICHENS

ARTHONIACEAE

Arthonia caesia (Korb.) Korb.

Micarea melanobola (Nyl.) Harris.

BUELLIACEAE

Buellia arnoldii Serv. & Nadv.

Buellia punctata (Hoffm.) Mass.

Rinodina milliaria Tuck.

CALICIACEAE

Calicium abietinum Pers.

Calicium salicinum Pers.

Calicium trabinellum (Ach.) Ach.

Mycocalicium subtile (Pers.) Szat.

Sphinctrina turbinata (Pers. ex Fr.) De Not.

CLADONIACEAE

Cladonia bacillaris Ny.

Cladonia botrytes (Hag.) Willd.

Cladonia cenotea (Ach.) Schaer.

Cladonia chlorophaea (Flk. ex Somm.) Spreng.

Cladonia coniocraea (Flk.) Spreng.

Cladonia crispata (Ach.) Flot.

Cladonia crisatella Tuck.

Cladonia deformis (L.) Hoffm.

Cladonia furcata (Huds.) Schrad.

Cladonia gracilis (L.) Willd.

Cladonia grayi Merr. ex Sandst.

Cladonia merochlorophaea Asah.

Cladonia mitis Sandst.

Cladonia multiformis Merr.

Cladonia pityrea (Flk.) Fr.

Cladonia rangiferina (L.) Wigg.

Cladonia rei Schaer.

Cladonia subulata (L.) Wigg.

Cladonia verticillata (Hoff.) Schaer.

LECANACTIDACEAE

Lecanactis chloroconia Tuck.

LECANORACEAE

Lecanora coilocarpa (Ach.) Nyl.

Lecanora meridionalis Magn.

Lecanora pallida (Schreb.) Rabenh.

Lecanora strobilina (Spreng.) Kieff.

Lecanora symmictera Nyl.

Lecanora thysanophora Harris.

LECIDEACEAE

Bacidia chlorococca (Graewe ex Stenh.) Lett.

Lecidea elaeochroma (Ach.) Ach.

Lecidea flexuosa (Fr.) Nyl.

Lecidea uliginosa (Schrad.) Ach.

PARMELIACEAE

Cetraria halei W. Culb. & C. Culb.

Cetraria orbata (Nyl.) Fink.

Cetraria pinastri (Scop.) S. Gray.

<u>Hypogymnia</u> <u>physodes</u> (L.) W. Wats.

<u>Parmelia</u> <u>bolliana</u> Mull. Arg.

<u>Parmelia</u> <u>caperata</u> (L.) Ach.

<u>Parmelia</u> <u>exasperatula</u> Nyl.

<u>Parmelia</u> <u>flaventior</u> Stirt.

<u>Parmelia</u> <u>olivacea</u> (L.) Ach.

<u>Parmelia</u> <u>rudecta</u> Ach.

<u>Parmelia</u> <u>subaurifera</u> Nyl.

<u>Parmelia</u> <u>subrudecta</u> Nyl.

<u>Parmelia</u> <u>sulcata</u> Tayl.

<u>Parmelia</u> <u>ulophyllodes</u> (Vain.) Sav.

<u>Parmeliopsis</u> <u>aleurites</u> (Ach.) Nyl.

<u>Parmeliopsis</u> <u>capitata</u> Harris.

<u>Pseudevernia</u> <u>consocians</u> (Vain.) Hale & Culb.

PHYSCIACEAE

<u>Physcia</u> <u>millegrana</u> Degel.

<u>Physcia</u> <u>stellaris</u> (L.) Nyl.

RAMALINACEAE

<u>Ramalina</u> <u>dilacerata</u> (Hoffm.) Hoffm.

<u>Ramalina</u> <u>fastigiata</u> (Pers.) Ach.

USNEACEAE

<u>Bryoria</u> <u>furcellata</u> (Fr.) Brodo & Hawksw.

<u>Bryoria</u> <u>trichodes</u> (Michx.) Brodo & Hawksw.

<u>Evernia</u> <u>mesomorpha</u> Nyl.

<u>Usnea</u> <u>cavernosa</u> Tuck.

<u>Usnea</u> <u>fulvoreagens</u> (Ras.) Ras.

Usnea hirta (L.) Wigg.

Usnea subfloridana Stirt.

Imperfect Lichens

Lepraria finkii (B. de Lesd. in Hue) Harris.

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PART III

BIBLIOGRAPHY
ON
SPHAGNUM BOGS

E. GORHAM

DEPARTMENT OF

ECOLOGY AND

BEHAVIORAL BIOLOGY

UNIVERSITY OF MINNESOTA

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PART IV

RECOMMENDATIONS FOR FURTHER VEGETATIONAL AND FLORISTIC STUDIES ON THE PEATLANDS OF NORTHERN MINNESOTA

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Introduction

The floristic and ecological survey of the Red Lake Peatland has produced significant new information on patterned peatlands in northern Minnesota, including an integrated hypothesis concerning the origin and interrelations of the patterns. The stage is now set for a broader regional survey that will test the general applicability of peatland concepts and categories derived from the Red Lake study. Farther north and farther east the factors in peatland development may be significantly different from those that prevail in the Red Lake area, e.g. climate, calcareous content of the upland soils, influence of atmospheric dust or other pollutants from agricultural or industrial areas. Such a survey will have value for land-use managers by 1) establishing the regional patterns of vegetation and landforms in the mires throughout northern Minnesota, 2) identifying areas of exceptional esthetic or scientific value for preservation, 3) identifying locations of rare and endangered species, and 4) providing qualitative information on the impacts of drainage ditches, roadways, and powerlines on the hydrology and vegetation of patterned mires in northern Minnesota.

The regional survey will have 3 phases. First, aerial photographs of the entire region of northern Minnesota will be examined to locate, classify, and map the various types of peatland pattern. Second, a field survey will be conducted in selected peatlands across the region, with the use of the same methods employed in the Red Lake study, to establish ground truth for aerial landscape analysis. Third, stratigraphic analyses will be conducted to test hypotheses on the development of peatland patterns and determine gross rates of peat accumulation across the region. Only if present developmental trends are understood can we judge the ultimate impact of human disturbance upon these peatlands.

Phase I: Aerial Photographs

Prior to field work the entire region of northern Minnesota will be surveyed from large-scale (1:15,840) and small-scale (1:24,000) aerial photographs. Orthophotoquads published by the U.S. Geological Survey are also available for large portions of Beltrami, Koochiching, and Itasca Counties. The objectives of this survey are to:

1) locate and map patterned mires in northern Minnesota.
2) classify major types of mire patterns on the basis of the Red Lake patterns and the literature.
3) determine the extent of impacts from power lines, drainage ditches, and roads on patterned mires in northern Minnesota.
4) formulate additional hypotheses on the development of mire patterns under both natural and disturbed conditions.

Phase II: Field Survey

A number of peatlands will be chosen from aerial photographs for examination on the ground. Field studies will focus on the relation of the flora and vegetation of patterned mires to the landforms and water chemistry. Special consideration will be given to large pristine peatlands and areas where mire patterns seem to be in a state of flux.

Particular attention will be paid to the relations between *Sphagnum* lawns on the flanks of raised bogs and on the manner by which incipient water tracks and ovoid islands develop. The sources of minerotrophic water in these internal water tracks must be identified.

One particular vegetation type that was not sampled in the Red Lake area is the transitional wetland bordering the peatland complex. A proper analysis is possible now that the major peatland communities have been established, and it is of great importance because the marginal areas may be those parts of the peatland complex most used by wildlife of interest to man (e.g., moose, deer, wildfowl, etc.). There appear to be large areas of willow scrub that may be of particular importance in this connection.

Additional field studies are planned for areas of fire scars, particularly on the ovoid islands, to see if fire has played a role in developing the open central part of the islands.

The field surveys will provide a more detailed basis for evaluating the qualitative effects of drainage ditches, roadways, power lines, and other human disturbances on patterned peatlands in northern Minnesota. At Red Lake the effects of drainage ditches was inferred by comparing the pristine upslope portions of water tracks with the ditched portions that are farther downslope. Similar comparisons will be made in other areas. More detailed analysis than this for a small area is not practical at this stage because:

1) the vegetation-landform patterns in disturbed areas vary greatly in time and space, so that results from one area may have little applicability elsewhere.
2) chance plays an overriding role in determining the dispersal, establishment, and succession of vegetation in disturbed areas. Weedy vegetation is often superimposed over remnants of the original vegetation, producing confusing and complex patterns.

3) detailed quantitative investigations require an enormous commitment of time and funds; integrated analyses of vegetation, geomorphology, and hydrology must be made over extended periods of time from before the time of disturbance until many years later.

Phase III: Stratigraphy

Stratigraphic analyses of peat cores will be undertaken to:

1) determine the development of patterned peatlands in relation to the regional climate and human activity.
2) test hypotheses on the origin of mire patterns.
3) determine gross rates of peat accumulation.

During the field survey short cores will be collected from the uppermost 20 cm of peat within each relevé. These cores will be analysed for pollen, plant macrofossils, and the gross composition of peat to provide a standard for interpreting fossil assemblages from deeper profiles of peat. A number of longer cores will also be collected down to mineral soil in areas where vegetation-landform types appear to be in a state of flux. Stratigraphic analyses of these cores provide the best means of testing hypotheses on the origin and development of patterned peatlands. For example, it will be possible to determine whether the teardrop islands in the western water track (especially along the northern edge) result from paludification of a continuous forest, or whether they originate as local obstructions to water flow and then become enlarged. It also should be possible to determine when the raised bogs and ovoid islands originated, and whether the peatland grew by the coalescence of local raised bogs or developed simultaneously over the entire area.

Stratigraphic work will also include analysis of interstitial water at different depths in the peat and in the underlying mineral soil to search for clues to the sources of water flowing in various parts of the peatland. The source of minerotrophic water in the water tracks within the major *Sphagnum* bog complexes is of particular interest in this connection. Some of the water may move upward under artesion pressure, thus possibly explaining unexpectedly high values of pH discovered in the heart of the complex of raised bogs. If the interstitial water has a high ionic content and high humic color compared to the surface water, then presumably it has been in contact with the decomposing peat for a long time, whereas if its chemical makeup is similar to that of the surface water then it may be moving rapidly through the peat under artesian pressure.

Stratigraphic information will be valuable in developing plans for managing pristine peatlands or for rehabilitating those peatlands already disturbed by human activity. Stratigraphic markers such as the rise in *Ambrosia* pollen, which is associated with the time of agricultural land clearance in northern Minnesota, will provide a means for determining recent rates of peat accumulation for various vegetation-landform types, and radiocarbon dating can be used to determine rates for earlier time intervals. This type of information may be particularly important in determining the origin and development of mire patterns, because some of the patterns are apparently products of differential rates of peat growth. It is also of interest to determine whether peat is still accumulating in the different bog and fen landforms or has reached some limiting thickness imposed by the present climate, at least in some landforms.

AN ECOLOGIST'S VIEW OF THE NORTHERN MINNESOTA PEATLANDS IN THE VICINITY OF RED LAKE

1. This extensive area of patterned peatlands is of extreme value because of both its wilderness state and its scientific interest. The intricate patterns of these peatlands represent probably the most delicate adjustment of vegetation to hydrology that we know, and yet their origin and development have scarcely been studied and are in consequence poorly understood.

2. The hydrological factors governing the origin and development of these peatlands are also poorly understood. No hydrological theories can currently be used to predict the effects of large-scale ditching, road-building, peat mining or any other major disturbance of regional hydrology adjacent to such large peatlands, which exhibit extremely gentle topographic gradients and (in consequence) unusually slow rates of water flow.

3. Current investigations by Paul Glaser and Gerald Wheeler, doctoral students at the University of Minnesota, indicate that effects of ditching and road-building have already had some marked effects upon vegetation and its patterns more than a mile away from these activities. Peat mining on a major scale could well alter regional hydrology over much greater distances, and have profound effects upon the peatlands. Unfortunately, the current state of peatland hydrology does not allow us to forecast such changes at all clearly, although ditching across the line of water flow may make upstream habitats wetter (presumably owing to damming by spoil-banks) and downstream habitats drier. Observations so far suggests that ridge-and-trough patterns may be accentuated by moderate drying, but may be obscured by more extreme drying because of invasion of the sedge meadows by shrubby brush species.

4. Not only are these peatland ecosystems unusual — resembling the "peat seas" of Siberia, Alaska, and the Hudson Bay Lowland, but they are unique in developing far south of the line of permafrost. It was formerly thought that permafrost was an integral part of their development, but studies in Minnesota make clear that it is not necessary. If we destroy or seriously damage peatlands, we may never come to understand their unique landscape features and how they came to develop here.

5. These peatlands contain at least 15 rare plants, of which 10 are extremely rare. For most of these plants, their Red Lake occurrences are their westernmost extensions in North America, and hence of unusual interest and significance. Some seem already to have been affected by ditching of the peatlands.

6. These peatlands, once damaged or destroyed, are neither restorable or replaceable. Moreover, their survival in a reasonably pristine state can only be assured by preservation of very large areas, allowing them to exist on a self-sustaining basis. Such areas must include as a bare minimum many

hundreds of square miles out of the 11,000 sq. mi. of peatland now present in Minnesota (and the nearly 4,000 sq. mi. in Beltrami, Lake of the Woods, and Koochiching Counties -- where the Red Lake peatland is located).

7. It is my hope that no peat-mining will be allowed in the most interesting peatlands west of Highway 72 between Waskish and Baudette; and that any peat-mining activity to the eastward will not be permitted to alter the regional hydrology in any way damaging to the preserved peatlands west of Highway 72. Other nearby areas, at present not subjected to adequate ecological investigation, may also deserve preservation.

Preservation cannot be assured without a considerable expansion of ecological and hydrological research in both preserved and exploitable areas prior to any peat-mining, and careful monitoring during and after such activity (so that any damage to the preserved peatlands which appears during and after adjacent peat-mining and landscape reclamation can be ameliorated if not reversed).

It is of the greatest importance that coordination of such research efforts in hydrology, plant and animal ecology be very close, with regular meetings of the diverse scientists involved.

Respectfully submitted

Eville Gorham

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