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ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

Interim Report on a Comparative Study of Benthic Algal Primary Productivity in the AOSERP Study Area

Project WS 1.3.4

November 1979

Sponsored jointly by

Alberta
ENVIRONMENT

Environment Canada
Environnement Canada

15th Floor, Oxbridge Place
9820 - 106 Street
Edmonton, Alberta, Canada
T5K 2J6

ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM
RESEARCH REPORTS

These research reports describe the results of investigations funded under the Alberta Oil Sands Environmental Research Program, which was established by agreement between the Governments of Alberta and Canada in February 1975 (amended September 1977). This 10-year program is designed to direct and co-ordinate research projects concerned with the environmental effects of development of the Athabasca Oil Sands in Alberta.

A list of research reports published to date is included at the end of this report.

Enquiries pertaining to the Canada-Alberta Agreement or other reports in the series should be directed to:

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Interim Report on a Comparative Study of
Benthic Algal Primary Productivity in the
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AOSERP Report 75

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The Hon. J.W. (Jack) Cookson
Minister of the Environment
222 Legislative Building
Edmonton, Alberta

and

The Hon. John Fraser
Minister of the Environment
Environment Canada
Ottawa, Ontario

Sirs:

Enclosed is the report "Interim Report on a Comparative Study of Benthic Algal Primary Productivity in the AOSERP Study Area".

This report was prepared for the Alberta Oil Sands Environmental Research Program, through its Water System, under the Canada-Alberta Agreement of February 1975 (amended September 1977).

Respectfully,

W. Solodzuk, P. Eng.
Chairman, Steering Committee, AOSERP
Deputy Minister, Alberta Environment

A.H. Macpherson, Ph.D
Member, Steering Committee, AOSERP
Regional Director-General
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INTERIM REPORT ON A COMPARATIVE STUDY OF BENTHIC ALGAL PRIMARY PRODUCTIVITY IN THE AOSERP STUDY AREA

DESCRIPTIVE SUMMARY

BACKGROUND

Investigations on primary productivity conducted by AOSERP started in 1977. Such investigations centred attention on the Muskeg and Steepbank river basins where species identification was accomplished and some seasonal quantitative measures were made (AOSERP Reports 58 and 67). In addition to the scope of these projects, a measure of the algal resources from a region-wide perspective was necessary. The present project intended to achieve such a measure in its first year by a comparative quantitative study of key basins. Also desirable were estimates of limiting factors in algae production in the studied tributaries and estimates of naturally occurring and man-made stress on this resource which are planned for a second year of study. This interim report deals with the first year of a two-year project.

ASSESSMENT

A draft of the report was reviewed by managers and scientists from Alberta Environment, the University of British Columbia, and University of Toronto and the authors had opportunity to consider their input. It is the impression of Program Management that the report is a valuable addition in defining the baseline state amount of the aquatic resources in and around the oil sands mining area. The Alberta Oil Sands Environmental Research Program accepts the report "Interim Report on a Comparative Study of Benthic

Algal Productivity in the AOSERP Study Area" as a useful contribution to be distributed widely and thanks the authors for their efforts.

S.B. Smith, Ph.D
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INTERIM REPORT ON A COMPARATIVE STUDY OF BENTHIC ALGAL PRIMARY PRODUCTIVITY IN THE AOSERP STUDY AREA

by

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ALBERTA OIL SANDS ENVIRONMENTAL
RESEARCH PROGRAM

Project WS 1.3.4

November 1979

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ABSTRACT

Studies concentrating upon the epilithon were conducted in five tributary rivers flowing into the Athabasca River: the Muskeg, Steepbank, Hangingstone, MacKay, and Ells rivers. The species composition of the epilithic algae was determined during June to November 1978. Diatoms and blue-green algae dominated numerically except in the Hangingstone River where chlorophycean species replaced the latter group. Seasonal fluctuations in algal species and numbers were followed together with seasonal measurements of standing crop and primary productivity. These latter results probably underestimate true productivity because non-circulating chambers had to be used until circulating ones were constructed. To examine the chief determinants causing species, standing crop, and productivity fluctuations, various chemical and physical factors were measured, their fluctuations described, and relationships examined. This preliminary analysis showed no single nutrient or physical factor to be responsible. Instead, a complex interaction of factors is involved. Current velocity appears to be the most important. Comparisons of the mean standing crops and mean discharge rates produced a highly significant correlation among these rivers. Other factors, including nitrate-nitrogen, dissolved silica, irradiance, and water temperature, were important. However, due to the small data base, these results should be viewed as tentative.

Largest mean standing crops for the June to November period occurred in the Steepbank, Ells, and Hangingstone rivers, while largest mean production rates occurred in the Ells and Muskeg rivers. The MacKay River possessed the smallest standing crop and was the least productive.

ACKNOWLEDGEMENTS

This research project, WS 1.3.4., was funded by the Alberta Oil Sands Environmental Research Program, a joint Alberta-Canada research program established to fund, direct, and co-ordinate environmental research in the Athabasca Oil Sands area of northeastern Alberta. The authors acknowledge with utmost appreciation Marianne Klemka and Judy Buchanan. Special thanks are extended to Fred Wiskar, Jack Leroux, Richard Churcott, Michael Jeffery, and Liftair for their support and assistance in field operations. The authors also wish to thank Dirk Hadler, Carl Closs, and the air systems crew, particularly Terry Thompson and Vic Nespliak, for meteorological data.

1. INTRODUCTION

Algae are affected by a myriad of factors, physical, chemical and biotic, which result in both spatial and temporal changes in species composition, succession, standing crop, and primary productivity. In the lotic (flowing water) system, plants, such as attached algae, can be of considerable importance trophically by producing energy for other components of the food chain, both directly and indirectly, as well as increasing niche availability for other organisms.

Difficulties surrounding investigations of attached communities found in both lakes and rivers have been reviewed by Wetzel (1964). Artificial substrata have been employed but results so obtained can be controversial (Tippett 1970; Hansmann and Phinney 1973). New approaches have been introduced (Eaton and Moss 1966; Hickman 1969, 1971, 1974; Hickman and Round 1970; Round and Hickman 1971; Backhaus 1967; Marker 1976a, 1976b), but no generalized approach to these communities has been developed, and information pertaining to many benthic algal communities, particularly the epilithon, is scarce compared with the enormous amount originating from work upon the phytoplankton. However, studies have illustrated the importance of attached algal communities (Westlake 1971; Hickman 1971; Marker 1976a, 1976b; Moore 1977). Studies of communities, such as the epilithon, possess many inherent problems, including those of sampling and actual removal of the algae from the rocks. Benthic communities characteristically possess inherent heterogeneity. Species composition and standing crop size, for example, in the epilithon are not uniform across a riverbed because of flow rate variation associated with increasing depth toward mid-stream (Golowin 1968). Also, the nature, size, and morphology of the rocks themselves play an important role.

Investigations of actual primary productivity of attached algae in flowing systems have been done utilizing a number of methods. Modification of the upstream-downstream oxygen change method originally introduced by Odum (1956) has been used (Stockner 1968; Flemer 1970; Kelly et al. 1974). However, such a method only determines total primary productivity and reveals little about individual algal communities. Other techniques have utilized some kind of vessel into which the algae are placed and the incubations performed in situ (Thomas and O'Connell 1966; Hickman 1974; Marker 1976b). Many times chambers in which no water circulation takes place have been used. However, work has shown that such systems can underestimate primary productivity compared to one where water circulation takes place (McConnell and Sigler 1959; Rodgers and Harvey 1976). Marker (1976b) devised a chamber for in situ measurements of epilithic algal primary productivity in a small river. However, this particular design proved inadequate for this present study because the propeller creating the circulation was electrically powered and these small motors proved inherently unreliable in the field. Also, heavy batteries were required to power these motors. Therefore, non-circulating chambers were initially used in this study. Since all rivers were treated in a similar manner results were comparable. By late autumn, simple circulating chambers had been designed and built. Therefore, by comparing results obtained using both circulating and non-circulating chambers simultaneously, corrections can be applied to results obtained during the first part of this study.

Within the Alberta Oil Sands Environmental Research Program (AOSERP) study area there are a number of tributary rivers feeding the Athabasca River. These tributaries are considered important to the overall fisheries of the region. Representative of these tributaries are the Muskeg, Steepbank, Hangingstone, Ells, and MacKay rivers (Figure 1). Such rivers also lie in close proximity to areas which have a potential of being disrupted by removal of oil sands. Consequently, this study was initiated to determine the baseline status of production and populations of algae in the key tributaries of the area and provide an estimate of their significance to the entire system. Specifically, this study concerns itself with the following:

1. Determination of species composition and species numbers;
2. Measurement of standing crop size;
3. Measurement of primary productivity of the benthic algae (epilithic algae);
4. Determination of factors controlling and influencing primary productivity, standing crop sizes and fluctuations, and species fluctuations; and
5. To provide a comparison of the significance of the algal resources of the tributaries studied.

This report provides information pertaining to the above points. However, it must be stressed that this is a preliminary report covering less than one year and as such cannot be expected to provide definite answers at this stage. Thus, it is necessarily descriptive and not too analytical because of the small data base.

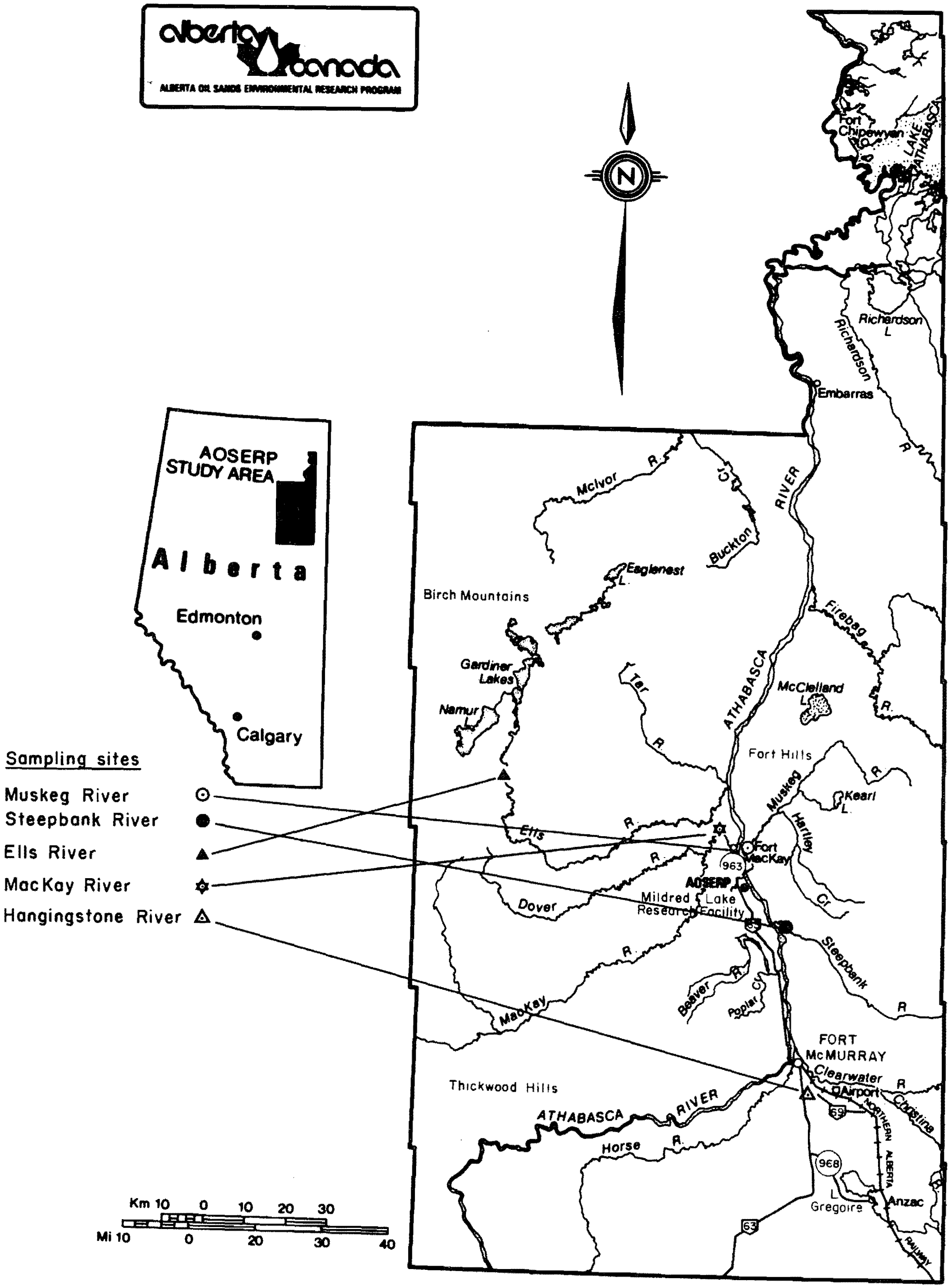

Figure 1. Map of the AOSERP study area.

2. SITE DESCRIPTION

The Muskeg River is a brown water river originating in the Muskeg Mountains. It meanders through the Clearwater Lowland to the Athabasca River, flowing in its upper reaches through clay, silty till, and muskeg, and through outwash sands and muskeg in its lower reaches. It drains an estimated area of 1455 km^2. The slope varies from 0.003 to 0.004 in the upper and lower reaches, respectively. Weekly sampling was conducted on this river, approximately 10 km upstream from the Athabasca River (Latitude 57°11'N, Longitude 111°34'W), where the predominant bed material is sand and limestone rocks.

Like the Muskeg River, the Steepbank River is also a brown water tributary draining about 1425 km^2 of surficial deposits of outwash sands and gravels derived from glacial drift and muskeg. The lower reaches flow through the Clearwater Lowland, while about 15 km from the Athabasca River it flows through exposed bitumen deposits of either McMurray or Athabasca oil sands (Cretaceous sandstones). Consequently, the river substrata vary from boulders, small stones, and gravels to oil sands. Samples were collected monthly from a site 1 km upstream from the Athabasca River, almost immediately downstream from the 1977 "fish fence" (Latitude 57°02'N, Longitude 111°25'W).

The Hangingstone River originates in the Stony Mountains south of Fort McMurray and meanders north across the Algar Plain, Methy Portage Plain and, finally, the Clearwater Lowland to the Athabasca River at Fort McMurray. It drains clay and silty till as well as muskeg and has a mean slope of 0.003 draining an area of 914^2km . Samples were collected fortnightly immediately west of Waterways, 1.5 km from the Athabasca River, and upstream of the effluent discharges associated with urban development in the vicinity of Fort McMurray (Latitude 56°40'N, Longitude 111°20'W). The river bed material ranged from sand and gravels to stones and boulders.

The MacKay River originates in the Birch Mountains and flows in an easterly direction before crossing the Algar Plain and the Clearwater Lowland. It drains hummocky moraine, drift sands, gravels, and silts, and muskeg, silty till, and lacustrine deposits in the upper and lower reaches, respectively. The catchment area is 5232 km^2, with an average slope of 0.002. Weekly samples were collected from the same site as investigated by AOSERP Project WS 1.3.1. at the fish fence (Latitude 57°12'N, Longitude 111°40'W) located 11 km from the Athabasca River. The bed material comprised gravel, oil sands, stones, and boulders.

The Ells River flows south from the Birch Mountains, then east across the Algar Plain and Clearwater Lowland, draining an area of 2700 km^2. Maximum watershed relief is 608 m (Psutka in prep.). It drains hummocky moraine, till, sands, gravels, and muskeg, and clay, silty till (alluvial lacustrine materials), and muskeg in the upper and lower reaches, respectively. The average slope is 0.002. Samples were collected fortnightly from a site in the upper reaches (Latitude 57°22'N, longitude 112°31'W) where bed materials ranged from gravel and small stones to boulders. Numerous lakes in the headwater area of the river had an attenuating action upon the discharge of this river resulting in no excessive flooding occurring (see Section 4.1.1).

3. MATERIALS AND METHODS

3.1 EPILITHIC ALGAL SAMPLING

Artificial substrata have frequently been used in investigations of attached algal communities to obtain both qualitative (i.e., floristic) and quantitative (i.e., standing crop and primary productivity) data (Hynes 1970; Sládecková 1962; Hohn and Hellerman 1963; Hufford and Collins 1976). Both cell numbers and chlorophyll *a* content have been used as standing crop measures. However, artificial substrata tend to be selective and, as a result, are generally considered inadequate for studies of natural attached algal communities because often this natural community is not accurately represented upon artificial substrata both floristically and quantitatively (Wetzel and Westlake 1969; Tippett 1970; Brown 1976). Therefore, in this study only the natural rock substrata dominating the river beds were investigated.

3.2 DETERMINATION OF ALGAL NUMBERS AND SPECIES COMPOSITION

Four 4 cm^2 areas of rock were delineated by a template and the area within scraped with a sharp scalpel and brushed to remove the epilithic algae. These scrapings were placed in sterile 20 mL vials together with 10 mL filtered river water and a few drops of Lugol's iodine solution as preservative before returning them to the AOSERP Mildred Lake Research Facility for analysis. Wherever possible, unpreserved samples were also examined immediately following collection to aid accurate identification of the algae.

Species composition and algal numbers were determined using the inverted microscope (Wild M-40) and sedimentation technique (Lund et al. 1958). Continuous transects were examined under 40X and 100X magnification and the algae identified and counted. A minimum of 200, but more frequently 800 to 2000, algae were counted. To enable diatoms to be identified, subsamples were treated with a mixture of concentrated nitric acid, potassium dichromate, and hydrogen peroxide to remove organic matter, followed by repeated washings in distilled water to remove all traces of acid before drying the cleared diatom frustules on coverglasses and mounting in Hyrax. Algae were identified according to Bourrelly (1966, 1968, 1970), Prescott (1961), Patrick and Reimer (1966, 1975), Cleve-Euler (1951-1955), Hustedt (1930) and Hindák et al. (1975).

3.3 DETERMINATION OF CHLOROPHYLL a CONTENT

Standing crop size, as measured by chlorophyll *a* content was determined in two ways. First, four 4 cm^2 scrapes of rocks were made and, second, entire rock surfaces were brushed and scraped clean of the epilithic algae. This latter method was employed in connection with the primary productivity measurements and the results for chlorophyll *a* appearing in this report are derived using this latter method.

At the termination of the primary productivity incubation period, the individual rocks were removed from the incubation chambers and immediately brushed and scraped clean of the epilithic algae. A known volume (depending upon population size) of this material was filtered onto a Whatman GF/A glass fibre filter, covered with anhydrous $MgCO_3$, wrapped in aluminum foil, and then stored in a freezer until analyzed.

Pigments were extracted in 90% acetone at 4°C for 24 h in the dark after homogenization using a Polytron-PCU-2-110 homogenizer to ensure complete extraction. The spectrophotometric method and equations of Moss (1967a, 1967b), where correction is made for naturally occurring pheophytin *a*, were used. Normality of the hydrochloric acid did not exceed that indicated by Riemann (1978).

Numerous workers have suggested that algae suspended within the water column contribute significantly to river productivity (Patrick 1961; Cairns et al. 1970; Swale 1964;

Whitford and Schumacher 1963). Therefore, 1 L water samples were collected from mid-stream, 10 cm below the surface, and filtered for pigment content determination. Further samples were collected for identification and enumeration of the algae.

3.4 PRIMARY PRODUCTIVITY

Primary productivity was measured utilizing the carbon-14 technique. Individual rocks, together with their attached epilithic algae, were carefully transferred to glass incubation jars. These were filled with river water (previously filtered through Whatman GF/A glass fibre filter paper to remove organisms and detritus) and inoculated with 10 μCi $NaH^{14}CO_3$ at 1000 h. Each jar was incubated in situ. Samples were taken from near the edge and mid-stream. Between 10 and 20 replicates were used. Both light and darkened chambers were used and the incubation period lasted until 1400 h. The jars were always filled to the top (Ilmavirta and Jones 1977). At the end of the incubation period, the algae were removed from the rocks as described earlier. Subsamples were taken for chlorophyll *a* analysis before the remainder was preserved with formalin. Each rock was labelled and retained for area determination which was done planimetrically.

Hydrochloric acid was used to acidify 20 mL subsamples to pH 2.0; subsamples used then aerated for 30 min to remove unincorporated inorganic carbon-14 (Schindler et al. 1972). Afterwards, 2 mL subsamples were placed in Aquasol fluor and the incorporated activity determined using a Nuclear Chicago Scintillation Computer, Model 6800. Corrections for quenching were also made.

In addition to using these non-circulating chambers, preliminary investigation of current effects upon epilithic algal primary productivity was initiated on all rivers because non-circulating chambers can underestimate primary productivity (Rodgers and Harvey 1976; McConnell and Sigler 1959; Hickman 1974).

The incubation jar was modified such that a shaft with propellers attached at both ends was fitted through the lid. The water current turned the outer propeller which in turn rotated the inner one. This then simulated river flow probably more accurately than an electrically driven propeller (Marker 1976b). The chamber is simple and lightweight. This is essential for field studies of this nature where transport to sites is via a helicopter.

3.5 WATER CHEMISTRY

Four 1 L samples of water were collected and immediately filtered through Whatman GF/A glass fibre filters to remove detritus and organisms (cf. Happey 1970). Of the samples collected, 2 L were frozen for subsequent metal analysis while the remaining 2 L were used for duplicate determination of pH, alkalinity, nitrate-nitrogen, and phosphate-phosphorus.

Sodium and potassium concentrations were determined using an IL. Flame Photometer, Model 148, while those of magnesium, iron, calcium, and manganese were determined by atomic absorption spectrophotometry.

Dissolved silica, chloride, phosphate-phosphorus, nitrate-nitrogen, and alkalinity were determined using methods outlined by Mackereth (1963) while sulphate was determined according to American Public Health Association (1976). Phosphate-phosphorus extractions using n-hexanol and ammonium molybdate were performed, as soon as feasible after collection, in the Mildred Lake Research Facility. Similarly, the 100 mL samples utilized for nitrate-nitrogen determinations were evaporated to dryness in flat-bottomed conical flasks in the same laboratory. Subsequent analysis took place at the University of Alberta. All results were expressed as $mg \cdot L^{-1}$.

Conductivity was measured with a YSI conductivity/ temperature meter (Yellow Springs Instrument Co.) YSI Model 33, S-C-I meter and PH with a Radiometer pH meter.

3.6 PHYSICAL FACTORS

Daily records of total irradiance were kept at the Mildred Lake Research Facility using a phranometer. Hourly summations were utilized in connection with the primary productivity studies. Additional measurement of available light upon the river bed were taken on each sampling trip using a quantum sensor, measuring quanta in Ph.A.R. (Photosynthetically Available Radiation, 400 to 700 nm) (LI-185, Lambda Instrument Co.).

Water depth and temperature were also measured. The latter was determined with a mercury thermometer accurate to within ± 0.5°C. Discharge data were supplied by Water Survey of Canada, Calgary, Alberta.

4. RESULTS

The results of the physico-chemical analyses are presented in Figures 2 through 24. A summary showing the ranges and mean values is presented in Table 1.

4.1 PHYSICAL FACTORS

4.1.1 Water Temperature and Discharge

Temperature and discharge rates were similar in each river (Figures 2 through 6). Maximum temperatures occurred during July and thereafter declined. Discharge rates were high during the spring and early summer, lowest during mid-summer, after which they rose rapidly and were greatest during the late summer and autumn when flooding and increased water levels occurred. Although this pattern was evident in the Ells River, the late summer-autumn discharge rates were lower than in the other four rivers, presumably due to the headwater lakes (Figure 6).

4.1.2 Irradiance

The seasonal pattern is shown in Figure 7. Variation from river to river occurs because the total irradiance on the day of sampling has been graphed. Maximum values occurred between mid-June and mid-August, after which they decreased.

4.2 WATER CHEMISTRY

4.2.1 Conductance

Conductance fluctuated least in the Ells River (Figure 8). Values were also lowest in this river whereas those found in the Muskeg, Hangingstone, and MacKay rivers were greater and followed a similar pattern. Values in the Steepbank River were intermediate. All rivers, except the Ells River, fluctuated similarly. Conductivity was high during the summer, low during maximal discharge rates of the autumn but increased slightly during November.

Table 1. Mean and range for various physical and chemical factors for the five rivers.

	Units	RIVER				
		Muskeg	Steepbank	Hangingstone	MacKay	Ells
Temperature	°C	0.5 - 19.0 x = 12.7	0.2 - 20.1 x = 10.9	0.2 - 19.0 x = 10.2	0.2 - 22.0 x = 10.2	0.0 - 19.3 x = 10.7
Discharge	c.f.s.	23.3 -1120.0 x = 353.0	41.4 -1180.0 x = 421.7	16.8 -892.0 x =187.6	13.9 -4180.0 x =1115.5	83.6 -552.0 x =292.8
Conductivity	µmhos·cm^{-2}	138.0 - 306.0 x = 227.5	118.0 - 240.0 x = 172.6	149.0 -302.0 x =225.6	158.0 - 342.0 x = 247.0	102.0 -120.0 x =109.9
Calcium	mg·L^{-1}	11.0 - 28.5 x = 18.6	8.0 - 21.0 x = 13.8	4.5 - 21.5 x = 14.3	10.0 - 24.0 x = 15.6	7.8 - 14.0 x = 10.3
Sodium	mg·L^{-1}	3.6 - 17.8 x = 9.7	4.3 - 14.8 x = 8.7	10.3 - 19.8 x = 14.1	8.5 - 26.2 x = 16.5	1.7 - 2.4 x = 2.0
Potassium	mg·L^{-1}	0.4 - 2.9 x = 0.9	0.1 - 1.2 x = 0.6	0.5 - 1.8 x = 1.2	0.5 - 1.2 x = 1.2	0.5 - 1.2 x = 0.7
Magnesium	mg·L^{-1}	2.9 - 8.9 x = 5.6	2.6 - 8.7 x = 4.9	1.8 - 10.6 x = 5.4	4.0 - 9.3 x = 5.6	2.5 - 4.3 x = 3.3
Iron	mg·L^{-1}	0.03 - 0.73 x = 0.16	0.05 - 0.21 x = 0.11	0.0 - 0.48 x = 0.16	0.04 - 0.32 x = 0.13	0.04 - 0.09 x = 0.06
Manganese	mg·L^{-1}	0.004- 0.041 x = 0.012	0.005- 0.019 x = 0.01	0.005- 0.075 x = 0.018	0.003- 0.024 x = 0.008	0.007- 0.011 x = 0.009
Sulphate	mg·L^{-1}	0.0 - 36.0 x = 11.1	35.0 - 104.0 x = 50.0	110.0 -270.0 x =161.3	161.0 - 316.0 x = 218.0	44.0 - 70.0 x = 52.4
Chloride	mg·L^{-1}	0.5 - 35.6 x = 5.8	0.5 - 2.0 x = 0.79	5.5 - 15.5 x = 9.5	0.5 - 17.5 x = 4.8	0.50 - x = 0.50
Nitrate-nitrogen	mg·L^{-1}	0.114- 0.298 x = 0.216	0.178- 0.345 x = 0.284	0.166- 0.425 x = 0.277	0.238- 0.515 x = 0.359	0.081- 0.155 x = 0.126
Phosphate-phosphorus	mg·L^{-1}	0.008- 0.352 x = 0.037	0.018- 0.026 x = 0.022	0.018- 0.547 x = 0.091	0.008- 0.150 x = 0.041	0.020- 0.151 x = 0.046
Dissolved silica	mg·L^{-1}	0.80 - 9.5 x = 5.3	1.2 - 7.2 x = 3.9	2.95 - 7.2 x = 5.2	0.45 - 8.0 x = 2.3	0.32 - 1.50 x = 0.885
pH		6.2 - 8.4 x = 7.7	6.5 - 8.3 x = 7.4	6.7 - 8.5 x = 7.9	6.9 - 8.7 x = 7.95	6.5 - 8.9 x = 7.9
Alkalinity	meq HCO_3^-·L^{-1}	1.2 - 3.25 x = 2.18	0.98 - 3.65 x = 1.88	1.0 - 2.9 x = 2.0	1.21 - 3.05 x = 2.0	0.80 - 1.50 x = 0.99

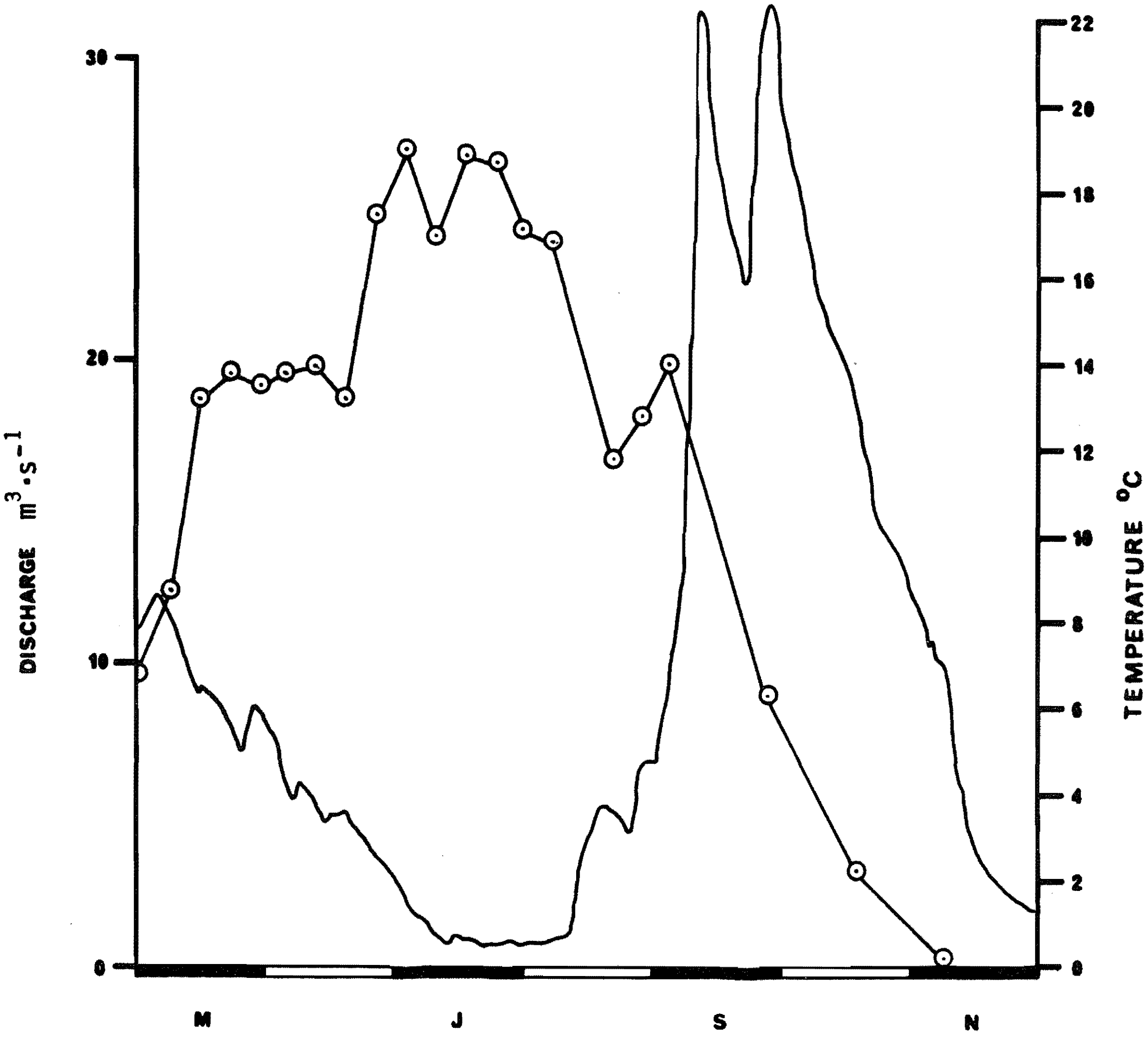

Figure 2. Water temperature (⊙) and discharge (———) for the Muskeg River.

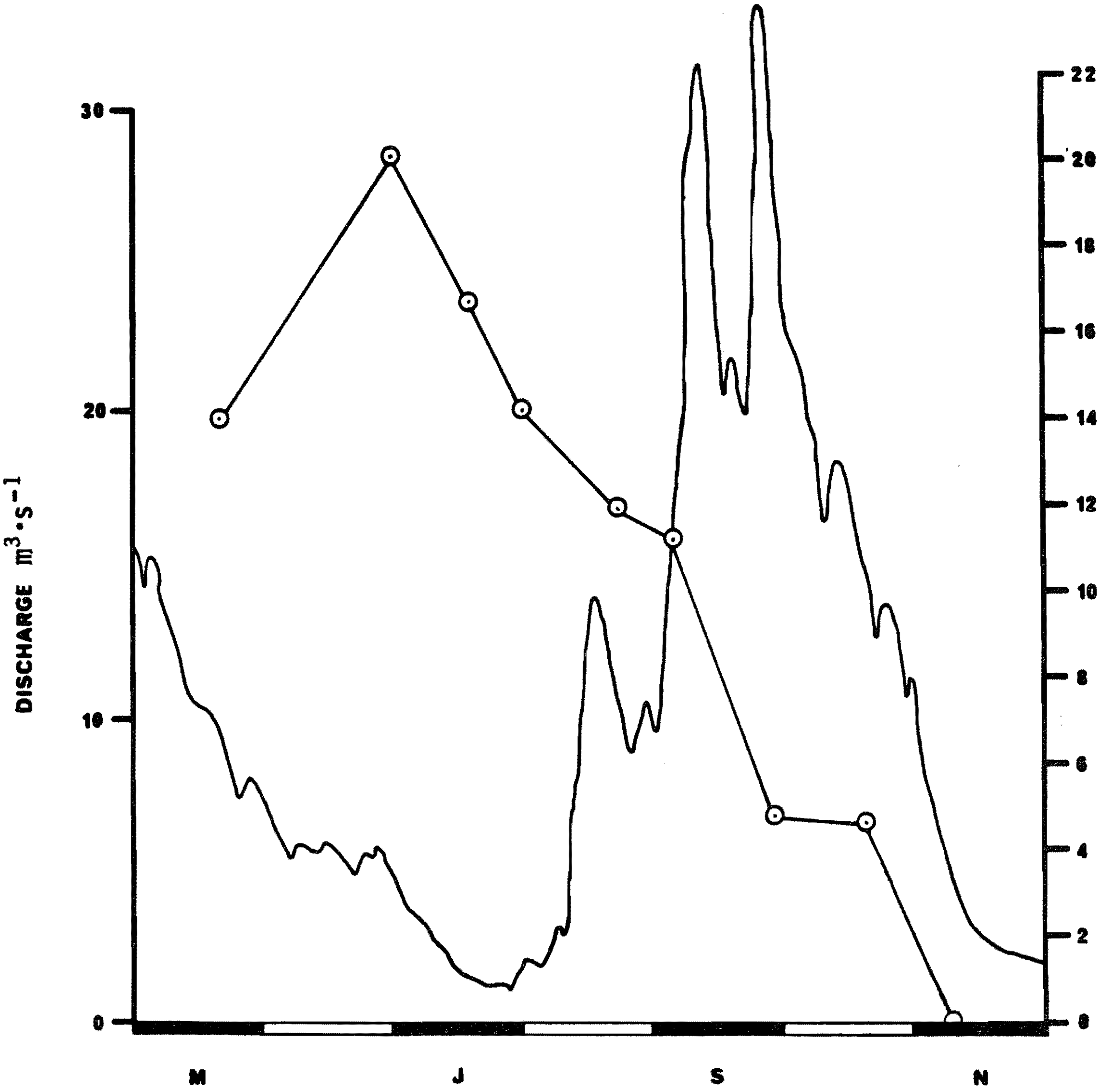

Figure 3. Water temperature (⊙) and discharge (———) for the Steepbank River.

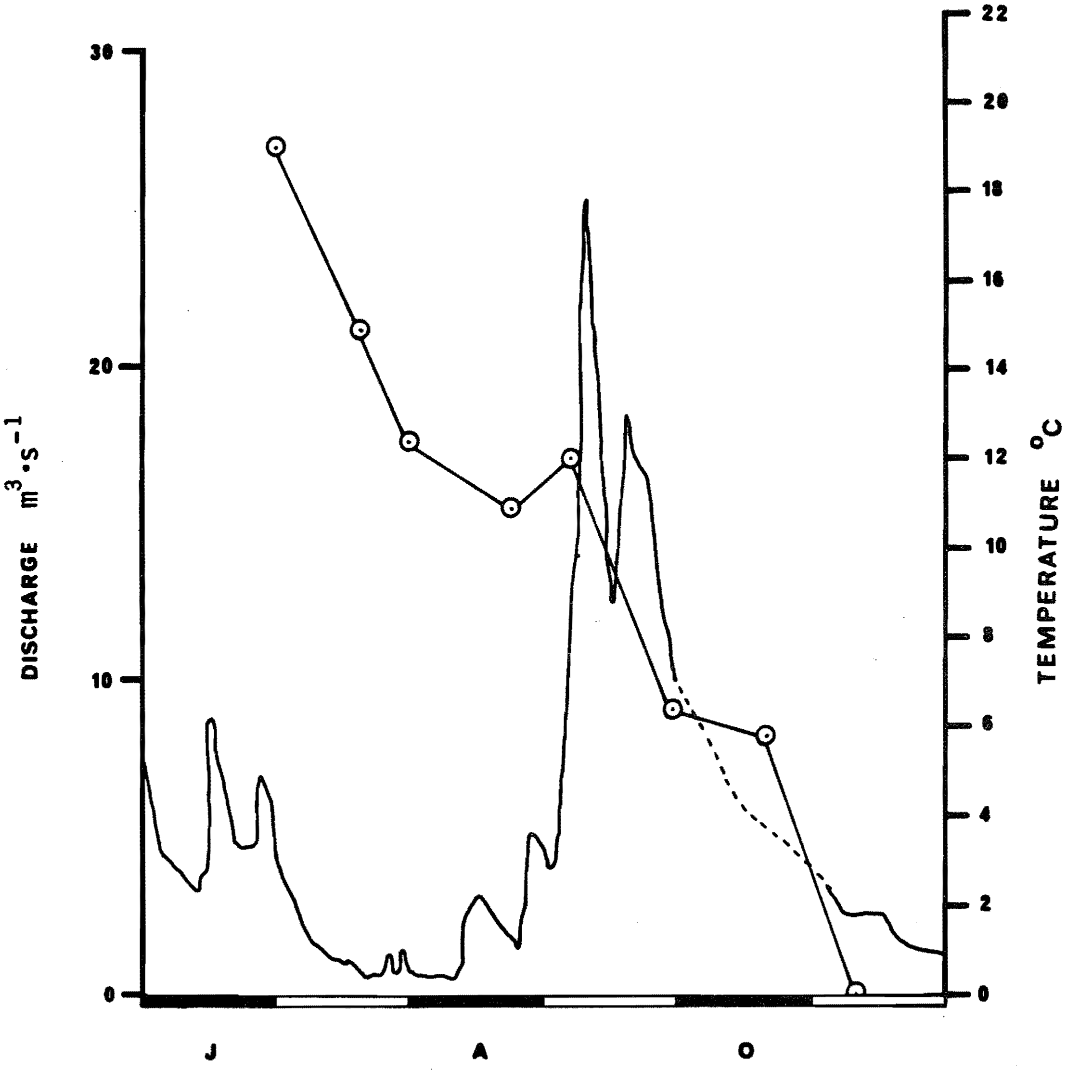

Figure 4. Water temperature (⊙) and discharge (———) for the Hangingstone River.

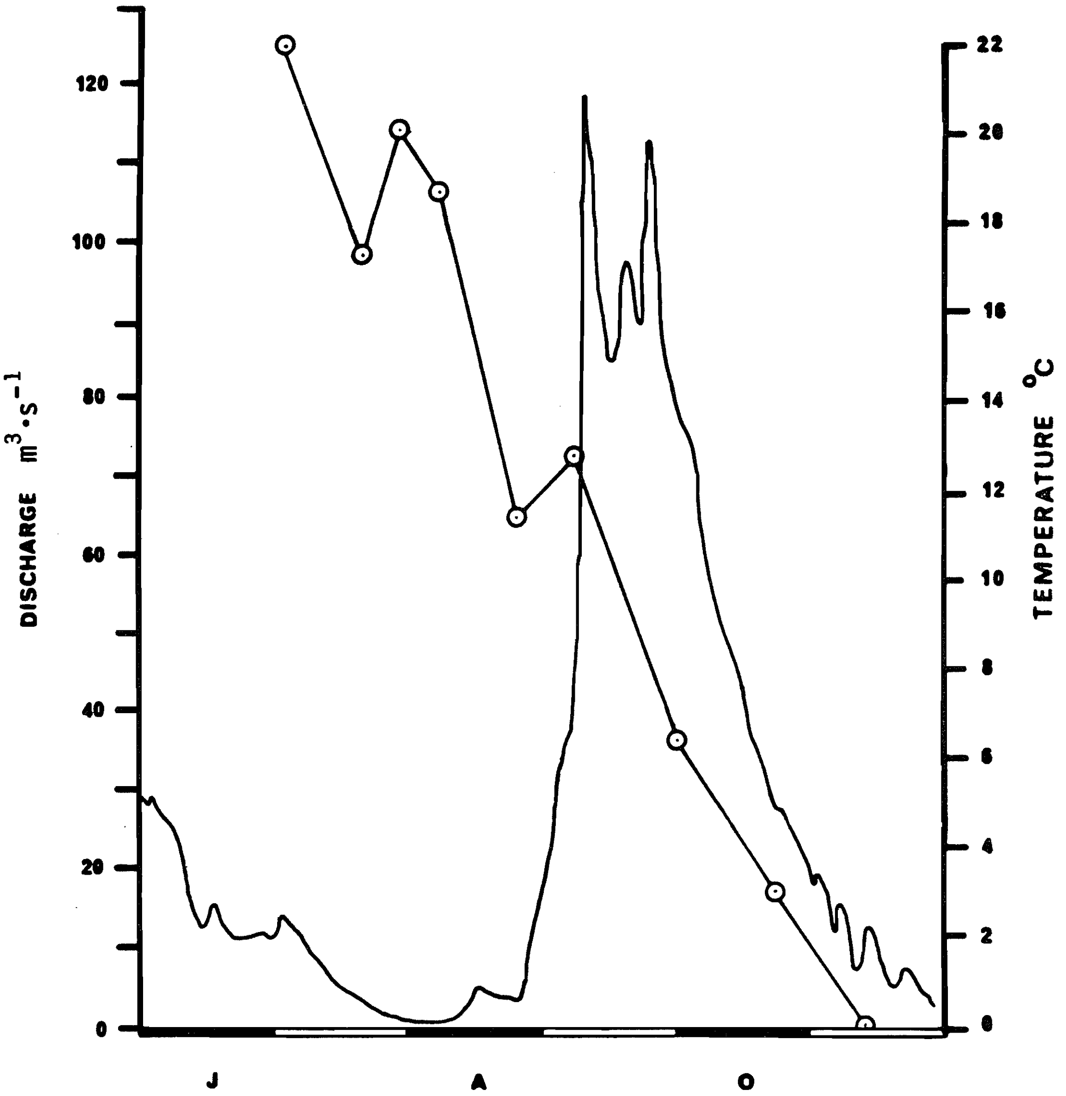

Figure 5. Water temperature (⊙) and discharge (———) for the MacKay River.

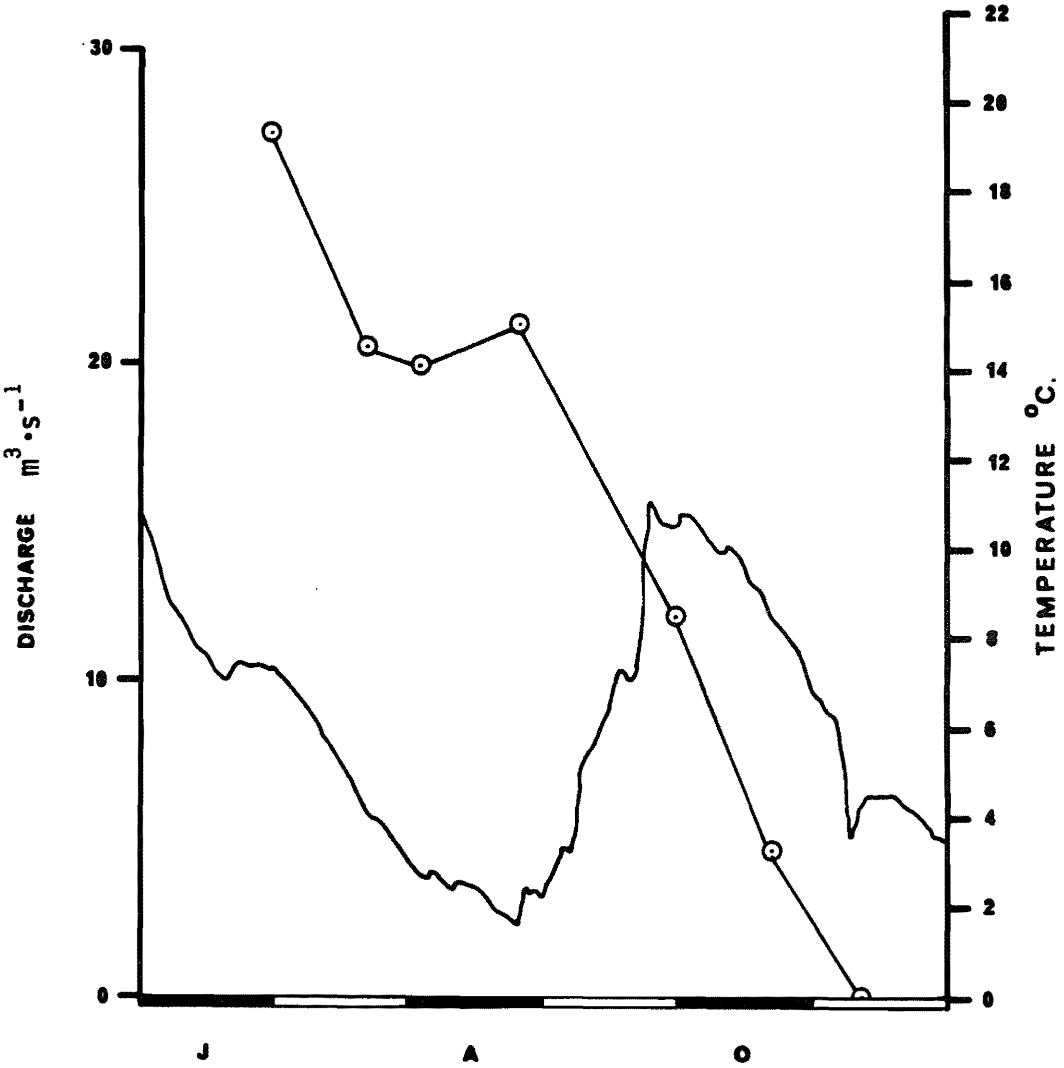

Figure 6. Water temperature (⊙) and discharge (———) for the Ells River.

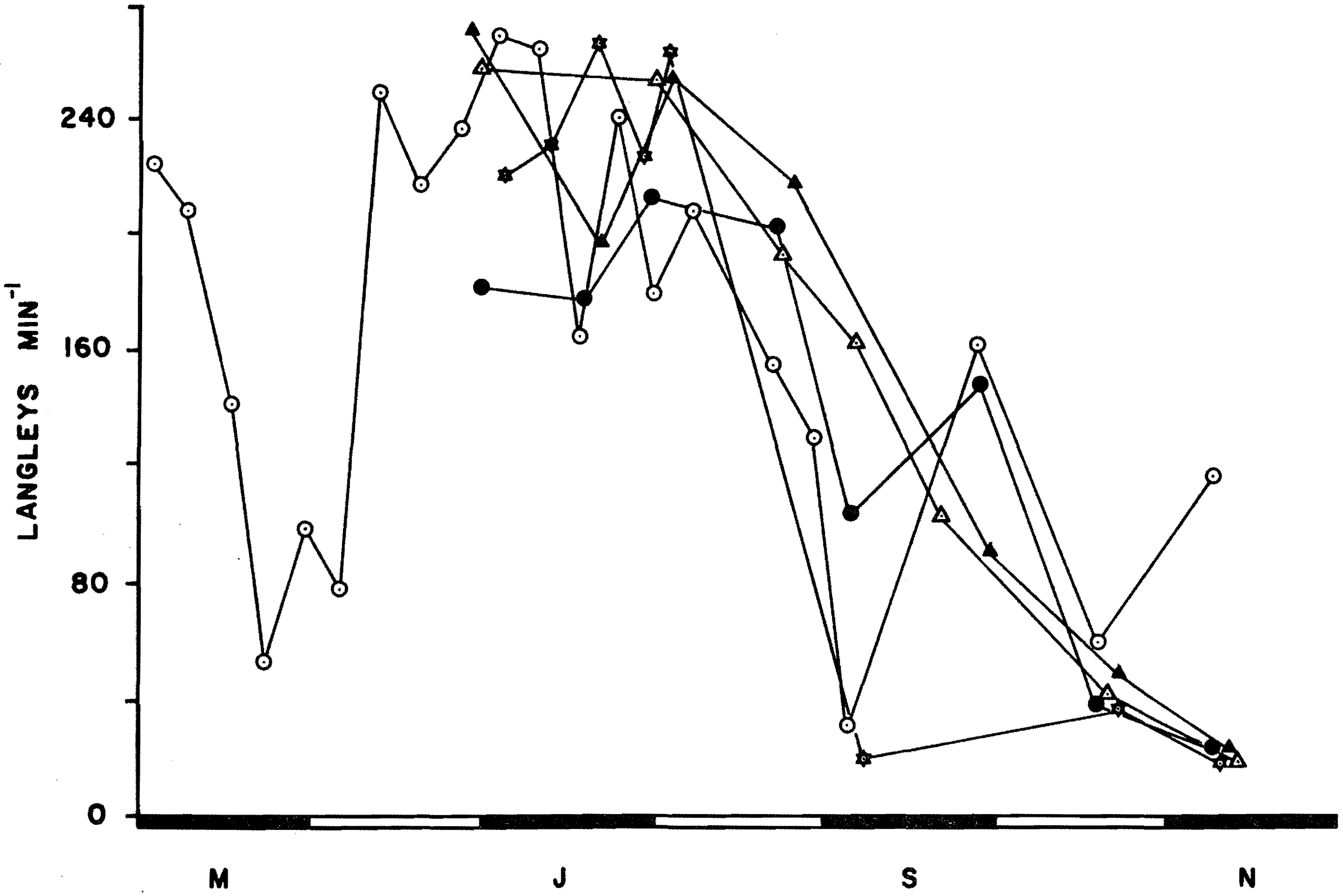

Figure 7. Daily irradiance (Langleys Min^{-1}) on the sampling dates at the Muskeg (⊙), Steepbank (●), Hangingstone (△), MacKay (✡), and Ells (▲) rivers.

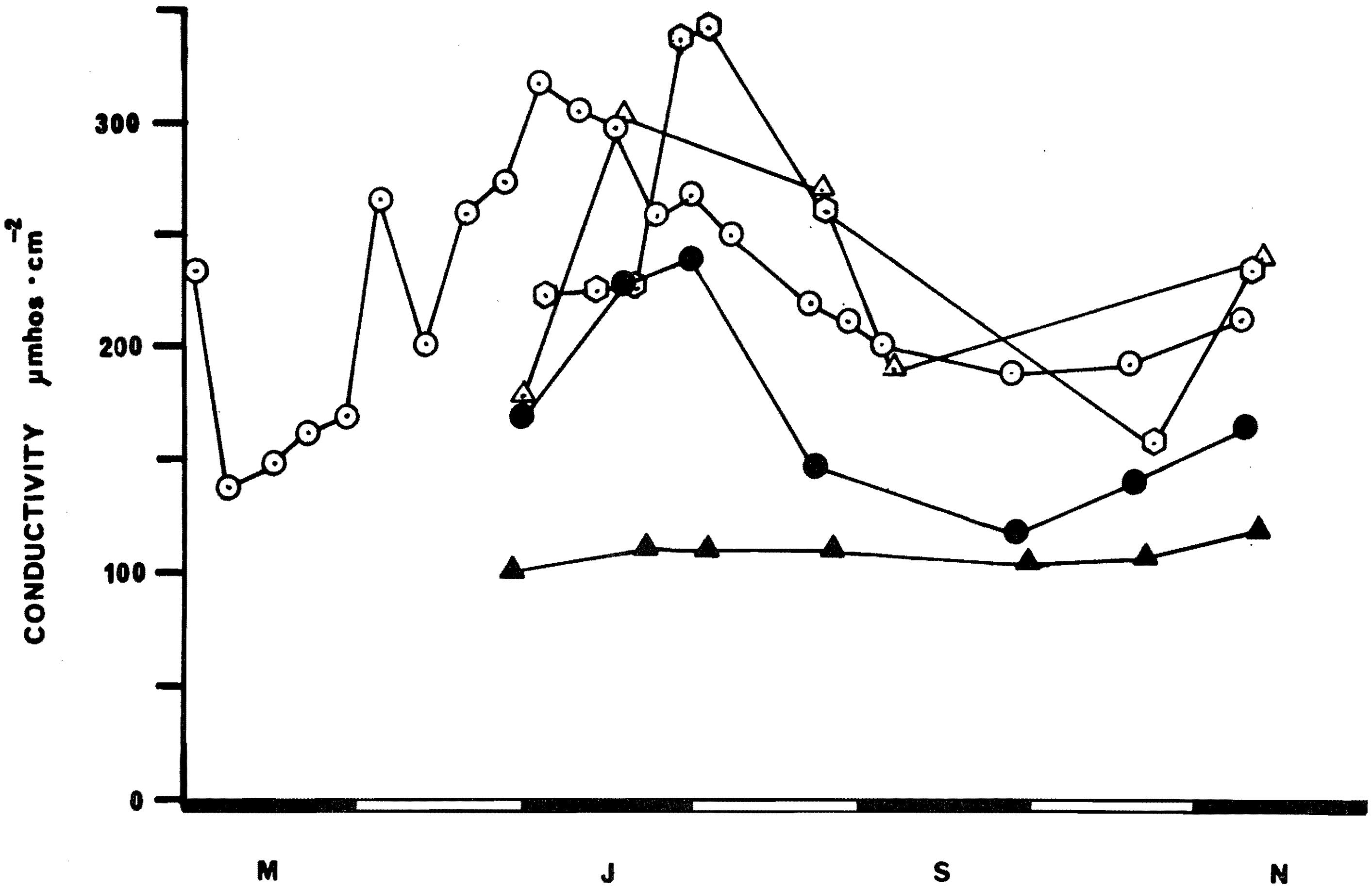

Figure 8. Conductance (µmhos·cm^{-2}) in the Muskeg (⊙), Steepbank (●), Hangingstone (◬), MacKay (⬡), and Ells (▲) rivers.

4.2.2 Calcium

Calcium concentrations were generally highest in the Muskeg River (Figure 9). Values were highest during the summer months although fluctuations were irregular. Decreases occurred during the late summer-autumn before concentrations again increased. This pattern was evident in all the other rivers except the Ells where values fluctuated the least.

4.2.3 Sodium

In the Muskeg River, sodium concentrations increased from a low value in May to a maximum in early July (Figure 10). Afterwards they decreased, but a small peak occurred in August prior to an autumn decrease. Fluctuations in the Steepbank, Hangingstone, and MacKay rivers were almost identical, with peaks occurring during late July-early August, unlike those found in the Muskeg River. However, like the Muskeg River, decreases occurred during the autumn before increases occurred in November. Sodium concentrations in the Ells River showed almost no fluctuation and were the lowest of all the rivers.

4.2.4 Potassium

The Muskeg River was characterized by irregular fluctuations in potassium levels (Figure 11). A major peak occurred in mid-July, but minor ones were apparent in early May, June, and early July. Values decreased during the autumn floods and again in early November. A more definite pattern occurred in the Steepbank River where a late July maximum was followed by a decrease in late August and low values during the autumn and early winter (Figure 11). In contrast, values were low during July in the MacKay River and increased in August reaching a peak value in mid-September before decreasing rapidly. Fluctuations of potassium levels in the Hangingstone River were similar to those of the Steepbank River but decreases did not occur until early

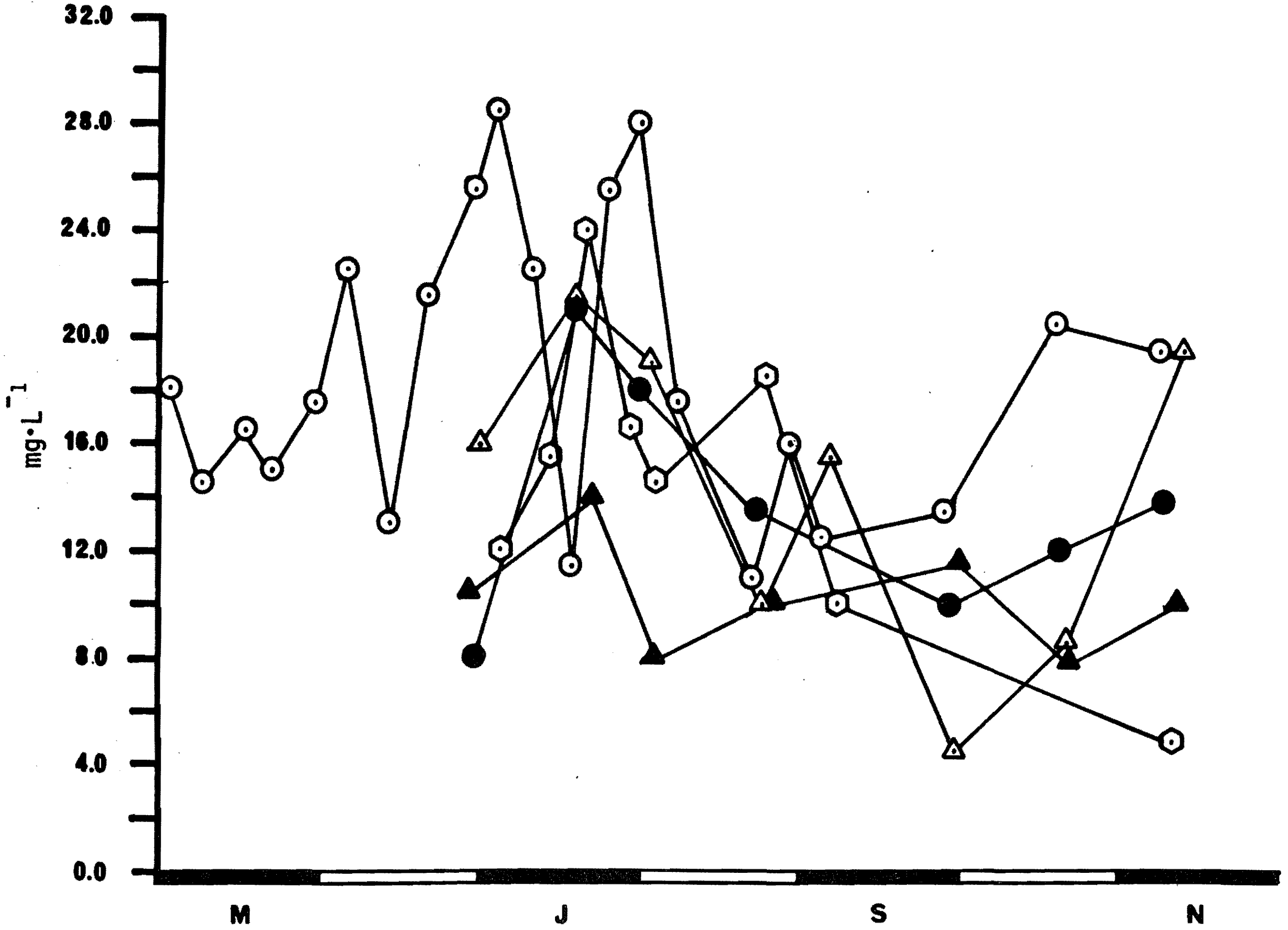

Figure 9. Calcium concentrations (mg·L^{-1}) in the Muskeg (⊙), Steepbank (●), MacKay (⬡), Hangingstone (△), and Ells (▲) rivers.

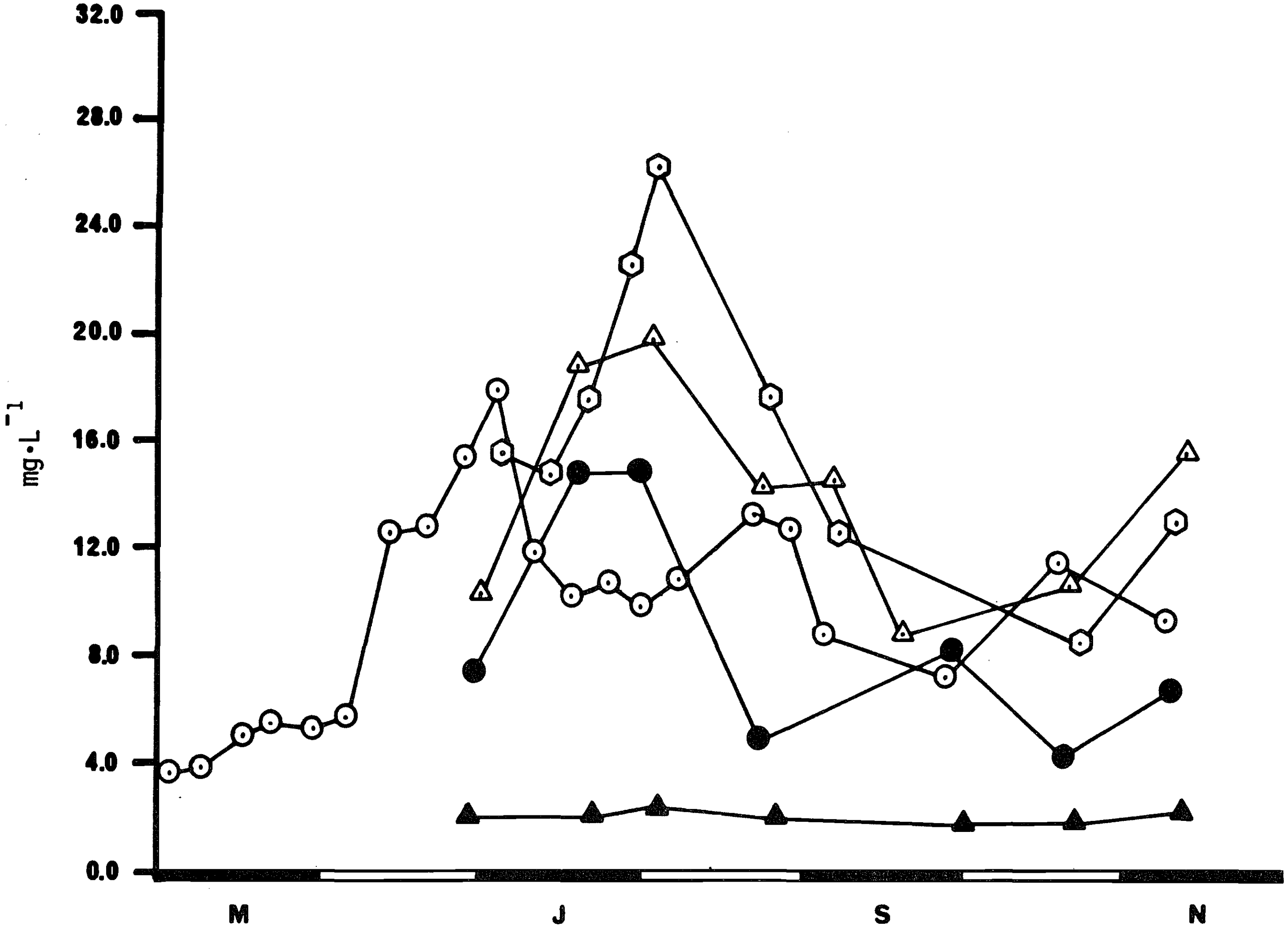

Figure 10. Sodium concentrations (mg·L^{-1}) in the Muskeg (⊙), Steepbank (●), MacKay (⬡), Hangingstone (△), and Ells (▲) rivers.

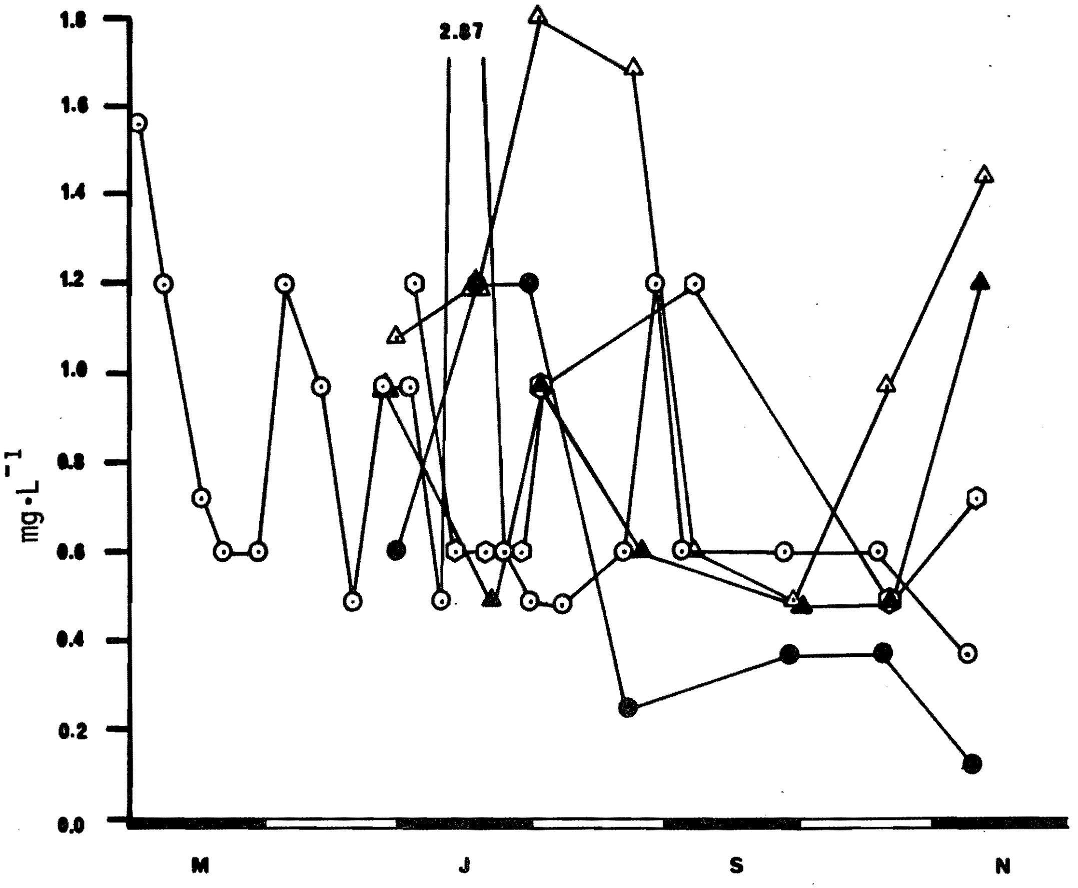

Figure 11. Potassium concentrations (mg·L^{-1}) in the Muskeg (⊙), Steepbank (●), MacKay (⬡), Hangingstone (△), and Ells (▲) rivers.

September, reaching a minimum at the end of this month after which they dramatically increased. Potassium levels in the Ells River fluctuated irregularly during the summer but the late summer-autumn decline and low values occurred as did the early November increase.

4.2.5 Magnesium

Magnesium levels fluctuated least in the Ells River (Figure 12). In the other four rivers, magnesium concentrations were high during the summer and low during the late summer-autumn floods before increasing in late autumn. Fluctuations in the Muskeg River were irregular during May and June.

4.2.6 Iron

In all five rivers, iron concentrations were lowest during late July-early August (Figure 13). Afterwards, levels increased through the autumn. Although the summer minimum was evident in the Ells River, iron levels fluctuated least in this river. In the Muskeg River, during May to early July, three peaks occurred (early May, early June, and early July).

4.2.7 Manganese

Manganese levels fluctuated most irregularly in the Muskeg River with peaks occurring in early May, June, July, and early November (Figure 14). Values were low during the autumn floods. The only other river in which manganese levels decreased during this period was the Hangingstone River. Values in the Steepbank River increased from late June onwards (Figure 14) while those in the Ells River fluctuated very little. In the MacKay River, manganese levels were fairly constant until early September, when a gradual then rapid increase occurred.

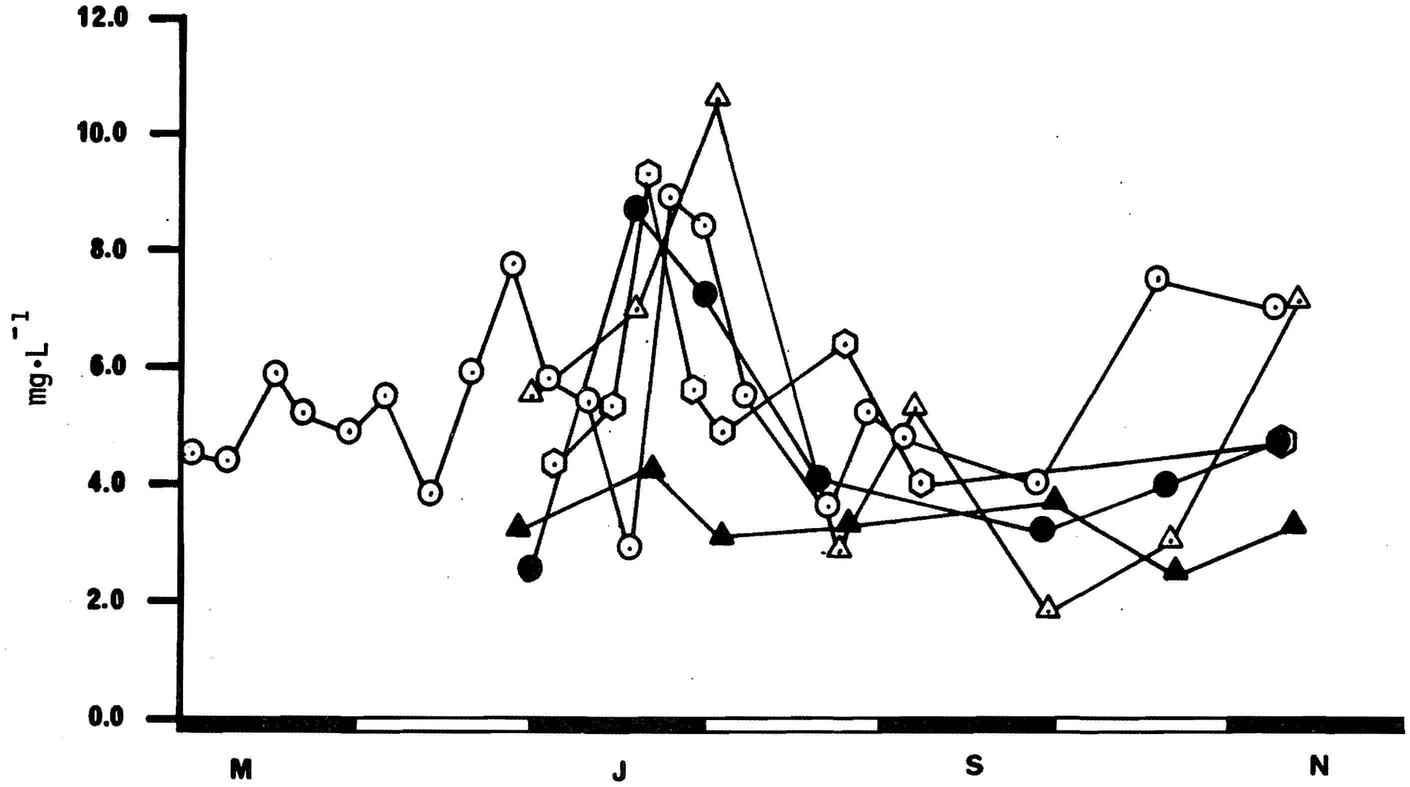

Figure 12. Magnesium concentrations (mg·L^{-1}) in the Muskeg (⊙), Steepbank (●), MacKay (⬡), Hangingstone (△), and Ells (▲) rivers.

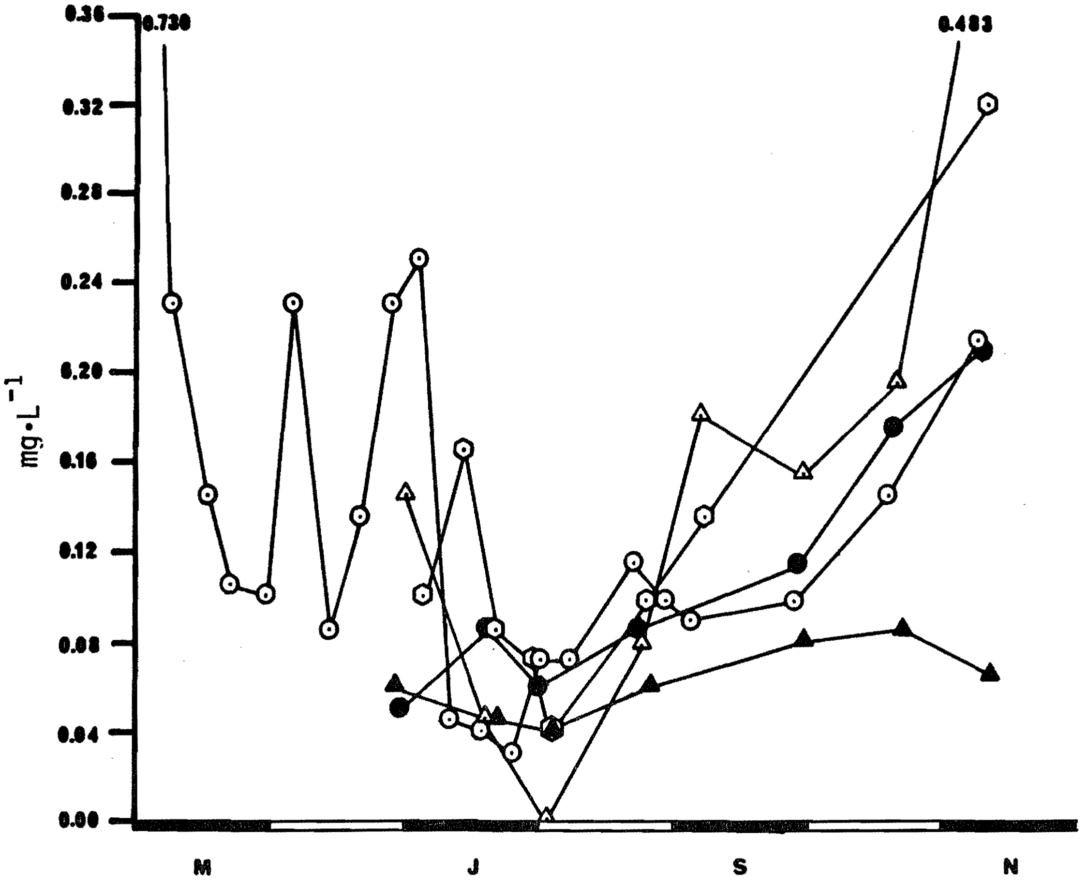

Figure 13. Iron concentrations (mg·L^{-1}) in the Muskeg (⊙), Steepbank (●), MacKay (⬡), Hangingstone (△), and Ells (▲) rivers.

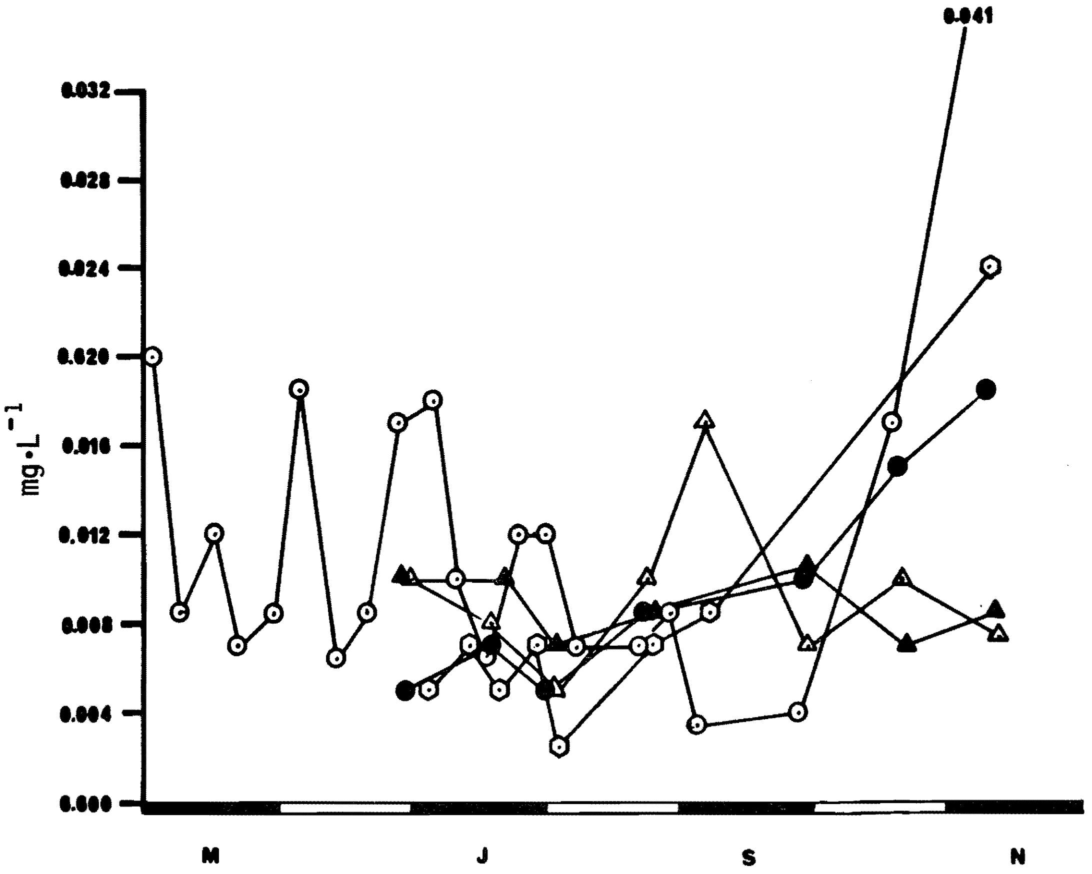

Figure 14. Manganese concentrations (mg·L^{-1}) in the Muskeg (⊙), Steepbank (●) MacKay (⬡), Hangingstone (△), and Ells (▲) rivers.

4.2.8 Sulphate

Lowest sulphate concentrations occurred in the Muskeg River where small irregular fluctuations occurred from May to early June (Figure 15). Afterwards, values remained almost constant until early November. Concentrations fluctuated little in the Ells and Steepbank rivers, but values were consistently greater than those found in the Muskeg River. The seasonal patterns in the MacKay and Hangingstone rivers were more distinctive (Figure 15). Maxima occurred in early August in both rivers. These were followed by low values during the autumn before slight increases occurred in early November. Concentrations in these two rivers were higher than the other three with those of the MacKay River being the highest.

4.2.9 Chloride

Chloride concentrations fluctuated widely in the Muskeg River (Figure 16). Two major peaks occurred in early June and July. After late August, values were extremely low and did not increase again until late autumn. Concentrations were extremely low in the Steepbank River, being undetectable on most occasions. However, a small peak occurred in mid-July. They were undetectable on all occasions in the Ells River. In both the MacKay and Hangingstone rivers, summer maxima occurred in early August and July, respectively, which were followed by decreases. However, that in the MacKay River was most dramatic. The late autumn increase in chloride levels was most dramatic in the Hangingstone River.

4.2.10 Nitrate-Nitrogen

In all rivers, nitrate-nitrogen concentrations generally increased from July to November (Figure 17). Little fluctuation occurred in the Ells River which possessed lowest concentrations. Decreases occurred in the Hangingstone and MacKay rivers during

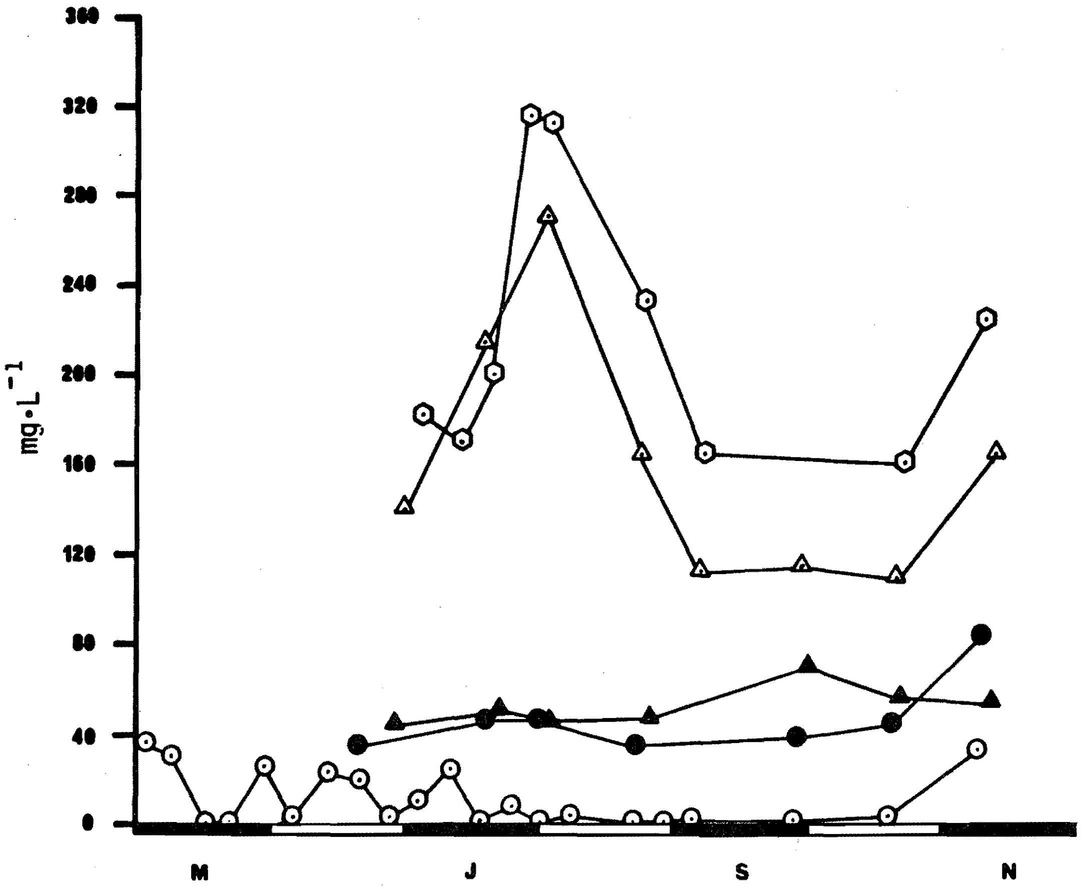

Figure 15. Sulphate concentrations (mg·L^{-1}) in the Muskeg (⊙), Steepbank (●), MacKay (⬡), Hangingstone (△), and Ells (▲) rivers.

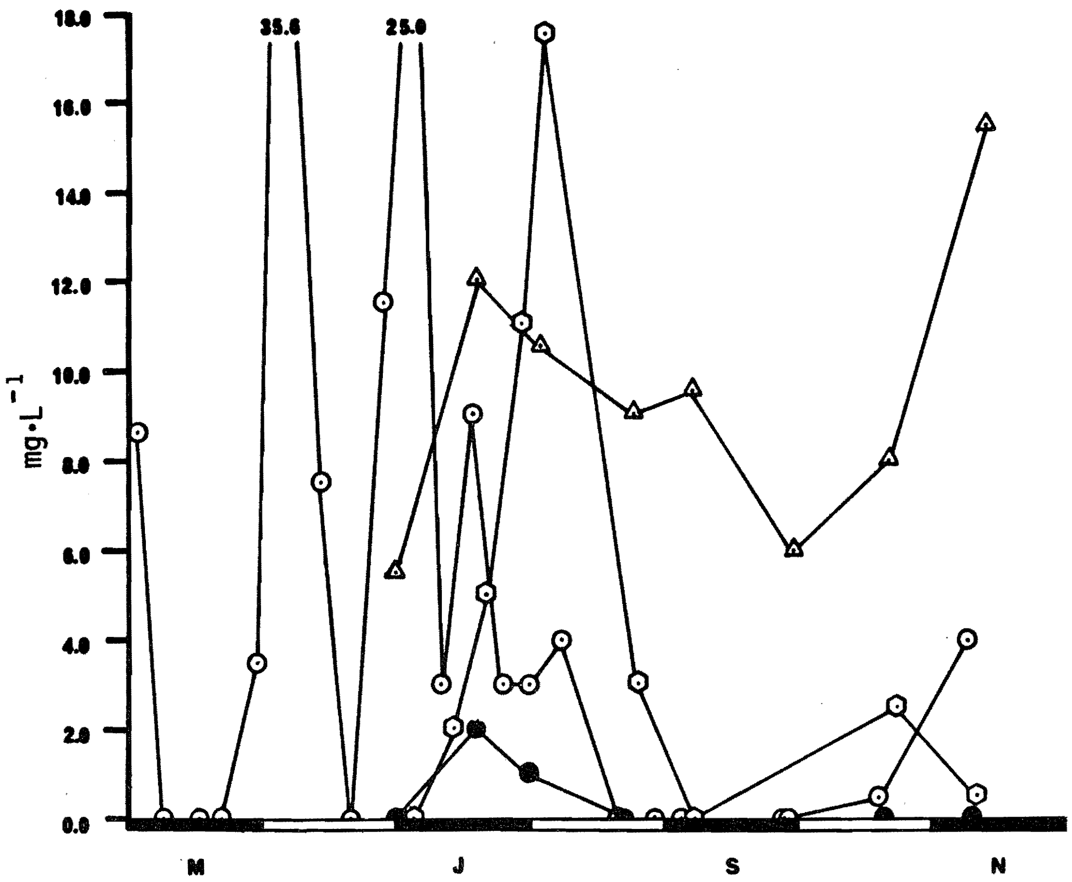

Figure 16. Chloride concentrations (mg·L^{-1}) in the Muskeg (⊙), Steepbank (●), MacKay (⬡), Hangingstone (△), and Ells (▲) rivers.

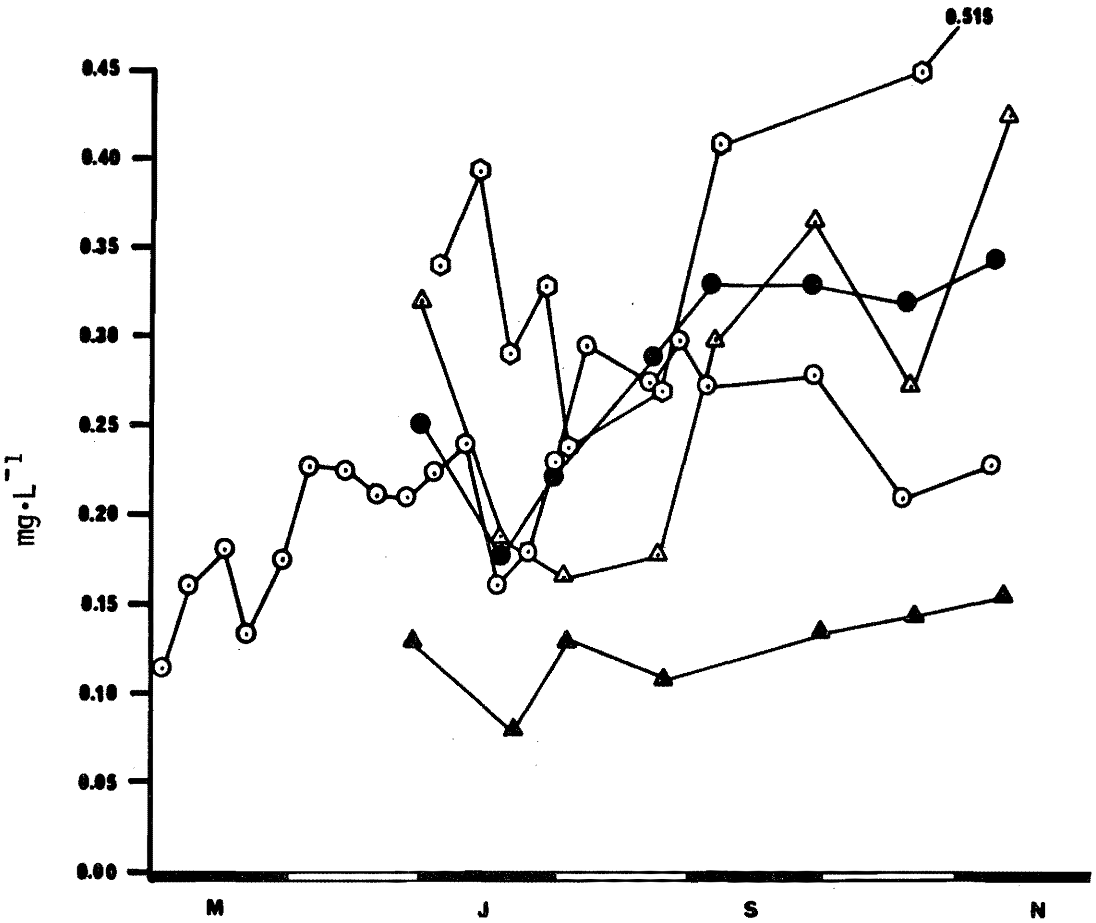

Figure 17. Nitrate-nitrogen concentrations (mg·L^{-1}) in the Muskeg (⊙), Steepbank (●), MacKay (⬡), Hangingstone (△), and Ells (▲) rivers.

the summer but nitrate-nitrogen levels increased quickly during the autumn floods. The summer decrease in the Steepbank River occurred earlier in mid-July and values increased afterwards and plateaued during the autumn period. Concentrations in the Muskeg River were highest from July to late September. Minima occurred in May and mid-July, between which, a small but prolonged peak occurred. After late September values generally decreased.

4.2.11 Phosphate-Phosphorus

Phosphate-phosphorus concentrations fluctuated least in the Steepbank River (Figure 18). Here they increased slowly until mid-September, declined, and then increased again. Fluctuations were more extreme in the other four rivers, with major peaks occurring in the MacKay River in mid-July, in the Hangingstone River in September, in the Ells River in August and September, and in the Muskeg River in September again. These autumn peaks corresponded to the period of maximum discharge rates. A smaller peak in the Muskeg River occurred in late June. The large autumn peaks in these four latter rivers quickly disappeared in late September and thereafter remained steady.

4.2.12 Dissolved Silica

In general, dissolved silica concentrations were greatest in the Muskeg and least in the Ells rivers (Figure 19). After a small peak in mid-May followed by an early June minimum, values increased to an August maximum in the Muskeg River. Fluctuations afterwards were irregular but concentrations remained high. Those of the Ells River fluctuated least, decreasing during the summer and reaching a minimum in early August. A small maximum occurred in late September. Fluctuations in the MacKay and Steepbank rivers were quite similar (Figure 19). Summer minima were followed by increases, with peaks occurring in early November. The cycle in the Hangingstone River was not too dissimilar but values remained

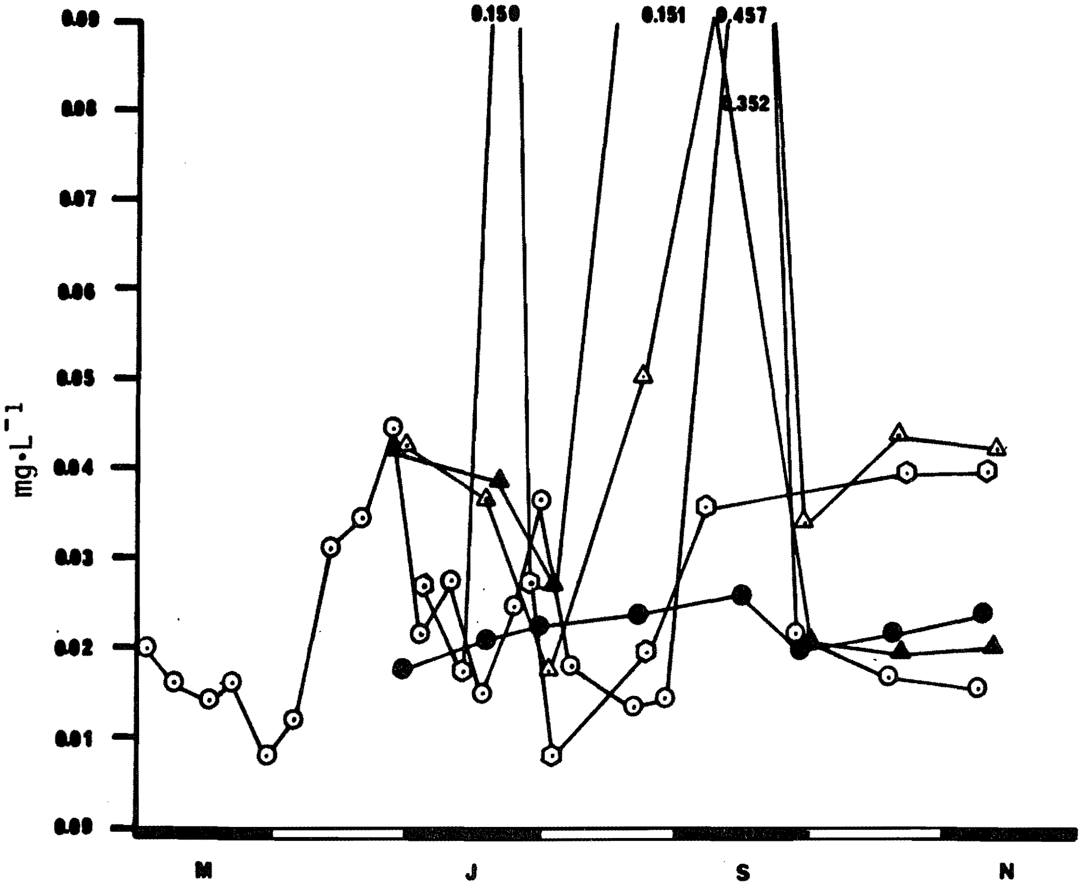

Figure 18. Phosphate-phosphorus concentrations (mg·L^{-1}) in the Muskeg (⊙), Steepbank (●), MacKay (⬡), Hangingstone (△), and Ells (▲) rivers.

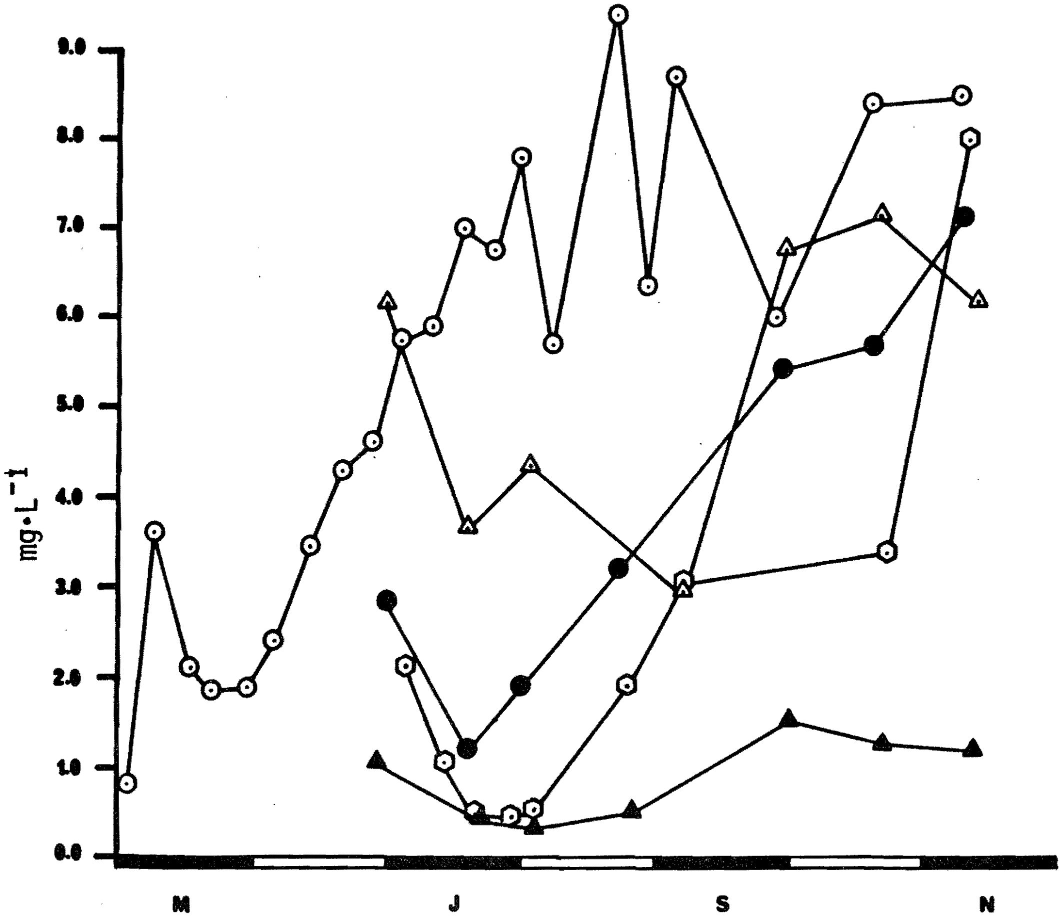

Figure 19. Dissolved silica concentrations (mg·L^{-1}) in the Muskeg (⊙), Steepbank (●), MacKay (⬡), Hangingstone (△), and Ells (▲) rivers.

much higher during the summer months and the minimum in this river did not occur until early September. It was immediately followed by a rapid increase, and like the Ells River but, unlike the MacKay and Hangingstone river, a decrease occurred in early November.

4.2.13 pH and Alkalinity

pH and alkalinity fluctuations are shown in Figures 20 through 24. In all rivers, pH varied from being acid (pH 6.20 to 6.90) to basic (8.25 to 8.65) (Table 1). Maximum values occurred during the summer period. Total alkalinity in all but the Ells River peaked in August followed by an autumn decrease. Increases occurred in early winter. In the Ells River, total alkalinity increased slowly to a late September peak, decreased afterwards, and then remained steady.

4.3 SPECIES COMPOSITION

Algae from four divisions dominated the epilithon in all five rivers. These were the Cyanophyta (blue-green algae), Chlorophyta (green algae), Bacillariophyta (diatoms), and Rhodophyta (red algae). A list of all the species encountered so far is presented in Table 2 together with an indication as to whether each species produced a dominant population.

In the Muskeg River, cyanophycean algae dominated with *Lyngbya aerugineo-caerulea* and *Phormidium* spp. being the most important species (Figures 25, 26, and 27). In late July, the blue-green algae accounted for 99.6% of the total epilithic algal community, but by late August this had decreased to 53%. Diatoms were most prevalent during October when they accounted for 22% of the total population. Here the most important species included *Synedra ulna, Nitzschia fonticola,* and *Synedra rumpens*. Chlorophycean algae were less important than these two groups accounting for only 3.5% during mid-summer when *Draparnaldia* sp. was present. During late autumn, a red alga, *Audouinella* sp., appeared accounting for about 1% of the total population.

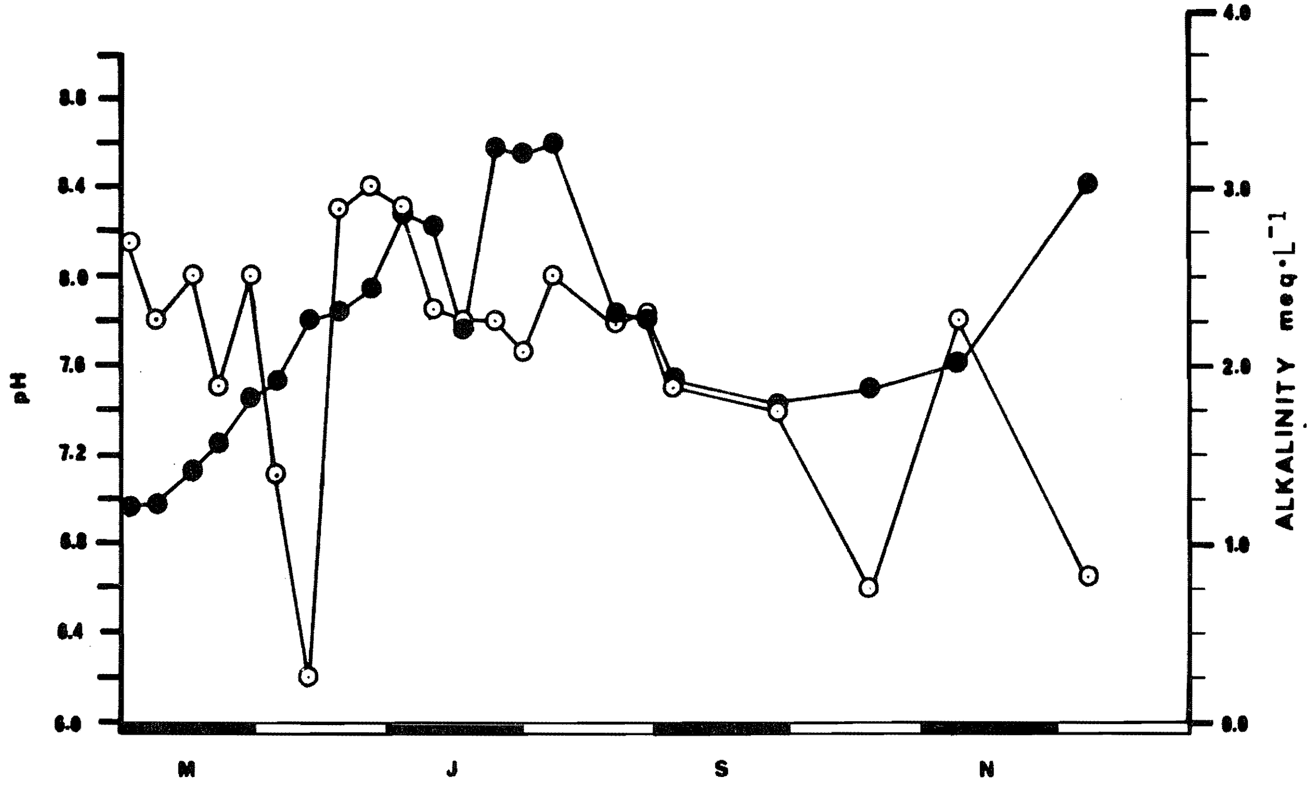

Figure 20. pH (⊙) and alkalinity (meq $HCO_3^-\cdot L^{-1}$) (●) in the Muskeg River.

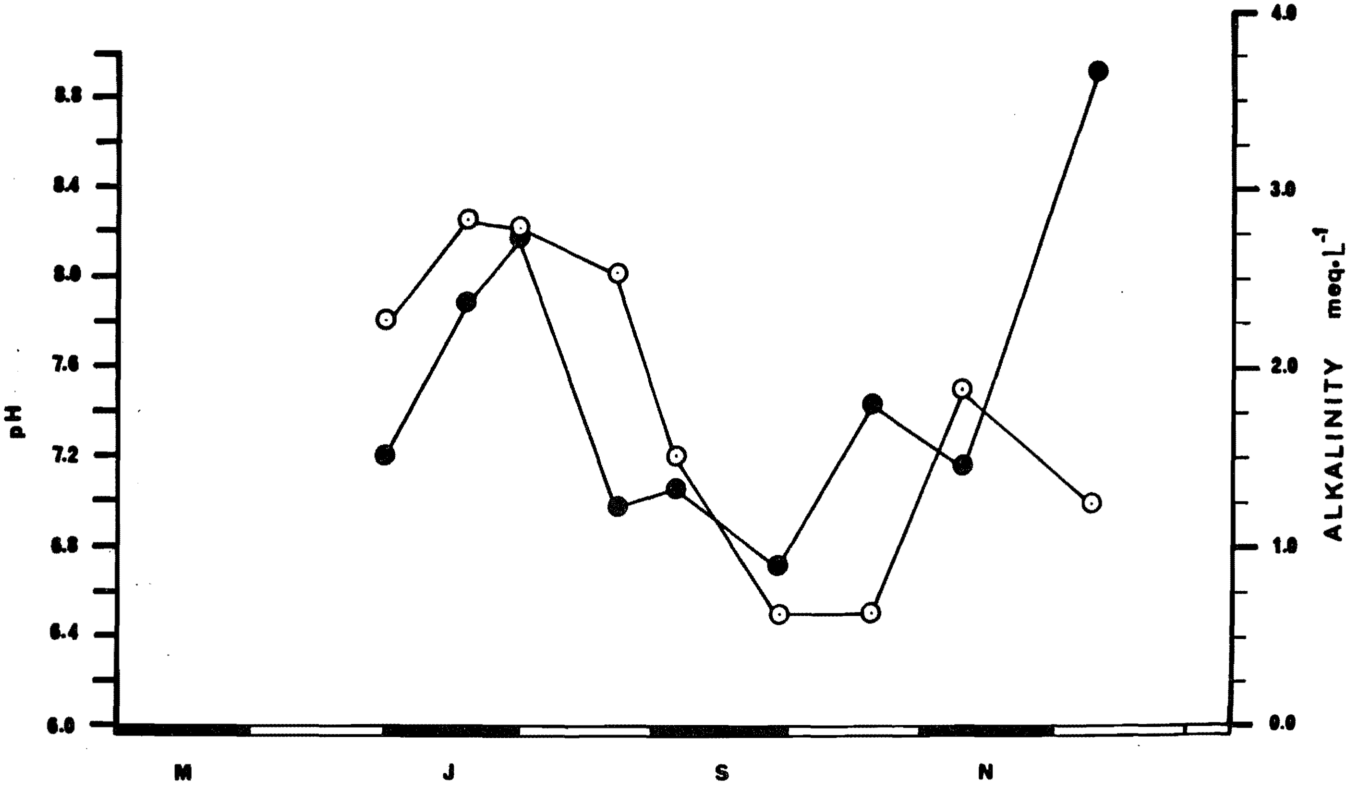

Figure 21. pH (○) and alkalinity (meg $HCO_3^- \cdot L^{-1}$) (●) in the Steepbank River.

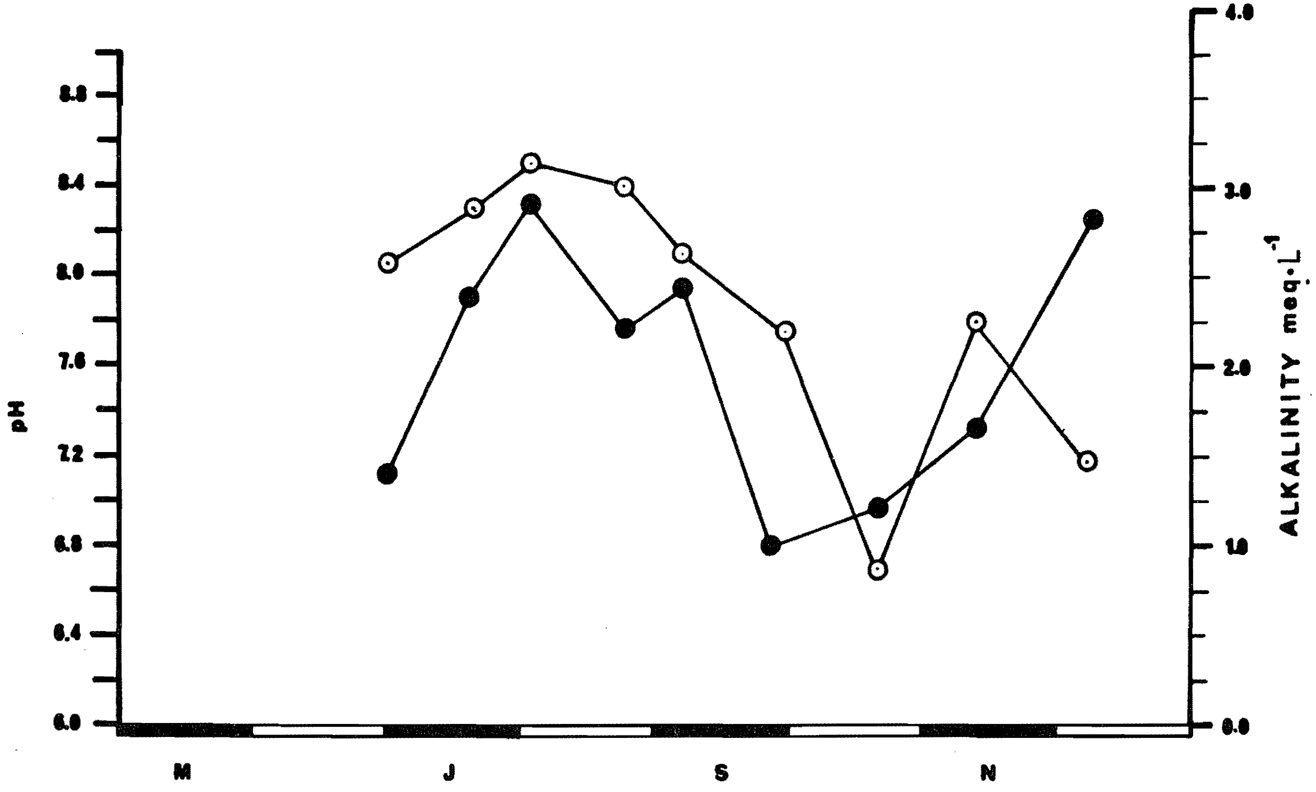

Figure 22. pH (⊙) and alkalinity (meq HCO_3^- L^{-1}) (●) in the Hangingstone River.

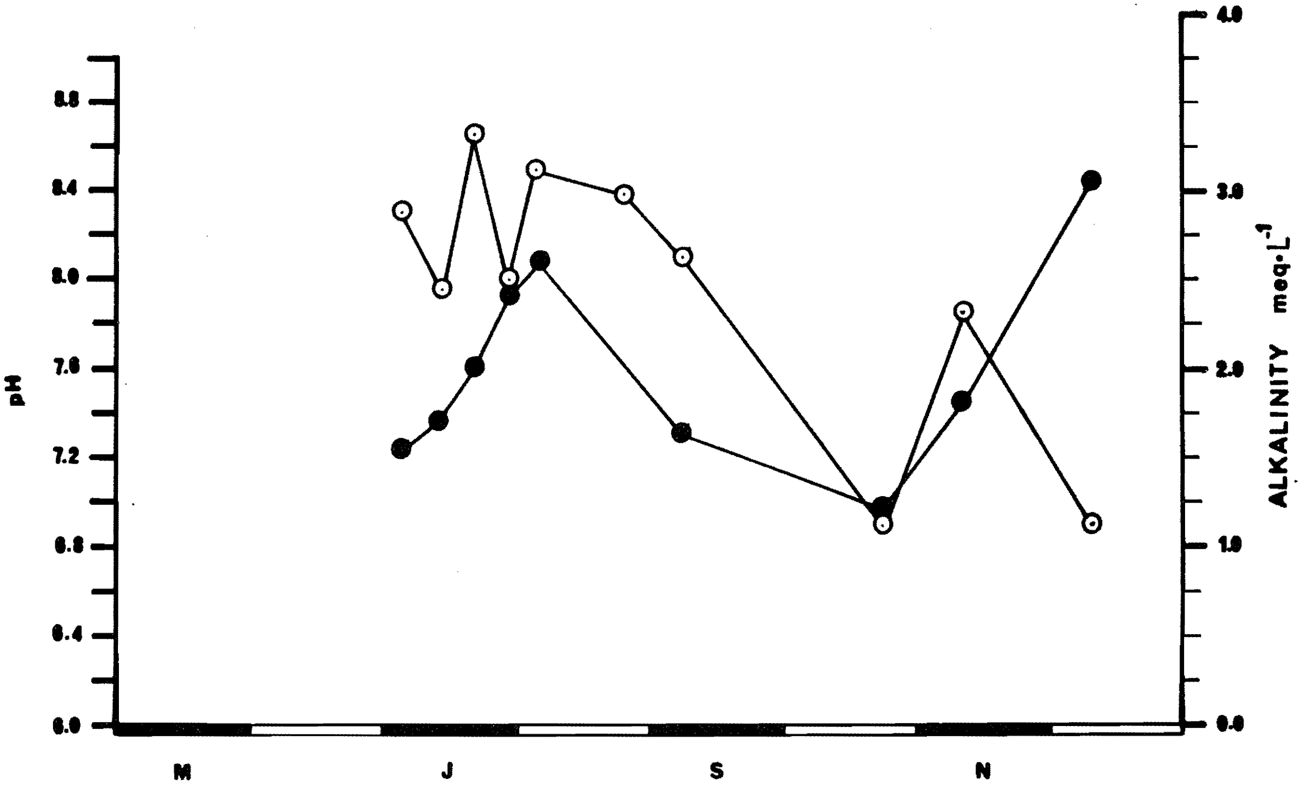

Figure 23. pH (⊙) and alkalinity (meg $HCO_3^- \cdot L^{-1}$) (●) in the MacKay River.

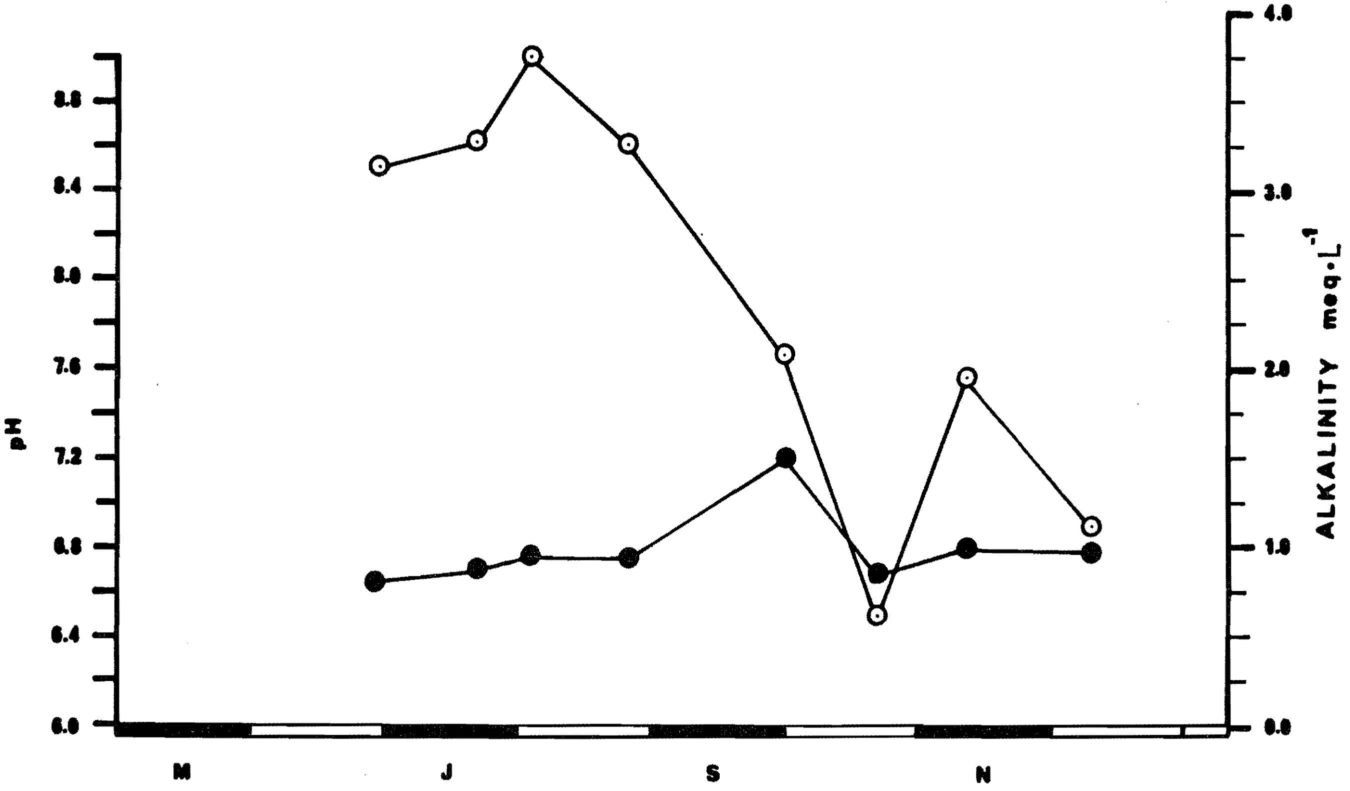

Figure 24. pH (⊙) and alkalinity (meg $HCO_3^-\cdot L^{-1}$) (●) in the Ells River.

Table 2. The complete list of algal species encountered in the five rivers (M = Muskeg River; SB = Steepbank River; HS = Hangingstone River; MK = MacKay River; E = Ells River; D = dominant; + = present; - = absent; √ = phytoplankton).

	M	SB	HS	MK	E
CYANOPHYTA					
Anabaena affinis Lemm.	+	+	D	+	D
A. inaequalis Borge	-	+	-	-	-
A. variabilis Kütz.	+	+	+	+	+
A. wisconsinense Prescott	+	-	-	-	-
Aphanizomenon flos-aquae (L.) Ralfs.	+√	-	-	-	-
Calothrix braunii Bornet & Flahault	+	+	D	D	D
C. breviarticulata West & West	D	D	-	-	-
C. fusca (Kütz.) Bornet & Flahault	+	-	-	-	-
Chamaesiphon incrustans Grunn.	+	+	-	-	-
Chroococcus limneticus Lemm.	+√	+√	-	+√	-
Fischerella muscicola (Borzi) Gomont	-	+	-	-	-
Lyngbya aerugineo-caerulea (Kütz.) Gomont	D	D	D	D	D
L. aestuarii (Mert.) Lieb.	-	+	-	-	-
L. epiphytica Hieronymus	+	+	-	-	-
L. nordgaardii Wille	+	+	-	-	-
L. taylorii Drouet & Strickland	+	+	-	-	-
L. versicolor (Watt.) Gomont	+	+	-	-	-
Merismopedia elegans A. Braun	+	-	-	-	-
Microcoleus vaginatus (Vauch.) Gomont	-	+	-	-	-
Microcystis aeruginosa Kütz. emend Elenkin	+	+	-	-	-
Nostoc sp.	+	+	+	+	+
N. commune Vaucher	+	+	+	+	+
N. microscopicum Carmichael	+	+	+	+	+

continued...

Table 2. Continued

	M	SB	HS	MK	E
N. verrucosum Vaucher	+	+	+	+	+
Oscillatoria sp.	+	+	-	-	D
O. lacustris (Kleb.) Geitler	+	+	-	-	-
O. tenuis C.A. Agardh.	+	+	-	-	-
Phormidium favosum (Bory) Gomont	+	+	-	-	-
P. tenue (Menegh.) Gomont	+	+	-	-	-
Rhaphidiopsis sp.	-	-	-	-	+√
Rivularia haematities (D.C.) C.A. Agardh.	+	+	-	-	-
Schizothrix tinctoria Gomont	+	+	-	-	-
Tolypothrix distorta Kütz.	-	+	-	-	-
CHLOROPHYTA					
Ankistrodesmus falcatus (Corda) Ralfs.	+√	+√	+√	+√	+√
A. spiralis (Turner) Lemm.	+√	-	-	-	-
Chaetophora incrassata (Hud.) Hazen	+	+	-	-	-
Chlamydomonas spp.	+	+	+	+	D
Cladophora glomerata (L.) Kütz.	+	D	D	D	+
Closterium sp.	+√	+√	+√	+√	+√
Coleochaete divergens Pringsheim	+	-	-	-	-
Cosmarium sp.	+√	+√	-	+√	-
Crucigenia tetrapedia (Kirch.) West & West	-	+√	-	-	-
Dictyosphaerium ehrenbergianum Naegeli	+√	+√	-	-	-
D. pulchellum Wood	+√	+√	-	-	+√
Draparnaldia acuta (C.A. Ag.) Kütz.	+	-	-	-	-
D. plumosa (Vauch.) C.A. Agardh.	D	-	-	-	-
Elakatothrix sp.	-	+	-	-	-

continued...

Table 2. Continued.

	M	SB	HS	MK	E
Mougeotia sp.	+	+	-	-	+
Oedogonium sp.	+	+	+	-	+
Pediastrum boryanum (Turp.) Meneghini	-	-	-	-	+√
Pithophora varia Wille	+	+	-	-	-
Rhizoclonium hierglyphicum (C.A. Ag.) Kütz.	+	+	-	-	-
Scenedesmus dimorphus (Turp.) Kütz.	-	-	-	-	+
S. obliquus (Turp.) Kütz.	+	+	-	+	-
Sorastrum spinulosum Naegeli	-	-	-	+	-
Spirogyra sp.	+	+	-	+	-
Stigeoclonium sp.	+	+	D	+	D
S. pachyderm Prescott	+	+	-	-	-
Staurastrum sp.	-	+√	+√	-	-
Tetraëdron asymmetricum Prescott	-	+√	-	-	-
Ulothrix sp.	+	+	+	+	+
U. subconstricta G.S. West	+	+	-	-	-
U. subtilissima Rabenhorst	-	+	-	-	-
U. zonata (Weber & Mohr) Kütz.	+	+	-	-	-
Zygnema sp.	+	-	-	-	-
RHODOPHYTA					
Batrachospermum vagum (Roth.) C.A. Agardh.	+	+	-	-	-
Audouinella violacea (Kütz.) Hamel	+	+	-	-	-
A. pygmaea Kütz.	+	+	-	-	-
EUGLENOPHYTA					
Phacus sp.	-	+	-	-	-

continued...

Table 2. Continued.

	M	SB	HS	MK	E
CHRYSOPHYTA					
Mallomonas caudata Iwanoff	+	+	+	+	+
CRYPTOPHYTA					
Cryptomonas erosa Ehr.	+	+	-	-	-
C. ovata Ehr.	+	+	-	-	-
BACILLARIOPHYTA					
Achnanthes lanceolata Bréb.	D	+	+	+	+
A. lanceolata v. *rostrata* Hust.	+	+	+	+	+
A. minutissima Kütz.	+	+	+	+	+
A. peragallii Brun & Hérbaud	-	-	-	+	+
Amphipleura pellucida Kütz.	+	+	+	+	+
Amphora ovalis Kütz.	+	+	-	-	+
A. perpusilla Grun.	-	-	-	-	+
Asterionella formosa Hass.	+√	+√	-	-	+√
Caloneis alpestris (Grun.) Cl.	+	-	-	-	-
Cocconeis pediculus Ehr.	+	+	+	+	+
C. placentula Ehr.	+	+	D	+	+
C. placentula v. *euglypta* (Ehr.) Cl.	+	+	-	-	-
Cyclotella catenata Brun.	-	-	+	-	-
C. comta (Ehr.) Kütz.	-	+	-	+	+
C. kuetzingiana Thwaites	-	-	+	-	-
C. meneghiniana Kütz.	+	+	+	+	+
Cymbella amphioxys (Kütz.) Grun.	-	-	-	-	+
C. cistula (Hemprich) Grun.	+	+	+	-	+
C. lanceolata (Ehr.) V.H.	-	-	-	+	-
C. naviculiformis Auerswald	+	-	-	-	+

continued...

Table 2. Continued.

	M	SB	HS	MK	E
C. prostrata (Berkeley) Cl.	+	+	+	-	+
C. sinuata Greg.	+	+	+	-	+
C. tumida (Bréb.) V.H.	-	-	+	-	+
C. ventricosa Kütz.	+	+	+	+	+
Diatoma elongatum Agardh.	+	+	+	+	+
D. anceps (Ehr.) Grunn.	+	-	-	-	-
D. vulgare Bory	+	D	+	+	+
D. vulgare v. *grandis* (Smith) Grun.	+	+	+	+	+
D. vulgare v. *producta* Grun.	-	-	-	+	+
Epithemia argus Kütz.	+	-	-	-	-
E. sorex Kütz.	+	D	D	+	+
E. turgida (Ehr.) Kütz.	+	+	-	-	-
E. turgida v. *granulata* (Ehr.) Grun.	+	+	+	+	+
E. zebra (Ehr.) Kütz.	-	+	-	-	-
Fragilaria capucina Desm.	+	+	+	-	+
F. capucina v. *acuta* Grun.	-	-	-	-	+
F. capucina v. *lanceolata* Grun.	-	-	-	-	+
F. construens (Ehr.) Grun.	+	+	+	-	+
F. construens v. *venter* (Ehr.) Grun.	+	+	+	+	+
F. crotonensis Kitton	-	+√	+√	-	-
F. leptostauron (Ehr.) Hust.	-	-	-	-	+
F. pinnata Ehr.	-	-	+	-	+
F. vaucheriae (Kütz.) BoyePet.	-	+	+	-	+
F. virescens v. *capitata* Krasske	-	+	-	+	-
Gomphonema acuminatum Ehr.	+	+	-	-	-
G. acuminatum v. *coronata* (Ehr.) W.Sm.	-	-	+	-	-
G. angustatum v. *producta* Grun.	-	-	-	-	+
G. bohemicum Reichelt & Fricke	+	+	+	+	+

continued...

Table 2. Continued.

	M	SB	HS	MK	E
G. constrictum Ehr.	+	-	-	-	-
G. lanceolatum Ehr.	+	+	+	+	+
G. longipes v. *subclavata* Grun.	-	+	D	-	D
G. olivaceum (Lyngb.) Kütz.	D	D	+	+	+
G. olivaceum v. *calcarea* Cl.	-	-	-	-	+
G. parvulum Kütz.	D	D	+	+	+
G. parvulum v. *exilis* Grun.	+	+	+	+	+
Gyrosigma acuminatum Kütz.	+	+	+	-	+
Hantzschia amphioxys f. *capitata* O. Müll.	-	-	-	+	+
Melosira granulata (Ehr.) Ralfs.	-	-	-	-	+
M. islandica O. Müll.	+	+	+	+	+
M. varians C.A. Agardh.	+	+	+	+	-
Meridion circulare Agardh.	+	+	+	-	+
Navicula bacilliformis Grun.	-	-	-	-	+
N. cryptocephala Kütz.	+	D	+	+	+
N. cuspidata Kütz.	+	+	-	-	+
N. dicephala (Ehr.) W.Sm.	-	-	-	+	-
N. gracilis Ehr.	+	+	-	+	+
N. hungarica v. *capitata* (Ehr.) Cl.	-	-	-	-	+
N. lapidosa Krasske	-	-	+	-	-
N. placentula (Ehr.) Grun.	-	+	-	+	+
N. placentula v. *rostrata* A. Meyer	-	-	+	+	+
N. pupula Grun.	+	+	-	-	-
N. pupula v. *rectangularis* (Greg.) Grun.	-	-	+	-	-
N. radiosa Kütz.	+	+	+	+	+
N. rhynchocephala Kütz.	+	+	-	+	-
N. scoliopleuroides Quint	-	-	-	-	+

continued...

Table 2. Continued.

	M	SB	HS	MK	E
Nitzschia acicularis W.Sm.	+	-	-	-	-
N. acuta Hantzsch.	-	-	+	-	-
N. amphibia Grun.	+	+	-	-	-
N. clausii Hantzsch.	-	-	-	+	-
N. commutata Grun.	-	+	-	-	-
N. dissipata (Kütz.) Grun.	+	+	+	+	+
N. fonticola Grun.	D	D	-	-	+
N. gracilis Hantzsch.	+	+	+	+	+
N. heurfleriana Grun.	-	-	-	-	+
N. ignorata	-	-	-	-	+
N. palea (Kütz.) W.Sm.	-	D	+	+	D
N. paleacea Grun.	-	-	-	-	+
N. recta Hantzsch.	-	-	+	-	-
N. romana Grun.	-	-	-	-	+
Opephora martyi Héribaud	-	-	-	-	+
Pinnularia mesolepta (Ehr.) W.Sm.	+	+	+	-	-
P. molaris Grun.	-	-	+	-	-
P. nodosa v. *constricta* Mayer	-	-	-	-	+
Rhoicosphenia curvata (Kütz.) Grun.	D	D	+	+	+
Rhopalodia gibba (Ehr.) O. Müll.	+	+	+	+	-
R. gibberula (Ehr.) O. Müll.	+	+	+	+	-
R. parallela (Grun.) O. Müll.	-	+	+	+	-
Stauroneis phoenicenteron Ehr.	-	-	-	-	+
S. legumen Ehr.	+	-	-	-	-
Stephanodiscus astraea (Ehr.) Grun.	-	-	+√	+√	+√
S. hantzschii Grun.	+√	+√	+√	+√	-
Surirella angustata Kütz.	-	-	+	+	+
S. didyma Kütz.	-	-	-	+	-
S. delicatissima Lewis	-	-	-	+	-

continued...

Table 2. Concluded.

	M	SB	HS	MK	E
Surirella linearis v. *helvetica* (Brun.) Meister	+	-	-	-	-
S. robusta v. *splendida* (Ehr.) V.H.	-	-	-	+	+
S. tenera Greg.	-	-	-	-	+
Synedra cyclopum Brutschii	-	-	-	-	+
S. capitata Ehr.	+	-	-	-	-
S. pulchella Kütz.	+	+	-	-	-
S. rumpens Kütz.	D	+	-	-	+
S. rumpens v. *familiaris* (Kütz.) Grun.	-	-	-	+	-
S. ulna (Nitzsch.) Ehr.	D	+	+	+	+
Tabellaria fenestrata (Lyngby.) Kütz.	+	+	+	+	+
T. flocculosa (Roth.) Kütz.	+	-	-	-	-

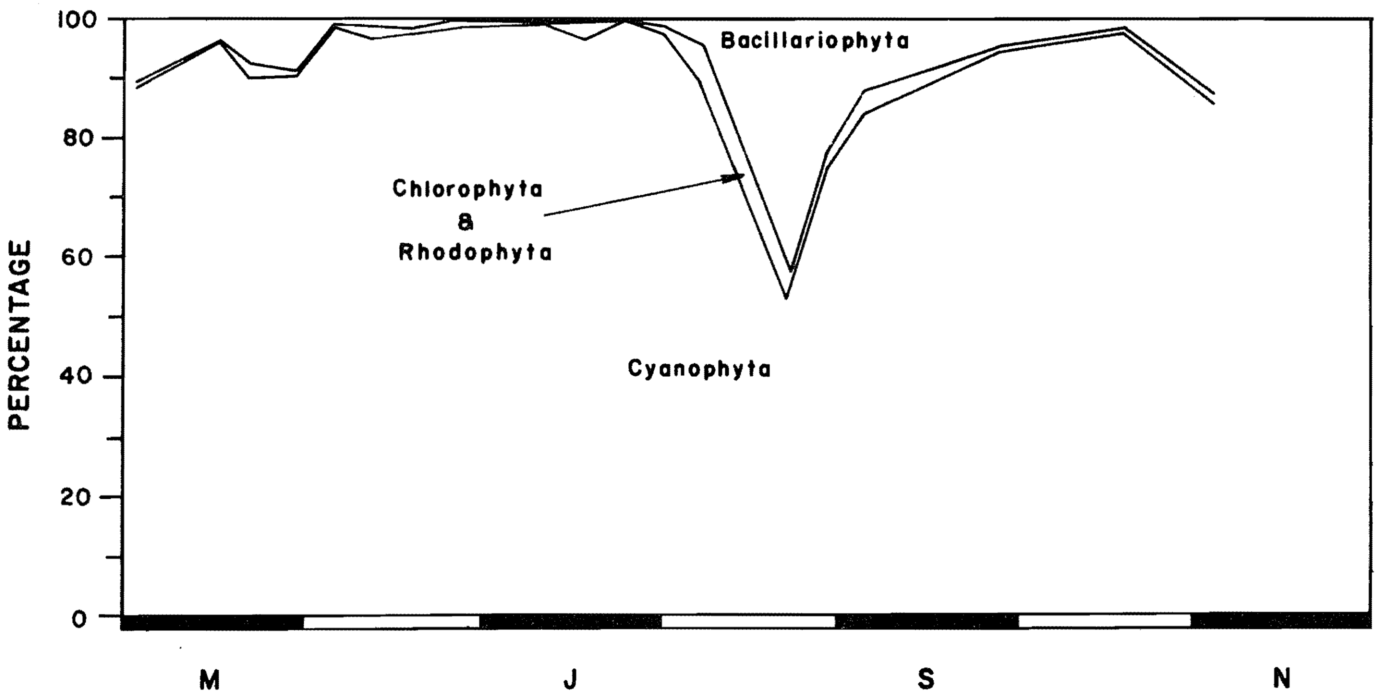

Figure 25. Changes in the percentage composition of the epilithon of the Muskeg River based upon cell count data.

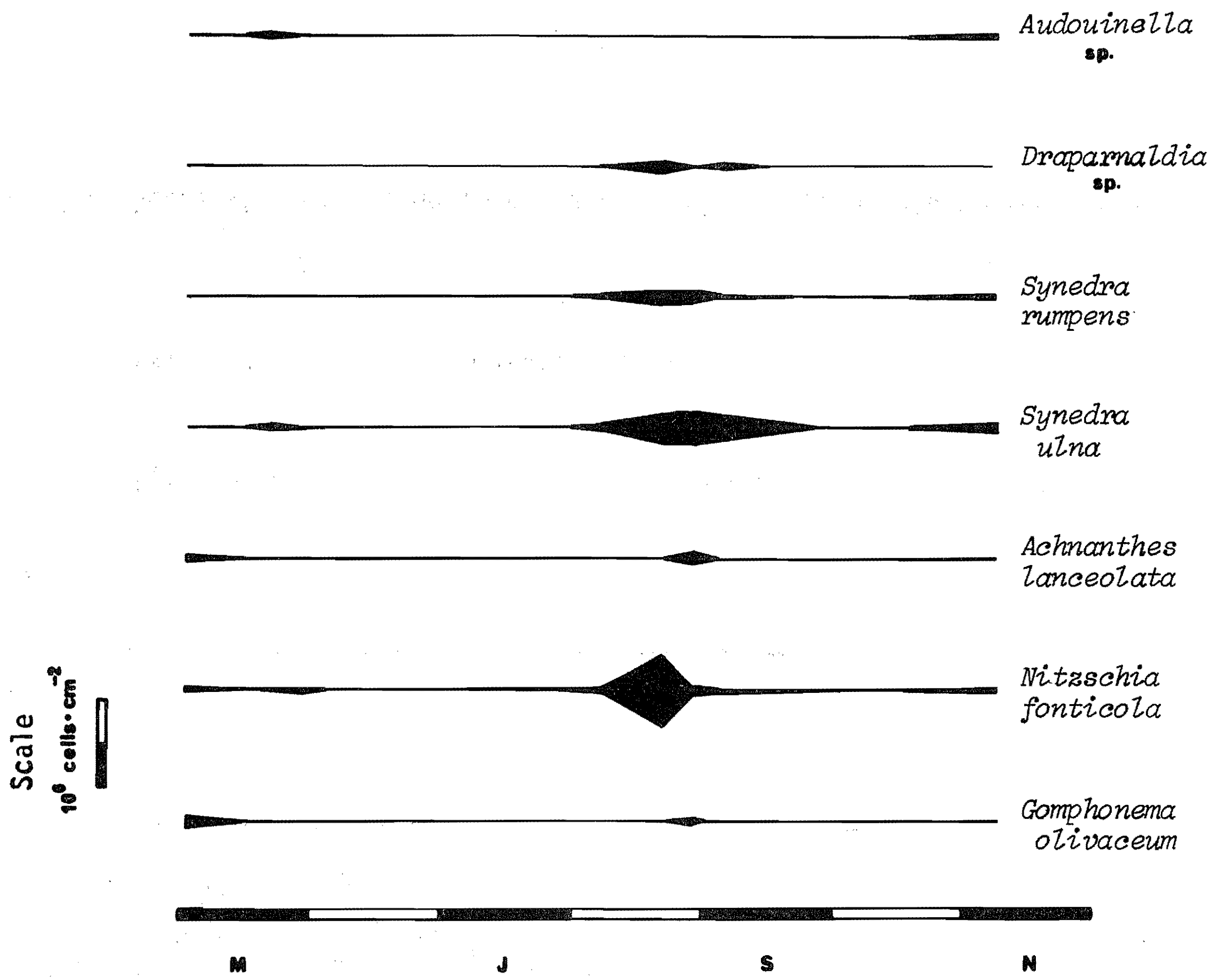

Figure 26. Succession of the dominant members of the Rhodophyta, Chlorophyta, and Bacillariophyta in the Muskeg River.

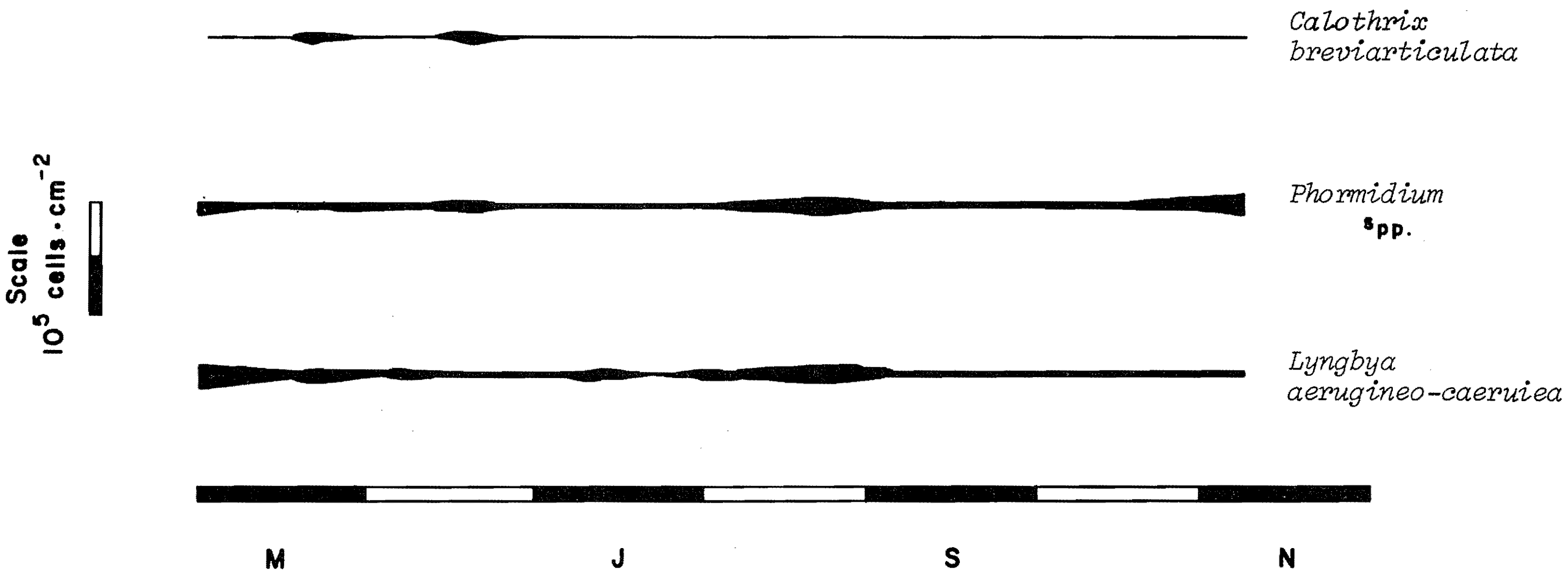

Figure 27. Succession of the dominant members of the Cyanophyta in the Muskeg River.

Again the cyanophycean algae were dominant in the Steepbank River (Figures 28, 29, and 30), accounting for 85% and 70% of the total population in mid-July and the autumn period, respectively. The dominant species were *Lyngbya aerugineo-caerulea* and *Calothrix breviarticulata* during July and only the former in the autumn. As a group, diatoms were most important during the summer and autumn months, accounting for 17% and 23% of the total population respectively. *Epithemia sorex* dominated during the summer, while *Diatoma vulgare, Nitzschia palea,* and *Nitzschia fonticola* dominated during the autumn. Members of the Chlorophyta formed insignificant populations and red algae were found but accounted for <1% of the epilithon at any time.

During the summer and late autumn, chlorophycean algae dominated in the Hangingstone River, accounting for 82% and 78%, respectively. *Stigeoclonium* sp., together with *Cladophora glomerata,* dominated during the summer, and the latter species dominated during the late autumn (Figures 31, 32, 33, and 34). Diatoms were also an important group and by early autumn accounted for 80% of the total population when *Epithemia sorex* and *Cocconeis pediculus* dominated. These species were succeeded by *Cocconeis placentula* and *Gomphonema longiceps* var. *subclavata*; then *Gomphonema olivaceum* became the dominant species in late October. Cyanophycean algae were most important during August, accounting for 50% of the total population. First, *Lyngbya* sp. and *Anabaena affinis* were the most important species. However, toward the end of August, *Lyngbya* sp. and *Calothrix braunii* dominated.

Cyanophycean algae and diatoms were the most important algae of the Ells River (Figures 35, 36, and 37). During August, the cyanophycean algae accounted for 84% of the total population when *Oscillatoria* sp., *Calothrix braunii*, and *Anabaena affinis* were dominant. By late August, these species were replaced by *Lyngbya* sp. Diatoms became increasingly more important during the autumn months, accounting for up to 40% of the total population.

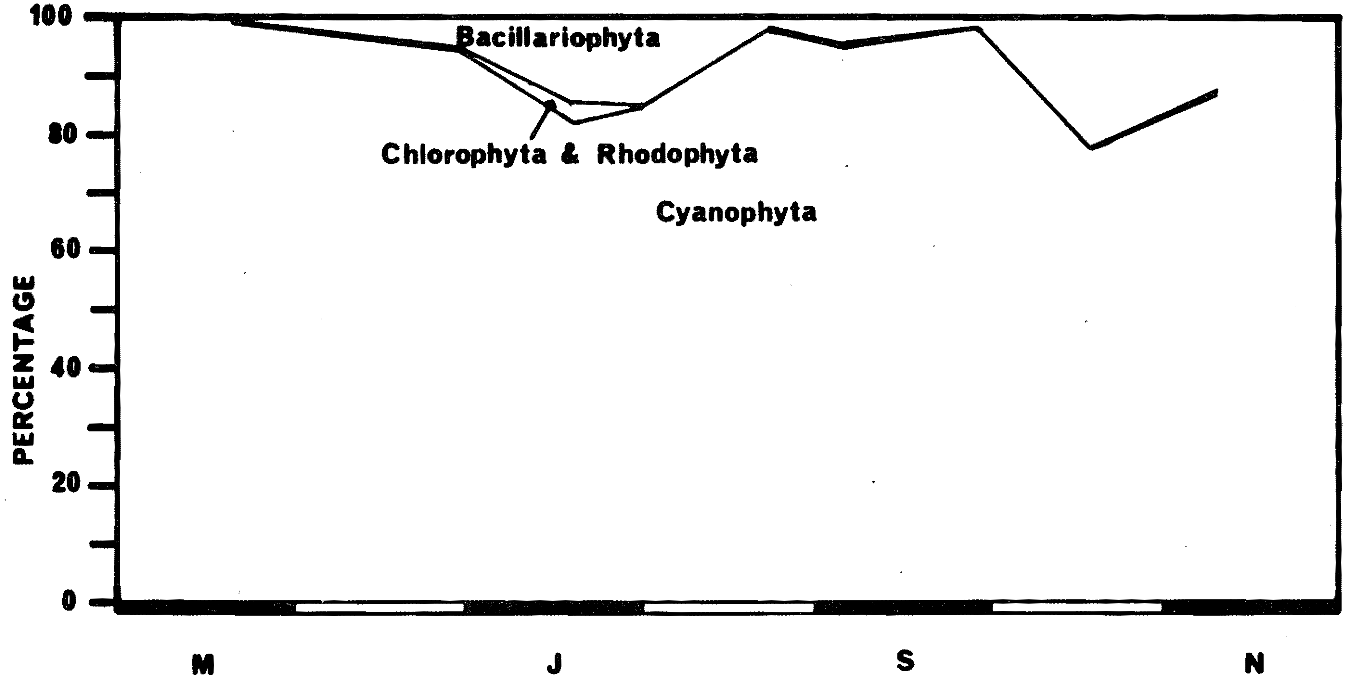

Figure 28. Changes in the percentage composition of the epilithon of the Steepbank River based upon cell count data.

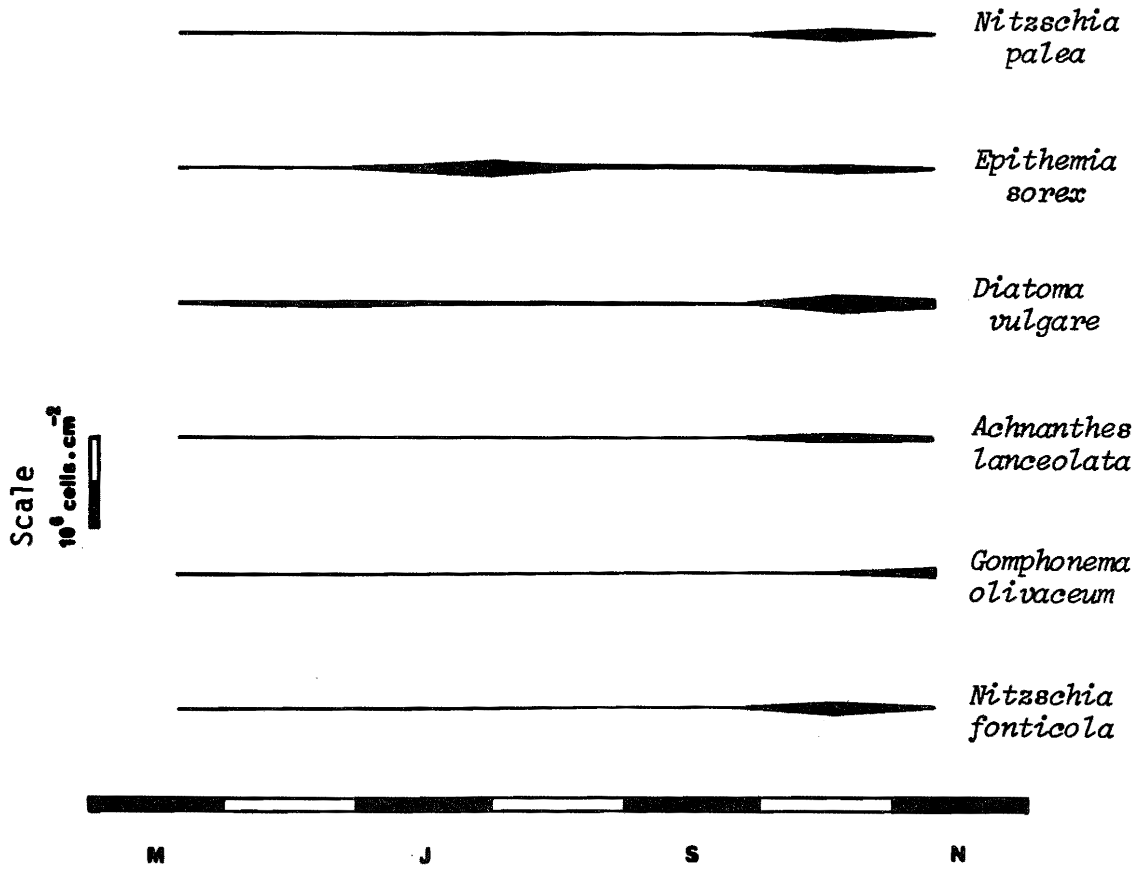

Figure 29. Succession of the dominant members of the Bacillariophyta in the Steepbank River.

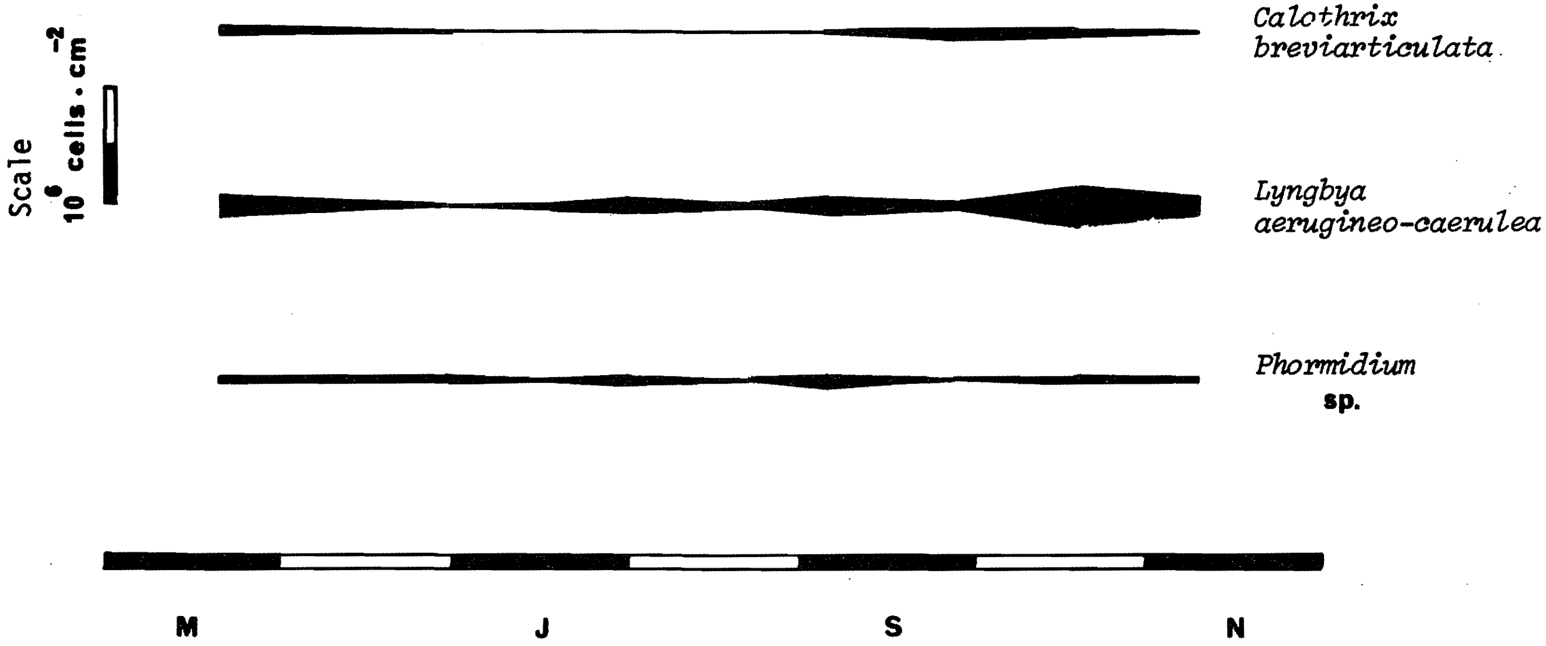

Figure 30. Succession of the dominant members of the Cyanophyta in the Steepbank River.

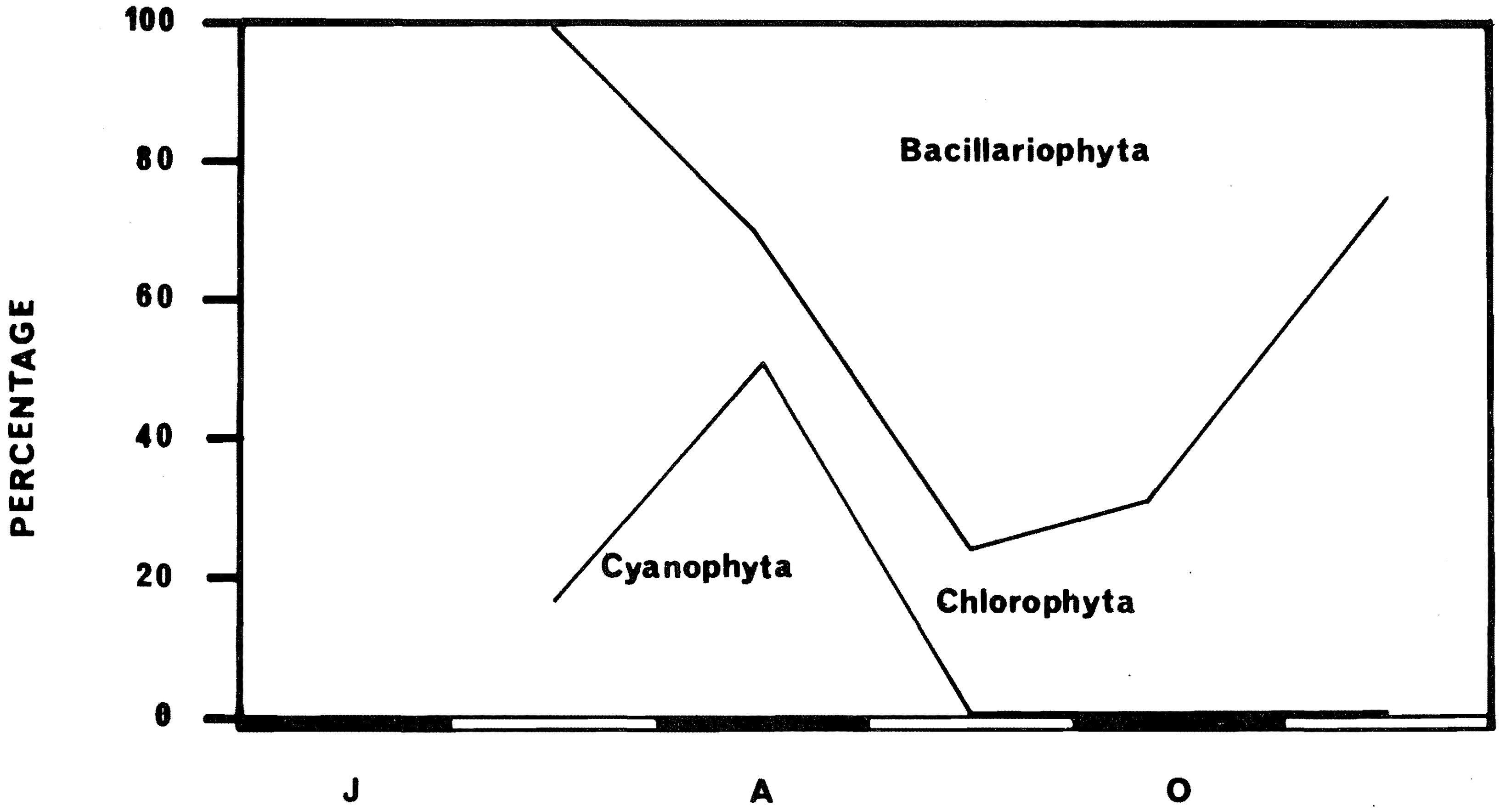

Figure 31. Changes in the percentage composition of the epilithon of the Hangingstone River based upon cell count data.

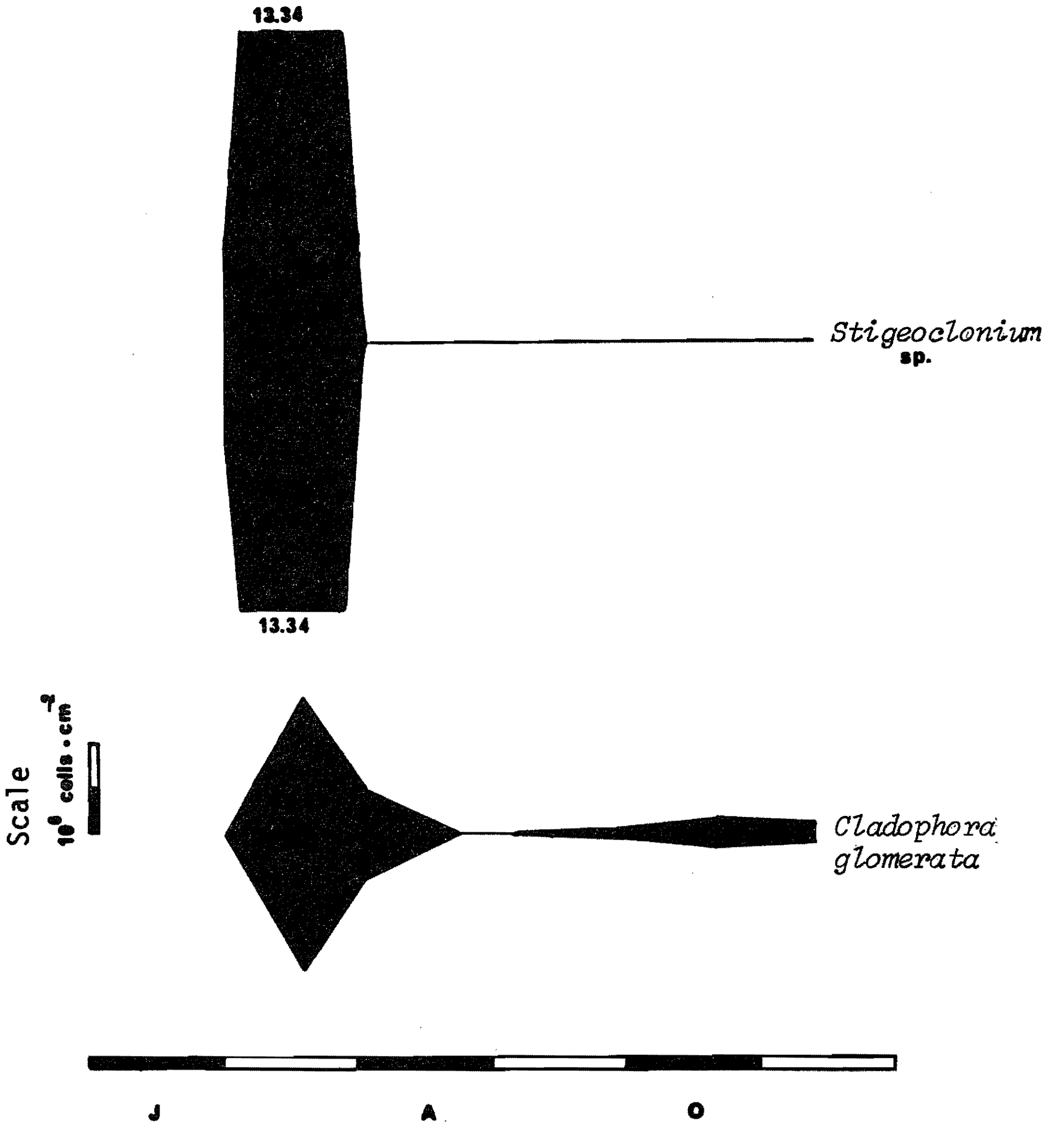

Figure 32. Succession of the dominant members of the Chlorophyta in the Hangingstone River.

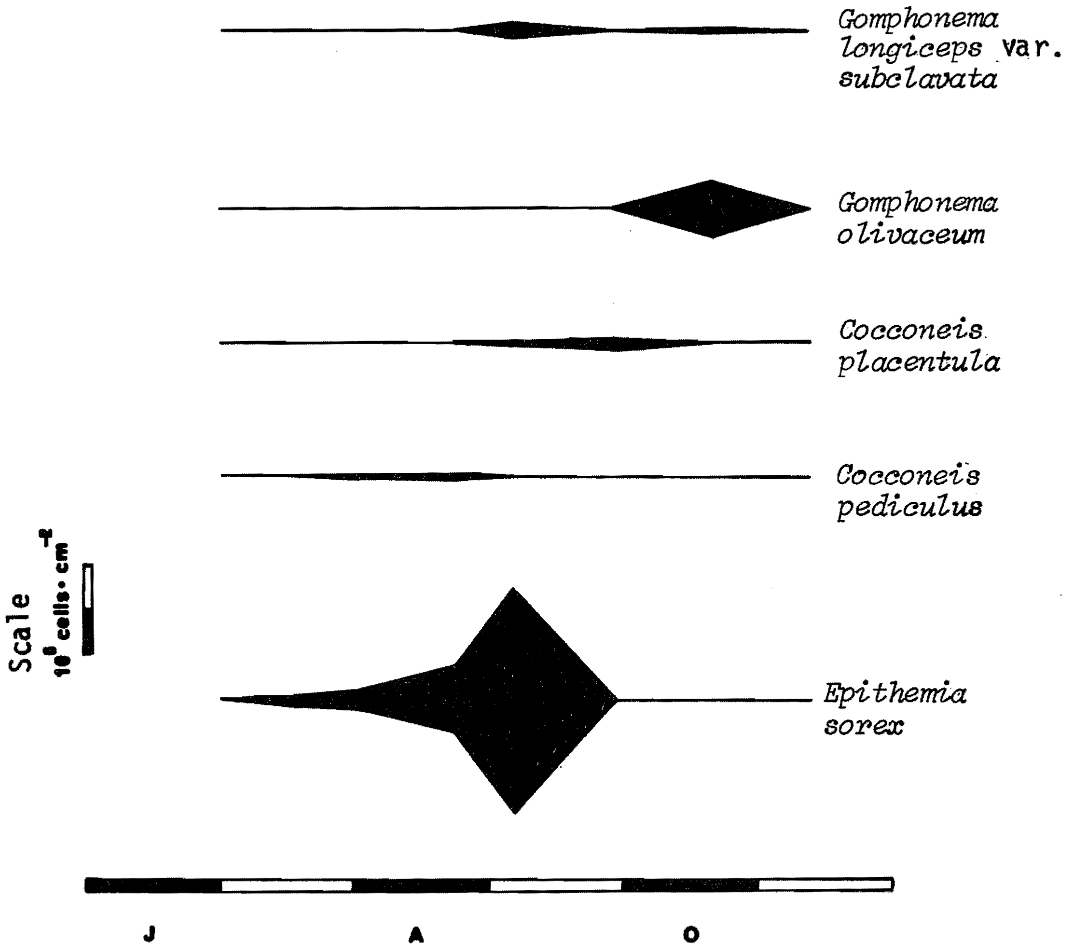

Figure 33. Succession of the dominant members of Bacillariophyta in the Hangingstone River.

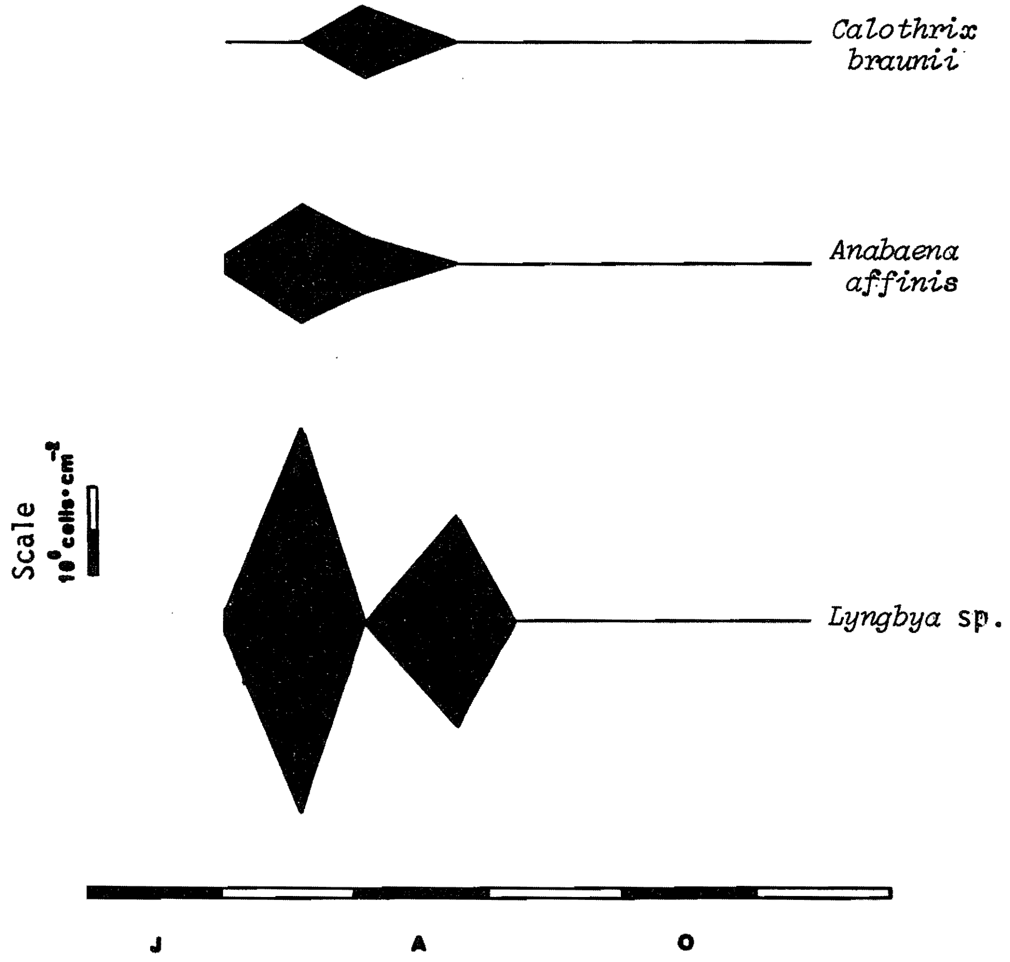

Figure 34. Succession of the dominant members of the Cyanophyta in the Hangingstone River.

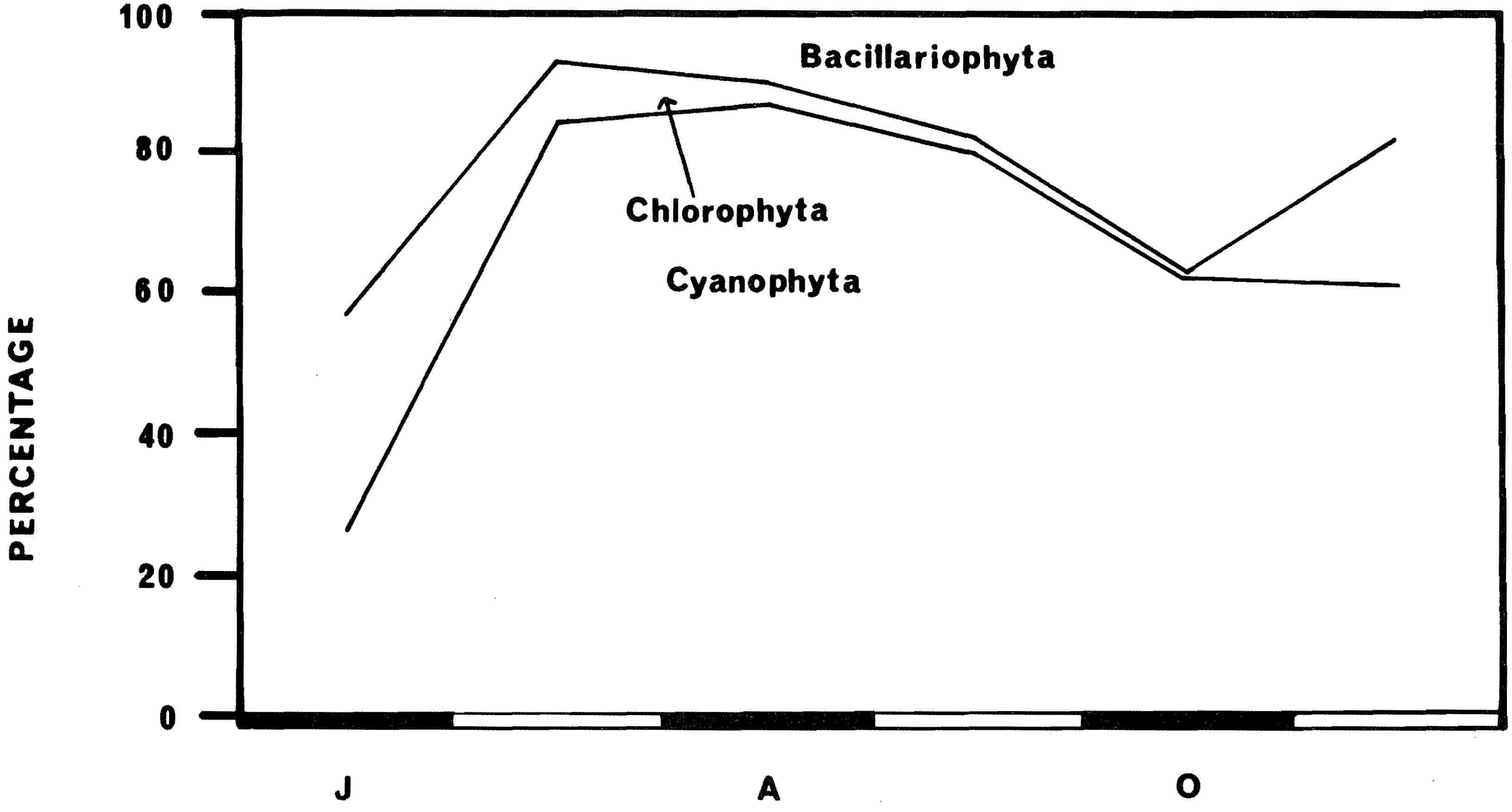

Figure 35. Changes in the percentage composition of the epilithon of the Ells River based upon cell count data.

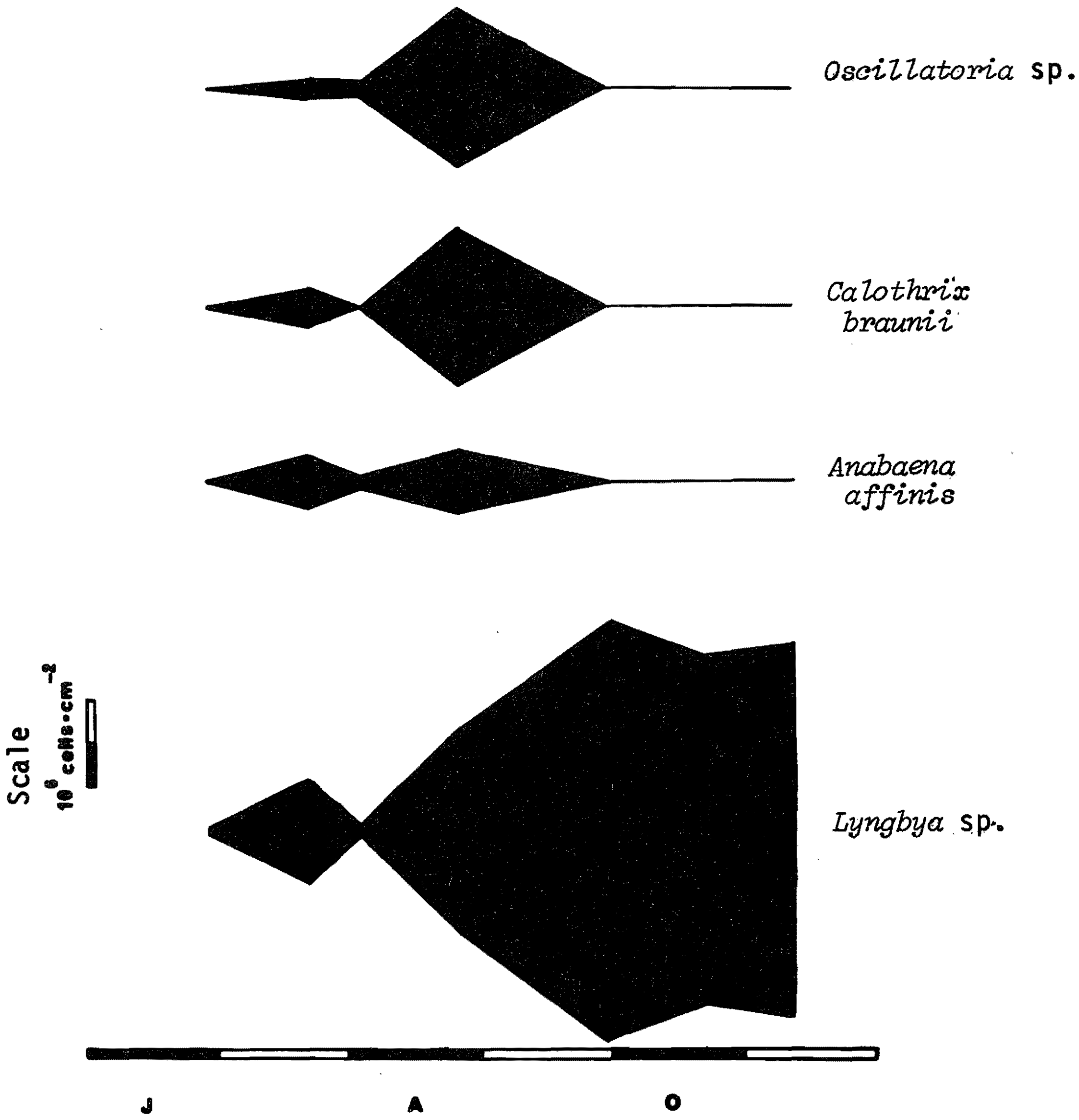

Figure 36. Succession of the dominant members of the Cyanophyta in the Ells River.

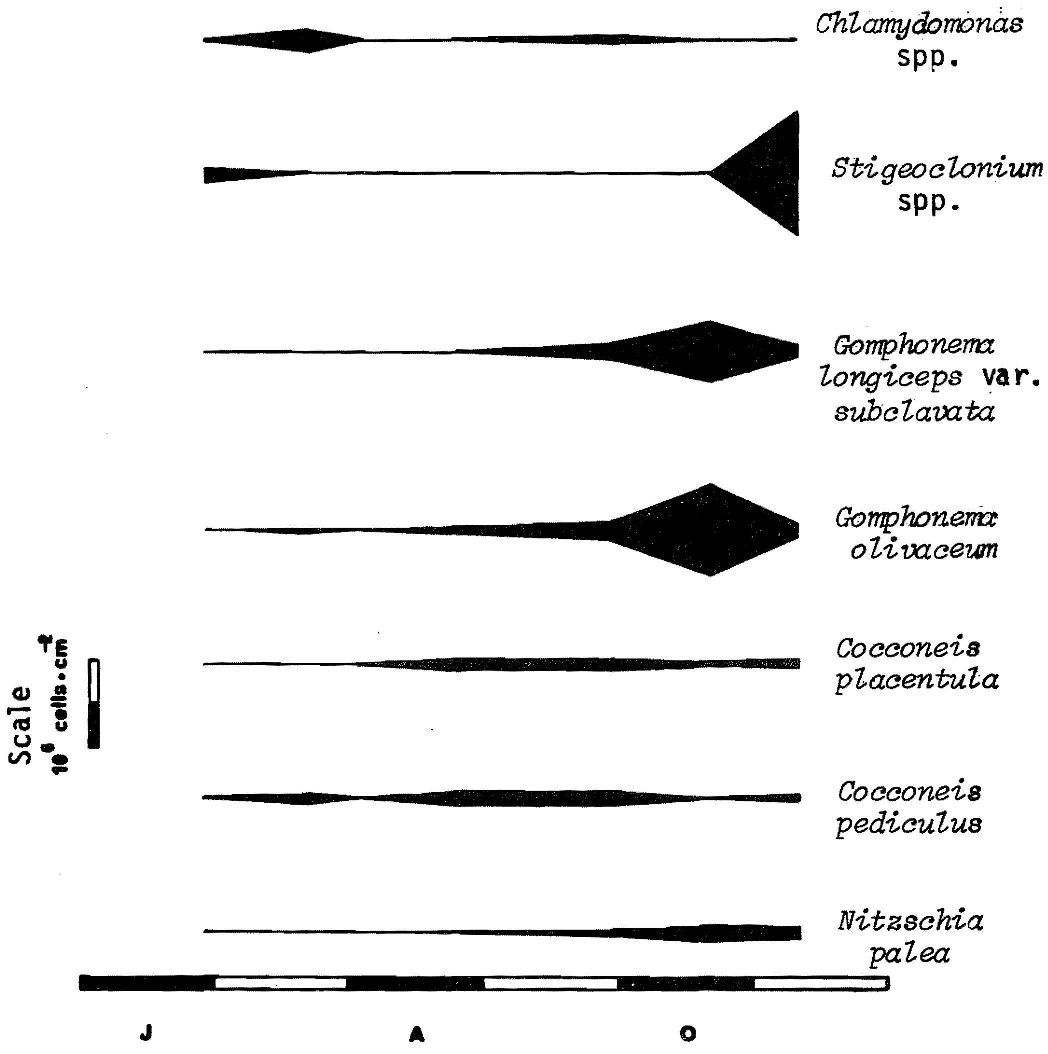

Figure 37. Succession of the dominant members of the Chlorophyta and Bacillariophyta in the Ells River.

Cocconeis pediculus, Cocconeis placentula, Gomphonema longiceps var. *subclavata,* and *Gomphonema olivaceum* dominated.

Chlorophycean algae in the Ells River were important during the summer and late autumn, accounting for 20% of the total population on both occasions. *Chlamydomonas* spp. together with *Stigeoclonium* sp. dominated during the early summer, but only *Stigeoclonium* sp. during the autumn.

The epilithon in the MacKay River was dominated by cyanophycean and chlorophycean algae (Figures 38, 39, and 40). During late July, when *Cladophora glomerata* dominated, chlorophycean algae accounted for 50% of the total population. Cyanophycean algae (*Calothrix braunii* and *Lyngbya* sp.) accounted for 40% and diatoms only 10%. By early August, the cyanophycean population had increased and now comprised 90% of the total population. The only dominant diatom was *Epithemia sorex*, particularly during July.

4.4 STANDING CROP

The epilithic algal standing crop fluctuations, as determined by chlorophyll *a* content, for all rivers are presented in Figure 41. Cell numbers are presented separately in Figures 42 through 46.

A spring standing crop peak occurred during May in the Muskeg River when the diatoms, *Gomphonema olivaceum* and *Nitzschia fonticola*, dominated. It then decreased to fluctuate irregularly during June, remained low during July, but peaked in late August when *Lyngbya aerugineo-caerulea* and *Phormidium* sp. dominated. During the autumn flooding, the standing crop in this river and all others, except the Ells River, decreased and remained low until November. In the Muskeg River, this increase was due to large populations of *Synedra acus* and *Nitzschia fonticola* (blue-greens) and *Audouinella* sp. (Rhodophyta) (Figure 42).

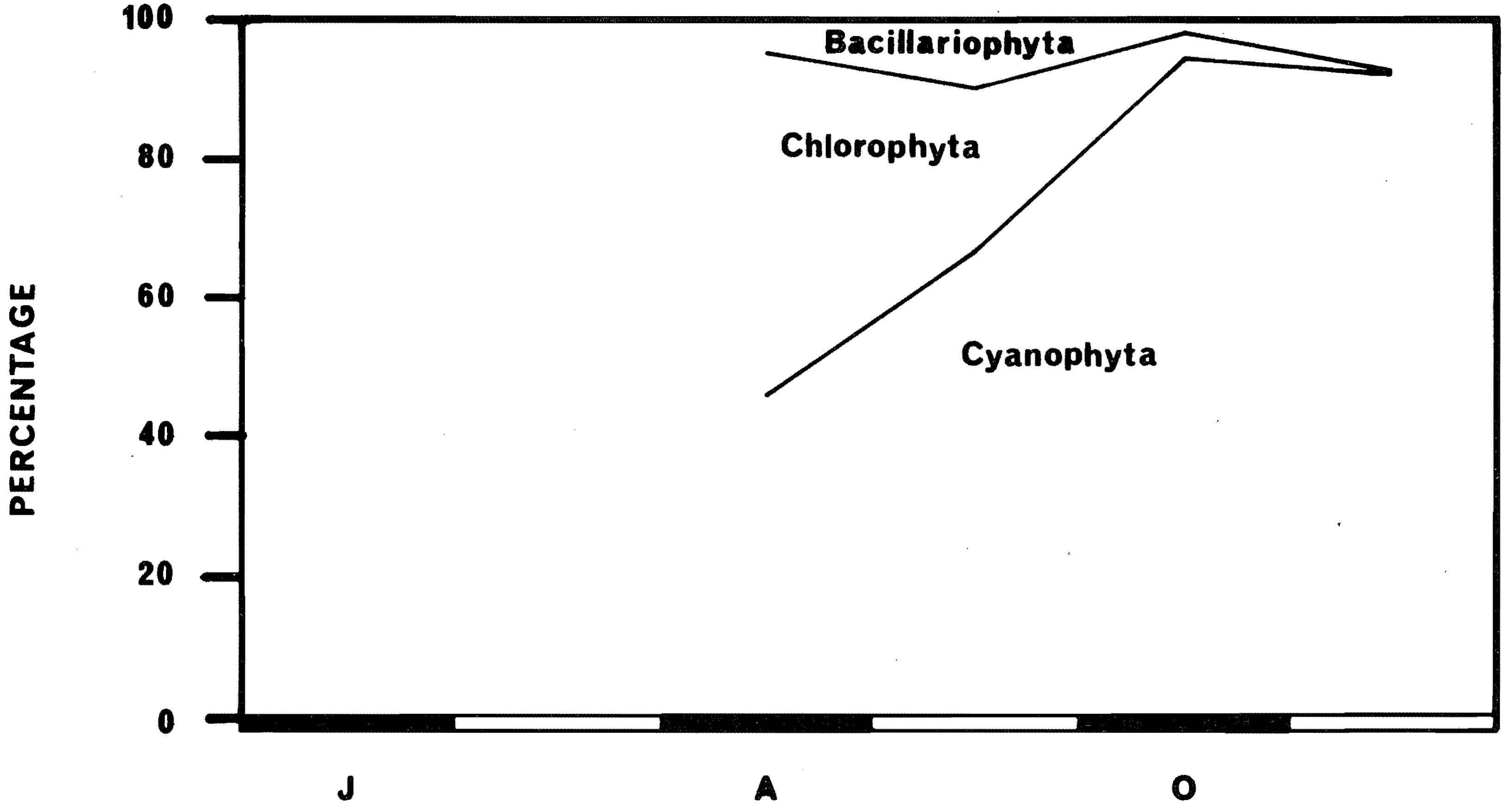

Figure 38. Changes in the percentage composition of the epilithon of the MacKay River based upon cell count data.

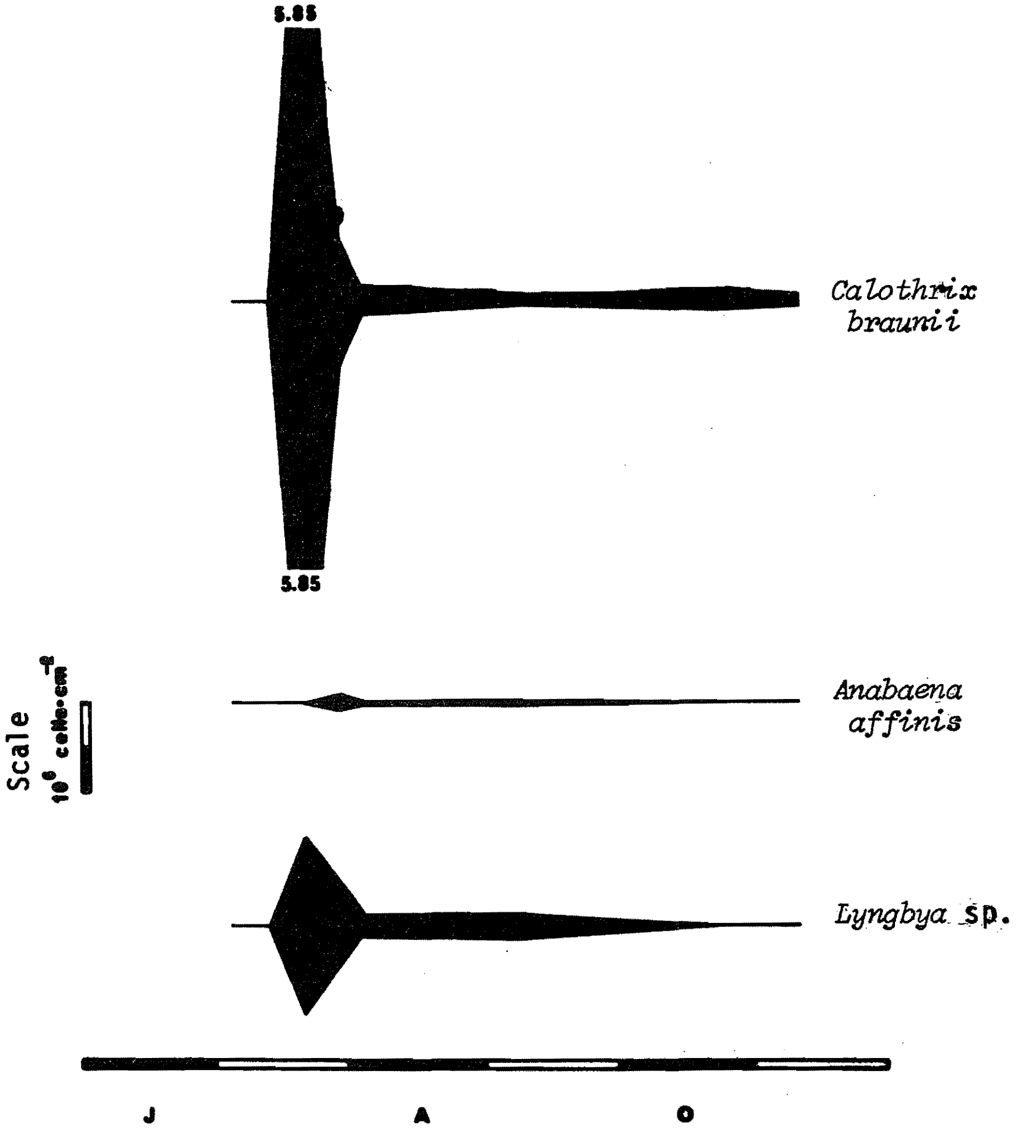

Figure 39. Succession of the dominant members of the Cyanophyta in the MacKay River.

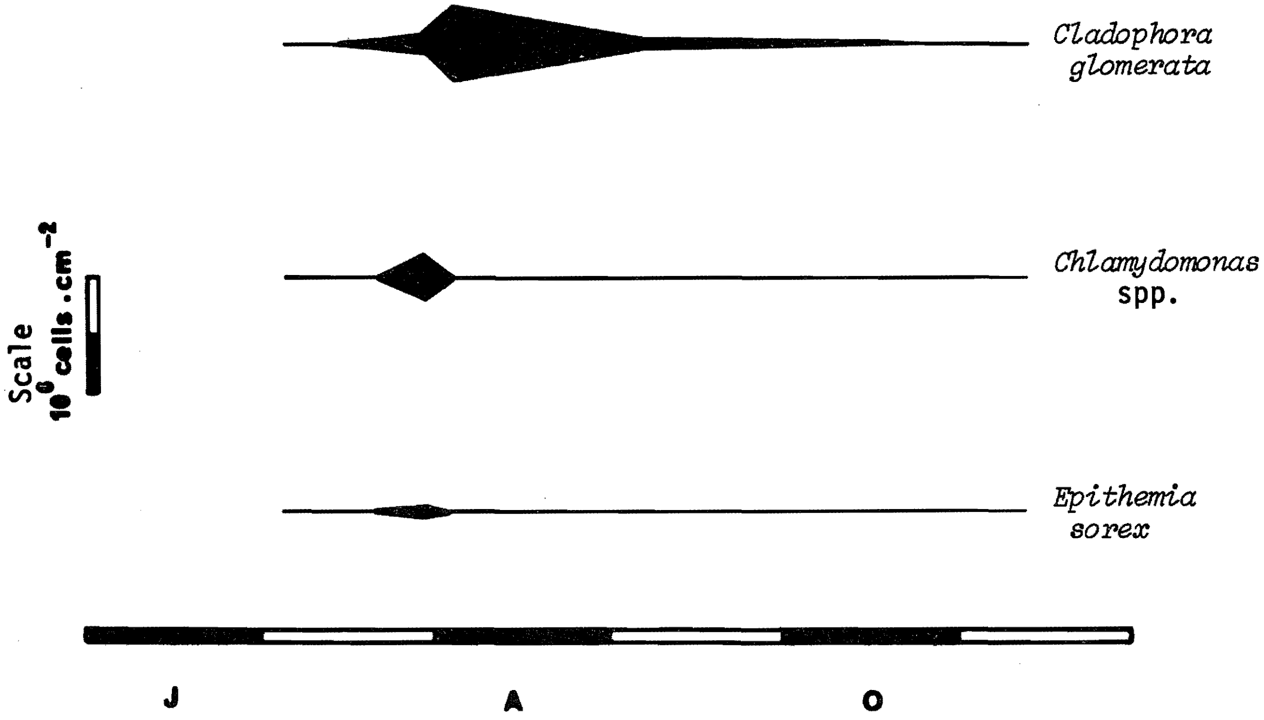

Figure 40. Succession of the dominant members of the Chlorophyta and Bacillariophyta in the MacKay River.

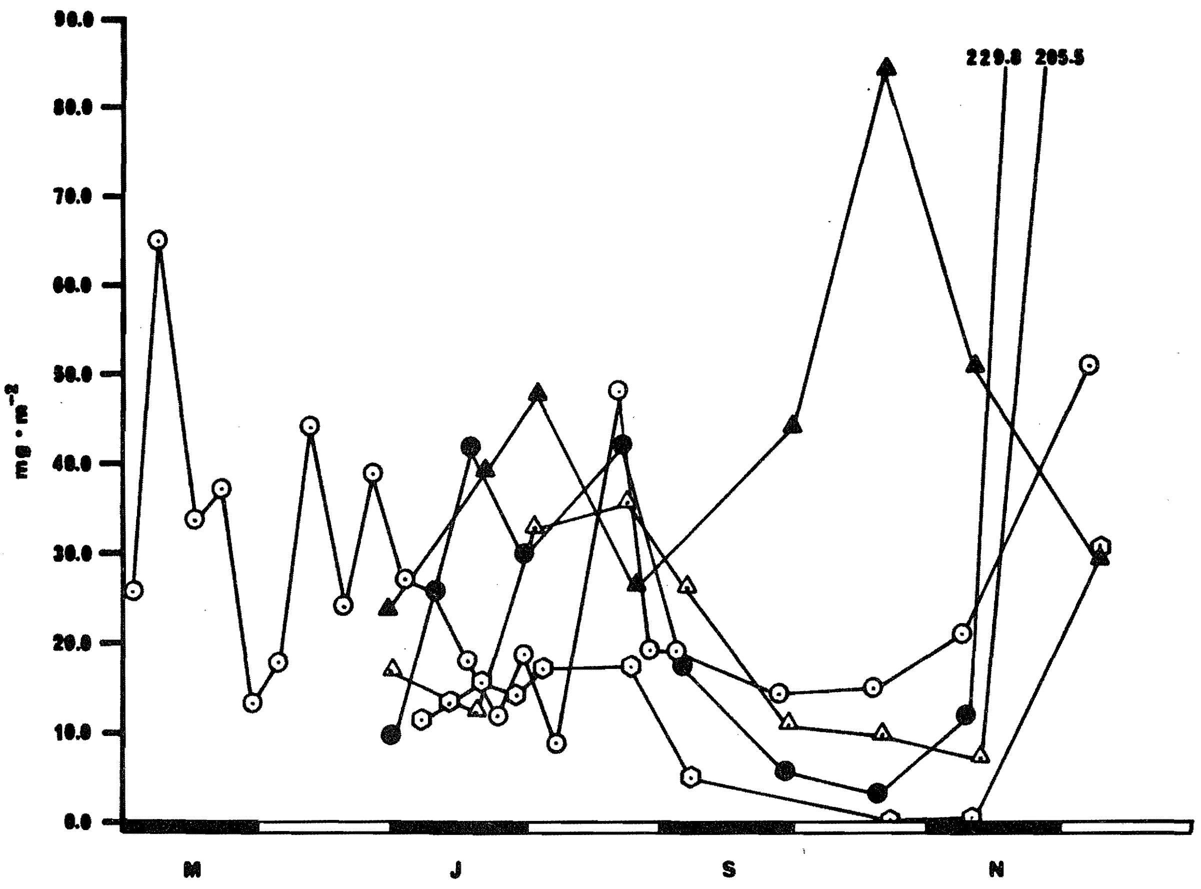

Figure 41. Standing crop, as determined by chlorophyll a, of the epilithon in the Muskeg (⊙), Steepbank (●), MacKay (⬡), Hangingstone (△), and Ells (▲) rivers.

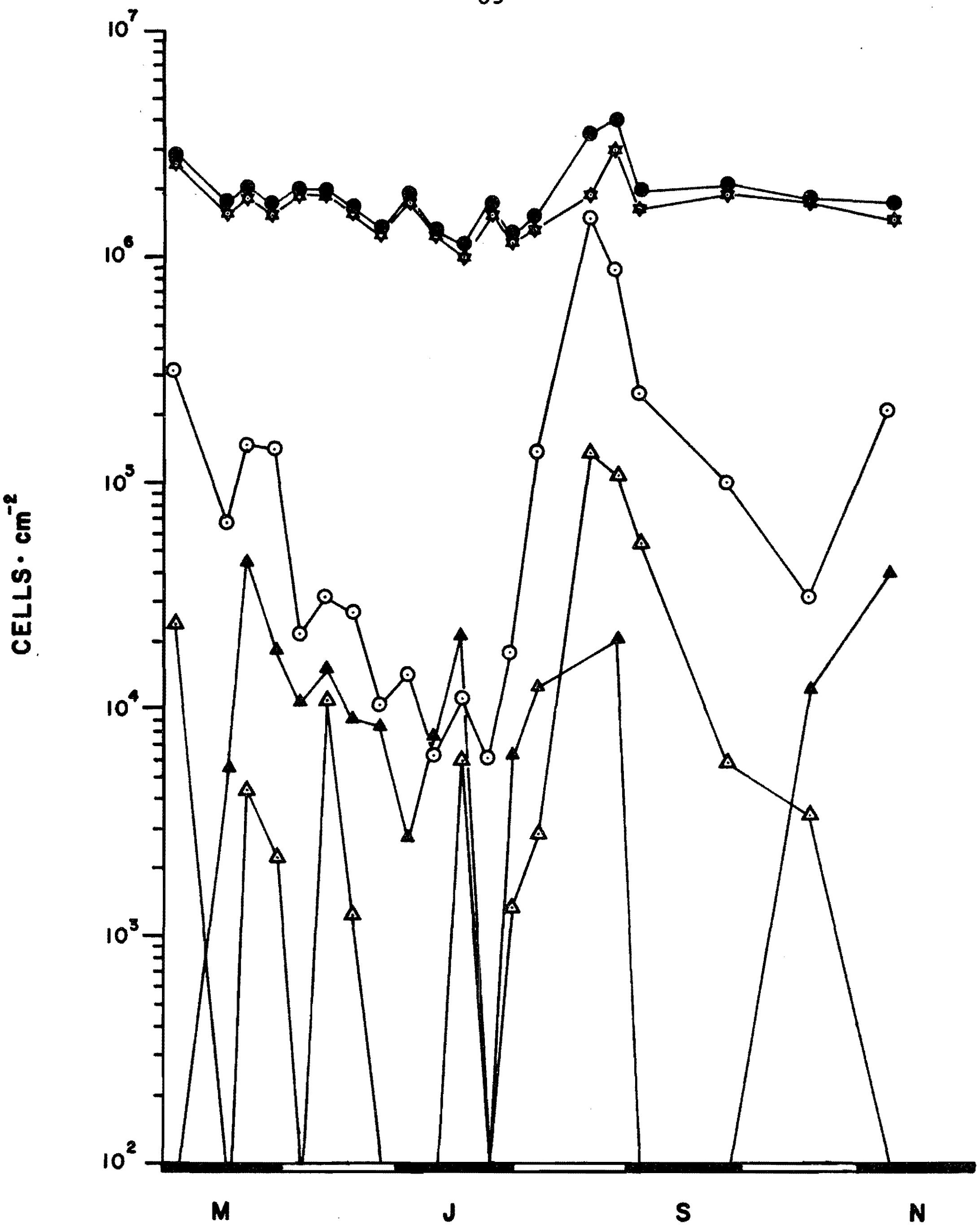

Figure 42. Cell number fluctuations of the epilithon in the Muskeg River. Total numbers (●) Cyanophyta (⬡), Bacillariophyta (⊙), Chlorophyta (△), and Rhodophyta (⬢).

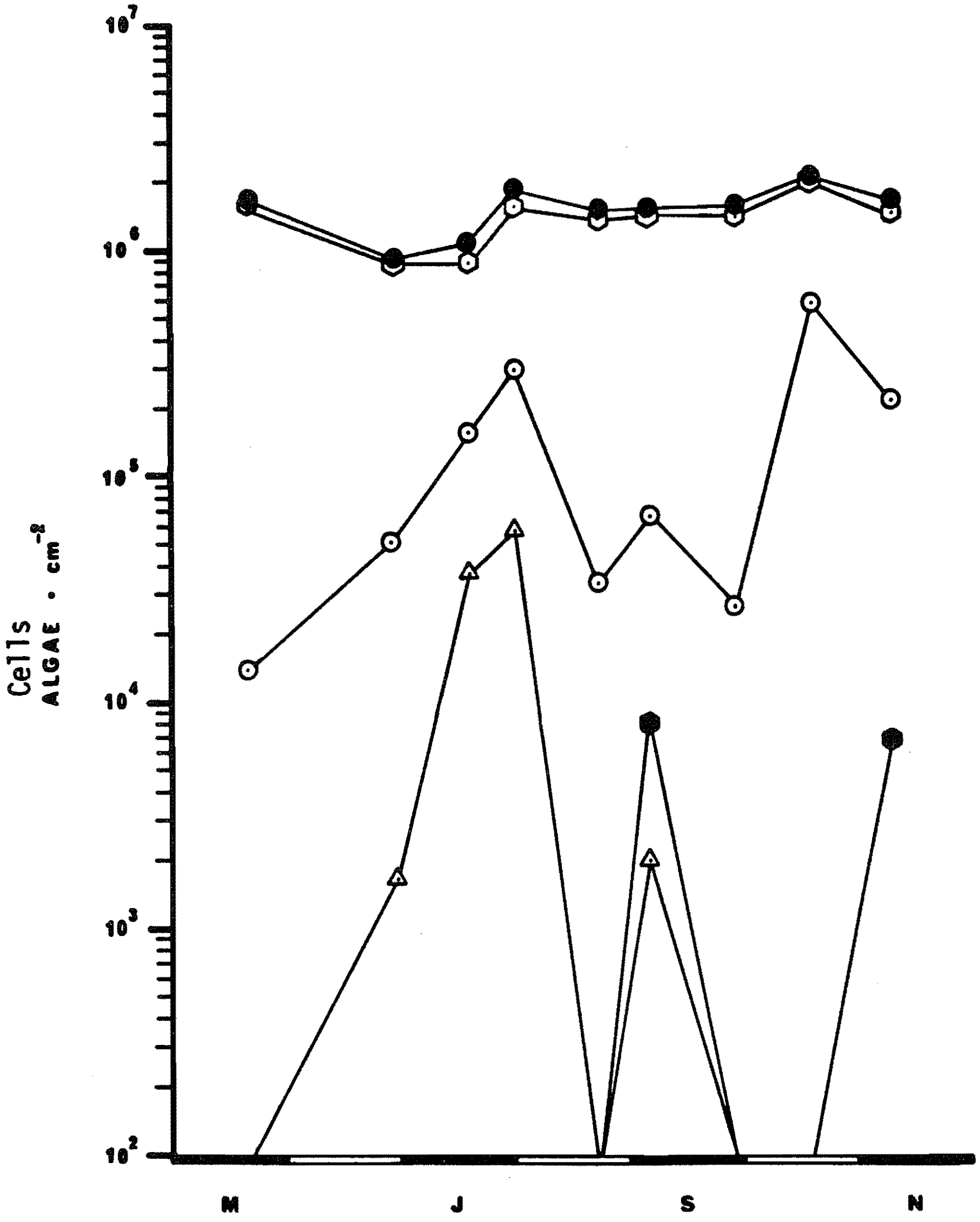

Figure 43. Cell number fluctuations of the epilithon in the Steepbank River. Total numbers (●), Cyanophyta (⬡), Bacillariophyta (⊙), Chlorophyta (△), and Rhodophyta (⬢).

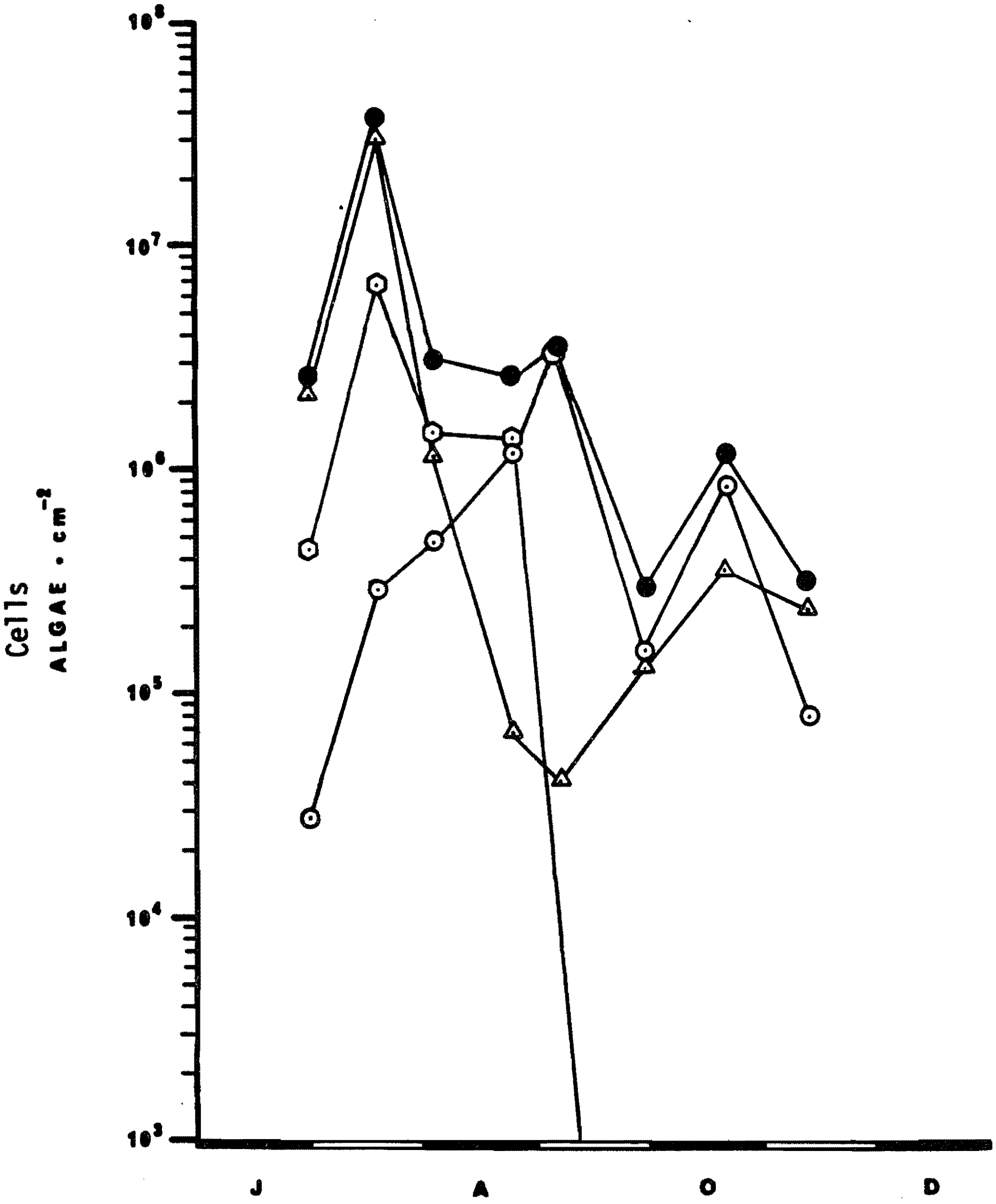

Figure 44. Cell number fluctuations of the epilithon in the Hangingstone River. Total numbers (●), Cyanophyta (⬡), Bacillariophyta (⊙), and Chlorophyta (△).

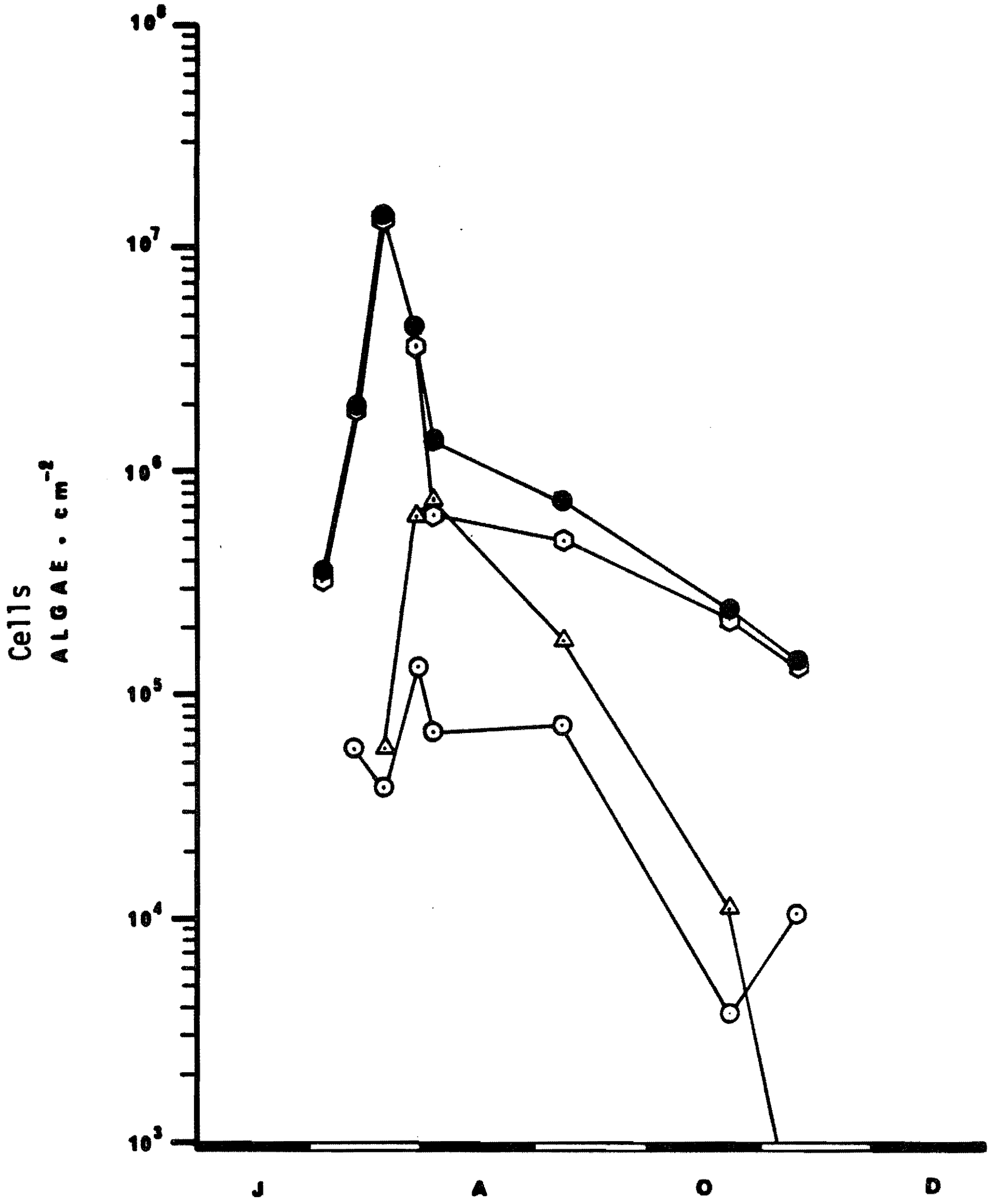

Figure 45. Cell number fluctuations of the epilithon in the MacKay River. Total numbers (●), Cyanophyta (⬡), Bacillariophyta (⊙), and Chlorophyta (△).

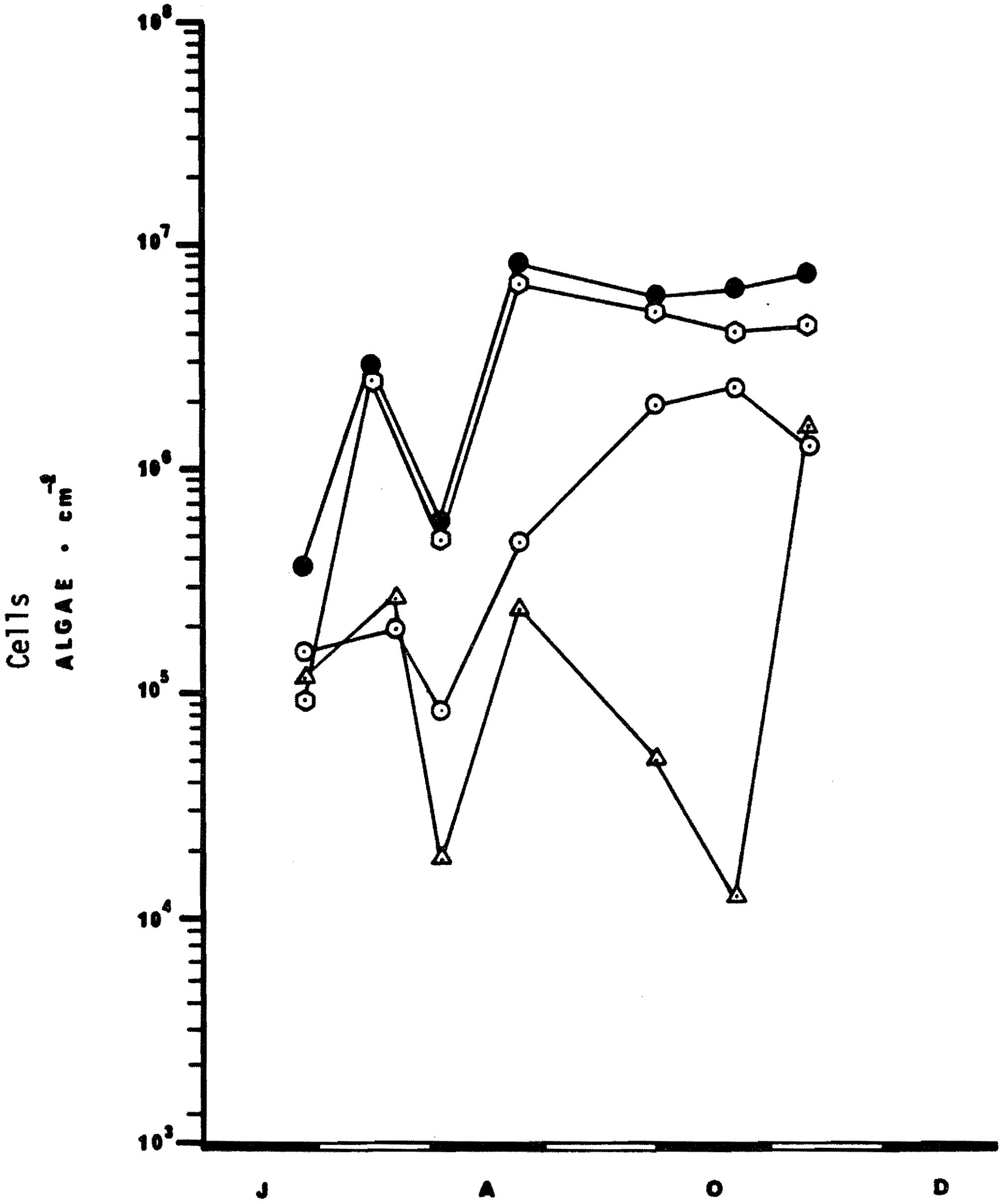

Figure 46. Cell number fluctuations of the epilithon in the Ells River. Total numbers (●), Cyanophyta (⬡), Bacillariophyta (⊙), and Chlorophyta (△).

In the Steepbank River, the standing crop was high during July and August, decreased in the autumn, and increased in early December when a massive peak occurred. This was dominated by blue-green algae *(Lyngbya aerugineo-caerulea)*, diatoms *(Diatoma vulgare, Gomphonema olivaceum,* and *Nitzschia fonticola)*, along with the red alga, *Audouinella* sp., as in the Muskeg River. In contrast, the summer peak was dominated by the diatoms, *Epithemia sorex* and *Lyngbya aerugineo-caerulea,* together with a number of green algae.

Standing crop fluctuations in the Hangingstone and MacKay rivers paralleled those found in the Steepbank River. However, the summer peaks were smaller appearing slightly later. The autumn flood-induced decreases were evident as were increases in early December, particularly in the Hangingstone River where it was only slightly less than that found in the Steepbank River. Summer peaks were dominated by *Stigeoclonium* sp. and *Cladophora glomerata* along with *Calothrix braunii, Anabaena affinis*, and *Lyngbya* sp., and *Calothrix braunii, Lyngbya* sp., *Cladophora glomerata,* and *Epithemia sorex* in the Hangingstone and MacKay rivers, respectively. (Species analysis and enumeration of samples corresponding with the maxima in early December are still in progress.)

A mid-summer standing crop peak also occurred in the Ells River when first *Lyngbya* sp. and then *Anabaena affinis* dominated. These were replaced by *Oscillatoria* sp. and *Calothrix braunii* along with *Lyngbya* sp. toward the end of the peak. Unlike all the other four rivers, no autumn decrease occurred in September; instead a maximum was evident because this river was not subject to intensive flooding and increased discharge rates to the same extent as the four other rivers. *Lyngbya* sp., *Gomphonema olivaceum*, and *Gomphonema longiceps* var. *subclavata* dominated in the autumn. The standing crop then decreased in contrast to the other rivers.

The mean and range of standing crop values for the five rivers during the June to November period are presented in Table 3. A disparity exists between the count data and chlorophyll *a* content. However, this is not surprising since the epilithic algal community comprises a vast heterogeneous collection of different algae of differing sizes, chloroplast size, divisions, and undoubtedly physiological state. Also, cell numbers will overemphasize the importance of tiny but numerically abundant algae and underestimate the larger but less abundant forms (Hickman 1973). Chlorophyll *a* is a measure of volume (organelle volume) and, in communities comprising such a heterogeneous collection of algae, is usually closely related to estimates of cell volume (Hickman 1973). Chlorophyll *a* is used to compare standing crops in the two rivers (cell volume determinations are currently in progress). Largest maxima occurred in the Steepbank and Hangingstone rivers, while the Steepbank and Ells rivers possessed virtually identical mean values, followed by the Hangingstone, Muskeg, and MacKay rivers.

Chlorophycean populations on average were greatest in the Hangingstone River followed by those in the Ells and MacKay. However, in these latter two rivers, numbers were 10 times less than found in the Hangingstone River. Then, in the Muskeg and Steepbank rivers, numbers were 100 times less (Table 4). Less of a difference existed among the rivers in the case of the numbers of diatoms. Again, largest numbers, on average, were found in the Hangingstone River closely followed by the Ells River. Populations in the Muskeg and Steepbank rivers were similar and less occurred in the MacKay River. Blue-green algal numbers were high in all rivers, with largest populations found in the Ells River followed by the MacKay, Muskeg, Steepbank, and Hangingstone rivers. Members of the Rhodophyta (mainly *Audouinella* spp. and *Batrachospermum* spp.) were found in two rivers only in relatively small numbers. These were the Muskeg and Steepbank rivers (Table 4).

Table 3. Mean and range of the standing crop of the epilithic algae as determined by: (1) chlorophyll *a*, (2) total cell numbers, and (3) plankton as determined by chlorophyll *a*, for the five rivers for the period June to November (except the Muskeg River where May to November is also presented).

River	(1) Chlorophyll a (mg m^{-2})	
	Range	Mean
Muskeg May-Nov.	8.71 - 65.7	27.3
June-Nov.	8.71 - 48.2	25.1
Steepbank	3.04 - 229.8	43.5
Hangingstone	7.1 - 205.5	39.7
MacKay	0.3 - 30.7	12.6
Ells	24.0 - 84.5	43.3
River	**(2) Total cell numbers (cells x 10^{10} m^{-2})**	
	Range	Mean
Muskeg	1.1 - 3.9	1.9
Steepbank	1.9 - 2.6	1.6
Hangingstone	29.2 - 3700.0	830.0
MacKay	14.0 - 1400.0	381.0
Ells	36.0 - 702.0	435.0
River	**(3) Plankton (mg·m^{-3} chlorophyll a)**	
	Range	Mean
Muskeg	0 - 18.1	2.4
Steepbank	0 - 57.1	9.7
Ells	0 - 11.1	5.1
Hangingstone	0 - 280.0	32.6
MacKay	0 - 75.8	10.3

Table 4. Mean and range of numbers of: (1) Chlorophyta, (2) Bacillariophyta, (3) Cyanophyta, and (4) Rhodophyta for the five rivers for the period June to November (except the Muskeg River where May to November is also presented).

River		(1) Chlorophyta (cells x 10^8 m^{-2})	
		Range	Mean
Muskeg	May-Nov.	0 - 13.7	1.8
	June-Nov.	0 - 13.7	2.07
Steepbank		0 - 5.8	1.2
Hangingstone		6.8 - 3000.0	430.0
MacKay		0 - 70.5	20.3
Ells		1.23 - 150	37.0

River		(2) Bacillariophyta (cells x 10^8 m^{-2})	
		Range	Mean
Muskeg	May-Nov.	0.6 - 149.0	19.5
	June-Nov.	0.6 - 149.0	20.2
Steepbank		1.4 - 58.3	18.0
Hangingstone		2.8 - 317.0	85.0
MacKay		0.4 - 14.0	5.2
Ells		8.2 - 224.0	7.8

River		(3) Cyanophyta (cells x 10^8 m^{-2})	
		Range	Mean
Muskeg	May-Nov.	102.0 - 290.0	160.0
	June-Nov.	102.0 - 290.0	160.0
Steepbank		86.4 - 200.0	130.0
Hangingstone		0 - 633.0	124.0
MacKay		0.13 - 1360.0	263.0
Ells		9.42 - 667.0	325.0

continued...

Table 4. Concluded.

River		(4) Rhodophyta (cells x 10^8 m^{-2})	
		Range	Mean
Muskeg	May-Nov.	0 - 4.4	1.2
	June-Nov.	0 - 4.0	1.0
Steepbank		0 - 0.7	0.1
Hangingstone		-	-
MacKay		-	-
Ells		-	-

In the determination of standing crop sizes, samples from the river's edge and mid-stream were analyzed and no statistically significant overall differences were evident between the two sets of samples, presumably because of the shallowness of the sampling sites which allowed for good light penetration.

The plankton of these rivers was dominated by a mixture of non-epilithic and senescing epilithic algae. In the Muskeg River, a spring standing crop peak (Figure 47) occurred dominated by *Microcystis aeruginosa* and a variety of desmids which undoubtedly originated in pools on the muskeg (Figure 47). A seasonal peak occurred during August as discharge rates began increasing. A similar mid-summer maximum occurred in the Steepbank river and occurring again during maximal epilithic standing crop size and increasing discharge. Again, the dominant forms were desmids and senescent epilithic algae. The seasonal fluctuation in the Hangingstone River was quite similar, with desmids and senescent epilithic algae being found. The peak at the onset of ice formation (280 $mg \cdot m^{-3}$ chlorophyll *a*) was the largest found in any river and comprised mainly detached epilithic algae. Fluctuation in the MacKay and Ells rivers followed the same general pattern as described above. The algae found in the Ells River were predominantly planktonic probably originating from the headwater lakes.

4.5 PRIMARY PRODUCTIVITY

Primary productivity fluctuations in the five rivers are presented in Figure 48. Epilithic algal productivity was low in all rivers during July and increased during August before decreasing slightly from the September peak. In all rivers, productivity decreased in early November and remained low under ice-cover into early December.

The range and mean primary productivity values are presented in Table 5. On average, epilithic algal primary productivity was

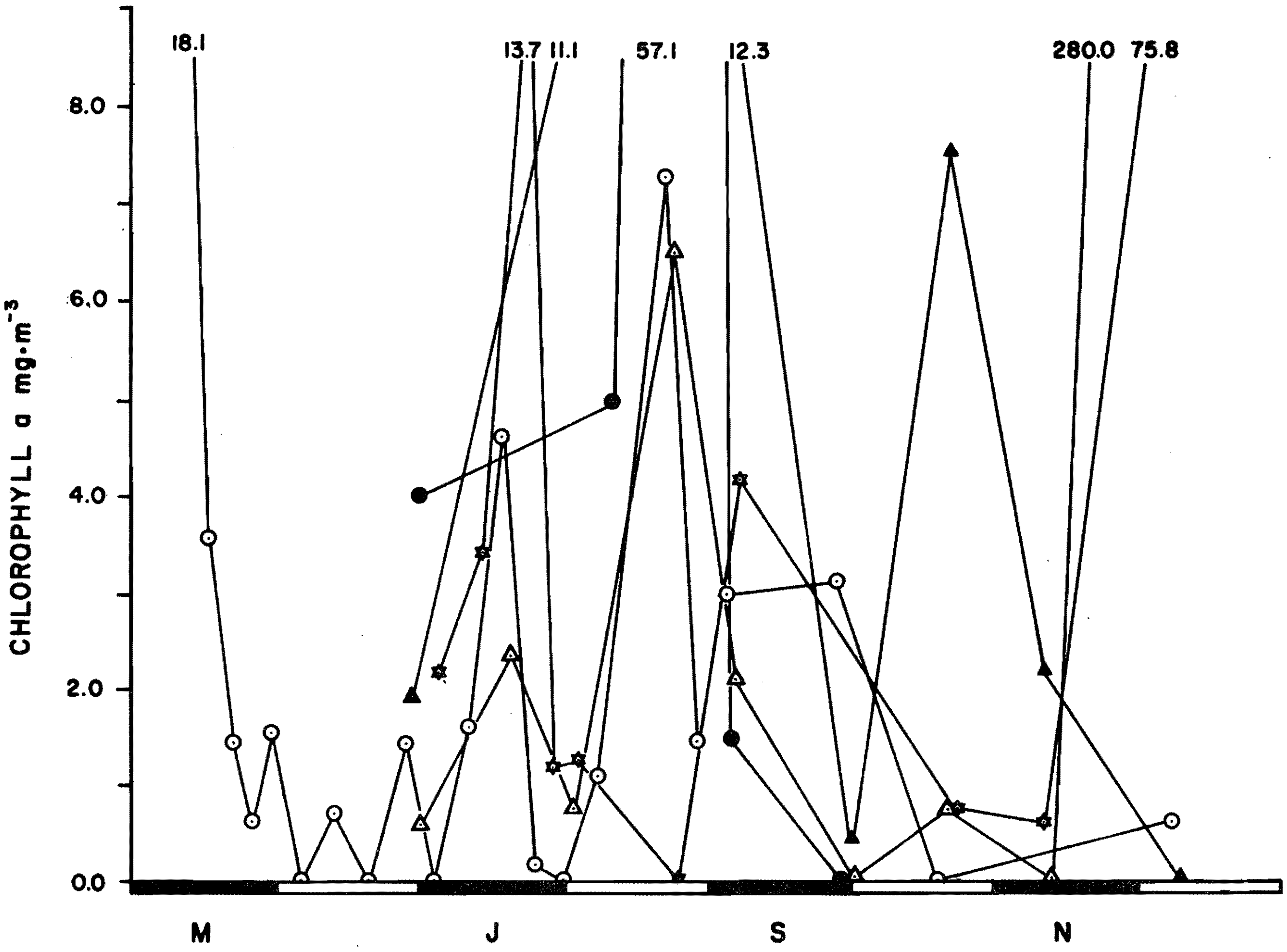

Figure 47. Plankton standing crop fluctuations in the Muskeg (⊙), Steepbank (●), Hangingstone (△), MacKay (✡), and Ells (▲) rivers.

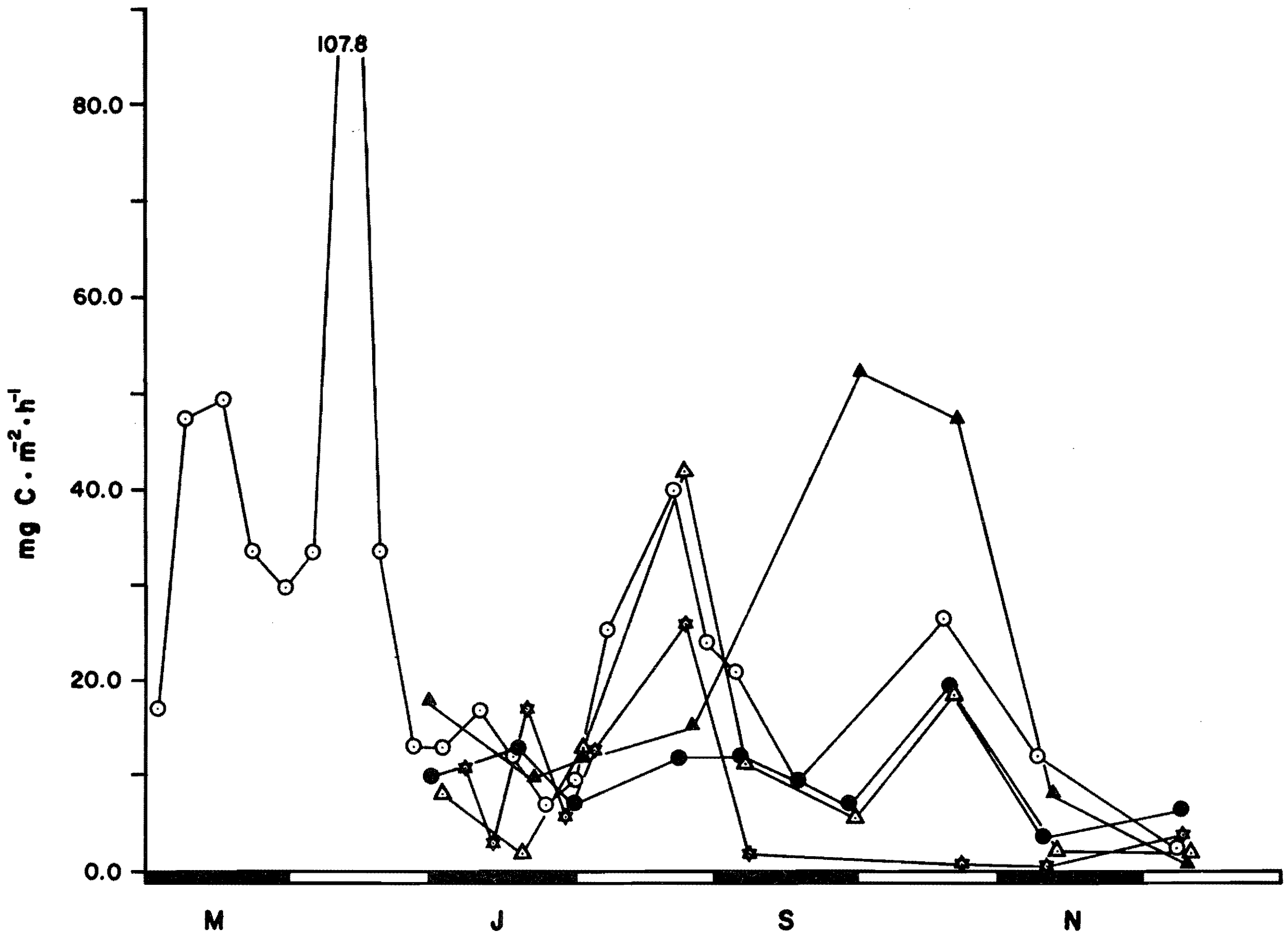

Figure 48. Primary productivity (mg C•m^{-2}•h^{-1}) of the epilithon in the Muskeg (⊙), Steepbank (●), Hangingstone (△), MacKay (✡), and Ells (▲) rivers.

Table 5. Mean and range of the primary productivity of the epilithic algae for the five rivers.

River	Primary Productivity mg $C \cdot m^{-2} \cdot h^{-1}$	
	Range	Mean
Muskeg	6.9 - 107.8	26.5
Steepbank	3.4 - 19.3	9.9
MacKay	0.5 - 26.0	8.2
Hangingstone	1.9 - 41.9	11.8
Ells	1.1 - 52.5	20.6
Muskeg (experiments performed under artificial shade)	0.4 - 56.7	12.8

highest in the Muskeg and Ells rivers and lower with no significant differences among the other three rivers.

Since a small section of the Muskeg River bed was artificially shaded, simultaneous experiments were performed underneath as well as in situ. On average, this shading resulted in an approximate halving of the primary productivity, thus illustrating the importance of irradiance in controlling primary productivity.

By early winter, the circulating chambers had been constructed and an experiment performed in early November (Table 6). Populations at this time were low in the MacKay, Hangingstone, and Steepbank rivers but high in the Ells River (Figure 41). In the first three rivers, populations ranged from 0.5 to 12.0 $mg{\cdot}m^{-2}$ chlorophyll *a* and in the Ells River a value of 50 $mg{\cdot}m^{-2}$ chlorophyll *a* was found. In all but the Steepbank River, higher results occurred in the circulating chambers (Table 6). Therefore, it is essential that these chambers be used during the remainder of this study and in the forthcoming year such that corrections to those results obtained with non-circulating chambers can be made since the latter underestimates true productivity. Correction factors will undoubtedly vary depending upon species composition, population size, and current velocity.

A comparison between epilithic algal primary productivity at the edge and mid-stream sites revealed no overall differences when mean values were examined. The results were variable (Table 7) with significant differences favouring the edge station only occurring on four occasions in the Muskeg River. These results were not unexpected because of the shallow nature of the river and the horizontal variability in standing crop size. A similar situation occurred with respect to standing crop size (shore and mid-stream overall mean standing crops were 25.3 and 22.2 $mg{\cdot}m^{-2}$ chlorophyll *a*, respectively).

Table 6. A comparison of primary productivity results using circulating and non-circulating incubation chambers (experiments performed in situ on 9, 10, 11, and 12 November 1978).

River	mg $C \cdot m^{-2} \cdot h^{-1}$	
	Non-Circulating Chamber	Circulating Chamber
Steepbank	4.9	2.9
MacKay	0.5	1.1
Hangingstone	2.3	2.5
Ells	8.0	11.5

Table 7. A comparison of primary productivity of epilithic algae at a shallow edge site and in mid-stream in the Muskeg River.

Date	Mid-Stream		Shallow Edge
	mg $C \cdot m^{-2} \cdot h^{-1}$		
29 May 1978	27.9	<	30.9
5 June	41.9	>	22.3
12 June	82.9	<	132.6
19 June	33.7	>	33.5
26 June	11.8	<	13.8
3 July	10.7	<	14.8
10 July	18.2	>	15.5
17 July	11.8	=	11.8
24 July	4.7	<	9.1[a]
31 July	10.4	>	8.8
7 August	12.6	<	42.3
21 August	50.3	>	18.7
28 August	17.1	<	31.0[a]
4 September	31.2	>	8.9
18 October	32.2	>	23.8
8 November	4.7	<	19.5[a]
7 December	1.9	<	2.6
	$\bar{x}$ 23.8		$\bar{x}$ 25.9

[a] Significantly different according to "t" test.

4.6 PRELIMINARY CORRELATIONS

Preliminary correlations between standing crop, growth of major algal groups, and primary productivity with various physical and chemical factors were examined to provided initial information about any controlling factors.

No one nutrient was limiting to standing crop size. In the Muskeg River, nutrient supply was more than adequate to support the standing crops; whereas, in the Steepbank, Hangingstone, and MacKay rivers, dissolved silica and nitrate-nitrogen were important (Table 8). Interestingly, iron also gave a significant negative correlation in the Hangingstone River while all three major nutrients, together with iron and manganese, did in the MacKay River. Only manganese was important in the Ells River.

Temperature was correlated with standing crop in only the Ells and MacKay rivers, negatively and positively, respectively (Table 9). Irradiance was important in all the rivers except the Muskeg River. The autumn decrease in standing crop size undoubtedly resulted from the increase discharge rates during this period.

Similarly, no one over-riding nutrient or physical factor was responsible for controlling fluctuations and population sizes of the major algal groups. Dissolved silica only appeared to be limiting to diatom growth in two rivers, namely, the Hangingstone and MacKay rivers; no other nutrients correlated with diatom growth in any river (Table 10). Irradiance was correlated with diatom growth in the MacKay and Ells rivers (Table 11) along with temperature in the latter. Both temperature and irradiance were negatively correlated with diatom growth. Correlations were less clear with the Chlorophyta (Table 10). Calcium was implicated in the Muskeg River, dissolved silica in the Steepbank River, nitrate-nitrogen and iron in the MacKay River, while none appeared limiting in either the Hangingstone or Ells rivers. Neither irradiance or temperature were correlated with the Chlorophyta (Table 11). Only nitrate-nitrogen correlated with the Cyanophyta and that happened

Table 8. Correlations between epilithic algal standing crop and potentially limiting nutrients.

Nutrient	River				
	Muskeg	Steepbank	Hangingstone	Ells	MacKay
SiO_2	N.S.	$r=-0.726$ $p< 0.10$	$r=-0.590$ $p< 0.10$	N.S.	$r=-0.854$ $p< 0.01$
NO_3-N	N.S.	$r=-0.675$ $p< 0.10$	$r=-0.679$ $p< 0.05$	N.S.	$r=-0.918$ $p< 0.01$
PO_4-P	N.S.	N.S.	N.S.	N.S.	$r=-0.932$ $p< 0.01$
Fe	N.S.	N.S.	$r=-0.591$ $p< 0.10$	N.S.	$r=-0.875$ $p< 0.01$
Mn	N.S.	N.S.	N.S.	$r=-0.610$ $p< 0.10$	$r=-0.774$ $p< 0.05$

N.S. = not significant.

Table 9. Correlations between epilithic algal standing crop and temperature and irradiance factors.

	River				
	Muskeg	Steepbank	Hangingstone	Ells	MacKay
Temperature	N.S.	N.S.	N.S.	r=-0.746 p< 0.05	r=0.893 p<0.01
Irradiance	N.S.	r=0.637 p<0.10	r=0.673 p<0.05	r=-0.695 p< 0.10	r=0.958 p<0.01

Table 10. Correlations between the major epilithic algal groups and potentially limiting nutrients.

	Diatoms	Chlorophyta	Cyanophyta	Rhodophyta
MUSKEG RIVER				
PO_4-P	N.S.	N.S.	N.S.	N.S.
SiO_2	N.S.	N.S.	N.S.	N.S.
NO_3-N	N.S.	N.S.	N.S.	N.S.
Mg	N.S.		N.S.	N.S.
Ca	N.S.	$r=-0.523$ $p< 0.10$	N.S.	N.S.
SO_4	N.S.	N.S.	N.S.	N.S.
Fe	N.S.	N.S.	N.S.	N.S.
STEEPBANK RIVER				
PO_4-P	N.S.	N.S.	N.S.	N.S.
SiO_2	N.S.	$r=-0.753$ $p< 0.05$	N.S.	N.S.
NO_3-N	N.S.	N.S.	N.S.	$r=-0.723$ $p< 0.05$
Mg	N.S.	N.S.	N.S.	N.S.
Ca	N.S.	N.S.	N.S.	N.S.
SO_4	N.S.	N.S.	N.S.	N.S.
Fe	N.S.	N.S.	N.S.	N.S.
HANGINGSTONE RIVER				
PO_4-P	N.S.	N.S.	N.S.	Not Present
SiO_2	$r=-0.614$ $p< 0.10$	N.S.	N.S.	
NO_3-N	N.S.	N.S.	$r=-0.581$ $p< 0.10$	

continued...

Table 10. Concluded.

	Diatoms	Chlorophyta	Cyanophyta	Rhodophyta
HANGINGSTONE RIVER				
Mg	N.S.	N.S.	N.S.	Not Present
Ca	N.S.	N.S.	N.S.	
SO_4	N.S.	N.S.	N.S.	
Fe	N.S.	N.S.	N.S.	
MACKAY RIVER				
PO_4-P	N.S.	N.S.	N.S.	Not Present
SiO_2	$r=-0.558$ $p< 0.10$	N.S.	N.S.	
NO_3-N	N.S.	$r=-0.639$ $p< 0.10$	N.S.	
Mg	N.S.	N.S.	N.S.	
Ca	N.S.	N.S.	N.S.	
SO_4	N.S.	N.S.	N.S.	
Fe	N.S.	$r=-0.609$ $p< 0.10$	N.S.	
ELLS RIVER				
PO_4-P	N.S.	N.S.	N.S.	Not Present
SiO_2	N.S.	N.S.	N.S.	
NO_3-N	N.S.	N.S.	N.S.	
Mg	N.S.	N.S.	N.S.	
Ca	N.S.	N.S.	N.S.	
SO_4	N.S.	N.S.	N.S.	
Fe	N.S.	N.S.	N.S.	

Table 11. Correlations between the major epilithic algal groups and temperature and irradiance factors.

	Diatoms	Chlorophyta	Cyanophyta	Rhodophyta
MUSKEG RIVER				
Temperature	N.S.	N.S.	N.S.	N.S.
Irradiance	N.S.	N.S.	N.S.	$r=-0.421$ $p< 0.10$
STEEPBANK RIVER				
Temperature	N.S.	N.S.	N.S.	N.S.
Irradiance	N.S.	N.S.	N.S.	N.S.
HANGINGSTONE RIVER				
Temperature	N.S.	N.S.	N.S.	Not Present
Irradiance	N.S.	N.S.	N.S.	
MACKAY RIVER				
Temperature	N.S.	N.S.	N.S.	Not Present
Irradiance	$r=-0.558$ $p< 0.10$	N.S.	N.S.	
ELLS RIVER				
Temperature	$r=-0.836$ $p< 0.05$	N.S.	N.S.	Not Present
Irradiance	$r=-0.87$ $p< 0.05$	N.S.	N.S.	

in the Hangingstone River and no physical factor was implicated. Members of the Rhodophyta, present in the Muskeg and Steepbank rivers only, correlated with nitrate-nitrogen and irradiance in the former and latter, respectively (Tables 10 and 11).

The discharge rate was extremely important in controlling overall population size and fluctuations in all rivers except the Ells River. This is exemplified by the highly significant correlation found between the mean discharge rates and mean standing crops for the five rivers ($r=-0.825$, $p<0.05$). Thus, rivers with the higher overall discharge rates possessed, on average, the lower overall standing crops.

Factors controlling primary productivity were also variable (Tables 12 and 13). Standing crops were important in the Muskeg, MacKay, and Hangingstone rivers but not in the Steepbank or Ells rivers. In fact, in the Steepbank, no factor examined correlated with primary productivity. In the Muskeg River, carbon and pH correlate with primary productivity as well as standing crop. In both the MacKay and Ells rivers, many factors correlated with productivity (Table 13).

Undoubtedly, current velocity is important as indicated by the one experiment reported already. A complex relationship between current velocity, population size, diffusion rates, physical factors, and primary productivity exists.

4.7 DISCUSSION

Numerically, blue-green algae and diatoms were the most important epilithic algae in all rivers but the Hangingstone River where chlorophycean algae, together with diatoms, were most important. Fluctuations of the epilithic algal populations were not controlled by a single factor but instead by a complex myriad of interacting factors, including both chemical and physical ones. Variations occurred from river to river, particularly when nutrients were examined, but less variation among the rivers occurred with irradiance which appeared to be an important factor controlling population size.

Table 12. Correlation between epilithic algal standing crop and primary productivity.

River		
Muskeg	r=-0.536	$p<0.05$
Steepbank	N.S.	
Hangingstone	r=-0.668	$p<0.10$
MacKay	r=-0.776	$p<0.05$
Ells	N.S.	

N.S. = not significant

Table 13. Correlations between epilithic algal primary productivity and physical and chemical factors.

	River				
	Muskeg	**Steepbank**	**Hangingstone**	**MacKay**	**Ells**
Irradiance	N.S.	N.S.	N.S.	$r=0.786$ $p<0.05$	N.S.
Temperature	N.S.	N.S.	N.S.	$r=0.649$ $p<0.10$	N.S.
Carbon	$r=0.711$ $p<0.01$	N.S.	N.S.	N.S.	$r=0.891$ $p<0.01$
NO_3-N	N.S.	N.S.	N.S.	$r=0.855$ $p<0.01$	N.S.
PO_4-P	N.S.	N.S.	N.S.	$r=-0.779$ $p<0.05$	N.S.
SiO_2	N.S.	N.S.	N.S.	$r=-0.625$ $p<0.10$	$r=0.712$ $p<0.05$
pH	$r=-0.633$ $p<0.01$	N.S.	N.S.	$r=0.779$ $p<0.05$	$r=-0.688$ $p<0.05$
Mg	N.S.	N.S.	N.S.	$r=0.664$ $p<0.10$	N.S.
Ca	N.S.	N.S.	N.S.	$r=0.649$ $p<0.10$	N.S.
Fe	N.S.	N.S.	N.S.	$r=-0.693$ $p<0.10$	$r=0.835$ $p<0.05$
Na	N.S.	N.S.	N.S.	$r=0.613$ $p<0.10$	$r=-0.7010$ $p<0.05$
SO_4	N.S.	N.S.	N.S.	N.S.	$r=0.776$ $p<0.05$

N.S. = not significant

Variations among the rivers occurred even among the major algal groups. Dissolved silica concentrations were related to the wax and wane of diatom populations only in the Hangingstone and MacKay rivers. Wang and Evans (1969) and Edwards (1974) also found a similar relationship in their studies, whereas Marker (1976b) did not in shallow chalk streams. Temperature was only important in the Ells and MacKay rivers even though its fluctuations and the dominant algae were similar in all rivers.

Discharge rates were closely correlated with the epilithic algal standing crop. The late summer/autumnal flood dramatically reduced population size in all but the Ells River where discharge rates fluctuated least. Again several interacting factors are implicated. Rapid disappearance rates of algae from rocks depend upon population size, the actual mode of attachment, and morphology of the dominant algae. As epilithic algal populations increase in size, the thickness of the algal growth alters the resistance to flow such that, during periods of high standing crops, effects become more devastating. Increased resistance also can occur through suspended sediment and detritus becoming trapped by the algal populations. This whole process will be further accentuated as the basal algal cells become senescent in dense populations, thus reducing the attachment properties. The importance of discharge rates in controlling overall epilithic algal standing crop size is further exemplified by the inverse relationship formed for these rivers.

Only in two rivers did epilithic algal standing crops begin to approach values that have been observed by Tominaga and Ichimura (1966), Edwards and Owens (1965), and McIntire (1966) in both natural and artificial streams, namely, the Hangingstone and Steepbank rivers. Here the maxima attained are comparable to estimates of the maximum phytoplankton standing crop per unit area of the euphotic zone of eutrophic lakes which may be expected on theoretical grounds (about 200 to 300 $mg \cdot m^{-2}$ chlorophyll *a*)

(Talling et al. 1973). Those rivers can be classified as eutrophic following Butcher (1946) who gave cell number of benthic algae between 2 to 10 x 10^9 cells·m^{-2} for eutrophic waters.

Primary productivity measurements presented here underestimate actual rates because non-circulating chambers were used until the simple circulating chambers became operative in the autumn. However, on a comparative basis over the study period, the productivity in the Muskeg and Ells rivers was greatest with little difference occurring among the other three. Primary productivity was related to standing crop size in all but the Steepbank and Ells rivers but to irradiance in only the MacKay River. Again, variability occurred among the rivers. Undoubtedly, productivity of the epilithic algae is greatly influenced by current velocities. Water currents affect respiration, gaseous diffusion, mineral uptake, and photosynthetic rates and, as indicated by McConnell and Sigler (1959) and Hickman (1974), any static chamber is likely to cause underestimations. This was further exemplified by the results using the circulating chamber in these rivers on small populations. This will be confirmed during the next phase of this project using the circulating chambers since natural current velocity provides the internal current.

Conversion of the standing crop data (mg·m^{-2} chlorophyll *a*) to organic dry weight [following Marker (1976a)] was made to gain an initial insight into the contribution in organic matter by the epilithic algae even though in natural populations chlorophyll *a* as a percentage of the dry weight can vary widely. Also, the conversion factor used by Marker (1976a) was determined upon an epilithic algal community dominated by diatoms. In a small chalk river, the maximum contribution during a diatom peak was between 12 to 15 gm organic matter·m^{-2} (Marker 1976a). Such values over the June to November period were approached only in the Hangingstone and Steepbank rivers (Table 14). Maximum values

Table 14. Maximum and mean contribution of the epilithic algae to the organic matter of the five rivers.

River	g organic matter·m^{-2} Maximum	Mean
Muskeg	3.29	1.37
Steepbank	11.49	2.18
Hangingstone	10.28	1.99
MacKay	1.54	0.63
Ells	4.25	2.17

were much lower in the other three rivers. Largest mean values were found in the Ells and Steepbank rivers and the lowest in the MacKay River.

The unattached "planktonic" algae cannot be ignored because of the significant standing crops found. These varied greatly depending upon discharge rates and flooding of surrounding muskeg. A times, when the epilithic populations become torn loose, more significant populations would be encountered, but all contribute to providing organic matter to these systems.

In summary, therefore, this initial study has described the major algal groups, species composition, and succession of dominants. It has provided an initial measurement of standing crops and primary productivity and examined factors affecting the above, both physical and chemical. No one factor is solely responsible, which was to be expected. However, one of the most important is discharge in all the rivers. Further investigation during this coming year will help to further elucidate the controlling factors.

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6. AOSERP RESEARCH REPORTS

1.		AOSERP First Annual Report, 1975
2.	AF 4.1.1	Walleye and Goldeye Fisheries Investigations in the Peace-Athabasca Delta--1975
3.	HE 1.1.1	Structure of a Traditional Baseline Data System
4.	VE 2.2	A Preliminary Vegetation Survey of the Alberta Oil Sands Environmental Research Program Study Area
5.	HY 3.1	The Evaluation of Wastewaters from an Oil Sand Extraction Plant
6.		Housing for the North--The Stackwall System
7.	AF 3.1.1	A Synopsis of the Physical and Biological Limnology and Fisheries Programs whithin the Alberta Oil Sands Area
8.	AF 1.2.1	The Impact of Saline Waters upon Freshwater Biota (A Literature Review and Bibliography)
9.	ME 3.3	Preliminary Investigations into the Magnitude of Fog Occurrence and Associated Problems in the Oil Sands Area
10.	HE 2.1	Development of a Research Design Related to Archaeological Studies in the Athabasca Oil Sands Area
11.	AF 2.2.1	Life Cycles of Some Common Aquatic Insects of the Athabasca River, Alberta
12.	ME 1.7	Very High Resolution Meteorological Satellite Study of Oil Sands Weather: "A Feasibility Study"
13.	ME 2.3.1	Plume Dispersion Measurements from an Oil Sands Extraction Plant, March 1976
14.		
15.	ME 3.4	A Climatology of Low Level Air Trajectories in the Alberta Oil Sands Area
16.	ME 1.6	The Feasibility of a Weather Radar near Fort McMurray, Alberta
17.	AF 2.1.1	A Survey of Baseline Levels of Contaminants in Aquatic Biota of the AOSERP Study Area
18.	HY 1.1	Interim Compilation of Stream Gauging Data to December 1976 for the Alberta Oil Sands Environmental Research Program
19.	ME 4.1	Calculations of Annual Averaged Sulphur Dioxide Concentrations at Ground Level in the AOSERP Study Area
20.	HY 3.1.1	Characterization of Organic Constituents in Waters and Wastewaters of the Athabasca Oil Sands Mining Area
21.		AOSERP Second Annual Report, 1976-77
22.		Alberta Oil Sands Environmental Research Program Interim Report to 1978 covering the period April 1975 to November 1978
23.	AF 1.1.2	Acute Lethality of Mine Depressurization Water on Trout Perch and Rainbow Trout
24.	ME 1.5.2	Air System Winter Field Study in the AOSERP Study Area, February 1977.
25.	ME 3.5.1	Review of Pollutant Transformation Processes Relevant to the Alberta Oil Sands Area

26.	AF 4.5.1	Interim Report on an Intensive Study of the Fish Fauna of the Muskeg River Watershed of Northeastern Alberta
27.	ME 1.5.1	Meteorology and Air Quality Winter Field Study in the AOSERP Study Area, March 1976
28.	VE 2.1	Interim Report on a Soils Inventory in the Athabasca Oil Sands Area
29.	ME 2.2	An Inventory System for Atmospheric Emissions in the AOSERP Study Area
30.	ME 2.1	Ambient Air Quality in the AOSERP Study Area, 1977
31.	VE 2.3	Ecological Habitat Mapping of the AOSERP Study Area: Phase I
32.		AOSERP Third Annual Report, 1977-78
33.	TF 1.2	Relationships Between Habitats, Forages, and Carrying Capacity of Moose Range in northern Alberta. Part I: Moose Preferences for Habitat Strata and Forages.
34.	HY 2.4	Heavy Metals in Bottom Sediments of the Mainstem Athabasca River System in the AOSERP Study Area
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36.	AF 4.8.1	Fall Fisheries Investigations in the Athabasca and Clearwater Rivers Upstream of Fort McMurray: Volume I
37.	HE 2.2.2	Community Studies: Fort McMurray, Anzac, Fort MacKay
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43.	TF 6.1	A Socioeconomic Evaluation of the Recreational Fish and Wildlife Resources in Alberta, with Particular Reference to the AOSERP Study Area. Volume I: Summary and Conclusions
44.	VE 3.1	Interim Report on Symptomology and Threshold Levels of Air Pollutant Injury to Vegetation, 1975 to 1978
45.	VE 3.3	Interim Report on Physiology and Mechanisms of Air-Borne Pollutant Injury to Vegetation, 1975 to 1978
46.	VE 3.4	Interim Report on Ecological Benchmarking and Biomonitoring for Detection of Air-Borne Pollutant Effects on Vegetation and Soils, 1975 to 1978.
47.	TF 1.1.1	A Visibility Bias Model for Aerial Surveys for Moose on the AOSERP Study Area
48.	HG 1.1	Interim Report on a Hydrogeological Investigation of the Muskeg River Basin, Alberta
49.	WS 1.3.3	The Ecology of Macrobenthic Invertebrate Communities in Hartley Creek, Northeastern Alberta
50.	ME 3.6	Literature Review on Pollution Deposition Processes
51.	HY 1.3	Interim Compilation of 1976 Suspended Sediment Date in the AOSERP Study Area
52.	ME 2.3.2	Plume Dispersion Measurements from an Oil Sands Extraction Plan, June 1977

53.	HY 3.1.2	Baseline States of Organic Constituents in the Athabasca River System Upstream of Fort McMurray
54.	WS 2.3	A Preliminary Study of Chemical and Microbial Characteristics of the Athabasca River in the Athabasca Oil Sands Area of Northeastern Alberta
55.	HY 2.6	Microbial Populations in the Athabasca River
56.	AF 3.2.1	The Acute Toxicity of Saline Groundwater and of Vanadium to Fish and Aquatic Invertebrates
57.	LS 2.3.1	Ecological Habitat Mapping of the AOSERP Study Area (Supplement): Phase I
58.	AF 2.0.2	Interim Report on Ecological Studies on the Lower Trophic Levels of Muskeg Rivers Within the Alberta Oil Sands Environmental Research Program Study Area
59.	TF 3.1	Semi-Aquatic Mammals: Annotated Bibliography
60.	WS 1.1.1	Synthesis of Surface Water Hydrology
61.	AF 4.5.2	An Intensive Study of the Fish Fauna of the Steepbank River Watershed of Northeastern Alberta
62.	TF 5.1	Amphibians and Reptiles in the AOSERP Study Area
63.		Calculate Sigma Data for the Alberta Oil Sands Environmental Research Program Study Area.
64.	LS 21.6.1	A Review of the Baseline Data Relevant to the Impacts of Oil Sands Development on Large Mammals in the AOSERP Study Area
65.	LS 21.6.2	A Review of the Baseline Data Relevant to the Impacts of Oil Sands Development on Black Bears in the AOSERP Study Area
66.	AS 4.3.2	An Assessment of the Models LIRAQ and ADPIC for Application to the Athabasca Oil Sands Area
67.	WS 1.3.2	Aquatic Biological Investigations of the Muskeg River Watershed
68.	AS 1.5.3 AS 3.5.2	Air System Summer Field Study in the AOSERP Study Area, June 1977
69.	HS 40.1	Native Employment Patterns in Alberta's Athabasca Oil Sands Region
70.	LS 28.1.2	An Interim Report on the Insectivorous Animals in the AOSERP Study Area
71.	HY 2.2	Lake Acidification Potential in the Alberta Oil Sands Environmental Research Program Study Area
72.	LS 7.1.2	The Ecology of Five Major Species of Small Mammals in the AOSERP Study Area: A Review
73.	LS 23.2	Distribution, Abundance and Habitat Associations of Beavers, Muskrats, Mink and River Otters in the AOSERP Study Area, Northeastern Alberta
-	--	Interim Report to 1978
74.	AS 4.5	Air Quality Modelling and User Needs
75.	LS 2.1	Interim Report on the Soils Inventory of the AOSERP Study Area

76.	AF 4.5.1	An Intensive Study of the Fish Fauna of the Muskeg River Watershed of Northeastern Alberta
77.	HS 20.1	Overview of Local Economic Development in the Athabasca Oil Sands Region Since 1961.
78.	LS 22.1.1	Habitat Relationships and Management of Terrestrial Birds in Northeastern Alberta.
79.	AF 3.6.1	The Multiple Toxicity of Vanadium, Nickel, and Phenol to Fish.

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