THE UNIVERSITY OF MANITOBA

NUTRIENT BUDGETS AND SEDIMENTATION IN CHAR LAKE, N.W.T., 74°42' N; 94°50' W.

by

LAURENCE DE MARCH

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE

DEPARTMENT OF ZOOLOGY

WINNIPEG, MANITOBA

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ABSTRACT

Supplies and losses of nitrogen, phosphorus, and organic carbon were measured at Char Lake, N.W.T. in 1972 and 1973. Parameters measured were inflows, precipitation, outflow and sedimentation.

Total supplies per square metre of lake area were 2.46 g organic carbon (C_o) yr^{-1}, 0.325 g N yr^{-1}, and 0.024 g P yr^{-1} as a two year mean. Only 12% of N and P and 16% of allochthonous C_o entered the lake in direct precipitation. Allochthonous C_o was found to be a minor component (10.5%) of the Char Lake C_o budget.

The lake was relatively inefficient in retaining nutrients. Only 63% of the N supply and 55% of the P supply were retained. Outflow losses of C_o were minor (8.9%).

Sediments were found to be unevenly distributed. They were thickest in the moss zone and at the maximum water depth (Z_m). Fine sediments were absent near shore and thin in water depths of 15 to 20 metres.

Low concentrations of C_o, N, and P were found in the sediments and these varied from place to place in the lake. The sediments were found to contain only 45% of the N retained by the lake, and 17% of the C_o not accounted for by other losses. Sedimented P accounted for 117% of the amount retained by the lake.

Factors affecting the supply, losses , and sedimentation of C_o, N, and P are discussed.

ACKNOWLEDGEMENTS

I wish to thank Dr. D.W. Schindler, my supervisor, for advice and counsel during the course of the study.

Thanks are due also to Dr. G.J. Brunskill, Dr. F.J. Ward, and Dr. K.W. Stewart for critically reviewing the manuscript.

I give a special thanks to Brigitte who kept the project enjoyable, and lent me her calculator.

B. Graham performed the X-ray diffraction analyses and lent me a C-H-N analyser. Dr. I. Lubinsky identified the mollusks from Char Lake sediments. I am grateful to them both.

I also want to thank all the people in the Freshwater Institute for use of their facilities and equipment and for willingly giving advice when it was needed.

Thanks too, to all the summer student assistants and graduate students at Char Lake who gave me help in the field.

I gratefully acknowledge the financial assistance provided by the Freshwater Institute and the Char Lake Project of the International Biological Program.

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INTRODUCTION

Char Lake was the subject of an intensive productivity and carbon flux study from 1969 to 1973 as part of the International Biological Program. An allochthonous organic carbon (allochthonous C_o) budget was required to determine the importance of external C_o sources in the total C_o budget of the lake.

The purpose of this study was to measure the supply, storage (i.e. net sedimentation), and outflow losses of C_o at Char Lake. Nitrogen (N) and phosphorus (P) were also studied because of the importance of the supply of these elements in controlling planktonic primary productivity in lakes (Vollenweider, 1968). Char Lake has one of the lowest rates of planktonic primary production known (Kalff and Welch, 1974).

This is the first study in which supply, outflow losses, and storage of C_o, N, and P have been studied simultaneously in one lake. Combining these with studies from other project members enabled the construction of budgets for C_o, N, and P. Factors considered for the C_o budget are given in Figure 1.

Production estimates for Char Lake have been published in Welch and Kalff (1974) and Kalff and Welch (1974), allochthonous C_o estimates in Stocker (1972) and de March (1975), C_o outflow losses in de March (1975), respiration estimates in Welch (1974) and Welch and Kalff (1974), and a preliminary estimate of C_o storage in Rigler (1974). Dissolved inorganic carbon was measured by Schindler et al. (1974). The results of these studies are summarized in Table 1. N and P supply and outflow losses for one year (1971) were reported in Schindler et al. (1974). Some of the 1972 and 1973 results from the present study were published in de March (1975).

Table 1. A summary of sources and losses of organic carbon in Char Lake. All values are presented as $g\ C_o\ m^{-2}$ lake area yr^{-1}.

Sources						=	Losses					
Allochthonous	+	Planktonic production	+	Benthic production	Total	=	Respiration	+	Outflow	+	Sedimentation	Total
0.9[1][a] or 2.5[2]	+	4.2[3]	+	16.9[4]	22 or 23.6[5]	=	15.9[6]	+	2.1[2]	+	5.8[7] or 1[8]	23.8 or 19[5]

[1] Stocker (1972), large particles only.

[2] de March (1975), DOC + FPOC.

[3] Kalff and Welch (1974).

[4] Welch and Kalff (1974).

[5] Totals using the result of the present study.

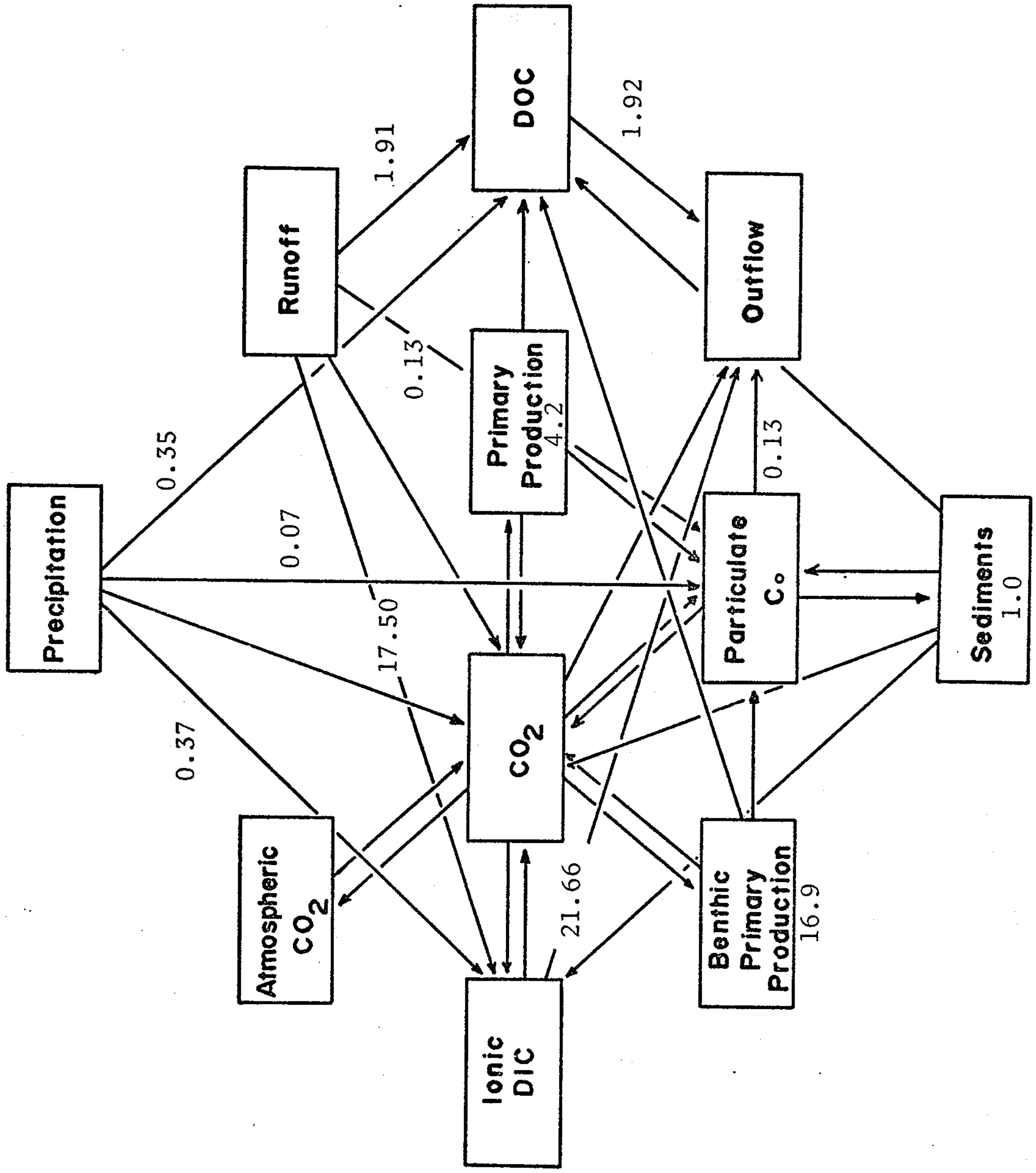
[6] Welch (1974).

[7] Rigler (1974), estimate from sediment trap data.

[8] Present study, total C_o in the sediments.

[a] The actual values reported were $10\ g\ m^{-2}\ yr^{-1}$ or a total of 480 kg. The latter value is equivalent to only $0.9\ g\ m^{-2}\ yr^{-1}$.

Figure 1. A simplified version of the carbon cycle in Char Lake, showing parameters that have been measured. All values are in g C m^{-2} lake area yr^{-1}. Production values are from Table 1.


Precipitation
Runoff
DOC
Outflow
Primary Production
4.2
Particulate Co
Sediments
1.0
CO2
Atmospheric CO2
Ionic DIC
Benthic Primary Production
16.9
0.35
1.91
1.92
0.13
0.07
17.50
0.13
0.37
21.66

Few papers have been published on sediments in polar lakes. Schindler *et al.* (1974) mentioned the chemistry of interstitial waters in Char Lake sediments, and Kalff and Welch (1974) gave an estimate of C_o concentrations in Char Lake surface sediments. Coakley and Rust (1968), Brunskill *et al.* (1973), and Livingstone *et al.* (1958) all reported sediment data, but in northern lakes which are not comparable to Char Lake because of their geographic location or their geological setting.

Many authors have used organic carbon as an indicator of past environmental conditions in lakes (e.g. Vallentyne and Swabey, 1955; Mackereth, 1966), but none have attempted to determine the total amount of C_o stored or an average sedimentation rate for C_o over the history of the lake. Rich and Wetzel (1972) reported a storage rate of 14.8 g C_o m^{-2} yr^{-1} for Lawrence Lake, but used only a single core to derive this figure.

One factor preventing such attempts is that lake histories are usually determined from cores obtained at the deepest point in the lake (Z_m) (e.g. Mackereth, 1966; Livingstone and Boykin, 1962). When a series of cores has been taken over an extensive area of a lake, they have been used for studies such as the mineralogical studies of Coakley and Rust (1968), or the turbidite studies of Ludlam (1974). An exception is Tessenow (1972, 1973a, 1973b, 1974a, 1974b) who studied the upper sediments of a small area of a bog lake in great detail, examining the factors affecting the sedimentation and migration of phosphorus.

It has long been realized (Ohle, 1962; Ludlam, 1974), but not been stressed often enough, that more sediment collects in the deeper parts of lakes than in the shallows. There are also physical and chemical differences between sediments of different depth zones of a lake (Whittaker, 1922; Coakley and Rust, 1968; Tessenow, 1973a, 1973b). Extrapolating over a whole lake from a single core that represents the unique conditions at Z_m is, therefore, not justifiable.

In this study a relatively large number of cores was obtained in order to map the distribution of sediments in the lake, and to estimate a 'true' sedimentation rate for the lake as a whole, rather than just at Z_m.

The Study Area

Char Lake is a polar lake (Hutchinson, 1957) at 74°42' N. latitude and 94°50' W. longitude on Cornwallis Island, N.W.T. It is situated approximately 1.5 km from the Arctic Ocean and 1.5 km from the Resolute Bay Airport (Fig. 2).

The lake is roughly circular in shape (Fig. 3), has an area of 52.6 ha., maximum depth of 27.5 m and a mean depth of 10.2 m (Rigler, 1972). The watershed (A' = 403.7 ha.) is underlain by Silurian limestones and dolomites of the Read Bay Formation (Thorsteinsson, 1958). The terrain is thinly mantled with frost - shattered rocks, mineral soils, and marine clays. Continuous permafrost underlies the watershed with the active layer penetrating to a maximum depth of 0.5 m in August. Plant cover, consisting of mainly Salix arctica, Saxifraga oppositifolia, Draba alpina, and Papaver radicum, is only 5 - 7% with an annual production of 1 to 8 g organic matter m^{-2} yr^{-1} (Arkay, 1972).

Four main streams and numerous temporary rivulets drain the watershed (Fig. 4). Streams 1, 2, and 3 drain a plateau and scarp along the northeast shore of the lake. Stream 1A drains a relatively level area on the north shore. The Department of Transport removed gravel

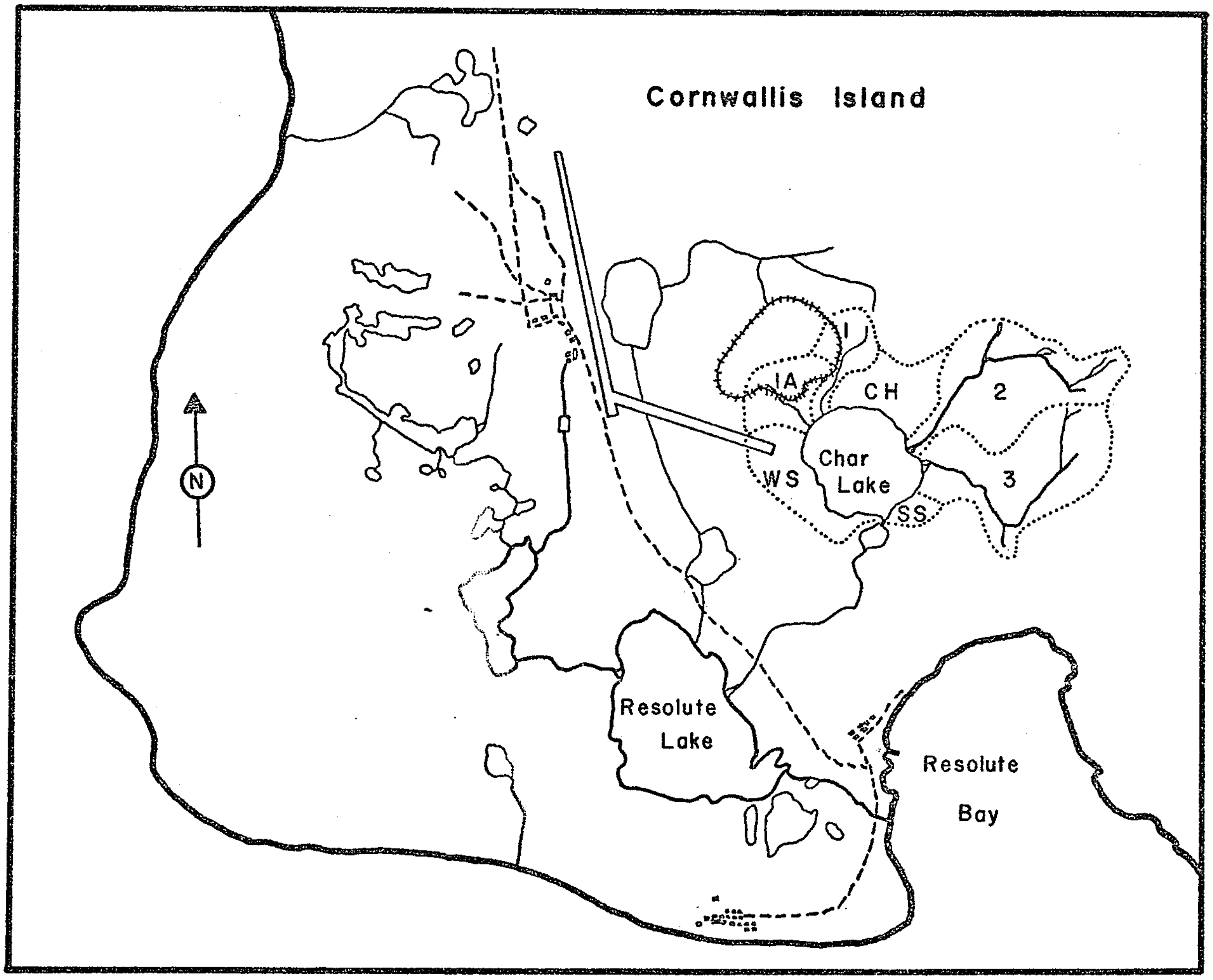


Figure 2 The Resolute Bay area. 1cm = 580 m. ++++++++++ Area of gravel removal. ------ Roads. ·········Char Lake drainage basin. After Rigler (1972).

Figure 3. A bathymetric map of Char Lake showing the rocky, moss, and 'silty' zones. Positions of the sediment cores are also shown. After Welch and Kalff (1974).

CHAR LAKE

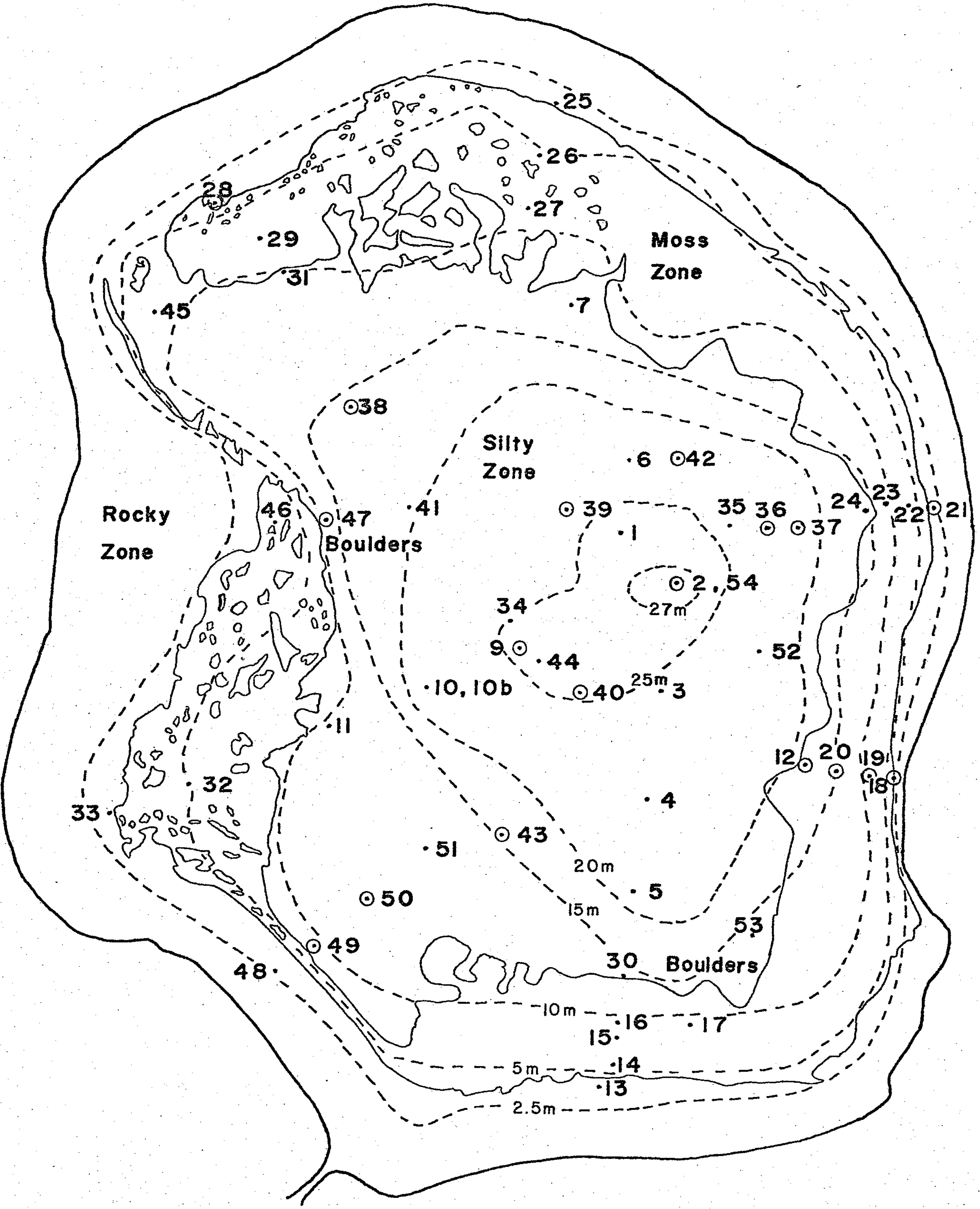
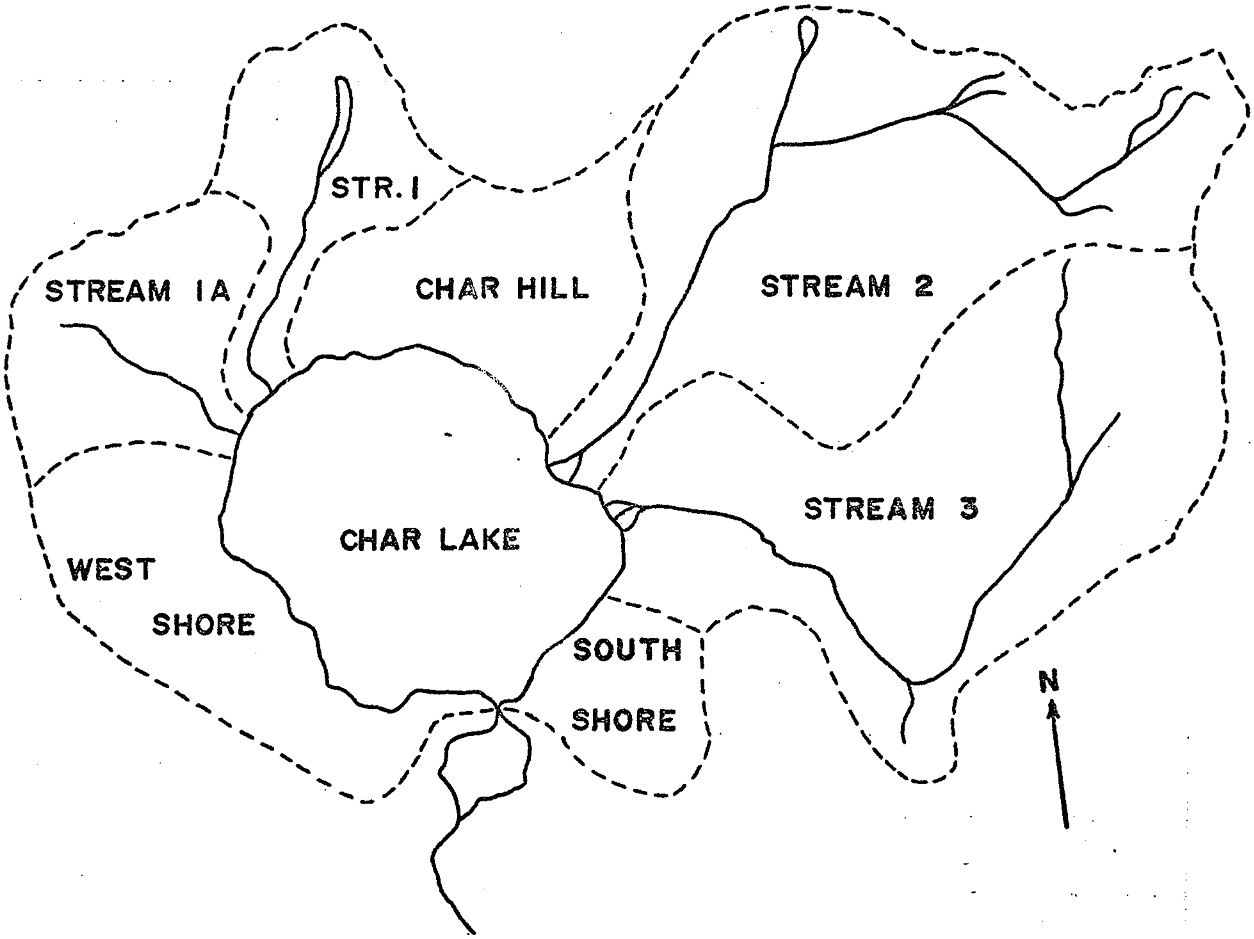

25
26
28
27
29
Moss
Zone
31
45
7
38
Silty
Zone
6
42
Rocky
Zone
46
47
41
39
35
36
24
23
22
21
37
Boulders
1
2,54
27m
34
9
44
52
10,10b
40
25m
3
11
12
20
19
18
32
33
4
43
51
20m
5
50
15m
53
49
48
30
Boulders
10m
16
17
15
14
5m
13
2.5m

Figure 4. A map of the drainage basin of Char Lake showing the major sub-basins and the major streams. After Stocker (1972).


STR. I
STREAM IA
CHAR HILL
STREAM 2
STREAM 3
CHAR LAKE
WEST
SHORE
SOUTH
SHORE
N

this area for runway construction from 1969 to 1973 (Fig. 2). Frozen ground from below the active layer was continually exposed to the sun and melting occurred in July and August.

The Resolute Bay area is a polar desert with annual precipitation averaging only 13.6 cm. About half of this falls as snow between September and May (McCann *et al.*, 1972).

The bottom of Char Lake can be divided into three major areas (Welch and Kalff, 1974) (Fig. 3). The rocky zone extends from the lakeshore to a depth of about 2.5 m and covers an area of 15.5 ha., or 29.4% of the lake area (Welch and Kalff, 1974). The only fine sediments are between the cobble sized rocks in the shallow parts of this zone, but are thicker and can be cored in the deeper parts.

The moss zone extends from the lower edge of the rocky zone to between 5 and 20 m. Generally the bottom is covered with a 10 to 20 cm thick layer of moss, only the upper portions of which are living. There are mossless patches within the moss zone, especially on the west side of the lake. The total area covered by the moss zone is 12.6 ha. or 23.9% of the lake area (Welch and Kalff, 1974). Mossless patches in the moss zone cover 2 ha. or 3.8% of the lake area (Rigler, 1972).

The remaining 22.5 ha. or 42.9% of the lake area constitutes the 'silty' zone (Welch and Kalff, 1974). Its surface is either bare silty sediment, algal mats or other growths of benthic algae.

Some areas (Fig. 3) have boulders with little fine sediment near them. They occur on steeper slopes of the lake bottom.

METHODS

I. Nutrient Budgets

Water samples from the four main streams, the lake (as a vertically integrated 10 m sample), and the outlet were collected daily during the period of maximum runoff and twice weekly thereafter. Smaller inflows were sampled at less frequent intervals. All water samples were filtered through Whatman GF/C glass fibre filters which had been ignited at 500°C for 10 hours. Filters were retained for analysis of particulate C, N, and P (particles $< \sim 1\ \mu$).

Snow depths and densities were measured on transects covering the whole drainage basin in 1972. In 1973 densities were measured at a number of points in the basin and the mean basin depths were extrapolated from snow depths on the lake. These measurements and snow samples for chemical analysis were taken at the end of May in both years. At this time, snow depths were at their maximum.

Bulk summer precipitation samples were collected in a $\frac{1}{4}\ m^2$ acrylic funnel on the shore of the lake near the outlet.

Water samples were analysed for conductivity (on a Beckman conductivity bridge, with results reported in μmhos cm^{-1} at 25°C), dissolved and fine particulate organic carbon (DOC and FPOC), nitrogen (TDN and FPN), and phosphorus (TDP and FPP) from May to August in 1972 and 1973.

Methods of analysis were according to Stainton et al. (1974) with the following exceptions. Samples for the analysis of TDN and TDP were sealed in ignited glass ampoules (1 hr. at 500°C) and autoclaved for later analysis. Because large amount of inorganic carbon (CO_3-C) were present in particulate samples, half of each filter for FPOC was analysed for total C in either a Carlo Erba Model 1100 C-H-N analyser or a Perkin Elmer Model 240 C-H-N analyser, and the other half for CO_3-C by the method described for sediments in Stainton (1973). FPOC was obtained by difference. Precisions of the methods are given in Stainton (1973) and Stainton et al. (1974).

To sample large particulate matter, screens of 6.35 mm mesh size were placed across one channel of each of the major streams near the point at which they entered the lake. Downstream from these were placed samplers of the inverted funnel type (Cushing, 1964) with nets of 1 mm mesh size. Nets and screens were cleared every few days in 1972.

Nutrient inputs to the lake were calculated as follows. The volume of water present as snow in each sub-basin was calculated from the average depth and density of snow. The volume of rainfall was added to the snow water volume and the total multiplied by the unweighted mean concentration of C_o, N, and P in stream water. The lack of weighting is partially compensated for by the fact that samples were taken 3.5 times more often during the period of maximum runoff than at other times.

II. Sediments

Fifty-four sediment cores from 25 to 104 cm in length were obtained either with a mini - Mackereth piston corer (Mackereth, 1958) using acrylic core tubes of 5 cm inside diameter, or by SCUBA and manual driving, using the same tubes. Cores were obtained in June, July, and August of 1972 and 1973. Fifty were obtained for the purpose of determining losses to the sediments of C_o, N, and P; seven from the lower rocky zone, seventeen from the moss zone, and twenty-six from the 'silty' zone.

Cores were extruded by forcing them up the tube with a piston powered by a manual water pump. Cores 2 to 33 were sectioned every 2 cm to 10 cm core depth, then at alternate 5 cm intervals to the bottom. Cores 35 to 53 had the 0 to 1 and 1 to 2 cm sections separated and then were sectioned at 2 cm intervals to 10 cm and at 5 cm intervals to the bottom.

Each core section of known volume was weighed to determine its wet density. After homogenization and drying at 105° C, the dry density (i.e. mass of dry material per unit of wet volume [d] was calculated. Water contents were calculated as the loss of weight on drying. After drying, sediment samples were ground to a powder in a mortar, then stored in glass vials.

For the following analyses, small samples (2 to 20 mg, depending on the analysis) were weighed out in pre - weighed aluminum pans on a Cahn Model G electrobalance. Samples were redried at 105°C and cooled in a desiccator before the final weight determination. All analyses were performed in duplicate and the results averaged.

Total C and N were measured on a Carlo Erba Model 1100 C-H-N analyser, CO_3-C by the method of Stainton (1973), and C_o was obtained by difference. P was determined by the method of Stainton _et al._(1974).

A small number of samples was subjected to X-ray diffraction analysis for the qualitative determination of the major mineral components in the sediments.

The recent sedimentation rate at Z_m was estimated using the ^{210}Pb dating method (Kipphut, pers. comm; see also Koide _et al._, 1973). Sediment thicknesses through the zone dated (2 to 8 cm) were recalculated at the density of the top 2 cm to give a sedimentation rate at that density. This value was recalculated to give a rate at the mean compacted density of the sediment (mean density from 8 to 83 cm) .

No radiocarbon dates were obtained, thus, an age for the lake had to be determined from uplift data in the literature. Using the age of the lake calculated from data in Andrews (1968), Andrews et al. (1971), and Blake (1970), and the sedimentation rate from the ^{210}Pb dating, a maximum sediment thickness at Z_m was calculated. Maximum sediment thicknesses in the moss zone were extrapolated from the available data (this study).

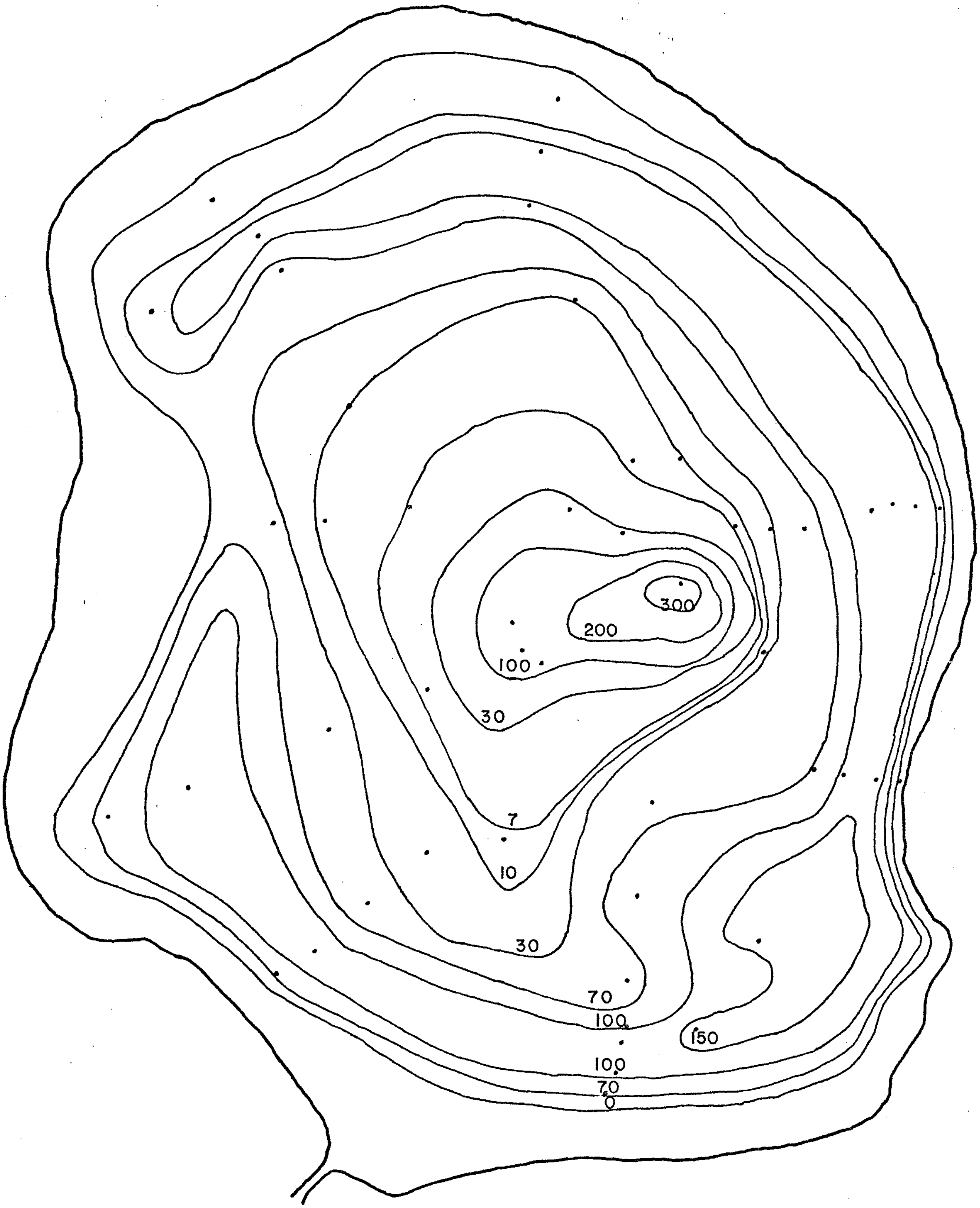
To calculate the masses of C_o, N, and P in the sediments, a map of sediment thicknesses (Fig. 5) was drawn using the 23 cores that reached the lacustrine - marine interface (see results). Areas between sediment thickness isopleths were measured by planimetry. Masses of each element were calculated using the mean concentration weighted by section thickness and the mean thickness and the area of sediment between isopleths. 'Doughnut' shaped areas were treated as rectangles with width equal to the mean radius of a torus of equal area. The volume below the minimum thickness of an area (for example the sediment from 1 to 2 m deep in the area between the 1 and 2 m thickness lines) was assumed to have a triangular cross section, and the elemental masses were calculated accordingly.

Concentrations of elements in sediments below the depth of cores which did not reach the marine sediments were assumed to equal the mean concentration of the lowest 30 cm of the core.

Dividing the total mass of C_o, N, and P in the sediments by the estimated age of the lake gave net sedimentation rates averaged over the whole period of lacustrine sedimentation. A mean sediment thickness was calculated from the area of the lake and the total wet sediment volume.

Figure 5. A map of lacustrine sediment thicknesses in Char Lake. Values given are in centimetres. Position of sediment cores are shown by dots.

CHAR LAKE



RESULTS

I. Precipitation

Total precipitation, including snowpack, was extremely low, only 15.84 cm of water in 1972 and 12.97 cm in 1973 (Table 2). At the Resolute Airport Weather Station the recorded precipitation was lower than the 13.6 cm average in both years (Atmospheric Environment Service, 1971, 1972, and 1973).

The stream watersheds and lake surface all received different amounts of snow because of their different topographies. These differences and stream basin areas were taken into account in calculating the water and nutrient budgets (Tables 2 and 3).

Based on my 1972 and 1973 precipitation data, and ignoring evaporation and evapotranspiration, the theoretical water renewal time for Char Lake is 9.2 years.

Concentrations of P and N in precipitation were low and similar to values reported for the area by Schindler et al. (1974). C_o concentrations were also low (Table 4).

Total atmospheric supplies of N, P, and C_o were small. Only small portions of these supplies (12% of N and P and 16% of C_o) fell directly on the surface of the lake (Table 3).

The terrestrial portion of the drainage basin retained only small percentages of N and P supplied by precipitation (Table 5).

II. Terrestrial Drainage

Concentrations of C_o, N, and P in the undisturbed streams were low (Table 6 and Appendix 1). There were variations between streams and between years, but these were relatively minor compared to the differences between the undisturbed streams and stream 1A, disturbed by

Table 2. Areas of the lake and the terrestrial watershed sub-basins, and the precipitation amounts in 1972 and 1973. Areas are in hectares, precipitation values are in centimetres.

		1972			1973		
Sub-basin	Area	Rain	Snow	Total	Rain	Snow	Total
Stream 1A	31.09	4.55	5.91	10.64	5.55	3.85	9.40
Stream 1	26.54	4.55	12.62	17.17	5.55	8.27	13.82
Stream 2	100.94	4.55	13.90	18.45	5.55	9.06	14.61
Stream 3	102.76	4.55	13.90	18.45	5.55	9.06	14.61
CH[1]	34.18	4.55	7.84	12.39	5.55	5.11	10.66
WS[2]	39.52	4.55	7.78	12.33	5.55	5.13	10.68
SS[3]	16.07	4.55	13.70	18.25	5.55	8.97	14.52
Lake	52.60	4.55	7.78	12.33	5.55	5.13	10.68
Average		4.55	11.29	15.84	5.55	7.42	12.97

[1] Char Hill

[2] West Shore

[3] South Shore

[4] Subbasins are shown in Figure 4.

Table 3. Budgets for N, P, and C_o at Char Lake. Supply and loss values in kg. Loads in g m^{-2} lake area yr^{-1}.

	1972								
Source	DOC	FPOC	TOC	TDN	FPN	TN	TDP	FPP	TP
Stream 1A	129	3	132	27	1	28	0.3	0.4	0.7
Stream 1	119	5	124	8	1	9	0.5	0.3	0.8
Stream 2	469	26	495	39	4	43	1.4	1.3	2.7
Stream 3	556	17	573	34	3	37	1.5	0.8	2.3
Remainder of watershed	248	30	278	15	14	29	1.5	5.2	6.7
Rain direct to the lake	103	34	137	7	5	12	0.4	0.3	0.7
Snow direct to the lake	49	15	64	6	1	7	0.4	0.1	0.5
Total supply (S)	1673	130	1803	136	29	165	6.0	8.4	14.4
Load	3.18	0.25	3.43	0.258	0.055	0.314	0.011	0.016	0.027
Outflow loss (O)	1540	78	1618	42	10	52	3.4	1.3	4.7
% of supply retained by the lake $\frac{S-O}{S} \times 100$	18	40	10	69	66	68	43	85	67

Table 3. (continued)

Source	DOC	FPOC	TOC	TDN	FPN	TN	TDP	FPP	TP
				1973					
Stream 1A	68	5	73	31	1	32	0.4	0.1	0.5
Stream 1	44	4	48	11	1	12	0.4	0.2	0.6
Stream 2	133	14	147	39	2	41	1.3	0.7	2.0
Stream 3	128	11	139	42	2	44	1.7	0.3	2.0
Remainder of Watershed	161	26	187	15	12	27	1.1	3.5	4.6
Rain direct to the lake	125	10	135	8	6	14	0.5	0.4	0.9
Snow direct to the lake	44	10	54	4	3	7	0.5	0.5	1.0
Total supply (S)	703	80	783	150	27	177	5.9	5.7	11.6
Load	1.34	0.15	1.49	0.285	0.051	0.337	0.011	0.011	0.022
Outflow loss (O)	488	69	557	66	10	76	5.5	1.4	6.9
% of supply retained by the lake $\frac{S-O}{S}$ x 100	31	14	29	56	63	57	7	75	41
Average Load	2.26	0.20	2.46	0.272	0.053	0.325	0.011	0.013	0.024
Average % of supply retained by the lake	15	34	16	62	64	63	25	81	55

Table 4. Concentrations of C$_o$, N, and P in precipitation at Char Lake and in some Temperate locations. Concentrations are given in $\mu g\ l^{-1}$.

	DOC	FPOC	TDN	FPN	TDP	FPP
Snow 1972	1208	363	143	27	8.0	3.1
Snow 1973	1639	381	154	100	10.8	18.8
Snow avg.	1423	372	147	64	9.7	11.0
Rain 1973	4295	330	291	163	16.3	13.4
Hubbard Brook	6400^1		$1690^{2\ a}$		8.0^3	
Clear Lake Rain			$755^{4\ a}$		17.5^4	3.5^4
Snow			$835^{4\ a}$		10.5^4	48^4
ELA Snow			$150\text{-}435^5$	$25\text{-}60^5$	$2\text{-}32^5$	$1\text{-}4^5$

1. Jordan and Likens (1975)
2. Likens *et al*. (1970)
3. Hobbie and Likens (1973)
4. Schindler and Nighswander (1970)
5. Barica and Armstrong (1971)

a. NH_3 + NO_3 only.

Table 5. Retentions (+) or losses (-) of N and P supplies as a percentage of precipitation input to the four main stream water sheds at Char Lake and at the Hubbard Brook and Rawson Lake watersheds.

		TDN	FPN	TN	TDP	FPP	TP
Stream 1A	1972	-391	+63	-320	+31	-150	-101
	1973	-454	+83	-293	+5	+73	+41
Stream 1	1972	-103	+72	+16	-109	-110	-109
	1973	-138	+81	+7	+17	+73	+52
Stream 2	1972	-118	+63	+2	+24	+13	+19
	1973	-130	+89	+15	+31	+73	+55
Stream 3	1972	-100	+77	+19	+19	+45	+30
	1973	-136	+91	+11	+15	+77	+50
Hubbard Brook				+68[1]			+78[2]
Rawson Lake				+84[3]			+84[3]

[1] $NO_3 + NH_4$- N 2 yr average for watershed 6, Likens et al. (1970).

[2] Losses include P in large particles (> 1 mm) in watershed 6 for 1 yr, Hobbie and Likens (1973).

[3] Schindler et al. (in prep.), four year mean.

Table 6. Average concentrations of DOC, FPOC, TDN, FPN, TDP, and FPP in the four main streams flowing into Char Lake in 1972 and 1973. DOC results are in mg l^{-1} ± 1 standard deviation, all others in ug l^{-1} ± 1 standard deviation.

Stream	DOC	FPOC	TDN	FPN	TDP	FPP
			1972			
1A	4.06 ± 2.52	178 ± 333	825 ± 496	31 ± 37	7.8 ± 3.4	10.8 ± 19.7
1	2.49 ± 2.79	104 ± 61	178 ± 84	15 ± 11	11.0 ± 4.9	5.5 ± 5.4
2	2.52 ± 1.69	139 ± 83	211 ± 154	22 ± 28	7.6 ± 3.8	6.8 ± 4.8
3	2.90 ± 1.81	90 ± 58	154 ± 71	13 ± 9	7.8 ± 3.9	4.6 ± 4.8
			1973			
1A	2.34 ± 0.71	159 ± 69	983 ± 514	24 ± 10	13.1 ± 3.8	4.2 ± 4.0
1	1.19 ± 0.52	110 ± 62	289 ± 142	23 ± 17	10.6 ± 3.7	5.7 ± 9.9
2	0.90 ± 0.25	93 ± 42	266 ± 146	15 ± 7	9.1 ± 1.5	4.5 ± 3.1
3	0.85 ± 0.26	74 ± 40	281 ± 175	11 ± 6	11.2 ± 2.6	2.0 ± 0.9

airport construction. Conductivity, DOC, and TDN were much higher in stream 1A while FPOC and FPN were somewhat higher (Table 6 and Appendix 1).

The most important factor influencing supplies of N, P, and C_o to the lake from the terrestrial drainage appeared to be the amount of water flowing from them. This factor in turn was influenced by the amount of snow collected by the stream basin, but was more dependent on the stream's watershed area (Table 2).

The inverted funnel samplers in the streams caught virtually nothing (less than 1% of total C_o)and were abandoned. The total mass of particles caught by the screens also contributed less than 1% of the allochthonous C_o and was ignored. Over 99% of allochthonous C_o was in the DOC and FPOC fractions.

III. The Lake and Outflow

Concentrations of C_o, N, and P in the lake were low and varied little throughout both summers. Except on a few dates, they were higher than concentrations in the outflow stream until the end of the melt season (Appendix 1). This fact is explained by the dilute layer of water that forms under the ice in summer (Schindler *et al.*, 1974). It is water from this layer that flows out of the outlet.

C_o, N, and P concentrations in the outflow, then, were lower than those in the lake. Percentage losses of N and P through the outflow are relatively large, however (Table 3).

Inverted funnel samplers in the outflow stream caught small amounts of material such as invertebrate exuviae and small numbers of young Arctic Char. It was decided not to include this material in the budgets for two reasons. First, it was impossible to quantify without accurate water flows, and second, I believed that outflow losses of large particulate material were insignificant because supplies of large particles were insignificant.

Other losses of material from Char Lake,such as chironomid emergence and fishing by Arctic Terns, were not considered. Chironomid emergence can account for no more than 4% of the N and P supplies to the lake, and 1% of total C_o (based on data in Welch, 1973).

IV. Sediments

All sediment cores had the surface layer intact with the exception of those obtained in the moss beds. The moss had to be pulled aside in order to core the sediments below.

Four facies were identified in most cores. They could be separated by colour, texture, physical, and chemical differences. The upper two, Cl 1 and Cl 2, are lake sediments, Cl 3 probably represents the time during which the lake was in transition from a bay in the sea to a lake, and the time it took to clear of salt water. Cl 4 represents the marine stage.

In areas with no moss cover, cores exhibited a 1 to 2 cm orange-brown surface layer of high water content (Cl 1). Below this, Cl 2 was denser, grey, and in cores from deeper parts of the lake, laminated. Cl 3, below a usually sharp transition, was not present in all cores. It was finely laminated with bands of brown or black alternating with bands of white or grey. There were up to 10 band pairs per mm.

Cl 4 was reached in 23 cores. It was a homogeneous, dense, grey sediment which usually contained small stones and marine fossils such as sea urchin spines (_Strongylocentrotus droebachiensis_) and mollusk shells (e.g. _Astarte crenata_, _Cylichna scalpta_, and _Nuculana pernula_). Joined pairs of _N. pernula_ valves were found in two cores, while other cores contained complete valves of other species with periostracum intact.

In all cores, the sediments were denser, and contained less water with increasing sediment depth. Concentrations of C∘, N, and P were generally low with the highest levels in Cl 1 and Cl 3. The greatest changes in concentrations, sediment density, and water content occurred through the top 10 cm of sediment and through Cl 3 (e.g. Core 6 Fig. 5; more core data may be found in Appendix 2).

Phosphorus concentrations were fairly constant between lake bottom zones, but C∘, N, and CO_3-C concentrations were highest in the moss and lower rocky zones and lowest in the 'silty' zone (based on the mean concentrations of all lacustrine sediments in all cores). Appendix 4 discusses the distribution of C∘, N, P, and CO_3-C in sediments of different lake bottom zones.

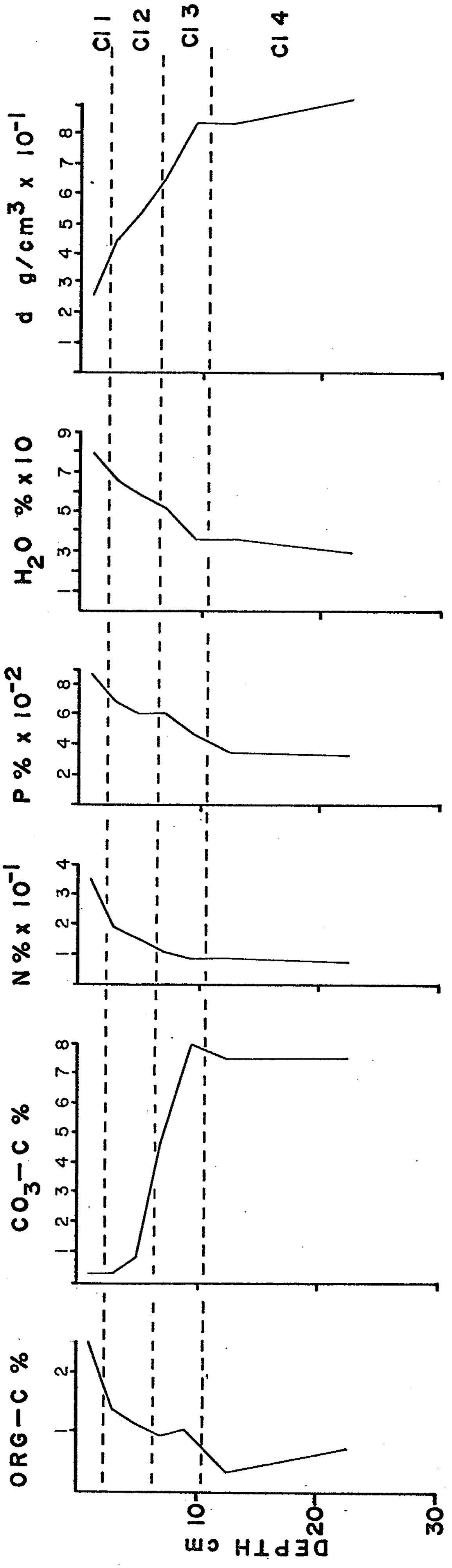
CO_3-C concentrations were low in Cl 1 and Cl 2, but rose through Cl 3 and were high in Cl 4.

X-ray diffraction analysis of sediments in Cl 1 and Cl 2 confirmed the low concentrations of CO_3-C. There were small amounts of calcite and dolomite, but quartz was the major mineral. There were also traces of clay minerals. Cl 3 and Cl 4 contained predominantly calcite and dolomite in approximately equal amounts. Quartz and traces of unidentified minerals were also present. A possible explanation for the low concentrations of CO_3-C in Char Lake sediments is given in Appendix 3.

Two rock samples from the watershed proved to be calcite and dolomite respectively (by X-ray diffraction). Both contained quartz. A soil sample from the delta of stream 2 contained mostly calcite with quartz and some dolomite.

A mean of maximum and minimum ages for the emergence level of Char Lake calculated from data in Andrews (1968), Andrews *et al.*(1971),

Figure 6. Water content (as a % of wet weight), density (d) (dry weight per unit of wet volume), and concentrations of C_o, CO_3-C, N, and P in the sediments of Core 6 in the 'silty' zone. Chemical concentrations are as a % of dry weight.


ORG—C %
CO3—C %
N % x 10-1
P % x 10-2
H2O % x 10
d g/cm3 x 10-1
Cl 1
Cl 2
Cl 3
Cl 4
DEPTH cm
10
20
30
1
2
3
4
5
6
7
8
9

and Blake (1970) was 6200 years. This figure, based on currently available data, is ± approximately 3000 years.

Figure 4 and the sedimentation data in Table 7 are based on the 6200 year age and a 0.5 mm yr^{-1} @ 0.52 g cm^{-3} sedimentation rate at Z_m (^{210}Pb dating, G. Kipphut, pers. comm.).

Sedimentation results based solely on the core taken at Z_m, and not taking into account the physical and chemical differences between cores, are also given in Table 7 for comparison with the results based on 50 cores.

The extremely uneven distribution of sediments in Char Lake (Fig. 5) is discussed in Appendix 6.

Losses of C_o, N, and P to the sediments were found to be small (Table 6). P sedimentation agreed well with the difference between supply and outflow loss in the budget (Table 3)(112% of expected). N storage (Table 7) was 43% of the difference between supply and outflow loss (Table 3). Stored C_o (Table 7) was only 17% of the C_o not accounted for by respiration and outflow loss.

Table 7. Permanent storage of total sediment (TS), C∘, CO_3-C, N and P in Char Lake. Given are the total amount of substance stored in the sediments in kg, the rate of permanent sedimentation in g m^{-2} yr^{-1}, and the concentration of each substance as a mean % of sediment dry weight.

	Total	Rate	Conc.
TS	10^8	30.7	
C∘	3.28×10^6	1.0	3.2
CO_3-C	1.55×10^6	0.48	1.6
N	2.83×10^5	0.087	0.28
P	5.84×10^4	0.018	0.059

Table 7a. The same data as above calculated from a single core from Z_m and the error as the factor by which the 7a value is greater than the 7 value (i.e. $\frac{7a}{7}$) for totals and for rates.

	Total	Rate	Conc.	Error
TS	8.3×10^8	255		8.3
C∘	9.85×10^6	3.0	1.41	2.7
CO_3-C	7.42×10^6	2.4	0.94	4.8
N	1.66×10^6	0.51	0.20	5.9
P	4.74×10^5	0.146	0.057	8.1

DISCUSSION

I. C_o, N, and P Budgets

Supplies

(a) Atmosphere

Supplies of C_o, N, and P to the lake are controlled by the dry climate of the high Arctic. The extremely low amount of precipitation (Table 2) combined with low concentrations of C_o, N, and P in precipitation (Table 4) results in the small atmospheric supplies of these elements.

Because of the small atmospheric supplies of N and P, Char Lake received inputs of these elements that were smaller than in more southerly lakes (e.g. Vollenweider, 1968; Kirchner and Dillon, 1975; Schindler _et al._, in prep.).

(b) Terrestrial Watershed

Runoff from the land at Char Lake was a more important source of N and P than at Temperate latitudes and a less important source of C_o. At Char Lake 88% of the N and P inputs were in runoff, compared to 50% at Rawson Lake (a lake of similar size and watershed area at the Experimental Lakes Area ,Northwestern Ontario (Schindler _et al._,in prep.)).

Although the Char Lake watershed exports less N and similar amounts of P compared to Temperate watersheds, the exports as a percentage of atmospheric supplies are much higher. The Rawson Lake watershed retained more than 80% of its N and P supplies while Char Lake's watershed retained only 2% of its N supply and 7% of its P supply. The difference is the plant cover which is almost non existent at Char Lake, but which at Rawson Lake consists of dense stands of pine and spruce which retain nutrients.

Conversely, the absence of plant cover at Char Lake limits the allochthonous C_o to 2.46 g C_o m^{-2} yr^{-1} or 11% of the lake's total C_o. At Marion Lake a complete forest cover provides forest litter that amounts to 240 g C_o m^{-2} yr^{-1} or 86% of the lake's total C_o (Efford, 1969).

Two major factors influenced the export of C_o, N, and P from the terrestrial watershed to Char Lake. The first was the amount of precipitation, especially snow. The lower precipitation and, thus, flow volumes in 1973 resulted in smaller amounts of FPOC, FPN, and FPP leaving the land in that year (Table 3). Concentrations of TDN and TDP increased with the lower flows, and their export remained about the same (Table 3).

The second and more important factor affecting terrestrial nutrient export was ground disturbance. Stream 1A received water from melting permafrost and this resulted in the elevated conductivity and concentrations of TDN, DOC, and TDP (Table 6 and Appendix 1). The mechanism by which permafrost water becomes enriched in salts and nutrients is not completely known, but is probably the result of freeze - thaw cycles and migration of the permafrost table.

Losses

C_o is lost primarily through respiration. This loss accounts for 67.5% of the C_o in Char Lake (Welch and Kalff, 1974). Some of the CO_2 resulting from respiration probably leaves the lake through gas exchange because the partial pressure of CO_2 in Char Lake is above atmospheric equilibrium in the ice free season (Schindler _et_ _al_., 1974).

Compared to respiration, losses of C_o through the outflow (8.9%) and storage in the sediments (4.2%) are not very important. 19.4% of total C_o in Char Lake is unaccounted for and probably represents errors in the measurements of all the parameters.

N and P losses from the outlet were relatively high compared to Temperate oligotrophic lakes (e.g. Schindler and Nighswander, 1970; Vollenweider, 1968). The two year average P retention of 55% (Table 3) was considerably lower than the 88% P retention predicted by the model of Kirchner and Dillon (1975). This suggests that Char Lake is relatively inefficient in utilizing its nutrient supplies. This may be because of low light levels and temperatures or possibly because there is such a fast flow through of nutrients in the spring before enough phytoplankon has developed to utilize them.

The difference between retention of P and the amount found to be stored in the sediment was so small as to be insignificant. The values may have been closer if precipitation in 1972 and 1973 had not been below normal (i.e. P inputs were likely lower than normal). The difference was also smaller than the natural variation in nutrient inputs that can occur between years (as much as a factor of 2 variation, Schindler _et_ _al_., in prep.).

Most of the P retained by the lake was that which entered in particulate form. (Table 3). If a large part of this P sank to the bottom without entering into the metabolism of the plankton, the effective P load would have been approximately 0.011 g m^{-2} yr^{-1} (i.e. TDP only) rather than 0.025 g m^{-2} yr^{-1} (Table 3). This value would be more consistent with the extremely low planktonic primary productivity of 4.2 g C_o m^{-2} yr^{-1} (Kalff and Welch, 1974).

Variation in the supply of N to the lake is extremely small (0.314 g m^{-2} yr^{-1} in 1971, Schindler et al., 1974; 0.314 g m^{-2} yr^{-1} in 1972, and 0.317 g m^{-2} yr^{-1} in 1973 [Table 3]) and is probably not a factor that can explain the fact that only 43% of the N presumably retained by the lake can be accounted for in the sediments. A possible modern increase in N supply to the lake and possibly release from the sediments seem to be the only explanations.

II. The Sediments

The 0.5 mm yr^{-1} sedimentation rate at Z_m in Char Lake is similar to figures reported in other lakes , such as those in the English Lakes District where sedimentation rates of 0.45 to 0.60 mm yr^{-1} were reported by Mackereth (1966). Concentrations of C_o, N, and P, however are at the low end of the range reported by Brunskill et al. (1971). This is not unreasonable in a lake of such low productivity situated in a watershed where terrestrial production is also low.

Extrapolating sedimentation rates from a deep water core to the rest of the lake (Tables 7 and 7a) resulted in large overestimations of average sediment thickness for the lake, total mass of dry sediment, the sedimentation rates of C_o, N, and P and of overall sedimentation rates. The error factors ranged from 3 to 8 in Char Lake which is morphometrically simple but could be much higher in other lakes, depending on a number of factors, including the complexity of lake morphometry, configuration of the inflows and outflows, and the presence or absence of a littoral zone.

In Char Lake, where the moss zone dominates the sediments, it is futile to say anything about sedimentation over the whole lake from a deep water core. One's remarks would have to be limited to paleolimnology (for Char Lake paleolimnology see Appendix 7), and sedimentation at that point in the lake. In order to obtain accurate data on sedimentation in lakes one must ensure a thorough sampling program.

It became evident from my data that a more useful method of presenting sedimentation data than in mm yr^{-1} would be to give the mean sedimentation rate of each element considered or of total sediment in $g\ m^{-2}$ lake area yr^{-1}. This allows easier comparison between lakes with sediments of different sediment densities or between sedimentation rates and nutrient budgets (Tables 3 and 7).

Origins of C_o in the sediments

Mackereth (1966) suggested that autochthonous C_o in lakes is almost totally respired and that C_o in the sediments is of allochthonous origin. Undoubtedly most of the C_o produced in Char Lake is respired (Table 1), but the input of FPOC (Table 3) and large particles is too small to account for the C_o in the sediments. Most of the C_o stored in Char Lake is in the moss zone, and here it is nearly all in the form of moss. In Char Lake at least 80% of the stored C_o is of autochthonous origin.

C_o is a minor component of Char Lake sediments, however, and the mineral component, which is the major portion, is derived from the terrestrial part of the watershed.

SUMMARY

Char Lake was found to have extremely small supplies of N (0.325 g m^{-2} yr^{-1}), P (0.024 g m^{-2} yr^{-1}) and C_o (2.46 g m^{-2} yr^{-1}). Only small percentages of these supplies (12% of N and P, and 16% of C_o) entered the lake in direct precipitation. The extremely small amount of precipitation is the primary factor limiting the supply of these elements to the watershed.

Allochthonous C_o was found to be a minor component of the C_o budget of the lake, contributing only 10.5% of total C_o.

The measured C_o loss to the sediments (4.2%) was a minor component of the C_o budget of Char Lake and agreed reasonably well with production, respiration, supply and outflow estimates. The small disagreement is probably the result of experimental errors.

Sedimentation estimates derived from a single deep water core in Char Lake were not indicative of sedimentation in the rest of the lake. Large differences in sediment thickness, physical parameters, and chemistry occurred from place to place in the lake and this precluded extrapolation. Average sedimentation rates for Char Lake are 30.7 g dry sediment m^{-2} yr^{-1}, 1 g C_o m^{-2} yr^{-1}, 0.48 g N m^{-2} yr^{-1}, and 0.018 g P m^{-2} yr^{-1}.

Retentions of P (55%) and N (63%) by Char Lake were lower than would have been expected in a similar lake at Temperate latitudes. This suggests that Char Lake is not as efficient at utilizing nutrient supplies as more southerly lakes.

REFERENCES

Andrews, J.T. 1968. Postglacial rebound in Arctic Canada: similarity and prediction of uplift curves. Can. J. Earth Sci. 5: 39-47.

Andrews, J.T., R. McGhee, and Lorna McKenzie Pollock. 1971. Comparison of elevations of archeological sites and calculated sea levels in Arctic Canada. Arctic 24 (3): 210-228.

Arkay, K. 1972. Species distribution and biomass characteristics of the terrestrial flora, Resolute, N.W.T. M. Sc. Thesis. McGill Univ. Geography Dept., Montreal, Canada.

Atmospheric Environment Service. 1971. Canada Dept. Environ. Monthly Record Meteorological Observations.

Atmospheric Environment Service. 1972. Canada Dept. Environ. Monthly Record Meteorological Observations.

Atmospheric Environment Service. 1973. Canada Dept. Environ. Monthly Record Meteorological Observations.

Barica, Jan, and F.A.J. Armstrong. 1971. Contribution by snow to the nutrient budget of some small northwest Ontario lakes. Limnol. Oceanogr. 18 (5): 734-743.

Blake, W., Jr. 1970. Studies of glacial history in Arctic Canada I: Pumice radiocarbon dates and different postglacial uplift in the eastern Queen Elizabeth Islands. Can. J. Earth Sci. 7: 634-664.

Brunskill, G.J., D. Povoledo, B. Graham, and M.P. Stainton. 1971. Chemistry of surface sediments of sixteen lakes in the Experimental Lakes Area, northwestern Ontario. J. Fish. Res. Board Can. 28 (2): 277-294.

Brunskill, G.J., D.M. Rosenberg, N.B. Snow, G.L. Vascotto, and R. Wageman. 1973. Ecological studies of aquatic ecosystems in the Mackenzie-Porcupine drainages in relation to proposed pipeline and highway development. Vol. I. Environmental-Social Committee, Northern Pipelines, Task force on Northern oil development.

Report No. 73-40.

Coakley, J.P., and B.R. Rust. 1968. Sedimentation in an Arctic lake. J. Sediment. Petrol. 38: 1290-1300.

Cushing, C.E., Jr. 1964. An apparatus for sampling drifting organisms in streams. J. Wildl. Manage. 28: 592-593.

Davis, Margaret B. 1968. Pollen grains in lake sediments: Redeposition caused by seasonal water circulation. Science 162: 796-799.

de March, L. 1975. Nutrient Budgets for a high Arctic lake (Char Lake, N.W.T.). Verh. Internat. Verein Limnol. 19: in press.

Efford. I.E. 1969. Energy transfer in Marion Lake, British Columbia with particular reference to fish feeding. Verh. Internat. Verein Limnol. 17: 104-108.

Garrels, R.M., and C.L. Christ. 1965. Solutions, Minerals, and Equilibria. Harper and Row. New York. 450 + xiii pp.

Geyh, M.A., J. Merkt, H. Muller, and H. Streif. 1974. Reconstitutions paléoclimatiques et paléoécologiques a partir de l'étude des sédiments lacustres de l'Allemagne méridionale. Société Hydrotechnique de France. XII^{mes} Journées de l'hydraulique (Paris 1974). Influence des activités de l'homme sur le cycle hydrométéorologique. Question 1. Rapport 7.

Hobbie, J.E., and G.E. Likens. 1973. Output of phosphorus, dissolved organic carbon and fine particulate carbon from Hubbard Brook watersheds. Limnol. Oceanogr. 18: 734-743.

Hutchinson, G. Evelyn. 1957. A Treatise on Limnology. Vol. I. Geography, Physics and Chemistry. John Wiley and Sons Inc. New York. 1015 pp. + xiv.

Jordan, M.J., and G.E. Likens. 1975. A carbon budget for an oligotrophic lake in New Hampshire, U.S.A. Verh. Internat. Verein Limnol. 19: in press.

Kalff, J., and H.E. Welch. 1974. Phytoplankton production in a natural and in a polluted polar lake, Cornwallis Island, Northwest Territories. J. Fish. Res. Board Can. 31: 621-636.

Kirchner, W.B., and P.J. Dillon. 1975. An empirical method of estimating the retention of phosphorus in lakes. Water Resources Research. 11: 182-183.

Koide, Minoru, Kenneth W. Bruland and Edward D. Goldberg. 1973. Th-228, Th-232 and Pb-210 geochronologies in marine and lake sediments. Geochim. Cosmochim. Acta 37: 1171-1187.

Likens, G.E., F.H. Bormann, N.M. Johnson, D.W. Fisher, and R.S. Pierce. 1970. Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook Watershed Ecosystem. Ecol. Monogr. 40: 23-47.

Livingstone, D.A., and J.C. Boykin. 1962. Vertical distribution of phosphorus in Linsley Pond mud. Limnol. Oceanogr. 7: 57-62.

Livingstone, D.A., K. Bryan Jr., and R.G. Leahy. 1958. Effects of an Arctic environment on the origin and development of freshwater lakes. Limnol. Oceanogr. 3: 192-214.

Ludlam, Stuart D. 1974. Fayetteville Green Lake, New York. 6. The role of turbidity currents in lake sedimentation. Limnol. Oceanogr. 19: 656-664.

Mackereth, F.J.H. 1958. A portable core sampler for lake deposits. Limnol. Oceanogr. 3: 181-191.

Mackereth, F.J.H. 1966 Some chemical observations on post-glacial lake sediments. Philos. Trans. R. Soc. Lond. B. Biol. Sci. 250: 165-213.

McCann, S.B., P.J.Howarth, and J.G. Cogley. 1972. Fluvial processes in a periglacial environment. Trans. Inst. Br. Geogr. 55: 69-82.

Mortimer, C.H. 1971. Chemical exchanges between sediments and water in the Great Lakes - speculations on probable regulatory mechanisms. Limnol. Oceanogr. 16: 387-404.

Ohle, Waldemar. 1962. Der Stoffhaushalt der Seen als Grunlage einer allgemeinen Stoffwechseldgnamik der Gewasser. Kieler Meeresforshungen 18: 107-120.

Preston, R.S., E. Person, and E.S. Deevey. 1956. Yale natural radiocarbon measurements II. Science N.Y. 122: 954. in Wiseman, 1966.

Rich, Peter H., and Robert G. Wetzel. 1972. The benthic carbon budget of a southern michigan marl lake. Verh. Internat. Verein Limnol. 18: 157-161.

Rigler, F.H. 1972. The Char Lake Project: A study in energy flow in a high Arctic lake. in Kajak and A. Hillbrecht-Ilkowska [eds.] Productivity problems of freshwaters. Polish Scientific Publishers, Warsaw. 918 pp.

Rigler, F.H. 1974. Char Lake Project PF-2 Final report 1974. Can. Committee for the I.B.P., Char Lake Project PF-2 Final Report 95 pp. + vi.

Schindler, D.W., and J.E. Nighswander. 1970. Nutrient supply and primary production in Clear Lake, eastern Ontario. J. Fish. Res. Board Can. 27: 2009-2036.

Schindler, D.W., H.E. Welch, J. Kalff, G.J. Brunskill, and N.Kritsch. 1974. Physical and chemical limnology of Char Lake, Cornwallis Island (75° N. Lat.). J. Fish Res. Board Can. 31: 585-607.

Schindler, D.W., R.W. Newbury, K.G. Beaty, and P. Campbell. in prep. Annual chemical budgets for regimes in the Rawson Lake (Lake 239) watershed, Experimental Lakes Area.

Stainton, M.P. 1973. A syringe gas stripping procedure for gas chromatographic determination of dissolved inorganic and organic carbon in freshwater and carbonates in sediments. J. Fish. Res. Board Can. 30: 1441-1445.

Stainton, M.P., M.J. Capel, and F.A.J. Armstrong. 1974. The chemical analysis of freshwater. Fish. Res. Board Can. Misc. Spec. Publ. 24. 119 pp.

Stocker, Z.S.J. 1972. The ecology of streams at Char Lake, Resolute Bay, Northwest Territories. M. Sc. Thesis. Waterloo Univ. Biology Dept., Waterloo, Canada.

Tessenow, Uwe. 1972. Losungs - Diffusions - und Sorptionprozesse in der Oberschicht von Seesedimenten I. Ein Langzeitexperimenten unter aeroben und anaeroben Bedingungen im Fliessgleichwicht. Arch. Hydrobiol. Supplementb. 38: 353-398.

Tessenow, Uwe. 1973a. Losungs - Diffusions - und Sorptionprozesse in der Oberschicht von Seesedimenten II. Rezente Akkumulation von Eisen (II) phosphat (Vivianit) im Sediment eines meromiktischen Moorsees (Ursee, Hochschwartzwald) durch postsedimentare Verlagerung. Arch. Hydrobiol. Supplementb. 42: 143-189.

Tessenow, Uwe. 1973b. Losungs - Diffusions - und Sorptionprozesse in der Oberschicht von Seesedimenten III. Die chemischen und physikalischen Bedingungen im Sediment - Wasser Ubergangsbereich meromiktischen Moorsees (Ursee) als Voraussezung zur Vivianitakkumulation. Arch Hydrobiol. Supplementb. 42: 273-339.

Tessenow, Uwe. 1974a. Losungs - Diffusions - und Sorptionprozesse in der Oberschicht von Seesedimenten IV. Reaktionsmechanismen im System Eisen - Mangen - Phosphat im Hiblick auf die Vivianitakkumulation im Ursee. Arch. Hydrobiol. Supplementb. 47:1-79.

Tessenow, Uwe. 1974b. Losungs - Diffusions - und Sorptionprozesse in der Oberschicht von Seesedimenten V. Die differenzierung der Profundalsedimente eines oligotrophen Bergsees (Feldsee, Hochschwartzwald) durch Sediment - Wasser - Wechselwirkungen. Arch. Hydrobiol. Supplementb. 47; in press.

Thorsteinsson, R. 1958. Cornwallis and Little Cornwallis Islands, District of Franklin, N.W.T. Geol. Surv. Can. Mem. 294. 134 pp.

Vallentyne, J.R., and Y.S. Swabey. 1955. A reinvestigation of the history of lower Linsley Pond, Connecticut. Am. J. Sci. 253: 313-340.

Vollenweider, R.A. 1968. The scientific basis of lake and stream eutrophication, with particular reference to phosphorus and nitrogen as eutrophication fac ors. Organ. Econ. Coop. Dev. Paris (DAS/CSI/68) Tech. Rep. 27: 1-182.

Welch, H.E. 1973. Emergence of Chironomidae (Diptera) from Char Lake, Resolute, Northwest Territories. Can. J. Zool. 51: 1113-1123.

Welch, H.E. 1974. Metabolic rates of Arctic lakes. Limnol. Oceanogr. 19: 65-73.

Welch, H.E., and J, Kalff. 1974. Benthic photosynthesis and respiration in Char Lake. J. Fish. Res. Board Can. 31: 609-620.

Whittaker, E.J. 1922. Bottom deposits of McKay Lake, Ottawa. Trans. R. Soc. Can. Ser. 3. 16: 141-158.

Wiseman, J.D.H. 1966. Evidence for recent climatic changes in cores from the ocean bed. J.S. Sawyer (ed.) Proc. of the Int. Symp. on World climate, 8000 - 0 B.C. Roy. Met. Soc. 84-98.

APPENDIX 1. Figures showing the temperature, conductivity, DOC, FPOC, TDN, FPN, TDP, and FPP in the inflows, lake, and outflow at Char Lake. 1972 results cover the period from the onset of the melt season to the time when the streams ceased flowing. 1973 results are from the beginning of the melt to approximately three weeks before the cessation of flows.

Figure 1. Temperatures of the inflows and outflow stream in 1972. Stream 1A ■, Stream 1 □, Stream 2 ●, Stream 3 ○, Outflow ⬡.

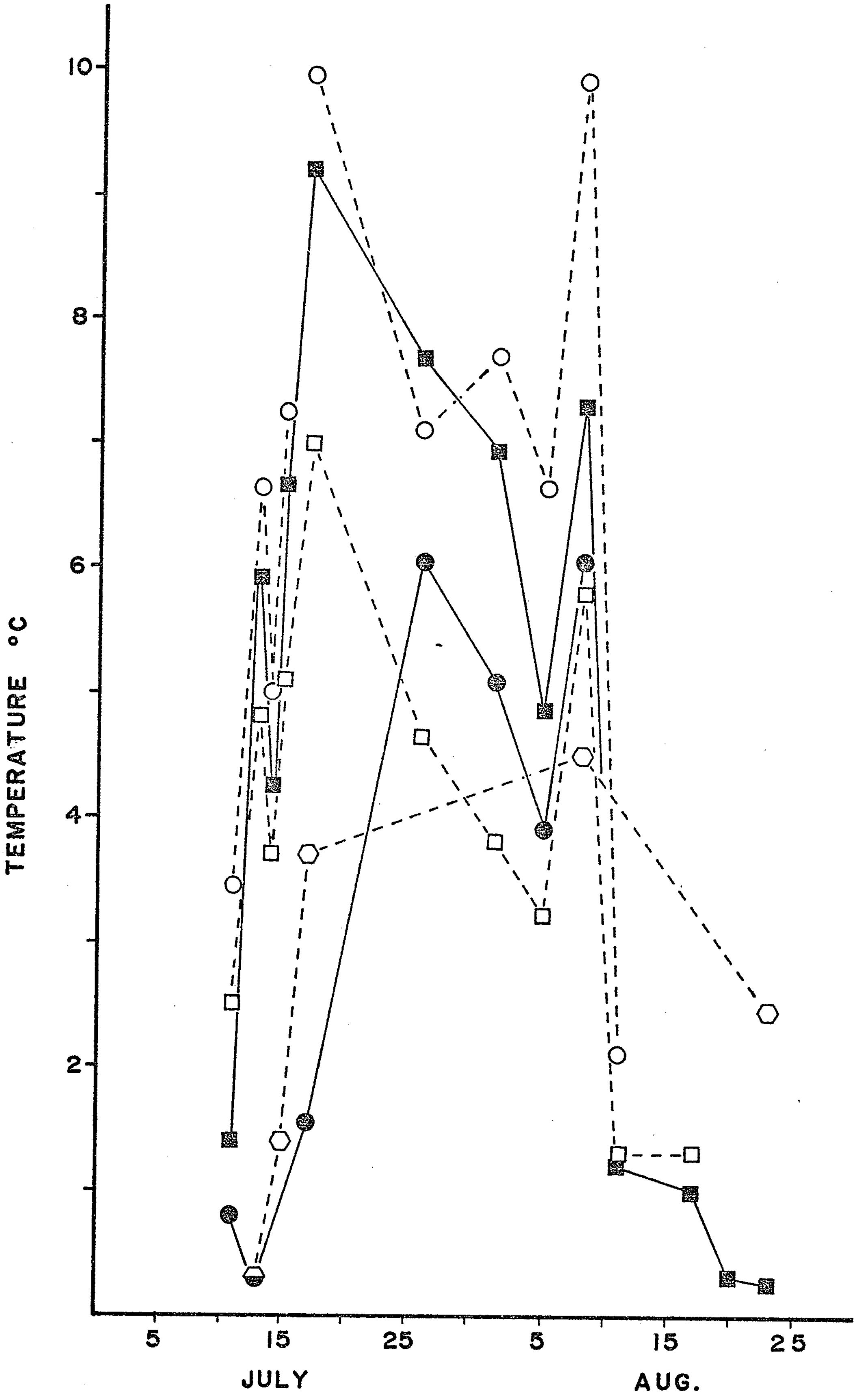
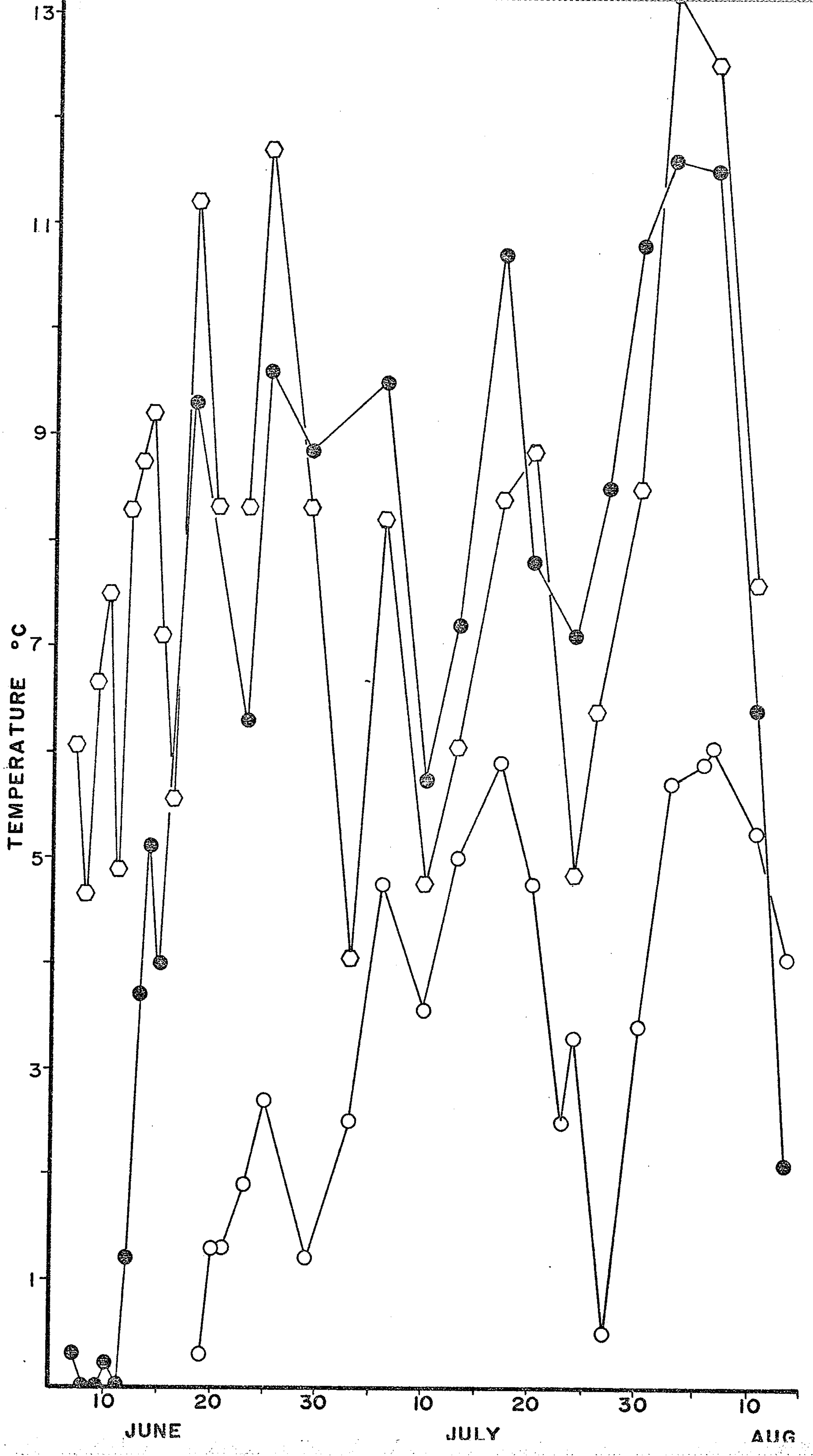

10
8
6
4
2
TEMPERATURE °C
5
15
25
5
15
25
JULY
AUG.

Figure 2. Temperatures of Stream 1A ●, Stream 3 ⬡, and the outflow stream ○ in 1973.


TEMPERATURE °C
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11
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10
JUNE
JULY
AUG

Figure 3. Temperatures of Stream 2 ●, and Stream 1 □ in 1973.

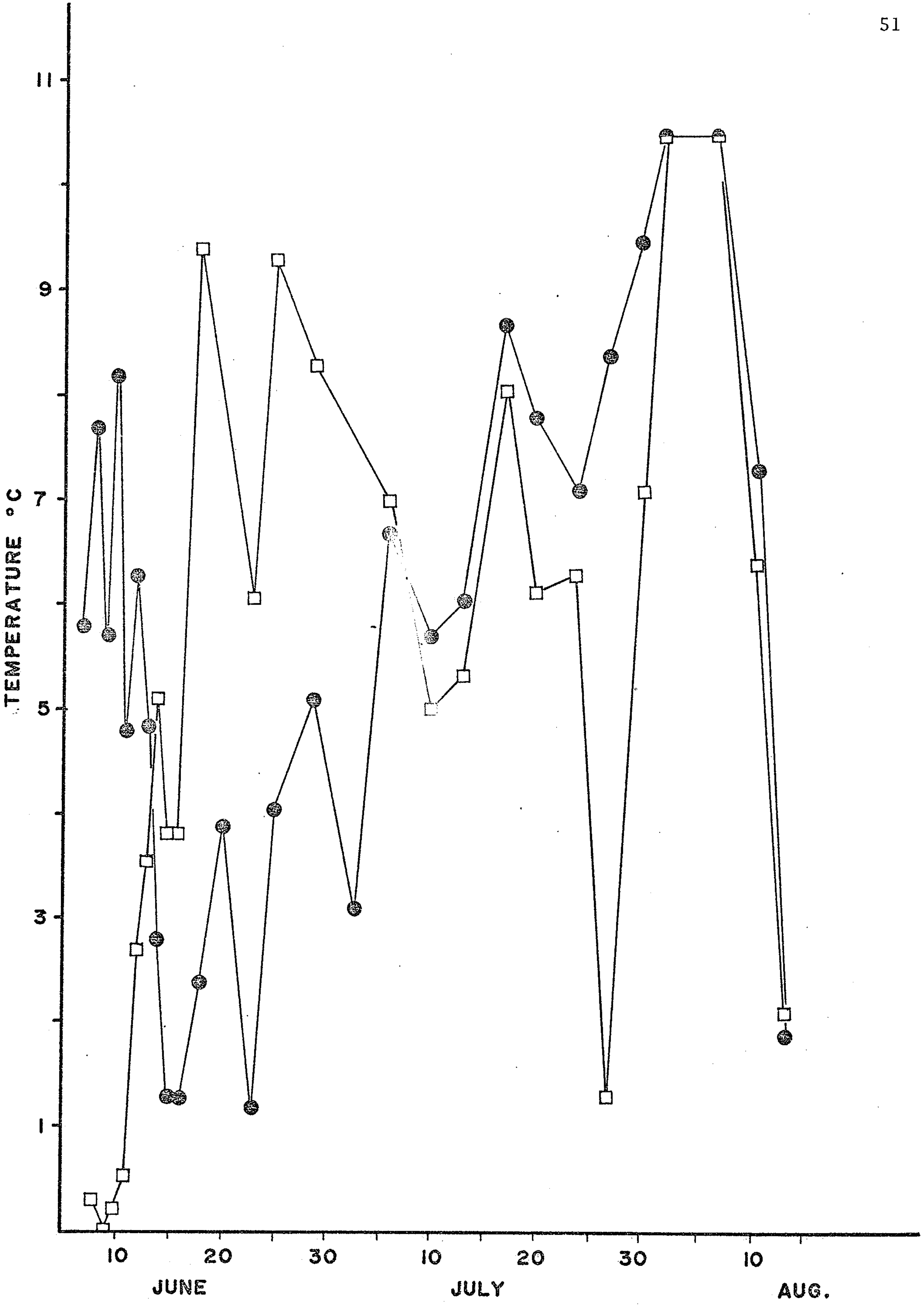

TEMPERATURE °C
11
9
7
5
3
1
10
20
30
10
20
30
10
JUNE
JULY
AUG.

Figure 4. Conductivity of Stream 1 ⬡, Stream 2 □, Stream 3 ▩, the lake ○, and the Outflow ● in 1972.

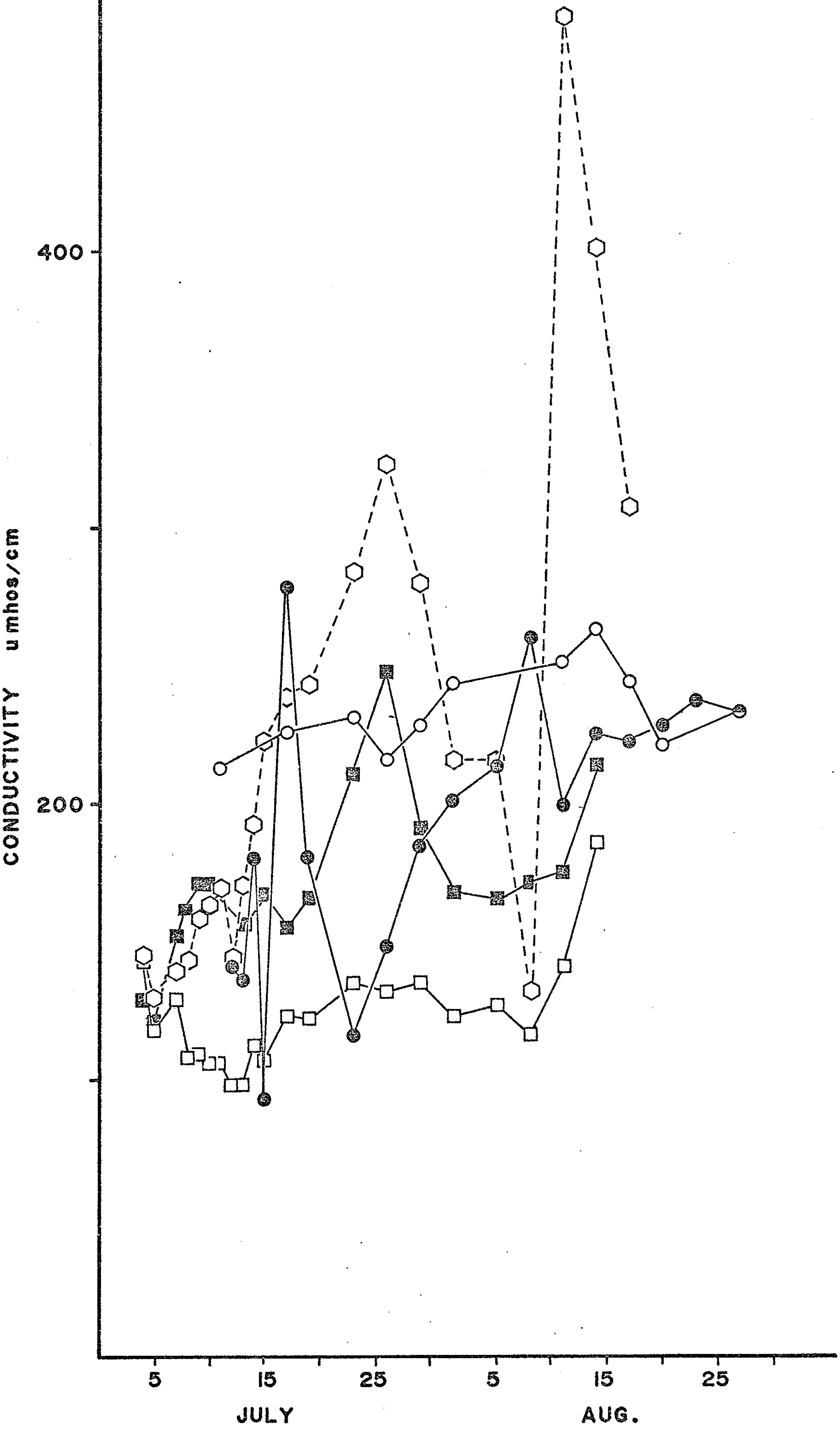

400
200
CONDUCTIVITY u mhos/cm
5
15
25
5
15
25
JULY
AUG.

Figure 5. Conductivity in Stream 1 □, Stream 2 ○, Stream 3 ●, the lake ■, and the Outflow ⬡ in 1973.

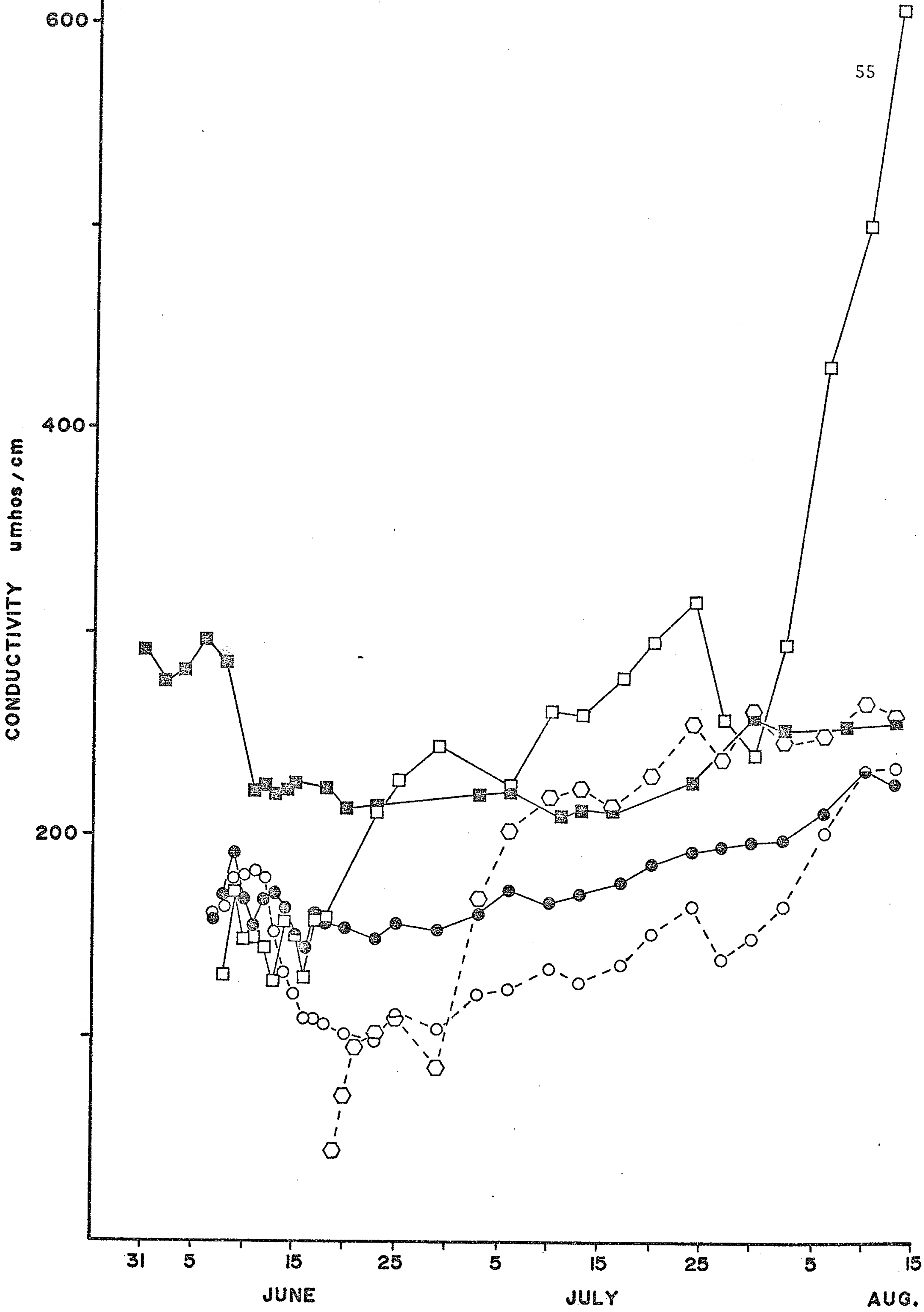

600
400
200
CONDUCTIVITY umhos / cm
31
5
15
25
5
15
25
5
15
JUNE
JULY
AUG.

Figure 6. Conductivity of Stream 1A in 1972 □, and 1973 ○.

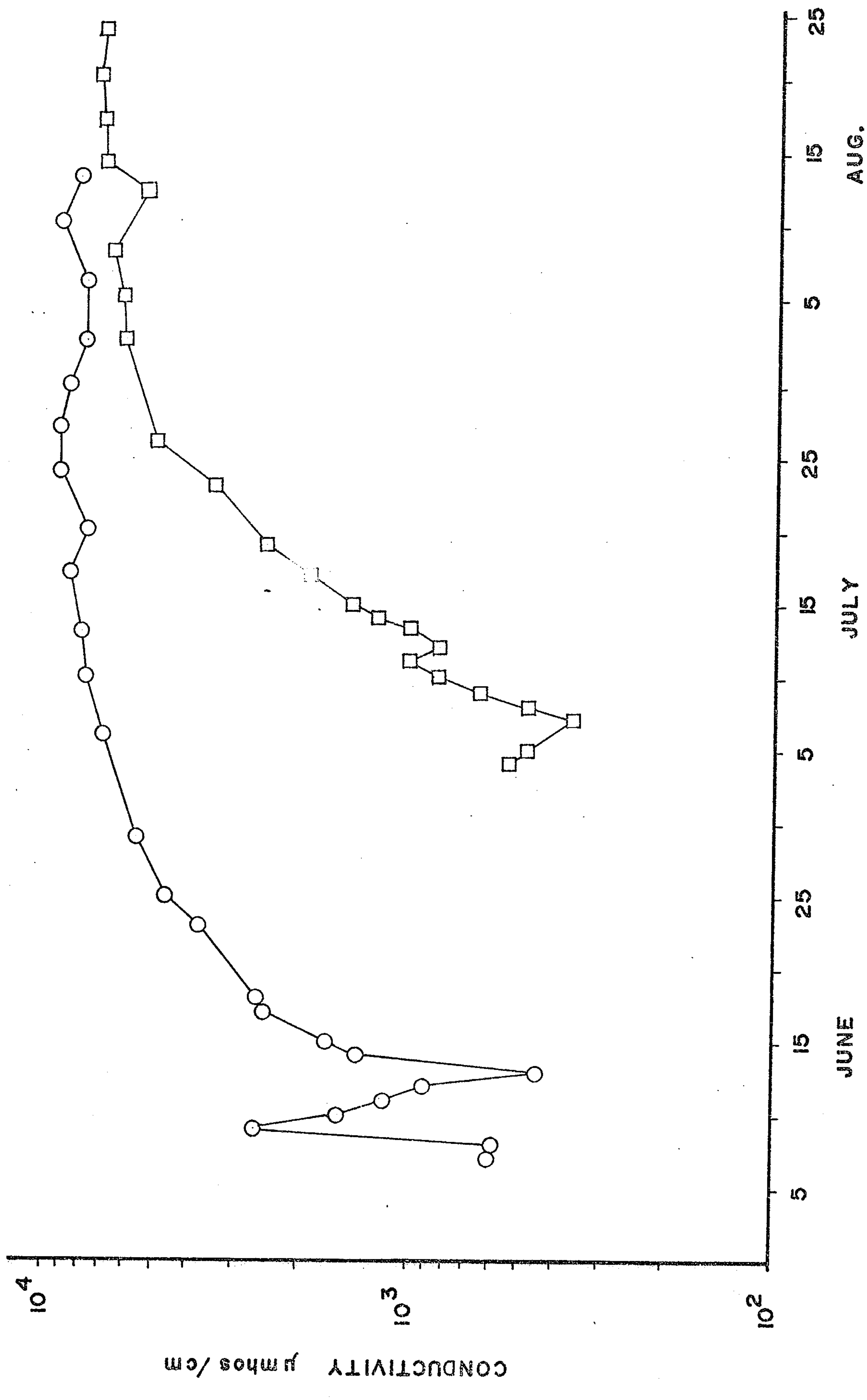

10^4
10^3
10^2
CONDUCTIVITY µmhos/cm
5
15
25
5
15
25
5
15
25
JUNE
JULY
AUG.

Figure 7. DOC concentrations in Stream 1A in 1972 ○, and 1973 ●.

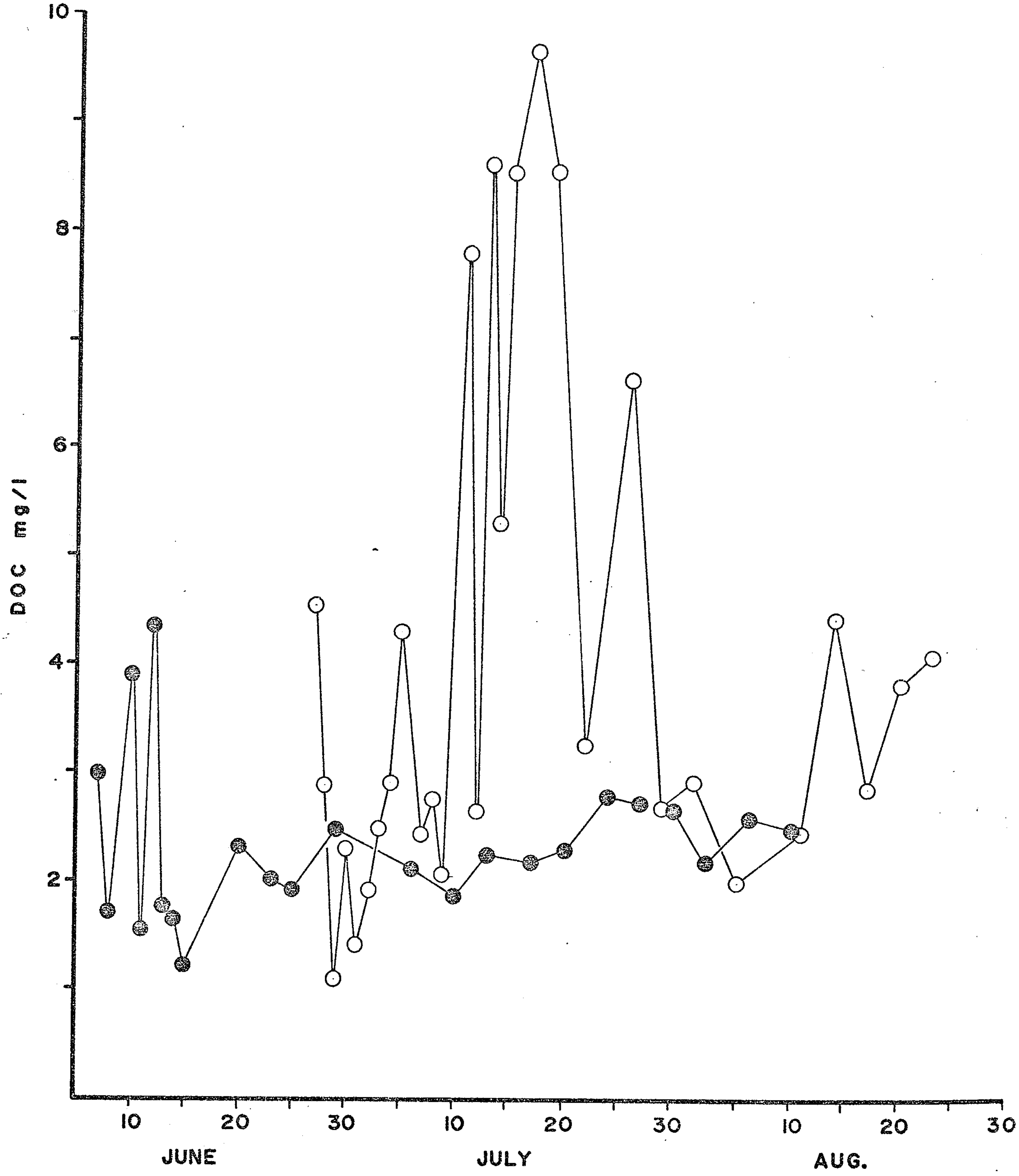

10
8
6
4
2
DOC mg/l
10
20
30
10
20
30
10
20
30
JUNE
JULY
AUG.

Figure 8. DOC concentrations in Stream 1 in 1972 ●, and 1973 ○.

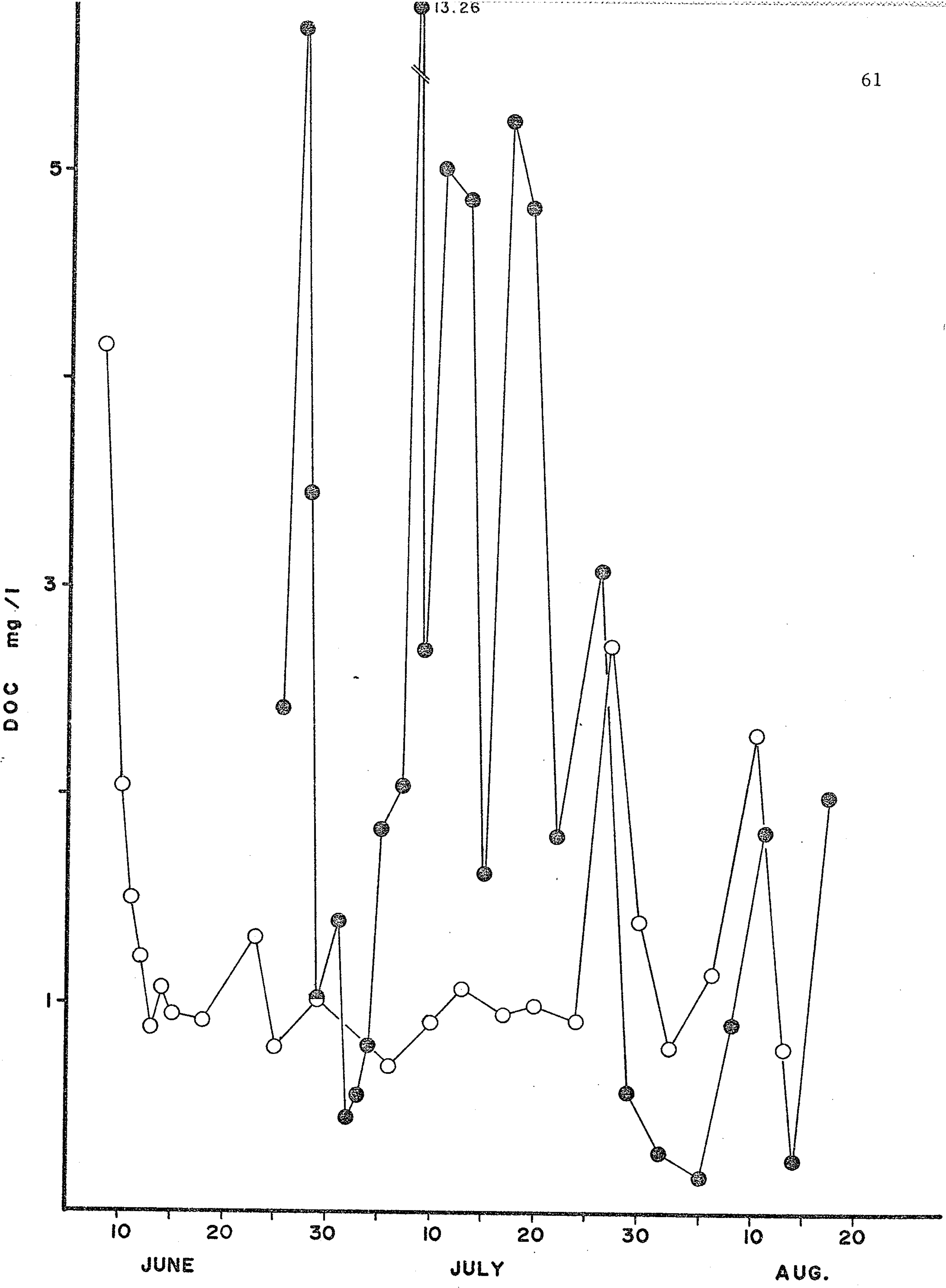

13.26
5
3
1
DOC mg / l
10
20
30
10
20
30
10
20
JUNE
JULY
AUG.

Figure 9. DOC concentrations in Stream 2 in 1972 ●, and 1973 ○.

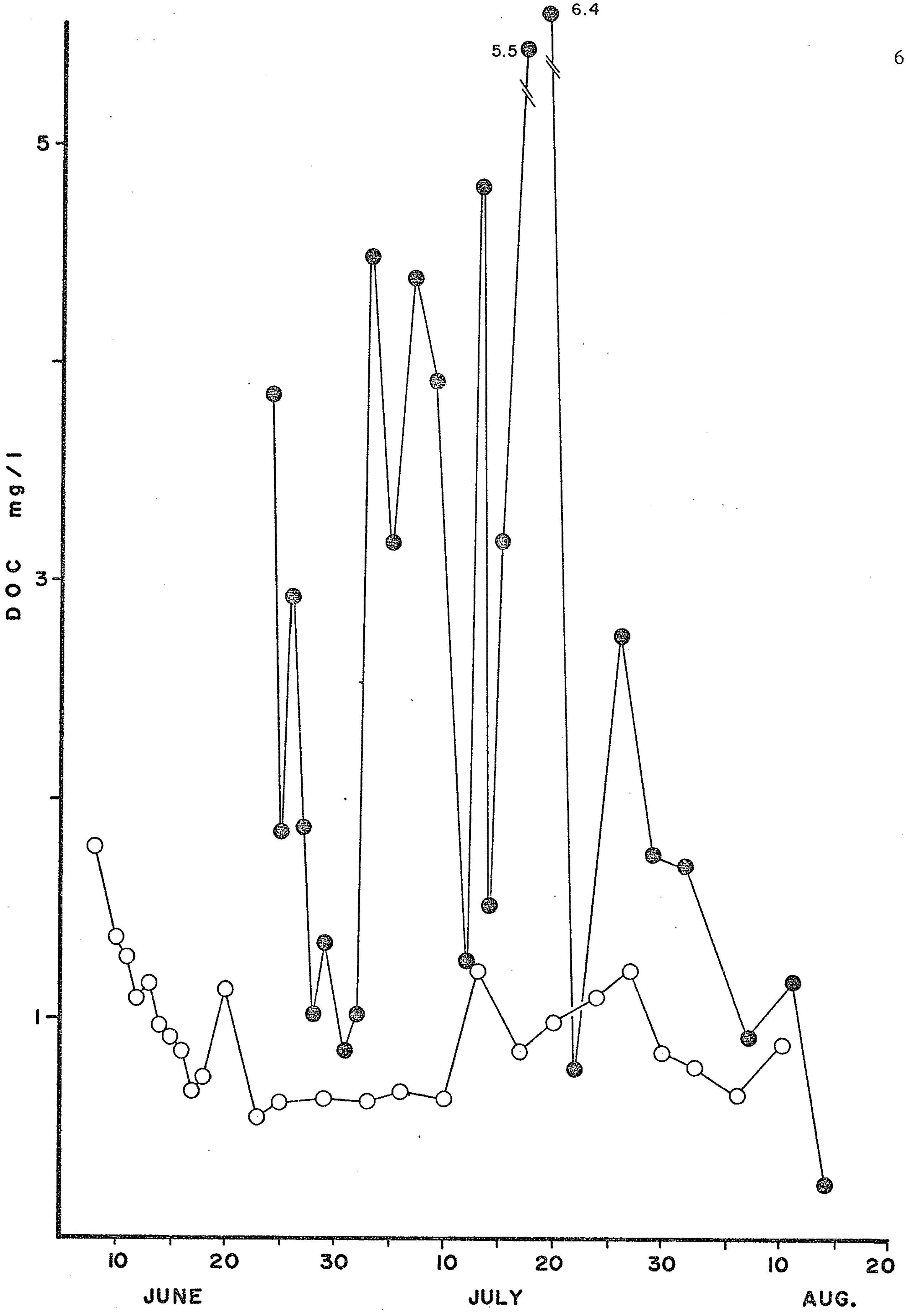
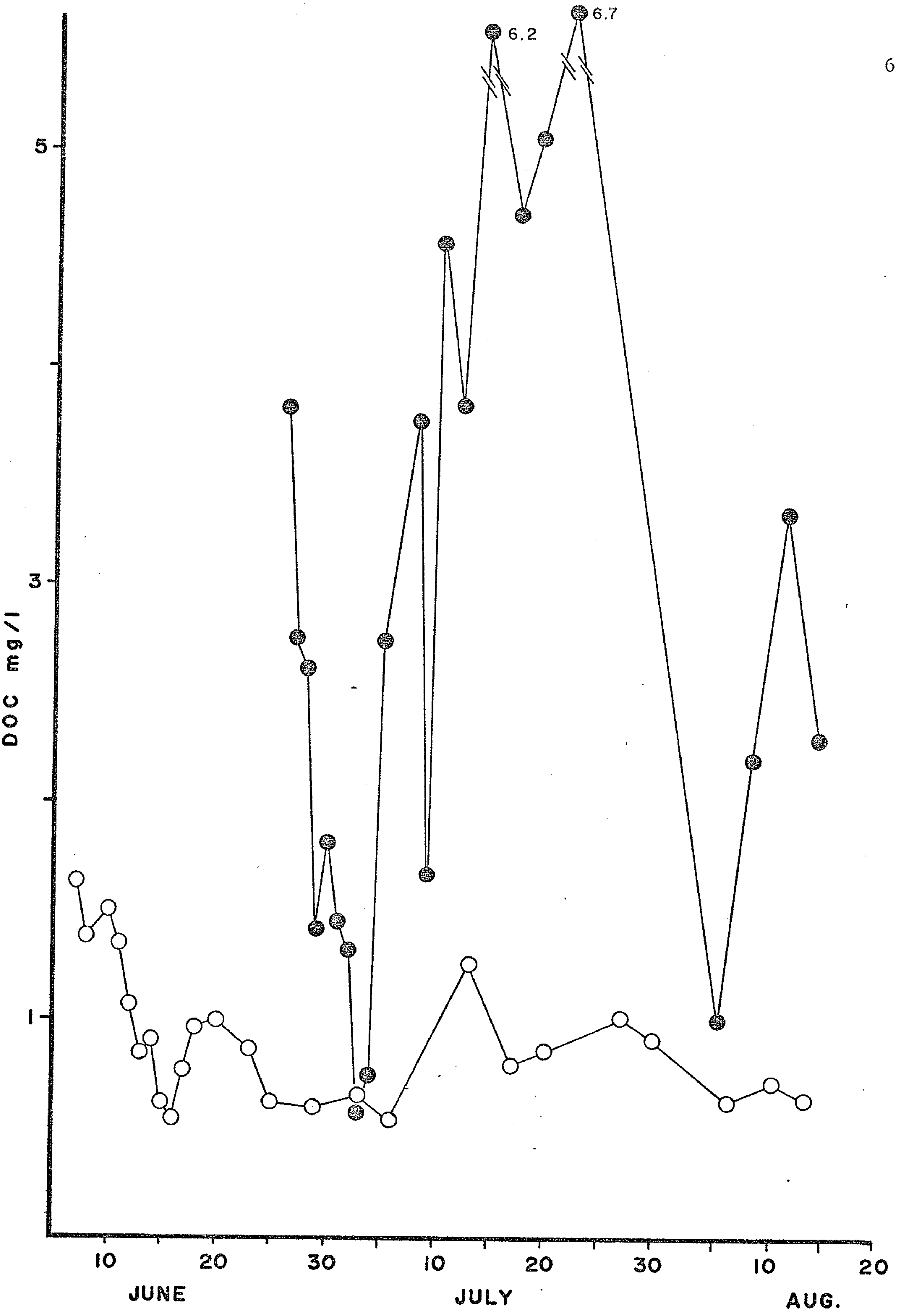

6.4
5.5
5
3
1
DOC mg/l
10
20
30
10
20
30
10
20
JUNE
JULY
AUG.

Figure 10. DOC concentrations in Stream 3 in 1972 ●, and 1973 ○.



6.2
6.7
5
3
1
DOC mg/l
10
20
30
10
20
30
10
20
JUNE
JULY
AUG.

Figure 11. TDN concentrations in Stream 1A in 1972 ●, and 1973 ○.

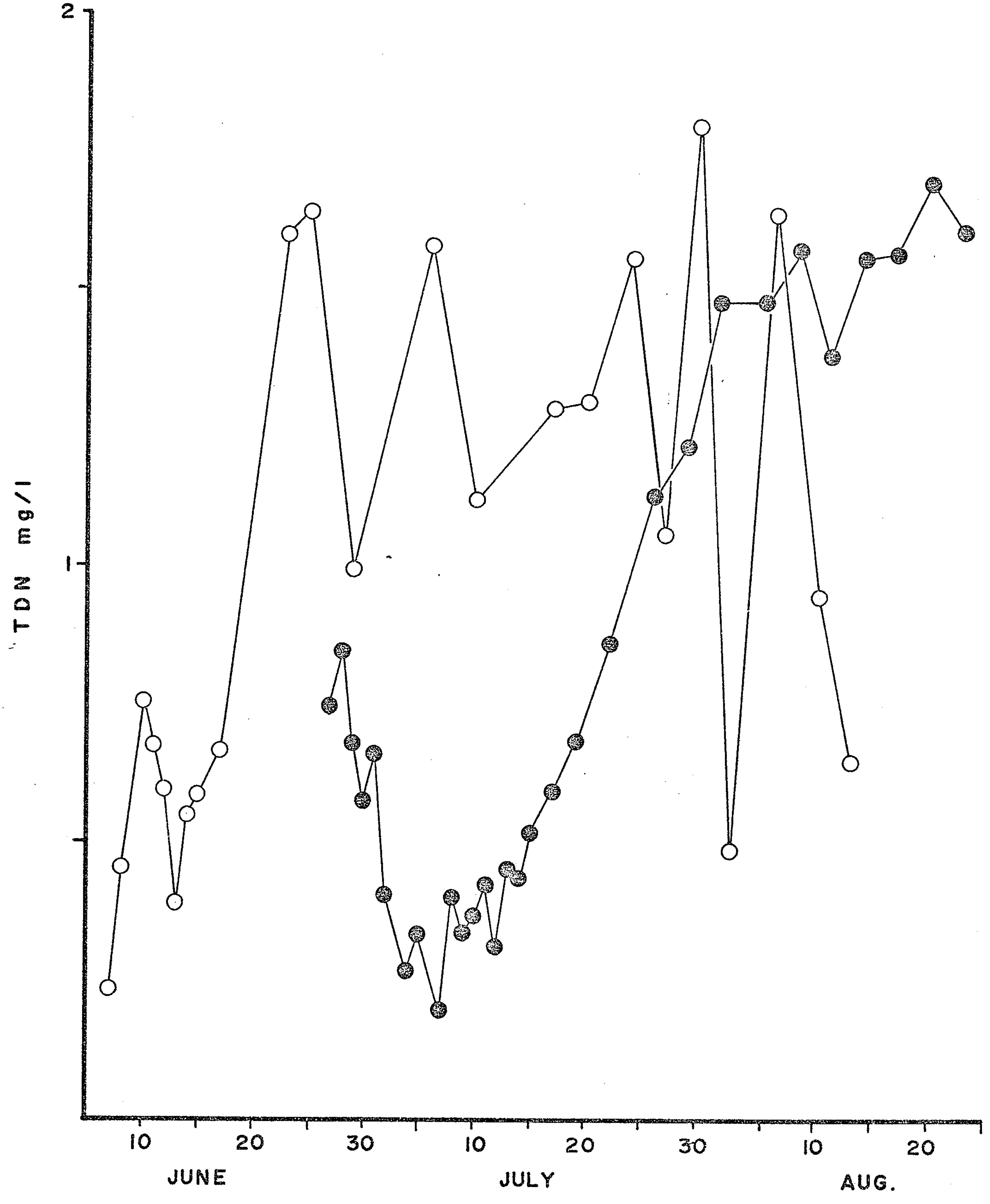

2
1
TDN mg/l
10
20
30
10
20
30
10
20
JUNE
JULY
AUG.

Figure 12. TDN concentrations in Stream 1 in 1972 ●, and 1973 ○.

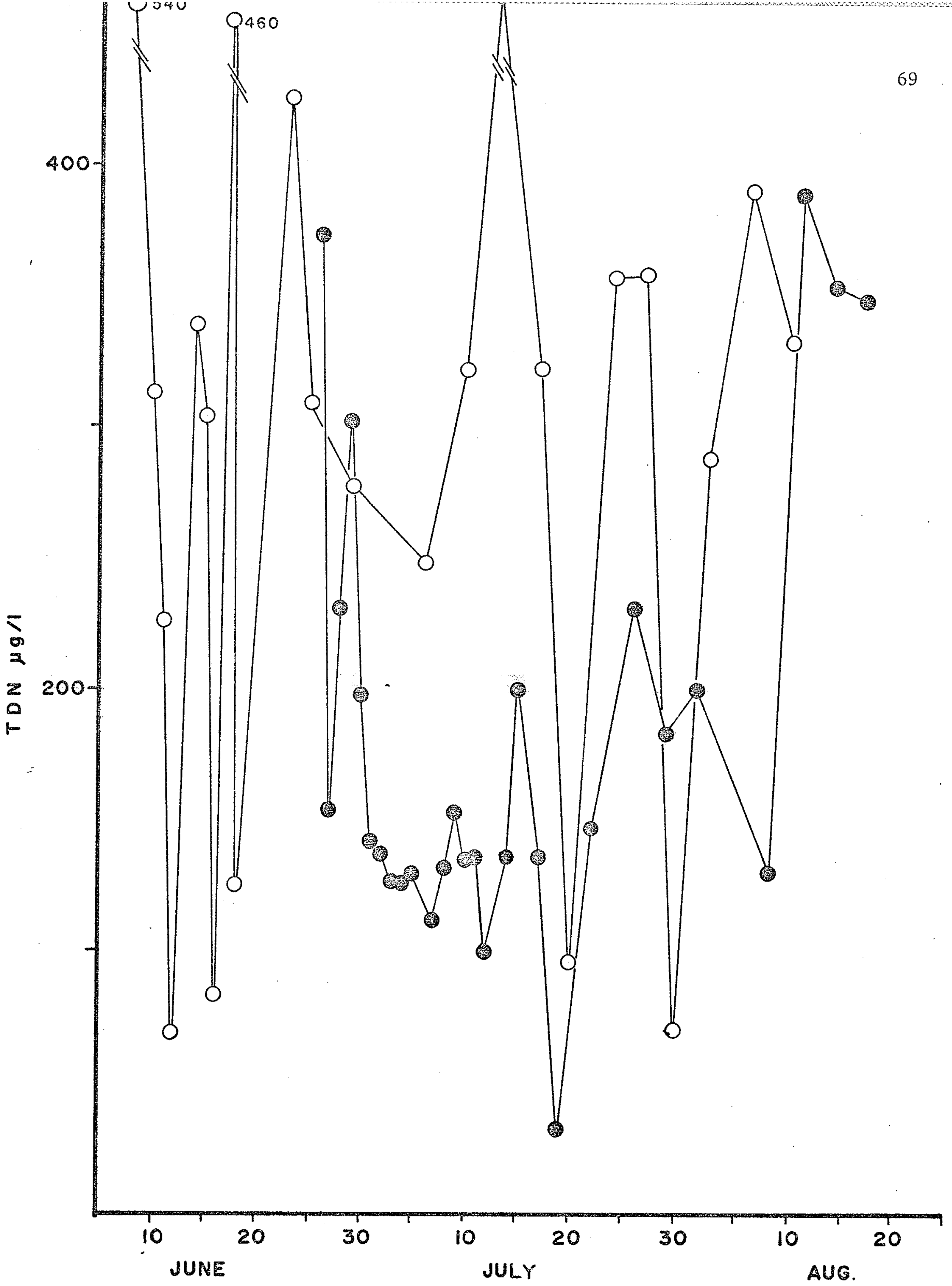

540
460
400
200
TDN µg/l
10
20
30
10
20
30
10
20
JUNE
JULY
AUG.

Figure 13. TDN concentrations in Stream 2 in 1972 ●, and 1973 ○.

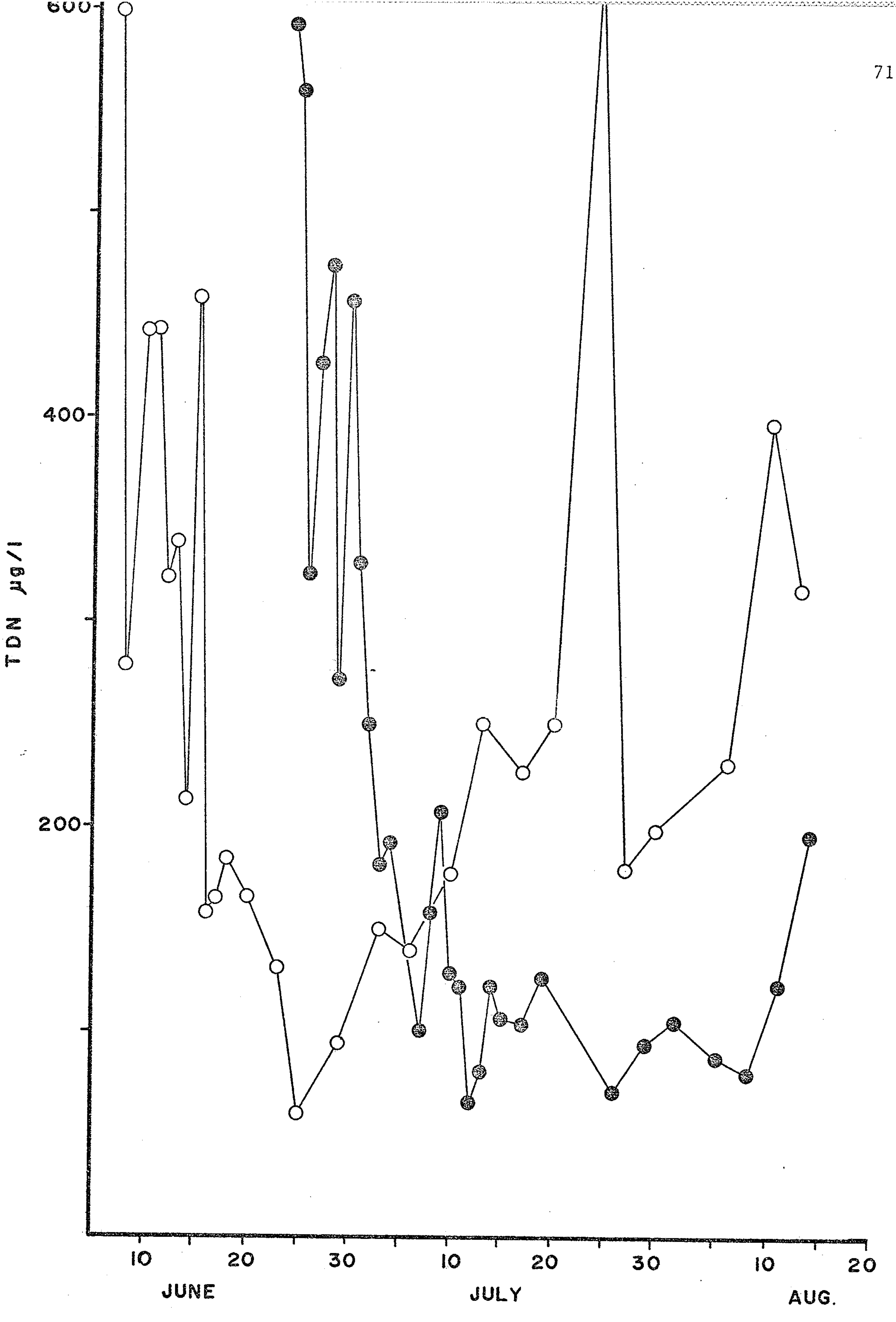

600
400
200
TDN µg/l
10
20
30
10
20
30
10
20
JUNE
JULY
AUG.

Figure 14. TDN concentrations in Stream 3 in 1972 ●, and 1973 ○.

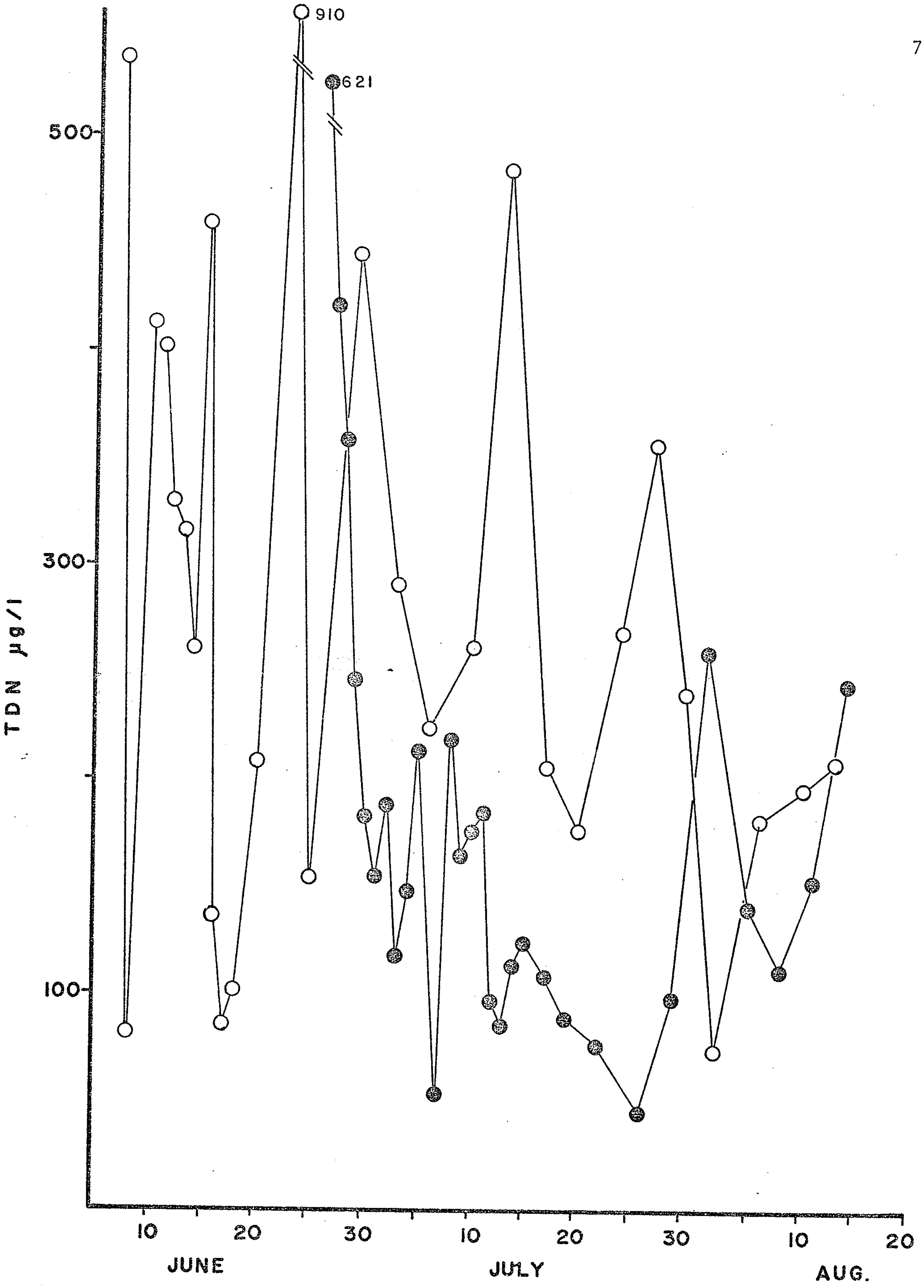

TDN µg/l
500
300
100
910
621
10
20
30
10
20
30
10
20
JUNE
JULY
AUG.

Figure 15. FPOC concentrations in Stream 1A ○, and Stream 2 □ in 1972, and FPN concentrations in Stream 1A, ●, and Stream 2 ■ in 1972.

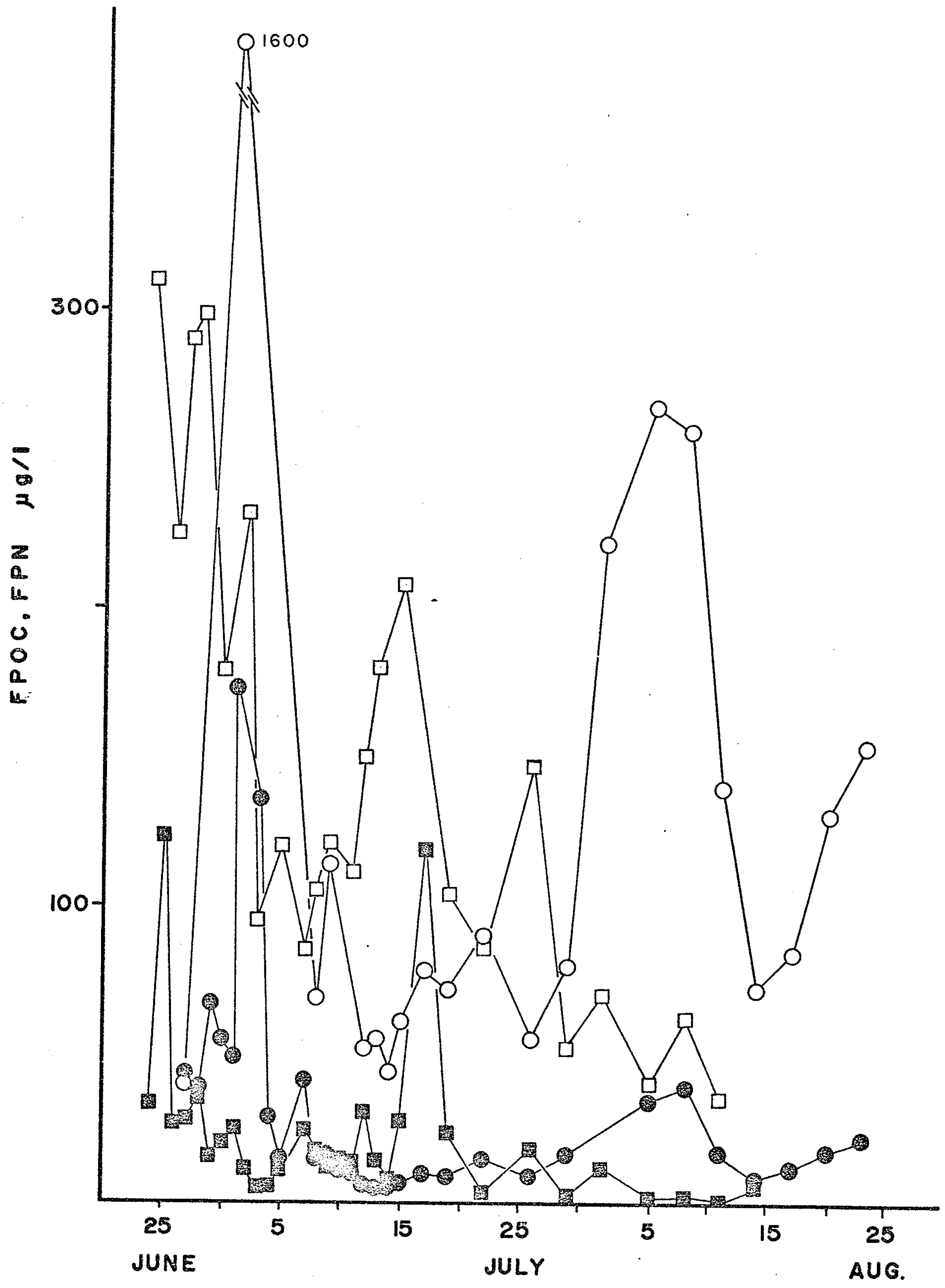

1600
300
100
FPOC, FPN µg/l
25
5
15
25
5
15
25
JUNE
JULY
AUG.

Figure 16. FPOC concentrations in Stream 1A ○, and Stream 2 □ in 1973, and FPN concentrations in Stream 1A ●, and Stream 2 ■ in 1973

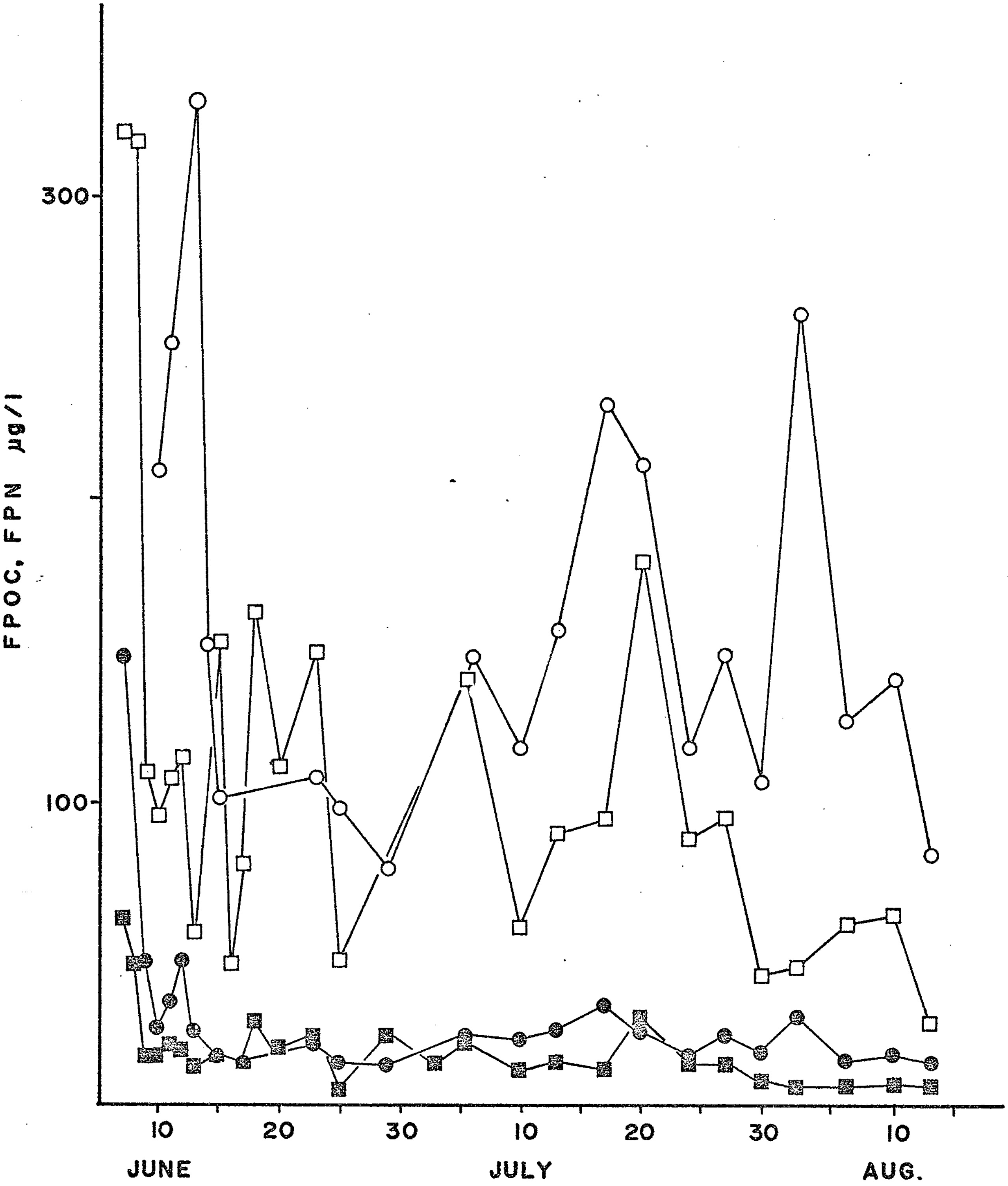

FPOC, FPN µg/l
300
100
10
20
30
10
20
30
10
JUNE
JULY
AUG.

Figure 17. FPOC concentrations in Stream 1 ○, and Stream 3 □ in 1972, and FPN concentrations in Stream 1 ●, and Stream 3 ■ in 1972.

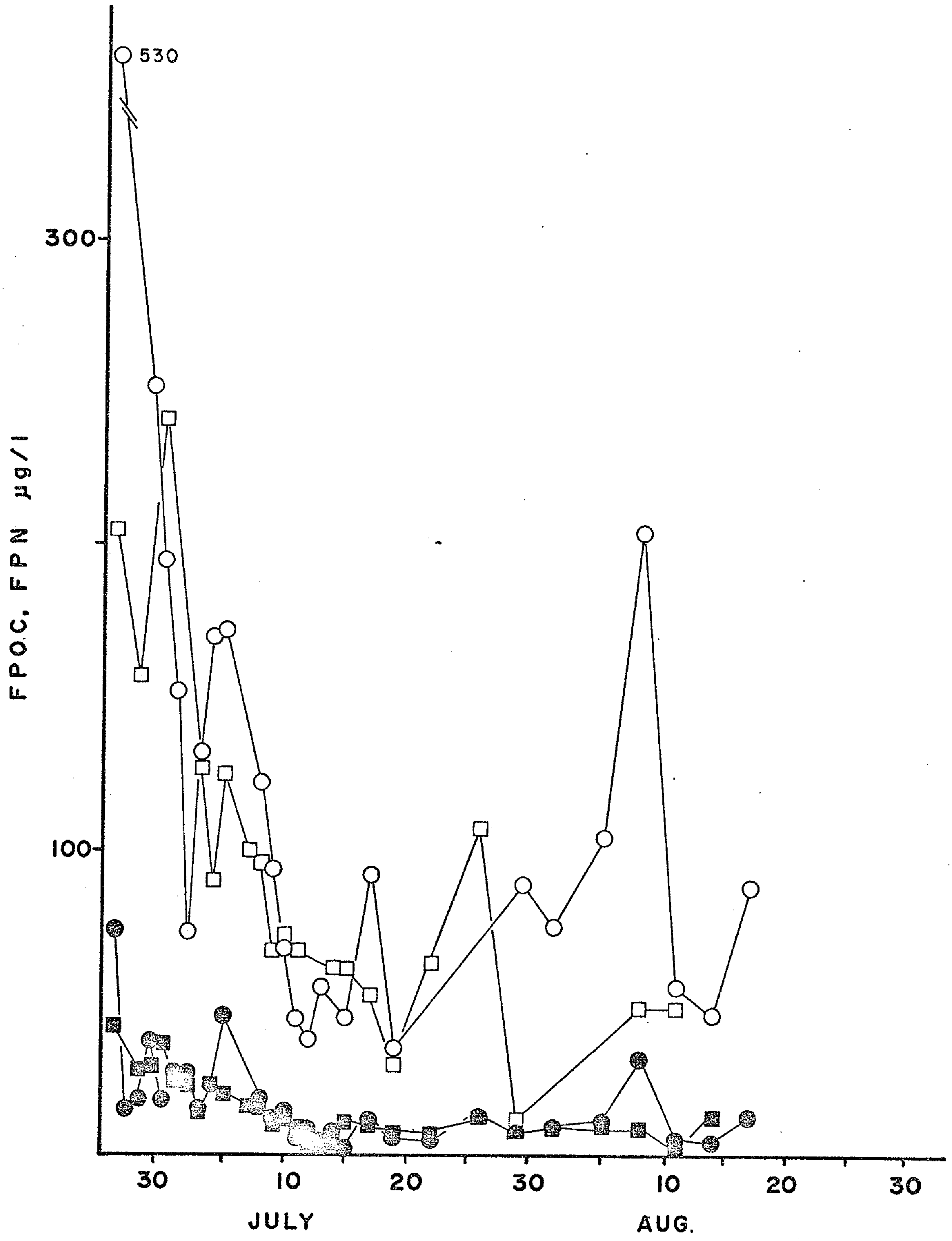

530
300
100
FPOC, FPN µg/l
30
10
20
30
10
20
30
JULY
AUG.

Figure 18. FPOC concentrations in Stream 1 ○, and Stream 3 □ in 1973, and FPN concentrations in Stream 1 ●, and Stream 3 ■ in 1973.

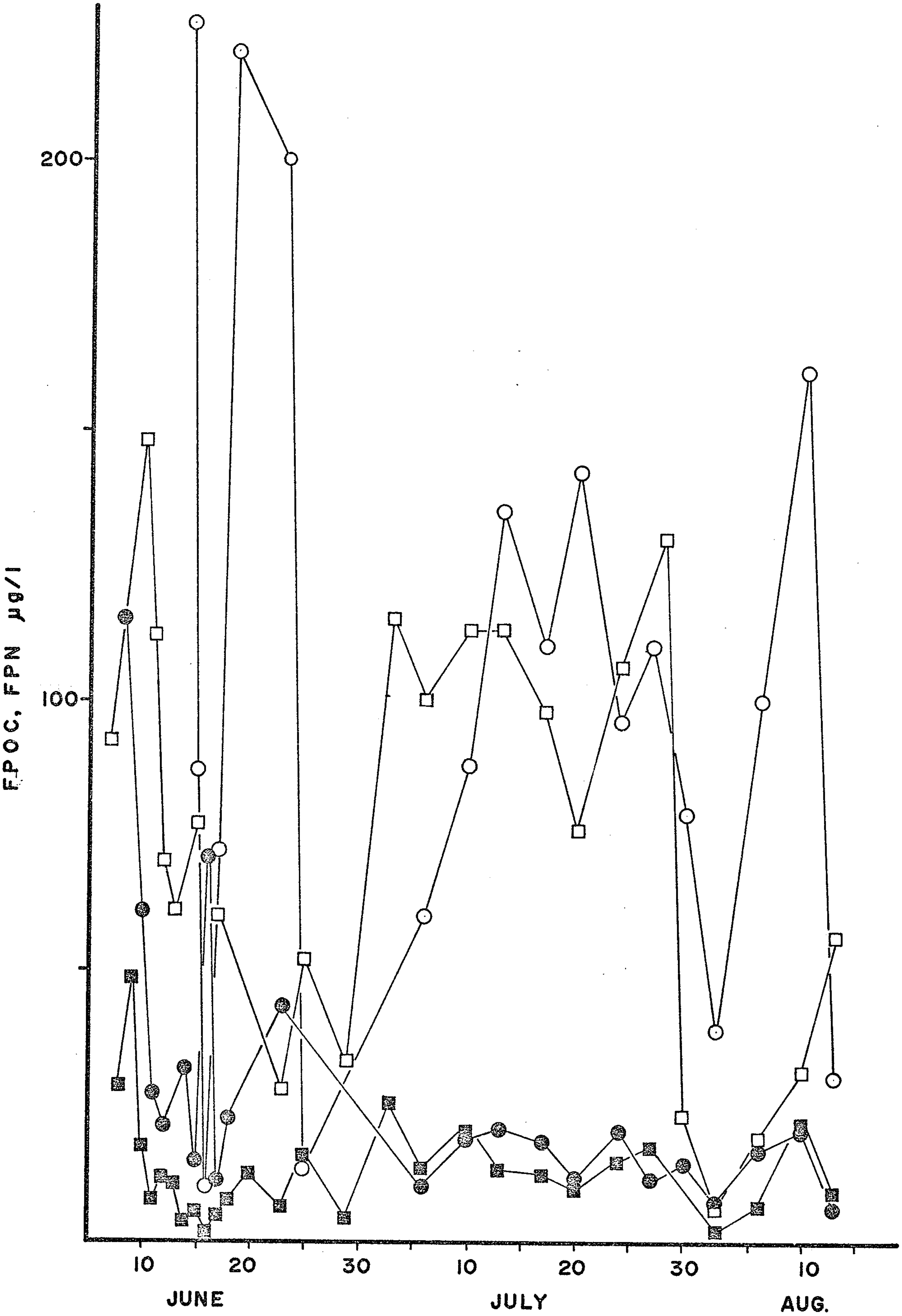

200
100
FPOC, FPN µg/l
10
20
30
10
20
30
10
JUNE
JULY
AUG.

Figure 19. TDP concentrations in Stream 1A in 1972 ●, and 1973 ○.
FPP concentrations in Stream 1A in 1972 ■, and 1973 □.

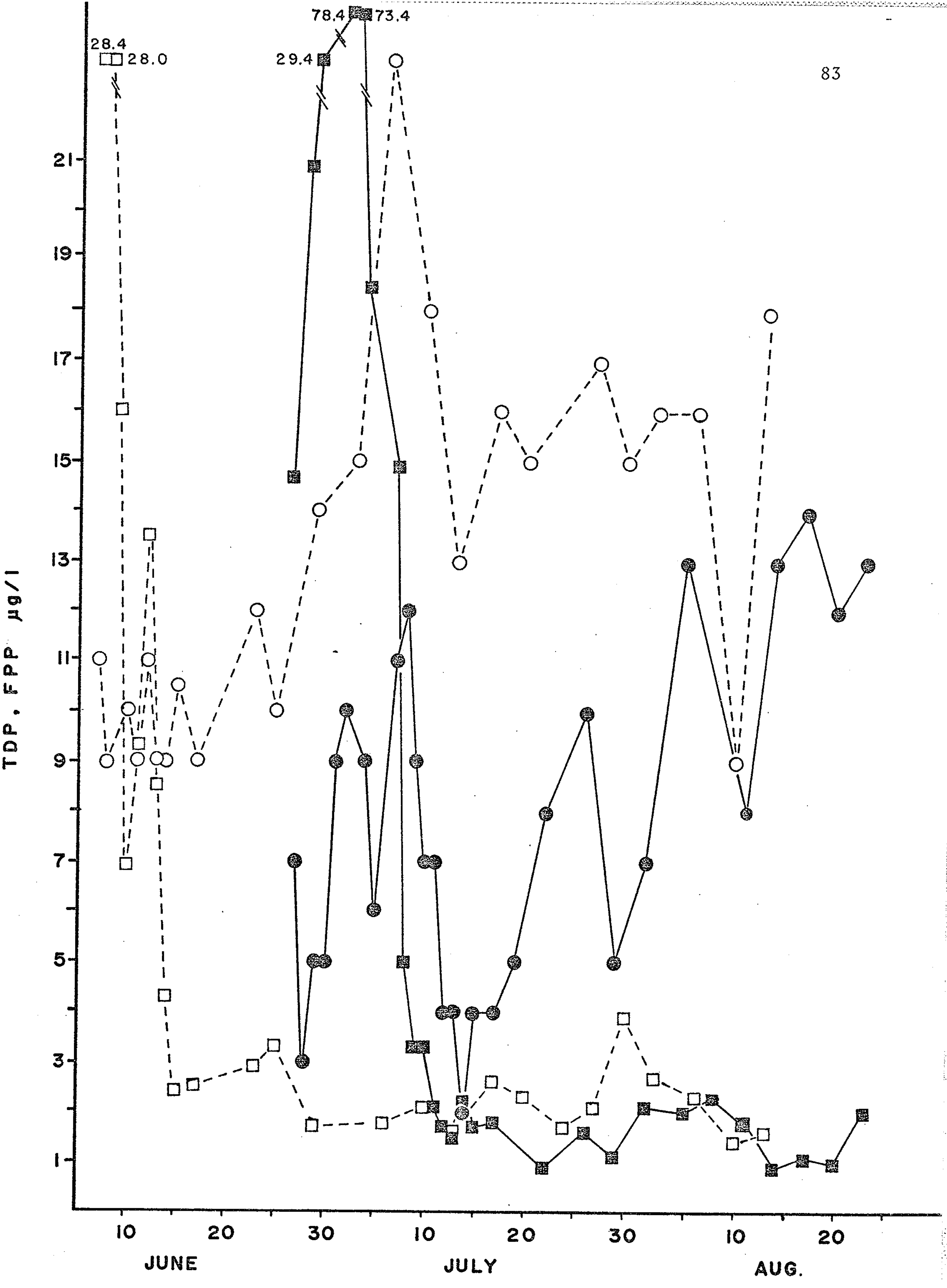

28.4
28.0
78.4
73.4
29.4
21
19
17
15
13
11
9
7
5
3
1
TDP, FPP µg/l
10
20
30
10
20
30
10
20
JUNE
JULY
AUG.

Figure 20. TDP concentrations in Stream 1 in 1972 ●, and 1973 ○.
FPP concentrations in Stream 1 in 1972 ■, and 1973 □.

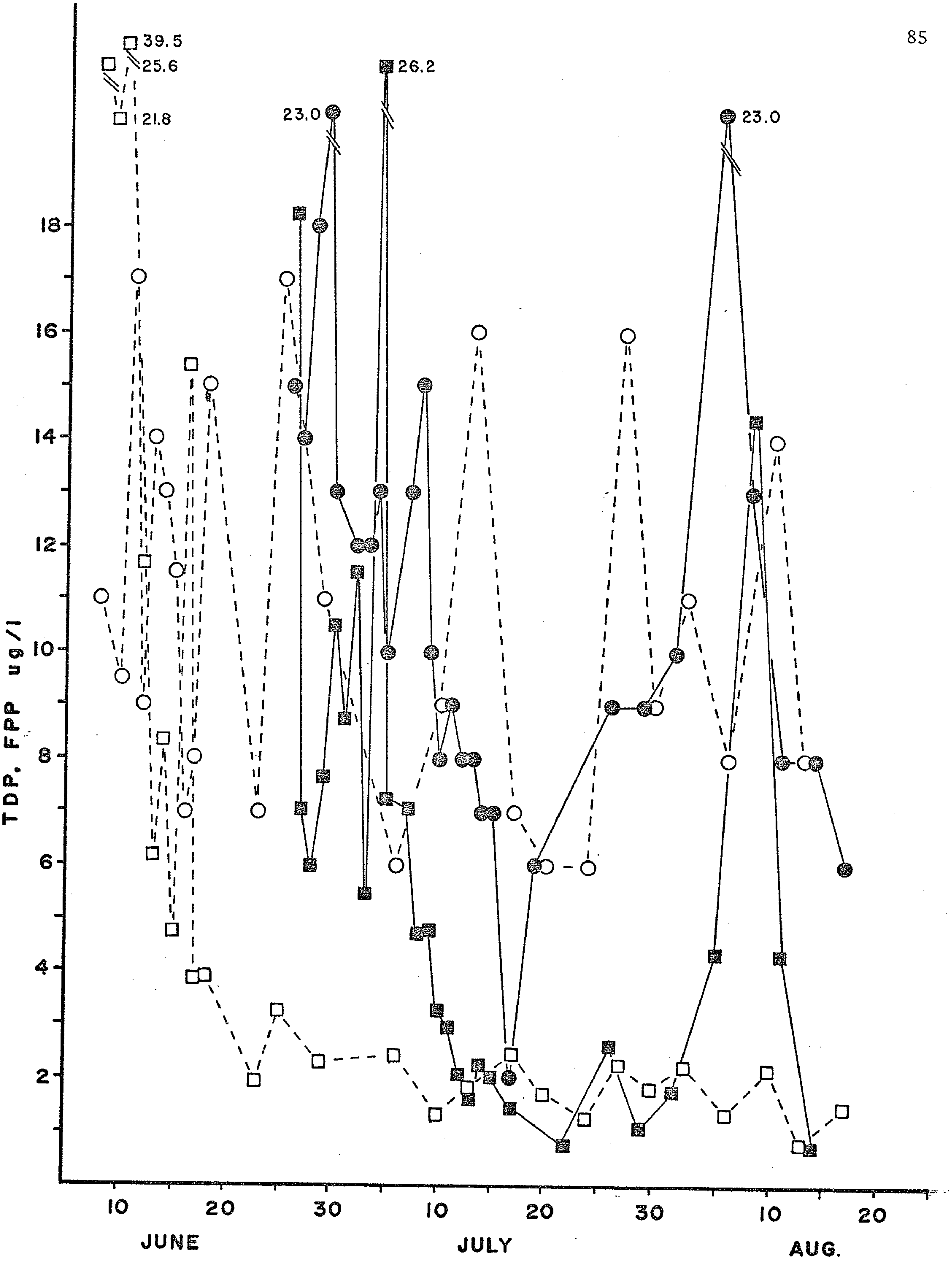

39.5
25.6
21.8
23.0
26.2
23.0
TDP, FPP ug/l
18
16
14
12
10
8
6
4
2
10
20
30
10
20
30
10
20
JUNE
JULY
AUG.

Figure 21. TDP concentrations in Stream 2 in 1972 ●, and 1973 ○.
FPP concentrations in Stream 2 in 1972 ■, and 1973 □.

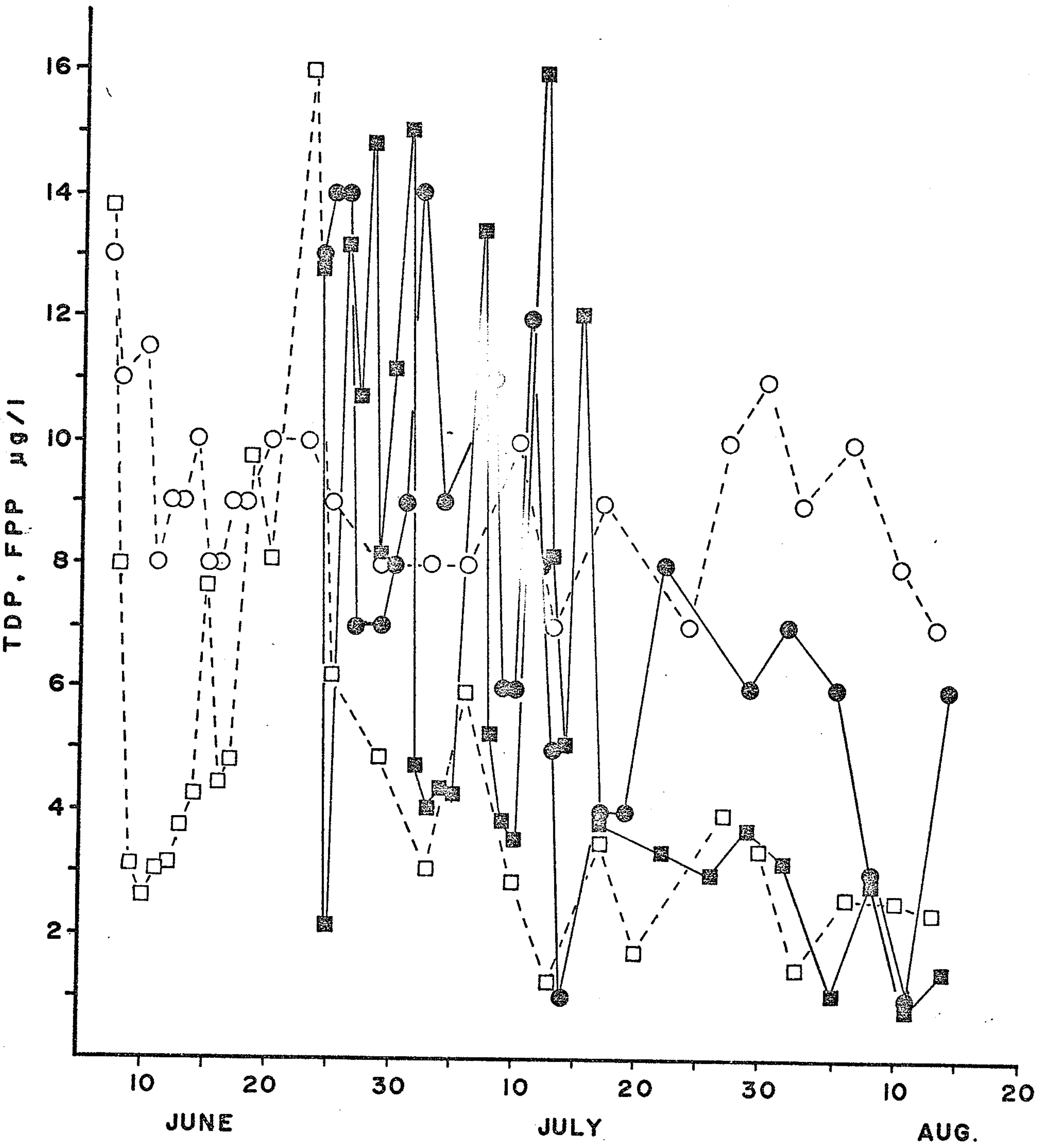

TDP, FPP µg/l
16
14
12
10
8
6
4
2
10
20
30
10
20
30
10
20
JUNE
JULY
AUG.

Figure 22. TDP concentrations in Stream 3 in 1972 ●, and 1973 ○.
FPP concentrations in Stream 3 in 1972 ■, and 1973 □.

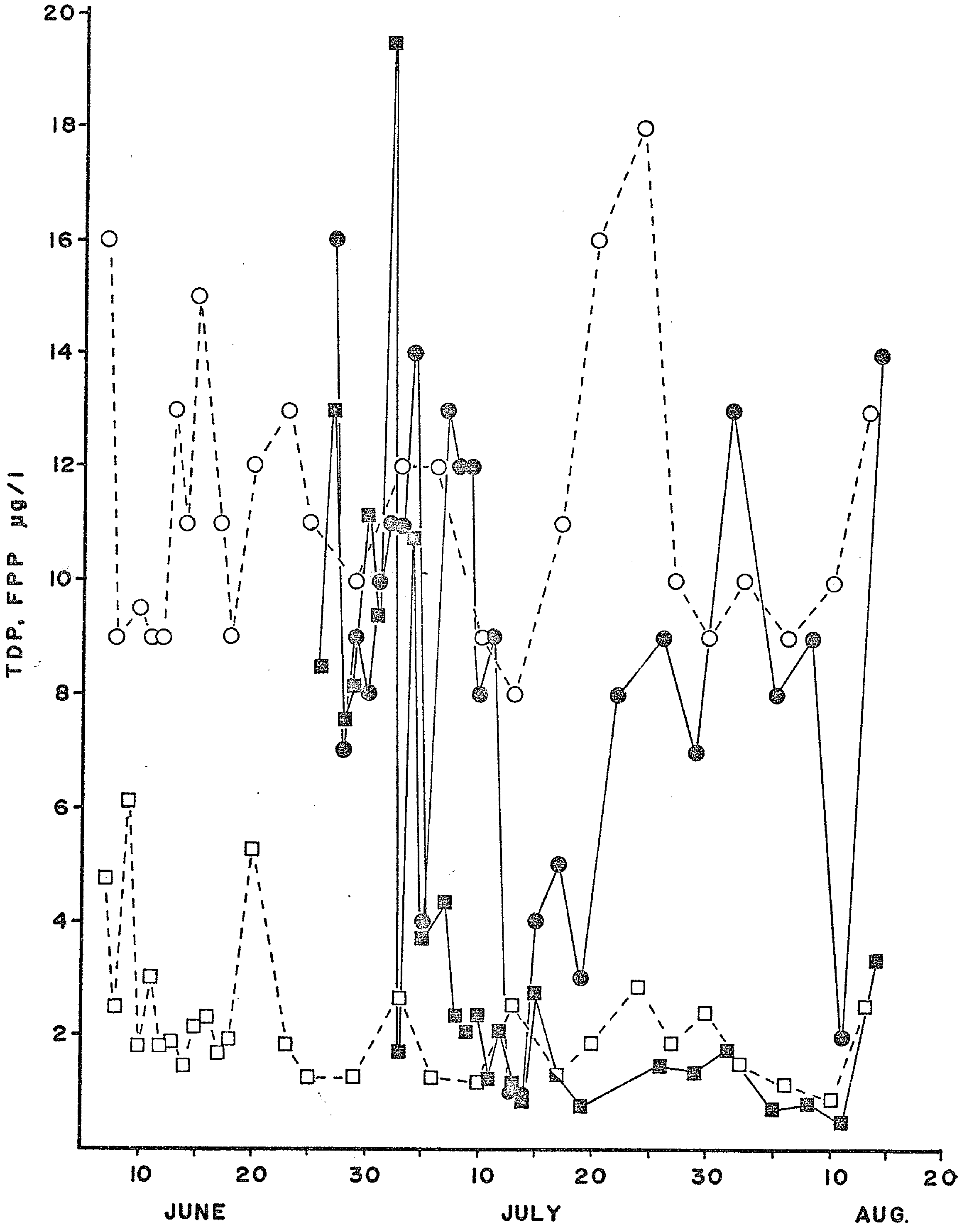

TDP, FPP µg/l
20
18
16
14
12
10
8
6
4
2
10
20
30
10
20
30
10
20
JUNE
JULY
AUG.

Figure 23. DOC concentrations in Char Lake in 1972 ●, and 1973 ○.

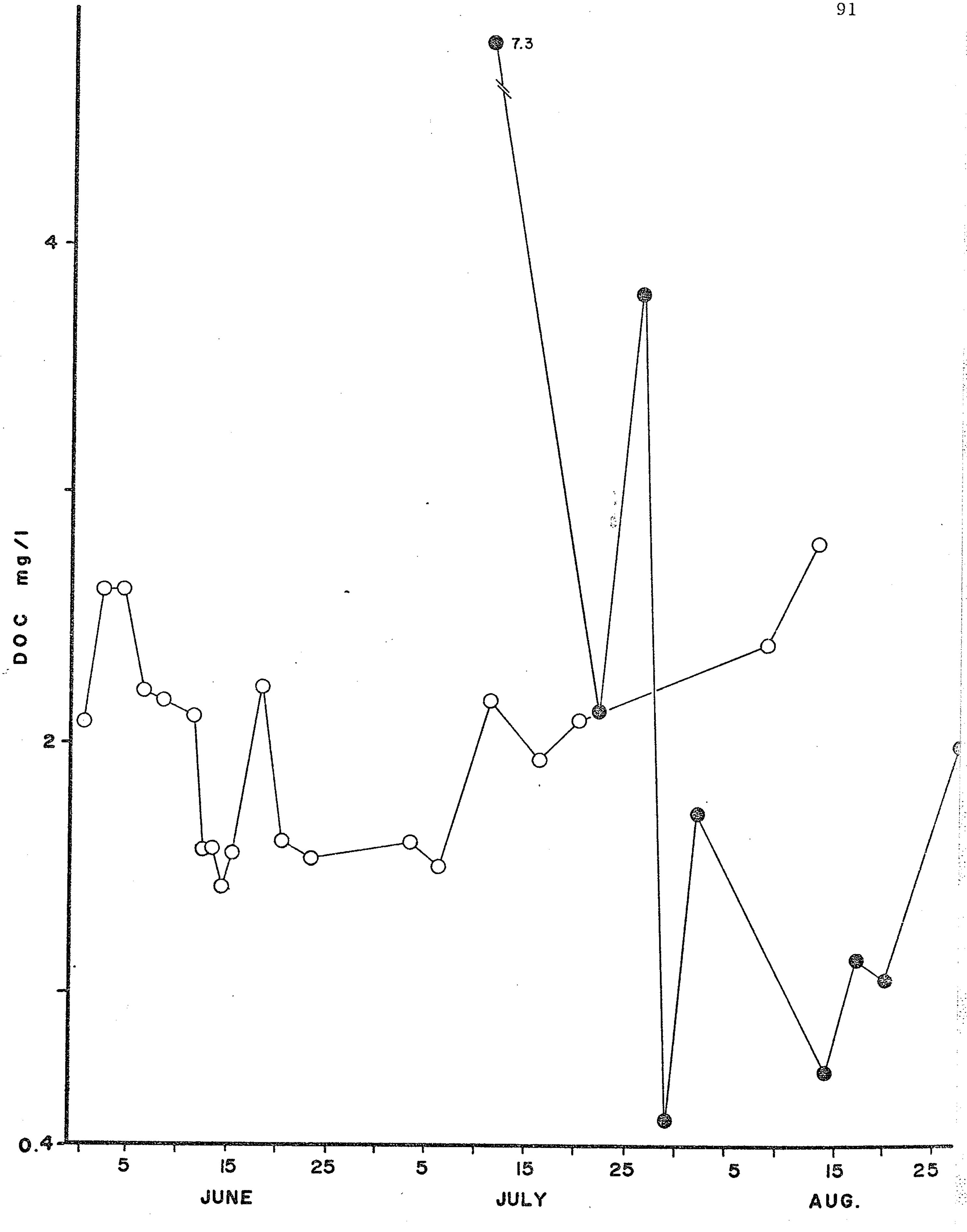

7.3
DOC mg/l
4
2
0.4
5
15
25
5
15
25
5
15
25
JUNE
JULY
AUG.

Figure 24. DOC concentrations in the Outflow in 1972 ●, and 1973 ○.

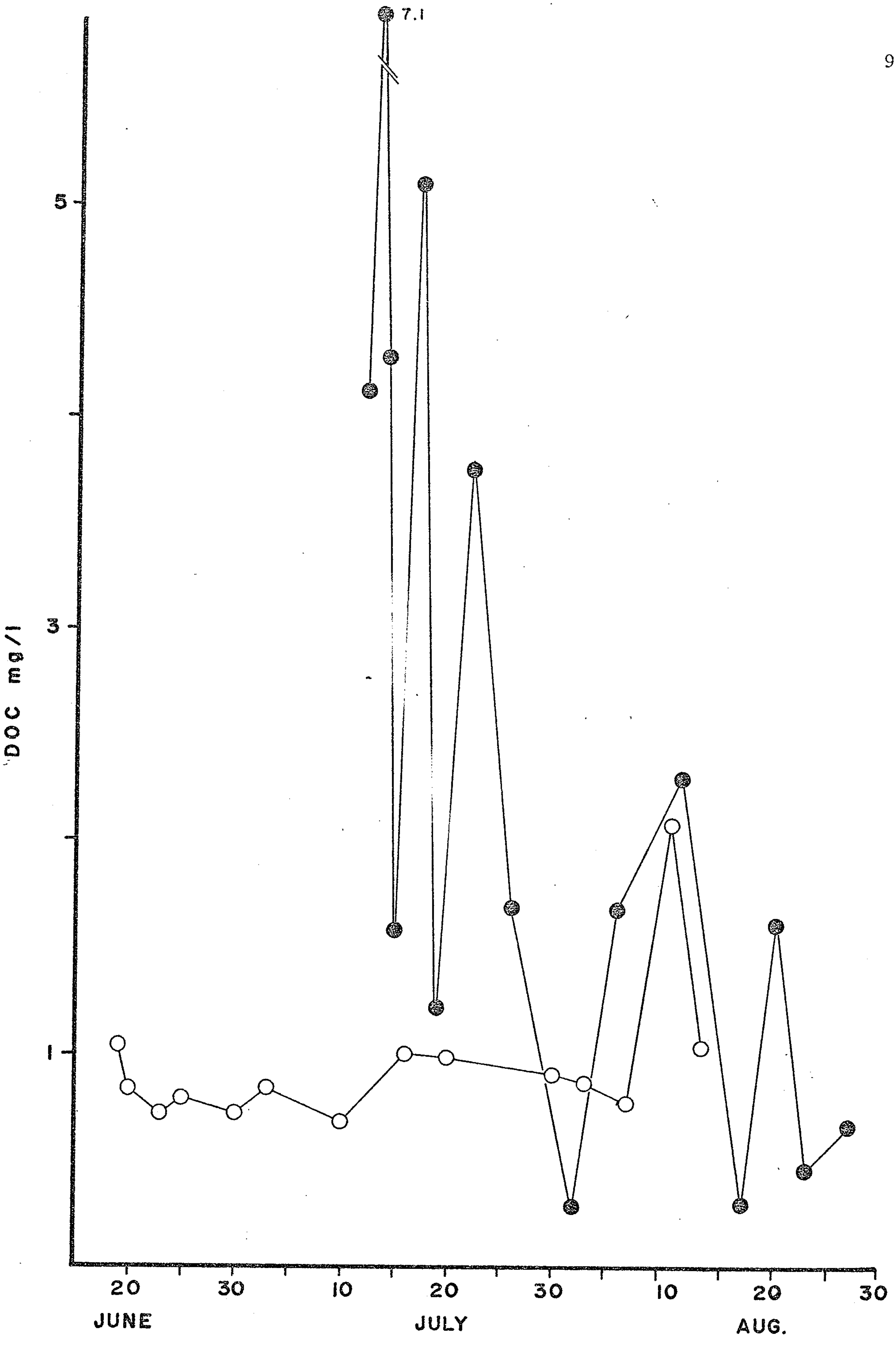

7.1
5
3
1
DOC mg/l
20
30
10
20
30
10
20
30
JUNE
JULY
AUG.

Figure 25. TDN concentrations in Char Lake in 1972 ●, and 1973 ○.

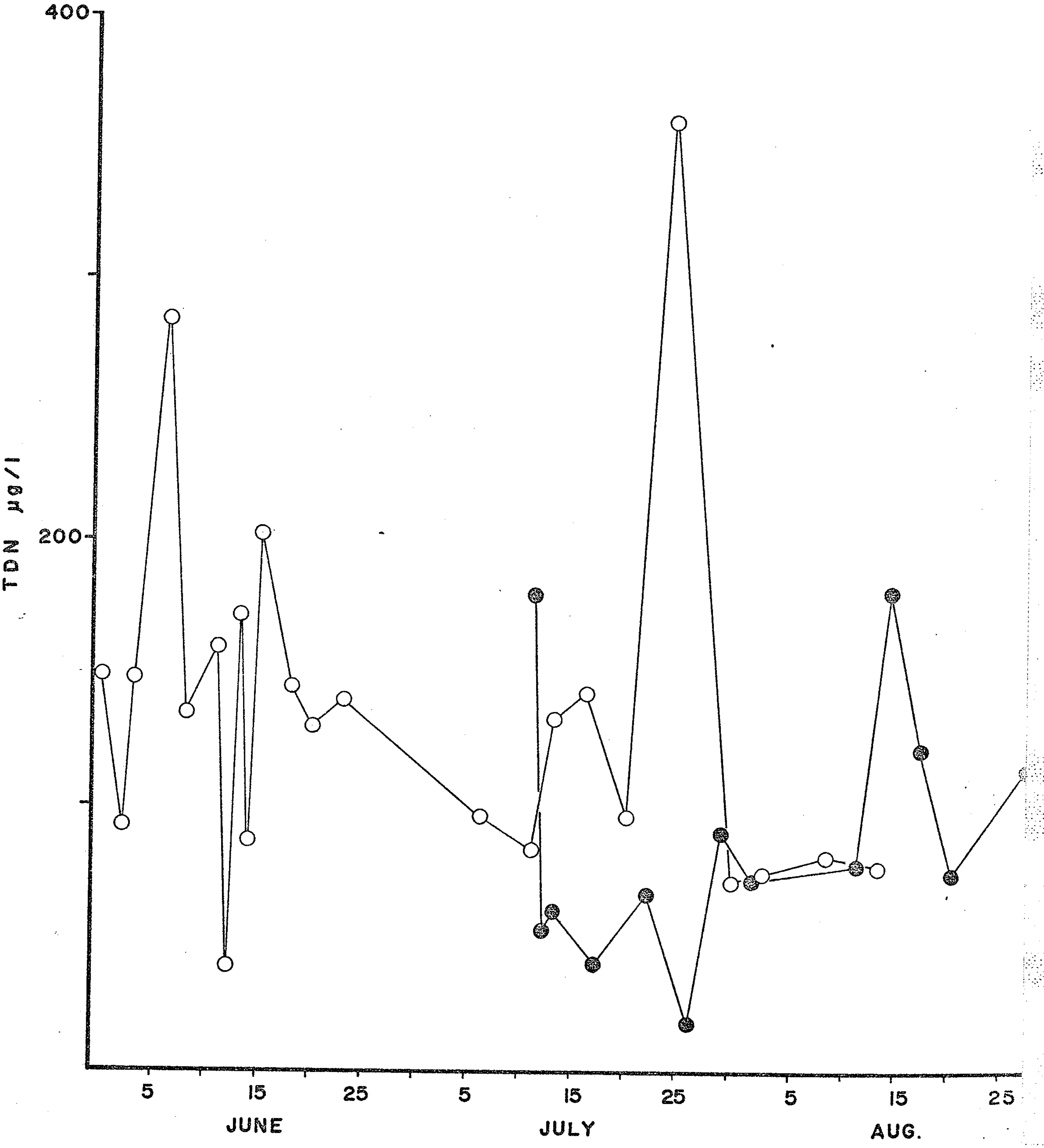

400
200
TDN µg/l
5
15
25
5
15
25
5
15
25
JUNE
JULY
AUG.

Figure 26. TDN concentrations in the Outflow in 1972 ●, and 1973 ○.

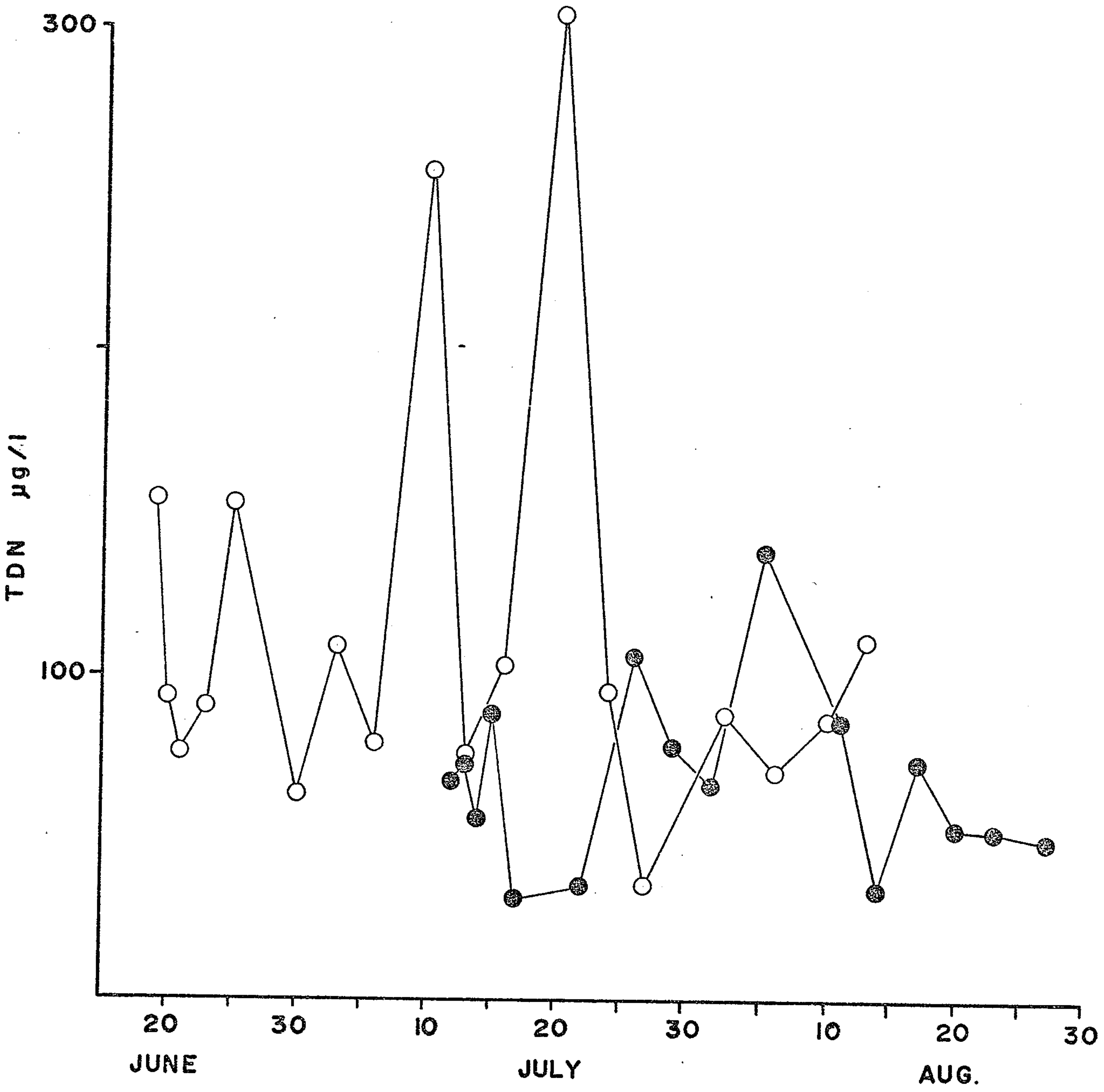

300
100
TDN µg/l
20
30
10
20
30
10
20
30
JUNE
JULY
AUG.

Figure 27. FPN concentrations in Char Lake □, and the Outflow ○ in 1972.

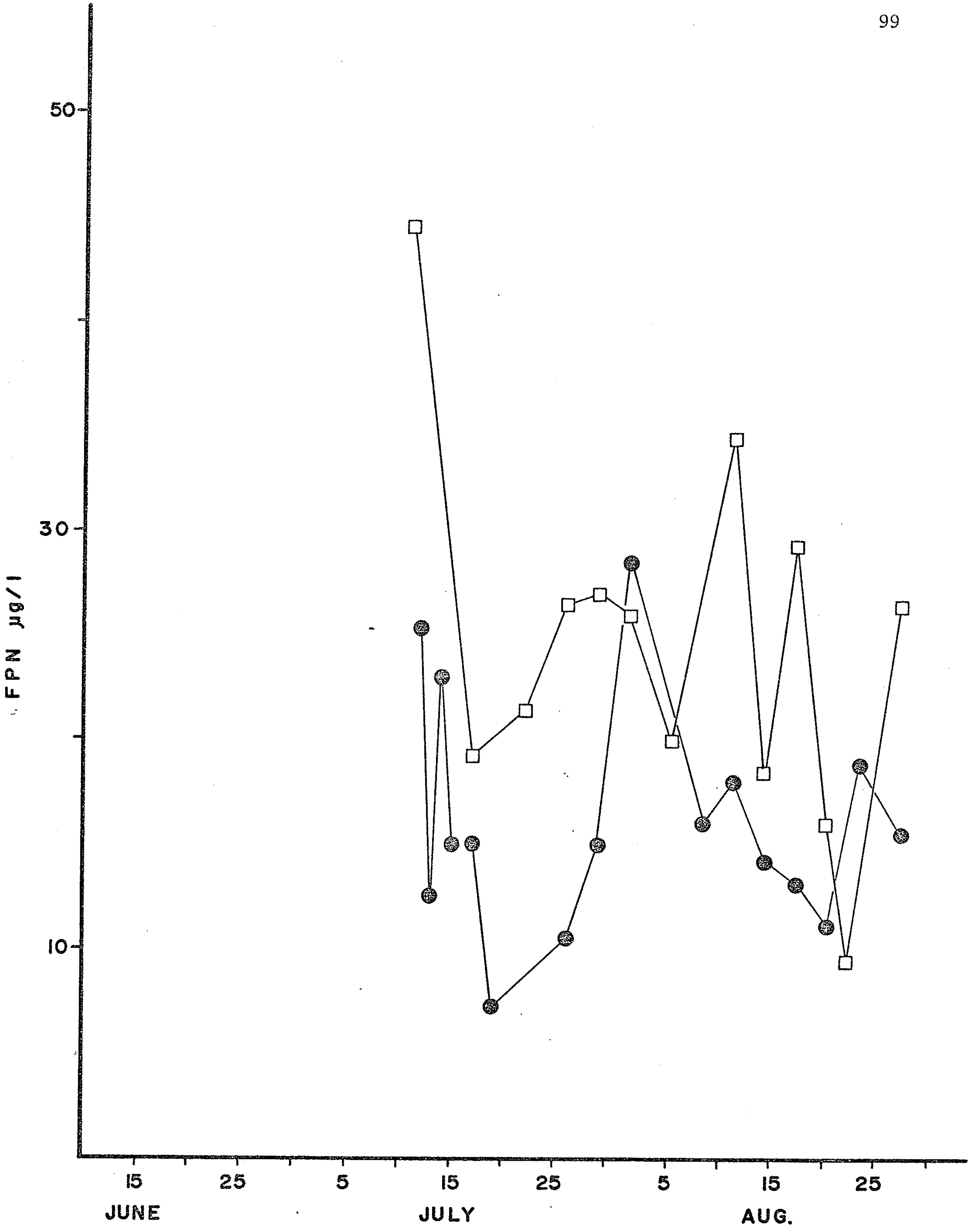

50
30
10
FPN µg/l
15
25
5
15
25
5
15
25
JUNE
JULY
AUG.

Figure 28. FPOC concentrations in Char Lake ●, and in the Outflow ■ in 1973, and FPN concentrations in Char Lake ○, and the Outflow □ in 1973.

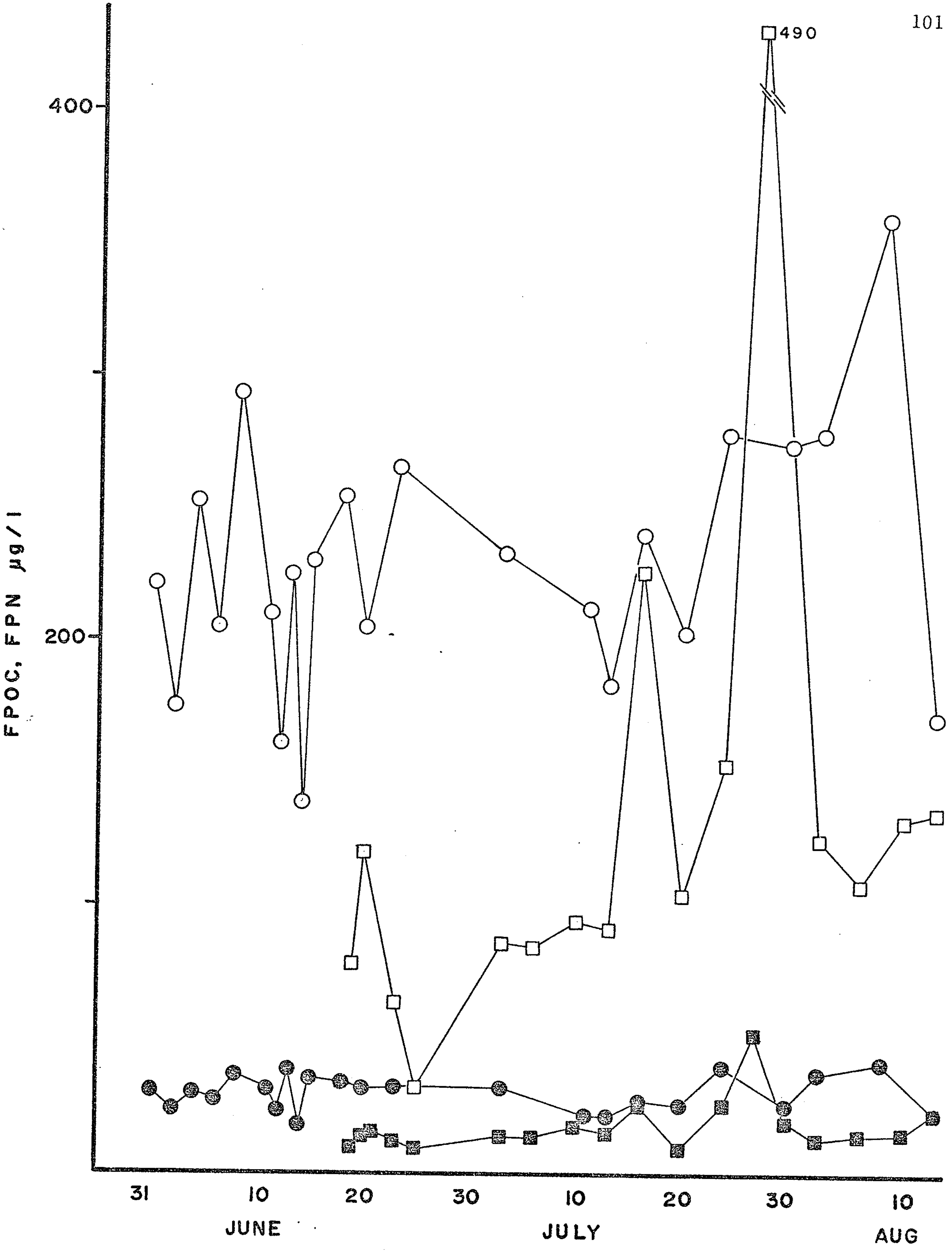

490
400
200
FPOC, FPN µg/l
31
10
20
30
10
20
30
10
JUNE
JULY
AUG

Figure 29. TDP concentrations in Char Lake in 1972 ●, and 1973 ○, and FPP concentrations in Char Lake in 1972 ■, and 1973 □.

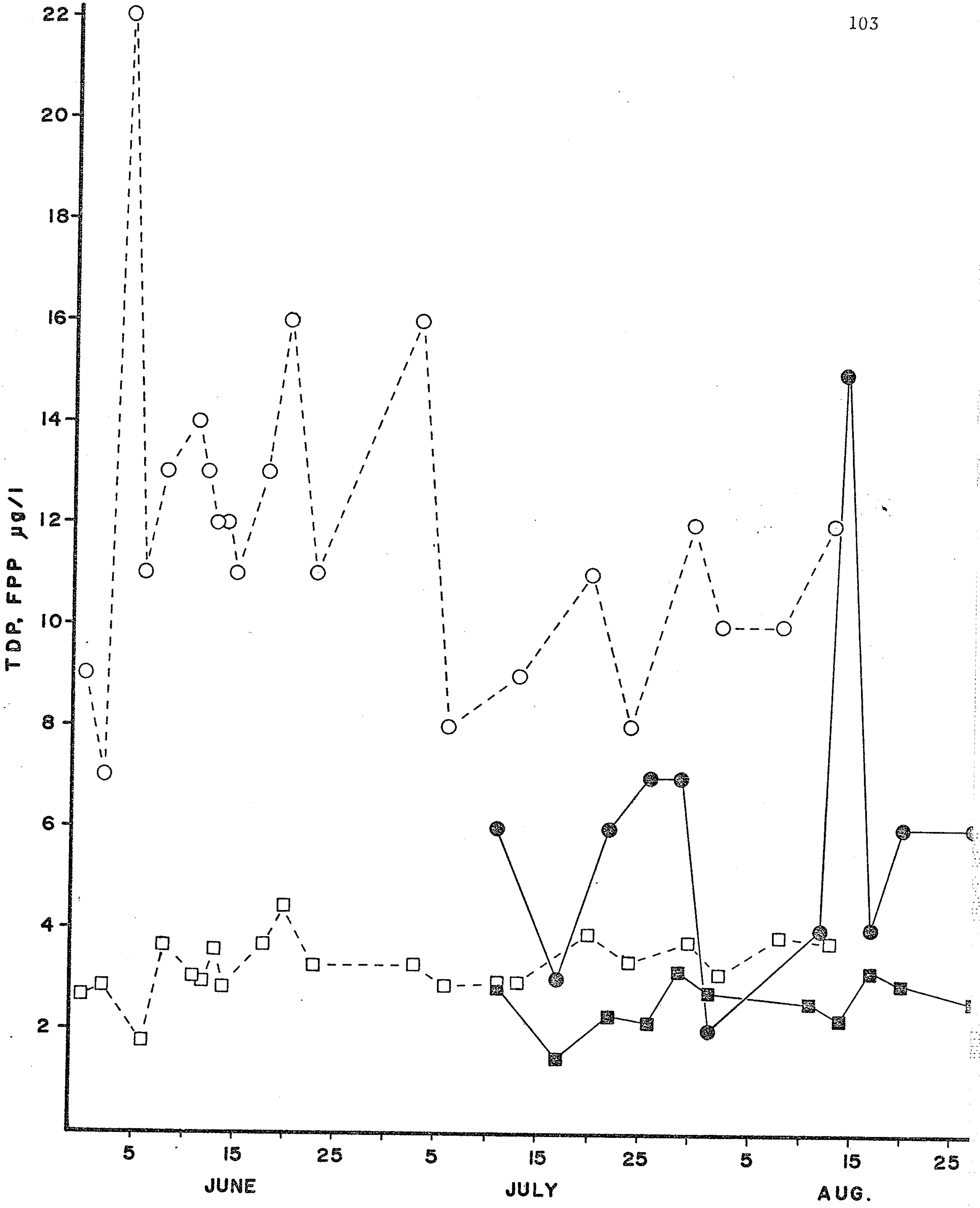
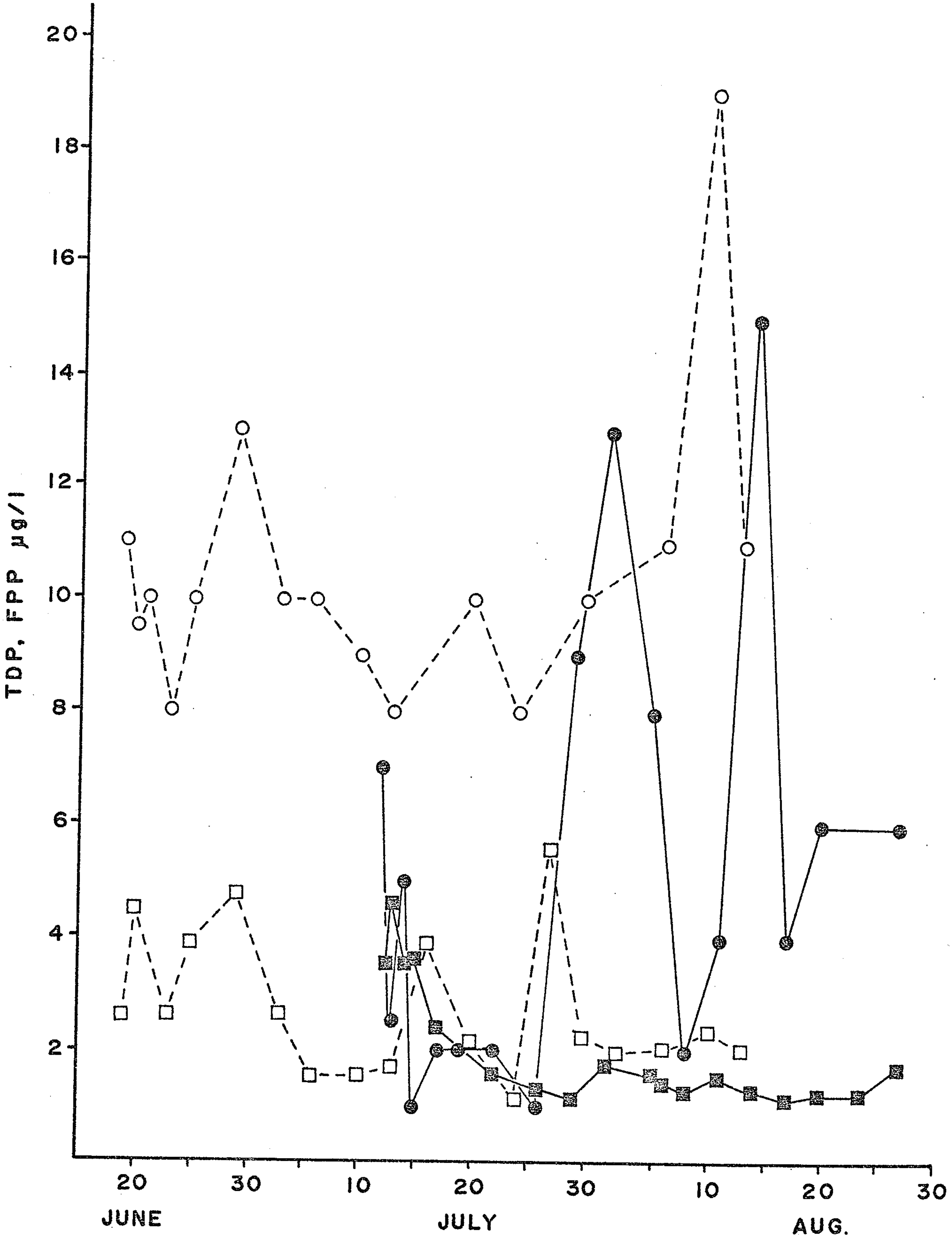

TDP, FPP µg/l
22
20
18
16
14
12
10
8
6
4
2
5
15
25
5
15
25
5
15
25
JUNE
JULY
AUG.

Figure 30. TDP concentrations in the Outflow in 1972 ●, and 1973 ○, and FPP concentrations in the Outflow in 1972 ■, and 1973 □.


TDP, FPP µg/l
20
18
16
14
12
10
8
6
4
2
20
30
10
20
30
10
20
30
JUNE
JULY
AUG.

APPENDIX II. Figures showing the water content (as a % of wet weight), density (d)(dry weight per unit of wet volume), and concentrations of C_o, CO_3-C, N, and P in the sediments of Char Lake. Chemical concentrations are as a % of dry weight. Cores 2 and 37 are from the 'silty' zone, cores 15, 20, and 22 from the moss zone, and cores 18, 28, and 48 from the deep edge of the rocky zone.

Figure 1. Physical and chemical parameters measured in Core 2.

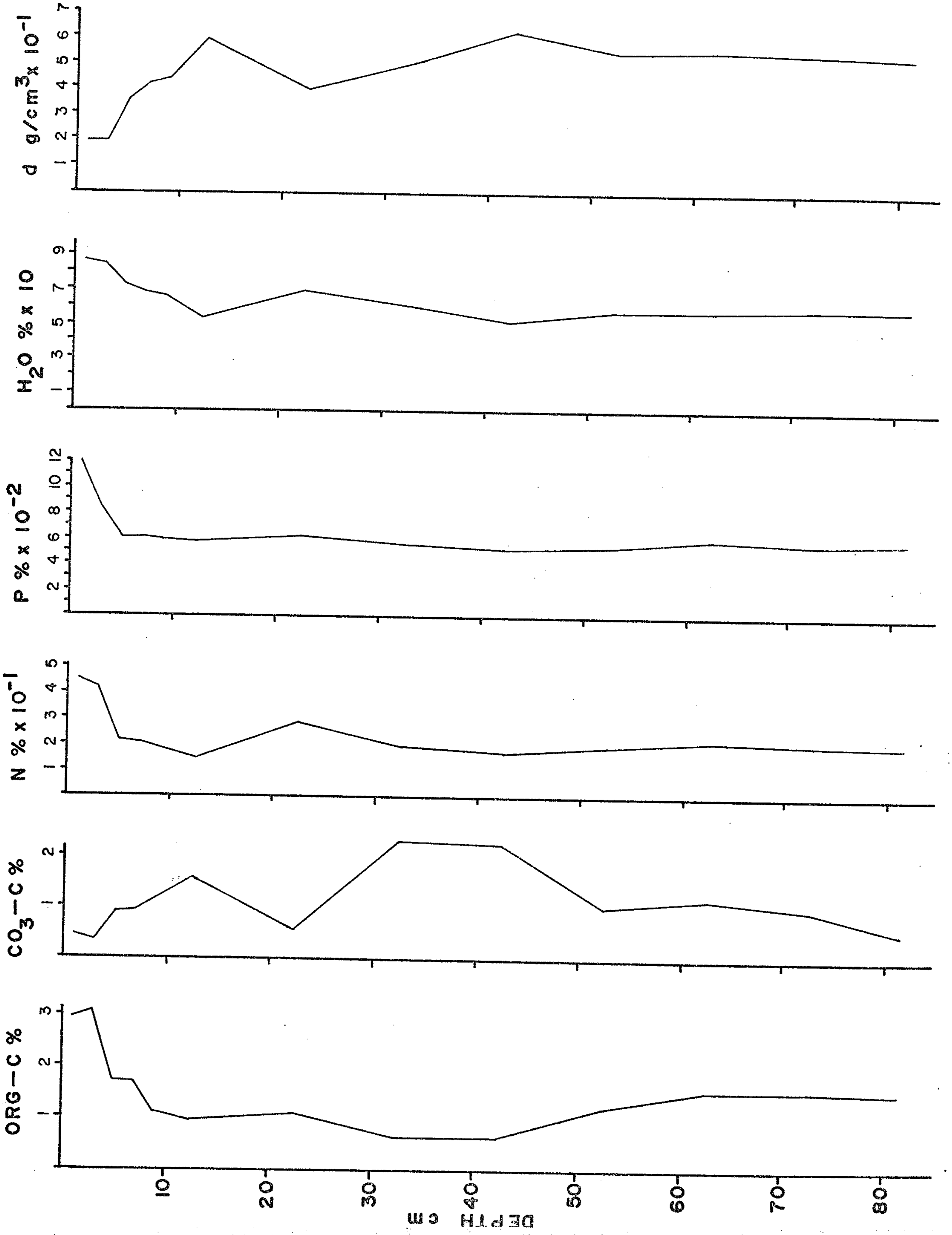

d g/cm3 x 10-1
1
2
3
4
5
6
7
H2O % x 10
1
3
5
7
9
P % x 10-2
2
4
6
8
10
12
N % x 10-1
1
2
3
4
5
CO3–C %
1
2
ORG–C %
1
2
3
10
20
30
40
50
60
70
80
DEPTH cm

Figure 2. Physical and chemical parameters measured in Core 37

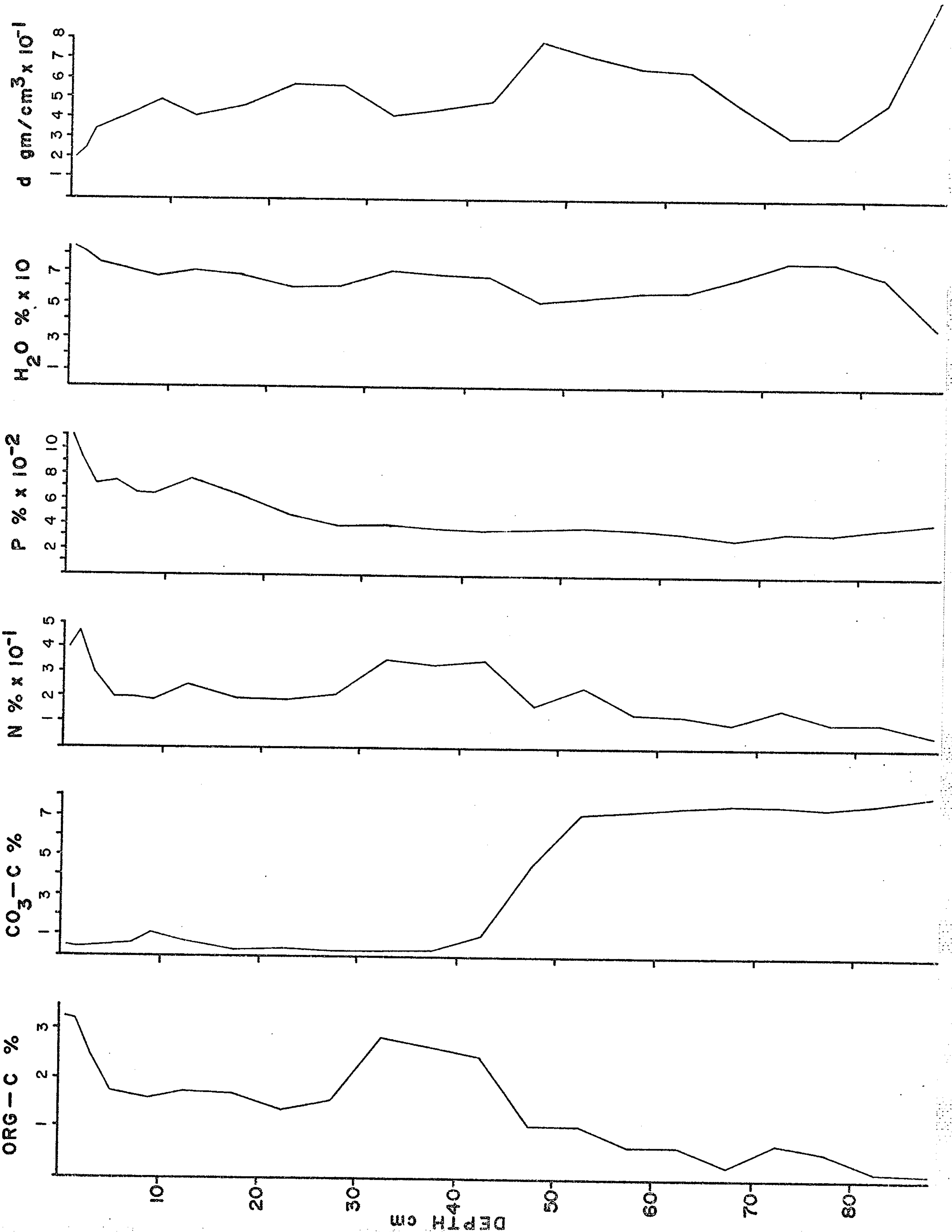

d gm/cm^3 x 10^{-1}
1 2 3 4 5 6 7 8
H_2O % x 10
1 3 5 7
P % x 10^{-2}
2 4 6 8 10
N % x 10^{-1}
1 2 3 4 5
CO_3 — C %
1 3 5 7
ORG — C %
1 2 3
10 20 30 40 50 60 70 80
DEPTH cm

Figure 3. Physical and chemical parameters measured in Core 15.

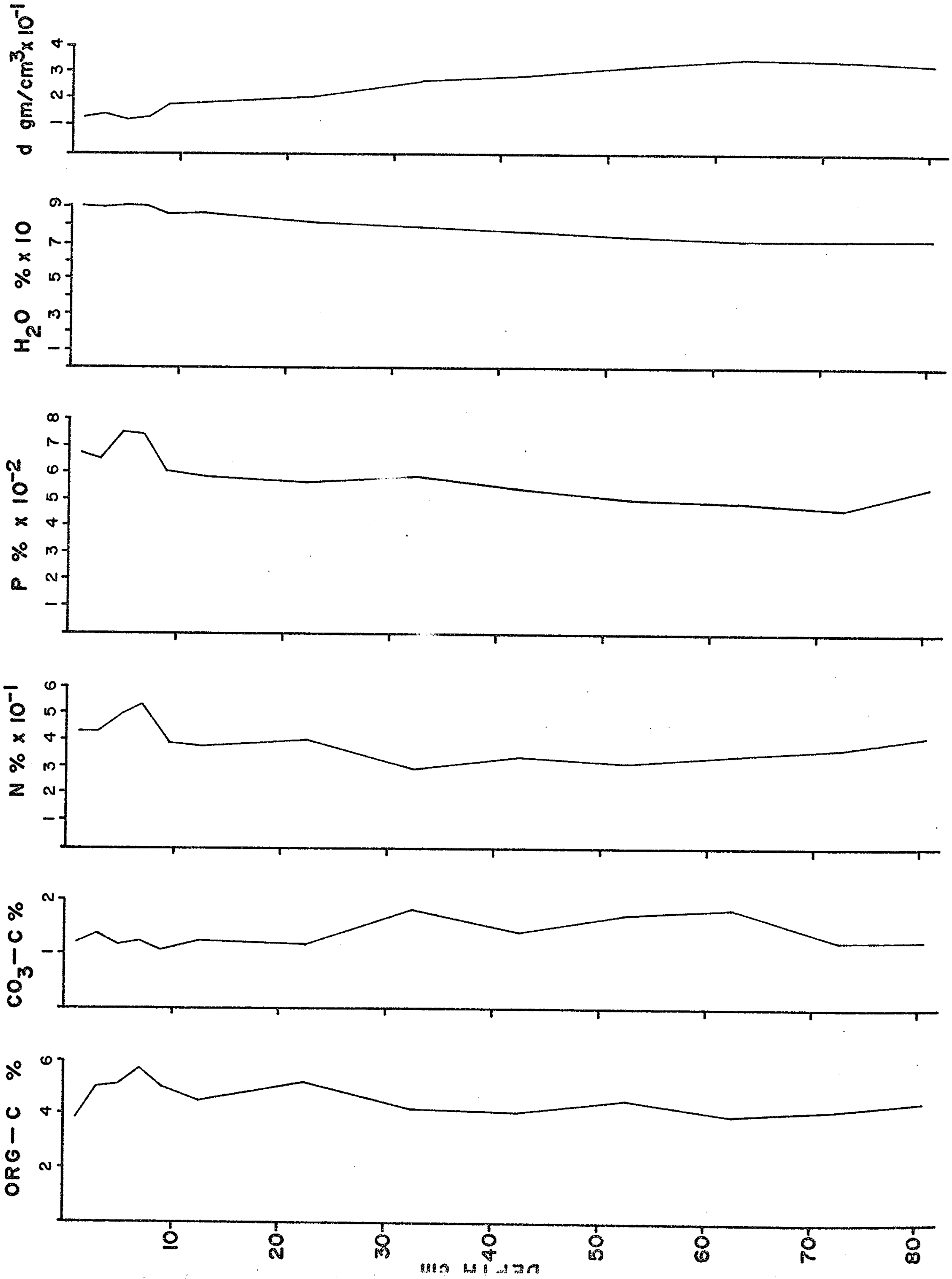

d gm/cm^3 x 10^{-1}
1
2
3
4
H$_2$O % x 10
1
3
5
7
9
P % x 10^{-2}
1
2
3
4
5
6
7
8
N % x 10^{-1}
1
2
3
4
5
6
CO$_3$—C %
1
2
ORG—C %
2
4
6
10
20
30
40
50
60
70
80
DEPTH cm

Figure 4. Physical and chemical parameters measured in Core 20.

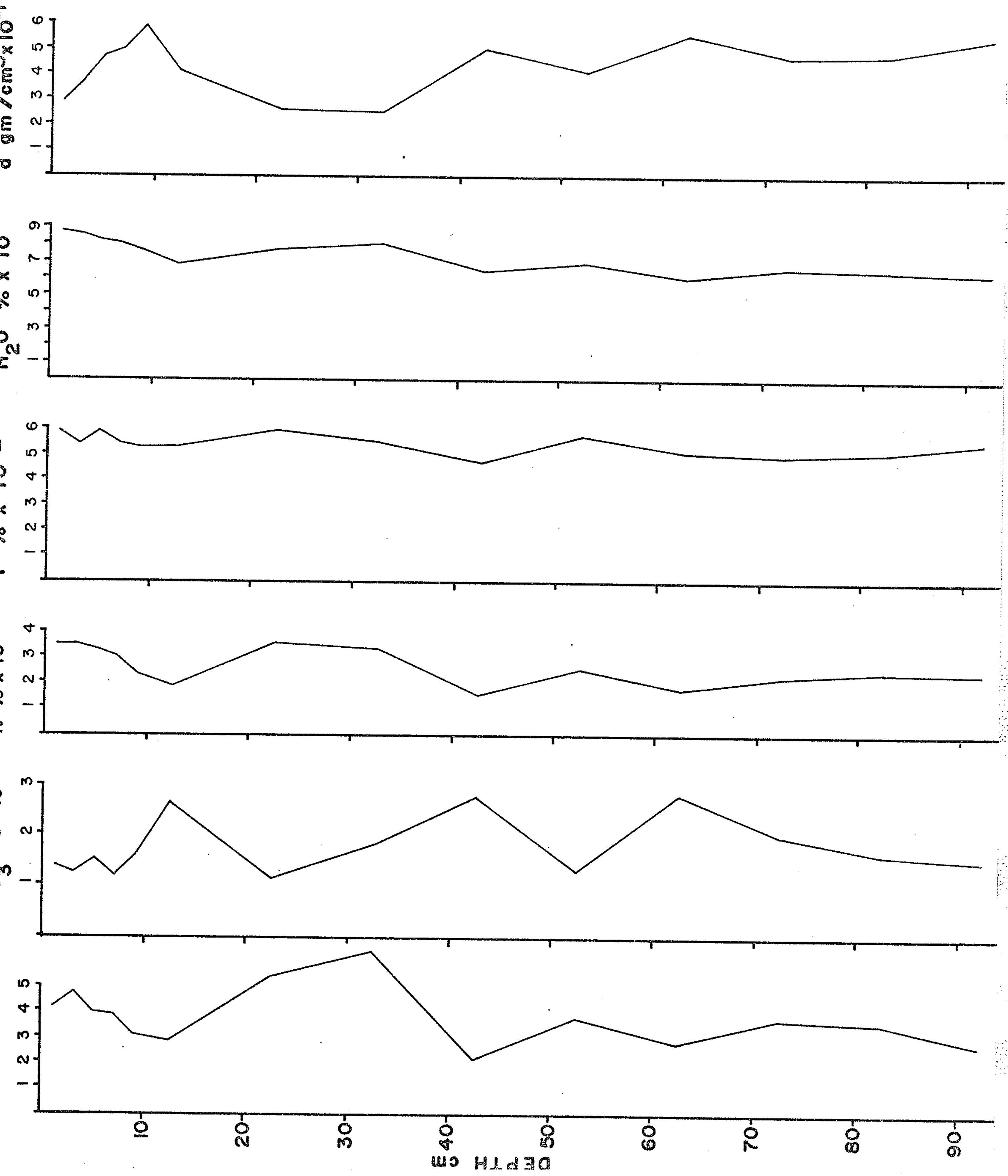

gm /cm x 10
1 2 3 4 5 6
H_2O % x 10
1 3 5 7 9
% x 10
1 2 3 4 5 6
% x 10
1 2 3 4
1 2 3
1 2 3 4 5
10 20 30 40 50 60 70 80 90
DEPTH cm

Figure 5. Physical and chemical parameters measured in Core 22.

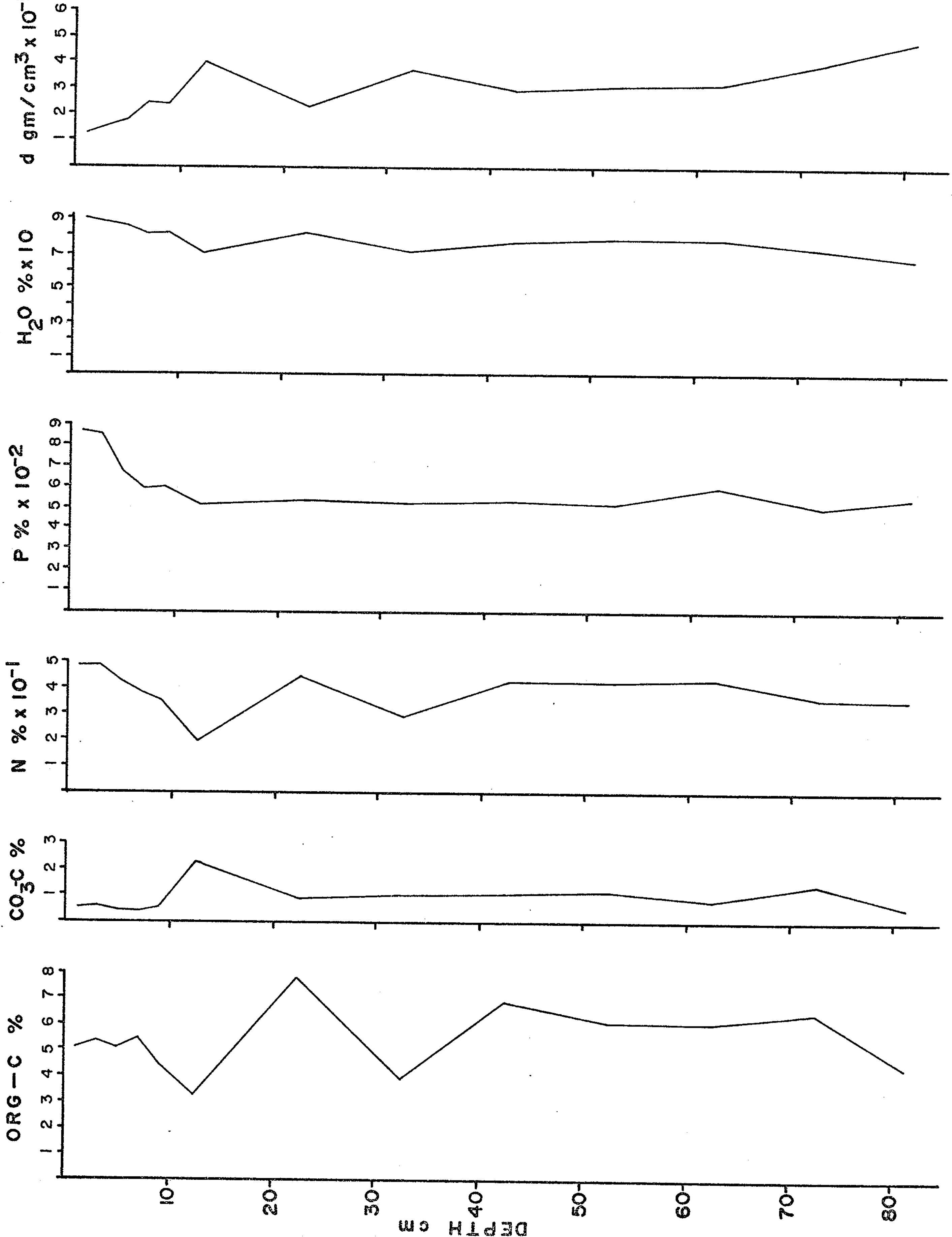

d gm/cm3 x 10-1
1
2
3
4
5
6
H2O % x 10
1
3
5
7
9
P % x 10-2
1
2
3
4
5
6
7
8
9
N % x 10-1
1
2
3
4
5
CO3-C %
1
2
3
ORG-C %
1
2
3
4
5
6
7
8
10
20
30
40
50
60
70
80
DEPTH cm

Figure 6. Physical and chemical parameters measured in Core 18.

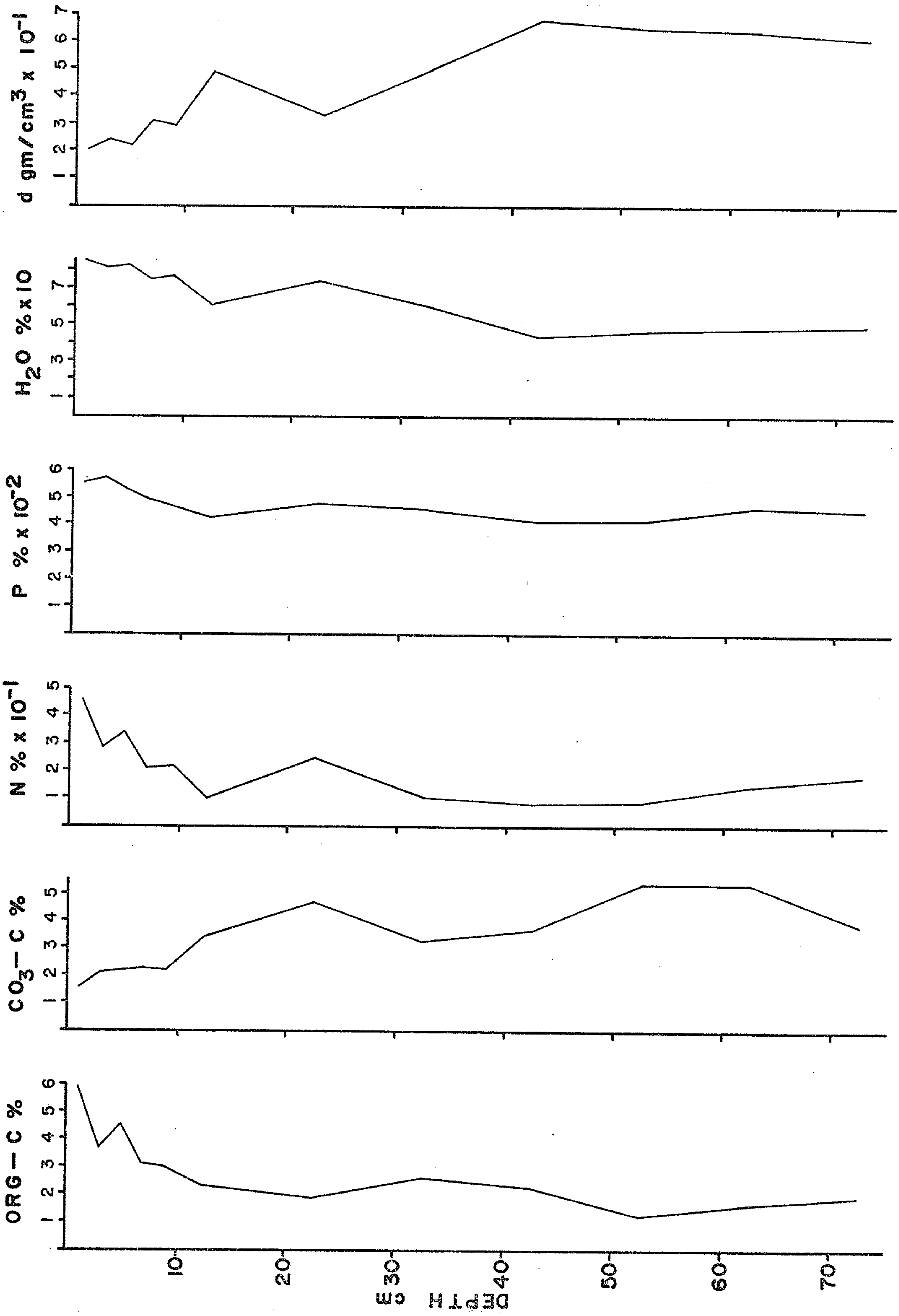

d gm/cm3 x 10-1
1
2
3
4
5
6
7
H2O % x 10
1
3
5
7
P % x 10-2
1
2
3
4
5
6
N % x 10-1
1
2
3
4
5
CO3– C %
1
2
3
4
5
ORG – C %
1
2
3
4
5
6
10
20
30
40
50
60
70
DEPTH cm

Figure 7. Physical and chemical parameters measured in Core 28.

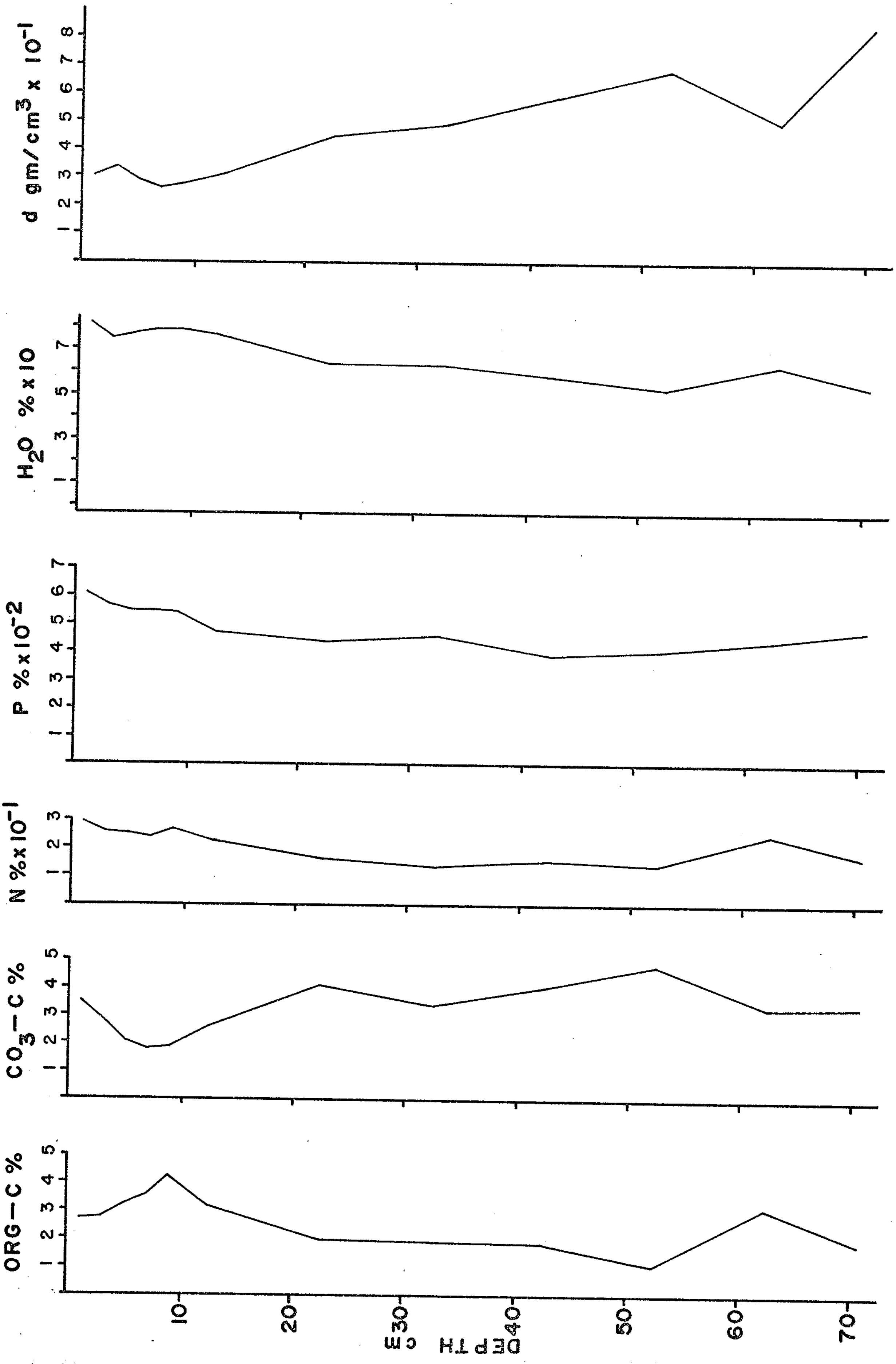
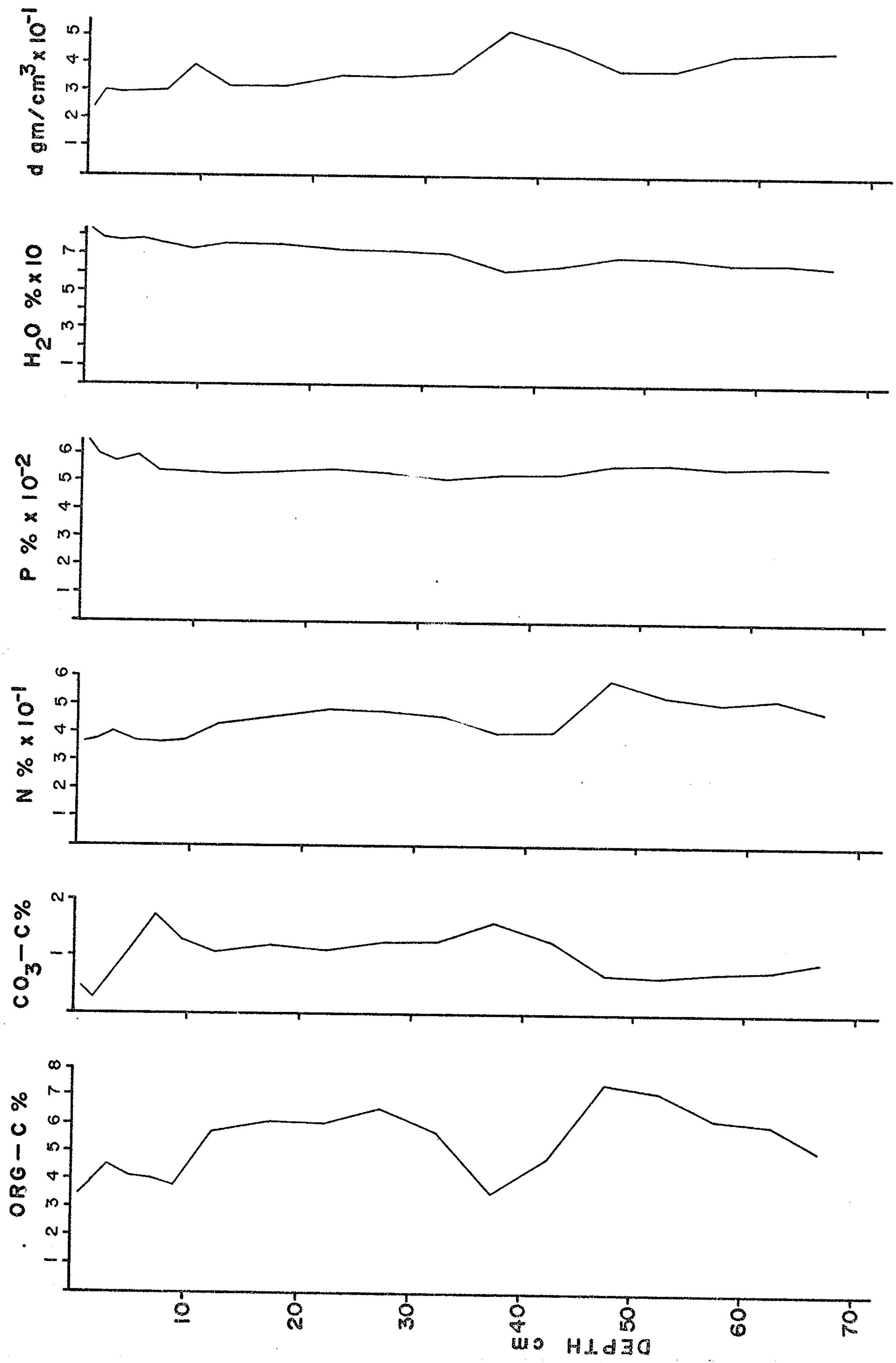

d gm/cm³ x 10⁻¹
1
2
3
4
5
6
7
8
H₂O % x 10
1
3
5
7
P % x 10⁻²
1
2
3
4
5
6
7
N % x 10⁻¹
1
2
3
CO₃—C %
1
2
3
4
5
ORG—C %
1
2
3
4
5
10
20
30
40
50
60
70
DEPTH
cm

Figure 8. Physical and chemical parameters measured in Core 48.


d gm/cm³ x 10⁻¹
1
2
3
4
5
H₂O % x 10
1
3
5
7
P % x 10⁻²
1
2
3
4
5
6
N % x 10⁻¹
1
2
3
4
5
6
CO₃ — C %
1
2
ORG — C %
1
2
3
4
5
6
7
8
10
20
30
40
50
60
70
DEPTH cm

APPENDIX III. A possible explanation for the low concentrations of CO_3-C in the sediments of Char Lake.

The extremely low concentrations of CO_3-C in Char Lake sediments (Appendix II) were unexpected because the terrestrial drainage consisted almost entirely of carbonate minerals, though both the calcite and dolomite did contain quartz (Thorsteinsson, 1958). This can be explained partially by the low particulate carbonate input to the lake. The 6.7 g CO_3-C $m^{-2}yr^{-1}$ input of carbonate minerals (calculated as 50% each of dolomite and calcite) is only 20% of the estimated total mineral input to Char Lake. Only 3.8 g $m^{-2}yr^{-1}$ of these carbonates can be accounted for in the sediments.

The small percentage of carbonates in the total mineral input suggests that solution is far more important than mechanical weathering in the Char Lake drainage basin. A 32.4 g $m^{-2}yr^{-1}$ input of dissolved Ca^{++} (Schindler _et al._, 1974) is 17 times the 1.9 g $m^{-2}yr^{-1}$ input of suspended Ca^{++} calculated from my CO_3-C data.

The 1% increase in the Ca^{++} content of the water in Char Lake over the winter (Schindler _et al._, 1974) (and which Schindler believes is insignificant, Schindler, pers. comm.) amount to a mass of 1700 kg (not 1.7 kg as stated in Schindler _et al._, 1974). This amount can account for the 1972 and 1973 average suspended Ca^{++} input to the lake.

There is probably an actual release of Ca^{++} and CO_3-C from the sediments to the interstitial water and lake water for the following reason. The equilibrium solubility products for Ca^{++} and CO_3^{--} with respect to calcite at the temperatures and ionic strengths in Char

Lake bottom water in summer and winter are 2.6 and 5.1 times higher respectively than the calculated ion activity products for Ca^{++} and CO_3^{--} (i.e. $\frac{IAP}{K_{eq}} > 1$) (data from Schindler et al., 1974; calculations according to Garrels and Christ, 1965). Under these conditions, one can expect the solution of $CaCO_3$ to occur.

If solution of $CaCO_3$ is responsible for its low concentrations, then factors affecting its solution are probably responsible for differences in CO_3-C concentrations between the different bottom zones of the lake, and between facies within cores.

The high concentrations of carbonate minerals in Cl 3 and Cl 4 likely resulted from deposition in waters that were at or near calcite saturation. In the case of Cl 4 deposition was in the ocean, and in the case of Cl 3 it was in sea water trapped at the bottom of the lake. More recent sediments have been deposited in water that is undersaturated with respect to calcite.

APPENDIX IV. The distribution of C_o, CO_3-C, N, and P between the different bottom zones of Char Lake.

The differences in the sediment concentrations of C_o, CO_3-C, and N can be explained by different rates of benthic production and respiration, the presence of the moss zone, and variations in the slope of the bottom.

Welch and Kalff (1974) found that the benthic primary productivity was higher in the moss and rocky zones than in the 'silty' zone. In the 'silty' zone respiration was higher than benthic production (Table 1), therefore, sedimented C_o in this zone has to come from the drainage basin, other areas of the lake bottom, or from the plankton. After accounting for respiration and storage, in the moss and rocky zones (Table 2), it is seen that only the rocky zone has a significant surplus of C_o that could contribute to sedimentation in the 'silty' zone.

Because N correlates with C_o in nearly all cores, it is likely that its variation between lake bottom zones is dependent on the same factors as C_o.

Higher concentrations of CO_3-C in the moss zone sediments may simply result from more carbonate minerals sedimenting there, both because the area is closer to shore, and because the moss traps particles. It is possible that by the time carbonate particles reach the 'silty' zone they will have partially dissolved. It is also possible that less CO_3-C is being released from the moss zone than from the 'silty' zone.

Both the lower rocky zone and the area of low sedimentation between 15 and 20 metres are unstable areas. The former is unstable because of wave action, the latter because it is an area of relatively high slope. Only larger, heavier particles, such as particles of calcite and dolomite, could be expected to settle permanently in these areas. If this is the case, one would expect the higher concentrations of CO_3-C that are found there.

Phosphorus concentrations are relatively constant between lake bottom zones, showing only a slight tendency to be higher near the deepest part of the lake.

Table 1. Benthic production and respiration in different areas of Char Lake (after Welch and Kalff, 1974). Values in g m^{-2} yr^{-1}.

Zone	Production	Respiration	Ratio P:R
Rocky	12.3	8.9	1.29
Moss	35.2	32.0	1.10
'Silty'	11.4	12.0	0.95
Mean	17.3	15.9	1.12

Table 2. C_o balance in the different bottom zones of Char Lake. Values are in g C_o m^{-2} yr^{-1}.

Zone	Production	Respiration	Sedimentation	Balance
Rocky	12.3	8.9	0.70	+2.70
Moss	35.2	32.0	2.91	+0.19
'Silty'	11.4	12.0	0.22	-0.82

APPENDIX V. A possible explanation for the lack of correlation between P and C_o in the sediments of Char and other lakes.

Because P is a biologically important element, one would expect it to be correlated with organic carbon in lake sediments. In the 'silty' zone of Char Lake it is, but in the moss zone, where C_o concentrations and C:P ratios are higher, it is not. In both areas of the lake P is negatively correlated with sediment density (d), which in Char Lake is equivalent to ash content because of the low organic content.

Brunskill et al. (1971) report similar findings in shield lakes. They found no correlation between P and either N or C_o. There was, however, a correlation between P and ash content. In the sediments of these lakes the C_o content was high, averaging 20% C_o, and the C:P ratio was also high at 103± 45. The ratio in the Char Lake moss zone would fit in this range (C:P = 72), but the value in the 'silty' zone (C:P = 30) would not.

A possible explanation for the seemingly contradictory relationships is as follows. P reaches the sediments predominantly in organic matter which is then oxidized to some extent. In Char Lake this amounts to 96% of the C_o supply to the sediments, more in the 'silty' zone, and less in the moss and rocky zones. Even though C_o is lost from the sediments, P remains bound, especially in lakes with an oxidized sediment-water interface.

The low production to respiration ratio in the 'silty' zone suggests that all of the respirable C_o is respired and that the C_o in the sediments is in oxidation resistent molecules. If P is not released from the sediments, as is suggested by the close agreement between storage and nutrient budget measurements (Results, Table 3), a low C:P ratio would be expected (C:P = 30) and C_o would also be correlated with P, as it is in a number of 'silty' zone cores.

The moss zone on the other hand, has a higher production to respiration ratio (Appendix IV, Table 2), and has a higher proportion of oxidation resistent molecules (cellulose in the moss). These result in more C_o and a higher C:P ratio (C:P = 72). Because C:P ratios can be variable in plant material, and oxidation of the larger amounts of C_o is variable, P may not be expected to correlate with C_o.

APPENDIX VI. The distribution of sediments in Char Lake.

A lake of simple morphometry, such as Char Lake, would be expected to exhibit a simple sedimentation pattern with the thinnest sediments near the edge of the lake, thickest sediments at Z_m, and a gradation in between. The actual pattern (Methods, Fig. 5), however, bears little resemblence to the expected one.

The pattern has been highly modified, mostly by ice, waves, inflows, and benthic mosses. Ice thicknesses on Char Lake regularly exceed 2 metres (Schindler et al., 1974), and, as the ice pan floats around the lake in summer, it scours the bottom near shore. This results in the rocky zone which is virtually free of fine sediments to a depth of 2.5 to 3 metres.

Wave action from the strong summer winds also must be responsible for resuspending shallow water sediments. This phenomenon has been documented in other lakes (e.g. Davis, 1968). Further support for its occurrence in Char Lake is the fact that higher concentrations of suspended nutrients were noted in Char Lake after periods of strong winds. Also, Rigler (1974) found an average of 453 g m^{-2} lake area yr^{-1} of sediment collecting in sediment traps. This amounts to 15 times the 30.7 g estimated from measurements on the sediments. Rigler's C_o sedimentation rates of 19.8 and 28.3 g C_o m^{-2} yr^{-1} average 24 times the 1 g estimated from the cores.

The moss growing in water depths from 3 to 15+ metres can explain both the high sedimentation rates in the moss zone and the low rates in water depths from 15 to about 20 metres. The moss acts as a trap for sediment particles that would normally have been transported towards the deepest part of the lake, either by being resuspended or by moving along the bottom in density or gravity currents.

The moss is buried in situ, as evidenced by the large masses of intact moss sprigs in moss zone sediments and their only occasional presence in sediments elsewhere in the lake. The moss would have to grow only 0.25 mm yr^{-1} to stay above the accumulating mound of sediment.

The bottom of the lake from 15 to 20 metres is left with less sediment because the moss zone interrupts the normal movement of particles. Particles destined to settle in this area are trapped by the moss. Finer particles still move to the deepest parts of the lake, and sediment thicknesses achieved there are greater.

The two deviations from the regularity of the Char Lake sedimentation pattern are an area of thin sediments on the west side of the lake, and an area of extension of the thicker moss zone sediments in the southeast part of the lake. The zone of lower accumulation on the west side of the lake corresponds to an area that is virtually free of moss. It is believed that moss cannot grow in this area because of heavy snow accumulations that reduce the intensity of light below the ice in spring (Welch and Kalff, 1974). Because there is no moss, sediments can be transported unhindered along the bottom to deeper water.

Thicker sediments occur in the southeast part of the lake because of the large amounts of suspended material entering in the two largest inflows which flow into the lake at this point.

APPENDIX VII. The paleolimnology of Char Lake.

The four facies in Char Lake sediments represent three periods in the lakes history. The bottom one, Cl 4, with its marine fossils, represents the time when Char Lake was a bay of the Arctic Ocean. The different characteristics of these sediments, i.e. high CO_3-C concentrations, high density, and low concentrations of N, P, and C_o (Results, Fig. 6) support the idea that they were deposited under quite different conditions from the overlying lake sediments.

Cl 3 sediments with their distinct laminations and chemical characteristics falling between those of the marine sediments and the sediments of Cl 2, may represent a time when salt water was being flushed from the lake. Judging from the fineness of the laminations, the lake was probably meromictic at the time. Geyh et al. (1974) describe similar sediments for the meromictic stage of Schleinsee. Their sediments were finely laminated, high in CO_3-C, and low in organic matter. The overlying sediments were low in CO_3-C just as in Char Lake.

Without ^{14}C dating it is impossible to say exactly how long it took for Char Lake to clear of salt water, but a rough estimate can be made. This is done by comparing the thickness of Cl 3 to that of Cl 2 plus Cl 3, assuming that the sedimentation rate has remained constant for the 6200 year history of the lake. Differences in CO_3-C concentrations and density are ignored to give a maximum time estimate. Using cores taken near Z_m one obtains a figure of about 3000 years.

Counting band pairs in Cl 3 would also give an estimate for this time period if these prove to be varves. Core 37 in 23 metres of water, had a maximum of 10 band pairs per mm in the few sections that were counted. Assuming that they are varves, this represents 3800 years. An average of 7 band pairs per mm (which I think is a reasonable estimate) gives a time span of 2900 years, which is approximately the figure estimated from the thicknesses of Cl 2 and Cl 3.

The higher concentrations of N and C_o in Cl 3 are probably the result of anoxic conditions at the sediment - water interface at the time, as well as a lack of benthic fauna, and a subsequently low respiration rate.

Another possible cause of C_o enrichment in Cl 3 is a milder climate at the time Char Lake emerged from the sea. There is a consensus that there was a climatic optimum at about 6000 B.P. (Preston et al., 1955 in Wiseman, 1966; Wiseman, 1966). Both terrestrial and phytoplanktonic production may have been greater than at present, resulting in a higher rate of organic sedimentation.

Other fluctuations of sediment C_o concentrations in Char Lake may also be the result of changing climatic conditions. A full length core, taken at Z_m, and cut into finer sections, could provide better resolution of these fluctuations.

Cl 1 and Cl 2 represent the sediments deposited in fresh water. The orange - brown colour of Cl 1 sediments is presumably due to the presence of oxidized iron compounds (Mortimer, 1971).