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THE KAWARTHA LAKES WATER MANAGEMENT STUDY - WATER QUALITY ASSESSMENT (1972 - 1976)

November 1976

Ministry of the Environment Ministry of Natural Resources

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PREFACE

The Kawartha Lakes Water Management Study was initiated in 1971 for the purpose of assessing water quality in the Kawartha Lakes and resolving some of the problems which are peculiar to this waterway.

To date, major water quality studies have concentrated primarily on problems of nutrient enrichment in the deeper, thermally stratified lakes of the Precambrian Shield. Little is known about the causes of problems such as nutrient loadings, nutrient cycling, excessive algal and macrophyte production, etc., in a predominantly shallow fertile waterway situated in an intensely urbanized and agricultural watershed.

This volume attempts to describe all the major physical, chemical and biological factors which ultimately interact to define the recreational quality of the Kawartha Lakes. The overall program incorporates contributions by numerous groups and individuals including: fisheries data collected by the Lindsay District of the Ministry of Natural Resources and information on water quality, phytoplankton, macrophytes, zooplankton and nutrient loadings provided by the Water Resources Branch of the Ministry of the Environment.

The main survey of the system was carried out in 1972. A subsequent survey was undertaken in 1976, with the assistance of Central Region staff of the Ministry of the Environment, to define any major changes which had occurred during the four year interim period. This follow-up survey covered only some of the major highlights of the 1972 program.

Since nuisance growths of aquatic plants appear to be one of the major problems in the Kawartha Lakes, a follow-up survey of plant distribution and factors influencing this distribution was completed in 1976. This information will be published separately at a later date, pending completion of necessary analyses. Similarly, information on the use of mechanical harvesting of aquatic vegetation as a means of ameliorating nuisance growths and improving recreational amenities will be published as a separate volume.

Finally, the present manuscript has been reviewed and approved by an editorial committee comprised of: I. Wile, P.J. Dillon, T.G. Brydges, D. Veal, K.H. Nicholls, R. Lewies and J. Allin.

SUMMARY AND CONCLUSIONS

This report describes the water quality, nutrient budgets, phytoplankton, zooplankton, macrophytes and fish communities of the Kawartha Lakes and attempts to define any changes which have occurred between 1972 and 1976.

Based on various indicator parameters, the Kawartha Lakes can be grouped into the following major categories:

a) Category 1: (meso-oligotrophic) includes the headwater lakes of the system, namely, Balsam, Cameron and Stony Lake (upper or east basin). These lakes are characterized by low concentrations of major ions, phosphorus (<20 µg/l) and chlorophyll *a* (<3 µg/l). Phytoplankton densities are low (0.5 to 1.1 mm^3/l) with populations dominated by the Chrysophyceae and Cryptophyceae. Similarly, zooplankton are relatively scarce (<1.0 $organisms/cm^2/m$) but well represented by a variety of species. Calanoid copepods are adequately represented and large-bodied zooplankton species are common. Although the Bald Lakes are headwater lakes, they can be placed within this or the subsequent category depending on the specific parameter examined.

b) Category 2: (meso-eutrophic) incorporates the central lakes on the system, including: Pigeon, Chemung, Buckhorn, Clear, Stony (lower or west basin) and Katchewanooka. These lakes have moderate concentrations of major ions, phosphorus (20 to 30 µg/l) and chlorophyll *a* (3 to 6 µg/l). Average phytoplankton biomass ranges from 1.6 to 3.3 mm^3/l with heterogeneous assemblages of taxonomic classes. Zooplankton communities are characterized by an increased number of organisms (1.0 to 4.0 $individuals/cm^2/m$) with a decrease in calanoid and an increase in cladoceran significance. Although the location of Sturgeon Lake places it within this category, based on the parameters examined, it appears to be either marginal or fits into the subsequent group.

c) Category 3; Includes the highly eutrophic lakes (Rice, Scugog, Bay of Quinte, Sturgeon) with high concentrations of major ions, phosphorus (>30 µg/l) and chlorophyll *a* (>6 µg/l). Average phytoplankton biomass ranges from 4.8 to 23.6 mm^3/l and is dominated by the Cyanophyceae (blue-green algae) and the Bacillariophyceae (diatoms).

The zooplankton communities are markedly different from the preceding categories. Calanoid numbers are insignificant, cladocerans are abundant and most large-bodied forms are absent or occur in low numbers.

Comparisons of 1972 and 1976 chemical and phytoplankton data for the Kawartha Lakes showed no deterioration in water quality during the four year period. Phosphorus concentrations in 1976 were generally similar or slightly lower than 1972 values; however, these changes were generally within the range of analytical error. Similarly, chlorophyll a concentrations in 1976 were within experimental error of the levels recorded in 1972 with the exception of Rice Lake where values doubled from 9.0 ppb to 18.6 ppb in 1976. This increase in chlorophyll a levels is not clearly understood, particularly since a similar change was not reflected in the phytoplankton biomass. Phytoplankton densities for Balsam, Sturgeon, Chemung as well as Rice Lake showed no significant changes from 1972 values.

Significant correlations were established between mean seasonal euphotic zone phosphorus concentrations and algal and zooplankton densities in the Kawartha Lakes. In view of the well defined relationship between phytoplankton biomass and phosphorus concentration, it is apparent that a decrease in phosphorus loadings, particularly in the highly eutrophic lakes, offers the greatest potential for ameliorating nuisance algal levels and improving water clarity. To permit prediction of changes in lake trophic state given a change in total phosphorus concentrations (resulting from either increased or decreased P loading) a nomogram was developed relating the most reliable trophic state indicators, such as phytoplankton biomass, percentage contribution by Chrysophyceae, Secchi disc visibility and total phosphorus concentration.

As the deepest lake in the Kawartha Lakes system, the eastern basin of Stony Lake was studied intensively to determine the magnitude and significance of nutrient regeneration from bottom sediments during the ice-free period of 1971.

The eastern basin was characterized by stable and well defined thermal stratification between June and mid-October. Severe rates of areal hypolimnetic dissolved oxygen depletion (580 $mg/m^2/day$) considered typical of eutrophic lakes, were not accompanied by other classical symptoms of eutrophy and generally excellent water transparency and moderately low chlorophyll a concentrations prevailed in the euphotic zone throughout most of the ice-free period. Of the total dissolved oxygen depletion rate in the bottom waters of the lake (0.10 mg/l/day), 80% was accounted for by CO_2 evolution and 4% by nitrification processes.

As judged by the absence of bottom water accumulations of both iron and phosphorus, regeneration of these elements from anoxic bottom sediments of the lake was found to be insignificant. Some accumulation of ammonia-N in the near-bottom waters by late summer and fall was found. Since it is probable that depletion of inorganic N in the euphotic zone contributed to the decline of the spring phytoplankton populations, some concern is expressed relative to the possibility in future of increased rates of ammonia-N regeneration under winter ice cover leading to magnification of springtime phytoplankton growths following circulation of the lake.

Nutrient budgets for total phosphorus, nitrogen and inorganic carbon were prepared for the Kawartha Lakes in 1972 and updated in 1976.

Land drainage is by far the largest source of nutrient loading to the Kawartha Lakes but because the materials enter the lake in very low concentrations and partly in a form unavailable to aquatic plants and algae, their impact is likely far less significant than their proportion of the total loading would lead one to believe. Atmospheric loadings are significant in the larger lakes although the availability of nutrients in rain and snowfall is not known.

Local inputs to most lakes are small sources in terms of gross loadings. Major sewage treatment plants, however, do contribute significantly and have an impact for many miles (and lakes) downstream. Because phosphorus from municipal sewage treatment plants is largely in the dissolved and biologically available form, phosphorus loadings from local sources have a major impact on water quality. Contrary to land drainage, the relatively low gross nutrient loadings from local sources are probably far more significant than the numbers indicate.

Phosphorus removal programs initiated at the major sewage treatment plants in 1975 have significantly reduced the loadings of phosphorus to the system.

In view of the prominence of macrophytes in the Kawartha Lakes, a combined aerial photographic and field survey was carried out in 1972 to establish distribution, abundance, species composition and nutrient concentrations in plant tissues. Problem growths of aquatic plants were found in the shallow lakes located in the St. Lawrence Lowlands, particularly where substrates were comprised of silt and organic deposits and water depths did not exceed 3m. In these lakes (Southern Pigeon, Buckhorn, Chemung, Rice) the plant communities, dominated by Vallisneria americana and Myriophyllum spp., formed dense, extensive beds with fresh weights generally well in excess of 1,000 g per m^2 and created a severe impediment to recreational usage. Phosphorus concentrations in the plant tissues reflected the fertility of the lakes and were well above any critical limits established in the literature, indicating that plant distribution and density were not affected by nutrient availability.

The Kawartha Lakes provide one of Ontario's most important sport fisheries. Numbers of anglers on the lakes are high, although short term data suggest a decline in angler use and harvest. Relatively long term data for Pigeon Lake indicate declining angler success. This decline is apparently limited to the walleye fishery, angler success for maskinonge remaining constant and that for bass, constant or improving. There has been an apparent shift in bass caught from a dominance of largemouth to a dominance of smallmouth.

The morphoedaphic index was used to compare the Kawartha Lakes trophically and to estimate their relative fish production potential. This estimation ignored the physical limitations inherent in the lakes. Harvest estimates from several of the lakes were similar but less than that predicted, attributable in part to the physical limitations of the lakes but also to selectivity of species by anglers and to the intensity of angler effort. The comparison among lakes was still considered valid since all the lakes are under similar environmental stresses and differ mainly with respect to mean depth and total dissolved solids. Fish species composition of the lakes appears compatible with the trophic classification suggested in chapters 1, 2 and 3. Age-length relationships of four sport fish species were similar among lakes and were comparable to those for other Ontario waters.

Salmonid-coregonid histories of Pigeon and Stony Lake indicated declining fish stocks. These declines were attributable to excessive exploitation, eutrophication, the introduction of walleye or to a combination of these factors.

RECOMMENDATIONS

1. Plans for additional cottage and/or municipal development within the Kawartha Lakes watershed should be cognizant of the implications to water quality, fish and wildlife habitat and should be prepared in consultation with the Ministries of Environment and Natural Resources, so that potential changes in lake water quality and fish and wildlife habitat can be projected.

2. Regular surveys of chemical and biological water quality parameters should be continued to establish changes resulting from a) reduced nutrient loadings at sewage treatment plants as a result of the phosphorus control programme implemented in 1975. b) current Ministry of the Environment criteria for septic tile fields and stricter enforcement of changes to update unsuitable private disposal systems to Ministry of the Environment criteria and c) impact of any additional cottage and/or municipal development. Information from other studies (ie Gravenhurst Bay and Lake Erie) clearly show that a lake's response to reduced loadings is well defined but may take a period of several years. It is therefore recommended that sampling of phytoplankton and nutrient levels be continued annually in Rice and Sturgeon Lakes (downstream of sewage treatment facilities) and a major survey of the entire Kawartha system be repeated within 5 years.

3. In view of the direct relationship between algal densities, water clarity and phosphorus concentrations in the lakes, it is apparent that phosphorus loadings must be reduced to effect an improvement in recreational quality, particularly in the highly eutrophic lakes such as Rice, Sturgeon, and Scugog. In this regard it is recommended that:

   a) all existing municipal sewage treatment plants should be maintained at their highest level of treatment efficiency and where possible, further emphasis should be placed on reducing the total phosphorus concentration in the final effluent to less than 1 mg/l.

b) Septic tank inspections throughout the Kawartha Lakes should be stepped up to ensure compliance with current MOE criteria.

c) Development of low lying or marshy areas should be discouraged since these areas are generally unsuitable for private waste disposal systems and may be subject to periodic flooding during spring thaw.

d) Use of lawn and garder fertilizers by cottage and home owners should be discouraged since leaching of the nutrients to the lakes may result.

e) The development of a buffer zone of native vegetation along the shorelines should be encouraged both to protect shorelines from erosion and to absorb some nutrient inputs from diffuse sources such as runoff following rainfall.

f) Proper land management techniques should be strictly followed to minimize soil and fertilizer losses from agricultural land and to ensure that runoff from barnyards, manure piles or silos does not gain access to tributary streams or the lakes.

4. Since the distribution and species composition of aquatic macrophytes is influenced by physical factors (substrate type, water depth, light penetration) rather than nutrient levels, any reductions in phosphorus loadings to the lakes will not likely ammeliorate nuisance macrophyte growths. Furthermore, substantial improvements in water clarity may extend suitable habitat by permitting plant growths at greater depths. It is therefore recommended that:

a) chemical control of nuisance vegetation along shoreline areas by local residents be continued (following acquisition of a permit from Ministry of the Environment).

b) Mechanical harvesting of aquatic vegetation be continued to facilitate recreational usage throughout the lakes. Efforts in this regard should be directed towards opening up access channels and clear-cutting large patches to accommodate boating, water skiing and fishing.

c) periodic surveys be carried out to record changes in the distribution and species composition of the macrophyte communities.

d) research into long-term control measures should be continued.

CHAPTER I

PHYSICAL - CHEMICAL LIMNOLOGY

OF THE KAWARTHA LAKES

(1972 and 1976)

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INTRODUCTION

This chapter summarizes information collected during 1972 to define the physical-chemical water quality of the Kawartha Lakes and to provide baseline data for future comparisons. In 1976, a subsequent survey of all key stations was completed to determine whether any significant changes in water quality had occurred.

DESCRIPTION OF THE STUDY AREA

The study area incorporates all the major lakes forming part of the Trent system between Balsam Lake and the Bay of Quinte (Figure 1). These lakes are located in the counties of Peterborough, Victoria and Durham, with station Q-42 located near Trenton in Hastings County. Most of the population centers in the watershed are small settlements with less than 5,000 people. The City of Peterborough is the largest centre with a population of 58,100 (1974). The second major center is the Town of Lindsay with a population of 13,000, located at the southern tip of Sturgeon Lake. The lakes range from deep, rocky bottomed basins situated on the Precambrian Shield to shallow basins, comprised partially of flooded land and located in the Paleozoic glacial deposits. Morphometric data for the Kawartha Lakes are provided in Table 1.

Table 1: Morphometric data for the Kawartha Lakes

Lake	Surface Area (km^2)	Volume (m^3)	Mean Depth (m)
Balsam	49.0	2.37×10^8	4.8
Cameron	14.4	9.97×10^7	6.9
Sturgeon	47.1	1.63×10^8	3.5
Pigeon	56.7	1.89×10^8	3.3
Little Bald	2.1	3.82×10^6	1.8
Big Bald	2.0	8.38×10^6	2.7
Buckhorn	32.3	7.42×10^7	2.3
Lower Buckhorn	13.1	4.19×10^7	3.2
Lovesick	2.9	6.68×10^6	2.3
Clear	10.5	6.17×10^7	5.9
Katchewanooka	3.7	8.10×10^6	2.2
Rice	100.1	2.40×10^8	2.4
Scugog	70.3	9.57×10^7	1.4

METHODS

Sampling stations (Figure 2), including the deepest point, were established on each lake. Data from stations S-105 (Stony Lake) and S-12 to 15 (Lake Scugog) are generally treated separately since they are not subject to inputs from other lakes in the system. Similarly, station P-21 on Pigeon Lake is also treated separately since it is extremely shallow (<1m), weedy and totally different from the deeper stations located in the northern portion of the lake.

Samples were collected during the ice-free period, on seven occasions in 1972 and six times during 1976. The following stations were excluded from the 1976 survey: Ca-4, 6; S-11; S-12, 14; P-19; B-25, 26; C-28; K-1, 3, 4; R-36 and Q-42.

Water clarity at each site was measured with a Secchi disc. Vertical temperature profiles were measured at 1m intervals and dissolved oxygen measurements were generally made from 1m below the surface and 1m off the bottom utilizing the azide modification of the Winkler method. Samples for pH, alkalinity, free CO_2 and conductivity were collected with a Van Dorn water sampler from 1m below the surface and 1m from the bottom and refrigerated for transit to the field laboratory. The pH was measured with a Corning pH meter; alkalinity was established by titration with 0.01 $N_2H\ SO_4$; free CO_2 was measured by titration with 0.02 N NaOH and conductivity was determined with an Electronic Switch-Gear Meter and expressed in μmhos/cm^3 at 25°C. Samples for chemical and chlorophyll a analysis were secured as composites through the euphotic zone (determined as twice the secchi disc depth) by lowering a 800 ml bottle with a restricted inlet through the water column at a rate allowing complete filling as the bottle was retreived to the surface. Chemical samples were also collected from 1m off the bottom with a Van Dorn sampler. Chlorophyll a samples were preserved with 1 ml of 2% magnesium carbonate, filtered through 1.2 millipore filters (ρ =) and refrigerated prior to shipment to Toronto. Determinations of total phosphorus nitrogen, orthosilicate, iron, manganese, sodium, calcium, magnesium, potassium, sulphate, chloride, inorganic carbon and chlorophyll a were completed by Ministry of the Environment Laboratory Services Branch in Toronto, utilizing standard methods. Analyses for manganese, potasium, sulphate, sodium and inorganic carbon were excluded from the 1976 survey.

RESULTS AND DISCUSSION

Temperature and Dissolved Oxygen

Temperature and oxygen profiles for the Kawartha Lakes during 1972 are illustrated in Figures 3 to 10. Profiles during 1976 were sufficiently similar to preclude the necessity of additional illustrations. Mean and extreme values for all sampling stations in 1972 and 1976 are provided in Table 1 of Appendix 'A'.

Water temperatures were relatively uniform with depth in the shallower lakes, suggesting that wind induced turbulence was effective in mixing the water column. Occasional periods of temporary thermal stratification were noted in Balsam, Sturgeon, Lower Buckhorn and Clear Lakes. Pronounced thermal stratification with well defined thermoclines was observed only in Cameron Lake, Stony Lake and at the deep water stations in northern Pigeon and Bald Lakes.

Mean surface temperatures in 1976 were generally 1 to 3^{o}C lower than in 1972, reflecting the generally colder conditions which prevailed during the 1976 summer season. The largest difference occurred in Lake Scugog where the mean summer values were 4^{o}C lower than in 1972. Bottom water temperature changes were less pronounced, usually less than 2^{o}C, except at the deep water stations P-17 and S-105 where increases of 1.3 and 2.9^{o}C were observed.

Dissolved oxygen levels were similar or slightly elevated in 1976, likely as a result of cooler water temperatures. Concentrations generally exceeded 80% saturation in the surface waters and were uniform with depth in the unstratified lakes. However, occasional oxygen reductions did occur in the bottom waters during prolonged periods of warm calm weather. In the deeper, stratified lakes, oxygen profiles were clinograde with well-oxygenated epilimnetic waters and anoxic conditions in the hypolimnia. These severe oxygen depletions in the stratified lakes undoubtedly reflect the oxidative processes which occur in the hypolimnion due to the sinking of organic matter from the trophogenic zones of the lake (Wetzel 1975). The dissolved oxygen profiles for the deepest sampling station S-105 (Stony Lake) will be discussed in more details in a subsequent chapter.

Major Ions and Free CO_2

Concentrations of the major ions are provided in Table 3 and additional data are supplied in the appendix. As expected for the bicarbonate dominated waters of the Kawartha Lakes, the cations were present in the following sequence: $Ca^{++} > Mg^{++} > Na^{+} > K^{+}$ with calcium dominant. Lowest calcium levels were recorded in the Shield lakes. Values increased progressively downstream with the highest levels found in Rice Lake, Lake Scugog and the Bay of Quinte. Calcium concentrations in 1976 were generally lower than the 1972 values, possibly as a result of increased photosynthetic activity of the vascular aquatic plants with the resultant deposition of calcium carbonate. The maximum decrease of 10 mg Ca/l occurred at Station P-21 in southern Pigeon Lake, which is characterized by dense macrophyte growth.

Magnesium values were similar throughout the lakes except for high values of 7.0 and 8.3 mg/l in southern Pigeon Lake and 6.9 and 6.1 mg/l in Lake Scugog in 1972 and 1976 respectively. Potasium levels were monitored only in 1972 and generally increased progressively downstream. Elevated concentrations in Sturgeon, Rice and Scugog Lakes are likely due to the cumulative effects of municipal inputs and fertilizer runoff.

Mean summer values for pH, CO_2, alkalinity, conductivity and hardness are presented in Table 2. Additional data are supplied in Appendix 'A'. Mean summer pH values increased slightly down the system, from near neutral in the headwater lakes to values as high as 9 in Rice Lake. Surface pH values were lowest in the spring and increased over the summer, particularly in the more productive lakes due to utilization of free CO_2 and HCO_3^- during the photosynthetic process. Values in the bottom waters of the thermally stratified lakes decreased over the summer season as a result of decomposition processes and the release of carbon dioxide. Maximum concentrations of CO_2 in surface waters occurred in the spring and diminished over the summer months. Bottom water accumulations of CO_2 were noted at the deeper water sampling stations during periods of thermal stratification.

Seasonal trends of alkalinity, hardness and conductivity are presented in Figures 11 to 16. These parameters increased progressively downstream, with lowest values recorded in Balsam Lake and the highest values in southern Pigeon Lake (P-21), Rice Lake, Lake Scugog and the Bay of Quinte. Values at Station B-1 were consistently lower than those recorded at the remaining stations in Balsam Lake, reflecting the diluting effect of the Gull River which drains soft water from the Precambrian Shield. Similarly, low values in Cameron Lake and Stony Lake (S-105) show the influence of the Burnt River, Eels and Jack Creeks. Bottom water alkalinity, conductivity and hardness approximated the surface values although slight increases in both alkalinity and conductivity

TABLE 2: Mean values for temperature (°C), pH, free CO_2 (mg/l), alkalinity (mg/l) and conductivity (μmhos/cm[3] at 25°C) for the Kawartha Lakes in 1972 and 1976.

LAKE	TEMPERATURE		pH		CO_2		ALKALINITY		CONDUCTIVITY	HARDNESS	
	1972	1976	1972	1976	1972	1976	1972	1976	1976	1972	1976
Balsam	18.6	16.8	7.6	7.9	1.9	1.0	38	39	104	56	53
Cameron	19.0	16.6	7.5	7.8	2.7	1.2	45	46	115	62	56
Sturgeon	18.9	16.8	8.6	8.1	1.4	1.0	60	71	177	80	87
Pigeon (P-16, 17, 20)	19.9	17.1	7.9	8.2	1.9	0.9	71	75	182	93	88
Pigeon (P-21)	20.2	16.8	8.2	8.5	1.2	ND	125	116	231	154	131
Balds	20.9	17.6	7.7	7.9	2.7	1.7	75	68	153	91	78
Buckhorn	19.7	17.0	8.0	8.4	1.5	0.1	73	78	191	98	92
L. Buckhorn	19.8	16.8	8.0	8.3	2.0	0.2	72	73	173	96	86
Stony (S-27)	20.8	17.3	7.9	8.1	1.7	0.7	71	74	174	95	85
Stony (S-105)	19.4	17.2	7.8	8.0	1.3	1.4	59	60	148	80	70
Clear	19.6	17.4	8.0	8.1	1.5	0.9	72	72	173	90	83
Katchewanooka	19.9	17.1	8.1	8.1	1.1	1.0	73	73	171	90	83
Rice	20.1	16.9	8.4	8.6	0.9	0.1	83	89	200	99	99
Scugog	18.9	14.8	8.4	8.4	0.6	0.3	134	132	316	157	149
Bay of Quinte	20.8	-	7.8	-	2.2	-	99	-	-	115	-

TABLE 3: Mean surface values for the major ions (mg/l) in the Kawartha Lakes in 1972 and 1976.

LAKE	1972						1976		
	Ca^{++}	Mg^{++}	Na^{++}	K^{+}	Cl^{-}	$SO_4^{=}$	Ca^{++}	Mg^{++}	Cl^{-}
Balsam	18	2.5	1.0	.36	3.1	11.9	16	2.1	2.4
Cameron	21	2.2	1.2	.36	3.3	11.9	19	2.2	2.8
Sturgeon	28	2.6	2.0	.56	5.0	13.6	29	3.3	4.7
Pigeon (P-16, 17, 20)	32	3.7	2.0	.47	4.8	14.7	30	3.1	4.4
Pigeon (P-21)	49	7.0	2.6	.28	5.0	16.6	39	8.3	4.6
Balds	31	3.3	1.8	.29	5.4	11.9	26	3.0	3.4
Buckhorn	33	3.3	2.1	.45	4.6	14.2	31	3.4	4.4
L. Buckhorn	32	3.4	2.0	.42	4.3	12.6	30	3.1	4.2
Stony (S-27)	34	2.6	2.0	.38	4.6	12.6	29	3.0	4.1
Stony (S-105)	26	3.2	1.2	.36	3.0	12.0	26	2.2	2.7
Clear	31	3.2	1.9	.42	4.6	13.5	29	2.8	4.0
Katchewanooka	32	2.4	2.3	.50	4.8	13.1	29	2.9	4.0
Rice	35	2.5	2.8	.69	6.1	12.6	34	3.5	5.4
Scugog	52	6.9	4.4	1.0	10.1	17.4	49	6.1	11.7
Bay of Quinte	40	3.3	4.0	.85	6.3	13.3	-	-	-

were noted at some of the deeper stations, indicating a build-up of inorganic carbon as well as free CO_2.

In 1976 both conductivity and hardness decreased from the 1972 levels. Changes in hardness reflect the previously mentioned reductions in calcium levels. The large change in conductivity is due in part to analytical errors in the 1972 results since calculated conductivities, based on ionic balances for that year were consistently lower than the recorded results.

Nutrient Considerations

Mean surface concentrations of phosphorus, nitrogen, silica, iron and inorganic carbon are presented in Tables 4 and 5, Figures 17 and 18, and Appendix 'A'. Seasonal trends for phosphorus and nitrogen in surface and bottom waters are illustrated in figures 19 to 23.

Phosphorus has long been regarded as the essential and often limiting requirement for plant growth in the aquatic environment (Hasler & Einsele) 1948, Hutchinson and Bowen 1950, Sawyer 1947, Wetzel 1966, Edmonson 1970). Based on seasonal average total phosphorus concentrations, the Kawartha Lakes can be roughly divided into three categories. Lowest concentrations were obtained in the headwater lakes such as Balsam, Cameron and upper Stony Lake. Marginally higher values were recorded in the Bald Lakes, possibly due to more intense cottage development.* The second category, with moderate phosphorus levels includes the central lakes of the system such as Stony (lower basin), Clear, Pigeon, Chemung and Katchewanooka. Sturgeon Lake shows somewhat elevated phosphorus values compared to the other lakes in this grouping, undoubtedly due to the municipal inputs from the Town of Lindsay and the influence of the Scugog River. The final category includes the highly eutrophic lakes such as Rice, Bay of Quinte and Scugog.

Vollenweider (1969) indicated that the concentration of phosphorus in a lake is largely determined by supply and is modified by water replenishment. In the Kawartha Lakes, the progressive downstream increase in phosphorus concentrations is largely a result of the change from forested drainage basins on the Shield which contain small concentrations of the alkaline earth elements to rich, agricultural basins which drain calcareous sediments. In addition, the lakes in the southern portion of the system are generally more heavily urbanized and receive inputs from the larger population centers.

Mean euphotic zone phosphorus concentrations in 1972 ranged from 0.014 mg/l in Upper Stony Lake to 0.056 mg/l in Rice Lake. Similar concentra-

*FOOTNOTE: Based on cottage density information from"Minimal Lake Survey, Ministry of Natural Resources, 1972, Lindsay (provided by R. Lewies)

TABLE 4: Mean euphotic zone values for total phosphorus (mg/l) and nitrogen (NH_3, Total Kjedahl, NO_2, NO_3 in mg/l) for the Kawartha Lakes in 1972 and 1976.

LAKE	Total Phosphorus		NH_3		TKN		NO_2		NO_3	
	1972	1976	1972	1976	1972	1976	1972	1976	1972	1976
Balsam	.016	.010	.02	.02	.32	.24	.003	.001	.04	.02
Cameron	.016	.009	.04	.02	.37	.26	.004	.002	.03	.02
Sturgeon	.027	.026	.03	.03	.56	.48	.003	.002	.02	.01
Pigeon (p-16, 17, 20)	.026	.023	.04	.04	.56	.53	.004	.002	.04	.01
Pigeon (p-21)	.025	.027	.03	.02	.68	.75	.003	.002	.01	< .01
Balds	.021	.020	.09	.03	.64	.55	.004	.002	<.01	< .01
Buckhorn	.023	.022	.02	.02	.51	.47	.005	.002	.04	< .01
L. Buckhorn	.022	.022	.03	.02	.51	.42	.004	.002	.03	< .01
Stony (S-27)	.024	.020	.05	.03	.49	.46	.004	.002	.03	.01
Stony (S-105)	.014	.010	.07	.03	.45	.32	.004	.003	.02	.02
Clear	.024	.015	.03	.04	.46	.47	.004	.002	.04	.01
Katchewanooka	.030	.019	.04	.03	.53	.49	.004	.002	.03	.01
Rice	.056	.049	.06	.04	.73	.71	.003	.001	.02	.01
Scugog	.040	.045	.07	.06	1.1	1.1	.003	.002	.01	.02
Bay of Quinte	.050	-	.02	-	.69	-	.006	-	.02	-

tions were recorded in 1976, with values ranging from 0.009 mg/l in Cameron Lake and Upper Stony Lake to a maximum value of 0.049 mg/l in Rice Lake. The slight reduction in P values in Rice Lake in 1976 is possibly due to the implementation of tertiary treatment at the Peterborough Sewage Treatment Plant. In Lake Scugog however, mean phosphorus concentrations increased slightly from 0.040 mg/l in 1972 to 0.045 mg/l in 1976. The changes were generally within the range of analytical error. Phosphorus concentrations in the euphotic zone were similar to those in the bottom waters at the shallower sampling stations. Pronounced hypolimnetic increases in phosphorus concentrations were observed at the deep water stations in Northern Pigeon, particularly Station P-17 (Figure 24) where a maximum concentration of 1.1 mg/l was measured in late August of 1972 and at Station S-27 in Stony Lake where the maximum concentration reached 0.310 mg/l. A similar increase (0.238 mg/l) was observed at Station S-27 in 1976, whereas a much smaller peak (0.198 mg/l) occurred at Station P-17. These increases corresponded to elevated iron concentrations, and occurred under conditions of well-defined thermal stratification with clinograde oxygen distributions, suggesting a classical iron-phosphate recycling mechanism (Hutchinson 1957, Mortimer 1941). Station S-105 in Upper Stony Lake experienced thermal statification and severe oxygen depletion; however, phosphorus and iron concentrations in the hypolimnion were similar to surface values. Hutchinson (1957) describes such lakes as having an orthograde redox-potential curve, even in the absence of oxygen in bottom waters, with reduction at the mud-water interface curtailed by a high redox potential, eliminating the need for classical iron-phosphorus recycling. The author states that this may be the case in oxygen concentrations as low as 1.0 mg/l.

Mean euphotic zone nitrogen concentrations (NH_3, NO_2, NO_2, Kjeldahl) were generally similar or slightly lower in 1976 compared to 1972. Inorganic nitrogen concentrations were lower than Sawyer's (1947) suggested value of 0.300 mg/l at spring overturn, required to produce algal bloom conditions. Euphotic zone ammonia concentrations were low, although somewhat elevated values were recorded in the Bald Lakes (0.09 mg/l), Stony Lake (0.05, 0.07 mg/l), Rice Lake (0.06 mg/l) and Lake Scugog (0.07 mg/l) in 1972. Levels were slightly lower in 1976. Mid-summer nitrate-nitrogen depletions characterized most stations, particularly in the more productive lakes. Total Kjeldahl nitrogen concentrations were high in the eutrophic lakes, particularly, Rice Lake (0.73 and 0.71 mg/l) and Lake Scugog (1.1 and 1.1 mg/l) in 1972 and 1976 respectively.

Bottom water accumulations of Kjeldahl nitrogen were observed at the deep

TABLE 5: Mean values for iron (mg/l), silica (mg/l SiO_2), inorganic carbon (mgC/l), chlorophyll a (ppb) and secchi disc (m) in the Kawartha Lakes in 1972 and 1976.

LAKE	Iron		Silica		Inorganic carbon		Chlorophyll a		Secchi disc	
	1972	1976	1972	1976	1972	1976	1972	1976	1972	1976
Balsam	.05	.05	2.4	1.5	7.8	-	2.3	2.2	4.0	3.8
Cameron	.11	.07	2.8	1.6	8.5	-	2.5	1.9	3.8	3.7
Sturgeon	.09	.09	2.3	1.3	11.3	-	8.4	8.6	2.3	2.1
Pigeon (P-16, 17, 20)	.08	.08	2.9	1.2	13.6	-	5.0	6.0	2.8	2.5
Pigeon (P-21)	.05	.06	2.7	0.8	24.8	-	2.4	3.9	1.6	1.3
Balds	.43	.22	2.1	1.2	15.1	-	3.8	5.4	2.8	1.9
Buckhorn	.06	.04	2.4	1.4	14.1	-	4.2	6.3	2.4	2.3
Lower Buckhorn	.07	.05	2.2	1.1	13.8	-	4.7	7.0	2.6	2.2
Stony (S-27)	.08	.05	2.1	1.1	12.2	-	4.7	5.7	2.5	2.3
Stony (S-105)	.09	.03	2.4	1.1	11.7	-	2.8	3.9	3.7	4.3
Clear	.07	.04	2.2	1.3	13.1	-	5.1	5.7	2.8	3.5
Katchewanooka	.07	.05	2.3	1.3	14.0	-	4.1	9.1	2.9	2.5
Rice	.10	.17	2.3	0.8	15.0	-	9.0	18.6	1.8	1.3
Scugog	.08	.17	3.7	1.3	25.4	-	16.1	14.3	0.8	0.8
Bay of Quinte	.12	-	2.9	-	18.0	-	14.4	-	1.2	-

water stations in northern Pigeon Lake, P-17 (2.0 mg/l) and at station S-27 in Stony Lake (2.1 mg/l) in 1972. Increases were less pronounced in 1976 (Figure 24). Ammonia concentrations increased in the bottom waters at all stations in the more productive lakes, reflecting decomposition processes. Maximum summer increases occurred at stations P-17 (1.1 mg/l) and S-27 (1.0 mg/l) in 1972 and at P-17 (0.52 mg/l), B-24 (0.50 mg/l) and S-27 (0.89 mg/l) in 1976.

Hutchinson (1957) indicated that phosphorus may limit production when the N/P ratio is high (total Kjeldahl plus nitrate to total phosphorus) whereas nitrogen would be expected to limit production when the ratio is low i.e. 20:1 (by moles) or 9:1 (by weight). Nitrogen-phosphorus ratios (by weight) for the Kawartha Lakes ranged from 13 to 33, indicating that phosphorus is probably limiting production. As expected, the highest ratios (32 and 33) were obtained for upper Stony Lake (S-105) and the lowest ratios (13 to 14) for Rice Lake and the Bay of Quinte.

Chlorophyll *a* and Secchi disc

Megard (1970) demonstrated that integral photosynthesis is a complex function of chlorophyll *a* concentrations in the water and suggested that chlorophyll *a* can be used as a legitimate index of algal population densities. Chlorophyll *a* concentrations (open-water averages) between 0 and 2 ppb indicate low algal densities. Concentrations ranging from 2 to 6 ppb are moderately high but considered to be acceptable for most water oriented recreational activities. Levels above 6 ppb generally reflect high algal densities and can result in an impairment of water usage. Based on data previously collected by the Ministry of the Environment from over 200 lakes, a good correlation has been established between mean chlorophyll *a* concentrations and water clarity (based on Secchi disc measurements). Eutrophic lakes with high chlorophyll *a* levels and corresponding restricted light penetration fall along the horizontal axis of the curve. Oligotrophic lakes with low algal densities and high water clarity lie along the vertical axis, whereas mesotrophic lakes fall along the central portion of the hyperbola.

As expected, the majority of the Kawartha Lakes fall in the mesotrophic portion of the graph (Figure 24). Balsam, Cameron and Stony (S-105) had the lowest algal densities and highest Secchi disc readings. Sturgeon Lake and particularly, Lake Scugog, Rice Lake and the Bay of Quinte supported massive algal blooms and were located at the eutrophic end of the scale.

Seasonal mean chlorophyll concentrations for 1972 and 1976 are summarized in Table 5. Mean seasonal chlorophyll *a* concentrations in most lakes in 1976 were within experimental error of the levels recorded in 1972 with the exception of Rice Lake where values doubled from 9.0 ppb in 1972 to 18.6 ppb in 1976. The overall increase in Rice Lake is a result of severe bloom conditions at stations R-33 and R-34 during the July, August and October surveys when values between 30 and 46 ppb were obtained. These bloom conditions may be partly due to changes in the macrophyte communities i.e. annual die-off of P. crispus in July and early August and general onset of macrophyte decomposition in October.

Relationships between Total Phosphorus Concentrations and Chlorophyll a Levels

The relationship between nutrient concentrations, particularly phosphorus and chlorophyll a levels (as an approximation of phytoplankton biomass) in lakes has been well documented (Sakomoto 1966, Brydges 1971, Dillon and Rigler 1974). However, these correlations between total phosphorus levels and chlorophyll a concentrations in lakes are largely based on data collected from deeper, stratified lakes.

The good correlation between seasonal average total phosphorus concentration and seasonal average chlorophyll level {$r = 0.80$ (1972), $r = 0.96$ (1976)} for the Kawartha lakes is surprising in view of the shallow nature of many of the lake basins and the interference of macrophyte growth (Figure 25). The variation in the slope of the regression line between 1972 and 1976 is due to the increases in chlorophyll a concentrations in 1976, particularly in Rice Lake (9.0 ppb in 1972, 18.6 ppb in 1976) compared to similar or only slightly reduced total phosphorus values.

In view of the strong relationship between phosphorus levels and chlorophyll a concentrations in the Kawartha Lakes, it is apparent that a significant reduction in phosphorus levels, if it can be achieved, offers the greatest potential for ameliorating nuisance algal levels and improving water clarity.

CONCLUSIONS

1. The Kawartha Lakes can be grouped into three categories:

   a) Category 1 - includes the headwater lakes with low concentrations of major ions, phosphorus and chlorophyll a.

b) Category 2 - includes the central lakes on the system with moderate ion concentrations, phosphorus and chlorophyll a levels. Although the location of Sturgeon Lake places it in this category, based on water quality parameters (particularly, phosphorus and chlorophyll a) the lake is borderline between this and the subsequent category.

c) Category 3 - includes the eutrophic lakes at the southern end of the system, namely, Rice Lake and the Bay of Quinte as well as Lake Scugog. These lakes have high concentrations of the major ions, and elevated phosphorus and chlorophyll a levels.

2) The progressive downstream deterioration in water quality is a reflection of the change in the type of drainage basins from those on the Precambrian Shield to the calcareous Ordovician sedimentary rock, combined with the cumulative inputs from agricultural and municipal sources.

3) Comparison of 1972 and 1976 chemical data for the Kawartha Lakes shows no deterioration in water quality during the four year period.

ACKNOWLEDGEMENTS

Appreciation is extended to Mr. D. Veal and Mr. K. Sherman of the Central Region Office, Ministry of the Environment for assistance with the 1976 survey.

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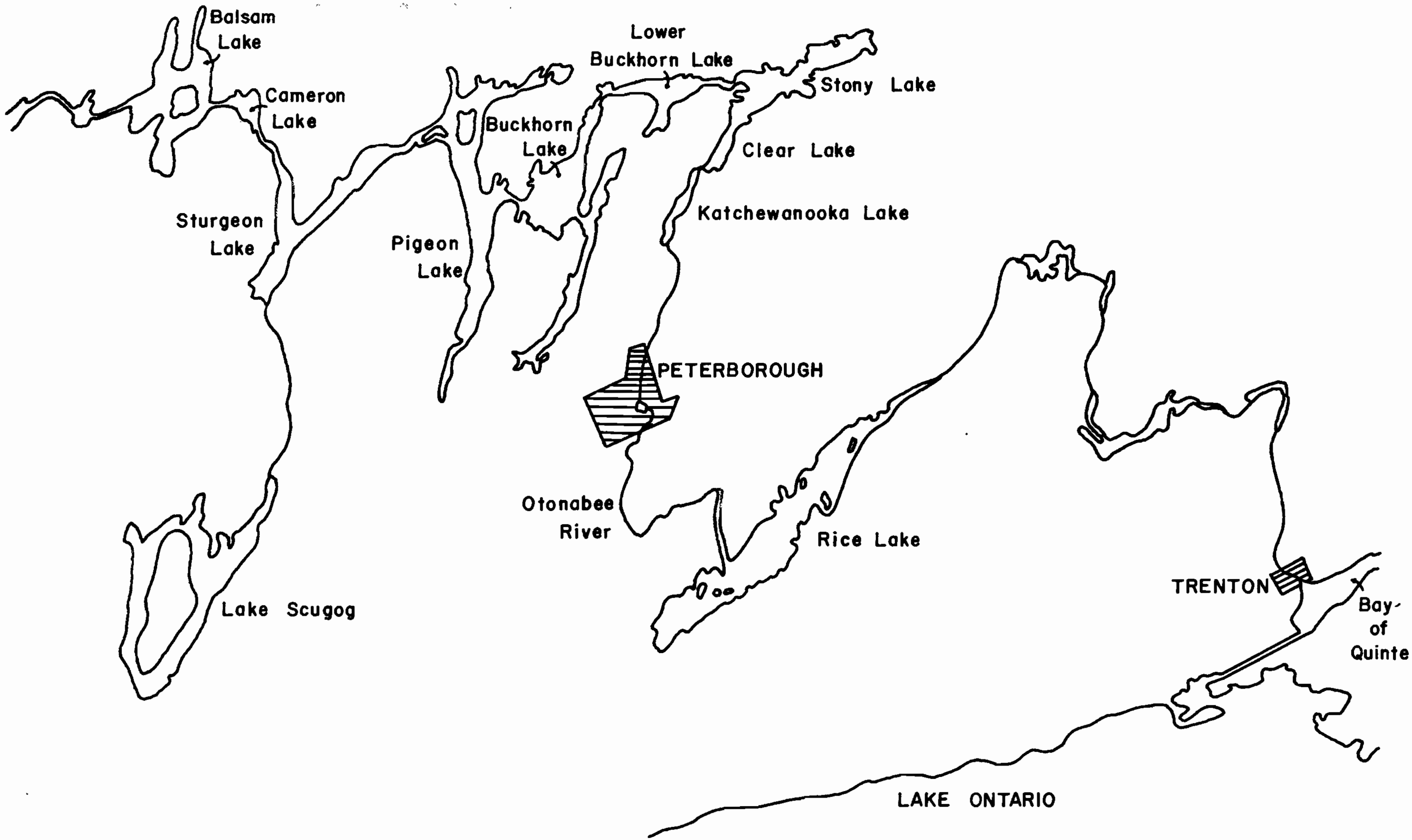

FIG. I The Kawartha Lakes (Balsam Lake to the Bay of Quinte).

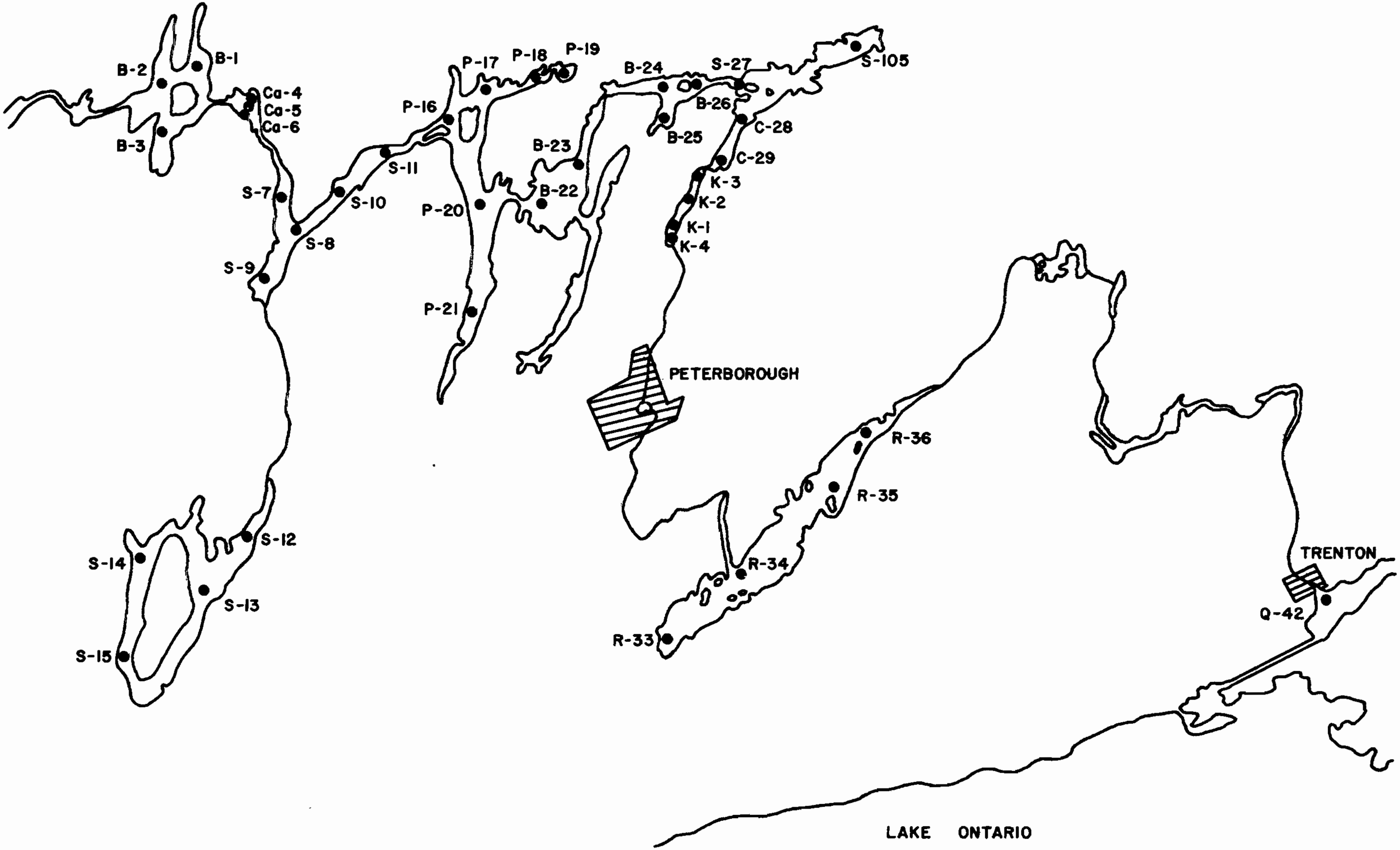

FIG. 2 Water quality sampling stations in the Kawartha Lakes in 1972.

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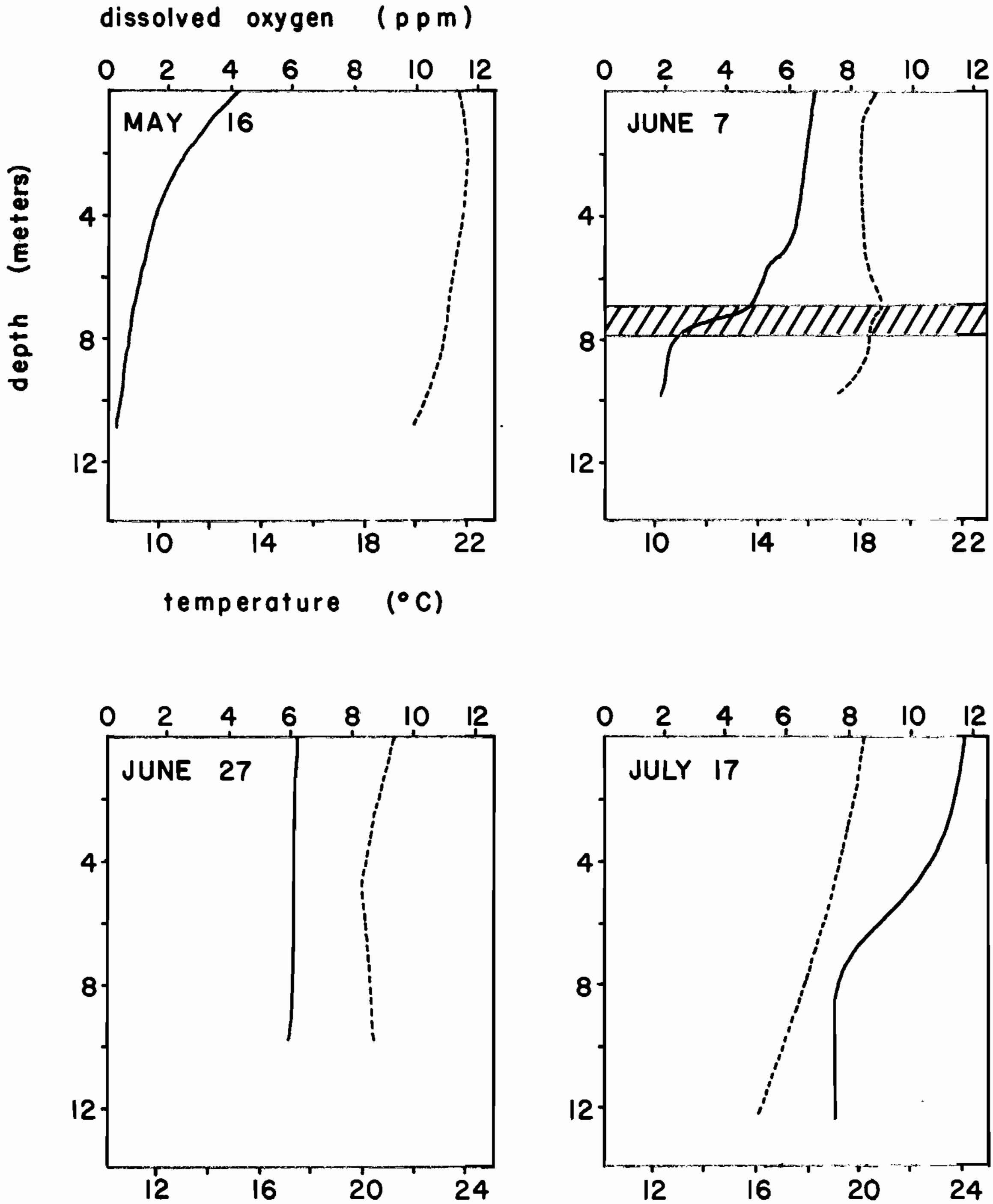

FIG. 3 Dissolved oxygen and temperature profiles at B-2 in Balsam Lake in 1972. (--- oxygen, —— temperature) Shaded area approximates extent of thermocline.

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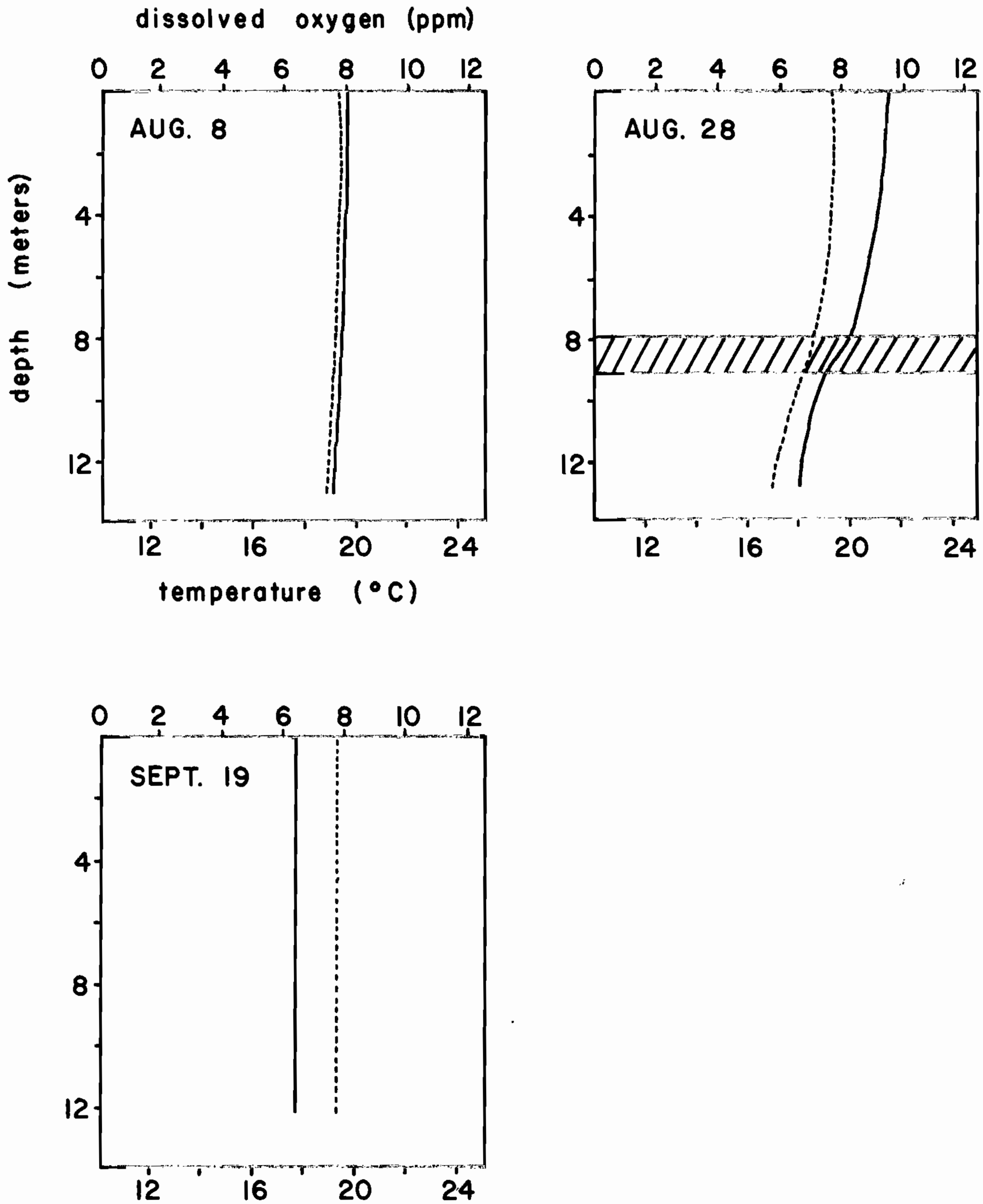

FIG.3 (cont.) Balsam Lake. (B-2).

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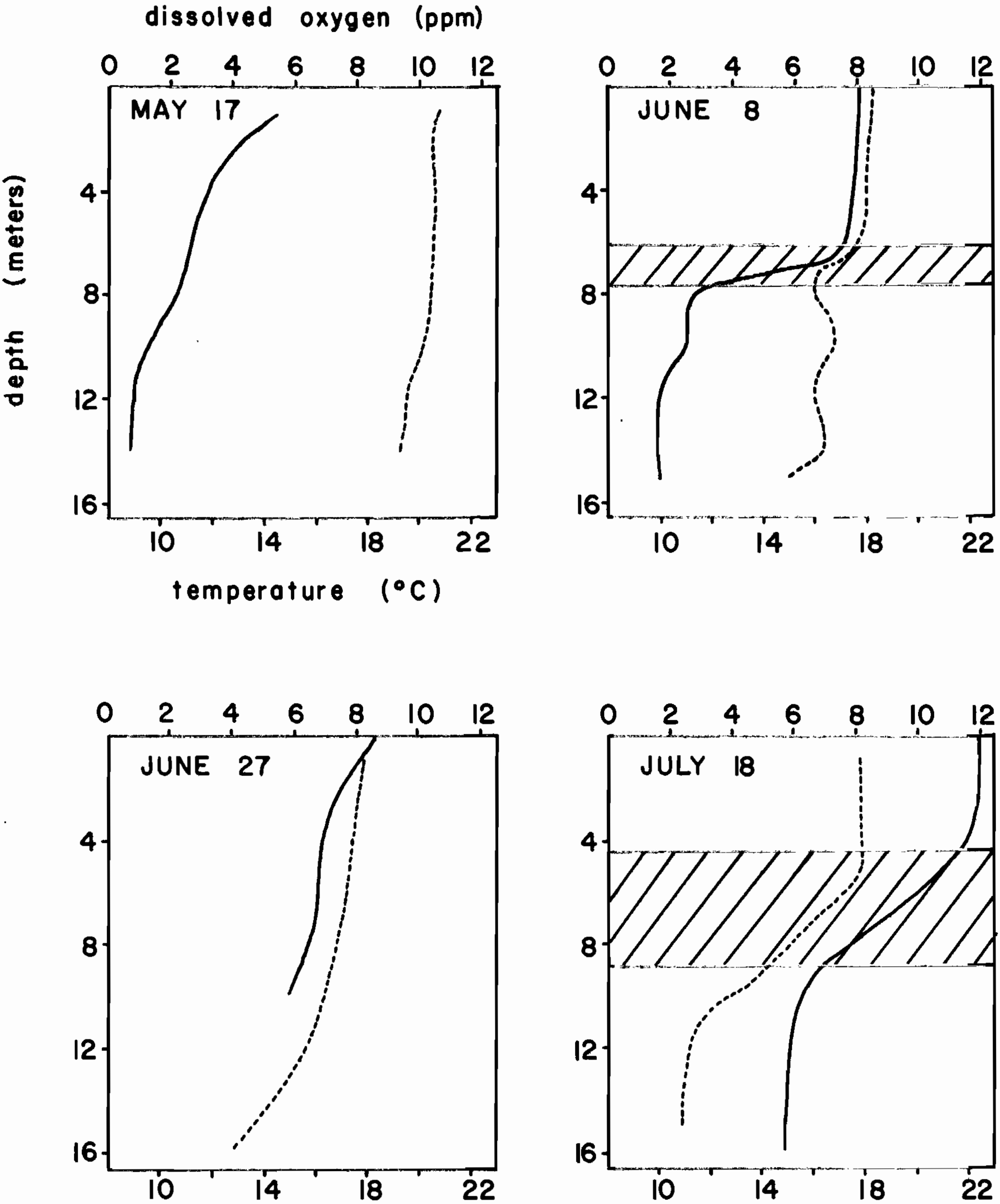

FIG. 4 Dissolved oxygen (---) and temperature (—) profiles in Cameron Lake at station Ca-5 in 1972. Shaded area approximates extent of thermocline.

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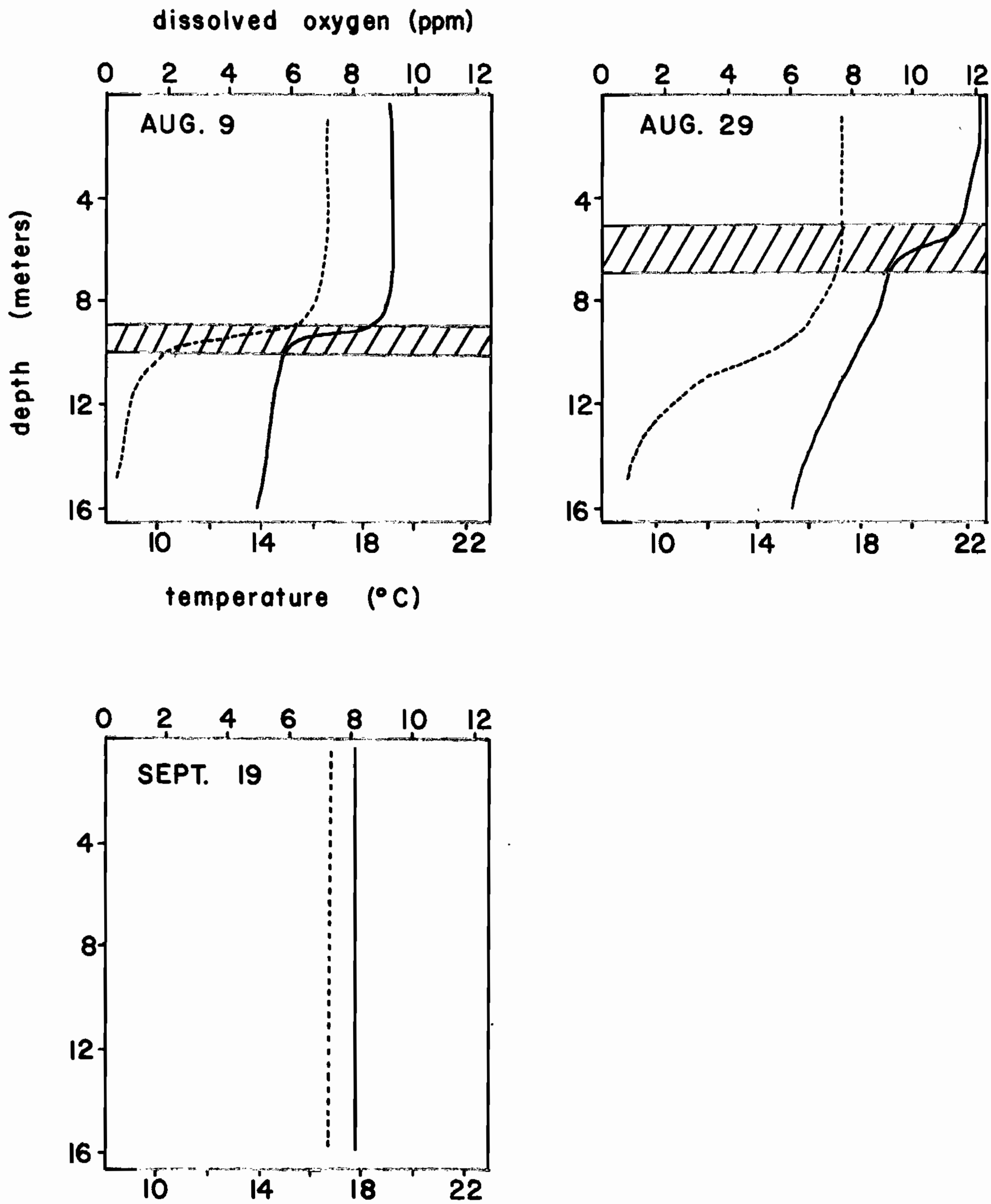

FIG. 4 (cont.) Cameron Lake (Ca-5).

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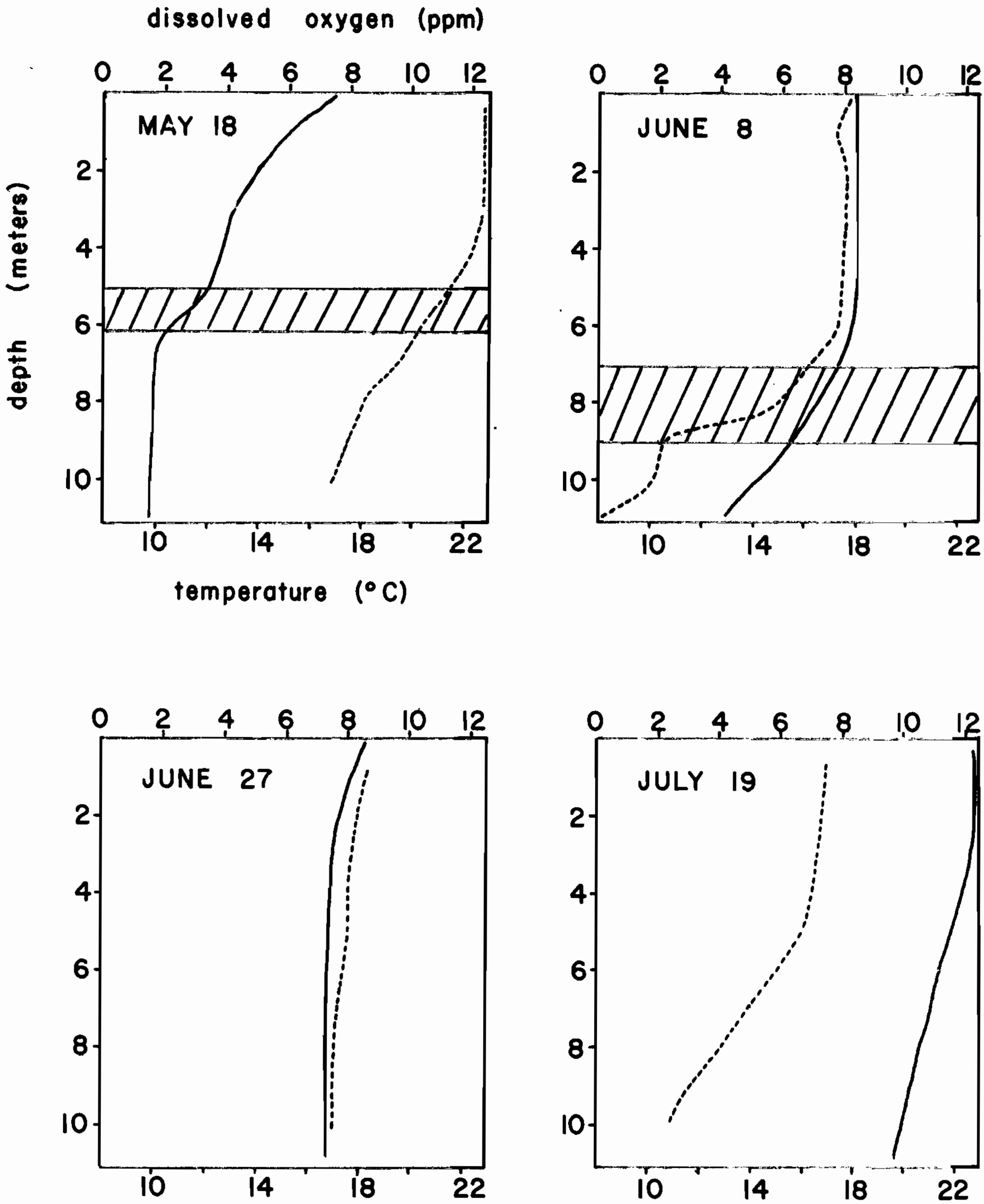

FIG. 5 Dissolved oxygen (---) and temperature (——) profiles in Sturgeon Lake at S-8 in 1972. Shaded area approximates extent of thermocline.

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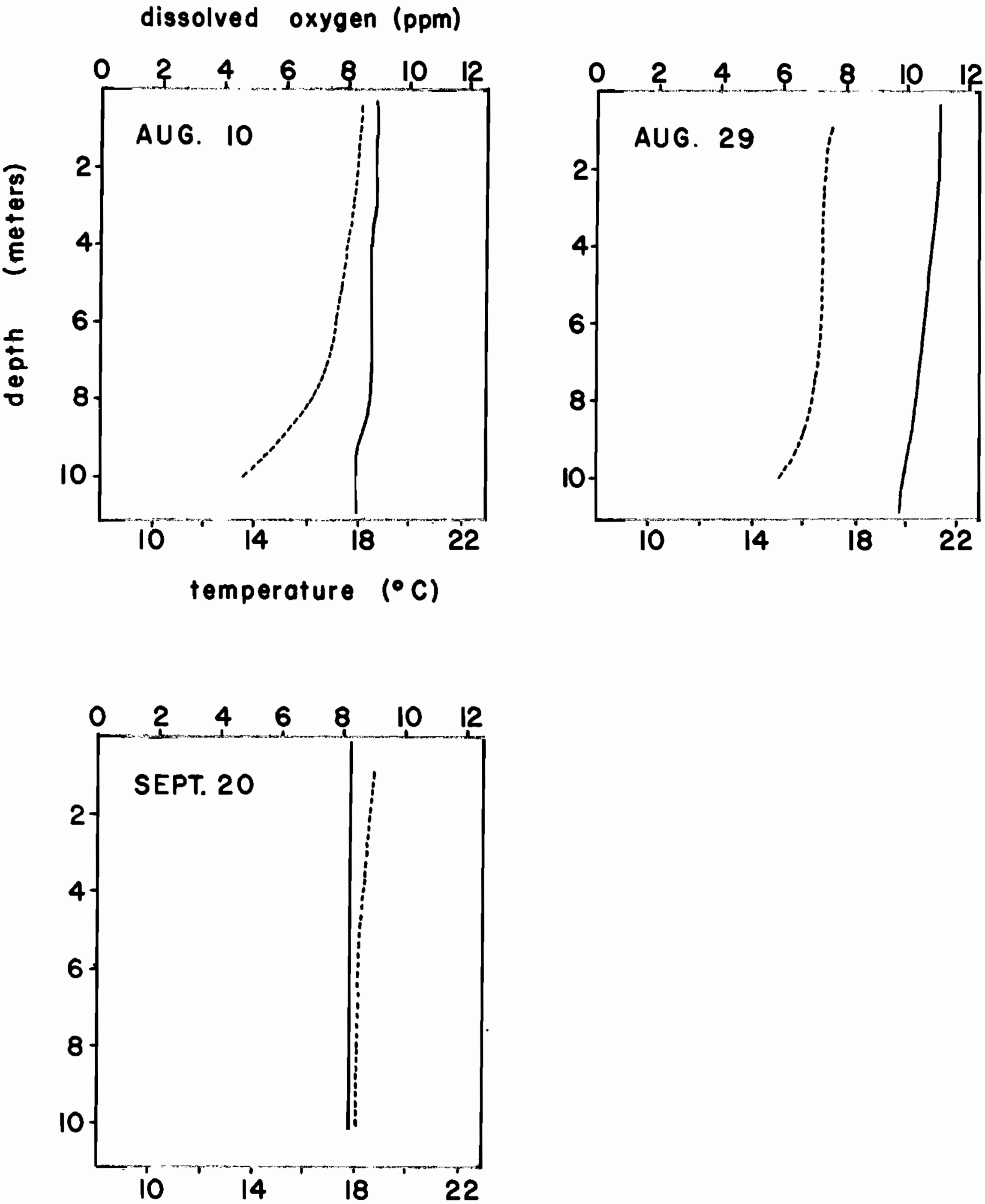

FIG. 5 (cont.) Sturgeon Lake (S-8).

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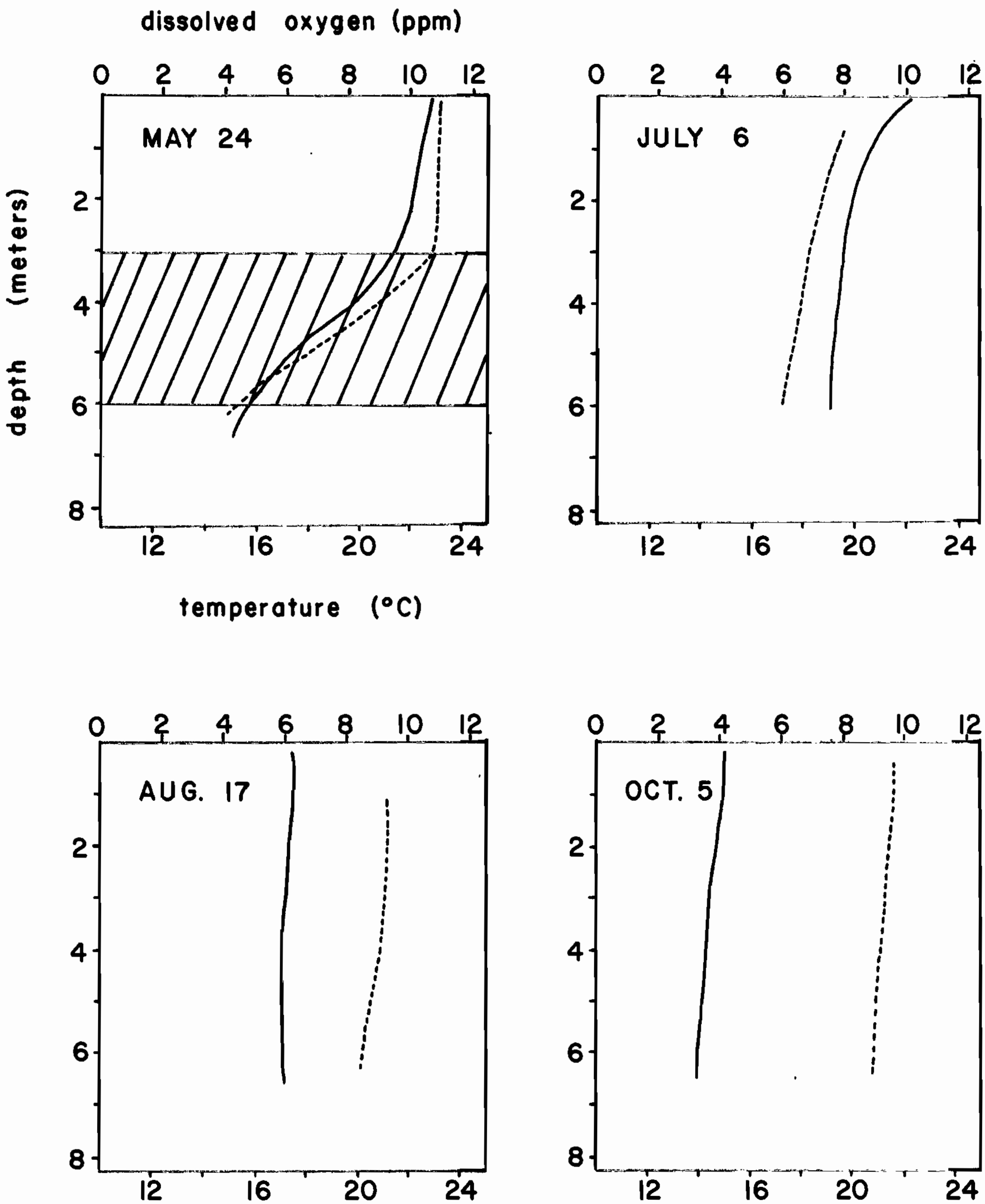

FIG. 6 Dissolved oxygen (---) and temperature (—) profiles in Lake Scugog at S-13 in 1972. Shaded area approximates extent of thermocline.

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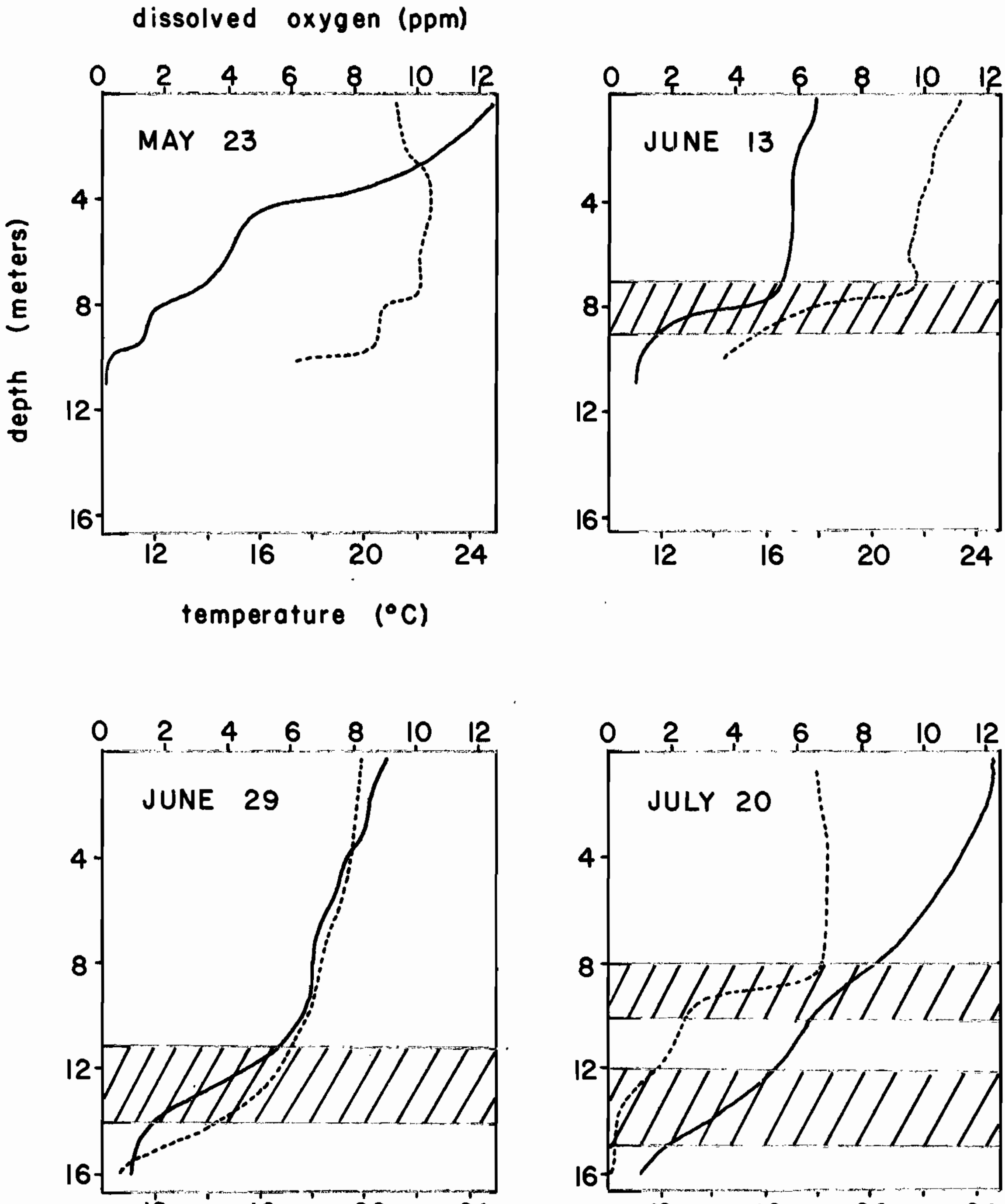

FIG. 7 Dissolved oxygen (- - -) and temperature (—) profiles in Pigeon Lake at P-17 in 1972. Shaded area approximates extent of thermocline.

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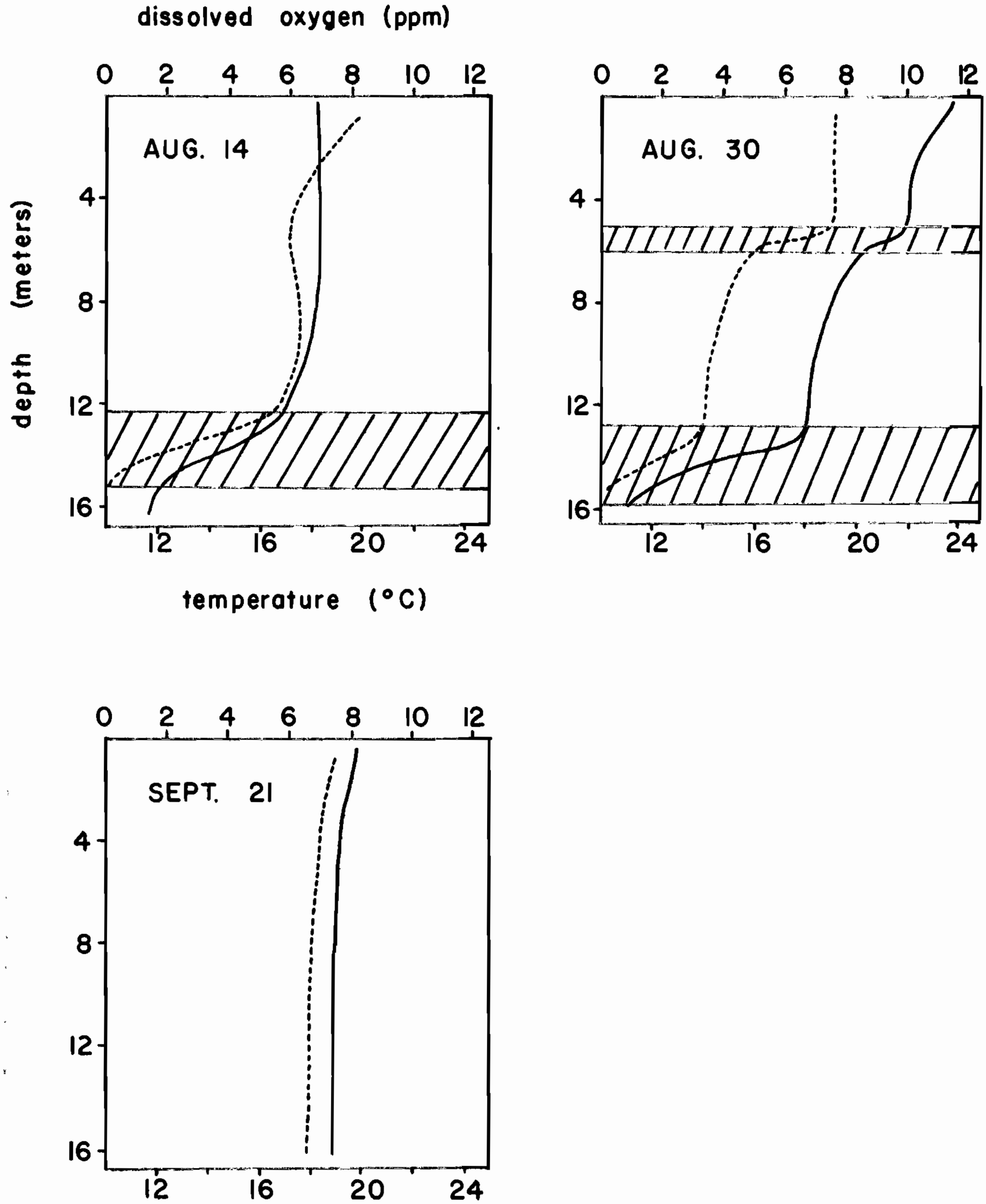

FIG. 7 (cont.) Pigeon Lake (P-17).

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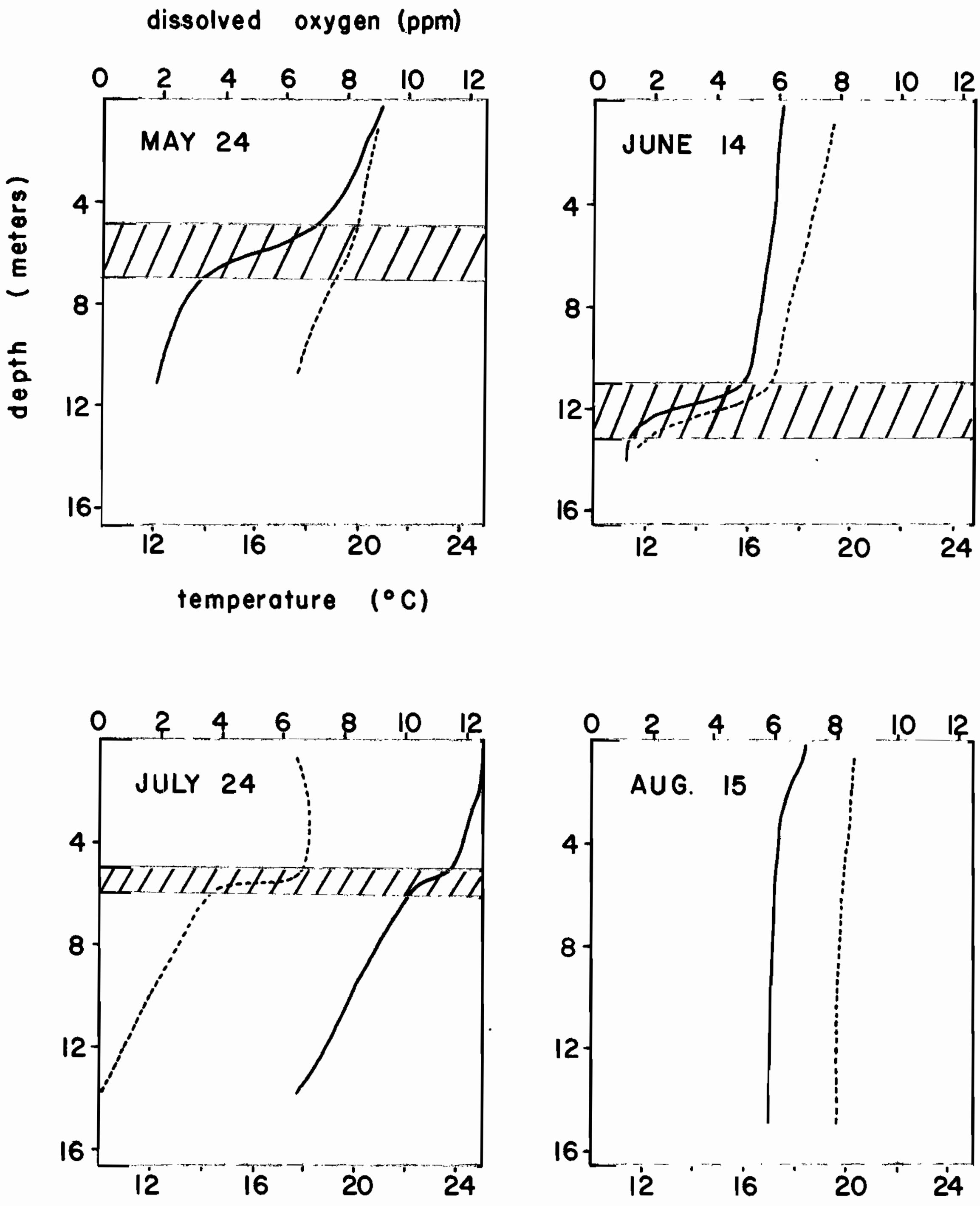

FIG. 8 Dissolved oxygen (---) and temperature (—) profiles in Lower Buckhorn Lake at B-24 in 1972. Shaded area approximates extent of thermocline.

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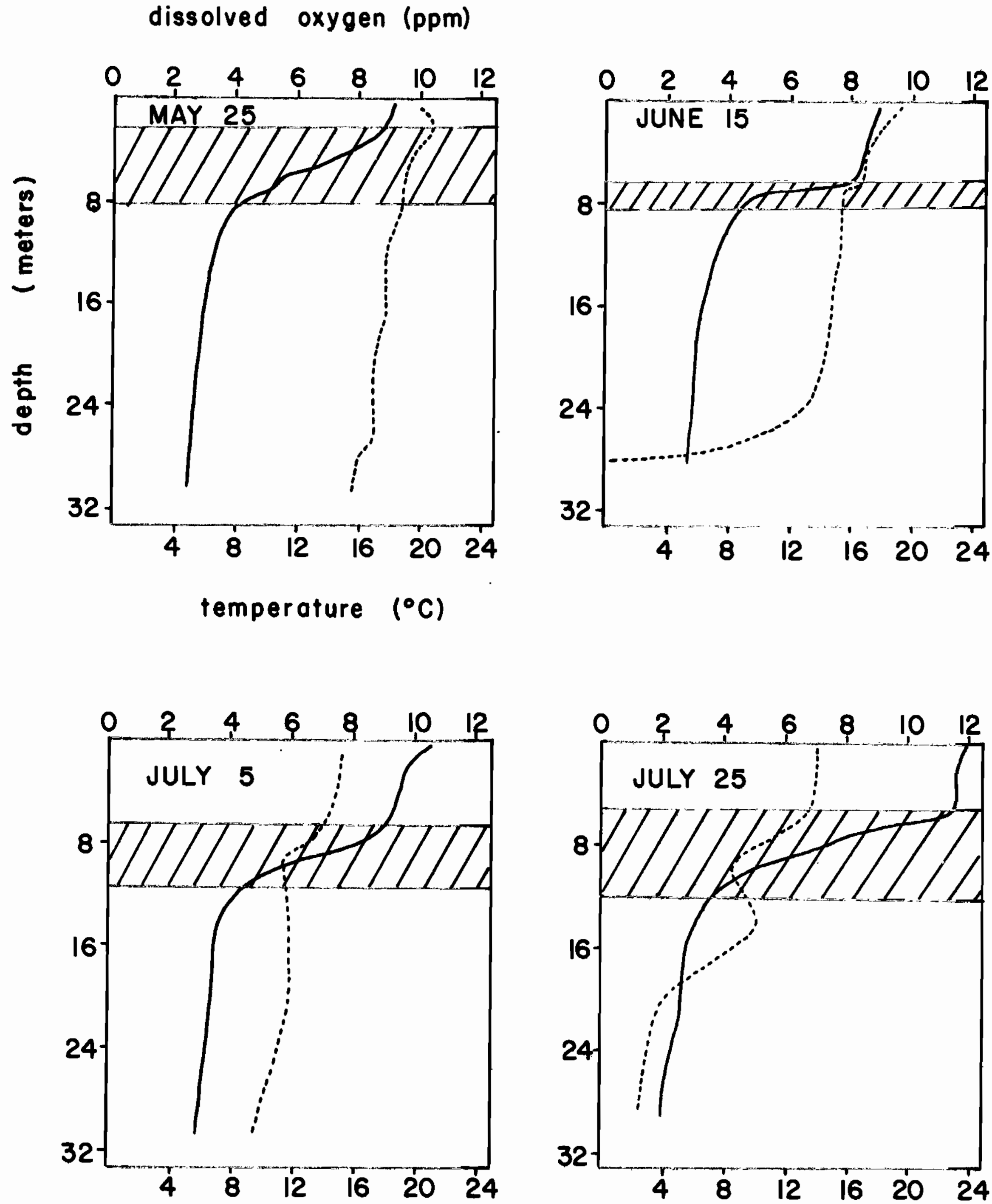

FIG. 9 Dissolved oxygen (---) and temperature (——) profiles in Stony Lake at S-105 in 1972. Shaded area approximates extent of thermocline.

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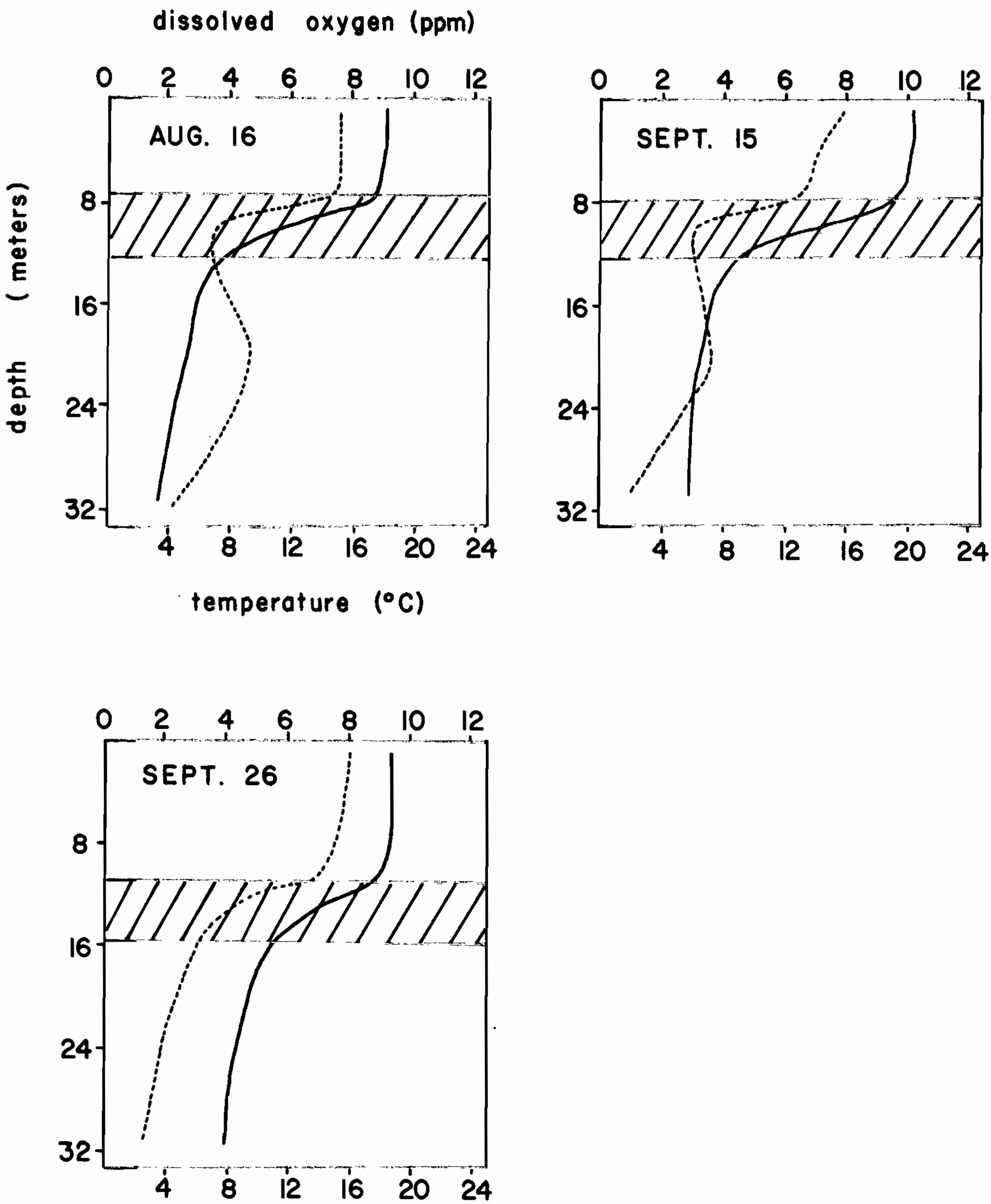

FIG. 9 (cont.) Stony Lake (S-105).

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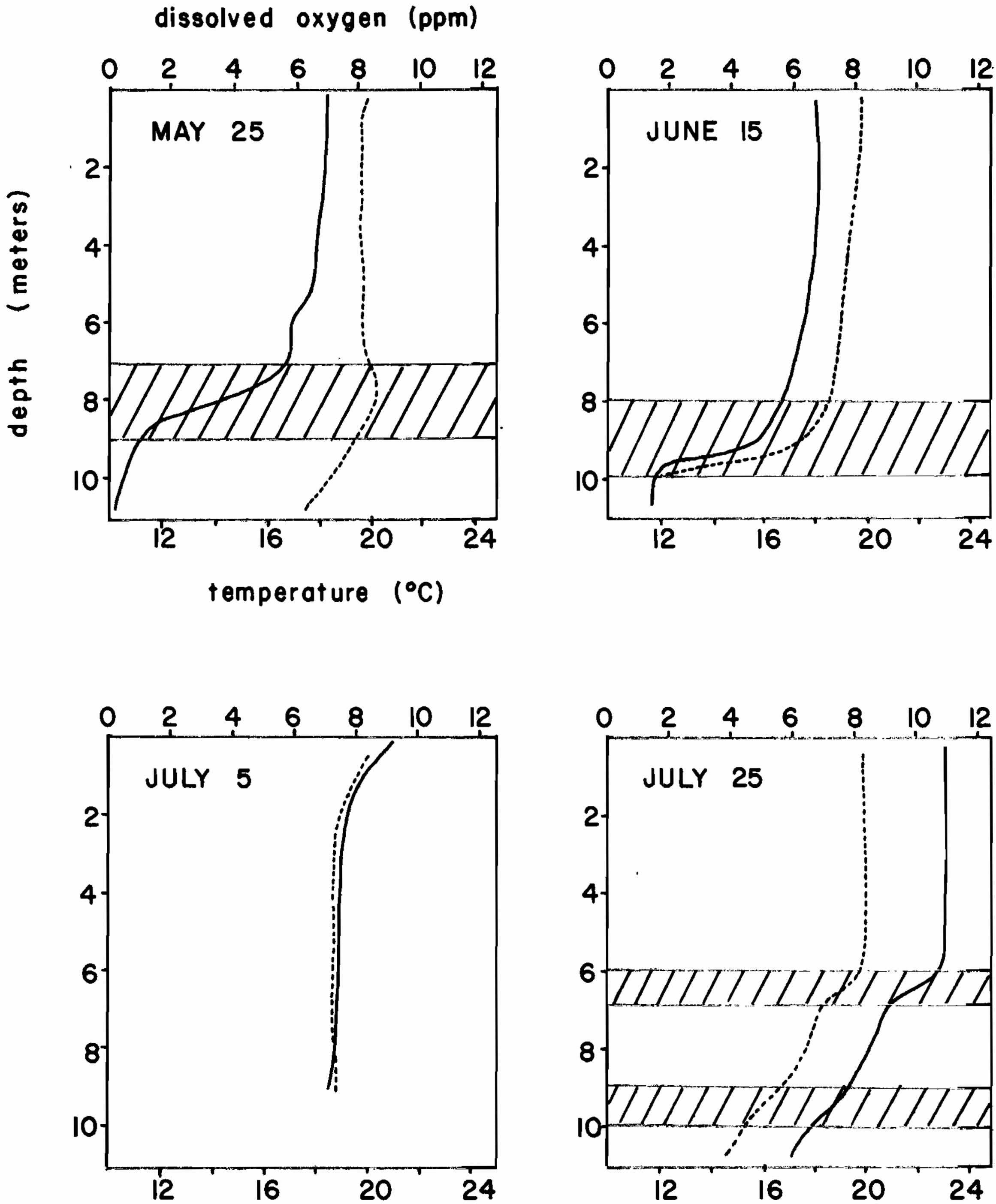

FIG. 10 Dissolved oxygen (---) and temperature (—) profiles in Clear Lake at C-29 in 1972. Shaded area approximates extent of thermocline.

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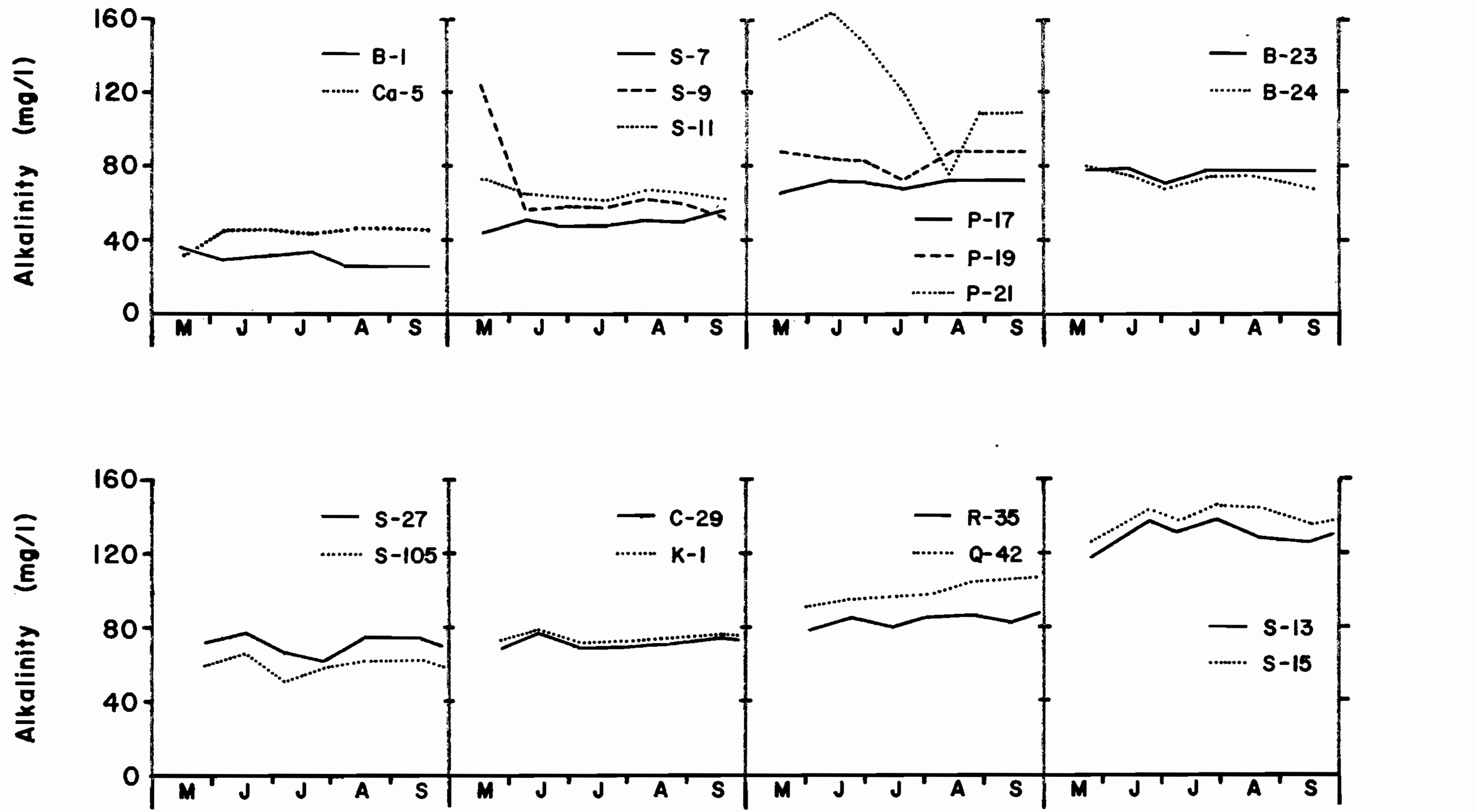

FIG. 11 Variations in total alkalinity (mg/l) in the Kawartha Lakes from May to September, 1972, in surface waters.

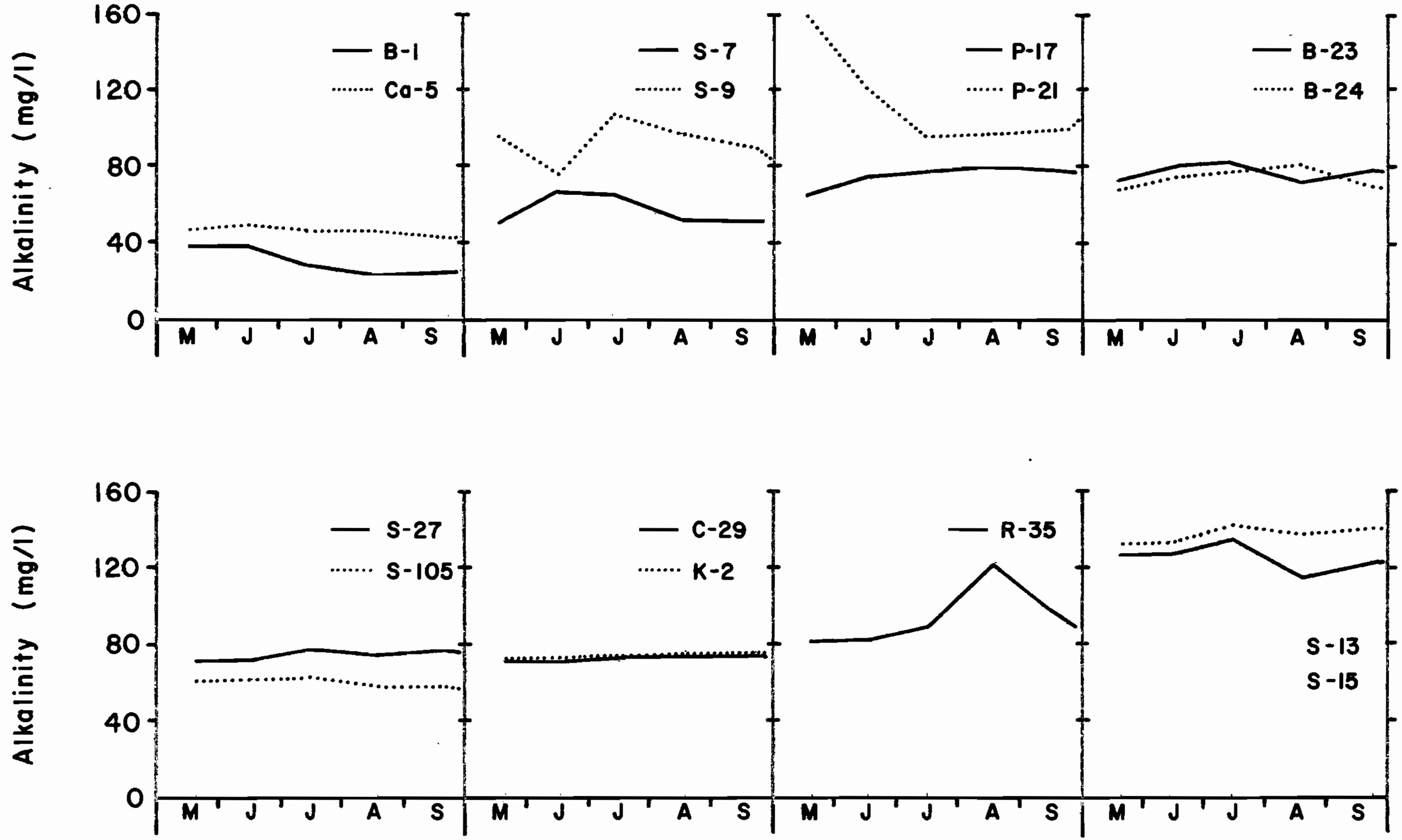

FIG. 12 Variations in total alkalinity (mg/l) in the Kawartha Lakes from May to September, 1976, in surface waters.

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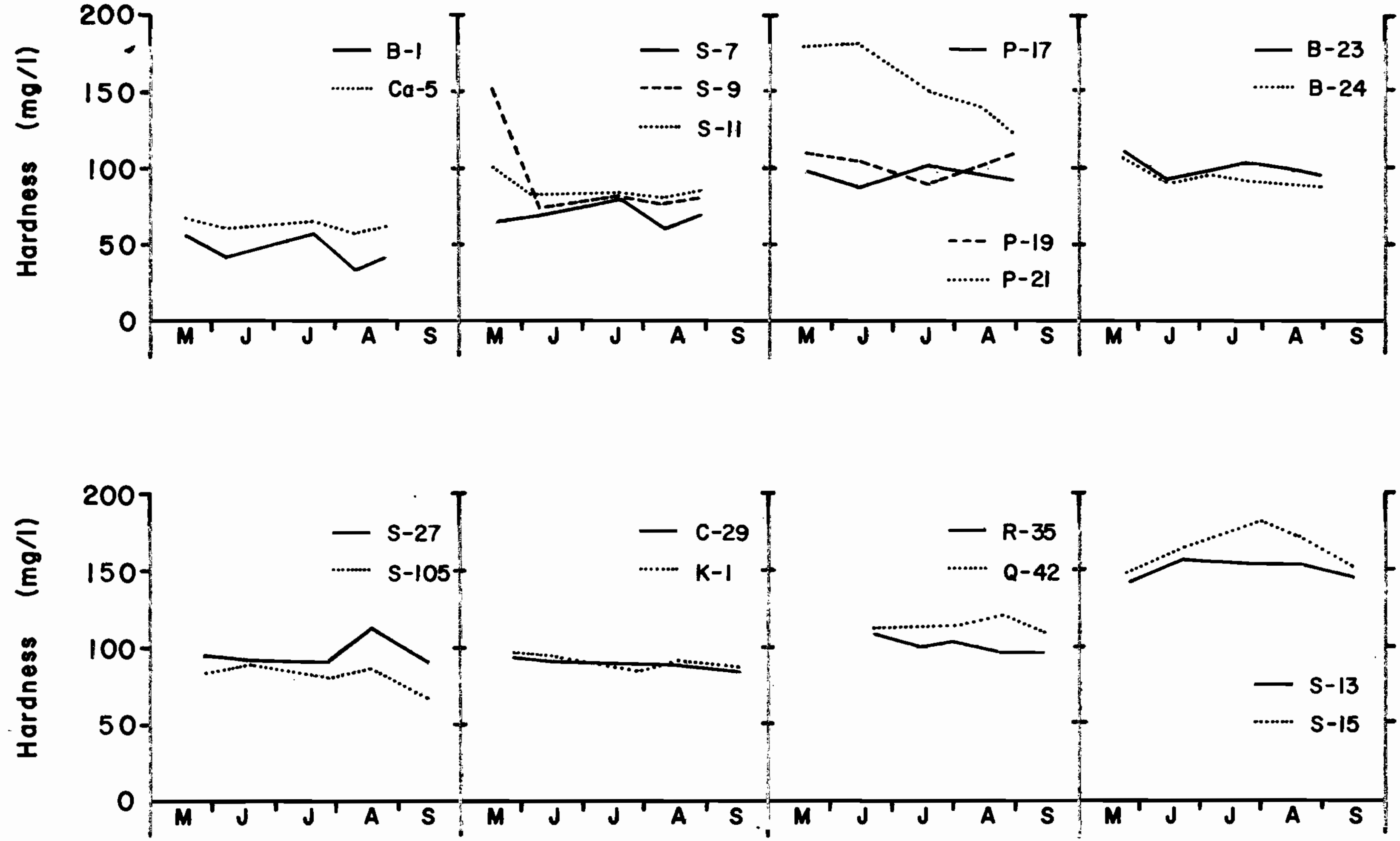

FIG. 13 Variations in total hardness (mg/l) in the Kawartha Lakes from May to September, 1972, in surface waters.

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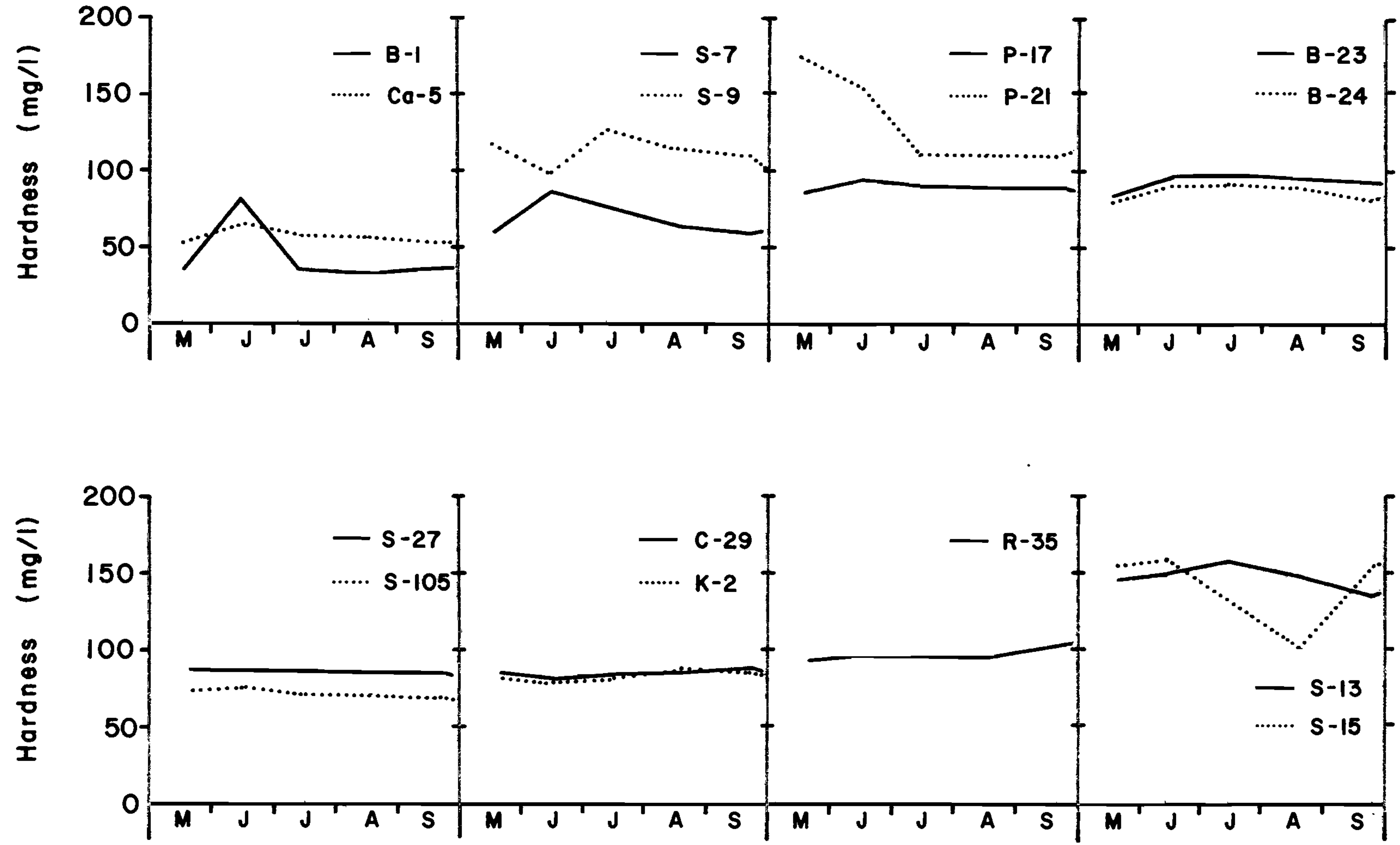

FIG. 14 Variations in total hardness (mg/l) in the Kawartha Lakes from May to September, 1976, in surface waters.

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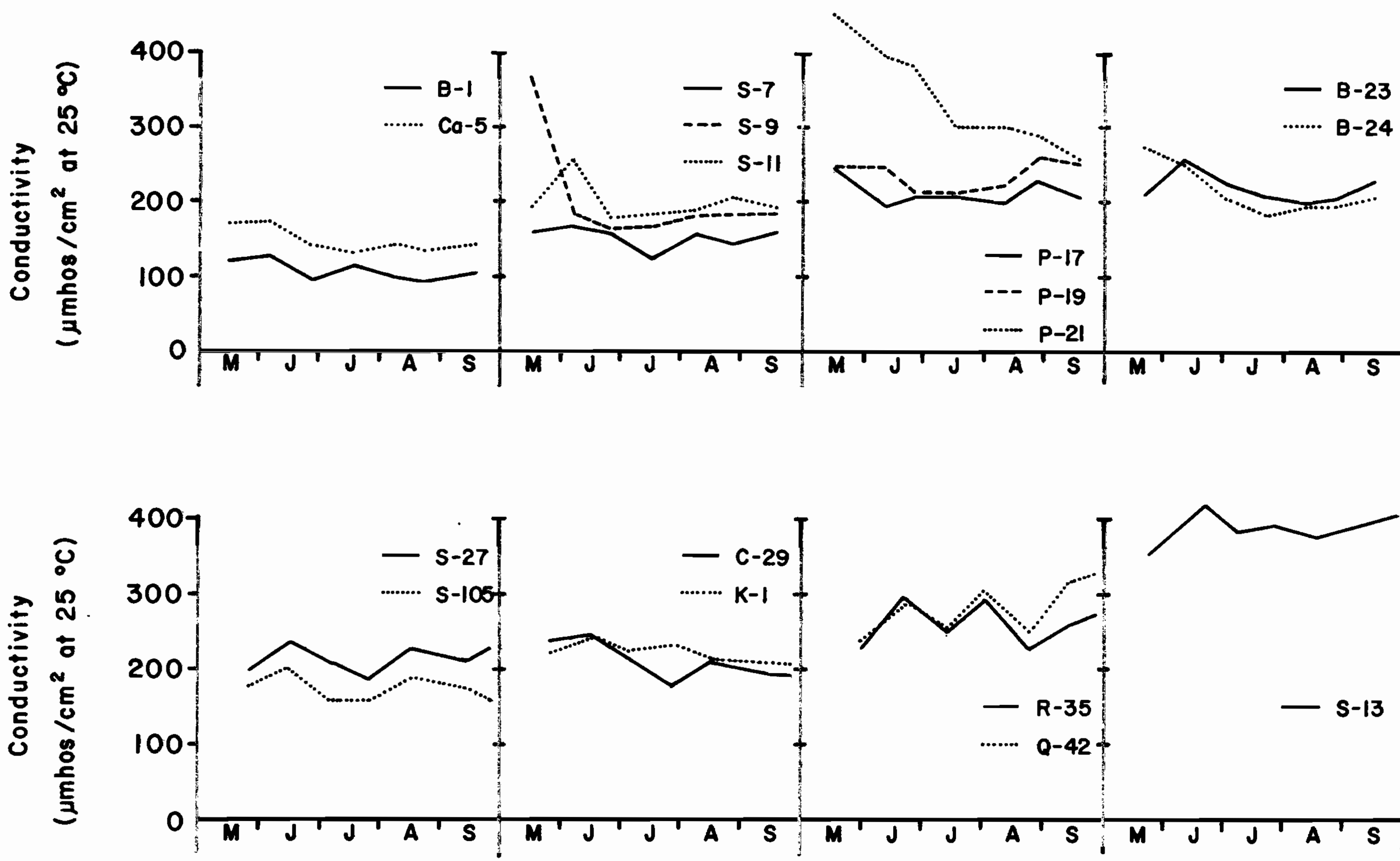

FIG. 15 Variations in conductivity (μmhos/cm^2 at 25°C) in the Kawartha Lakes from May to September, 1972, in surface waters.

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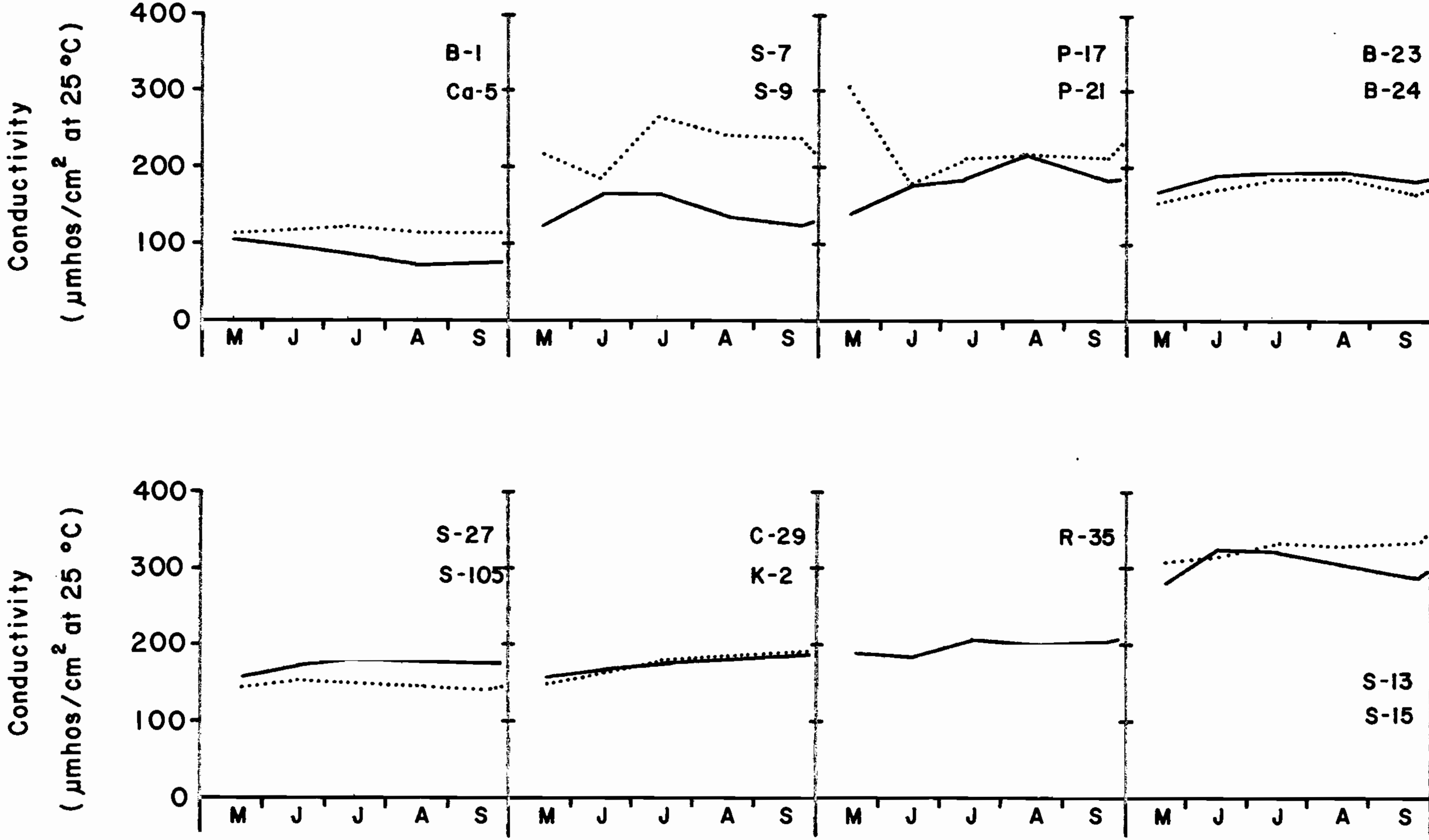

FIG. 16 Variations in conductivity (μmhos/cm^2 at 25°C) in the Kawartha Lakes from May to September, 1976, in surface waters.

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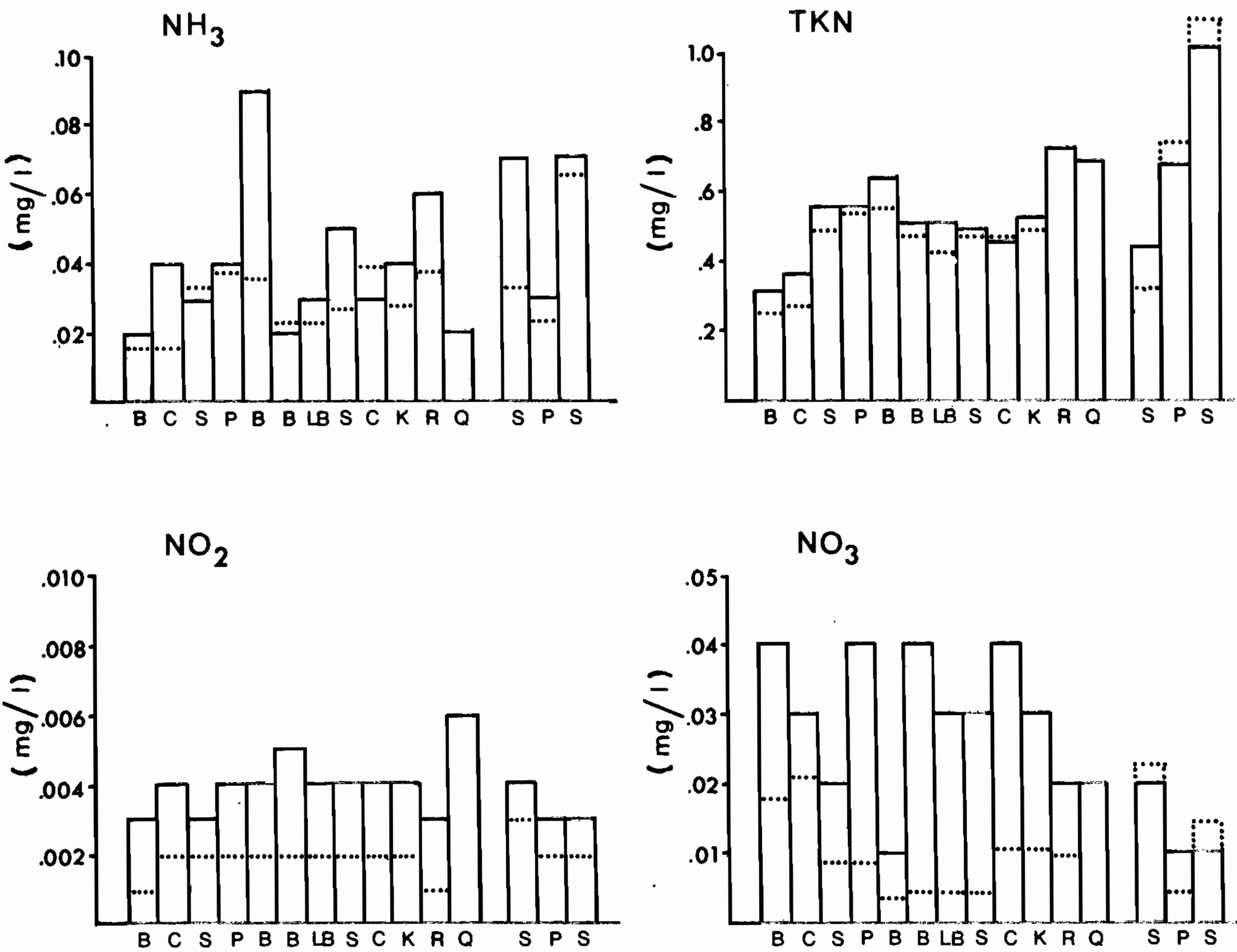

FIG. 17 Mean nitrogen concentrations (mg/l) in the surface waters of the Kawartha Lakes in 1972 (—) and 1976 (·····).

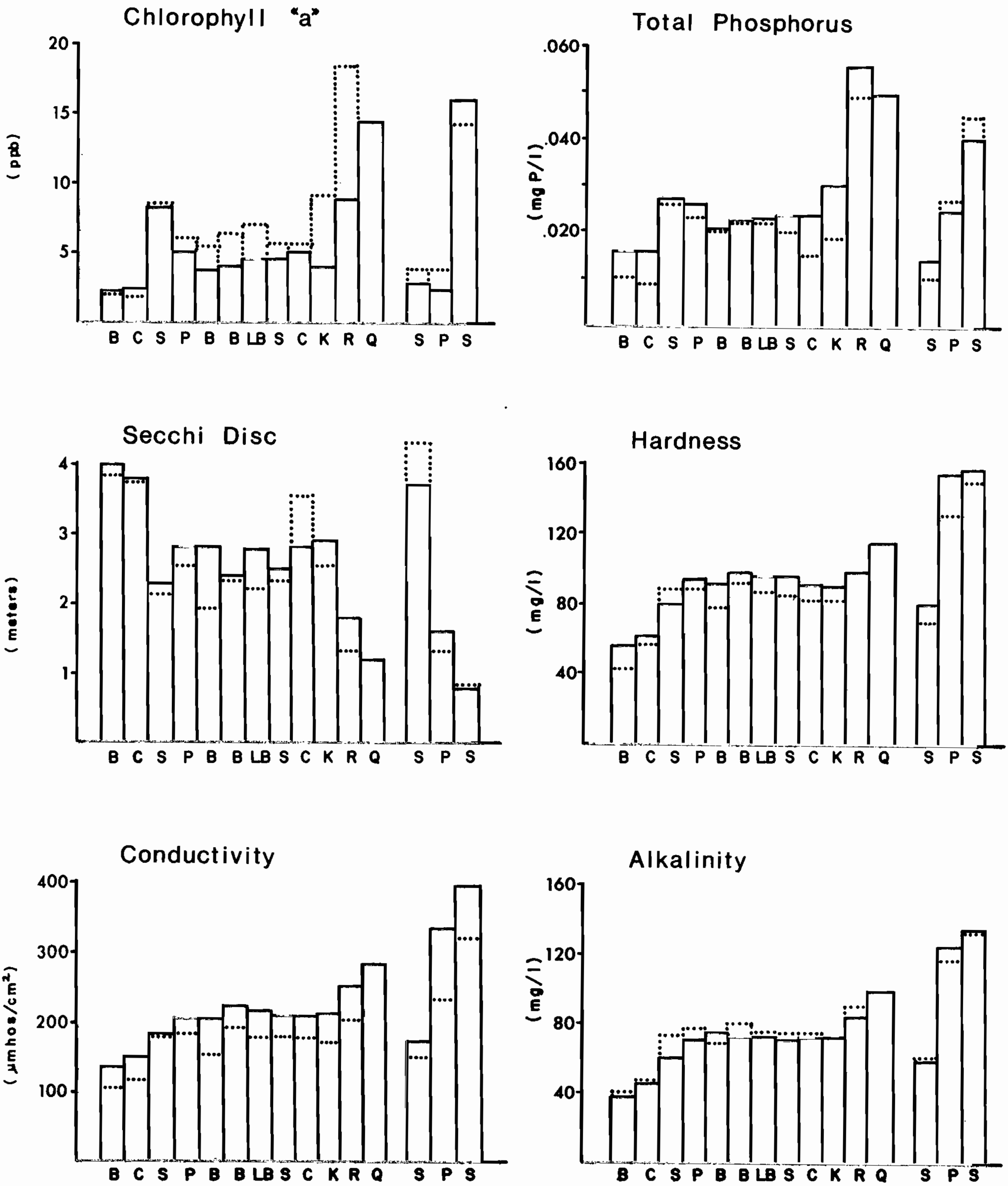

FIG. 18 Seasonal means for chlorophyll a (ppb), total phosphorus (mgP/l), secchi disc(m), hardness (mg/l), conductivity (µmhos/cm²), and alkalinity (mg/l), in the Kawartha Lakes in 1972 (—) and 1976 (·····).

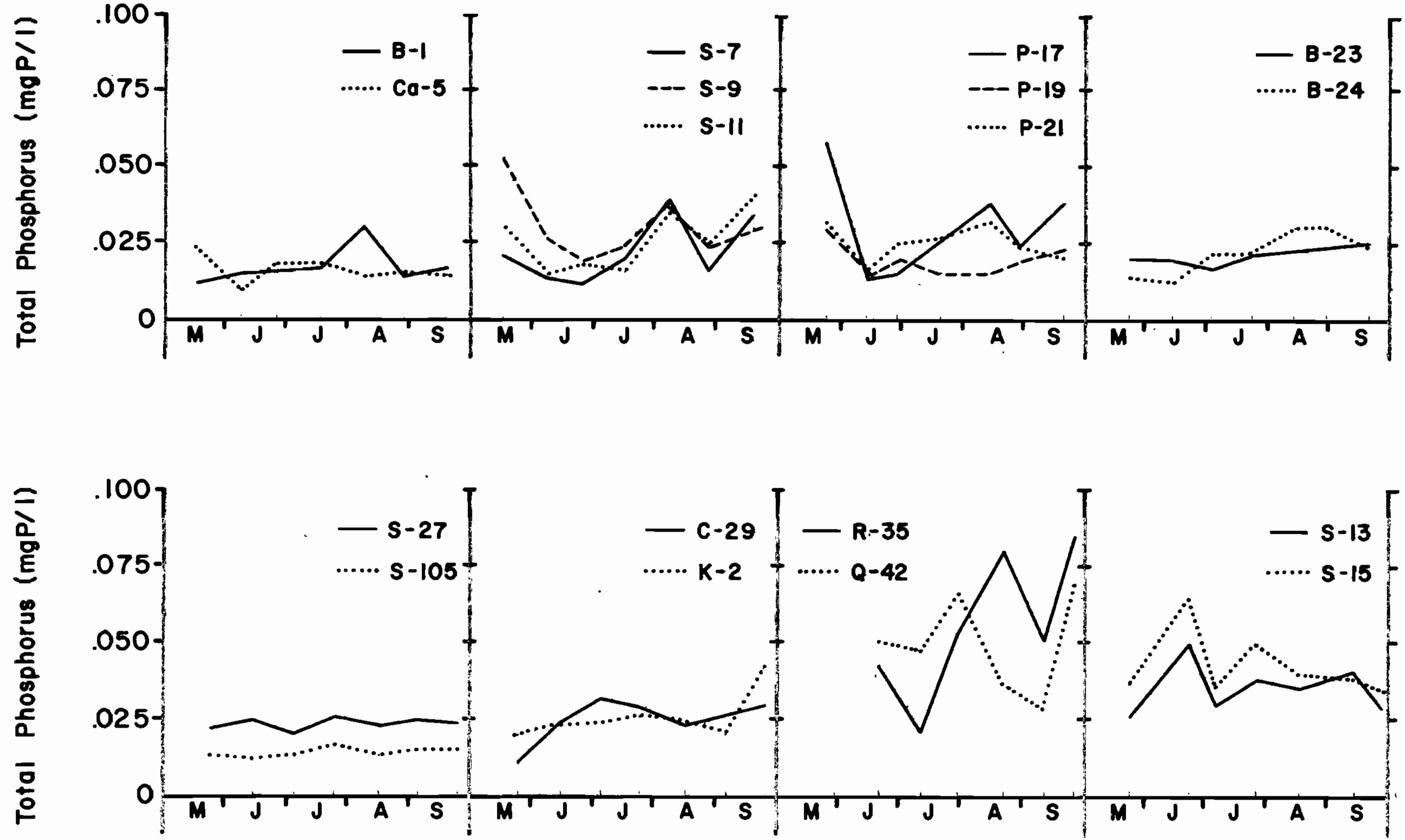

FIG. 19 Variations in total phosphorus (mgP/l) in the Kawartha Lakes from May to September, 1972, in surface waters.

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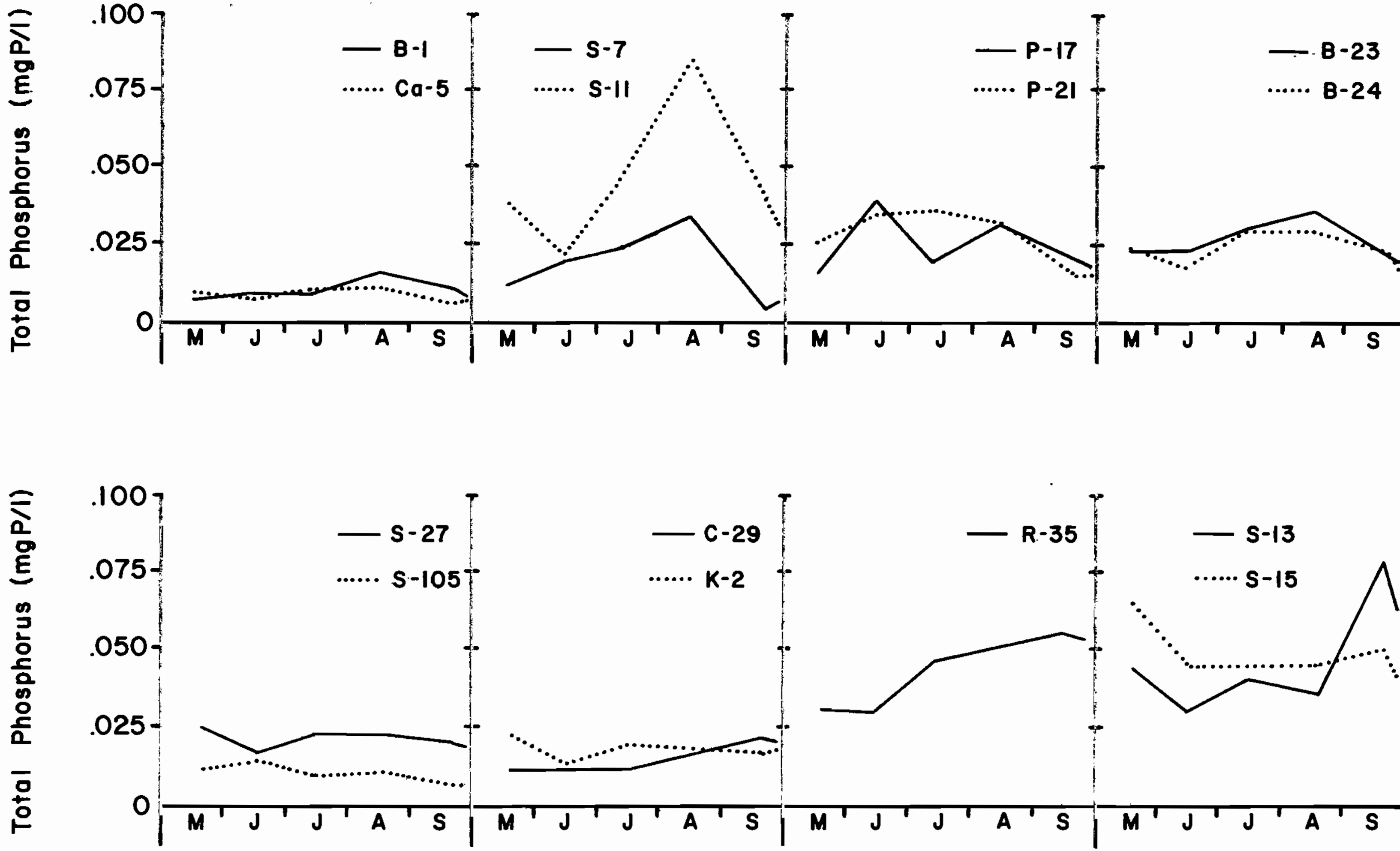

FIG. 20 Variations in total phosphorus (mgP/l) in the Kawartha Lakes from May to September, 1976, in surface waters.

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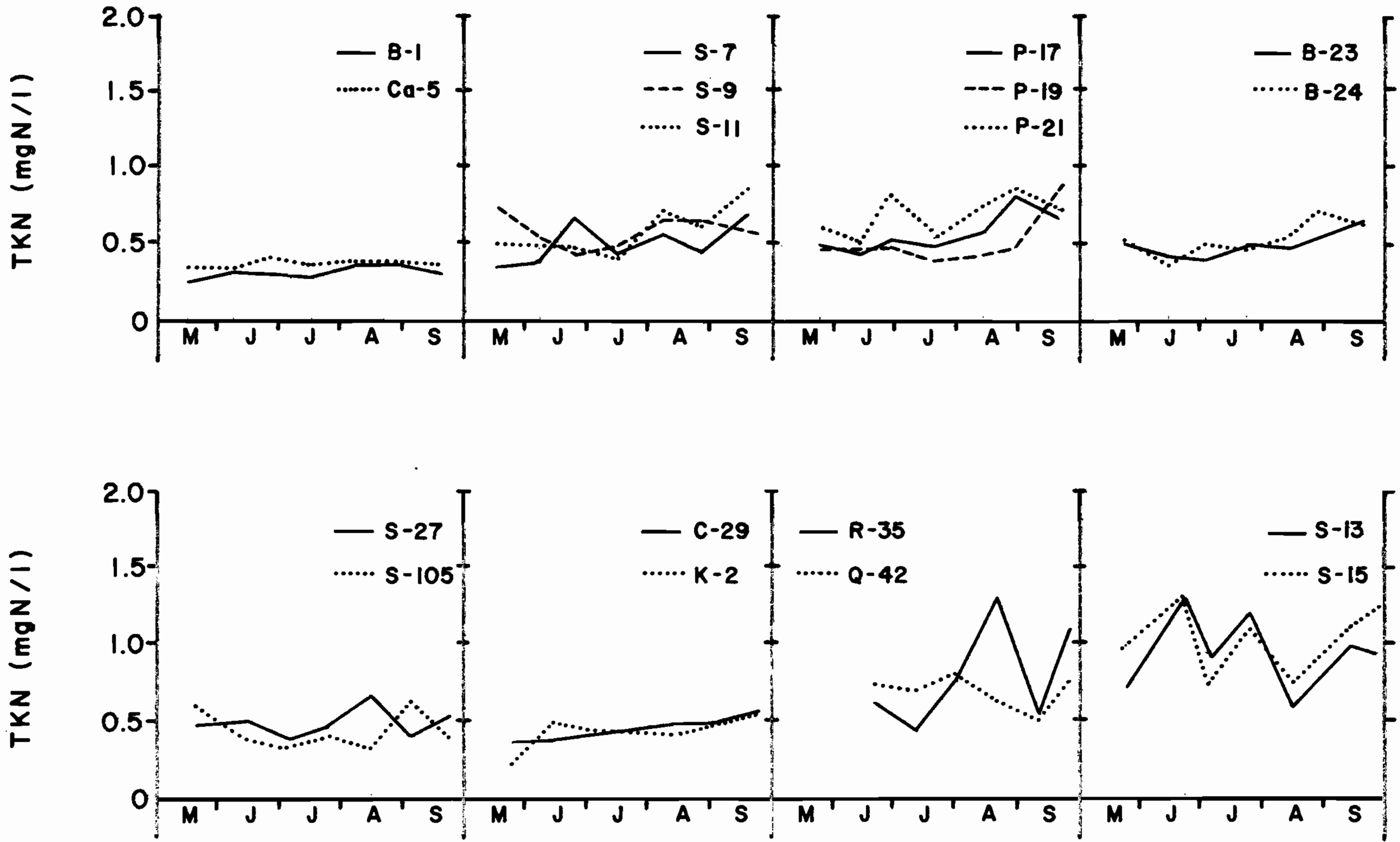

FIG. 21 Variations in total Kjeldahl nitrogen (mg N/l) in the Kawartha Lakes from May to September, 1972, in surface waters.

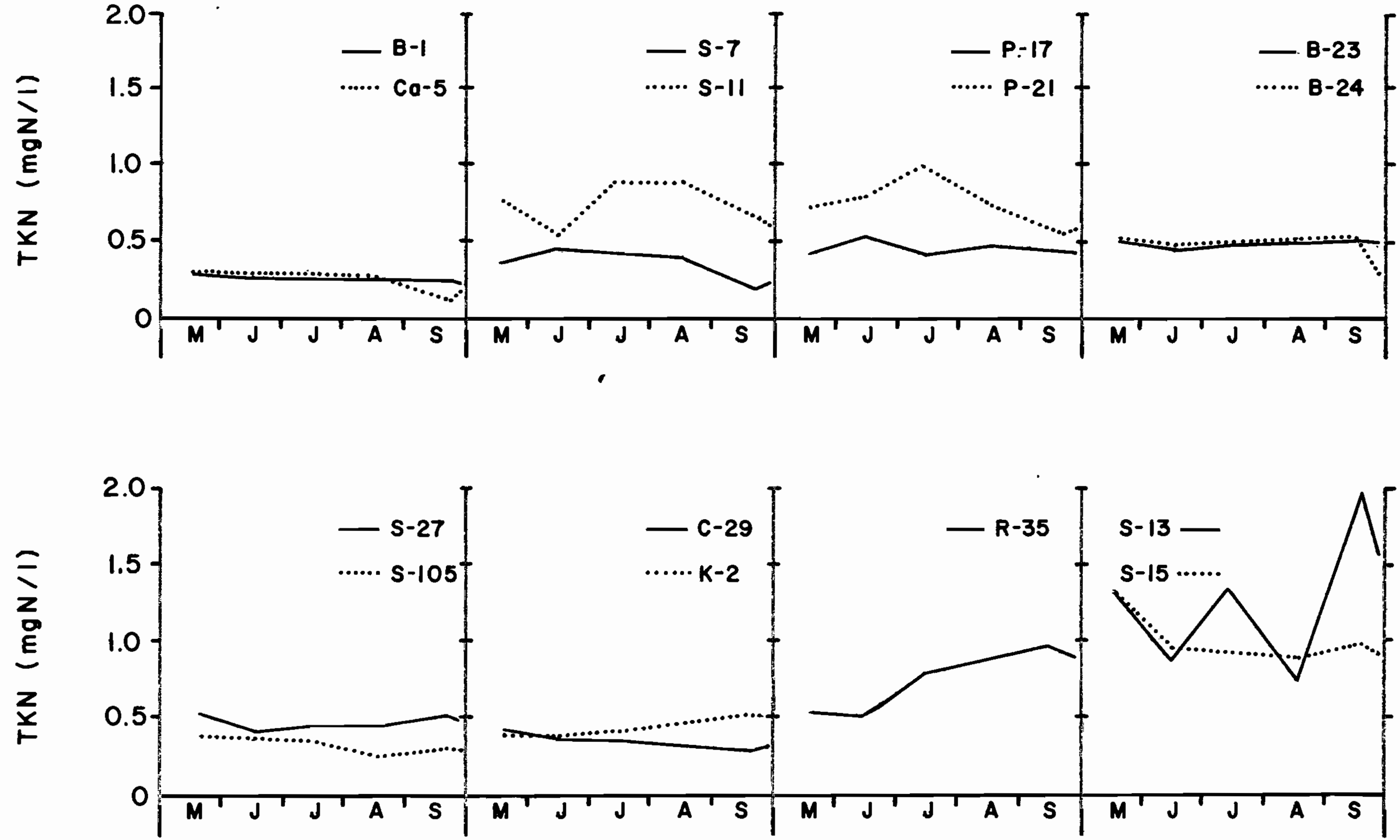

FIG. 22 Variations in total Kjeldahl nitrogen (mgN/l) in the Kawartha Lakes from May to September, 1976, in surface waters.

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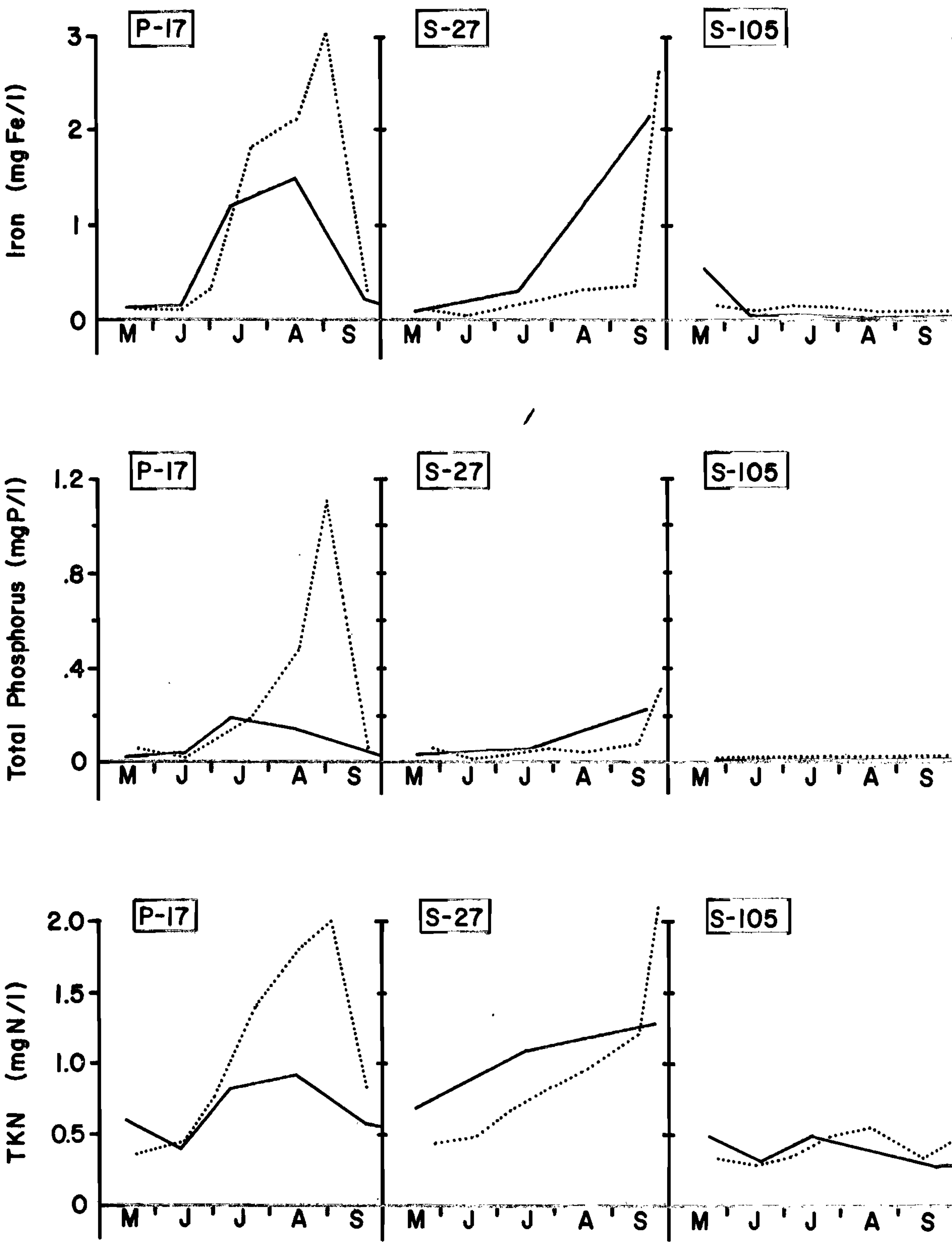

FIG.23 Bottom water accumulation of iron (mg Fe/l), total phosphorus (mg P/l), and total kjeldahl nitrogen (mg N/l) at three deep-water Kawartha Lake stations, from May to September, 1972 (......) and 1976 (—).

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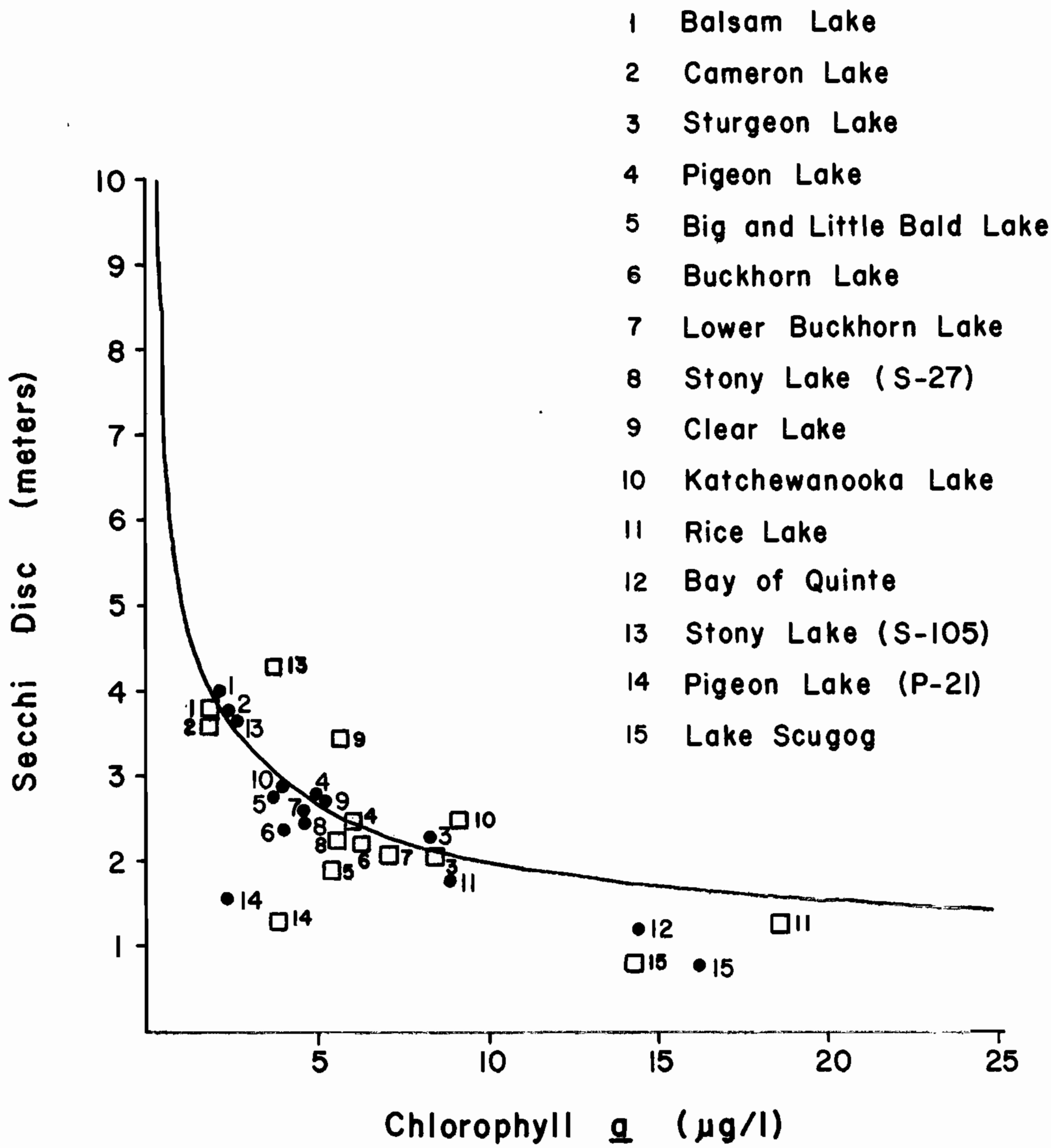

FIG.24 The relationship between chlorophyll a (µg/l) and secchi disc (m), including summer means for the Kawartha Lakes sampled in 1972 (●) and 1976 (□).

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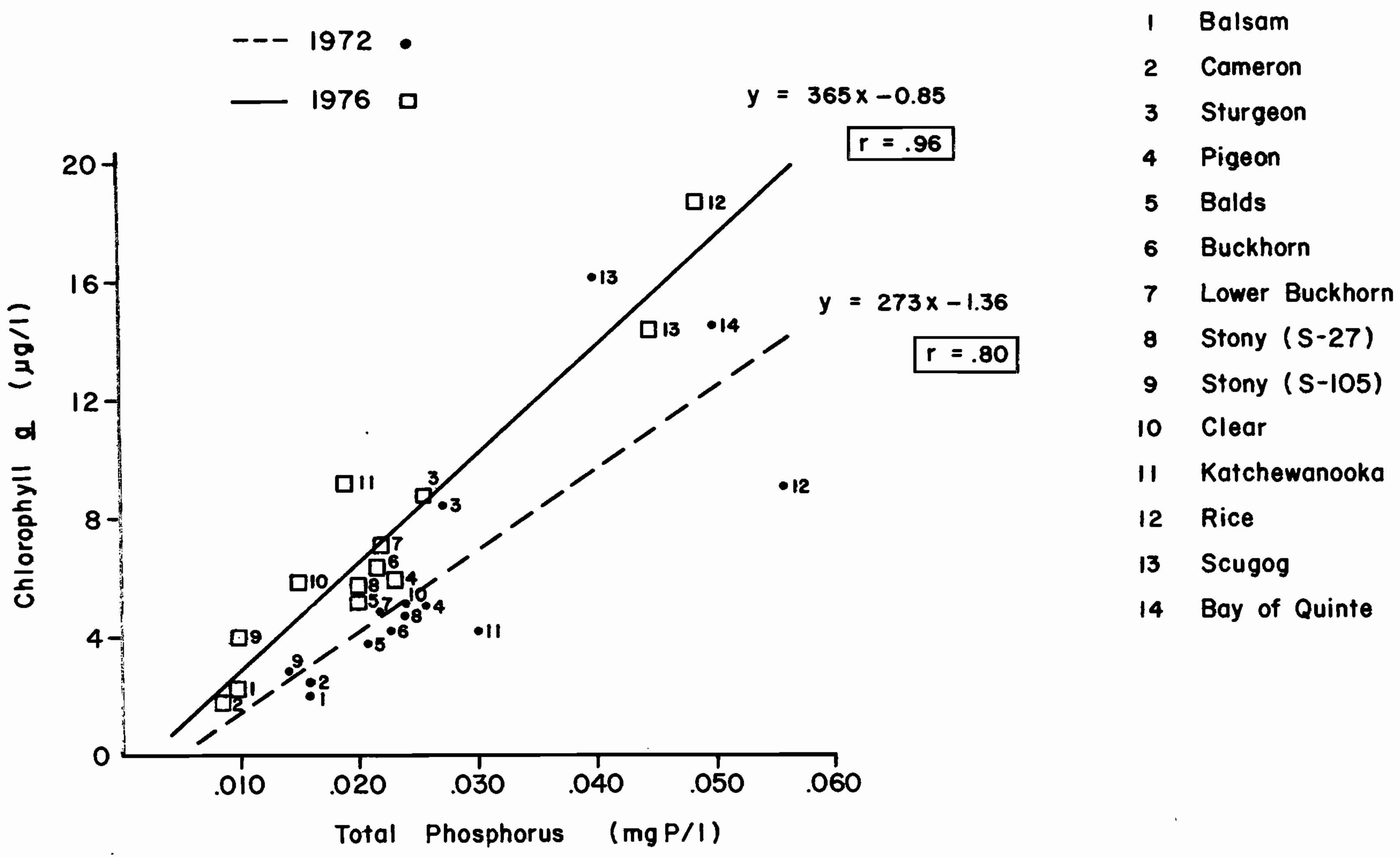

FIG. 25 The relationship between total phosphorus and chlorophyll a in the Kawartha Lakes in 1972 and 1976.

CHAPTER 2

THE PHYTOPLANKTON OF THE KAWARTHA LAKES

(1972 and 1976)

Prepared by

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Limnology and Toxicity Section
Ontario Ministry of the Environment
November, 1976.

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LIST OF FIGURES

INTRODUCTION

The value of regional studies of phytoplankton and limnology has been recognized for about 50 years (Pearsall 1921; Naumann 1929). These early works demonstrated that geology and land use within a lake's basin have a profound effect on the phytoplankton, and changes in phytoplankton biomass and composition often result from changes in mineral and nutrient inputs to the lake from its surroundings.

Several of the more recent regional studies of phytoplankton (Willen 1962; Sparling and Nalewajko 1970; Olrik 1973; Gorham et al 1974; Tarapchak 1974) have not included seasonal differences in phytoplankton density and taxonomic composition owing to inadequate sampling programmes (in some cases only one sample from each lake). Also, important physical/chemical data are sometimes lacking and consequently probable relationships between phytoplankton and other limnological components of the lake system, which may have predictive value in other lake systems can't be determined.

With the exception of the Federal Government's investigations of phytoplankton in the Experimental Lakes Area of northwestern Ontario (Kling and Holmgren 1972), comprehensive regional studies of Ontario lakes and their phytoplankton communities have not been done.

The following account of the phytoplankton of the Kawartha Lakes is an attempt to highlight important differences (and similarities) in the phytoplankton of the lakes with a view to characterizing lake trophic state and providing some information about factors controlling density and taxonomic composition of the phytoplankton in the lakes of the Kawartha system. Additionally, the data provide essential background information prior to the implementation of phosphorus removal programmes at major municipalities discharging treated sewage wastes to lakes of the Kawartha system.

METHODS

Phytoplankton samples were collected as composites of the euphotic zones (between surface and twice the depth of the Secchi disc visibility) at approximately monthly intervals between late May and early October of 1972 and were analyzed from 27 of the 46 sampling stations established for limnological reconnaissance (Figure 1).

Samples were fixed immediately after collection with Lugol's iodine and identification and enumeration were carried out with inverted microscopes after concentration by sedimentation. Phytoplankton biomass was expressed as cell volume by an approximate comparison of the cells to geometric objects of known volume.

Most of the phytoplankton samples were analyzed by J. Beaver, M. Gordon, C. Hammett, and L. Heintsch-Harris. Mrs. L. Heintsch-Harris and Miss C. Babuska summarized many of the data.

RESULTS AND DISCUSSION

(a) Total Phytoplankton Biomass

A great range in phytoplankton biomass existed throughout the Kawartha Lakes system, with generally low algal densities in lakes with little or no agricultural activity in their drainage basins, with a low density of human habitation and receiving predominantly dilute, nutrient-poor runoff waters from the Precambrian Shield. This group included Balsam, Cameron, Big Bald and Little Bald Lakes and the deep eastern basin of Stony Lake which had low average phytoplankton biomass values ranging from 0.5 to 1.1 mm^3/l (Table 1) and are comparable to the densities found from Precambrian Shield lakes of northwestern Ontario (Kling and Holmgren 1972).

In contrast, several of the Kawartha Lakes south of the Precambrian Shield located on soils derived from Ordovician sedimentary rock, were characterized by much higher densities of phytoplankton, with two sub-groupings identified. Phytoplankton biomass was especially high in those parts of the system receiving nutrients in treated municipal sewage discharges from Port Perry, Lindsay and Peterborough. The resultant average biomasses in Scugog, Sturgeon and Rice Lakes ranged from 4.8 to 23.6 mm^3/l (Table 1) and indicate decidedly eutrophic states which are comparable to the most eutrophic inshore areas of the Laurentian Great Lakes such as Lake Erie's Western Basin, Lake Huron's Saginaw Bay and Penetang Bay (of Georgian Bay) and Lake Ontario's Bay of Quinte (Munawar and Munawar 1975; Nicholls et al. 1976; Nicholls and Carney 1975).

Additionally, Pigeon, Chemung, Clear, Stony (west basin) and Katchiwanooka Lakes comprise an intermediate group of lakes (meso-eutrophic) receiving drainage from both Precambrian hardrock and Ordovician sedimentary areas and which are characterized by moderate densities of phytoplankton ranging from 1.6 to 3.3 mm^3/l (Table 1).

The relations between standing crop of algae in the Kawartha Lakes and the geological and edaphological character of the surrounding landscape are remarkably similar to those in the English Lake District (Great Britain). Pearsall (1921) found the poorly productive English Lakes were surrounded by rocky land with a low percentage of cultivable area, while the productive lakes were those that were silted and located in more productive agricultural areas. Gorham et al. (1974) developed further Pearsall's (loc. cit.) theories by demonstrating that the fertile lakes were richer in dissolved ions and that a strong correlation existed between algal standing crop and the percentage of the drainage basin under cultivation.

It is suggested that only a small portion of the observed increased algal biomass of lakes in agricultural watersheds is related directly to agricultural activities since sedimentary soils typical of the southeastern Kawartha system are very efficient in their retention of fertilizer phosphorus (Webber and Elrick 1967; Black 1970; MacLean and MacDonald 1973). A more reasonable explanation is that the factors contributing to favourable agricultural production (soils of adequate depth and high natural fertility) are also those providing an environment conducive to high aquatic production.

In establishing the three groups of lakes within the Kawartha system based solely upon average phytoplankton biomass data, the major influence of bedrock geology, natural soil fertility, and municipal sewage waste discharges have become apparent. Evidently, these major influences (geologic, edaphic and demographic) overlap in some parts of the Kawartha system, resulting in the intermediate or meso-eutrophic group of lakes.

Table 1: Average phytoplankton biomass of seven samples collected at approximately monthly intervals between late May and early October of 1972 at 27 sampling locations in the Kawartha-Trent system. The average percentage composition (by Class) is also indicated and is keyed as follows: Bacil - Bacillariophyceae; Cyano - Cyanophyceae; Chloro - Chlorophyceae; Chryso - Chrysophyceae; Crypto - Chrysophyceae; Crypto - Cryptophyceae; Dino - Dinophyceae.

Lake Station	Total Phytoplankton (mm^3/ℓ)	Bacil	Cyano	Chloro	Chryso (percent)	Crypto	Dino
Balsam Lake							
B-1	0.7	29	6	5	32	24	3
B-2	0.5	31	11	6	29	21	2
B-3	1.1	34	6	5	32	16	6
Cameron Lake							
C-5	0.5	33	11	4	22	30	1
Scugog Lake							
S-13	15.4	29	42	12	13	2	2
S-15	23.6	36	40	10	6	1	12
Sturgeon Lake							
S-7	2.7	45	21	2	15	13	4
S-9	5.4	50	25	5	10	9	0.5
S-10	4.8	40	44	1	6	9	0.3
Pigeon Lake							
P-16	2.7	48	39	2	3	5	0.3
P-21	0.6	20	21	13	19	22	4
Little Bald Lake							
P-18	1.0	9	22	5	33	27	4
Big Bald Lake							
P-19	1.0	41	10	3	25	16	5
Upper Buckhorn Lake							
B-23	2.4	59	20	3	9	7	1
Lower Buckhorn Lake							
B-24	3.3	63	17	3	8	8	1
B-25	3.3	61	19	3	5	9	2
Chemung Lake							
C-2	2.2	39	28	6	14	6	7
Stony Lake							
S-27	2.7	56	24	2	10	5	2
S-105	0.8	20	18	5	21	26	10
Clear Lake							
C-29	2.1	46	23	3	6	22	1
Katchiwanooka Lake							
K-2	1.6	47	27	7	6	13	1
Little Lake							
O-31	3.0	37	24	5	9	13	10
Rice Lake							
R-33	11.8	61	27	2	1	7	2
R-35	8.7	57	25	4	2	4	9
Seymore Lake							
T-37	7.4	60	23	4	1	6	6
Trent River							
T-40	4.9	69	17	6	2	5	1
Upper Bay of Quinte							
Q-42	3.3	55	14	16	3	8	1

Although other factors must interact with these major influences identified above, factors such as lake basin morphometry and nutrient input from faulty cottage waste treatment systems are apparently masked by the more important major influences. However, this is not without exception. For example, southern Pigeon Lake (Station P-21) is located in the more fertile soils south of the Precambrian Shield. Average phytoplankton biomass (0.6 mm^3/l) is similar to that found in the softer waters of the Shield where nutrient concentrations are far lower. Southern Pigeon Lake is very shallow (1.2m) and is heavily infested with macrophytes (see Chapter 5 of Vol. III) which undoubtedly interfere with phytoplankton growth, either by successfully competing for light and nutrients or by some direct inhibitory mechanism (Fitzgerald 1969) and thereby precludes, as major determinants of phytoplankton biomass, the influences of geologic and edaphic characteristics of the drainage basin.

A similar broad (but overlapping) categorization of the Kawartha Lakes into three groups of lakes (meso-oligotrophic, meso-eutrophic and highly eutrophic) can be obtained from the hyperbolic relationship between lake water transparency (Secchi disc visibility) and chlorophyll a concentration (Figure 2) as has been suggested by Dobson et al. (1974) for the Laurentian Great Lakes and by Dillon and Rigler (1975) for inland Ontario Lakes. However, it should be emphasized that measurements of chlorophyll a provide only an approximate index of phytoplankton biomass and it is noteworthy that for the Kawartha Lakes data the relationship between phytoplankton cell volume and Secchi disc visibility is better defined than the chlorophyll a - Secchi disc relationship (Figure 2).

b) Composition

Those lakes of the Kawartha system with high phytoplankton densities were distinctly different in taxonomic composition from those lakes supporting only low phytoplankton biomass. The important differences are best illustrated by comparing data from three eutrophic sites (S-9, S-15 and R-35) with three meso-oligotrophic locations (B-2, P-19 and S-105). The most notable differences between the two "groups" of lakes relate to the strong representation by Bacillariophyceae (diatoms) and Cyanophyceae (blue-green algae) at the eutrophic sites (Figure 3) and the more equitable distribution of all Classes at the meso-oligotrophic locations (Figure 4).

Although representation by blue-green algae was substantial in the meso-oligotrophic lakes during the mid-to-late summer period (Figure 4), total biomass of the group was low; however, the less obnoxious blue-green algae Chroococcus and Aphanothece were more important at the upper lake locations than at the eutrophic sites where the bloom-forming species of Anabaena, Aphanizomenon, Microcystis, Oscillatoria and Lyngbya dominated the Class. Similar distinctions can be made with regard to the Bacillariophyceae, in that the taxa usually associated with eutrophic waters (Fragilaria, Tabellaria, Stephanodiscus and Melosira (esp. M. granulata and M. ambigua) were abundant throughout most of the lower Kawartha-Trent system where the Class generally contributed between 40 and 70 percent of the total phytoplankton biomass (Table 1). In contrast, the diatom genera Rhizosolenia and Cyclotella were better represented in the Upper Kawartha Lakes (Balsam, Cameron, Little and Big Bald Lakes and Stony Lake, eastern basin). These findings are consistent with the known ecology of the above mentioned taxa in other lakes of Ontario (Schindler and Nighswander 1970; Kling and Holmgren 1972; Michalski et al 1973, 1975; Nicholls 1976[a], 1976[b]).

Cryptophyceae, represented mainly by Rhodomonas minuta and several species of Cryptomonas were better represented in the lakes with low total phytoplankton biomass (Table 1). The ecology of the Cryptophyceae is poorly understood since the group sometimes dominates oligotrophic waters (Eloranta 1974) and sometimes, eutrophic waters (Nicholls et al. 1976).

Among the Kawartha Lakes data, there exist direct relations between the average total phytoplankton biomass and the percentage of the total phytoplankton contributed by Bacillariophyceae and Cyanophyceae; however, these relationships are not as well defined as the inverse relationship existing between total phytoplankton biomass and the percentage contribution by Chrysophyceae (Figure 5). It is generally believed that Chrysophyceae are most important in oligotrophic lakes (see for example, Kling and Holmgren 1972 or Willen 1962). This hypothesis is clearly substantiated by the Kawartha Lakes data (Figure 5 and Table 1) illustrating that lakes with low biomass of total phytoplanton have a relatively high proportion of Chrysophyceae, and conversely, lakes with high densities of total phytoplankton are poorly represented by Chrysophyceae. In addition to phytoplankton-Secchi disc and total phosphorus-phytoplankton relationships (see Section C), the phytoplankton-percentage Chrysophyceae relationship (Figure 5) offers another "tool" for the characterization of trophic state of lakes.

At those Kawartha Lake locations well represented by Chrysophyceae, Uroglena was the most important genus followed by several species of Dinobryon and Mallomonas. Contribution by the Class tended to be highest during the spring and early summer periods with the autumn phytoplankton generally poorly represented. However, at two locations (Balsam Lake, Station B-2 and Little Bald Lake, Station P-18) the highest percentage of Chrysophyceae was found during mid-August at 46% and 65%, respectively.

The blue-green algae, Microcystis, Aphanizomenon, Anabaena and Gloeotrichia are of direct concern for reasons of public health and economics. High densities of these organisms tend to float at or near the surfaces of lakes and as a result of wind action, large masses can accumulate in shoreline areas where they may present a danger to livestock and other animals ingesting the toxins excreted by these algae. Severe blooms of blue-green algae have been a common occurrence on certain of the Kawartha Lakes since at least 1949 when Provincial Government documents note that the Captain of the tug "Trent" of Ottawa noticed a bloom in Sturgeon Lake for the first time. In the period from 1948 to 1951, records have been found of 36 cattle and one dog dying as a result of drinking water from Sturgeon Lake, supposedly contaminated with toxins excreted by blue-green algae. Additionally, in late August of 1951, five cattle were reported killed at Fiddler's Bay of Clear Lake from similar causes (Neil 1957). Although there are no recent reports of such deaths to animals in the Kawartha Lakes, blue-green algae are still a problem and enquiries relative to excessive shoreline accumulations of algae are made of Ministry of the Environment staff every summer by concerned cottagers and residents on several of the Kawartha Lakes.

Sampling of inshore areas was not undertaken during this study, but measurements of blue-green algal densities at mid-lake locations provide some indication of potential accumulation in inshore and embayment areas. For example, on September 20, 1972, Anabaena spp. contributed 84% of the total phytoplankton biomass in Sturgeon Lake (Station S-10) at 13.0 mm^3/l, and at 3.8 mm^3/l on September 12, Microcystis spp. contributed 30% of the total phytoplankton biomass in Seymore Lake (T-37).

Another noteworthy inclusion in a discussion of blue-green algae relates to the presence of Raphidiopsis mediterranea at several of the eutrophic Kawartha-Trent sampling locations. This alga has only recently been reported from North America for the first time (Gerrath and Nicholls, 1975), but has since been found in Lake Ontario's Bay of Quinte, Penetang Bay of Lake Huron, Dow's Lake (Ottawa) and the St. Lawrence River at Brockville (Ministry of the Environment, unpublished data). The known worldwide distribution of this alga suggests that it is restricted to eutrophic waters and may serve as a valuable indicator of water quality improvement should it become less abundant in the Kawartha-Trent system as a result of management programmes designed to enhance water quality.

c) Phytoplankton-Nutrient Relationships

As a further reinforcement of the findings from the English Lake District (introduced in Section 'a') several authors [reviewed by Topping (1975); Fabris and Hammer (1975)] have correlated algal standing crop with total dissolved solids concentration in lakewater. Similarly, a correlation exists between the average phytoplankton biomass and the concentration of major ions in the Kawartha Lakes. It should be emphasized that phytoplankton biomass is not dependent on the dissolved ionic content "per sé" (contributed mainly by calcium, magnesium, sulphate, bicarbonate and chloride) but rather by the concentration of phosphorus (Michalski and Conroy 1973) or nitrogen and phosphorus (Schindler et al. 1973). Correlations of phytoplankton biomass on total dissolved solids apparently exist only because the total ionic content of lakewater most often provides a fundamental indication of the nutrient content.

Correlations between total phosphorus concentration and suspended chlorophyll a in lakewaters throughout the world have been well documented (reviewed by Dillon and Rigler 1974). Similarly, a correlation exists between chlorophyll a and total P data from the 27 phytoplankton sampling locations of the Kawartha Lakes system (Figure 6). However, the relationship is much better defined for the majority of data when phytoplankton cell volume replaces chlorophyll a in the regression (Figure 6) indicating again that chlorophyll a data provide only a rough index of algal biomass.

In view of rather poorly defined relationships between phytoplankton biomass and other plant nutrients, the strong correlation with total phosphorus also demonstrates the importance of controlling phosphorus input to the Kawartha Lakes if improved water clarity and decreased algal densities are to materialize.

Since an inverse relationship exists between total phytoplankton biomass and the portion of that total contributed by Chrysophyceae, and in view of the total P - total phytoplankton relationship described above, it follows that there should exist an inverse relationship between total phosphorus concentration and the percentage of the total phytoplankton biomass contributed by Chrysophyceae (Figure 7). This relationship would appear to have particular value in defining improvement in a eutrophic lake following an attempt to reclaim the lake by decreasing the phosphorus loading.

For example, prior to implementation of a P removal programme at local sewage treatment facilities during 1971, Gravenhurst Bay of Lake Muskoka had high concentrations of total P and high phytoplankton biomass represented by Chrysophyceae to the extent of less than one percent. By 1975, significant declines in total P concentration and total phytoplankton biomass had occurred and were accompanied by an increase in the representation by Chrysophyceae to 11% (Figure 7).

From the monthly samples collected during May through September of 1976, phytoplankton data from Balsam, Sturgeon, Chemung and Rice Lakes indicate no significant changes from 1972 (see table below).

AVERAGE PHYTOPLANKTON BIOMASS (mm^3/l)

Balsam Lake			Sturgeon Lake			Chemung Lake	Rice Lake	
B-1	B-2	B-3	S-7	S-9	S-10	C-2	R-33	R-35
0.5	0.6	0.7	1.8	3.4	3.7	1.6	9.4	13.4

Similarly, there has been little change yet in phosphorus concentrations in lakes downstream of sewage treatment facilities as a result of the phosphorus control programme implemented during 1975 (see Chapter 1). However, during a pilot study to remove phosphorus from Lindsay's sewage wastes, Neal (1957) demonstrated some benefits relative to decreased densities of algae in the Scugog River below Lindsay. More recent information on the phytoplankton of Gravenhurst Bay of Lake Muskoka and Lake Erie's Western Basin, clearly show that a lake's response to reduced phosphorus loadings is well defined but may take a period of several years.

In this regard, it is recommended that sampling for phytoplankton and related trophic state indicators be continued in future years in Sturgeon and Rice Lakes at least (and other lakes downstream of sewage treatment facilities if possible) to define changes which may be related to the phosphorus control programme.

The relationships among total phosphorus, total phytoplankton, Secchi disc visibility and the percentage contribution by Chrysophyceae logically lead to the development of a nomogram (Figure 8) from which changes in a variety of trophic state indicators can be predicted, given a change in average lake concentration of total P (as will result from implementation of phosphorus removal programmes at sewage treatment facilities). It is suggested that declines in the average total phosphorus concentration will materialize in certain areas of the Kawartha Lakes as a result of decreased loadings of phosphorus resulting from controls initiated during 1974-75. On the basis of the empirical relationships thus far established (Figures 2, 5, 6 and 7), it is likely that decreases in total phytoplankton biomass, increases in representation by Chrysophyceae and improved water clarity will correspond to those predicted from Figure 8.

Similarly, the nomogram can be used to predict some effects of additional phosphorus input (as may result from additional housing development) providing the resultant lake concentration of phosphorus can be predicted (the data needed for these calculations i.e. total P loadings, P retention coefficient, mean depth and flushing rate of the lake, are available in Chapter VI). There remains only the simple task of translating the trophic state indices of the nomogram into expressions which have implications for lake management. These are likely to be dependent upon the designated use of the lake but in most cases will probably include the aesthetic considerations (for swimming etc.) of algal density, lake water clarity, the likelihood of obnoxious "algal blooms" as well as the suitability of the algal composition relative to the food web of the lake, and to potential algal related taste and odour problems in private and public water supplies.

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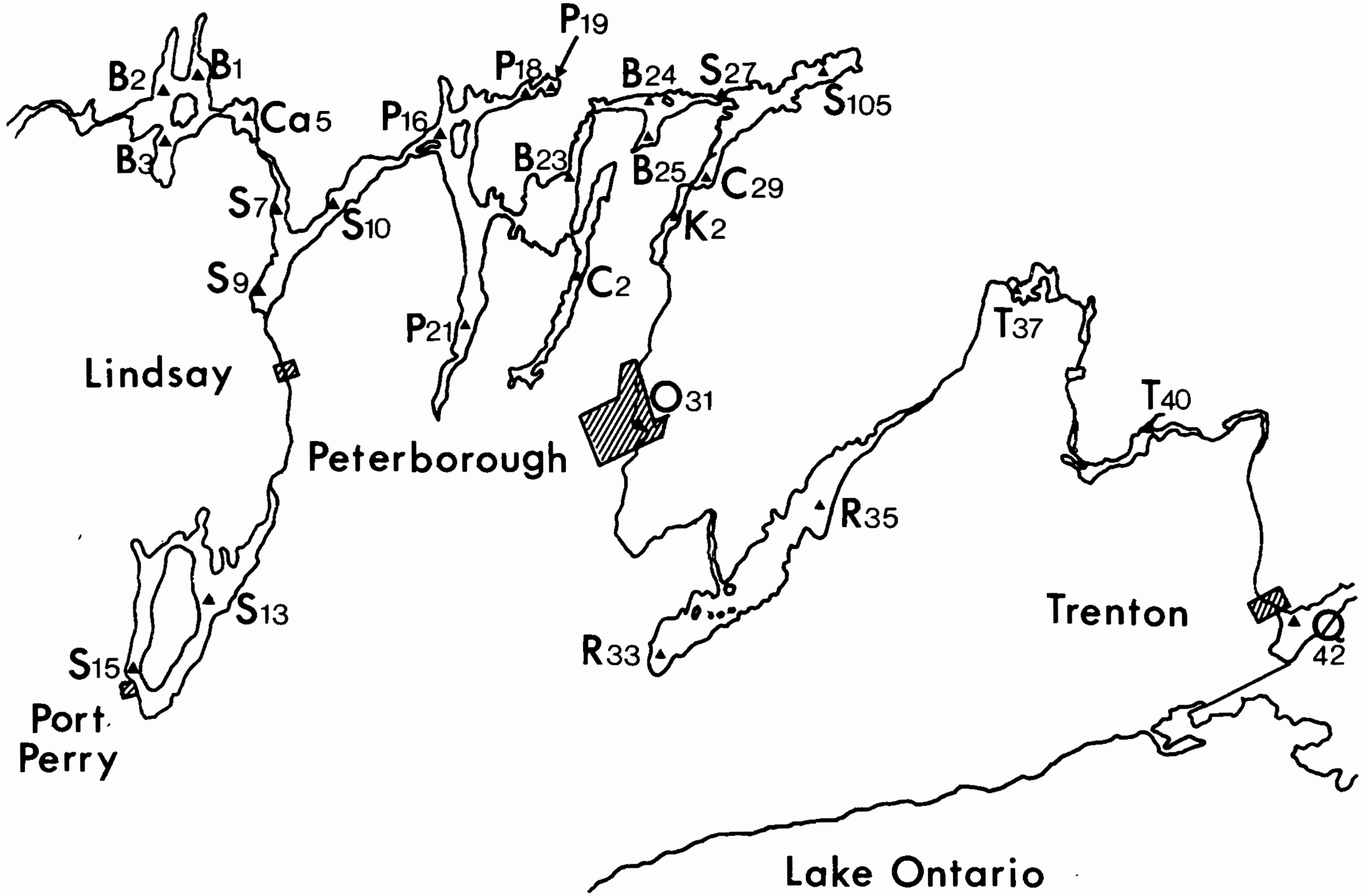

Figure 1. Map of the Kawartha Lakes - Trent River System showing locations established for phytoplankton sampling during the ice-free period of 1972.

sampling during the ice-free period of 1972.

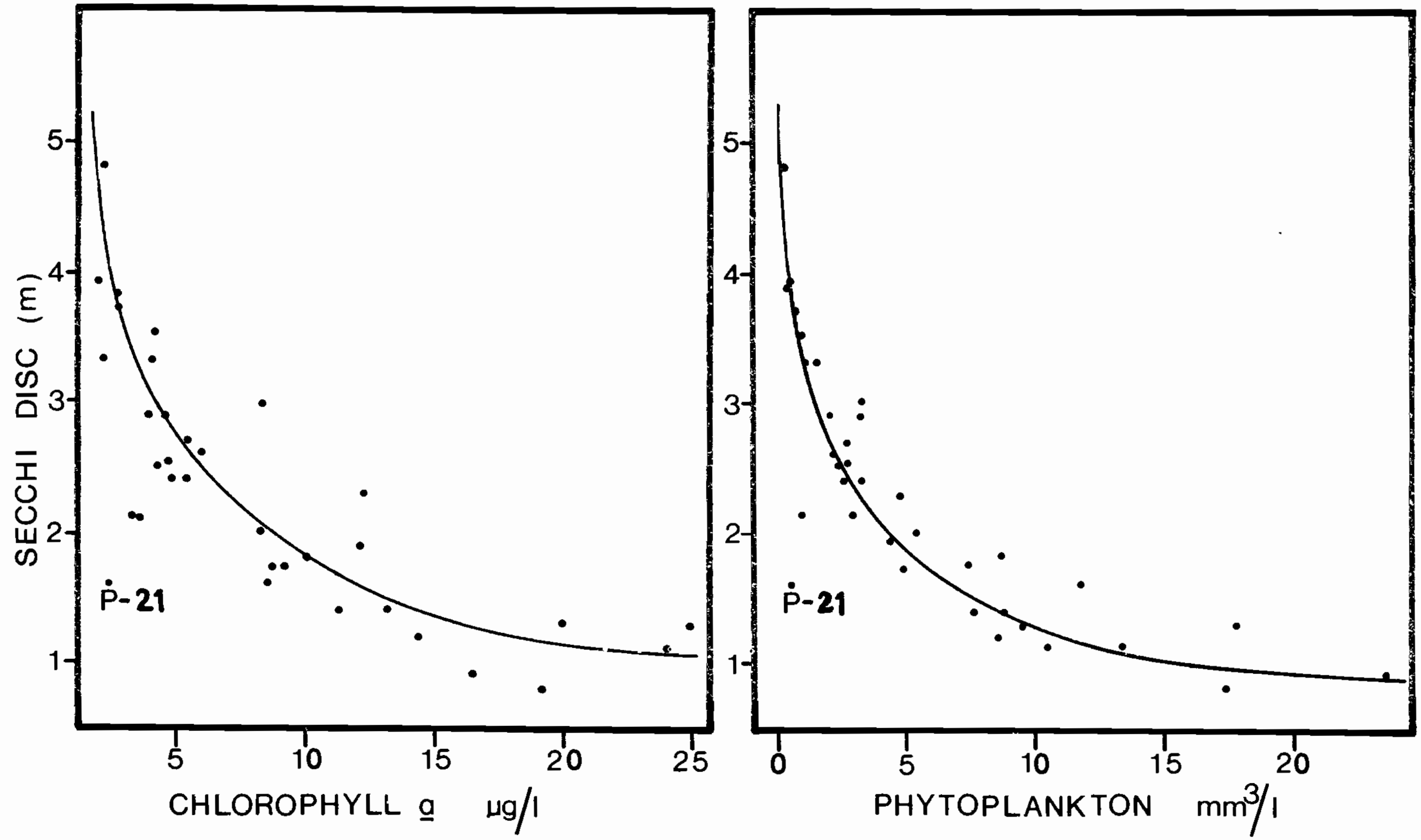

Figure 2. Relationships between chlorophyll a concentration and Secchi disc visibility and between phytoplankton cell volume and Secchi disc visibility (averages of the ice-free period) at the Kawartha-Trent sampling locations and including data from 7 "downstream" locations in the Bay of Quinte. Data from Station P-21 are a poor fit for reasons explained in the text.

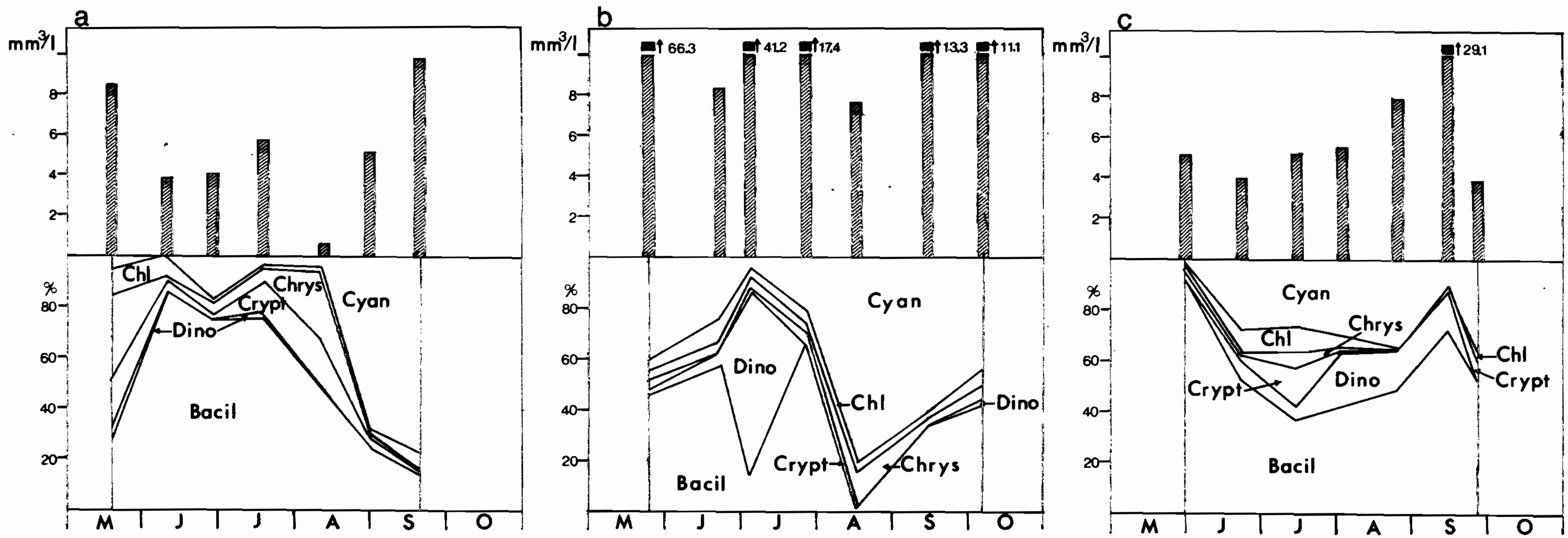

Figure 3. Seasonal distribution of total phytoplankton biomass and percentage contribution by major Classes at three highly eutrophic locations in the Kawartha-Trent System (a - Sturgeon Lake, Station S-9; b - Lake Scugog, Station S-15; c - Rice Lake, Station R-35). Keyed as follows: Cyan - Cyanophyceae; Chl - Chlorophyceae; Chrys - Chrysophyceae; Crypt - Cryptophyceae; Dino - Dinophyceae; Bacil - Bacillariophyceae.

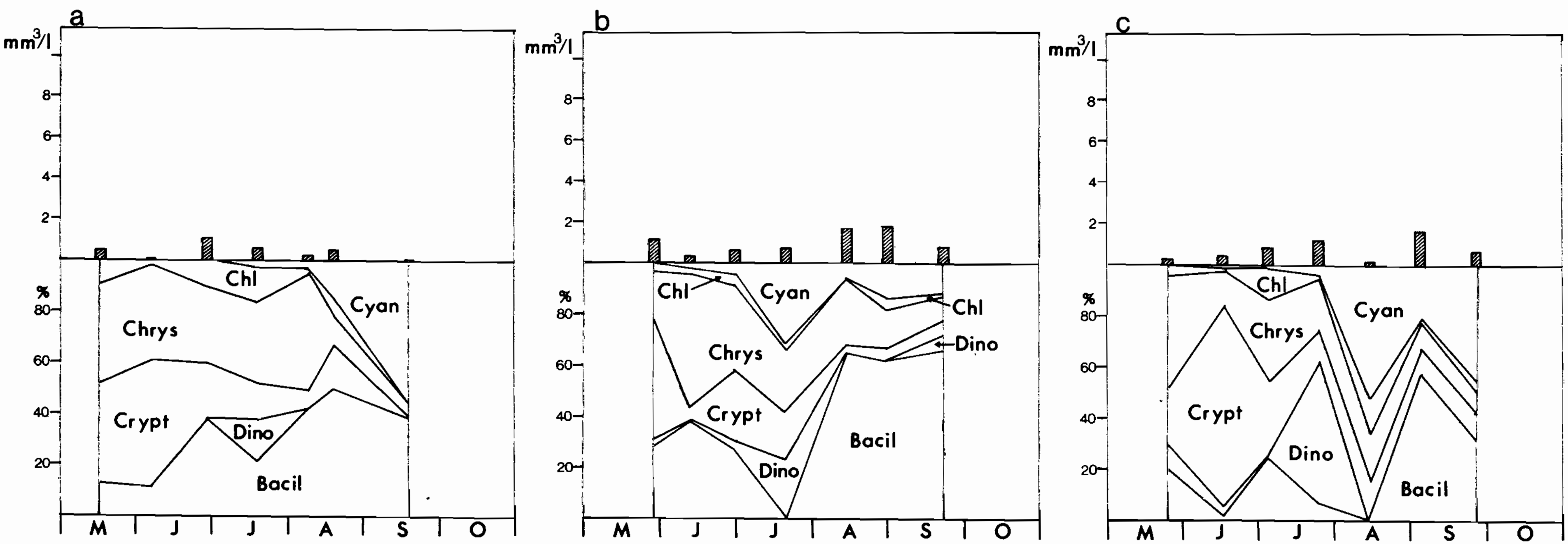

Figure 4. Seasonal distribution of total phytoplankton biomass and percentage contribution by major Classes at three meso-oligotrophic locations in the Kawartha-Trent System (a - Balsam Lake, Station B-2; b - Big Bald Lake, Station P-19; c - Stony Lake, East Basin, Station S-105). Keyed as for Figure 3.

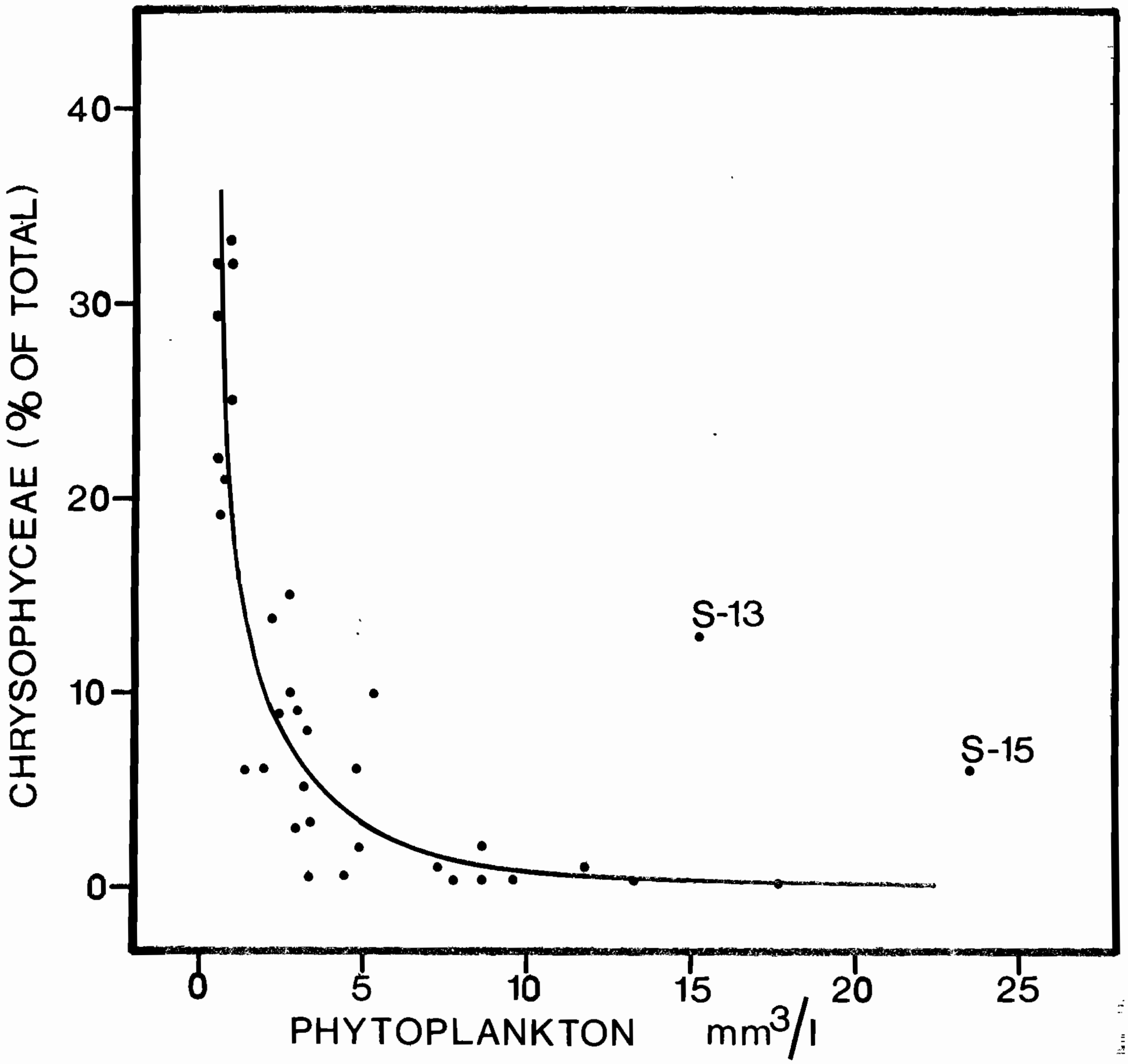

Figure 5. Relationship between average total phytoplankton biomass and the percentage of that total contributed by Chrysophyceae at the 27 Kawartha-Trent phytoplankton sampling locations and at 7 locations in the Bay of Quinte between Trenton and Lake Ontario. Reasons are not apparent why Lake Scugog data (S-13 and S-15) do not fit (as in Figures 5 and 7) yet do fit the relationship described by Figure 8. The domination of the phytoplankton of Lake Scugog by tiny Oscillatoria spp., which may have closer affinities to bacteria than algae, perhaps in some way accounts for the apparent discrepancy.

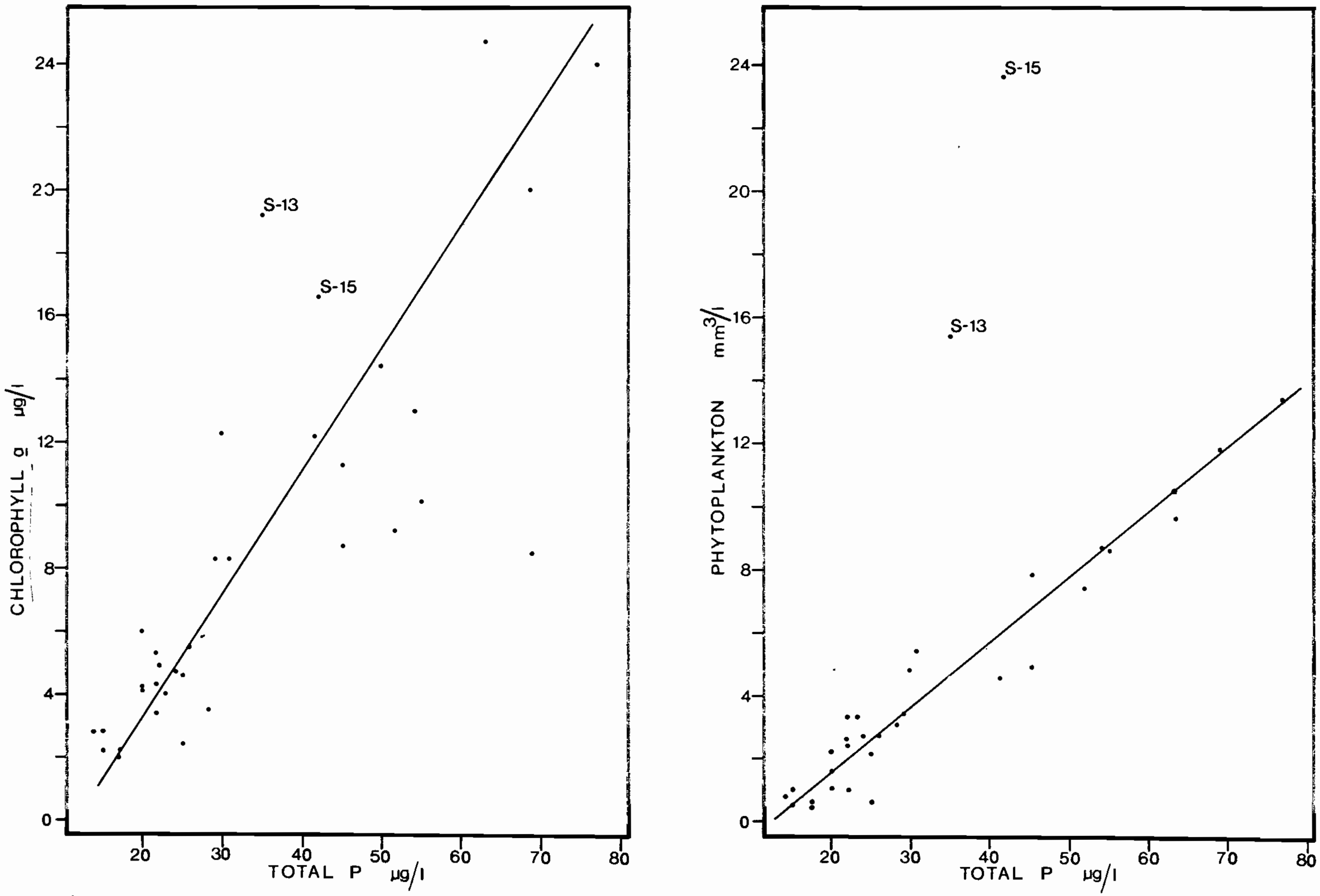

Figure 6. Relationships between average total phosphorus concentration and chlorophyll a and between total phosphorus concentration and total phytoplankton cell volume at the 27 Kawartha-Trent phytoplankton sampling locations and at 7 "downstream" locations in the Bay of Quinte between Trenton and Lake Ontario. In delineating the regression of average total P onto average phytoplankton cell volume, the noticeable outliers (S-13, S-15 and Station B - Belleville, Bay of Quinte) were ignored. Note that these three data points are within the much broader range of scatter of the total P - chlorophyll a relationship. See also the caption for Figure 5.

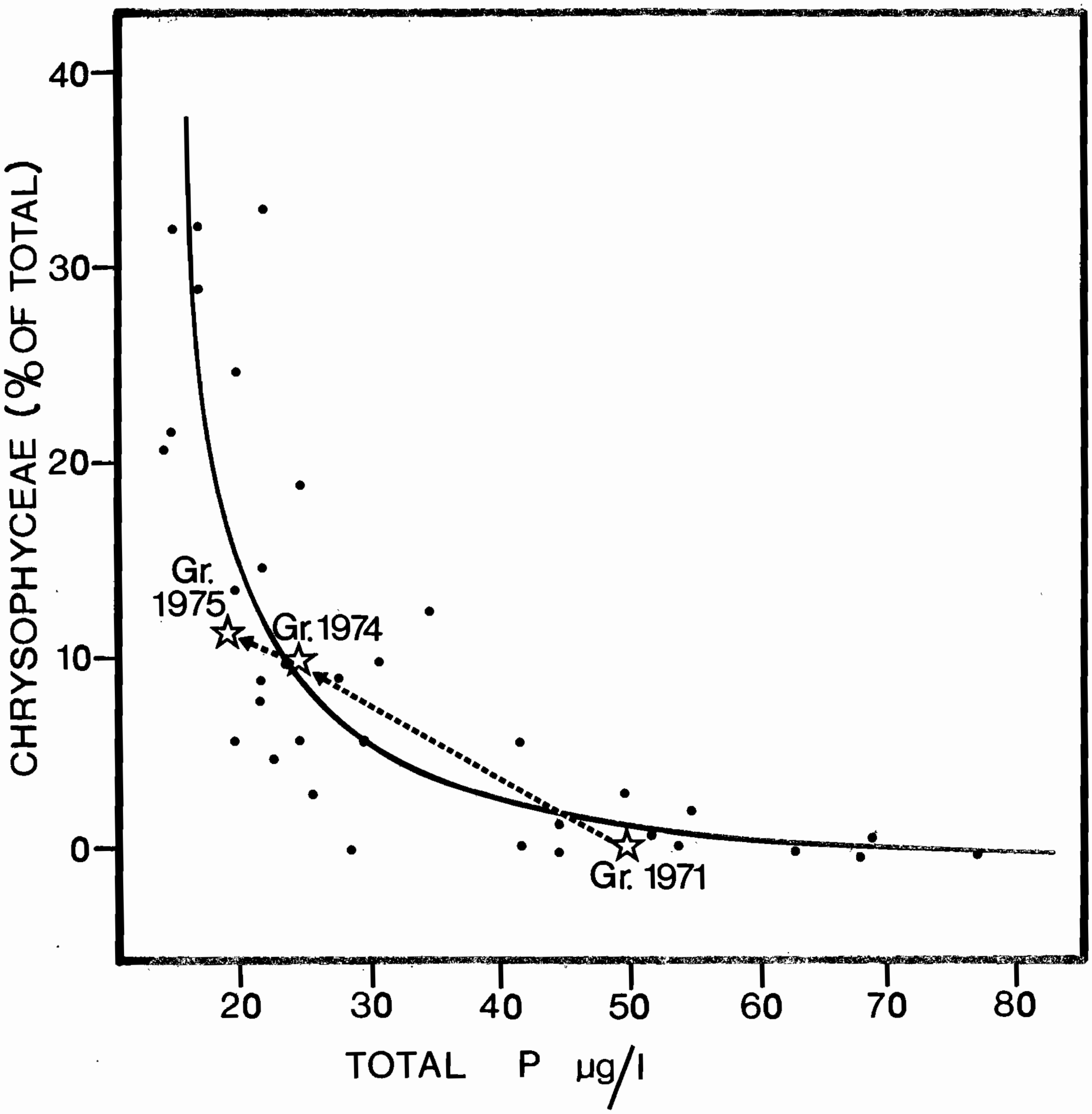

Figure 7. Relationship between average total phosphorus concentration and the percentage contribution by Chrysophyceae to the total phytoplankton biomass at the 27 Kawartha-Trent phytoplankton sampling locations and at 7 "downstream" locations in the Bay of Quinte between Trenton and Lake Ontario. Also indicated are 1971 data from Gravenhurst Bay of Lake Muskoka prior to reductions in phosphorus loading from municipal sewage treatment facilities and 1974-75 data illustrating the change resulting from implementation of a phosphorus removal programme (tertiary treatment) during 1971.

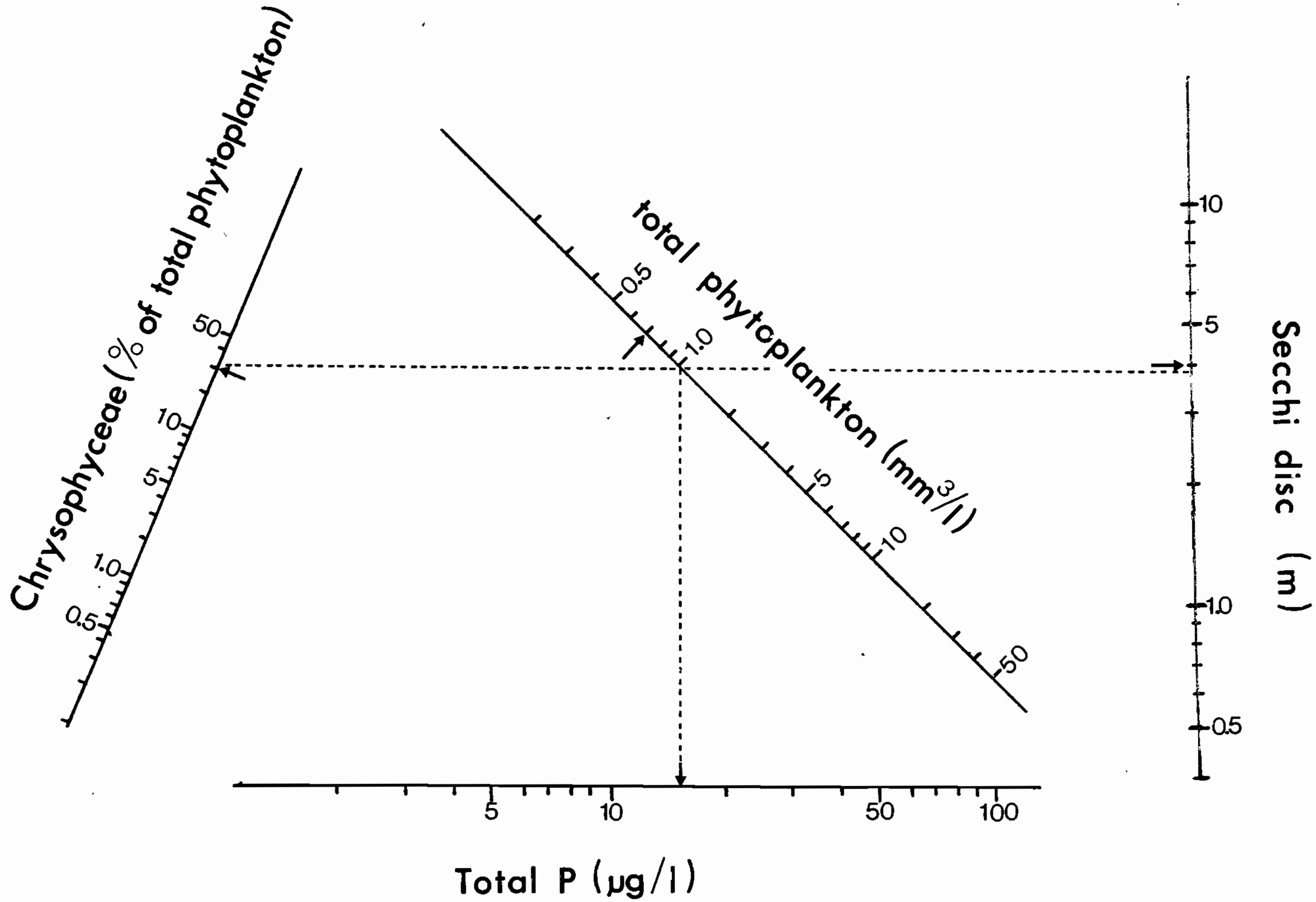

Figure 8. Nomogram prepared from data presented in Figures 2, 5, 7 and 8 facilitating intercomparisons of the most reliable trophic state indicators. Data from all of the Kawartha-Trent sampling locations (including the Bay of Quinte) generally fit the nomogram very well. To illustrate the use of the nomogram for predictive purposes, Balsam Lake average total phosphorus concentration and the resulting predicted values of total phytoplankton biomass, Chrysophyceae representation and Secchi disc visibility are indicated. The arrows indicate the measured values (average of Stations B-1, B-2 and B-3).

CHAPTER 3

THE ZOOPLANKTON OF THE KAWARTHA LAKES - 1972

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SUMMARY

The degree of eutrophication in each of the Kawartha Lakes appeared to have had a marked influence on the zooplankton communities present. Increasing eutrophy contributed to a reduction in calanoid copepod significance, an increase in cladoceran numbers, and a shift from large-bodied to small-bodied species. Crustacean densities appeared to be directly related to the quantity of phytoplankton present (measured as chlorophyll a) and the quality of phytoplankton present. Similarly zooplankton numbers were directly related to the fertility of the surrounding water (or total phosphorus content of the photic zone). Lakes were categorized according to the type of zooplankton community present and it is suggested that any shift in category will indicate a shift in water quality.

INTRODUCTION

In view of the virtual absence of prior information on the crustacean populations of the Kawartha Lakes, zooplankton samples were collected throughout the system during 1972. The following chapter presents information on zooplankton densities, community structure, and seasonal variations and considers this information in relation to the existing trophic conditions of the Kawartha Lakes. In addition, the data presented will serve as a valuable baseline for future comparisons of water quality, and provides an excellent opportunity to study the effects of different trophic levels on the zooplankton community.

METHODS

Field Methods

During the summer of 1972, plankton samples were collected from eleven of the Kawartha Lakes, plus the inner Bay of Quinte. (Chapter 1). One to five stations per lake were sampled, starting in late May and ending in early October. Each station was sampled seven times, at approximately three-week intervals, by means of a vertical net haul from one metre off the bottom, using a Wisconsin-type plankton net (with a 12 cm. upper ring diameter and #20 mesh). Samples were preserved in a 4% formaldehyde solution.

Water chemistry samples (for chlorophyll *a* and nutrient content) were taken and physical properties (temperature, dissolved gases, secchi disc) were measured on each sampling date at all the stations.

Lab Methods

Each zooplankton sample was emptied into a petri dish and examined (qualitatively and quantitatively) using a dissecting microscope with a 40X maximum magnification. In some instances (due to excessive plankton numbers) it was necessary to sub-sample. This was accomplished by diluting the original sample to 40 mls and removing 10 ml aliquots with a large-bore pipette while the sample was being shaken vigourously. To facilitate identification, a compound microscope proved useful for clarifying the more detailed taxonomic features. Taxonomic references consulted included Edmondson (1959), Brooks (1957), Czaika and Robertson (1968) and Brandlova et al (1972). Zooplankton abundance was expressed as the number of organisms/cm^2/m. Nauplii (immature copepods) and cladoceran juveniles were included.

Physical and chemical analytical procedures conform to those outlined in the Kawartha Lakes - Trent River Water Management Field Methodology (Michalski - 1972) and Standard Methods 13th Edition.

Explanation of Method

In the phytoplankton, Findenegg (1942) found that total number per unit area could be the same in oligotrophic and eutrophic lakes (because of varying depth of photic zones) but that number per unit volume was a good measure relating to trophic status. Since bacteria and detritus can serve as a major food source of zooplankton, collections were made as a vertical net haul from one meter off the bottom to ensure that animals grazing on phytoplankton in the trophogenic zone as well as animals feeding on bacteria and detritus in the tropholytic zone were sampled. Results were expressed as number of individuals/cm^2/m so that zooplankton densities in lakes of different depths could be realistically compared.

RESULTS

Zooplankton Diversity and Density

Thirty-six species of crustaceans were identified from the Kawartha Lakes (Table 1); 13 were in the order Copepoda and 23 were in the order Cladocera. The greatest diversity was found in the upper lakes, where the number of dominant species (those accounting for more than 10% of the total population) exceeded that of the lower lakes (Table 2). Proceeding down the system, from Balsam Lake to the Bay of Quinte, the percentage composition of calanoid copepods underwent a significant decrease, from 12.1% in Balsam to 0.5% in the Bay of Quinte. At the same time cladoceran composition increased from 30.3% in Balsam to 78.4% in the Bay of Quinte (Table 3).

Plankton numbers generally increased down the system from 1.1 individuals/cm^2/m in Balsam to 9.3 individuals/cm^2/m in Rice Lake (Table 3). Lake Scugog and the Bay of Quinte were notable exceptions, with lower numbers.

Species Composition

Standing stocks and various components of the zooplankton communities for each lake are illustrated in Fig. 2-7. Although there was a significant change in the relative abundance of individual species, the species composition in all the lakes was remarkably similar, except for Stony Lake (Table 4).

Of the calanoid species present in the Kawarthas, *Diaptomus oregonensis* was dominant. *Diaptomus minutus* was observed on several occasions. Calanoid composition was markedly different in Stony Lake. Several species were well represented over the entire summer, including *Limnocalanus macrurus*, *Diaptomus minutus*, and *Diaptomus oregonensis*. *Senecella calanoides* and *Epischura lacustris* were also frequently encountered.

Four species of cyclopoid copepods were prominent throughout the system; *Mesocyclops edax*, *Cyclops vernalis*, *Tropocyclops prasinus mexicanus* and *Cyclops bicuspidatus thomasi*.

Table 1: List of species and their occurrence in the Kawartha Lakes during the summer of 1972 (+++abundant, ++common, +rare).

Species Name	Stony	Bald	Balsam	Cameron	Sturgeon	Pigeon	Buckhorn	Clear	Rice	Quinte	Scugog
Diaptomus oregonensis (Lilljeborg)	+++	+++	++	++	++	++	++	++	++	+	+
Diaptomus minutus (Lilljeborg)	++			+	+						
Epischura lacustris (Forbes)	++	+	+	++	+	+	+	+	+		
Limnocalanus macrurus (Sars)	+++							+			
Senecella calanoides (Juday)	+							+			
Cyclops bicuspidatus thomasi (Forbes)	+++	+	+++	++	++	+++	++	++	++	+	
Cyclops vernalis (Fischer)	+++	+	+++	++	+++	+++	+++	+++	+++	++	+++
Cyclops scutifer (Sars)				++	+						
Eucyclops agilis (Koch)					+	+	+		+		+
Orthocyclops modestus (E.B. Forbes)						+					
Macrocyclops albidus (Jurine)					+		+		+		
Mesocyclops edax (Forbes)	+++	+++	+++	+++	+++	+++	+++	+++	+++	++	+++
Tropocyclops prasinus mexicanus (Kiefer)	+++	+++	++	++	++	++	+	+++	+++	++	+++
Acroperus harpae (Baird)	+					+					
Alona affinis (Leydig)										+	+
Alona quadrangularis (O.F. Müller)					+	+			+	+	
Alona sp.		+		+			+	+	+	+	+
Eubosmina coregoni (Baird)	++	+++	+		+++	+++	+++	+++	+++	+++	+
Bosmina sp. (prob. longirostris)	++	+	+++	++	+	+					+
Ceriodaphnia lacustris (Birge)	+	++	+		+	++	+	+	+	++	+
Chydorus sphaericus (O.F. Müller)	++	++	++	+++	+++	+++	+++	+++	+++	+++	+++
Daphnia catawba (Coker)	++	+++	+++	++	+++	+++	+++	+++	+	+	+
Daphnia galeata mendotae (Birge)	+++	+++	+++	+++	+++	+++	+++	+++	+++	+	+
Daphnia pulex (Richard)	++		+	+	++	+++	++	++	+		
Daphnia retrocurva (Forbes)	++	+++	++	+	+	+	++	+++	+++	+	+
Daphnia rosea (Sars)			+	+	+						
Diaphanosoma leuchtenbergianum (Fischer)	+++	++	++	+	+	++	++	++	++		+
Drepanothrix dentata (Eurén)											+
Eurycercus lamellatus (O.F. Müller)					+						
Graptoleberis testudinaria (Fischer)		+	+				+				
Holopedium gibberum (Zaddach)	+	+	+	+		+	+	+			
Latona setifera (O.F. Müller)			+		+						
Polyphemus pediculus (Linne)	+		+					+			
Rhynchotalona falcata (Sars)						+					
Sida crystallina (O.F. Müller)		+	+	+	+		+			+	
Leptodora kindtii (Focke)		+	+	+	+	+	+	+	+		+

Table 2: Number of dominant species in each of the Kawartha Lakes during the summer of 1972, taken as a summer average and maximum (dominant means a species that accounted for more than 10% of the population).

	Number of dominants (over 10% of the population)	
	maximum	summer average
Stony	8	4
Bald	7	5
Balsam	7	3
Cameron	4	3
Sturgeon	5	4
Pigeon	7	2
Buckhorn	6	3
Clear	6	4
Rice	5	4
Quinte	4	2
Scugog	3	1

Table 3: Mean percentage composition of planktonic crustaceans in the Kawartha Lakes during the summer of 1972, and density (individuals/cm^2/m).

	calanoids	nauplii	cyclopoids	cladocera	ind/cm^2/m
Stony	32.6	18.2	23.2	26.0	0.3
Bald	13.3	24.7	39.7	22.3	3.0
Balsam	12.1	38.3	19.3	30.3	1.1
Cameron	7.5	32.7	25.4	34.4	0.9
Sturgeon	4.3	17.0	25.2	53.5	2.4
Pigeon	5.6	29.2	23.4	41.8	2.3
Buckhorn	5.8	24.6	23.8	46.0	3.0
Clear	7.5	25.5	28.5	38.5	1.8
Rice	1.7	12.8	18.9	66.6	9.3
Quinte	0.5	9.6	11.5	78.4	2.5
Scugog	1.2	19.6	30.5	48.7	3.9

Table 4: Percentage composition and list of species found in Stony Lake during the summer of 1972

Diaptomus oregonensis	(Lilljeborg)	32.6% (Calanoids)
Diaptomus minutus	(Lilljeborg)	
Epischura lacustris	(Forbes)	
Limnocalanus macrurus	(Sars)	
Senecella calanoides	(Juday)	
Cyclops bicuspidatus thomasi	(Forbes)	23.2% (Cyclopoids)
Cyclops vernalis	(Fischer)	
Mesocyclops edax	(Forbes)	
Tropocyclops prasinus mexicanus	(Kiefer)	
Nauplii		18.1%
Daphnia catawba	(Coker)	26.1% (Cladocerans)
Daphnia pulex	(Richard)	
Daphnia galeata mendotae	(Birge)	
Daphnia retrocurva	(Forbes)	
Acroperus harpae	(Baird)	
Bosmina coregoni coregoni	(Baird)	
Bosmina sp.		
Ceriodaphnia sp.		
Chydorus sphaericus	(Müller)	
Diaphanosoma leuchtenbergianum	(Fischer)	
Holopedium gibberum	(Zaddach)	
Polyphemus pediculus	(Linne)	

Cladocerans were well represented by Daphnia catawba, Daphnia pulex, Daphnia galeata mendotae, Eubosmina coregoni and Chydorus sphaericus. The latter two comprised over 80% of the cladoceran species found in Lake Scugog and the Bay of Quinte. Table 5 illustrates the percentage composition of the cladocera for the major species. As indicated there was a definite reduction in the number of large-bodied species (D.g. mendotae, D. catawba) and an increase in the number of small-bodied species (E. coregoni, C. sphaericus) down the system.

DISCUSSION

Stony Lake Zooplankton

Stony Lake, in contrast to the remainder of the Kawartha Lakes, is relatively deep (33 m) and has a sharply defined thermocline during the summer months. Although the Stony Lake zooplankton community was strikingly similar to those found in the other Kawartha Lakes, there was one notable exception. Whereas the calanoids were of less significance in the shallower lakes of the system, they were the dominant group in Stony Lake, accounting for 32.6% of the yearly (summer sampling period) total of crustaceans. The two species L. macrurus and S. calanoides were found only in Stony Lake (the rare occurrence of these species in Clear Lake probably resulted from their passive transport by surface and/or bottom currents). This may be a case where lake morphometry is the important feature in regulating species composition and indeed the community difference observed may result solely from fundamental morphometric differences.

In his study of the ELA lakes, near Kenora, Patalas (1971a) concluded that lake area and depth were more significant in determining community composition than latitude of the lake. As the present study has shown, the fact that Stony Lake is connected to the other Trent Canal Lakes does not necessarily mean it will have a similar plankton population. Similarly, Patalas (1971a) reported the species Senecella calanoides and Epischura lacustris from only the large, deep lakes in the ELA area. S. calanoides is characteristic of deep lakes being found in all the Great Lakes but Lake Erie.

Table 5: Percentage composition of the cladocera in the Kawartha Lakes during the summer of 1972.

	Stony	Bald	Balsam	Cameron	Sturgeon	Pigeon	Buckhorn	Clear	Rice	Quinte	Scugog
D. catawba	21	16	8	17	20	30	16	30	<1	<1	0
D.g. mendotae	39	18	29	59	22	8	8	16	18	3	<1
D. pulex	20	1	1	13	8	13	8	13	1	0	0
D. retrocurva	1	26	11	<1	1	1	2	9	30	1	<1
B. sp.	11	0	29	19	0	0	0	0	0	0	0
C. lacustris	0	10	<1	0	<1	8	<1	<1	<1	10	<1
C. sphaericus	9	5	7	1	12	9	30	22	25	25	97
D. leuchtenbergianum	15	7	2	<1	2	3	5	6	2	0	<1
E. coregoni	0	16	0	0	40	40	35	15	23	58	<1

In the Great Lakes Region Limnocalanus, as well as Senecella and Mysis (opposum shrimp), also found in Stony Lake, are considered as part of the glacial relict fauna. Its life history has been studied by a number of authors, Carter (1969), and Gannon & Beeton (1971). It is one of the largest freshwater copepods (2-3 mm) and requires a stable mass of cold water to exist throughout the summer months. Also influencial in the distribution of Limnocalanus is the rate and extent of dissolved oxygen depletion in the hypolimnion. Strom (1946) gave a detailed description of Limnocalanus in a Norwegian Lake in which it was confined to the waters below 10 meters where the temperature was less than 14°C and dissolved oxygen concentrations were greater than 5.6 mg/l. Carter (1969) found a daytime upper temperature limit for adult Limnocalanus of 7°C in Parry Sound. McNaught & Hasler (66) in their study of vertical migrations in Lake Michigan observed that 75% of the population of Limnocalanus showed a marked tendency to remain below the thermocline and concluded it was because of physiological reasons or other factors including feeding and avoidance of predators at lower light intensities.

As outlined in chapter 1, thermal stratification lasts from late spring until late autumn in Stony Lake, with hypolimnal water temperatures between 5 and 9.0°C. Temperatures of this nature fall well below the upper temperature limit of Limnocalanus. However, associated with the development of the thermocline is a rapid oxygen depletion in the hypolimnion. Distribution of this species would be further restricted by a lower oxygen limit. Ideal conditions are limited to a narrow layer of water in the vicinity of the thermocline. One might expect a reduction or elimination of Limnocalanus as a consequence of increased nutrient enrichment and its associated oxygen depletion. Present observations will therefore serve as a useful baseline for future water quality comparisons in Stony Lake.

Kawartha Lakes Zooplankton

Interpretation of changes in relative abundance and species composition of the zooplankton community is difficult due to the great natural variation that exists. Hubschman (1960) found numbers of cladocerans present at one station on successive days could vary by a factor of five fold.

Gannon (1972) reported differences of 50% in total abundance on sampling dates one year apart and considerable differences in species composition. The difficulty is further compounded when one attempts to relate specific changes in a zooplankton population to a change in lake trophy. Differences that exist in a lake are a result of a complex series of interrelationships of a wide variety of environmental parameters, including lake morphology, chemical composition, dissolved gases, temperature, phytoplankton populations, shifting water mass, predation pressures, etc. Most studies of crustacean communities are generally limited to one lake or one species and few long term studies are available on yearly variability. The Kawartha Lakes, however, provide an excellent opportunity to study the effects of different trophic levels on zooplankton community structure, in that they offer a wide range of conditions (oligotrophy through to eutrophy).

Although it is difficult to isolate some indicator organisms that might be sensitive to changes in trophy, some general observations can be made. Perhaps the most pronounced responses to aquatic enrichment (or increasing eutrophy) are in the production of blue-green algae. Most of this group of algae is relatively unsuitable as a food source for planktonic herbivores and cannot be utilized by most. However, many blue-green algae are a source of food and substrate for C. sphaericus. In the present study this species increased dramatically in abundance down the system, corresponding to the increases exhibited by the phytoplankton. It is not surprising then, that maximum numbers were observed in Lake Scugog and the Bay of Quinte, where blue-green algal densities were highest.

E. coregoni is considered typical of rather shallow, warm eutrophic lakes (Patalas 1971b) and was a prominant part of the plankton community from Sturgeon Lake through to the Bay of Quinte.

The trend of decreasing calanoid significance and increasing cladoceran and cyclopoid significance with increasing eutrophy has been observed in the Great Lakes (Patalas 1972b) and in the Muskokas (Hitchin 1973). Watson (1974) concluded that these variations only reflect changes in the relative abundance of the latter groups. He observed that increasing eutrophication apparently resulted in greater numbers of cladocerans and cyclopoids, while the population of calanoids remained roughly the same. Kawartha Lake results, however, indicate a marked reduction not only in relative abundance, but also absolute numbers of calanoid copepods. It is likely that the decline in calanoid copepods from the upper to the lower Kawartha system relates more to the lack of cold deep lakes in the lower system than to the presence of the more enriched and productive waters of the lower system. Calanoids in Lake Ontario, for example, are more abundant offshore than inshore (Patalas 1969).

With the exception of the Bay of Quinte, the Kawartha Lakes can be characterized by mid-summer minima in zooplankton numbers. This is contrary to Patalas' (1972) observations of maximum zooplankton numbers in mid-summer in the Great Lakes.

Considerable variation could exist if numbers of organisms in a vertical net haul are expressed in abundance (ind/m^2) under a unit area (Patalas 1972) or in terms of concentration (ind/m^3) in a water column (Watson & Carpenter 1974). Although a vertical net haul integrates the water column it doesn't differentiate from what stratum the organisms were captured. Vertical variation may have been significant in this study but was accounted for by the integrated sampling method, and it is interesting to compare our concentrations to other lakes of known trophic state. As demonstrated in Table 6, lakes in the upper Kawartha system have numbers comparable to the oligotrophic to mesotrophic Great Lakes while lakes in the lower system have numbers comparable to the mesotrophic to eutrophic Great Lakes.

Zooplankters have three primary food sources, phytoplankton, bacteria, and detritus. Under certain conditions any one of these may serve a major role in supporting a zooplankton population. However, under normal circumstances, phytoplankton is the main source. Although the dependence of zooplankton on phytoplankton may assume the character of a succession and in some cases may greatly outnumber phytoplankton stocks in a lake (having actually eaten the lakes empty and subsisting on stored body fat), a general assumption can be made that when algal stocks are high, the potential food source is high, and when phytoplankton stocks are low the potential food source is low. Extremely high algal levels, consisting mostly of blue-green

Table 6a: Crustacean concentration in the Great Lakes (Watson - 1974)

Lake	Accepted Trophic Status	Maximum Numbers at Period of Peak Biomass (individuals/m^3)
Lake Superior (1 cruise)	oligotrophic	8,000
Lake Huron	mesotrophic	22,000
Lake Ontario	mesotrophic	55,000
Lake Erie	eutrophic	225,000

Table 6b: Crustacean concentration in the Kawartha Lakes.

Lake	Summer Mean (individuals/m^3)	Maximum (individuals/m^3)
Stony	2,500	5,600
Balsam	10,700	34,400
Cameron	9,200	18,300
Sturgeon	24,200	70,700
Pigeon	22,800	150,870
Buckhorn	30,200	60,500
Clear	17,500	35,300
Rice	93,300	352,600
Bay of Quinte	24,500	92,000
Scugog	38,600	365,000

forms are generally unacceptable to most zooplankton species, and have eliminated them either because of some physical or chemical unsuitability or competition for space.

While it is recognized that cell volume provides a better index of algal biomass than chlorophyll a, the former was not available at the time this chapter was prepared.

The increasing algal levels expressed as chlorophyll a from Balsam to the Bay of Quinte (Chapter 1) correspond to increasing zooplankton densities. (High algal levels, consisting of species generally not suitable as food sources in the Bay of Quinte and Lake Scugog may have reduced zooplankton numbers). Patalas (1972) found a similar trend in zooplankton numbers in the Great Lakes, with the more oligotrophic lakes having lower numbers (43 individuals/cm^2 in Lake Superior) than the eutrophic lakes (400 individuals/cm^2 in Lake Erie). When algal levels and zooplankton numbers were compared for the Kawartha Lakes, other than Lake Scugog and the Bay of Quinte, a highly significant coefficient of correlation resulted ($r = 0.79$) (Fig. 3).

Standing stocks of algae in a lake are usually related to the fertility of the surrounding water. As outlined in Chapter 1, this was especially true when algal levels (chlorophyll a) were compared to total phosphorus concentrations in the photic zone, yielding an r value of 0.80. Since the number of zooplankton is somewhat dependent on the quantity of food available (measured indirectly as chlorophyll a) and the fact that chlorophyll a and total phosphorus are highly correlated, a relationship between zooplankton numbers and phosphorus levels is indicated. This was indeed the case with a highly significant $r = 0.94$. (Fig. 3). Nutrient enrichment has contributed to increased concentrations (zooplankton - phytoplankton) in the Kawartha Lakes from Balsam to Rice Lake, and hindered zooplankton numbers in Lake Scugog and Bay of Quinte due to excessive production of an unsuitable food source. (Chapter 2).

When considering interpretations of plankton data, differences that exist in the zooplankton communities of these lakes might be explained by fish predation rather than limnological conditions. The influence that such planktivorous fish (at least in their younger stages) may have on a plankton community have been studied by Galbraith (1967) and Hutchison (1971). A shift from large-bodied to small-bodied crustaceans may materialize when predation is intense, as the larger, more visible forms are competitively eliminated. Decreases in the larger forms of Daphnia and the subsequent

Table 7: Categorization of the Kawartha Lakes, based on average summer values for 1972, for a number of parameters, including chloro *a* (ppb), total P (mg P/l), no. of ind/cm^2/m, secchi disc (m), % calanoids and % cladocera

	Category	chloro *a*	total P	#/cm^2/m	secchi disc	% calanoids	% cladocera
Stony		2.8	.014	0.3	3.7	32.6	26.0
Balsam	I	2.1	.017	1.0	4.4	12.1	30.3
Cameron		2.5	.016	0.9	3.0	7.5	34.4
Bald		4.2	.020	3.0	3.5	13.3	22.3
Sturgeon		7.3	.027	2.4	2.2	4.3	53.5
Pigeon	II	5.0	.026	2.3	2.8	5.6	41.8
Buckhorn		4.2	.021	3.0	2.4	5.8	46.0
Clear		5.1	.023	1.8	2.8	7.5	38.5
Rice		9.0	.055	9.3	1.8	1.7	66.6
Quinte	III	14.4	.050	2.5	1.2	0.5	78.4
Scugog		15.3	.040	3.9	0.9	1.2	48.7

rises in the smaller-bodied forms (such as D. retrocurva and E. coregoni) was evident in the Kawarthas proceeding down the system. Undoubtedly predation by fish populations have affected zooplankton populations in the Kawartha Lakes, although further studies relating to the feeding habits of these fish is necessary to determine to what extent it alters zooplankton numbers and composition.

Brooks and Gliwicz (1969) consider zooplankters are smaller in more eutrophic lakes because bacteria and detritus are more available food items. Any further interpretation of zooplankton community differences will have to include feeding studies of the zooplankton itself.

An objective interpretation of zooplankton data from the lakes of the Kawartha-Trent chain indicates that they can be divided into three basic categories (Table 7).

Category I

This category represents the headwater lakes of the system; Stony and Balsam and including Cameron. (Lake Scugog, being a shallow headwater lake on an enriched substrate, with vastly different limnological conditions has been excluded from this category. Also Big Bald Lake has several parameters like higher nutrient content and algal populations that place it in the next category). These lakes are generally deeper, cooler and have better overall water quality than lakes downstream. Nutrient contents are relatively low (total P in photic zone <.020 mg/l) resulting in low phytoplankton stocks, as indicated by chlorophyll a concentrations <3.0 µg/l. The zooplankton communities of these lakes are relatively small (<1.0 organism/cm^2/m) but well represented by a variety of species. Calanoid copepods are adequately represented, generally accounting for more than 10% of the crustaceans present. Large-bodied zooplankton species are common, especially among the cladocerans.

Category II

Lakes in this intermediate category, including Bald, Sturgeon, Pigeon, Buckhorn and Clear, are farther down the system, shallower in nature and have reduced water quality. Total phosphorus concentrations between .020 mg/l and .030 mg/l are capable of supporting moderate to moderately high algal populations (>4 μg/l as chlorophyll a) and bloom conditions occur frequently. Zooplankton communities in these lakes are characterized by higher numbers or organisms (1.0 - 4.0 individuals/cm^2/m) and by reduced calanoid significance with correspondingly greater cladoceran significance.

Category III

These lakes (Rice, Scugog and the Bay of Quinte) are fairly shallow, warmer and have relatively high nutrient contents (total P >40 mg/l), resulting in impaired water quality. Algal levels are high (>9.0 μg/l as chlorophyll a), blue-green species are common and blooms occur frequently. The zooplankton communities of these lakes are markedly different than in the preceding categories. Calanoid numbers are insignificant (<2%), while cladocerans are in abundance. Species characteristic of eutrophic lakes are common, and most large-bodied forms have been either reduced or completely eliminated. Zooplankton density appears to be greater, especially in Rice Lake, although phytoplankton unsuitability has probably reduced numbers in Scugog and the Bay of Quinte.

Having developed the relationships between nutrient concentrations, algal levels, and zooplankton abundance, it seems logical to conclude that any changes in the physical or chemical nature of these lakes which will ultimately affect water quality could be monitored by changes in zooplankton species composition and community structure. These changes may be useful indicators of shifts in lake trophic status. They may also be valuable tools to monitor the effects of remedial measures to improve water quality, such as phosphorus removal and weed harvesting. This data will provide useful baseline information for future comparisons.

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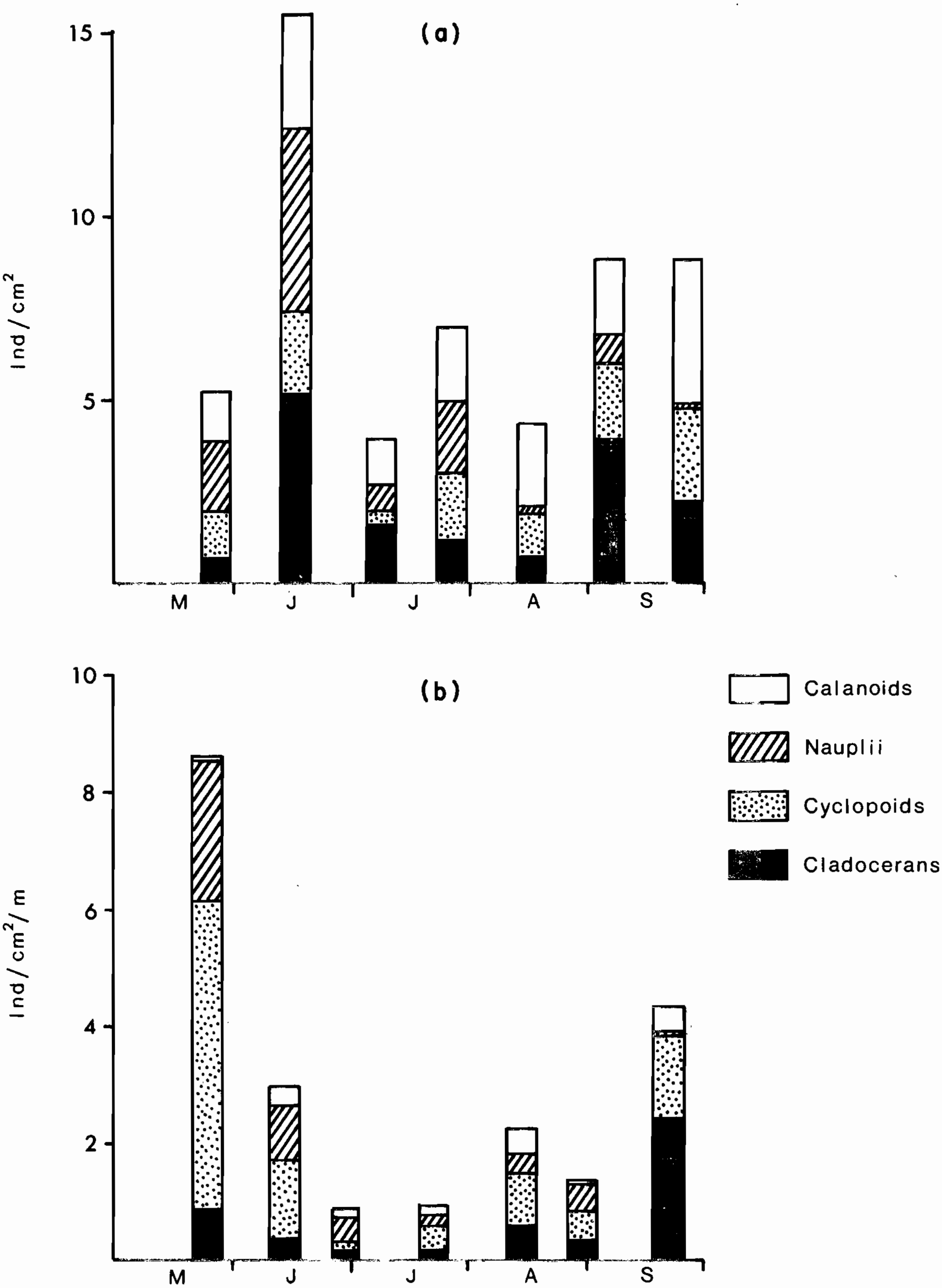

FIG. I Species composition and relative abundance of crustaceans in (a) Stony Lake, and (b) Big Bald Lake in 1972.

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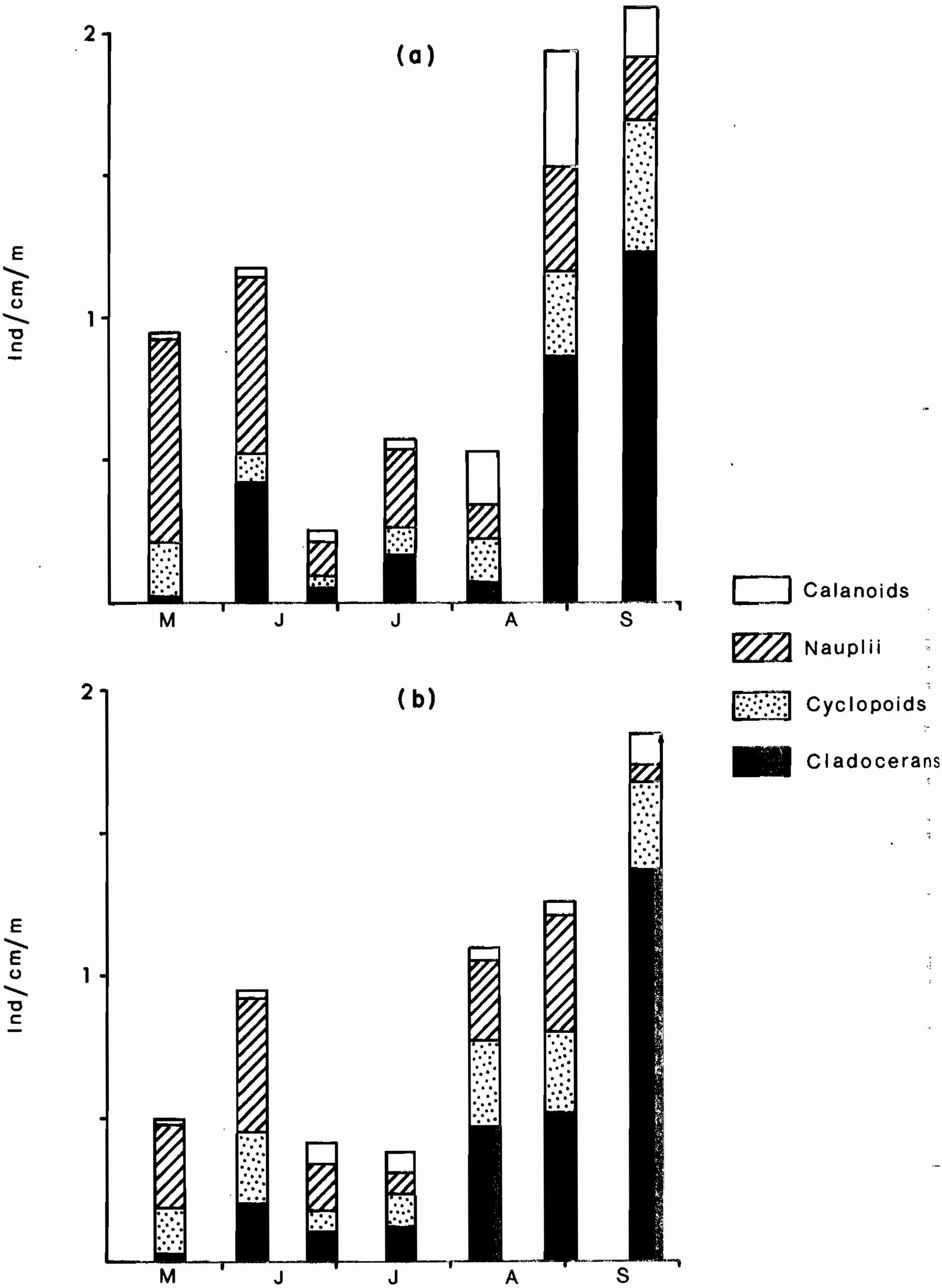

FIG. 2 Species composition and relative abundance of crustaceans in (a) Balsam Lake, and Cameron Lake (b) in 1972.

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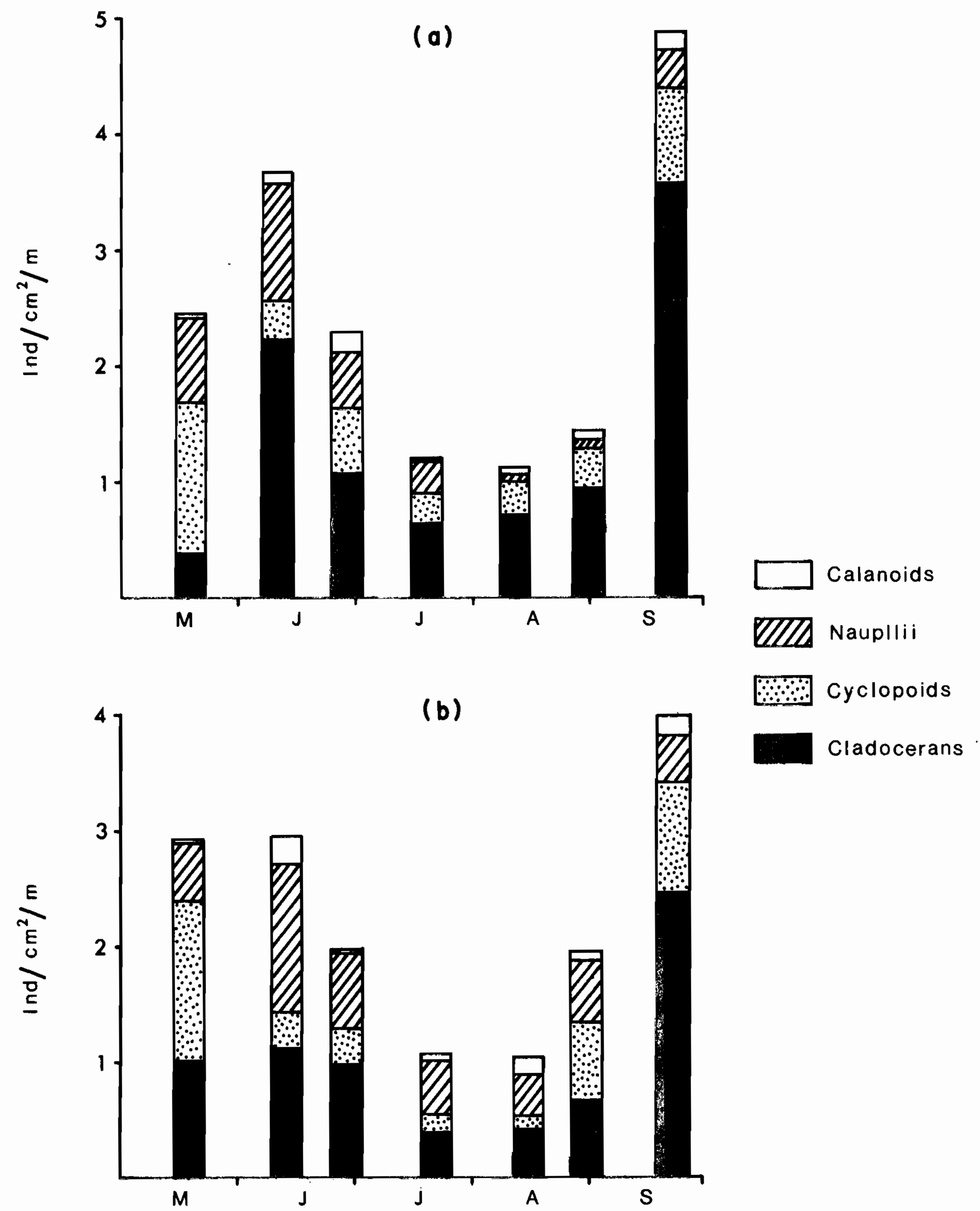

FIG. 3 Species composition and relative abundance of crustaceans in (a) Sturgeon Lake, and Pigeon Lake (b) in 1972.

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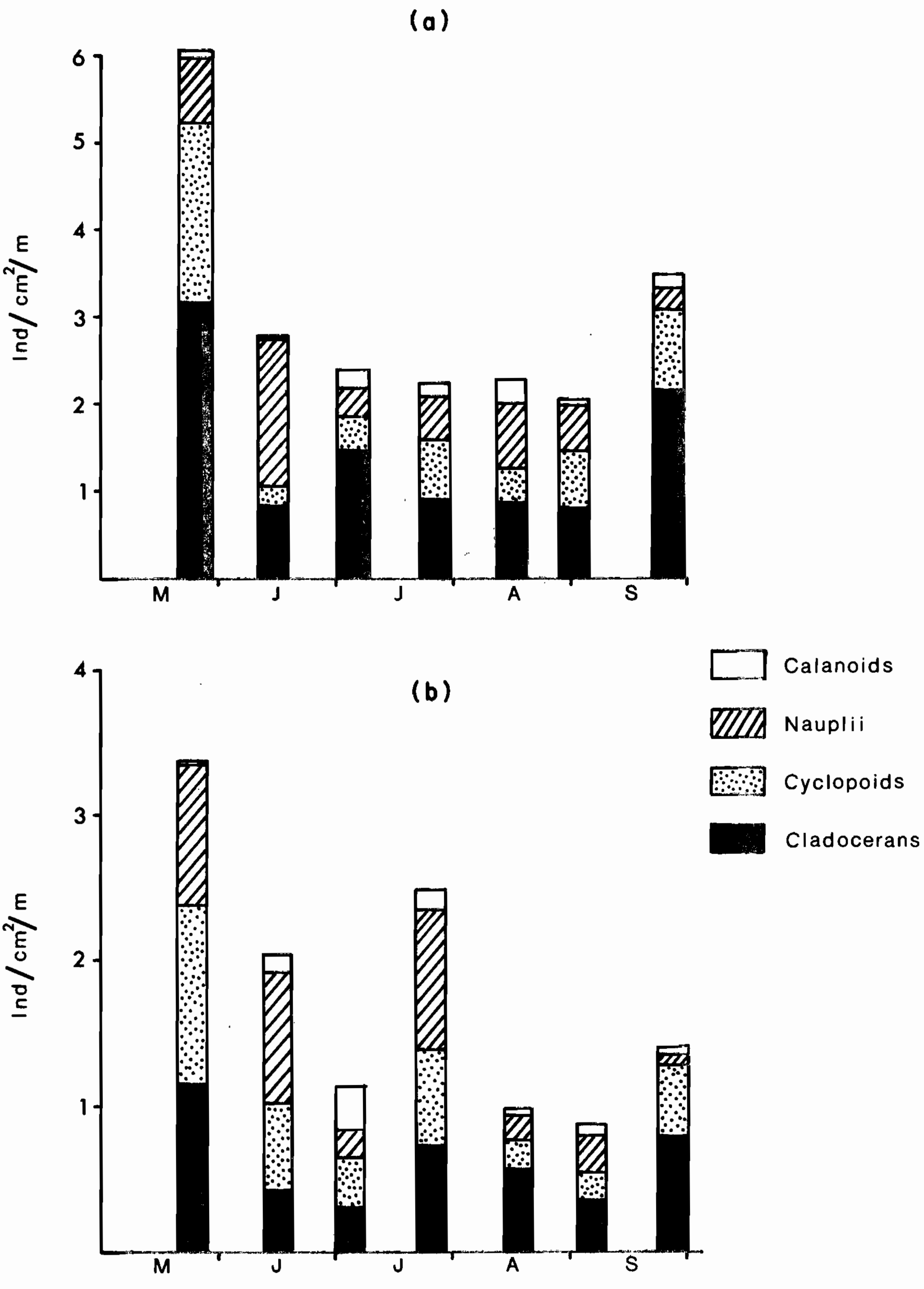

FIG.4 Species composition and relative abundance of crustaceans in (a) Buckhorn Lake, and (b) Clear Lake in 1972.

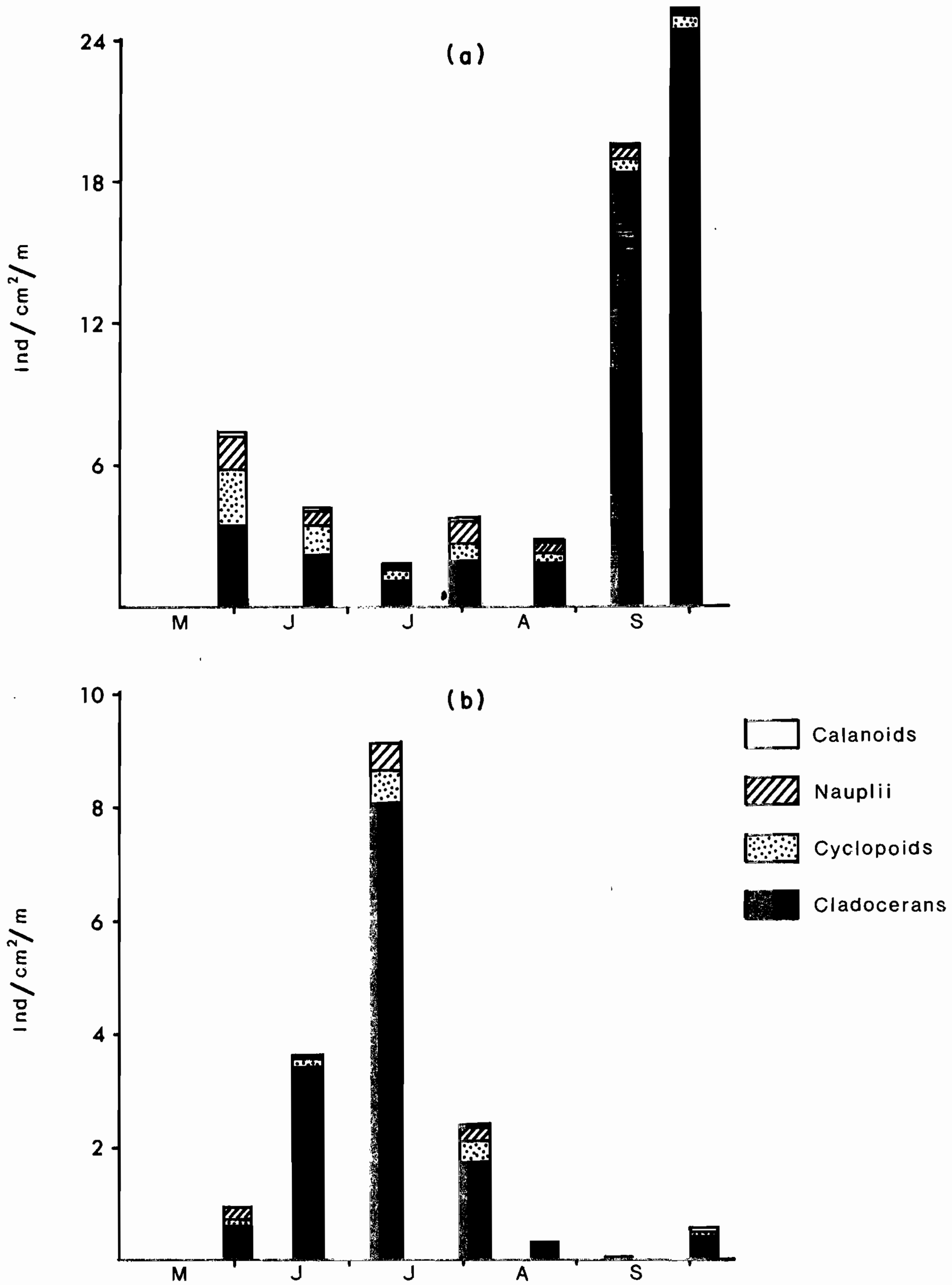

FIG. 5 Species composition and relative abundance of crustaceans in (a) Rice Lake, and (b) Bay of Quinte in 1972.

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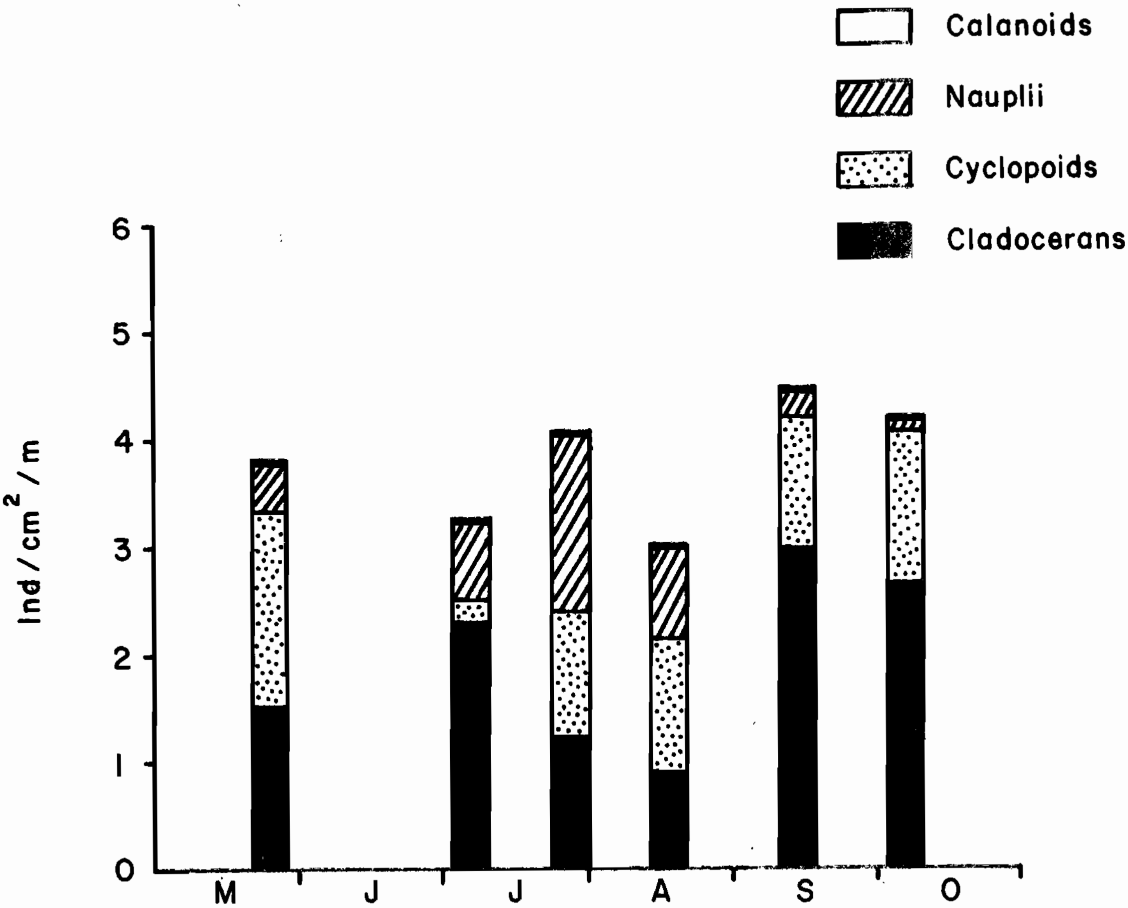

FIG. 6 Species composition and relative abundance of crustaceans in Lake Scugog in 1972.

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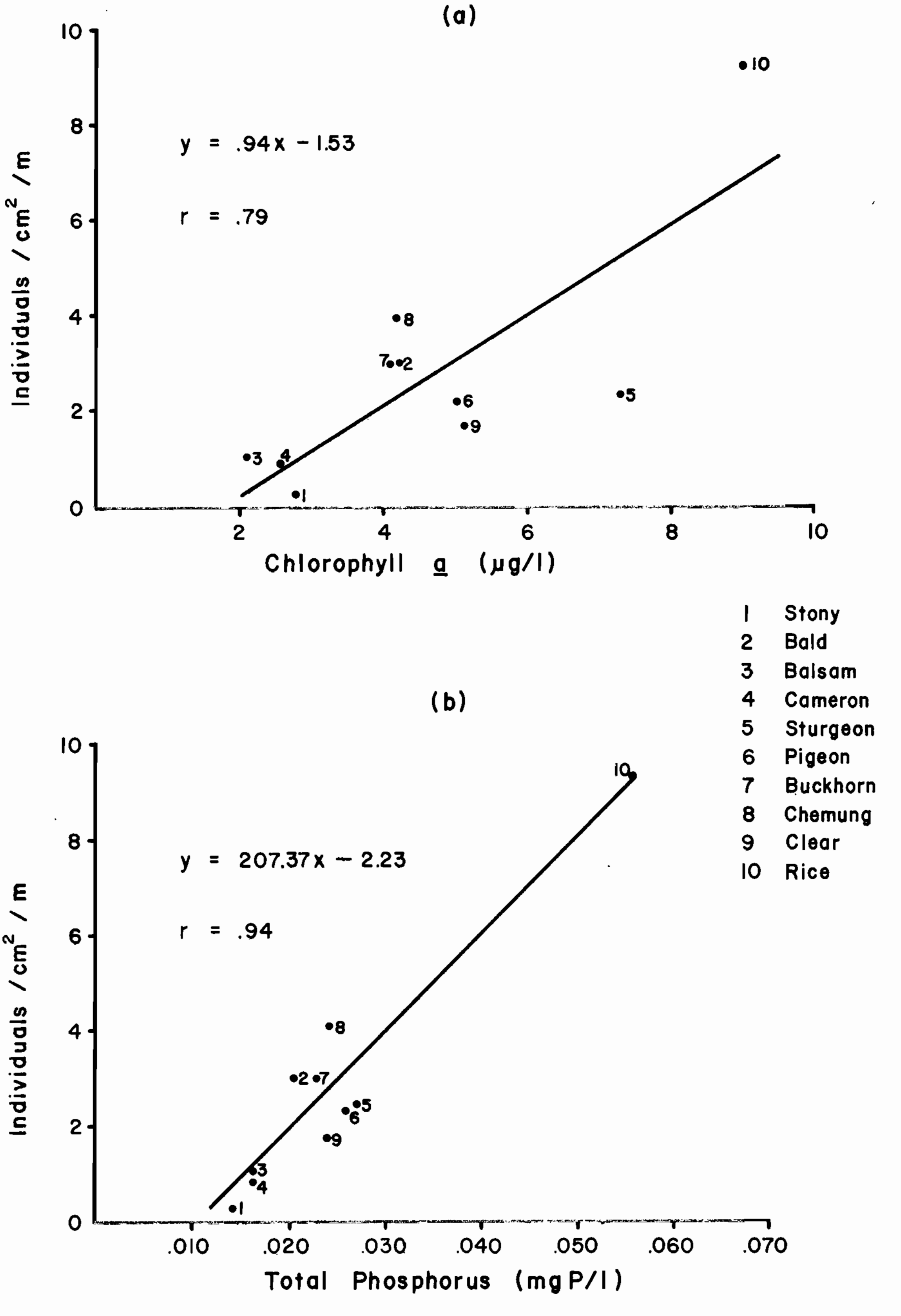

FIG. 7 Relationship between crustacean abundance (ind./cm^2/m) and (a) chlorophyll a (µg/l) and (b) total phosphorus (mgP/l) in the photic zone, in the Kawartha Lakes in 1972. (based on summer means)

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CHAPTER 4

THE MACROPHYTES OF THE KAWARTHA LAKES - 1972

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INTRODUCTION

Aquatic plants when present in moderate quantities play an important role in the aquatic ecosystem. They provide food, shelter and attachment for many types of aquatic organisms and spawning areas for many species of fish. Through their root systems, these plants effectively stabilize bottom sediments and through the process of photosynthesis they supply the overlaying waters with abundant oxygen. In many of the Kawartha Lakes, the presence of extensive shallow areas combined with an abundant supply of nutrients from both natural and artificial sources has resulted in a tremendous proliferation of plant growth. This excessive production of vegetation has become a major detriment to man's utilization of these waters by interferring with many recreational pursuits such as swimming and boating.

In view of the prominance of aquatic plants throughout the Kawartha Lakes and their significant impact on recreational usage, this chapter presents information on their distribution and abundance to assist in the interpretation of existent conditions and to provide a baseline for future comparisons.

METHODS

The variable distribution and extent of the areas supporting plant growth precluded the use of standard field techniques for this survey. For this reason, aerial photographic methods were used to delineate plant distribution throughout the Kawartha Lakes. Experimental flights were completed over Chemung Lake on August 21, 1972 utilizing two 70 mm Vinten cameras and both false color infrared film #2443 and conventional negative color film #2445 at various altitudes ranging between 600 and 3,000 meters. Following examination of the imagery, the conventional negative color film and an altitude of 1500 meters were selected for coverage of the entire Kawartha system (Wile, 1973).

The overflights were successfully completed on September 15, 1972 with the exception of flight lines over Sturgeon and Scugog Lakes which were aborted owing to the development of turbulent weather conditions. The imagery obtained from these overflights was used to prepare detailed maps of the plant distribution and the areas supporting plant growth were measured by planimetry.

In conjunction with the aerial survey, ground truth information was collected from Balsam, Pigeon, Chemung and Rice Lakes both for interpretative purposes and to provide information on the abundance and species composition of the vegetation in these lakes. Transect lines marked at 1 meter intervals and running perpendicular from the shoreline to the outer limits of the plant beds, were used to record information on species composition and abundance. In addition, vegetation was collected from randomly placed ¼ m^2 quadrats to provide some indication of plant densities or biomass. Following collection, the plant material was washed, partly dried to remove surface adherant water and the fresh weights recorded. Samples of the more common plant species from each of these lakes were submitted to the Laboratory for chemical analysis including: nitrogen, phosphorus and percent loss on ignition. The analytical methods used have been detailed elsewhere (Wile and McCombie, 1972).

Information on the common plant species of Cameron, Katchewanooka, Clear and Stony Lakes was obtained from previous studies conducted by the Ministry of the Environment. Detailed data on the vegetation of southern Chemung Lake was available from sampling carried out in conjunction with the Ministry of the Environment experimental weed harvesting programme (Wile, 1974).

RESULTS AND DISCUSSION

Distribution, Abundance and Species Composition

As illustrated in Figures 1 to 7, the imagery obtained from the aerial photographic survey was used to develop detailed maps showing the distribution of aquatic vegetation throughout the Kawartha Lakes. Based on variations in colour tones of the imagery, it was possible to distinguish areas supporting light to moderate or heavy plant growths, however, numerical values could not be assigned to these areas and data on plant densities and specie composition is based solely on the field sampling.

A listing of the plant species identified during the field sampling programme has been provided in Table 1. Tapegrass, *Vallisneria americana* was the most common plant, occurring in varying degrees in all the lakes. Growth of this plant usually commences in late May or early June, although the plants are relatively inconspicuous until mid-July.

TABLE 1. AQUATIC PLANTS OF THE KAWARTHA LAKES
(x-species present)

Species	Balsam	Cameron	Pigeon	Clear & Stony	Katchewanooka	Rice	Chemung
Potamogeton amplifolius Tuckerm.	X	X	X	X	X		X
crispus L.	X					X	X
foliosus Raf.	X				X		
gramineus L.	X	X		X			
nodosus Poir.	X			X			
pectinatus L.				X			X
praelongus Wulfen.				X			X
pusillus L.	X		X				X
richardsonii (Benn.) Rydb	X	X	X	X	X	X	X
robbinsii Oakes	X	X	X	X	X		X
strictifolius Benn.							X
zosteriformis Fern.	X	X	X	X	X	X	X
natans L.				X	X		
vaseyi Robbins				X			
Vallisneria americana Michx.	X	X	X	X	X	X	X
Elodea canadensis Michx.	X	X	X	X	X	X	X
Heteranthera dubia (Jacq.) MacM.	X		X		X	X	X
Najas flexilis (Willd.)	X	X	X	X	X		X
Myriophyllum spp.	X	X	X	X	X	X	X
Ceratophyllum demersum L.	X		X	X	X	X	X
Utricularia vulgaris L.				X	X		X
Bidens beckii G.			X		X		X
Ranunculus trichophyllus Chaix.	X			X		X	X
Eleocharis acicularis R. & S.				X			
Sagittaria sp.	X	X	X	X			X
Chara spp.	X	X	X	X	X	X	X
Nitella sp.		X		X		X	X

Since this plant generally attains maturity and flowers in early August, it was particularly conspicuous at the time of the field surveys. Water milfoil, Myriophyllum spp. was also widely distributed although several different species were identified from the various lakes. In Cameron lake, the milfoil was primarily Myriophyllum alterniflorum D.C. and Myriophyllum heterophyllum Michx., whereas in Balsam, Clear and Stony Lakes, Myriophyllum heterophyllum Mich. and Myriophyllum exalbescens Fern. were identified. Two species of milfoil abundant in lower Pigeon, Chemung and Rice Lakes were identified as Myriophyllum exalbescens Fern. and tentatively, Myriophyllum spicatum L. The latter species is a European invader which was first collected in Chesapeake Bay in 1902 and has since spread throughout the U.S.A. It is an extremely aggressive plant with wide ecological amplitude which soon crowds out the more desirable plant species particularly in deeper waters with soft silt or organic substrates (Nichols and Mori 1971). The remaining plant species including the pond-weeds Potamogeton spp., Elodea canadensis and Heteranthera dubia occurred in more moderate quantities, generally growing in well mixed communities.

In Balsam Lake submersed aquatic plants occupied a total area of 540 ha or about 10% of the lake surface. Luxuriant beds of macrophytes were found in the soft organic substrates adjacent to the marshes in West and South Bays and near Coboconk, where the Gull river enters the lake. The plant communities in these areas were generally continuous, dense and heterogeneous, although tapegrass, Vallisneria americana was the most prominant plant species. The fresh weight of plant material collected from numerous random quadrats was fairly consistent and averaged 700 g/m^2 in West Bay, 800 g/m^2 in South Bay and 1200 g/m^2 in the Coboconk area. A band of vegetation bordered the shoreline areas of Balsam Lake where silt, organic or sandy substrates provided a suitable rooting medium. This growth was generally patchy in distribution and extended out to a maximum depth of some 10 meters. Although the flora in the shoreline areas was quite diverse, tapegrass was the most common plant species, undoubtedly due to its ability to thrive on both organic and sandy substrates. Other common species included Najas flexilis, Elodea canadensis, Potamogeton robbinsii, P. richardsonii, Ceratophyllum demersum and Heteranthera dubia. Fresh weights of the plants were extremely diverse, fluctuating between 3 and 800 g/m^2.

In Cameron Lake, the macrophytes were largely confined to Sachett and Cranberry Bays and to small mixed communities along portions of the shoreline. In all, vegetation covered some 80 ha or approximately 6% of the lake area. Tapegrass, Valisneria americana was the most abundant species, although Elodea canadensis, Potamogeton zosteriformis, P. amplifolius, P. richardsonii and Myriophyllum alterniflorum were also common.

Pigeon Lake was characterized by prolific plant growths in the southern portion of the lake, below the Gannon Narrows. This section of the lake provides ideal conditions for plant growth since it is extremely shallow and has a rich organic substrate. The vegetation, largely dominated by Vallisneria americana covered an area of 1620 ha and ranged in density between 1,000 and 4700 g/m^2, averaging 2,370 grams fresh weight per m^2. Other common plant species included, Myriophyllum spp., Chara sp. and Potamogeton richardsonii. In the northern portion of the lake, macrophytes occupied a total area of 160 ha and were largely confined to the mouths of Nogies and Volturno Creeks, Tait Bay, Bach Channel and some sections of the shoreline, particularly on the west side. The flora was more diverse than in the southern portion of the lake and included V. americana, Myriophyllum spp., P. zosteriformis, P. richardsonii, N. flexilis and C. demersum. Plant densities were more moderate, generally not exceeding 500 grams fresh weight per m^2 except near Nogies and Volturno Creeks.

In Buckhorn Lake the vegetation formed dense impenetrable beds which covered some 2800 ha or about 85% of the lake area. Based on a brief visual assessment, the vegetation was largely dominated by Myriophyllum sp. (tentatively identified as M. spicatum L.) although Vallisneria americana, Najas flexilis and Potamogeton strictifolius were also common.

Chemung Lake, particularly south of the causeway is characterized by shallow water depths and organic or silt substrates, providing ideal conditions for plant growth. In the southern section of the lake, the vegetation covers an area of 435 ha or some 50% of the surface area, growing in bands along the shoreline just south of the causeway and forming dense beds right across the lake between Fife Bay and the southern tip. North of the causeway the vegetation covers about 40% of the lake surface (660 ha) and forms a band around the shoreline in addition to dense beds scattered throughout the lake. This irregular distribution of the plants appears to be largely due to variations in the bottom contours. Vallisneria americana is the most abundant species in the lake, although water milfoil, Myriophyllum spp. is also very common, particularly in the scattered beds north of the causeway. Other common plant species include: Chara sp., P. zosteriformis, N. flexilis, E. canadensis and H. dubia. Fresh weights of plant material in southern

Chemung Lake averaged a high 3,400 g/m^2 with values at numerous stations ranging between 4,000 and 5,000 g/m^2. Values in northern Chemung Lake were generally lower, averaging 1,806 g/m^2 with most individual values varying between 500 and 3,000 g/m^2. However, two high values of 6,630 and 3,930 g/m^2 were obtained from the west side just north of the causeway and near Hickson Point, respectively.

Aquatic plant growths in Clear and Stony Lakes occupied less than 1% of the lake areas and were localized in bays and inlets, particularly Fiddler Bay, MacKenzie Bay, Bryson's Bay, Hamilton Bay, Gilchrist Bay, Northey Bay, Big Duck Pond and the mouth of Eels Creek. Although tapegrass was the most abundant plant, other common species included: P. robbinsii, P. amplifolius, P. zosteriformis, Myriophyllum spp., C. demersum and N. flexilis. With the exception of average fresh weights of 1,620, 995, and 1,194 g/m^2 in Byson's Big Duck and Northey Bays, plant densities were quite low ranging between 175 and 425 g/m^2.

Plant distribution in Lake Katchewanooka was fairly irregular owing to the bottom topography which is characterized by extensive areas of exposed rock, sand or gravel. Vegetation covered a total area of some 130 ha or approximately 30% of the lake area. A total of 15 plant species were identified with Vallisneria americana the most abundant species and P. zosteriformis, Myriophyllum sp., C. demersum and Chara sp. also widely distributed. Fresh weights of plant material collected from the lake were moderate, averaging 430 g/m^2 with individual values ranging between 125 and 1,200 g/m^2.

In Rice Lake plant growth covered some 2,120 ha or approximately 20% of the lake area. This lake is relatively shallow in nature with much of its area less tham 4m in depth and has a rich organic substrate. As a result, it is characterized by prolific stands of aquatic plants, particularly in the Bewdley area, the mouths of the Otonabee and Indian Rivers, Serpent Mounds Provincial Park area and in the vicinity of White Island. Water milfoil Myriophyllum sp. is the most abundant plant in the lake occurring at 58 of the 61 stations sampled. Elodea canadensis was also quite abundant, occurring at more than one half of the sampling sites. Other common species included Vallisneria americana, Heteranthera dubia, Ceratophyllum demersum and Potamogeton crispus. The latter species is known to abound in Rice Lake, however, since it thrives early in the season and usually dies back by mid-July, its importance in the lake was likely underestimated during the August survey. Highest fresh weight values for plant material collected in Rice Lake were obtained near the mouths of the Otonabee and Indian Rivers and in the vicinity of White Island with average values of 1,791, 1,804 and 2,204 grams per m^2 respectively and individual quadrat values ranging as high as 4,088 g/m^2. Somewhat lower values were obtained in the Bewdley area (740 g/m^2) and in the vicinity of Serpent Mounds Provincial Park (930 g/m^2).

From the foregoing, it is evident that problem growths of aquatic plants exist in the shallow, fertile lakes located in the St. Lawrence Lowlands, particularly where substrates are comprised of silt and organic deposits and water depths do not exceed 3 meters. In these lakes, i.e. southern Pigeon, Chemung, Buckhorn and Rice, the plants, particularly Vallisneria americana and Myriophyllum sp. form dense impenetrable beds, with fresh weights generally well in excess of 1,000 g/m^2 over areas several hundred hectares in size and create a severe impediment to recreational usage. Both these plant species are known to thrive under a wide range of environmental conditions including turbid or polluted waters (Kladec & Wentz 1974). In contrast, plant growths in the lakes bordering on the Canadian Shield (i.e. Balsam, Cameron, upper Pigeon, Clear, Stony) are more moderate in density and localized in distribution, generally confined to isolated bays and shoreline areas where suitable clay, silt, organic or sand substrates have accumulated. Although plant growths in these areas frequently occur at water depths of 8 to 10 meters, the plant communities are less dense, well diversified and usually well below the water surface, thus seldom creating nuisance conditions.

Nutrient Concentrations in Plant Tissues

Nitrogen and phosphorus concentrations in plant tissues were measured for the more common plant species collected from Balsam, Pigeon, Chemung, Katchewanooka and Rice Lakes (Table 2). According to Boyd (1967) submerged aquatic plants usually contain 3 to 4% nitrogen and 0.1 to 0.6% phosphorus on a dry weight basis. Nitrogen concentrations in plants collected from the Kawartha Lakes were somewhat lower than Boyd's estimates, ranging between 1.0% and 3.3%, with the highest values corresponding to plants collected from Rice Lake. Phosphorus concentrations for plant tissues from Balsam, Pigeon, Chemung and Katchewanooka Lakes were fairly similar, ranging between 0.13 and 0.35%. Consistently higher phosphorus concentrations were found in plants collected from Rice Lake with values ranging between 0.38 and 0.76% and averaging 0.52%.

Table 2. Nitrogen and Phosphorus concentrations in plant tissues (expressed as a % of the dry weight).

Plant Species	Balsam Lake		Pigeon Lake		Chemung Lake		Katchiwano Lake		Rice Lake	
	%P	%N	%P	%N	%P	%N	%P	%N	%P	%N
P. richardsonii	.18	2.1	.23	1.9	.22	2.05	.19	2.4	-	-
P. crispus	-	-	-	-	-	-	-	-	.52	2.8
E. canadensis	.13	1.0	-	-	.22	1.78	.26	2.0	.49	3.1
V. americana	.35	2.4	.19	1.8	.13	1.45	.25	1.9	.38	2.4
H. dubia	.15	1.7	-	-	.31	1.97	.29	2.0	.55	2.8
N. flexilis	.19	1.9	.18	1.7	.23	1.7	.23	1.7	-	-
Myriophyllum sp.	-	-	.22	2.2	.26	1.87	.25	2.5	.41	2.1
C. demersum	.19	1.9	.25	2.6	.18	1.85	.15	1.7	.76	3.3
Mean	.20	1.83	.21	2.04	.22	1.81	.23	2.03	.52	2.75
N/P ratio	9.2		9.7		8.2		8.8		5.3	

Considerable evidence exists in the literature to indicate that the uptake of nutrients by aquatic plants is greater with increasing ambient levels of these elements. For example, Adams et al (1971) reported significant increases in phosphorus levels and slight increases in nitrogen concentrations in Elodea canadensis tissues with increasing levels of environmental nutrient enrichment. Similarly, Caines (1965), showed that significant increases in P concentrations in Myriophyllum alterniflorum and Potamogeton praelongus occurred shortly after the addition of calcium superphosphate to their environment. Nitrogen and phosphorus concentrations in plant tissues from the Kawartha Lakes reflect the increasing enrichment of the waters from Balsam to Rice Lake. Figure 8 illustrated a significant relationship between total P concentrations in surface waters and phosphorus concentrations in tissues of the more common plant species, with a correlation coefficient of 0.83. Utilizing a mean P tissue concentration for all plant species collected from each lake, the correlation coefficient increased to 0.96. The relationship between nitrogen concentrations in plant tissues and ambient nitrogen levels was less clearly defined. No correlation was found between inorganic N levels in surface waters and N concentrations in plant tissues. However, a marginal relationship ($r = 0.51, 0.73$) was found when ambient total N concentrations were compared to individual and mean plant tissue nitrogen levels.

According to Wagner (1966), the increased availability of ambient phosphorus can lead to an alteration of the normal nitrogen/phosphorus relationship in an organism. Nitrogen/phosphorus ratios in plant tissues from the Kawartha Lakes were remarkably similar (8.2 to 9.7) with the exception of Rice Lake where a ratio of 5.3 was obtained. Wagner (1966) reported a similar low N/P ratio of 5.1 for Potamogeton perfoliatus growing in a highly enriched area of Lake Constance compared to a ratio of 8.0 for the same plant species collected from the less polluted reaches of the same lake.

Gerloff and Krombholz (1966) used tissue analysis as an index of the availability of N and P in lakes for plant growth and established critical tissue concentrations of 1.3% N and 0.13% P in laboratory experiments with angiosperm aquatic plants. Tissue concentrations above these critical limits would have no effect on yields and represent "luxury uptake". Values below the critical levels indicate that plant growth is restricted by the availability of that element. In a similar series of experiments, Wilson (1972) indicated that the critical phosphorus tissue concentration for

Myriophyllum exalbescens would fall in the range of 0.06 to 0.08%. Tissue concentrations of N and P in plants collected from the Kawartha Lakes were generally well above these critical levels, indicating that plant growth was not restricted by the availability of these elements. Furthermore, based on the regression lines in Figure 8, ambient total P levels of less than 14 μg/l, based on Gerloff's critical tissue concentrations, and lower than 8 μg/l, based on Wilson's limits, would be required to achieve a reduction in plant biomass in the Kawartha Lakes.

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FIGURE 1 - DISTRIBUTION OF AQUATIC VEGETATION IN BALSAM LAKE

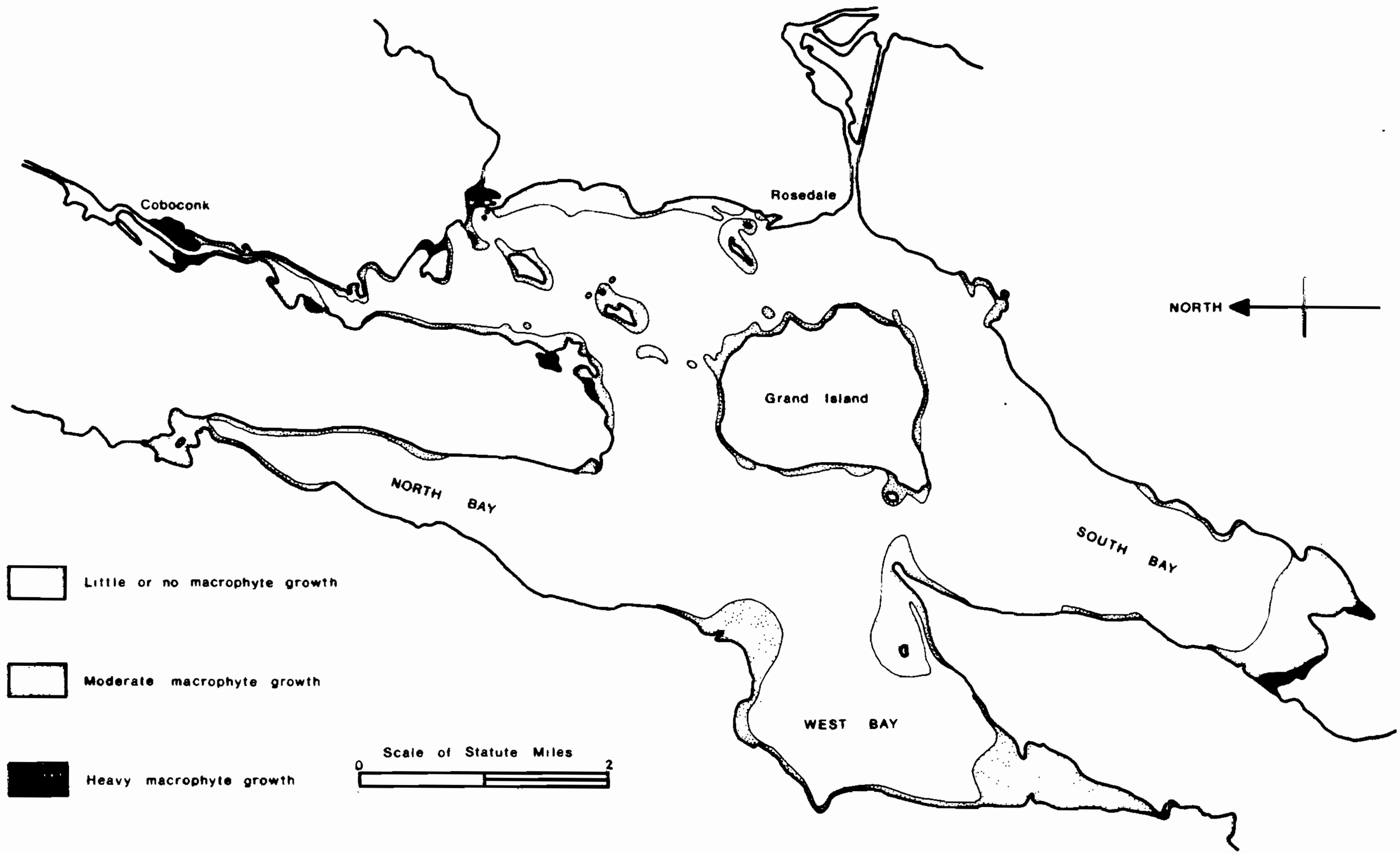


FIGURE 2 - DISTRIBUTION OF AQUATIC VEGETATION IN CAMERON LAKE

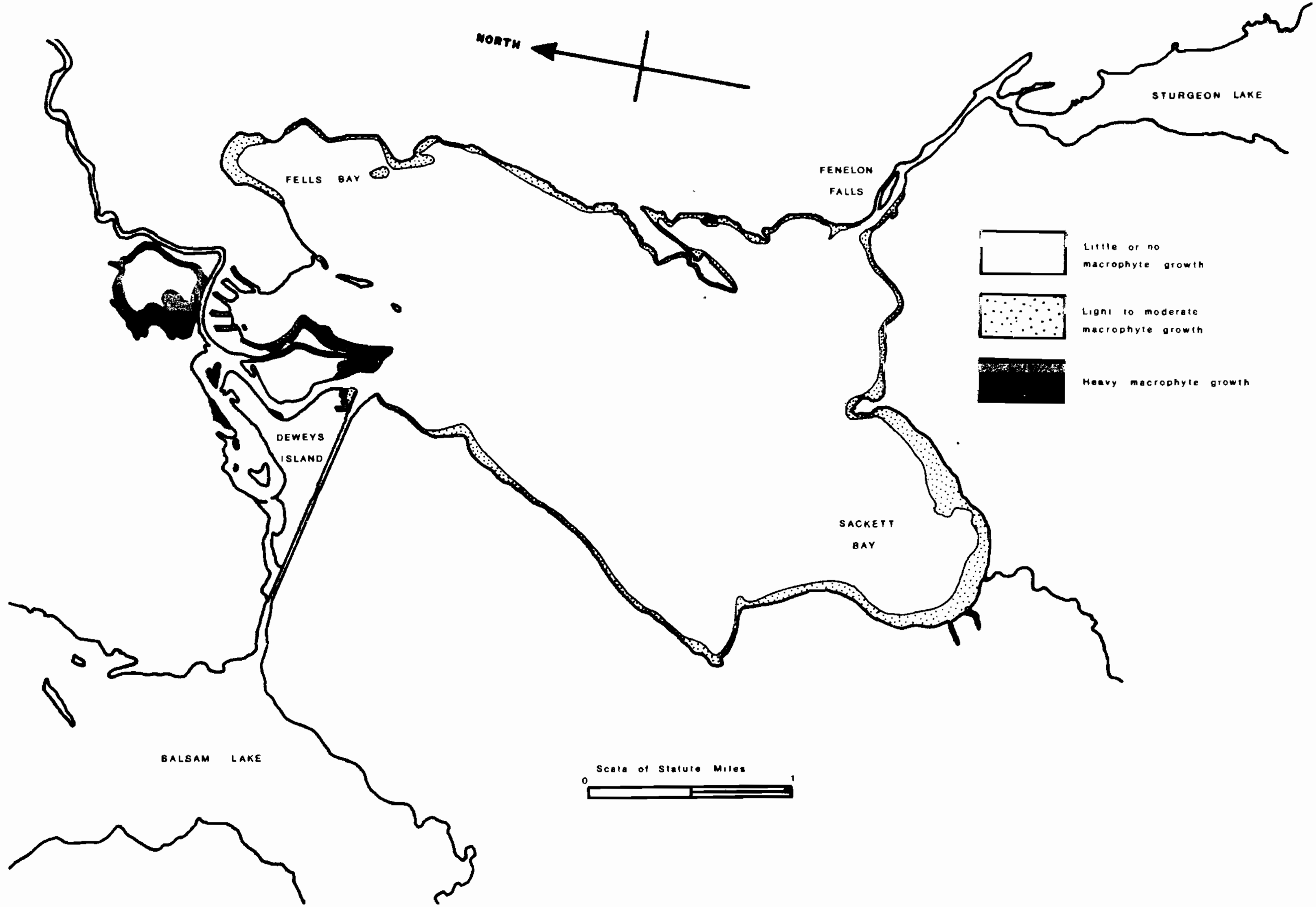


FIGURE 3 - DISTRIBUTION OF AQUATIC VEGETATION IN SOUTHERN PIGEON LAKE

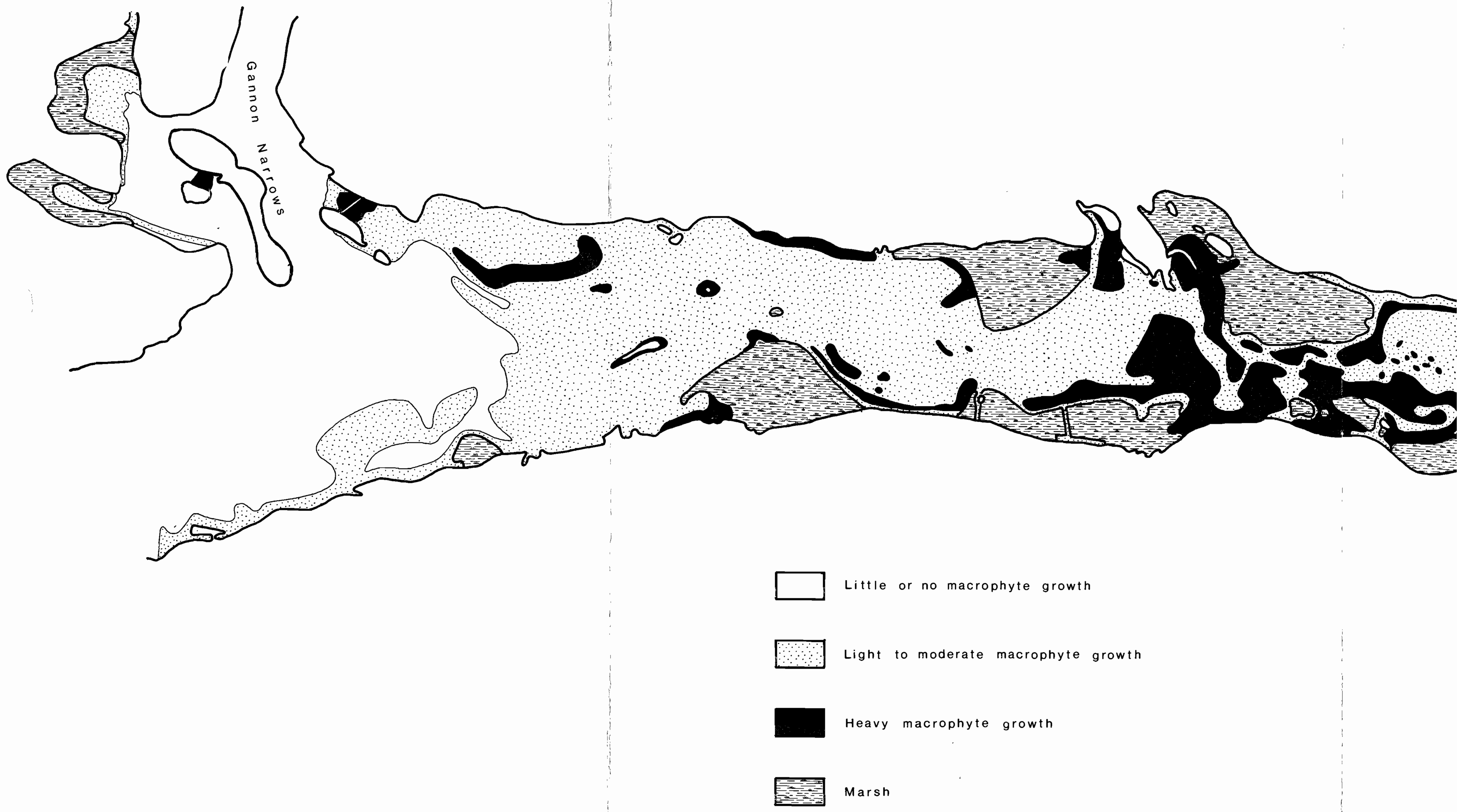


FIGURE 3 - DISTRIBUTION OF AQUATIC VEGETATION IN SOUTHERN PIGEON LAKE

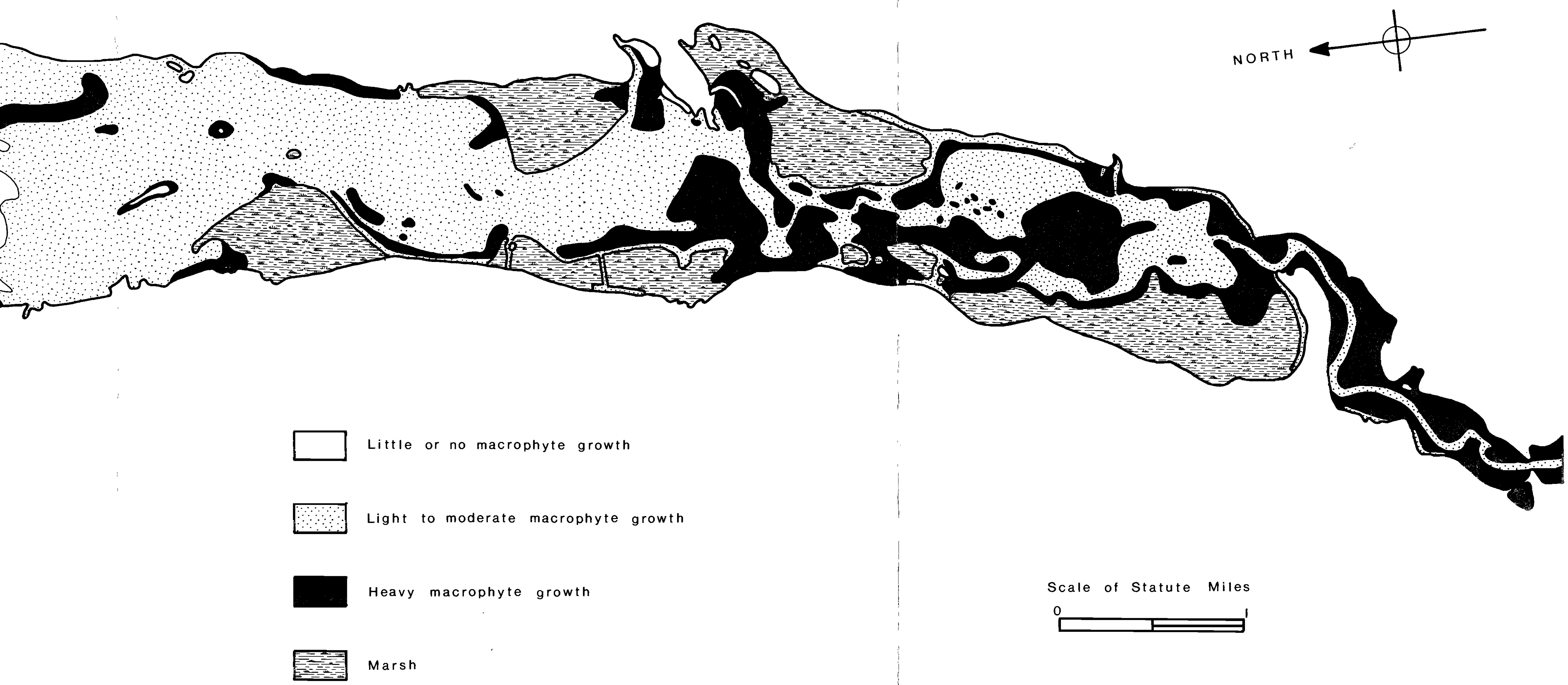


FIGURE 4 - DISTRIBUTION OF AQUATIC VEGETATION IN BUCKHORN LAKE

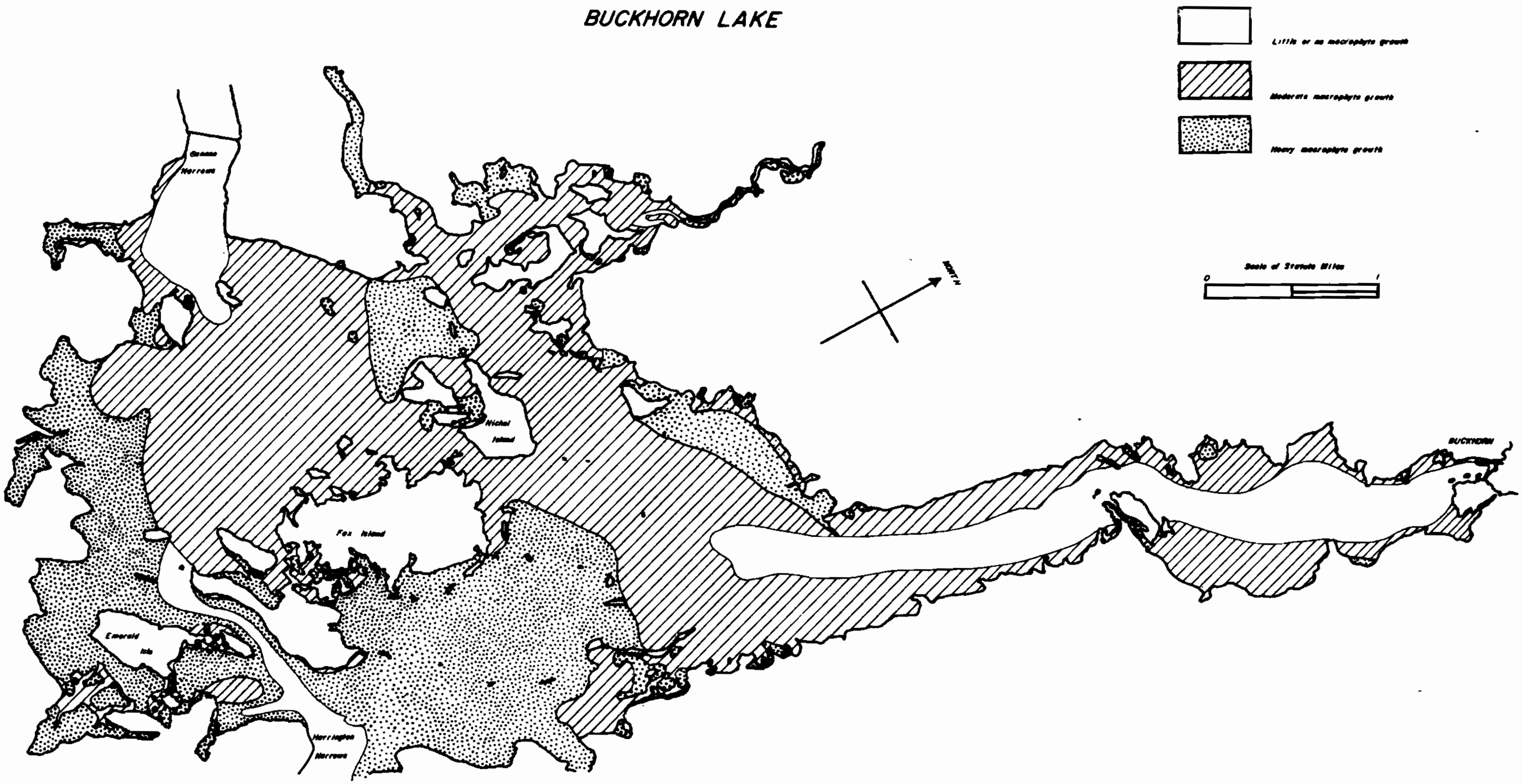


FIGURE 5 - DISTRIBUTION OF AQUATIC VEGETATION IN CHEMUNG LAKE

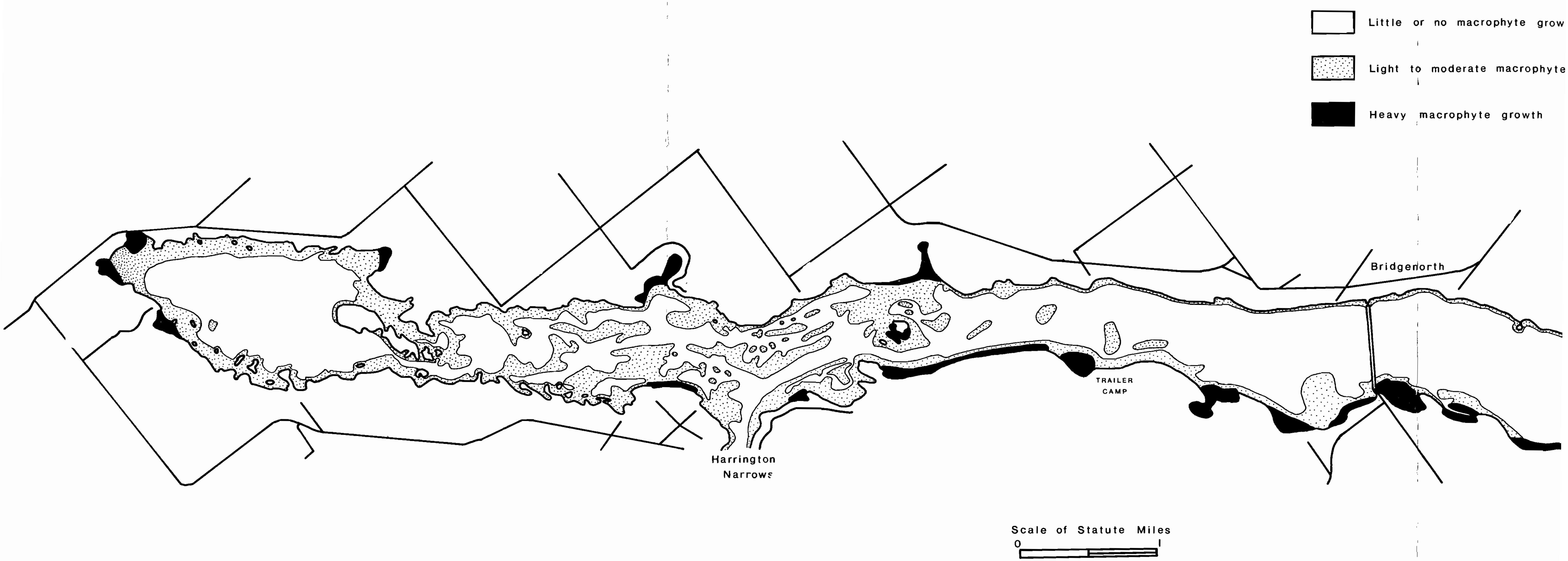


FIGURE 5 - DISTRIBUTION OF AQUATIC VEGETATION IN CHEMUNG LAKE

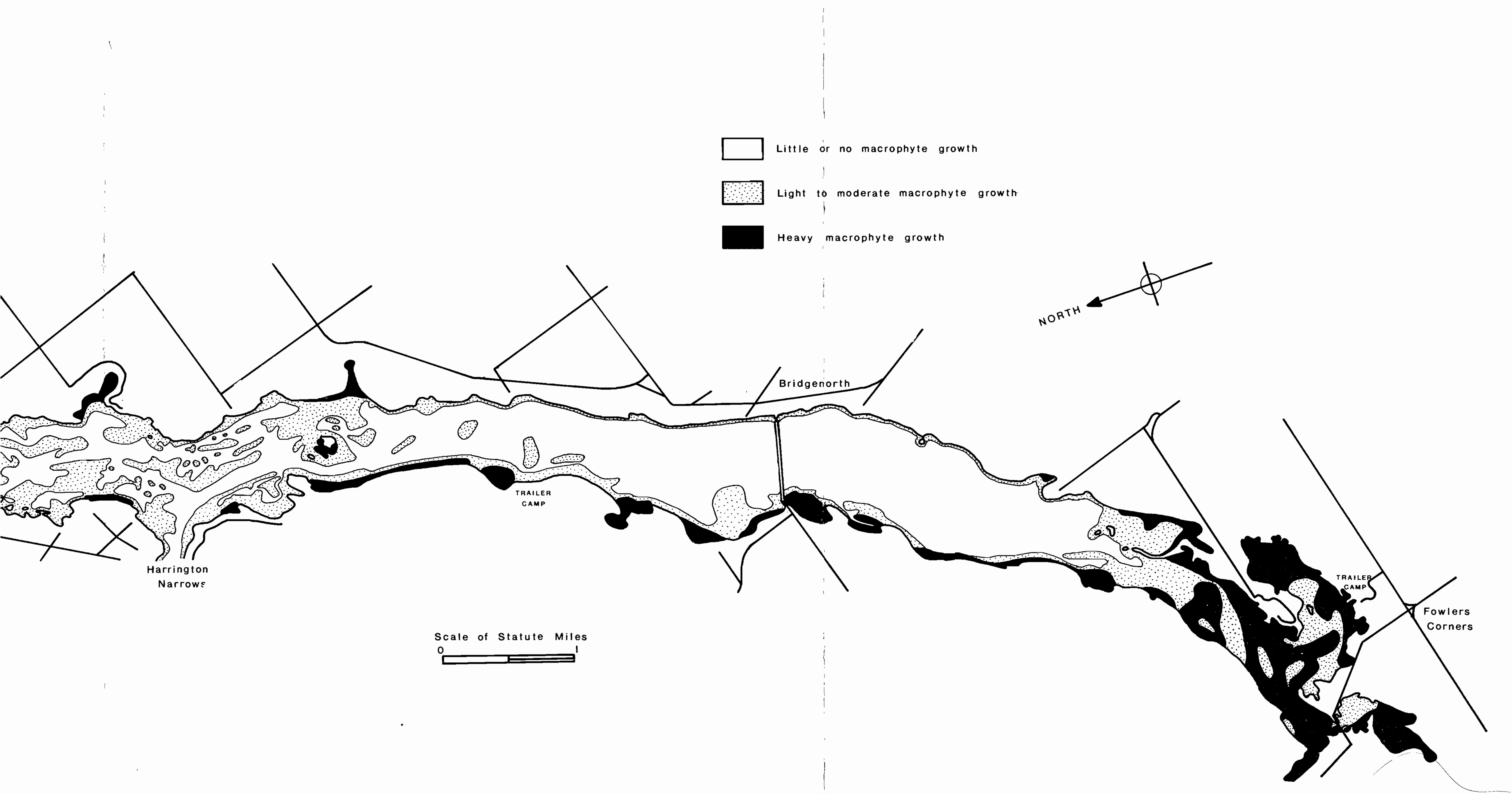


FIGURE 6 - DISTRIBUTION OF AQUATIC VEGETATION IN KATCHIWANOOKA LAKE

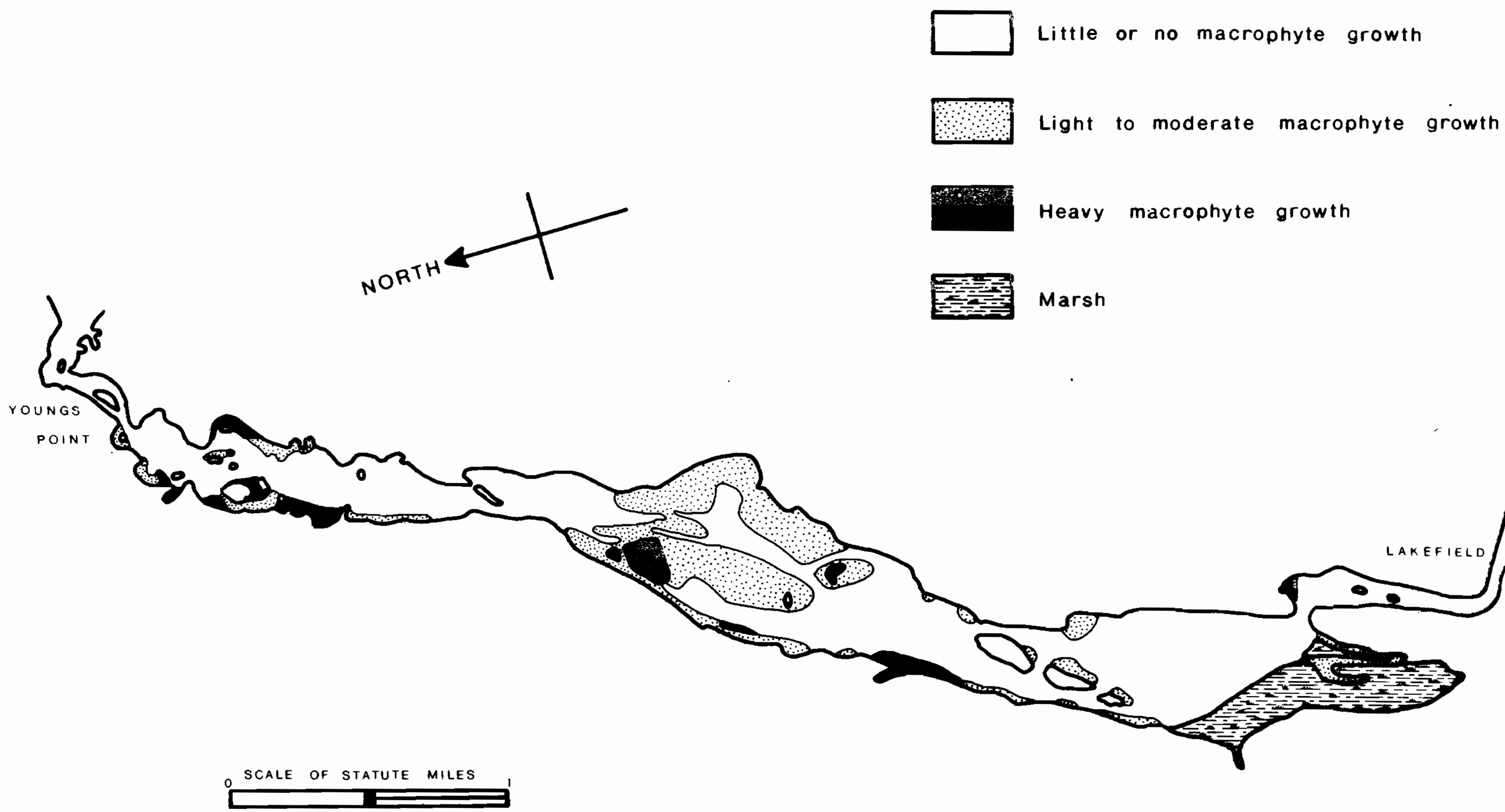


FIGURE 7 - DISTRIBUTION OF AQUATIC VEGETATION IN RICE LAKE

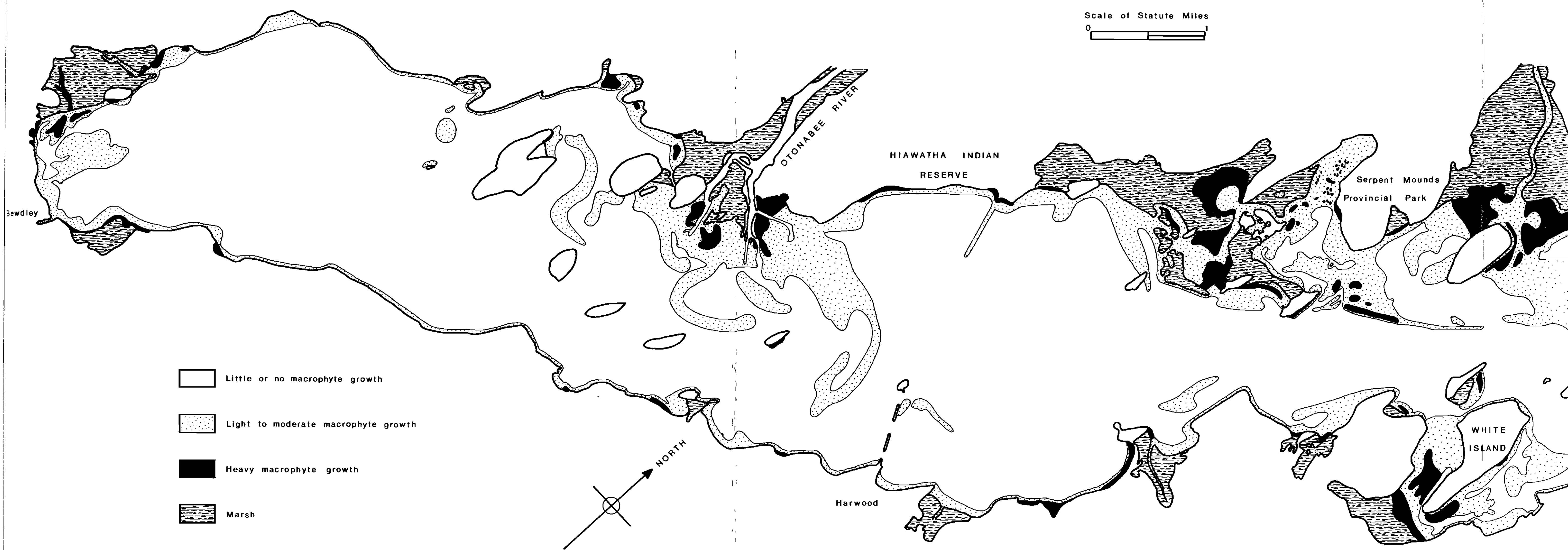
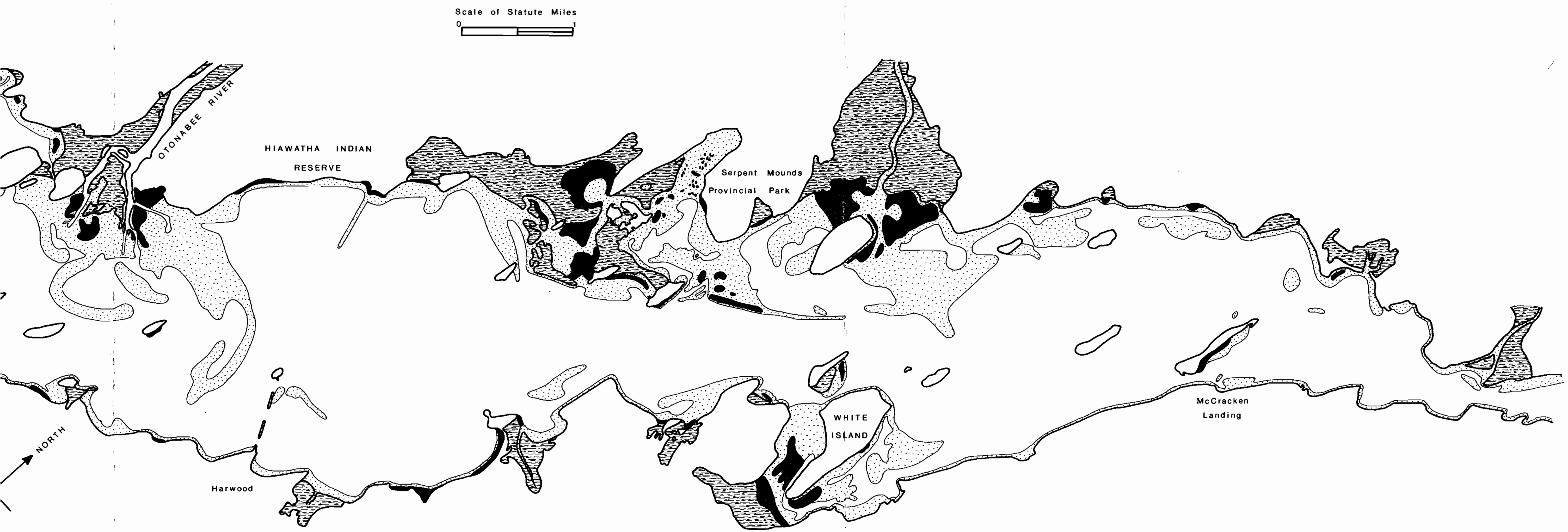
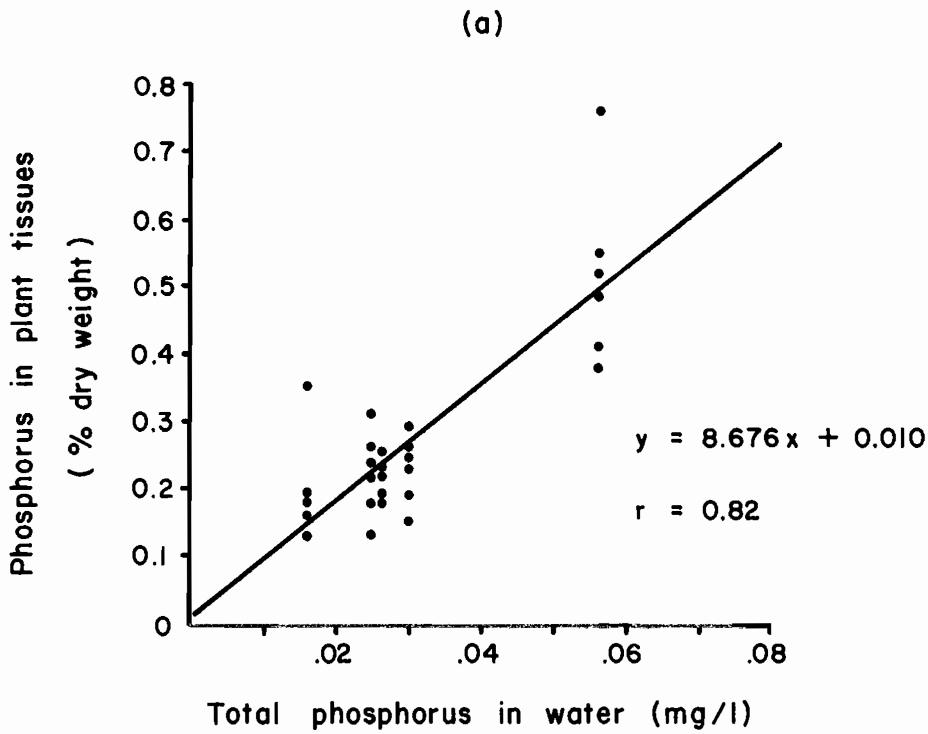


FIGURE 7 - DISTRIBUTION OF AQUATIC VEGETATION IN RICE LAKE





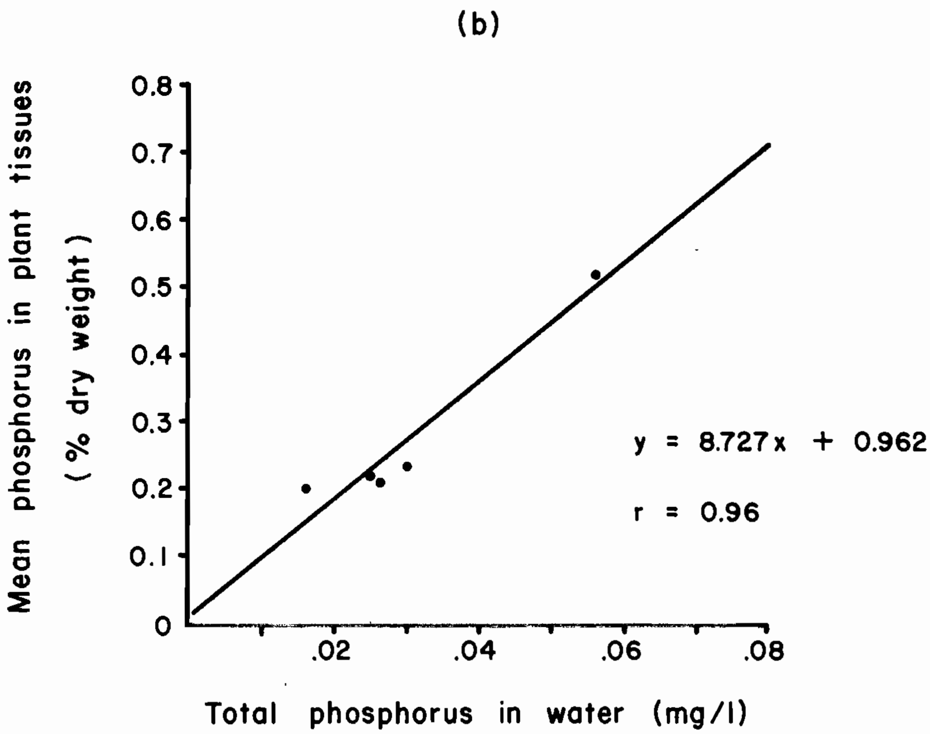


FIG. 8 Relationship between (a) phosphorus and (b) mean phosphorus in plant tissues and total phosphorus in water.

GH

CHAPTER 5

THE FISHERIES OF THE

KAWARTHA LAKES

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November 1976

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INTRODUCTION

The relative importance of the Kawartha Lakes in supplying approximately 9% of the angler recreation in the provice was established by the Provincial Creel Survey of 1970 document (Cox and Straight, 1975). Few other comprehensive studies of the Kawartha Lakes have been completed. It was therefore necessary to utilize available fisheries information for the various lakes in conjunction with physical and chemical data and hearsay evidence to describe some of the Kawartha Lakes fisheries.

The natural trophic status of the Kawartha Lakes could basically be expected to reflect the physiography and fertility levels of the surrounding landform modified to some degree by the source of inflow into a particular lake. The southern lakes, Scugog and Rice are larger, uniformly shallow lakes of high mineral content. They are characteristically productive of warm water, littoral fish species such as those of the percid, cyprinid, centrarchid and esocid families. Conversely, Stony Lake, on the north, surrounded by and overlying granitic bedrock is an historically more oligotrophic lake with deep, cold water, and a history of salmonid and coregonid production. It is the very high natural productivity combined with highly desired fish stocks that have attracted anglers to the Kawartha Lakes in record number.

FISHING

According to the Provincial Creel Survey (Cox and Straight 1975), fishing provided an estimated 40.8 million angler days of recreation across the province in 1970.

Because the questionnaire included a grid map where anglers were asked to mark the locations of their fishing trips, it was possible to segregate areas of some size with a fairly good degree of accuracy. This analysis indicated that the Kawartha Lakes provided 9.07% of the angler recreation in the province, or about 3.7 million angler days per year. By way of comparison, Lakes Simcoe and Couchiching provided about 1.6 million angler days in 1970.

To examine the fisheries in more detail it is necessary to consider individual lakes for which the best information is available. Data discussed will therefore be most representative of conditions as they exist for specific waters with some relationship to other lakes in the chain in varying degrees depending on environmental similarities and differences.

During 1973 and 1974, 3393 anglers were contacted on Pigeon Lake and another 6327 on Chemung Lake. The difference in numbers of anglers contacted between lakes was a function of the effort expended to collect data rather than an indication of relative angler density. Fom these data it was determined that the majority of anglers fished for walleye (Stizostedion vitreum vitreum) with only small percentages fishing other species (Table 1). This preponderance of walleye anglers was reflected in the dominant position of walleye in the harvest estimates. Table 2 illustrates this finding with walleye making up nearly half of the fish creeled.

Yellow perch (Perca flavescens) also comprised a large percentage of the creeled fish even though only a small percentage of the anglers appeared to be actively seeking this species. This suggests a high incidental catch by anglers actively seeking other species of fish, mainly walleye.

Over time there has undoubtedly been an increase in angling pressure on the lakes as the number of commercial camps and private cottages has increased. However, data are not available to quantify this angler effort. Short term data collected from Chemung Lake (1970-1975) and illustrated in Figure 1 exhibit a decline in angler effort from approximately 36 angler hours per ha. per 100 days (hr/ha/100) in 1970 to 20 hr/ha/100 in 1975. At the same time there was a corresponding decrease in both the numbers and weight of fish harvested (Fig. 2). Numbers of fish declined from 7.9 fish per ha per 100 days in 1970 to 2.7 in 1975. Estimates of biomass harvested went from approximately 3.9 kg/ha/100 days in 1970 to approximately 1.6 in 1975. A cause and effect relationship cannot be determined with any certainty. Declining fish catches may have driven down the fishing effort or conversely the declining effort may have decreased the catch. Factors other than catch which might have influenced effort include increased weed growth and distribution, economic inflation and perhaps even redirection of public uses of the waters.

Table 1: Angler preference for fish by species in Pigeon and Chemung Lakes, 1973 and 1974.

Lake	Walleye	Maskinonge	Largemouth and Smallmouth Bass	Yellow Perch	Bullhead Pumpkinseed Rockbass	Anglers Contacted (Number)
			%			
Pigeon	87.7	6.6	2.4	3.3	-	3,393
Chemung	92.0	2.6	4.0	1.1	0.2	6,329
TOTAL	-	-	-	-	-	9,722

Table 2: Percentage of fish creeled by species in Pigeon and Chemung Lake, 1973 and 1974.

Lake	Walleye	Maskinonge	Largemouth Bass	Smallmouth Bass	Yellow Perch	Pumpkinseed	Rock Bass	Bullhead
Pigeon	48.9	1.0	0.6	2.5	37.0	6.4	0.5	3.0
Chemung	46.6	0.9	1.6	4.8	29.4	11.5	3.0	2.1

Some fairly strong support for catch influencing effort was found by èxamining long term data on angler success rates for name species walleye, maskinonge, largemouth and smallmouth bass in Pigeon Lake. The measure of the rate of angling success was catch per unit of effort (CUE), in this case, the number of sport fish taken per hour of angling time. Creel data collected from 1946 to 1950 had a mean CUE of 0.27 sport fish per angler hour. Between 1961 and 1969 (four years data) there was a mean value of 0.14 sport fish per angler hour and the mean value for 1973-74 was 0.12 (Fig. 3).

During the 1940's creel data were collected for each of the four sport fish species separately. During the 1960's data for all fishing were lumped although panfish were ignored. In the 1970's information on species was again kept separately with the exception of largemouth and smallmouth bass (Micropterus salmonides and M. dolomieui) which were grouped for effort estimates. Use of the 1960's data in making comparisons among species is thus precluded. Walleye fishing success between the 1946-50 period and the 1973-74 period showed a decline in CUE from 0.29 to 0.13 fish per angler hour (Fig. 4). Maskinonge (Esox masquinongy) fishing success appears to have remained constant at 0.031 and 0.030 fish per angler hour while the rate for bass success appears to have increased from 0.38 to 0.48 fish per angler hour (Fig. 5 and 6). However, the reliability of these data sets depends greatly on sample size. Large samples were available for the walleye analysis, a function of both the number of walleye anglers and the abundance of walleye in the catch. However, sample sizes for both maskinonge and bass were comparatively small. Similarities or differences in the results of these latter species may have been a function of random variability.

It is readily apparent that walleye fishing was predominant in establishing the general sport fish CUE and that this CUE has undergone a decline. What is not clear is just why this should be so. Two phenomena have apparently occurred in the Kawartha Lakes that are worthy of note here. During the 1920's walleye were introduced into the Kawartha Lakes and it apparently took about 20 years to establish a fishery. This means that the data from the 1940's probably represent the initial effort at the walleye fishery. From that time it is interesting to look at what occurred in the bass fishery. Table 3 indicates the weight ratio between largemouth and smallmouth bass creeled over a broken series of years between 1946 and 1974 on Pigeon and Chemung Lakes. Early dominance of

Table 3: Relative abundance of smallmouth bass to largemouth bass in angler harvest creeled by weight ratio in Pigeon and Chemung Lakes.

		YEAR								
Lake	Species	1946	1947	1948	1949	1950	1971	1972	1973	1974
Pigeon	Largemouth	1	1	1	1	1	-	-	1	1
	Smallmouth	.41	.62	.69	.68	.80	-	-	2.41	5.25
Chemung	Largemouth				1		1	1	1	1
	Smallmouth				.62		.52	.64	2.15	5.14

the largemouth bass in this comparison changed with time until more recently smallmouth bass has been the dominant species. While data are inconclusive with respect to population levels, it is interesting to speculate that as the popularity of walleye increased anglers moved from fishing the more traditional largemouth bass areas. More anglers fishing walleye could then have depressed the CUE for that species. When walleye fishing success declined, anglers seeking an alternative may have turned to fishing smallmouth instead of returning to largemouth areas.

FISH PRODUCTION

The Morphoedaphic Index

The morphoedaphic index (MEI), (Ryder 1965), Ryder et al. 1974) has been used to compare potential fish production among the Kawartha Lakes (Table 4, Fig. 7). However, its strict application may not be appropriate to the Kawarthas for several reasons. The MEI was initially developed empirically to predict the annual sustained yields of unexploited lakes by comparing yields from moderately to heavily fished lakes. These yields were found to be correlated with an index derived from the ratio of mean total dissolved solids (TDS) to mean depth. Factors which detract from the predictability of harvest by this technique seem to be especially relevant to the Kawartha Lakes.

In north temperate lakes of less than 5m mean depth, winter kill may reduce the total productivity of the lake. The best example of this in the Kawarthas is Mitchell Lake, which suffers oxygen depletions annually, and has a history of severe winter kills (Ontario Ministry of Natural Resources unpublished data). Winter oxygen testing has indicated severe oxygen depletion (less than 1 ppm) over most of the lake by the end of March (Barwell, 1971). Any fishing on this lake likely is supplied, most years, by immigration from Balsam Lake. Only four of the 17 Kawartha Lakes have a mean depth of 5m or greater, and the productivity of these lakes is probably limited by hypolimnetic oxygen depletion during thermal stratification (Chapter 1). Also, in reservoir systems, such as the Kawarthas, a lower predictive efficiency of the MEI can be expected because of the more lotic nature of the waters for, as stated by Ryder et al. (1974) these waters are "neither lake nor stream but somewhere in-between.

Table 4: Comparison of potential fish production of the Kawartha Lakes using Ryder's Morphoedaphic Index.

Lake	Area		Mean Depth (summer)		T.D.S.	M.E.I.		Estimated Annual Sustained Yield From M.E.I.	
	Area++	Km^2	ft.	M	mg/1xx	English	Metric	lbs/acre/yr*	Kg./ha./yr+
Scugog	20,400	82.6	4.5	1.4	262	58.2	187	12.8	14.4
Canal	2,680	10.8	4.6	1.4	248	53.9	176	12.4	13.9
Mitchell	780	3.2	2.2	.68	117	53.2	172	12.3	13.8
Buckhorn	7,880	31.9	7.0	2.1	146	20.7	69.3	8.1	9.1
Rice	24,800	100.4	8.6	2.6	167	19.4	64.2	8.0	8.9
Chemung	5,630	22.8	8.6	2.6	167	19.4	64.2	8.0	8.9
Katchewanooka	870	3.5	7.1	2.2	139	19.6	63.3	7.9	8.9
Balds (2)	960	3.9	7.2	2.2	134	18.6	60.9	7.7	8.7
Pigeon	13,200	53.5	10.4	3.2	158	15.2	49.3	7.0	7.9
Lovesick	636	2.6	8.1	2.5	108	13.3	43.2	6.6	7.4
Lower Buckhorn	3,050	12.4	11.4	3.5	143	12.5	41.0	6.5	7.2
Sturgeon	11,100	45.0	12.7	3.9	119	9.3	30.4	5.7	6.4
Clear	2,340	9.5	18.9	5.8	136	7.2	23.5	5.0	5.7
Stony	6,980	28.3	19.8	6.0	124	6.3	20.7	4.8	5.3
Balsam	11.500	46.6	16.3	5.0	84.8	5.2	17.0	4.4	4.9
Cameron	3,220	13.0	18.9	5.8	95.1	5.0	16.4	4.3	4.8

++ Measured on hydrographic charts from Canadian Hydrographic Service

xx T.D.S. conversion from conductivities obtained from Ministry of Environment survey, 1972 (Chapter on physical and chemical limnology) where possible. Canal, Mitchell, Chemung and Lovesick Lakes from Natuaral Resources records.

*Y = 2.094 X 0.4461 X = M.E.I. (English units) Y = lbs/acre/yr.

\+ Kg./ha./yr = lbs/acre/yr ÷ .89

The MEI relationship among the lakes of the Trent Waterway may still be relevant at some different level of sustainable harvest from that predicted. Present criteria for use of the MEI are that lakes of a comparison set must have basically the same environmental conditions, but may vary significantly in mean depth and TDS (Ryder et al. 1974). Examination of harvest estimates for Sturgeon Lake (Armstrong 1968, 1970), Pigeon Lake (Weir 1950; Ontario Ministry of Natural Resources 1961, 1965) and Chemung Lake (Ontario Ministry of Natural Resources unpublished data) show a remarkable similarity which might be expected from similar lakes of confluent nature (Figure 7). It is also evident that the harvest level is somewhat less than that predicted by the MEI. Care should be taken in interpreting the significance of this discrepancy because of the multiplicity of factors influencing the harvest estimates and the actual harvest. Included among these factors are the effects of random sampling and experimental error, physical and chemical limitations of the lakes, intensity of fishing efforts and the species selectivity of the angling fraternity.

Figure 7 shows the predicted angling yield of the Kawartha Lakes plotted against three other Ontario lakes, Lake Opeongo (Martin and Fry, 1972), Lake Simcoe and Lake St. Clair (E.T. Cox, personal communication). Opeongo is representative of those lakes which produce good populations of lake trout and are characteristically deep, clear and cold with low productivity. Simcoe and St. Clair are two lakes noted for their fish production and mixed communities of fish similar to those found in the Kawarthas. The comparison suggests that the Kawarths have the potential for some of the highest fisheries production in the province.

Percids, centrarchids and esocids

The fish species composition of the Kawartha Lakes (Table 5) is quite consistent with the trophic classification described in Chapters 1, 2 and 3. The occurrence of percids, centrarchids and esocids in all the lakes plus historic mention of large numbers of bass and maskinonge in Sturgeon Lake (Langton, 1926) suggests a certain consistency with time.

Variation in species composition may only reflect shifts in relative abundance in response to impoundment, exploitation or the introduction of walleye into the Kawarthas in the 1920's and 1930's. Little trend-in-time information is available for these species. Tables 6, 7, 8 and 9 indicate age-length relationships, survival and mortality rates for

TABLE 5. FISH SPECIES IDENTIFICATION IN THE KAWARTHA LAKES FROM O.M.N.R. RECORDS

O.M.N.R. CODE NO.	SPECIES	CANAL	MITCHELL	SCUGOG	CHEMUNG	BUCKHORN	RICE	KATCHEWANOOKA	BIG BALD	PIGEON	LITTLE BALD	LOVESICK	STURGEON	LOWER BUCKHORN	BALSAM	STONY	CLEAR	CAMERON	SPECIES COMMON NAME
81	Salvelinus namaycush															0			Lake Trout
90	Coregonus clupeaformis															0	0		Lake Whitefish
93	Coregonus artedii				0		0			0			0					0	Cisco, Lake Herring
132	Esox masquinongy	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Maskinonge
141	Umbra limi	X			X										X			X	Central Mudminnow
163	Catastomus commersoni	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	White Sucker
185	Couesius plumbeus			X	X														Lake Chub
186	Cyprinus carpio	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Carp
194	Notemigonus crysolcucas		X	X	X	X		X	X	X	X				X	X	X		Golden Shiner
196	Notropis atherinoides				X														Emerald Shiner
199	Notropis heterodon				X	X					X								Blackchin Shiner
200	Notropis heterolepis								X	X	X								Blacknose Shiner
201	Notropis hudsonius		X	X	X	X		X	X	X	X			X		X	X		Spottail Shiner
208	Pimephales notatus	X		X	X	X		X	X	X	X	X		X	X	X	X	X	Bluntnose Minnow
209	Pimephales promelas												X		X				Fathead Minnow
212	Semotilus atromaculatus			X	X						X		X		X	X			Creek Chub
214	Semotilus margarita							X											Pearl Dace
232	Ictalurus natalis	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Yellow Bullhead
233	Ictalurus nebulosus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Brown Bullhead
261	Fundulus diaphanus				X														Banded Killifish
271	Lota lota						X			X		X	X	X		X	X	X	Ling
281	Culacea inconstans				X										X				Brook Stickleback
291	Percopsis omiscomaycus			X									X		X				Trout Perch
311	Ambloplites rupestris	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Rockbass
313	Lepomis gibbosus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Pumpkinseed
316	Micropterus dolomieui	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Smallmouth Bass
317	Micropterus salmoides	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Largemouth Bass
331	Perca flavescens	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Yellow Perch
334	Stizostedion vitreum vitreum	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Walleye, Yellow Pickerel
338	Etheostoma exile	X	X	X	X	X		X	X		X			X	X	X	X	X	Iowa Darter
339	Etheostoma flabellare				X										X				Fantail Darter
341	Etheostoma nigrum		X																Johnny Darter
342	Percina caprodes					X		X				X		X		X	X		Log Perch
381	Cottus bairdi				X	X									X				Mottled Sculpin

0 considered rare or extinct X recorded as captured

the four major sport fish species in various lakes studied between 1956 and 1975.

Since little variation is apparent in the age-length relationships among lakes over time, the data were grouped to give general relationships for the Kawartha Lakes sport fish which may be used as a baseline for future comparisons. A direct arithmetic mean was used to determine the average condition to avoid weighing the data in favour of fish from any one lake. General agreement with age-length relationships for fish from other Ontario waters can be noted in Tables 6 to 9.

Estimates of survival and mortality were approximated using the age frequencies of fish sampled for the age-length relationships. Maskinonge survival and mortality estimates showed the least variability (approx. ± 13% of the mean value) lake to lake and year to year, while those for smallmouth bass demonstrated the greatest (approx. ± 34%) variation. Survival rates were approximated as ± 25% for walleye and ± 22% for largemouth bass. In each of the four species examined, the individual ranges demonstrate central tendency of the means suggesting normal distribution and that variation is more likely attributable to inherent randomness of estimates than to any real differences.

Figures 8, 9, 10 and 11 depict weight-length regressions for the same four fish species in Pigeon Lake during 1963-64-65 and 1975. During both time periods total lengths were recorded only for maskinonge. Measurements for the other species changed from fork length to total length during the interval. Regression curves for maskinonge show excellent agreement and differences between curves for the other species can be attributed mainly to the length of the fork in the tail. This suggests that there has been no significant change in condition of the fish during the short time interval involved. The value of the data is again essentially that of establishing a point-in-time base line for future comparisons.

Salmonids and Coregonids

Salmonids and coregonid histories in the Kawartha Lakes are those of fisheries under stress. There was rumoured to be a natural population of lake trout (*Salvelinus namaycush*) in Stony Lake which has become

TABLE 6

MASKINONGE

AGE-LENGTH RELATIONSHIPS, SURVIVAL AND MORTALITY RATES IN THE KAWARTHA LAKES

AGE CLASS		1	2	3	4	5	6	7	8	9	10	11	12	s	a	Z
							Length (cm)									
LAKE	YEARS(S) SAMPLED															
Cameron	1963-64	43.4	52.1	59.4	68.1	78.7	69.6	90.2	86.4	94.2	-	-	-	.58	.42	.55
Sturgeon	1963-64	-	49.0	55.4	66.3	70.9	80.5	83.8	99.8	-	109.7	-	-	.66	.34	.41
Stony	1956&58	-	38.1	50.0	59.1	67.6	72.1	82.5	99.1	109.5	116.8	-	-	.51	.49	.67
Rice*	1969	-	45.2	57.6	-	-	88.4	-	-	-	-	-	-	-	-	-
Katchewanooka*	1971	-	45.9	60.1	73.2	83.9	96.5	-	-	111.8	-	-	-	.53	.47	.63
Pigeon*	1963-64-65	-	51.0	63.0	71.1	75.4	81.8	91.4	103.1	102.1	108.4	113.5	123.2	.58	.42	.54
Pigeon*	1975	-	53.0	65.7	74.5	81.7	87.5	94.2	-	95.8	-	-	-	.54	.46	.61
Mean Fork Length		43.4	46.4	54.9	64.5	72.4	74.1	85.5	95.1	101.8	113.2	-	-	.57	.43	.57
Mean Total Length		-	48.8	61.6	72.9	80.3	88.5	92.8	103.1	103.2	108.4	113.5	123.2			
St. Lawrence River Fork Length +		-	47.6	58.7	69.2	79.8	82.4	87.6	95.6	105.6	113.7	112.5	109.3			

* Total length, otherwise fork length

\+ Hourston (1952) from Scott and Crossman (1973)

s = annual survival rate a = rate of annual total mortality

Z = instantaneous rate of total mortality

TABLE 7

LARGEMOUTH BASS

AGE-LENGTH RELATIONSHIPS, SURVIVAL AND MORTALITY RATES IN THE KAWARTHA LAKES

AGE CLASS		1	2	3	4	5	6	7	8	9	10	11	12	s	a	Z
		Length (cm)														
LAKE	YEAR(S) SAMPLED															
Cameron	1963-64	18.5	25.4	30.0	33.5	35.8	39.6	38.9	-	45.5	-	46.5	-	.52	.48	.64
Sturgeon	1963-64	-	23.9	29.7	33.3	39.1	40.1	40.4	42.2	47.5	46.7	49.8	46.5	.72	.28	.32
Rice	1967	20.8	-	27.1	30.8	33.9	37.3	38.8	42.0	43.2	45.0	47.2	-	.66	.34	.42
Katchewanooka	1971	-	-	-	33.8	39.1	42.7	46.5	43.7	46.7	-	-	-	-	-	-
Pigeon	1963-64-65	-	22.1	24.4	33.8	34.5	37.6	40.4	43.2	40.6	46.0	42.9	46.0	.82	.18	.20
Pigeon*	1975	-	25.9	32.8	36.3	38.2	41.6	44.0	45.0	43.0	47.7	-	-	.65	.35	.43
Mean Fork Length		19.6	23.8	27.8	32.8	35.8	38.6	39.6	42.5	44.2	45.9	46.6	46.2	.67	.33	.39
Mean Total Length		-	25.9	32.8	35.0	38.6	42.2	45.2	44.4	44.8	47.7	-	-			
Lake Simcoe * +		10.2	20.3	25.4	30.5	34.3	36.8	41.9	43.2	44.5	45.7	48.3	50.3			
Ontario Avg. * ++		17.0	19.6	28.7	32.0	34.8	39.1	42.7	45.0	45.7	49.0	46.2	50.3			

* Total length, otherwise fork length

\+ MacCrimmon and Skobe (1970) from Scott and Crossman (1973)

++ MacKay (1963) from Scott and Crossman (1973)

s = Annual Survival Rate, a = Rate of Annual Total Mortality, Z = Instantaneous Rate of Total Mortality

TABLE 8

SMALLMOUTH BASS

AGE-LENGTH RELATIONSHIPS, SURVIVAL AND MORTALITY RATES IN THE KAWARTHA LAKES

AGE CLASS		1	2	3	4	5	6	7	8	9	10	11	12	s	a	Z
		Length (cm)														
LAKE	YEAR(S) SAMPLED															
Cameron	1963-64	13.0	19.0	24.4	29.2	32.2	39.4	40.6	43.7	43.2	-	-	-	.59	.41	.52
Sturgeon	1963-64	-	18.5	23.6	29.0	32.8	36.8	39.4	41.1	41.6	42.2	-	45.7	.49	.51	.72
Rice	1966	-	-	23.7	27.2	33.0	37.8	40.4	43.2	46.7	46.2	47.0	-	.38	.62	.96
Rice*	1969	-	-	29.5	33.3	39.6	42.7	44.4	46.2	-	-	-	-	.56	.44	.58
Katchewanooka	1971	-	-	28.4	31.2	35.4	40.7	41.0	45.8	47.3	50.2	-	49.3	.77	.23	.26
Pigeon	1963-64-65	-	19.1	24.4	29.7	34.4	37.1	42.4	43.5	44.3	46.7	48.5	-	.51	.49	.67
Pigeon*	1975	-	23.0	26.6	31.9	37.2	40.0	42.7	43.9	46.4	48.0	46.2	48.8	.76	.24	.27
Mean Fork Length		13.0	18.9	24.0	28.8	33.1	37.8	40.7	42.9	44.0	45.0	47.8	45.7	.58	.42	.54
Mean Total Length		-	23.0	28.2	32.1	37.4	41.1	42.7	45.3	46.8	49.1	46.2	49.0			
Lake Huron +		14.0	17.8	21.1	24.6	27.4	30.5	33.0	35.1	38.6	39.1	39.6	41.1			
L. Nipissing ++		-	20.6	23.9	27.7	29.7	34.0	35.6	37.6	39.4	41.1	41.4	-			

* Total length, otherwise fork length

\+ White (1970) from Scott and Crossman (1973)

++ Tester (1932) from Scott and Crossman (1973)

s = Annual Survival Rate, a = Rate of Annual Total Mortality

Z = Instantaneous Rate of Total Mortality

TABLE 9

WALLEYE

AGE-LENGTH RELATIONSHIPS, SURVIVAL AND MORTALITY RATES IN THE KAWARTHA LAKES

AGE CLASS		1	2	3	4	5	6	7	8	9	10	11	12	s	a	Z
							Length (cm)									
LAKE	YEAR(S) SAMPLED															
Cameron	1963-64	-	28.7	31.5	37.1	38.4	45.7	46.0	48.0	49.0	51.0	-	58.4	.46	.54	.77
Sturgeon	1963-64	20.8	25.6	31.5	37.6	40.9	43.2	47.0	52.6	55.4	54.1	57.9	61.7	.68	.32	.39
Rice	1967	-	24.1	29.0	33.5	38.4	41.9	45.7	48.3	50.8	50.5	50.5	51.6	.65	.35	.44
Rice*	1969	-	29.7	34.5	39.4	44.2	48.5	53.8	59.9	62.5	-	-	-	.47	.53	.76
Katchewanooka	1971	-	31.1	34.2	41.0	46.9	50.9	54.5	57.2	61.9	63.8	67.9	68.0	.77	.23	.26
Pigeon	1963-64-65	-	-	33.1	36.1	39.9	43.2	46.2	48.5	51.6	55.1	57.4	57.9	.59	.41	.53
Pigeon*	1975	-	29.0	34.0	39.1	42.7	45.3	49.0	52.5	53.7	58.7	59.5	68.5	.66	.34	.42
Mean Fork Length		20.8	26.1	31.3	36.1	39.4	43.5	46.2	49.4	51.7	52.7	55.6	57.4	.61	.39	.49
Mean Total Length		-	29.9	34.2	39.8	44.6	48.2	52.4	56.5	59.4	61.2	63.7	68.2			
Bay of Quinte +		21.3	32.3	40.1	46.5	51.8	55.6	58.4	61.5	63.5	65.0	66.8	66.5			

* Total Length, otherwise fork length

\+ Payne (1964) from Scott and Crossman (1973)

s = Annual Survival Rate, a = Rate of Annual Mortality

Z = Instantaneous Rate of Total Mortality

extinct. No hard evidence of the truth of this rumour was found, but stocking records reveal lake trout plantings in Stony Lake in 1922, 1924, 1925 and 1926, and in Clear Lake in 1922, 1946 and 1947. Possibly these plantings were in response to a lake trout fishery that had failed or conversely the lake trout rumours may have originated from the earliest plantings. More concrete evidence is available for the existence of lake whitefish (Coregonus clupeaformis) in Stony Lake. Burleigh Falls was the site of a heavy fall spawning run of whitefish said to have been in the 6 to 7 kg range. Scott and Crossman (1973) reported records of 20 pound (9 kg) whitefish from the Great Lakes, 50 or more years ago, lending veracity to these reported weights for Stony Lake whitefish. Local residents were reported to have fished these spawning runs with nets and dynamite and to have hauled the catch away by the ton (J.C. Weir, personal communication). Records of the Ministry of Natural Resources for Stony Lake, 1962, relate the results of an experimental whitefish netting, stating that "large whitefish (8-14 pounds) in limited numbers dominated the catch and disappeared entirely as the spawning season approached".

In spite of the use of small mesh gill nets (11.4 cm stretch mesh) no whitefish smaller than 6 pounds (2.7 kg) were taken. No spawning run materialized below Burleigh Falls that year and net set in that general area caught nothing. Several factors were mentioned as possible contributors to the demise of the whitefish including:

"1. A gradual rise in summer water temperatures.
2. Fluctuating water levels.
3. Oxygen depletions at lower depths brought about by the decomposition of aquatic plants and algae.
4. Sliming over of spawning beds by the death of an extensive crop of algae or possible pollution.
5. Predation by a dominant population of walleye on such species as herring and young whitefish."

Strangely, no mention was made of poaching as a possible contributor to the elimination of the spawning run. Regardless of the initial cause of the collapse of the whitefish population, present chemical data demonstrate a severe oxygen depletion of hypolimnetic waters (Chapter 1). It is doubtful if Stony Lake could now support anything more than, at most, a remnant population. Although definite conclusions await further study, it appears that a once suitable habitat for coregonids has deteriorated because of a change in trophic status.

At Bobcaygeon, on the major inflow to Pigeon Lake, there is also a history of a major coregonid spawning run (likely Coregonus artedii) in the fall of the year. These runs disappeared in the late 1940's as walleye stocks increased (Stan Nicholls and R.M. Simpson, personal communication). At present there is believed to be only a remnant population as evidenced by the occasional capture of cisco by spring trap netting in adjacent waters and a very few taken by hook and line in the canal at Bobcaygeon. Again walleye introductions and oxygen depletions may be responsible for restricting cisco production. Which of these stresses was most important is a matter of conjecture and may only be dependent on which occurred first.

Colby et al. (1972) examined the problem of changes in ichthyofauna induced by a trophic shift (eutrophication) in great detail for a number of lakes and have proposed mechanisms to explain them. The sequence of species response appears to be from lake trout to whitefish to cisco (Figure 12). The Stony and Pigeon Lake histories, supported by both rumour and fact appear to be consistent with this general response. Similarly, Christie et al. (1972) considered the effects of species introductions on salmonid communities. While no specific examples of walleye introductions were used in their paper, the processes involved appear to apply in this case.

After its introduction to the Kawartha Lakes, walleye used many man-made spawning sites such as dam tail races at Bobcaygeon, Burleigh Falls, and Rosedale; causeways at Gannon Narrows and Chemung Lake; and a sunken railway bed in Rice Lake. Such structures may have created habitat required by the walleye to succeed and become the most populous and popular sport fish in the Kawartha Lakes. Their piscivorous habit and large numbers could then have placed significant pressure on coregonid populations.

Thus, salmonid-coregonid history in the Kawarthas appears to have been one of declining fish stocks. Early exploitation of lake whitefish at Burleigh Falls was reported to have been extreme. Eutrophication and introductions have also appeared as possible contributing factors in the decline.

SUMMARY

The Kawartha Lakes provide one of Ontario's most important sport fisheries. Numbers of anglers on the lakes are high although short term data collected from Chemung Lake suggest a decline in angler use and harvest. Relatively long term data from Pigeon Lake indicate declining angler success. This decline is apparently limited to the walleye fishery, angler success for maskinonge remaining constant and that for bass, constant or improving. There has been an apparent shift in bass caught from a dominance of largemouth to a dominance of smallmouth.

The morphoedaphic index was used to compare the Kawartha Lakes trophically and to estimate their relative fish production potential. This estimation ignored the physical limitations inherent in the lakes. Harvest estimates from several of the lakes were similar but less than predicted, attributable in part to the physical limitations of the lakes but also to selectivity of species by anglers and to the intensity of angler effort. The comparison among lakes was still considered valid since all the lakes are under similar environmental stresses and differ mainly with respect to mean depth and total dissolved solids.

Fish species composition of these lakes appears compatible with the trophic classification of Chapters 1, 2 and 3. Age-length relationships of four sport fish species were similar among lakes and over time and were comparable to those for other Ontario waters. Length-weight regressions developed for two time periods on fish of Pigeon Lake indicated similar conditioning of the fish with no apparent change.

Salmonid-coregonid histories of Pigeon and Stony Lake indicated declining fish stocks. These declines were attributable to excessive exploitation, eutrophication, the introduction of walleye or to some combination of these factors.

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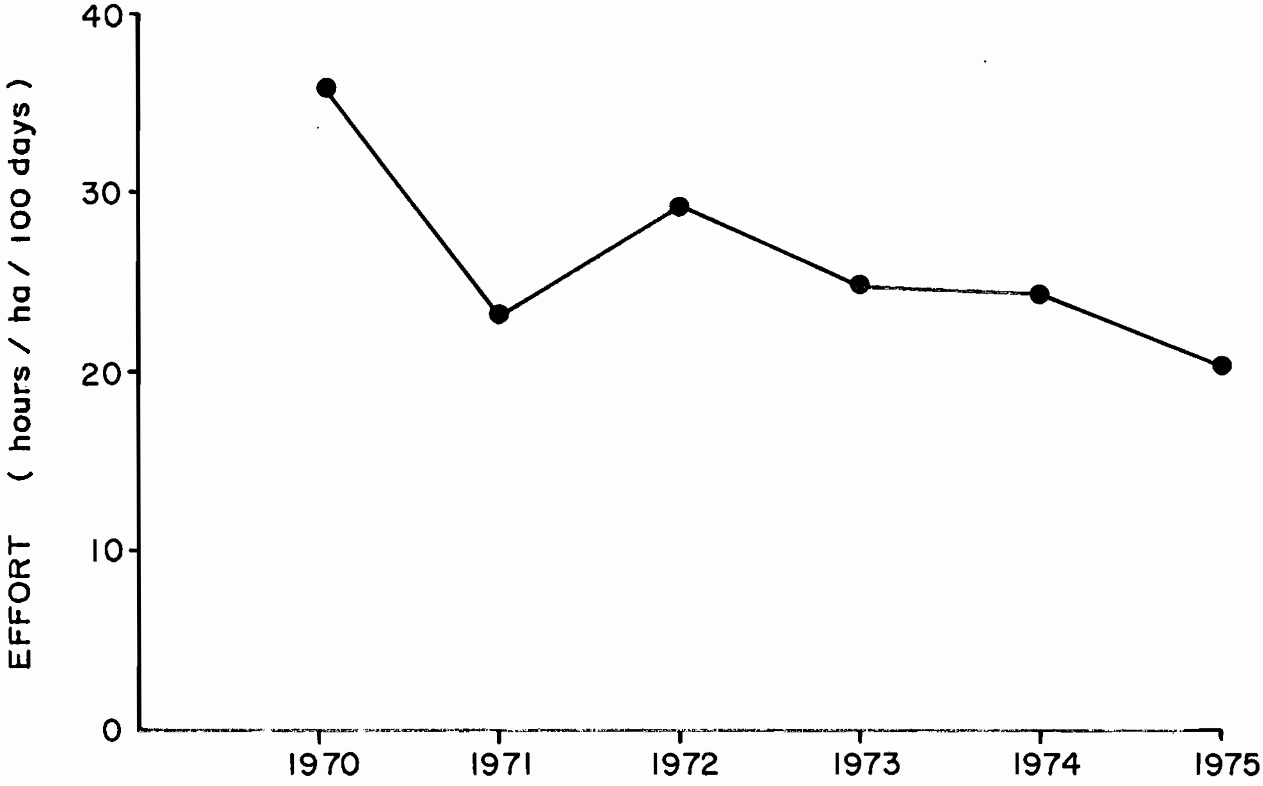

FIG. 1 Chemung Lake creel census estimates of angler effort.

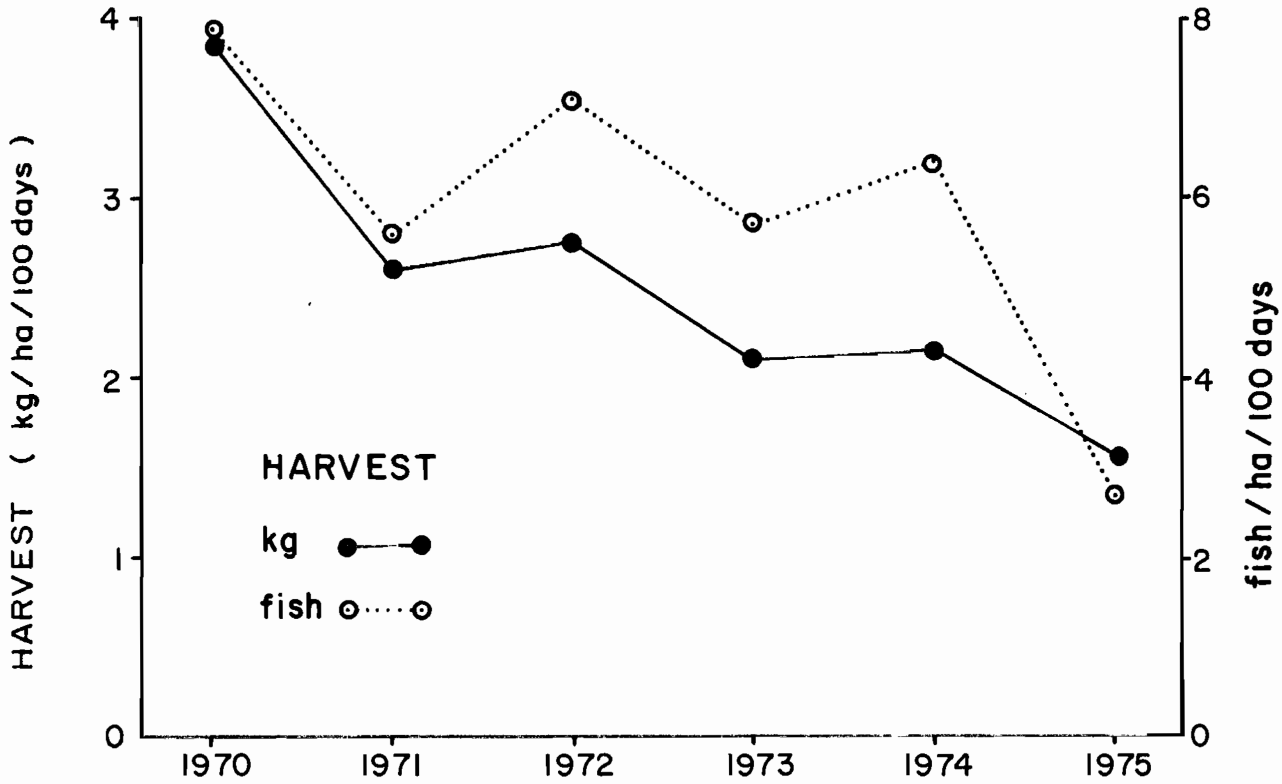

FIG. 2 Chemung Lake creel census estimates of angler harvest.

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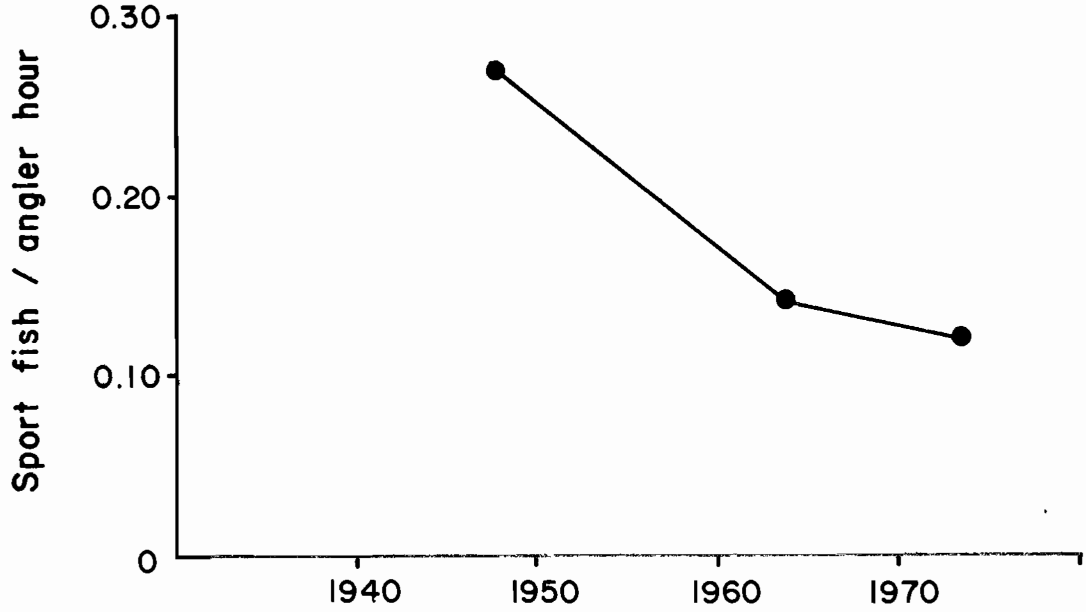

FIG. 3 Pigeon Lake creel census estimates of sport fish catch per unit effort showing mean values for 1946-50, 1961-69, and 1973-74.

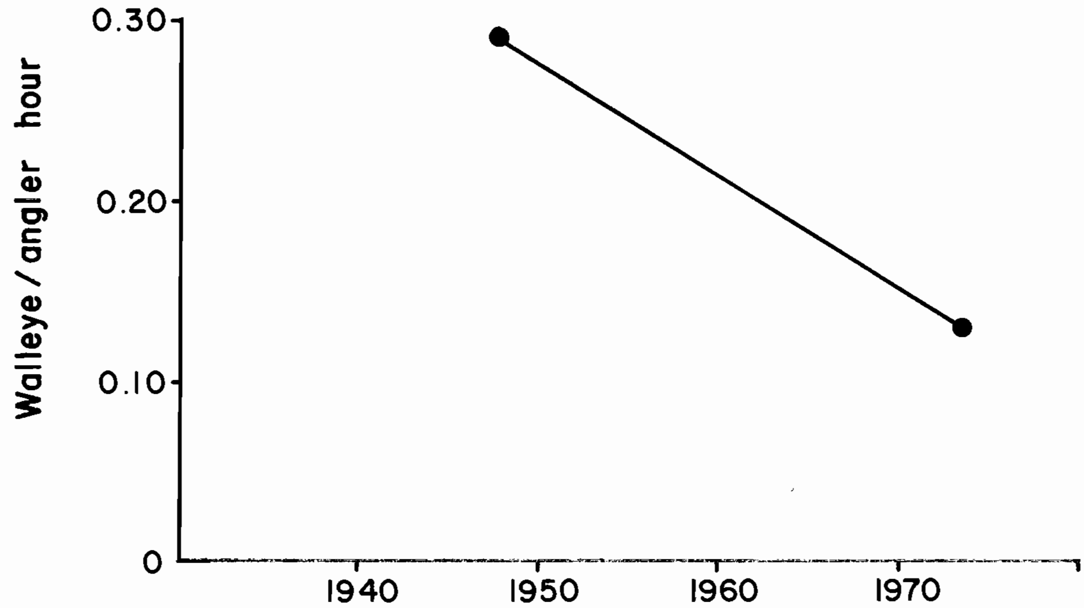

FIG. 4 Pigeon Lake creel census estimates of walleye catch per unit effort with means for 1946-50 and 1973-74.

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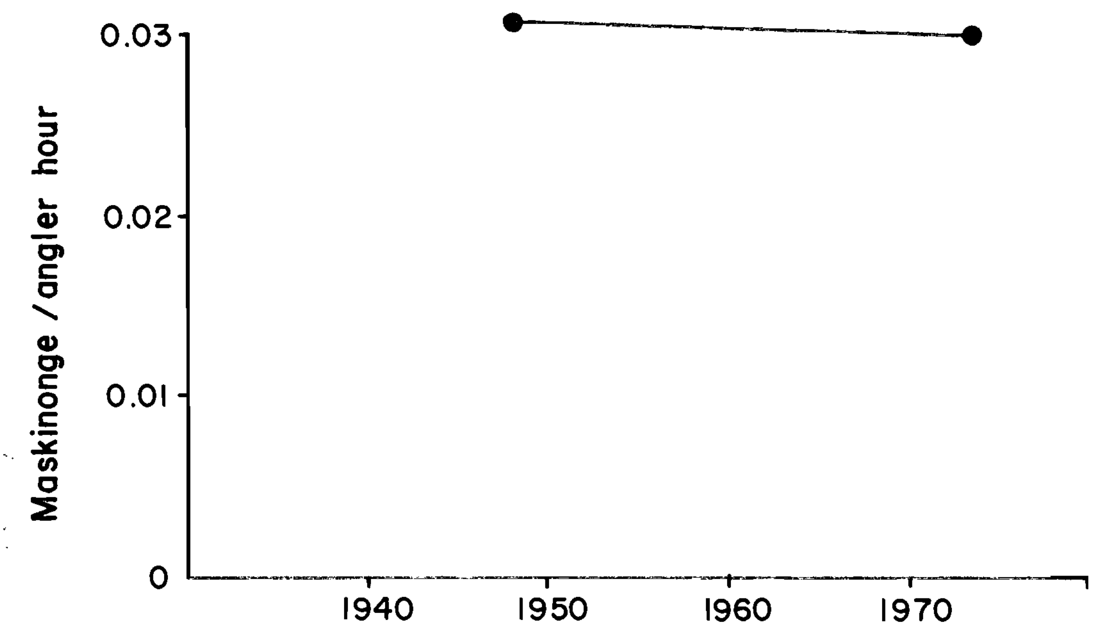

FIG. 5 Pigeon Lake creel census estimates of maskinonge catch per unit effort showing mean values for 1946-50 and 1973-1974.

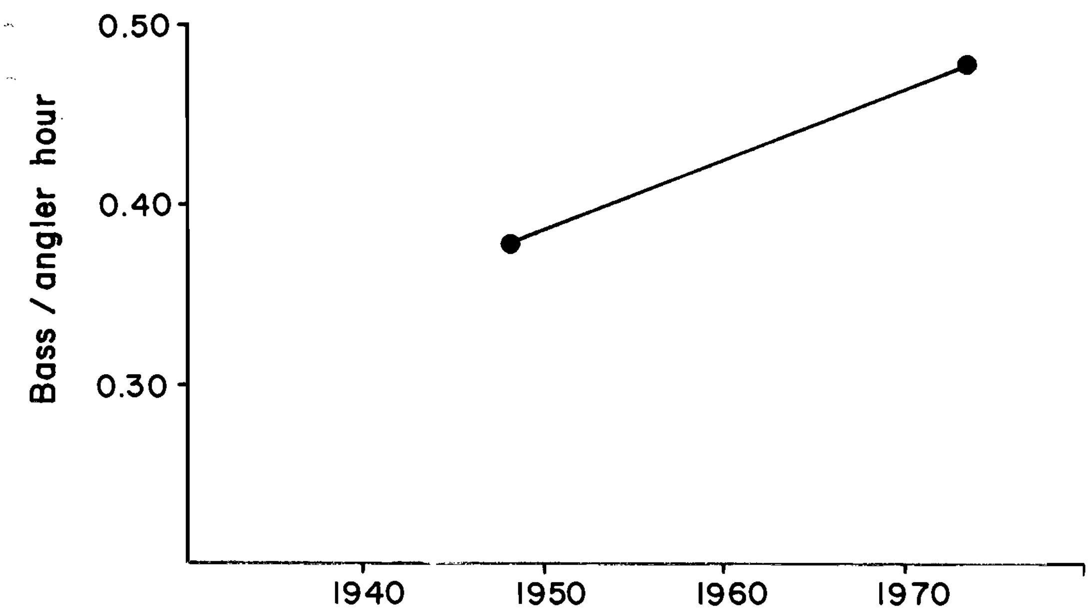

FIG. 6 Pigeon Lake creel census estimates of bass catch per unit effort showing mean values for 1946-1950 and 1973-1974.

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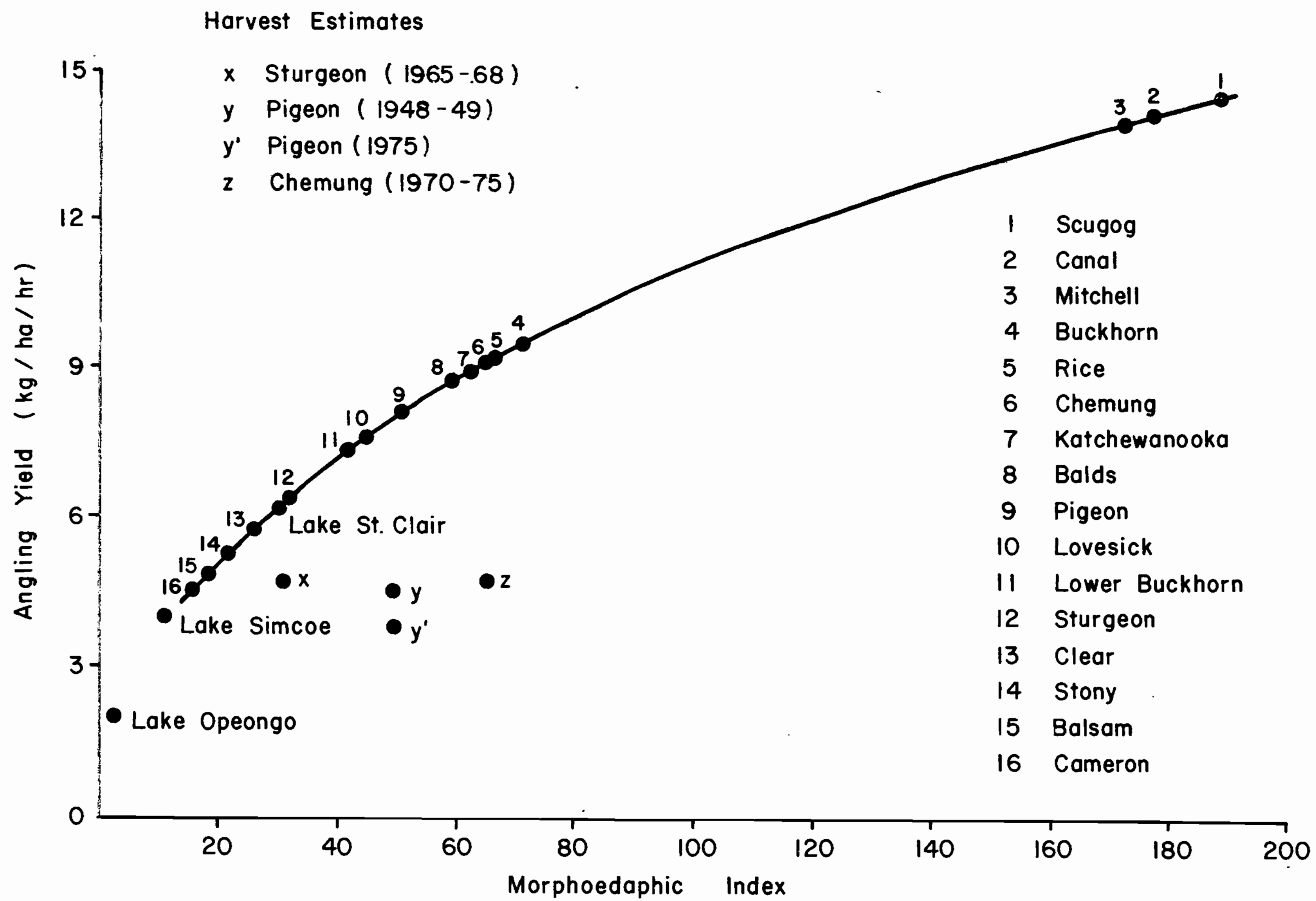

FIG. 7 Theoretical annual sustained yield vs M.E.I. for the Kawartha Lakes.

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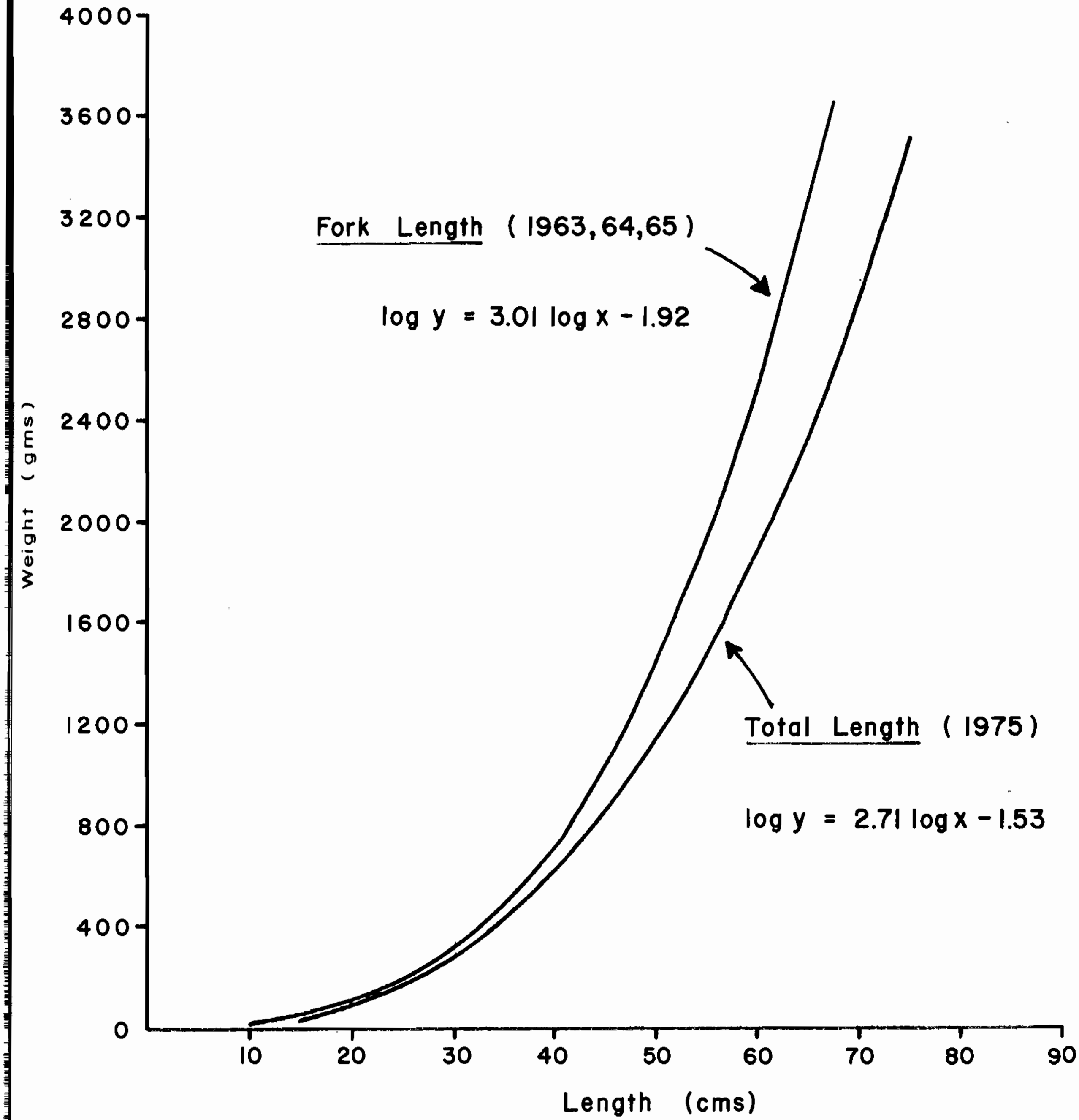

FIG. 8 Length - weight regression for Walleye in Pigeon Lake.

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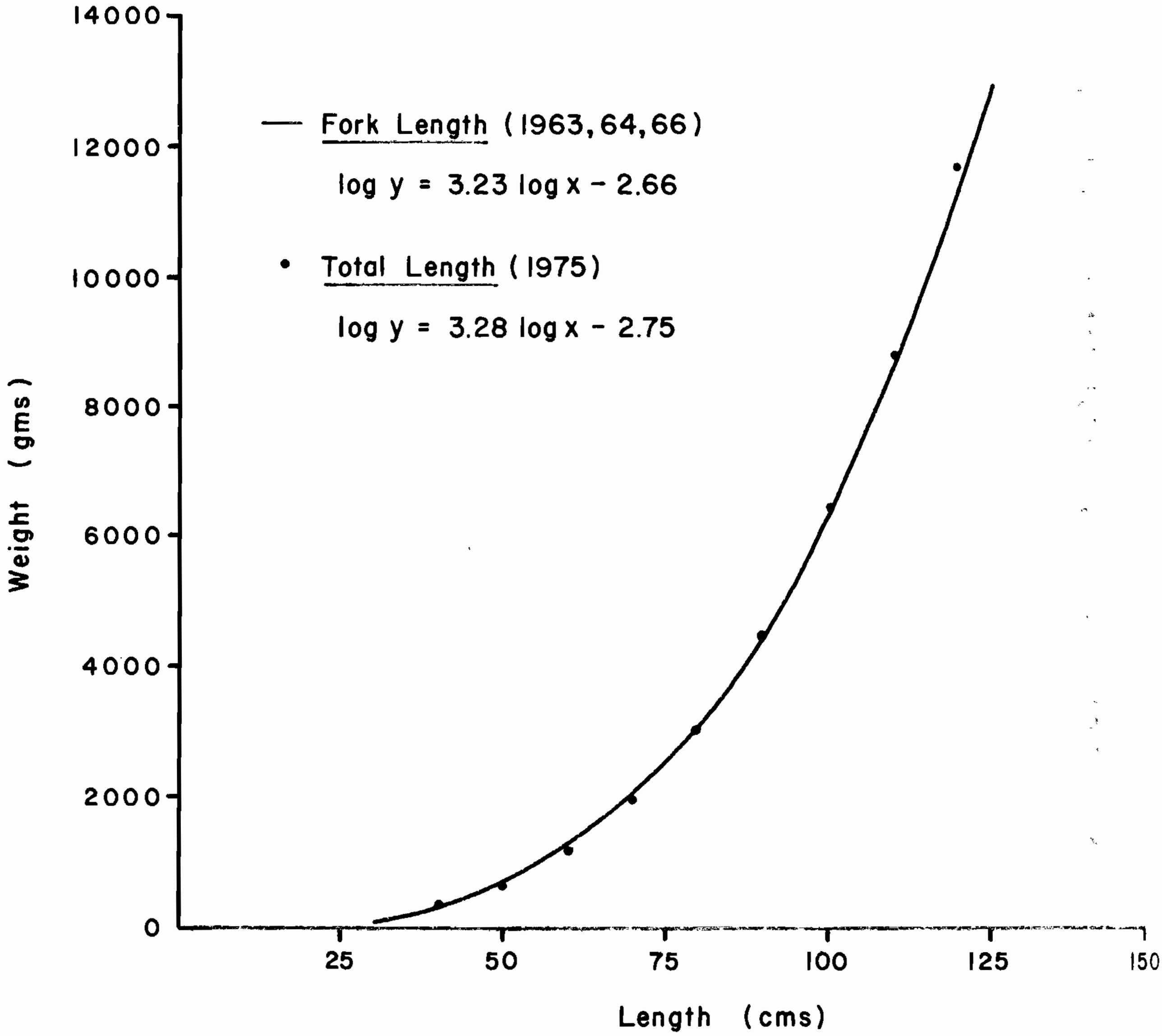

FIG. 9 Length – weight regression for Maskinonge in Pigeon Lake.

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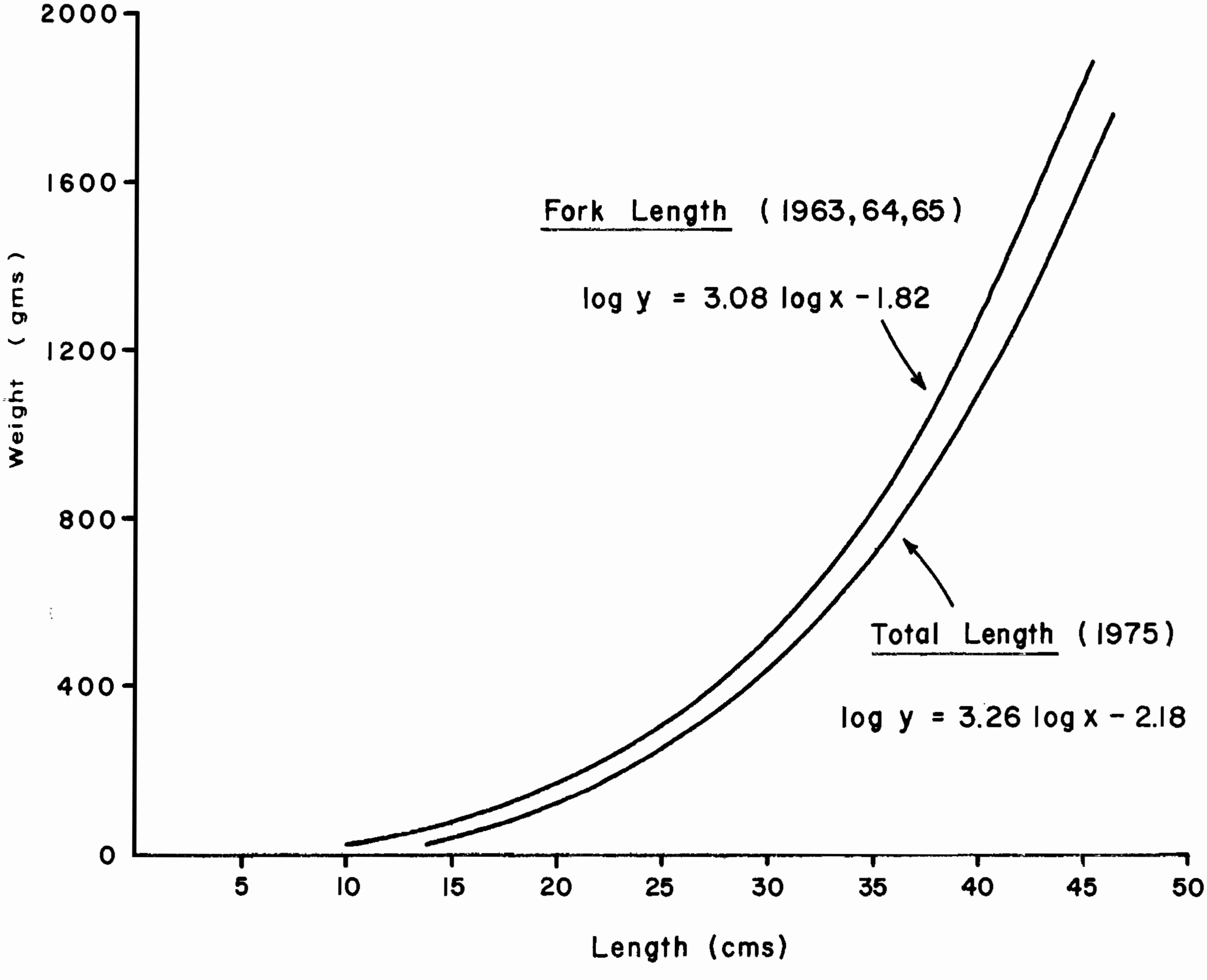

FIG. 10 Length - weight regression for Largemouth Bass in Pigeon Lake.

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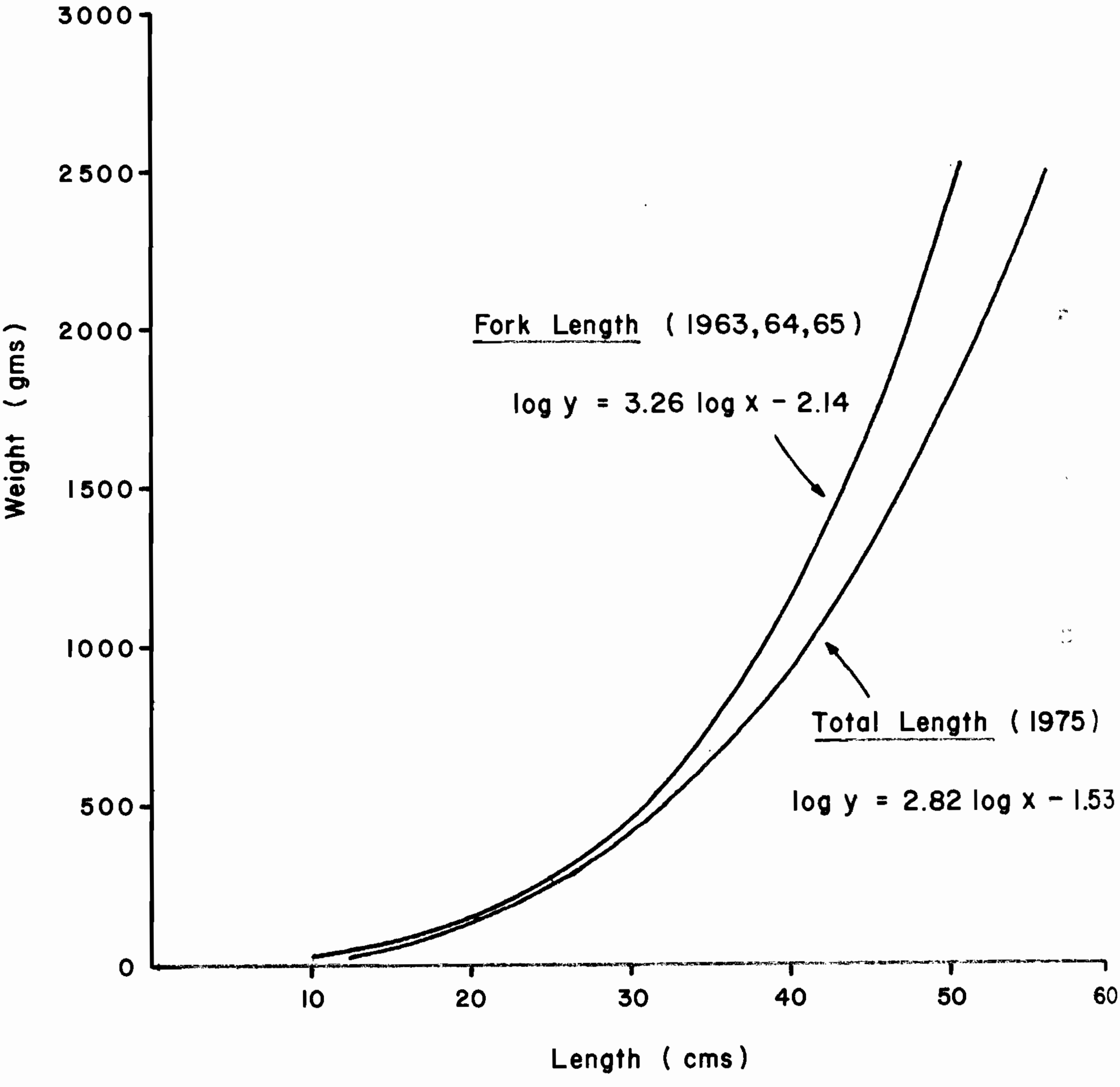

FIG. 11 Length - weight regression for Smallmouth Bass in Pigeon Lake.

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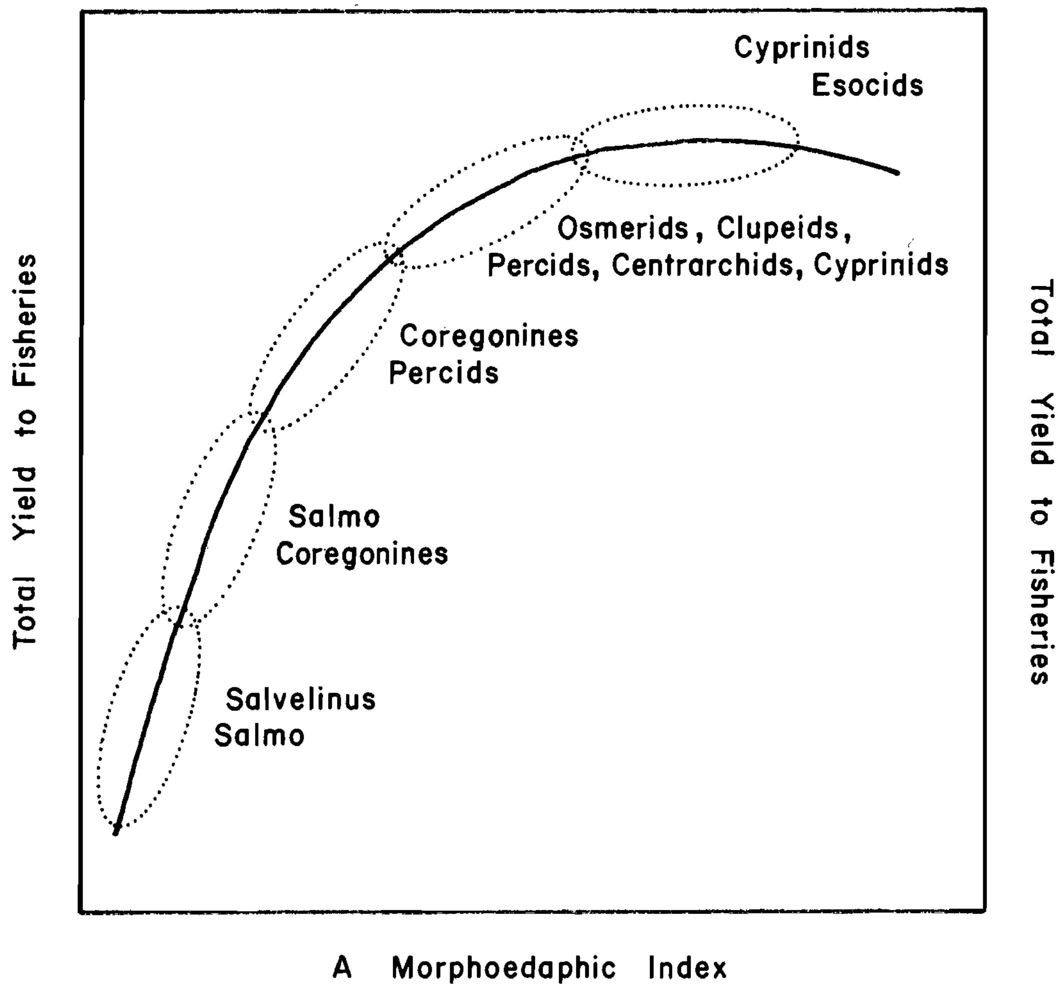

FIG. 12 Suggested relation between total yield and an index of productivity and the relationship between fish communities and trophic status. [From Colby et al., 1972]

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CHAPTER SIX

NUTRIENT BALANCE

May, 1971 to April, 1972
with an updating to reflect
recent loading changes

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Water Resources Branch
November, 1976

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SUMMARY

Land drainage is by far the major source of nutrient input to the Kawartha Lakes. The concentrations of materials entering the lakes are very low and in a form generally unavailable to aquatic plants and algae. As a result their impact is less significant than their proportion of the total loading would imply.

Atmospheric loadings are significant in the larger lakes although the availability of nutrients in rain and snowfall is not known.

Local inputs to most are small sources in terms of the total loadings. Major sewage treatment plants, however, do contribute significantly and have an impact for many miles (and lakes) downstream. Because phosphorus from municipal sewage treatment plants may be in the dissolved and biologically available form, phosphorus loadings from local sources can have a major impact on water quality. Unlike land drainage, the relatively low nutrient loadings from local sources are probably far more significant than their proportion of the total loading indicate.

Phosphorus removal programs initiated at the major sewage treatment plants in 1975 have significantly reduced the loadings of phosphorus to the system.

INTRODUCTION

Nutrient inputs were measured or calculated for all the major lakes in the Trent-Kawartha System (Figure 1) for total phosphorus, total nitrogen and organic carbon.

The bulk of information contained in this report is based on literature reviews and file searches, questionnaires and intensive and extensive water sampling programs carried out during the early 1970's. An update to reflect the impact of major changes affecting the nutrient loadings that have occurred since 1972 is included in the last part of this of this chapter. Budgetary and time limitations precluded a re-survey at the depth and with the scope of the 1971-72 program.

The hydrologic budget, sampling and data collection techniques and the computation of the nutrient loadings are described in the following sections.

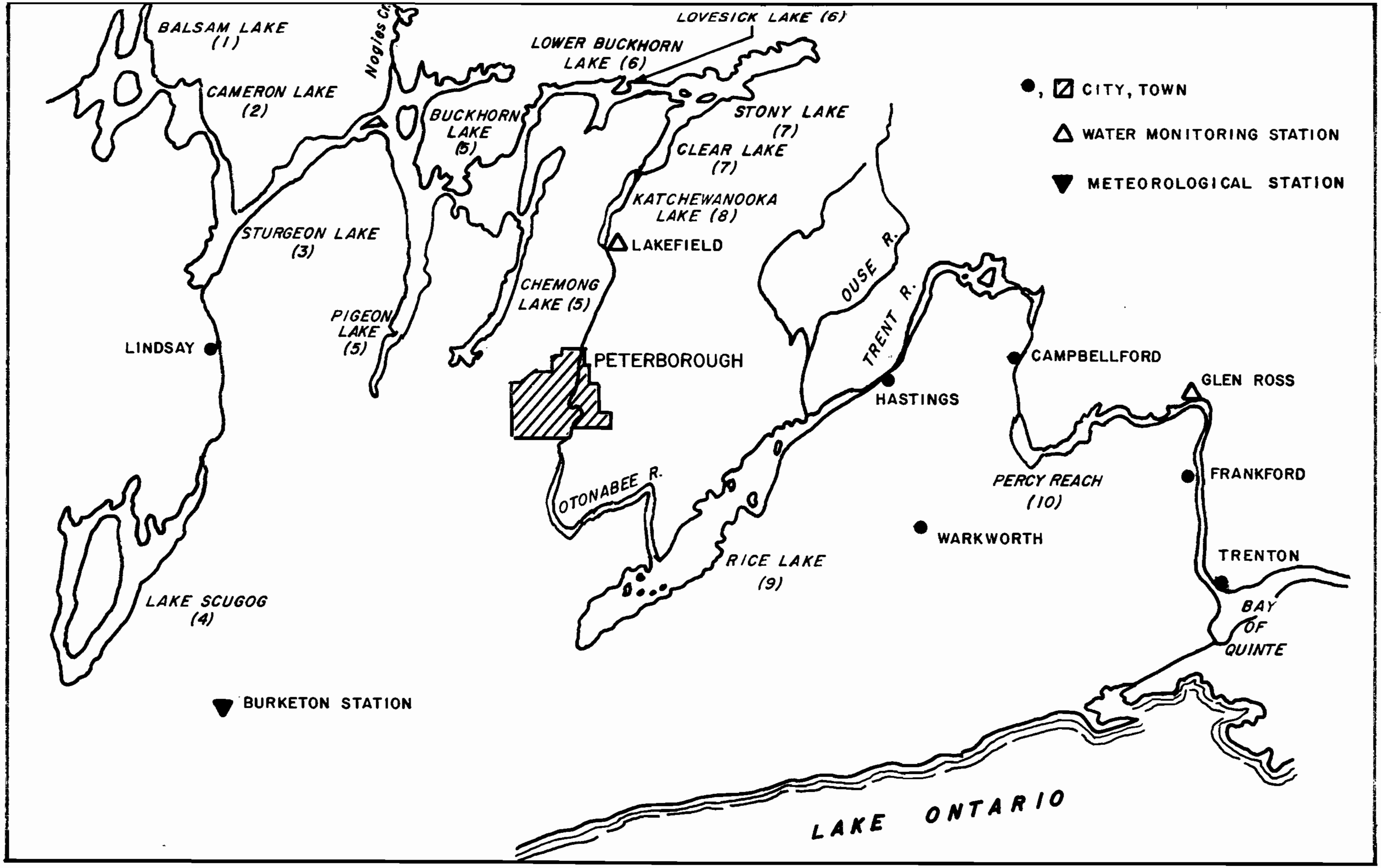

FIGURE 1 : TRENT – KAWARTHA SYSTEM

METHODS

The Water Budget

A necessary prerequisite to calculating a nutrient balance is an accurate water budget for the Kawartha-Trent system. Principal sources of information for the budget include: daily streamflow records for gauges operated by the Water Survey of Canada (Environment Canada); daily and intermittent streamflow records from Canada Department of Transport (now maintained by the Department of Indian and Northern Affairs); selected streamflow measurements by the Ontario Ministry of the Environment (measurements usually taken when water quality samples were being collected); and precipitation and evaporation records of the Atmospheric Environment stations of Environment Canada. The water budget was divided into ten sequential sub-basins beginning with Balsam Lake and its tributary streams and ending with the Trent River (Rice Lake outlet to Trenton). Details of the water budget are presented in Table 1.

In computing the water budget, six principal components were identified as follows:

Gains

1. Main Channel Inflow

From the configuration of the Kawartha Lakes chain, the main channel inflow is, in most cases, equal to the main channel outflow from the adjacent upstream lake. This component is the largest single gain in each case. Balsam Lake and Lake Scugog being head water lakes do not have a main channel inflow component. Their outflows are the sum of tributary inflow, overland drainage, local inputs and precipitation less evaporation.

2. Tributary Inflow

This is the volume of water entering a lake from rivers or streams (that are tributaries) to the lake. Wherever available, continuous streamflow records were employed; however, for a stream having only intermittent flow data,

TABLE 1

WATER BALANCE

May 1971 - April 1972
(millions of cubic metres)

LAKE	MAIN CHANNEL INFLOW	GAINS			LOSSES	GAINS (+) AND LOSSES(-) FROM CHANGES IN LAKE STORAGE	MAIN CHANNEL OUTFALL
		TRIBUTARY INFLOW	PRECIITATION	OVERLAND DRAINAGE	EVAPORATION		
BALSAM	NIL	528	36.1	78.3	30.4	- 1.6	610
CAMERON	610	453	11.0	95.8	9.3	- 1.5	1160
STURGEON	1160	193	33.3	74.9	29.3	+ 4.3	1430
SCUGOG (off system)	NIL	35.8	67.9	68.7	51.2	-22.2	99.0
PIGEON BUCKHORN CHEMUNG	1430	52.2	85.6	171	78.2	+ 7.1	1670
LOWER BUCKHORN LOVESICK	1670	80.4	10.7	76.6	9.7	- 1.3	1830
STONY CLEAR	1830	144	26.1	46.4	23.9	- 0.2	2020
KATCHEWANOOKA	2020	NIL	2.7	38.7	2.4	-	2060 2070*
RICE	2230	150	66.5	116	60.4	+ 3.4	2440
TRENT RIVER	2440	708	NIL	399	NIL	-	3500
TOTAL	—	2340	340	1160	295	—	—

* Data obtained from Water Survey of Canada gauge 2 HJ002

a comparison between it and a nearby stream with continuous records were calculated. A listing of tributary streams and methods of determining flow are appended in 6-A.

3. Precipitation

In this balance precipitation gains were calculated to be rain or snow falling directly on the lakes' surfaces. Precipitation records from eleven meteorological stations in the Trent River basin area were employed using the Thiessen Polygon method. Lake surface areas were calculated by the Acres Consulting Service Limited as part of a study being carried out for the Department of Indian Affairs and Northern Affairs. Precipitation falling on land within the watershed is included in tributary inflow or overland drainage.

4. Overland Drainage

This is the volume of water entering a lake from land draining to that lake, but not accounted for in the tributary inflow. This inflow cannot be measured directly, but must be calculated. It was decided that data from two tribu-aries - Nogies Creek (Pigeon Lake basin, representative of the northern, Precambrian drainage area) and the Ouse River (Rice Lake basin, representative of the southern, Paleozoic drainage area) would be employed to determine the unit-area yields. These figures would then be appropriately applied to determine overland flow for the entire study area.

Losses - Evaporation

Evaporation was considered for only the major lakes forming the Kawarthas' chain. Evaporation rates measured at the Burketon Station (Lake Scugog basin) by Atmospheric Environment Service, Environment Canada, were employed to determine this water loss.

Storage - Lake Level Fluctuations

Water levels in most of the main and head water lakes are controlled to minimize flood damage in the spring, to maintain suitable water levels for recreational use of the Kawartha Lakes, and to ensure sufficient streamflow for navigation in the Trent Canal System. The usual pattern for lake level control is to maintain fairly constant levels during the summer and fall recreational periods, and then during the winter months, drop the lake levels in anticipation of spring snowmelt when once again the reservoirs are filled. Typical lake level fluctuations for the 1971-72 study period are illustrated in Appendix 6-B.

In the water balance, changes in main channel outflow resulting from storage or spilling of water are calculated using monthly mean changes in lake levels and lake surface areas.

Verification of Water Budget

Because of the lack of daily streamflow data in the Kawartha Lakes Area, one of the principal assumptions in calculating the water balance was that the main channel inflow to a lake was equal to the total outflow of the adjacent upstream lake after taking lake level regulation (storage or spillage) into account. This assumption was used until the computed outflow from Lake Katchewanooka was compared to the Water Survey of Canada's continuous streamflow records from the Otonabee River gauge (2 HJ 002) at Lakefield.

The difference between calculated and measured volume was not significant (0.3%), thus confirming the validity of the assumption. From that point to the mouth of the basin, data from continuous recording streamflow gauges were available and employed in subsequent calculations.

With the excellent correlation between calculated and measured streamflows at Lakefield, the other assumptions, i.e. (1) Nogies Creek and the Ouse River data being employed to estimate overland drainage and (2) evaporation data from the Burketon Station being applied to the entire study area, were deemed reasonable. In order to compare the streamflow conditions for the May 1971 to April 1972 survey period to the long-term average and extreme conditions, average flows for each month of the study year were compared to the monthly averages and extreme flows for eleven years of records at the federal streamflow gauge at (2 HK 0024) Glen Ross (1964-74). The results of this comparison, illustrated in Figure 2 show that, for the most part, survey period flows were slightly lower than the mean values but did not equal or exceed the extremes at any time. In the analyst's view, the hydrologic component of the materials balance is reasonably typical and representative of the stream flow throughout the Kawartha-Trent System.

The Nutrient Budget

Nutrient gains and losses were calculated according to the following categories which roughly parallel the water balance components:

Gains: Main channel inflow
Tributary inflow
Overland drainage
Precipitation
Local inputs (municipal discharges, cottages, etc.)

Losses: Main channel outflow
Fish export

It should be noted at this point before developing the details of the nutrient loadings that the information which follows does not, in fact, represent a complete nutrient balance. Factors such as permanent or temporary sinks within a lake (i.e. nutrient loss to lakebed storage and uptake by rooted or attached aquatics) or sources such as nutrient regeneration from lake sediments were or could not be measured for each lake. The following section, therefore should be viewed as an identification of the major external sources of nutrients showing their relative magnitude in terms of total loading.

Water chemistry data and material input loadings were obtained from long term programs, special studies, sewage treatment plant records, consultation with appropriate specialists and literature surveys. Details on data collection and computation methods are discussed in the following sections.

Loadings for the various components of the nutrient budget are presented in Tables 2 to 6.

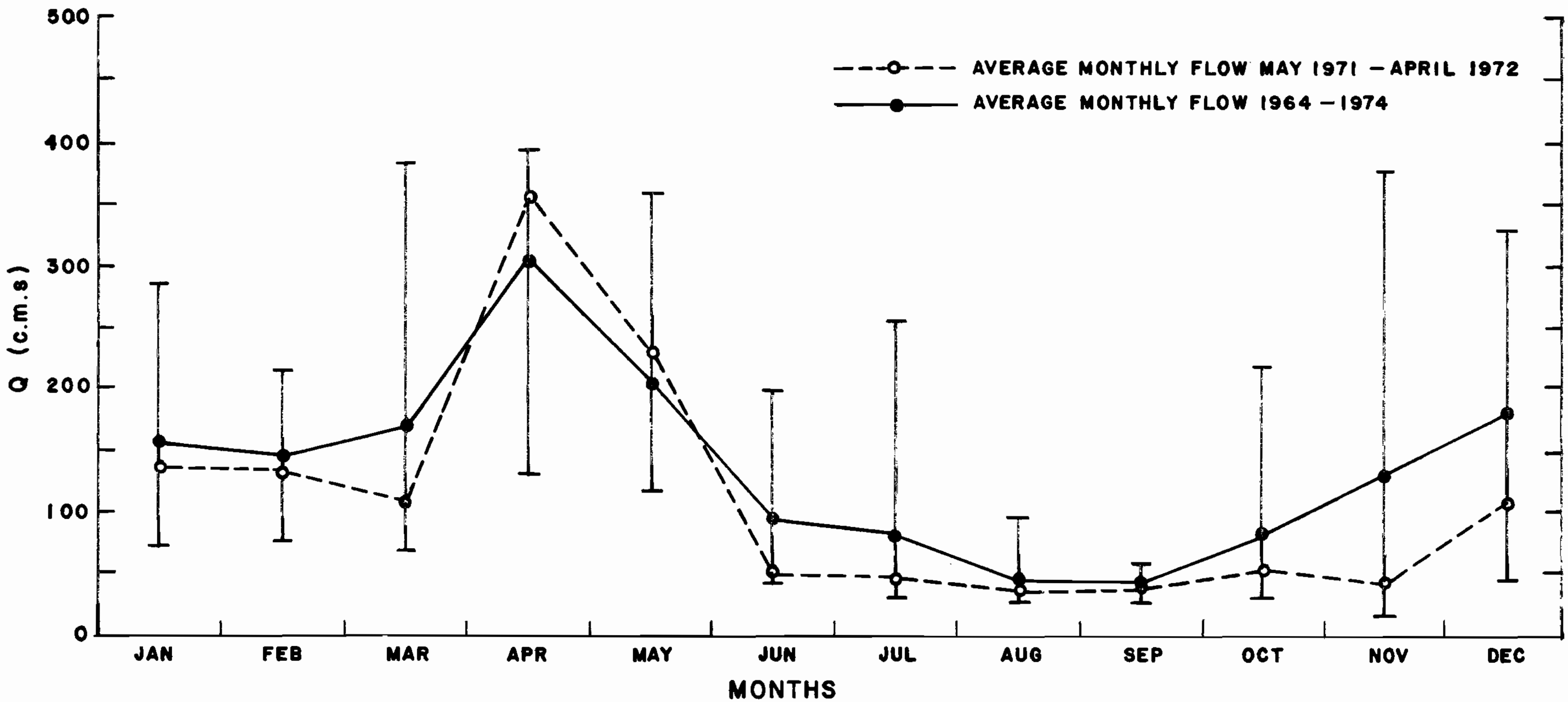

FIGURE 2 : FLOWS AT TRENT RIVER GLEN ROSS GAUGE (ZHK004)

Gains

1. Main Channel Inflows and Tributary Loadings

Water quality sampling stations were located in the channels connecting the Kawartha Lakes, along the Otonabee and Trent rivers and near the mouths of all major tributaries.

A computer program, OWRYIELD, was employed to calculate the mass of materials entering and being carried through the system. Daily stream flows were measured or calculated as discussed in the water balance section. Although water quality samples were collected at two week intervals, daily values were calculated by linear interpolation between sampling days. Daily loadings and yields were subsequently summed to obtain monthly and annual values.

2. Overland Flow

This category of nutrient sources represents inputs from land runoff, which enters the lakes via small rivulets, surface runoff, etc., otherwise not taken into account through tributary inflows. As with the volume of flow from these sources, quality characteristics could not practicably be measured by a sampling program but had to be calculated on a unit-area yield basis from a measurable source. Overland drainage quality characteristics for the northern drainage area were pro-rated from data collected from Nogies Creek and information for the southern drainage area from Ouse River data.

3. Precipitation

Only precipitation that fell directly on the Kawartha Lakes' surfaces were considered in calculating inputs from this source. As described in the water budget, precipitation quantity was determined from records of local meteorological stations. No direct sampling for precipitation quality was conducted during the field survey. In lieu of survey data, precipitation chemistry data collected by other investigations in the vicinity of the Kawartha Lakes[1] was incorporated into the Nutrient Budget.

Precipitation Quality		
	Mean Concentrations in mg/l	
	Rainfall	Snowfall
Total N	0.75	0.63
Total P	0.021	0.060

4. Local Sources

(a) Municipalities with Sewage Collection and Treatment Facilities (M.O.E. 1972).

Several communities throughout the basin have municipal sewage collection and treatment systems. The largest by far is the 12 MIGD activated sludge plant serving the City of Peterborough with discharge to the Otonabee River.

Effluent flow rates and concentrations of phosphorus and nitrogen were obtained from sewage treatment plant operating records. Organic carbon concentrations were estimated for each plant.

(b) Municipalities without Communal Sewage Treatment Facilities.

All municipalities without sewage collection and treatment systems (e.g. Rosedale, Buckhorn, Youngs Point etc.,) were assumed to be served by individual septic tank and tile field systems. In order to calculate estimates of nutrient loadings from these municipalities, populations were taken from the 1971 Municipal Directory or, where population figures were not available, community sizes were estimated from house counts from 1:50,000 topographical maps multiplied by a household occupancy of 3.7 persons (Regional Development Branch, 1968).

From a literature review, per capita contributions of 1.3 kilograms/year of total phosphorus and 4.0 kilograms/year of total nitrogen were employed[2]. The loading rate employed for phosphorus made allowance for the use of high phosphate detergents. A per capita loading of 16 kilograms/year for organic carbon was obtained from the nutrient budget chapter of the Muskoka Lakes Water Quality Evaluation Report (Michalski, Johnson and Veal, 1973).

In calculating the total nutrient loading to the Kawartha-Trent system from these communities it was assumed that 80%[3] of the raw waste discharges would be retained in the septic tank or tile field with the remaining 20% of the materials ultimately reaching the lakes or rivers[3].

(c) Cottages and Permanent Residences

Contributions from cottages and permanent residences located directly on the lakes, outside of those municipalities discussed above, were considered. The actual number of dwellings per lake was determined from the Land Tenure Survey conducted in 1970 (Department of Tourism and Information, 1970). The number of full-time occupancy residences for each lake was also determined from the Land Tenure Survey. A fulltime occupancy rate of 3.7 persons per dwelling per year and a cottage occupancy of 2.7 per year was determined from the Kawartha Lakes questionnaire[4] and by a 1968 Economic Report for the region respectively (Regional Development Branch, 1968).

The per capita nutrient yields and 80% retention in the septic tank systems as discussed above, were similarly employed in calculating loadings from these sources.

(d) Motels and Resorts

All motels and resorts located directly on the lakes and those within a town that did not have communal sewage treatment plant service were considered. The number of units for each motel was determined from the most recent figures available (Department of Tourism and

Information, 1967, 1970). Data from a representative sample group of motels and resorts indicated most were open six months each year (May to October), with less than 6% open all year. The average occupancy rates for operating units were 73% in the summer season, and 44% in the winter (Department of Tourism and Information, 1970). It was calculated that an occupied unit served an average of four people. These figures were used to determine motel population levels in each basin and then the per capita nutrient yields and the retention factor were applied as before to determine the net loading.

(e) Campgrounds

It was assumed that the significant months of the year for camping were June, July, August and September. The number of days of use in July and August was taken to be 31, whereas June and September were assumed to be ten days each, to account for weekend use only. To estimate the actual occupancy it was assumed that each site served five people and that the 73% occupancy rate for motels and resorts applied also to the campsites. Yield determinations were then performed employing the same nutrient yield per capita and retention factor as used in the other sections.

(f) Leaf Fall

The nutrient input from leaves falling directly into the Kawartha Lakes was estimated. From literature it was determined that each metre of treed shoreline contributed 465 grams total dry weight each year (Kaushik and Hynes, 1968). Also from literature, it was determined that the average yield of nitrogen was about 1.26% of the dry weight of the leaf (Kauskik and Hynes, 1968). Employing the general phytoplankton ratio of 106:16:1 for C, N and P respectively[5], and an estimate of the lengths of treed shoreline from aerial photographs, the nutrient yield from leaf-fall to each lake was calculated. Even the scanty amount of knowledge about dead-leaves in aquatic habitats has produced many complicated variables which affect the process of decomposition of submerged leaf material. Therefore, for this study it was assumed that the nutrient input from leaves was uniformly distributed throughout the year.

(g) Shoreline Application of Lawn Fertilizers

This source of nutrients considers runoff from shoreline property of cottages and permanent residences. The Kawartha Lakes cottage questionnaire indicated the quality and kinds of fertilizers in use. Most employed a "7-7-7" fertilizer mix containing 7% nitrogen, 7% phosphorus, and 7% potash by weight. Average application rates ranged from 71.7 kg/cottage/yr on Rice Lake to 144.9 kg/cottage/yr on Sturgeon Lake[6]. Runoff rates for nitrogen and phosphorus were estimated to be approximately 2% and 2.5% respectively of the applied load[7].

Losses

1. Main Channel Outflow

This is the outflow from the upstream basin to the adjacent downstream basin. Methodology for determining this outflow was similar to that of the main channel inflow and constitutes the major outflow value for the nutrient budget.

2. Fish Export

The amounts of phosphorus, nitrogen and carbon removed from the Kawartha-Trent System through the taking of fish by anglers is based on information supplied by the Ministry of Natural Resources[8] and a paper from Auburn University (Lawrence 1968).

Data on angling was extrapolated on a unit area yield basis to the entire basin using information collected from Chemung Lake. It was calculated that angling removed an average of 3.6 kilograms of fish per hectare of lake surface per year. Approximately 80% of a fish's weight is water. Of the remaining weight the percent concentration of carbon, nitrogen and phosphorus is 40.23, 10.03 and 3.5 respectively (Lawrence 1968). Average values of 0.34 kg organic carbon, 0.05 kg nitrogen and 0.02 kg phosphorus per fish were used in the nutrient budget calculations.

Commercial fishing for carp is carried out in Sturgeon and Rice lakes generally during the winter. From Ministry of Natural Resources data covering the period 1973-75, the average commercial catch was 2.2 kilograms per hectare per season . The carbon, nitrogen and phosphorus components of this total weight are 0.19, 0.05 and 0.02 kilograms per hectare respectively.

Verification of the Nutrient Budget

As described in the water balance and nutrient budget sections of this chapter, water quantity and quality data were, in some cases, direct measures (e.g. monitoring programs, automatic streamflow gauges, sewage treatment plant records, etc.,) but in other instances no field survey data were available and appropriate information from other studies in Ontario or literature had to be extrapolated to the Kawartha Lakes.

In order to check the accuracy of the calculated data, the "Land Drainage", "Precipitation" and "Local Inputs" components of a cumulative nitrogen and phosphorus budget at the point of outflow from Clear Lake were summed and the loadings in kilograms were converted to concentrations in mg/l. These figures were then compared to nutrient concentrations measured at the Ministry of the Environment's Young's Point routine water quality monitoring station. Flow data required for the conversion from loading to concentrations were extrapolated from the continuously recorded streamflow gauge located nearby at Lakefield.

As illustrated below, the data compare favourably.

Comparison of Nutrient Budget Data and Monitoring Records Stony-Clear Lakes Outlet 1971-72

	Total P mg/l	Total N mg/l	Organic C mg/l
Routine Monitoring Data	0.025	0.554	9
Nutrient Budget Data	0.023	0.555	10

RESULTS

Cumulative Loadings

Tables 3 through 5 illustrate that on an individual, lake-by-lake analysis of data, the bulk of nutrient inputs to each of the lakes come from the "Main Channel Inflow" and "Land Drainage" components with much smaller inputs from "Precipitation" and the various sources categorized under "Local Inputs". The noteable exception is Sturgeon Lake where municipal inputs from Lindsay and to a much lesser extent, Fenelon Falls and cottages account for about one quarter of the total phosphorus loading to that lake. In most of the other lakes local inputs account for about 5-10% of the total loading.

For a more accurate evaluation of the relative significance of the principal sources of nutrients throughout the Kawartha-Trent system, the cumulative downstream impact of each source must be evaluated. In this analysis the inter-lake flow columns ("Main Channel Inflow" and "Main Channel Outflow") of the nutrient budget as identified in Tables 3 to 6, are partitioned into the three basic components "Land Drainage", "Precipitation" and "Local Inputs". This partitioning is achieved by determining and applying this ratio to the measured "Main Channel Outflow" loading for that lake.

To illustrate the method, assume that in Balsam Lake "Land Drainage" accounted for 83% of the total phosphorus input, "Precipitation" - 9% and "Local Inputs" - 8%, then the "Main Channel Outflow" loading of 8.86 metric tonnes per year would be divided proportionally into its three components and applied to Cameron Lake, the next lake down the chain.

The "Local Input" loading then for Cameron Lake would be the residual "Local Input" loading from Balsam Lake which is 8% of 8.86 tonnes plus the local phosphorus inputs as measured or calculated flowing directly into Cameron Lake (these loadings are identified in Table 2).

"Land Drainage" and "Precipitation" loadings to Cameron Lake are calculated in a similar fashion and the entire process is repeated progressing from lake to lake downstream through the chain.

TABLE 2 : Nutrient Budget - Local Sources (1971-72 Study Period)
Local Gains and Losses of Total Nitrogen, Total Phosphorus and Organic Carbon

(metric tonnes per year)

Key: Org. C. / TP | TN

LAKES		Gains: Munici-palities	Cottages	Motels	Camp Grounds	Permanent Homes (outside mun)	Leaves	Lawn Fertilizers	TOTAL INPUT	Losses: FISH EXPORT	NET INPUT
BALSAM	Org. C.	3.40	5.40	3.73	0.13	1.27	2.33	---	16.20	1.62	14.58
	TP	0.27	0.44	0.30	0.01	0.10	0.02	0.01	1.15	0.14	1.01
	TN	0.80	1.35	0.94	0.03	0.32	0.35	0.01	3.80	0.38	3.42
CAMERON	Org. C.	4.34	1.73	1.02	0.50	0.57	0.82	---	8.98	0.49	8.49
	TP	0.41	0.14	0.08	0.04	0.04	0.01	0.01	0.73	0.04	0.69
	TN	1.64	0.43	0.26	0.12	0.14	0.12	0.01	2.72	0.12	2.60
STURGEON	Org. C.	29.22	9.48	1.65	1.34	1.81	2.87	---	46.37	1.49	44.88
	TP	10.8	0.77	0.13	0.11	0.15	0.03	0.04	12.0	0.13	11.9
	TN	21.3	2.37	0.41	0.34	0.44	0.43	0.05	25.3	0.35	25.0
SCUGOG	Org. C.	6.45	5.49	0.10	0.24	2.83	3.14	---	18.25	2.72	15.53
	TP	1.12	0.45	0.01	0.02	0.23	0.03	0.01	1.87	0.24	1.63
	TN	2.72	1.37	0.03	0.06	0.71	0.47	0.01	5.37	0.64	4.73
PIGEON, BUCKHORN CHEMUNG	Org. C.	6.79	100.9	2.37	4.20	5.74	8.69	---	37.90	4.14	33.75
	TP	0.55	0.82	0.19	0.34	0.46	0.08	0.03	2.47	0.37	2.10
	TN	1.70	2.52	0.59	1.05	1.41	1.31	0.04	8.62	0.98	7.64
LOWER BUCKHORN LOVESICK	Org. C.	1.23	1.53	0.74	---	0.32	1.51	---	5.33	0.52	4.81
	TP	0.22	0.13	0.06	---	0.03	0.01	0.01	0.46	0.05	0.41
	TN	0.54	0.37	0.19	---	0.08	0.23	0.03	1.44	0.12	1.32
STONY, CLEAR	Org. C.	---	4.63	0.75	0.12	0.63	2.79	---	8.92	1.27	7.65
	TP	---	0.38	0.06	0.01	0.05	0.03	0.01	0.54	0.12	0.42
	TN	---	1.15	0.19	0.03	0.16	0.44	0.01	1.98	0.30	1.68
KATCHEWANOOKA	Org. C.	2.56	0.68	0.23	---	1.18	0.62	---	5.27	0.13	5.14
	TP	0.32	0.06	0.02	---	0.10	0.01	0.01	0.52	0.01	0.51
	TN	1.63	0.17	0.06	---	0.30	0.09	0.01	2.26	0.03	2.23
RICE	Org. C.	*4.30	6.59	3.40	12.36	0.34	3.22	---	30.21	3.20	27.01
	TP	0.35	0.54	0.28	0.09	0.87	0.03	0.01	2.17	0.28	1.89
	TN	1.08	1.65	0.86	0.29	3.04	0.49	0.01	7.42	0.75	6.67
TRENT RIVER	Org. C.	54.33	5.28	1.48	1.00	4.28.	---	---	66.37	1.00	65.37
	TP	6.95	0.43	0.12	0.08	0.35	---	0.02	7.95	0.10	7.85
	TN	21.29	1.06	0.37	0.25	1.15	---	0.02	24.14	0.30	23.84

*The City of Peterborough sewage treatment plant discharges to the Otonabee River and is included in the "Main Channel Input" columns of Tables 3, 4, 5 and 6.

TABLE 3 : Nutrient Budget - Total Phosphorus (loadings in metric tonnes per year) - 1971-72

LAKE	Main Channel	Land Drainage	Precip-itation	Local Inputs	Total Inputs	Main Channel Outflow	Storage
BALSAM	---	10.3	1.13	1.01	12.4	8.86	+3.58
CAMERON	8.86	15.2	0.35	0.69	25.1	16.2	+8.95
STURGEON	16.2	16.5	1.05	11.1	45.6	42.1	+3.15
SCUGOG (off-chain)	---	4.67	1.90	1.63	8.20	3.35	+4.85
PIGEON, BUCKHORN CHEMUNG	42.1	8.49	2.90	2.10	55.6	44.8	+10.8
LOWER BUCKHORN LOVESICK	44.8	2.29	0.36	0.41	47.9	45.9	+1.96
STONY, CLEAR	45.9	3.38	0.89	0.42	50.6	41.2	+9.39
KATCHEWANOOKA	41.2	1.89	0.09	0.51	43.7	51.2	-7.52
RICE	124	12.5	2.24	1.89	141	76.7	+64.2
TRENT RIVER	76.7	34.8	---	7.85	119	181	-61.5

*This "Main Channel Input" to Rice Lake includes a loading of 37 metric tonnes of total phosphorus from the Peterborough STP which discharges to the Otonabee River upstream from Rice Lake.

TABLE 4 : Nutrient Budget - Total Nitrogen (loading in metric tonnes per year)
- 1971-72

LAKE	Main Channel	Land Drainage	Precip-itation	Local Inputs	Total Inputs	Main Channel Outflow	Storage
BALSAM	---	241	27.3	3.42	272	194	77.3
CAMERON	194	293	8.33	2.60	498	426	77.7
STURGEON	426	458	25.3	25.0	935	880	54.9
SCUGOG (off-chain)	---	76.8	46.0	4.73	127	99.6	27.8
PIGEON, BUCKHORN CHEMUNG	880	236	70.1	7.64	1190	1010	188
LOWER BUCKHORN LOVESICK	1000	81.7	8.73	1.32	1100	1020	75.7
STONY, CLEAR	1020	75.0	21.5	1.68	1120	1050	67.8
KATCHEWANOOKA	1050	53.5	2.17	2.23	1110	1210	100
RICE	1670	336	54.2	6.67	2070	1590	481
TRENT RIVER	1580	931	---	23.8	2540	2530	+5.46

*This "Main Channel Input" to Rice Lake includes a loading of 169 metric tonnes of total nitrogen from the Peterborough STP which discharges to the Otonabee River upstream from Rice Lake.

TABLE 5 : Nutrient Budget - Organic Carbon (Loading in metric tonnes per year) - 1971-72

LAKE	Main Channel	Land Drainage	Precip-itation	Local Inputs	Total Inputs	Main Channel Outflow	Storage
BALSAM	---	5110	---	15	5120	4090	1030
CAMERON	4090	5570	---	8	9670	9100	+567
STURGEON	9100	7310	---	45	16500	14200	2280
SCUGOG (off-chain)	---	2500	---	16	2520	2000(e)	+516
PIGEON, BUCKHORN CHEMUNG	14200	3460	---	34	17700	12200	5470
LOWER BUCKHORN LOVESICK	12200	1680	---	5	13900	16200	2330
STONY, CLEAR	16200	2050	---	8	18300	15200	3090
KATCHEWANOOKA	15200	625	---	3	15800	22200	6430
RICE	25100	1890	---	27	28000	30000	2020
TRENT RIVER	30000	13800	---	66	43900	42700	1200

*This "Main Channel Input" to Rice Lake includes a loading of 68 metric tonnes(e) of organic carbon from the Peterborough STP which discharges to the Otonabee River upstream from Rice Lake.

Cumulative loadings for phosphorus and nitrogen are presented in Tables 6 and 7.

These tables clearly illustrate the cumulative downstream impact of large sources on a lake. This is evident because of the significant and sustained increase in total phosphorus resulting from the Lindsay municipal lagoon discharge to the Scugog River and its effect on the "Local Inputs" component downstream in Sturgeon, Pigeon, Buckhorn and the lower lakes. These lakes (Table 3), had local input loadings of one-half to two tonnes of phosphorus per year or one to four percent of the total inputs. The residual impact of the Lindsay discharge increased this component to over eleven tonnes per year or 20 to 25% of the total inputs. A similar increase is shown in Rice Lake and the Trent River reflecting the impact of the Peterborough Sewage Treatment Plant discharge.

Nitrogen, Table 7 compared with Table 4, also showed sustained increases downstream from the major point sources but the magnitudes were much less because "Land Drainage" and "Precipitation" are the dominant sources of nitrogen in the system.

Updating the Nutrient Source Analysis

As indicated at the beginning of this chapter, budgetary and time limitations did not permit a massive data collection program to duplicate the 1971-72 surveys.

In order to update the nutrient loading figures, major changes which have occurred over the past four years were reviewed and, where applicable, incorporated. The major changes include:

1. Phosphorus reduction to 1 mg/l in the effluent of all sewage treatment plants exceeding one million gallons per day capacity. This change took place in 1975 and represents about an 80% reduction in effluent phosphorus.

2. Restructuring the formulation of laundry detergents to reduce phosphate (P_2O_5) content from 20% (1971-72) to 5% (1973 and thereafter).

3. Construction of municipal sewage treatment facilities to serve the communities of Fenelon Falls and Lakefield.

TABLE 6 : Nutrient Budget - Total Cumulative Phosphorus Loading (loading in metric tonnes per year) - 1971-72

LAKE	Land Drainage	Precipitation	Local Input	Total Input	Main Channel Outflow
BALSAM	83% - 10.3	9% - 1.13	8% - 1.01	12.4	8.86
CAMERON	90% - 22.5	5% - 1.15	5% - 1.40	25.13	16.2
STURGEON	68% - 31.0	4% - 1.86	28% - 12.7	45.6	42.1
SCUGOG (off-chain)	57% - 4.7	23% - 1.90	20% - 1.63	8.20	3.35
PIGEON, BUCKHORN CHEMUNG	67% - 37.1	8% - 4.59	25% - 13.9	55.6	44.8
LOWER BUCKHORN LOVESICK	68% - 32.3	8% - 3.95	24% - 11.6	47.9	45.9
STONY, CLEAR	68% - 34.6	9% - 4.57	23% - 11.4	50.6	41.2
KATCHEWANOOKA	69% - 30.0	9% - 3.80	22% - 9.99	43.8	51.2
RICE	59% - 83.8	5% - 6.85	36% - 50.2	141	76.7
TRENT RIVER	67% - 80.1	3% - 3.84	30% - 35.5	120	181

TABLE 7 : Nutrient Budget - Total Cumulative Nitrogen Loading (loading in metric tonnes per year) - 1971-72

LAKE	Land Drainage	Precipitation	Local Input	Total Input	Main Channel Outflow
BALSAM	89% - 241	10% - 27.3	1% - 3.4	272	194
CAMERON	93% - 466	6% - 27.8	1% - 4.5	498	426
STURGEON	91% - 854	6% - 50.8	3% - 29.3	934	880
SCUGOG (off-chain)	60% - 76.7	36% - 46.0	4% - 4.7	127	99.6
PIGEON, BUCKHORN CHEMUNG	87% - 1040	10% - 123	3% - 34.0	1190	1010
LOWER BUCKHORN LOVESICK	87% - 956	10% - 109	3% - 31.5	1100	1020
STONY, CLEAR	86% - 963	11% - 124	3% - 32.3	1120	1050
KATCHEWANOOKA	86% - 958	11% - 118	3% - 33.8	1110	1210
RICE	86% - 1770	11% - 238	3% - 56.8	2070	1585
TRENT RIVER	90% - 2290	7% - 174	3% - 71.4	2540	2530

A comparison of precipitation records for the 1971-72 survey and 1975-76 review periods show that precipitation during the latter period was about 15% higher. Without supporting 1975-76 precipitation chemistry data and a reasonable comparison of precipitation quantities throughout most of the two study periods, it was decided not to alter the 1971-72 "Precipitation" loading data.

An updated cottage count throughout the Kawartha-Trent System was not available. Undoubtedly there were more cottages in 1976 than in 1971-72, but the authors decided that the reduction of phosphorus in detergents likely compensated for increased cottage activity. The phosphorus loadings from private waste disposal facilities (i.e. septic tanks, etc.,) were not altered. Alternations to the nitrogen loadings were not considered to be significant from these sources and no changes were made in the input figures.

Total cumulative phosphorus and nitrogen loadings reflecting the major changes that have occurred between 1972 and 1976 are presented in Table 8 and 9 respectively.

Effects of the Major Changes on the Nutrient Balance

The beneficial impact of the phosphorus removal program is apparent in the "Local Inputs" column for Sturgeon Lake where phosphorus loadings have been reduced from 12.7 tonnes per year in 1971-72 to 8.8 tonnes per year in 1975-76. Expressed as percentage of total phosphorus loading to the lake, a reduction from 18 to 21% has occurred. The reduction, primarily attributed to phosphorus removal at Lindsay is reflected in reduced total phosphorus loadings in the remaining lakes down the chain.

Another major reduction is noted in the Rice Lake column where phosphorus removal at the Peterborough Sewage Treatment Plant has reduced "Local Inputs" from 50.2 to 29.9 tonnes per year. The beneficial impact of phosphorus removal is also reflected in the Trent River reach.

Conversely, without any controls to reduce nitrogen from local inputs, loadings in 1975-76 are higher than 1971-72 loadings from Sturgeon Lake downstream. This change is due principally to increased loadings at municipal sewage treatment plants.

TABLE 8 : Nutrient Budget - Total Cumulative Phosphorus Loading (loading in metric tonnes per year)
- updated to reflect 1975-76 conditions

LAKE	Land Drainage	Precipitation	Local Input	Total Input	Main Channel Outflow
BALSAM	83% - 10.3	9% - 1.1	8% - 1.0	12.4	8.9
CAMERON	90% - 22.5	5% - 1.2	5% - 1.4	25.1	16.2
STURGEON	74% - 31.1	5% - 1.9	21% - 8.8	41.8	38.2
SCUGOG (off-chain)	57% - 4.7	23% - 1.9	20% - 1.6	8.2	3.4
PIGEON, BUCKHORN CHEMUNG	71% - 36.8	9% - 4.8	20% - 10.1	51.7	40.9
LOWER BUCKHORN LOVESICK	71% - 31.4	9% - 4.0	20% - 8.6	44.0	42.0
STONY, CLEAR	71% - 33.2	10% - 4.7	19% - 8.8	46.7	37.3
KATCHEWANOOKA	71% - 28.4	10% - 3.8	19% - 7.6	39.8	47.3
RICE	70% - 86.0	6% - 7.0	24% - 29.9	123	54.8
TRENT RIVER	75% - 73.2	3% - 3.3	22% - 21.0	97.5	159

TABLE 9 : Nutrient Budget - Total Cumulative Nitrogen Loading (loading in metric tonnes per year)
- Updated to reflect 1975-76 conditions

LAKE	Land Drainage	Precipitation	Local Input	Total Input	Main Channel Outflow
BALSAM	89% -241	10% - 27	1% - 3	271	194
CAMERON	93% -466	6% - 28	1% - 5	499	426
STURGEON	90% - 854	5% - 51	5% - 42	947	893
SCUGOG (off-chain)	60% - 77	36% - 46	4% - 5	128	100
PIGEON, BUCKHORN CHEMUNG	86% - 1040	10% - 115	4% - 52	1210	1020
LOWER BUCKHORN LOVESICK	86% - 957	10% - 111	4% - 42	1110	1030
STONY, CLEAR	85% - 965	11% - 125	4% - 43	1130	1070
KATCHEWANOOKA	85% - 959	11% - 119	4% - 45	1120	1220
RICE	85% -1800	11% - 244	4% - 76	2120	1650
TRENT RIVER	90% - 2330	7% - 181	3% - 90	2600	2600

DISCUSSION

From the preceding presentation of the Kawartha-Trent nutrient loading analysis, it is quite apparent that the major source of phosphorus, nitrogen and carbon is land drainage.

For the most part materials from this source are introduced to the Kawartha Lakes and Trent River via relatively unpolluted streams draining the Precambrian Shield area to the north and east of the lakes. Streams draining from the Palaeozoic area to the south and west of the lakes are of lesser quality than the Shield Streams, likely a natural result of the soils they pass through but influenced to some extent by the agricultural activities more prevalent in the southern areas than in the Shield Region. Phosphorus from land drainage is primarily in particulate form and not immediately available to plant life. In some lakes, large tributary streams may have a beneficial, diluting effect on local water quality but considering the long retention time in the Kawartha-Trent System and changes in form that nutrients can undergo in lakes, land drainage must be regarded as an important and largely uncontrollable source of nutrients.

Atmospheric inputs are important sources of nitrogen and phosphorus in lakes with large surface areas. Little is known about the form and availability of nutrients from this source, but because of the magnitude of the loadings, the effects of atmospheric inputs should not be disregarded. Due to the widespread and varied number of sources of nitrogen and phosphorus to the atmosphere, this source must, at present, be considered as uncontrollable.

Throughout most of the Kawartha Lakes, local inputs constitute a small portion of the total nutrient loading. Municipal discharges from Lindsay to the Scugog River and from Peterborough to the Otonabee River and Rice Lake represent the major components of this input. The cumulative downstream effect as described earlier in this chapter shows that these sources, in particular, have an impact for many miles downstream of the source.

An important point to keep in mind is that municipal discharges, and likely many of the other local inputs, contain phosphorus primarily in the dissolved form that is readily available to biological life. The impact of local inputs, while relatively small in magnitude compared to the other sources, may be the most significant in terms of impact on water quality particularly related to aquatic plant and algal growth.

Experience over the past few years has shown that phosphorus removal at sewage treatment plants is efficient and reasonably inexpensive. A comparison of the 1971-72 and 1975-76 phosphorus balance data clearly shows the beneficial impact of the phosphorus removal program. Waste treatment specialists suggest that even further reductions to 0.5 mg/l of phosphorus (about 90% removal) can be achieved.

Nutrient inputs from other local inputs such as cottages, resorts, motels, etc., constitute a relatively small portion of the total loadings, usually less than five percent. Lake degradation caused by malfunctioning private waste disposal systems is usually very localized and problems can be resolved by ensuring that approved systems are installed and maintained.

With respect to new cottage or small commercial resort development, recent advances in private waste disposal system technology will assure that the domestic waste impact from such new development will likely have an immeasurable effect on water quality. It must be kept in mind however, that other cottage and resort development activities such as land disruption for buildings and access road construction, dredging and land filling, etc., may also have severe impacts on water quality. Approved construction methods must be employed to minimize water quality degradation.

To summarize the significance and impact of local inputs, nutrient loadings from existing cottages, campgrounds, resorts and motels are small and any degradation caused by these sources is usually localized and can be corrected reasonably easily. New cottage or resort developments should not contribute significantly to pollution of the Kawartha-Trent system if the latest private waste disposal systems are installed and appropriate construction practices employed.

Point source discharges are by far the most significant local sources of nutrients. Phosphorus reduction to 1 mg/l in the major plants has had a significant influence on total phosphorus loadings. Waste treatment specialists indicate that further phosphorus reductions to 0.5 mg/l (about 90% removal) can be achieved.

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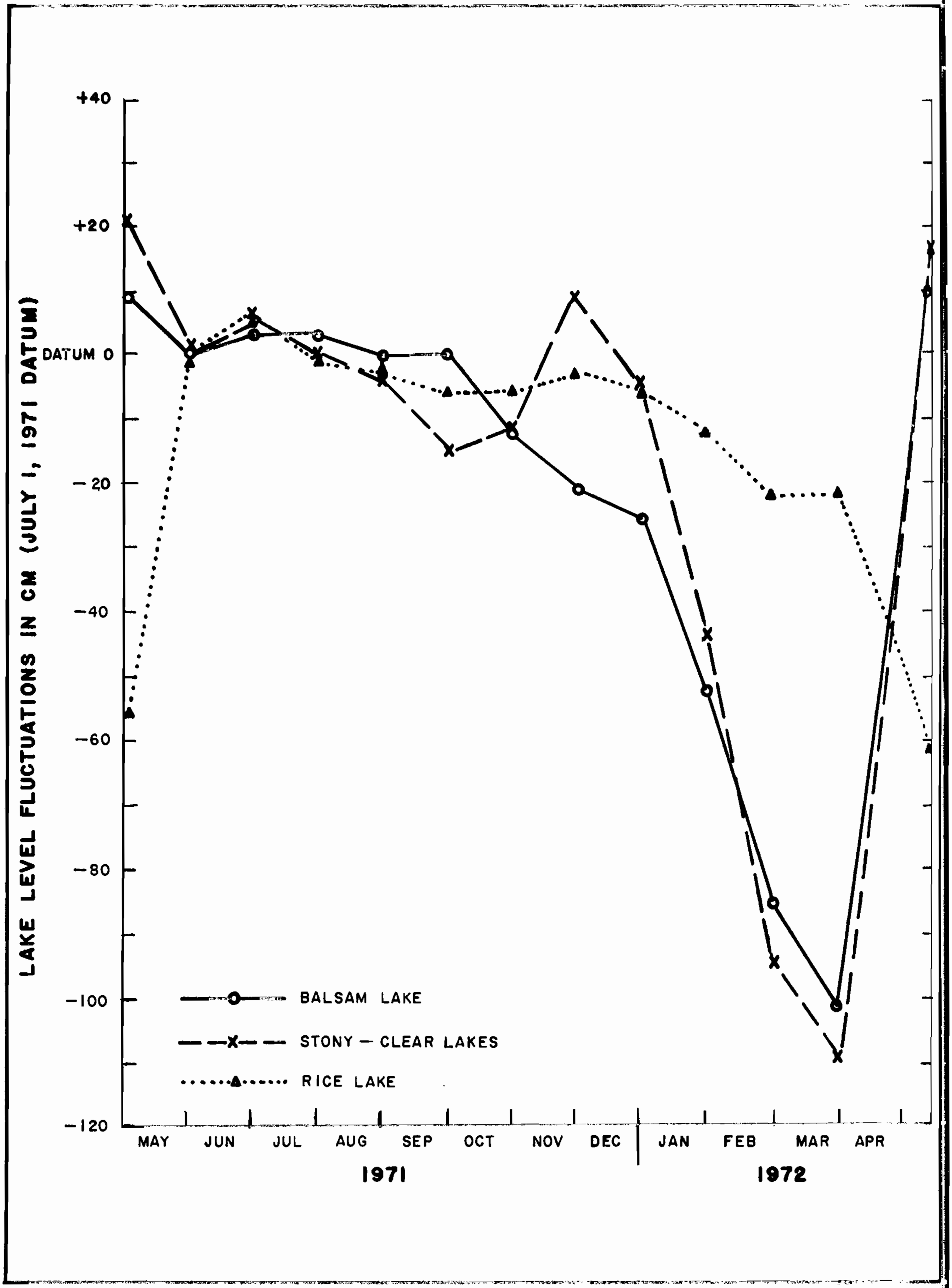
APPENDIX A : Tributary Inflow - Sources of Data

1. Tributaries with Continuous Streamflow Records

Stream	Receiving Basin	Gauge Location and Operator
Gull River	Balsam Lake	Norland - 2HF002 - Water Survey of Canada
Burnt River	Cameron Lake	Burnt River - 2HF003 - Water Survey of Canada
Scugog River	Sturgeon Lake	Lindsay - Canada Department of Indian & Northern Affairs
Eel's Creek	Stoney Lake	Apsley - 2HH001 - Water Survey of Canada
Ouse River	Rice Lake	Westwood - 2HJ003 - Water Survey of Canada
Indian River	Rice Lake	Outlet at Stoney Lake - Dept. of Indian & Northern Affairs
Crowe River	Trent River	Marmora - 2HK003 - Water Survey of Canada

2. Tributaries with Intermittent Streamflow Measurements by Ontario Ministry of the Environment

Stream	Receiving Basin	Method of Determining Streamflow
Nogies Creek	Pigeon Lake	Polyregression from Eel's Creek Records
Pigeon River	Pigeon Lake	Incorporated into Overland Drainage Component
Mississauga River	Buckhorn Lake	Polyregression from Burnt River Records
Jack Creek	Stony Lake	Polyregression from Eel's Creek Records
Nonquon River	Lake Scugog	Pro-rated from Daily Records for the Beaverton River (2EC011)
Cold Creek	Trent River	Incorporated into Overland Drainage Component



APPENDIX B — TYPICAL LAKE LEVEL FLUCTUATIONS MAY 1, 1971 TO APRIL 30, 1972

CHAPTER 7

A LIMNOLOGICAL INVESTIGATION OF THE DEEP BASIN OF STONY LAKE (1972)

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November, 1975

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INTRODUCTION

Reviews by Lee (1970), McKee et al (1970[a], 1970[b]) and Golterman (1973) point out the importance of studies on sediment-water nutrient relationships to the development of an understanding of lake eutrophication and reclamation processes. Several authors, including Einsele (1936) and Mortimer (1941, 1942) and more recently, Schinder and Comita (1971), Hynes and Greib (1970), Gahler (1969) and Burns and Ross (1972) have documented significant release of nutrients from anaerobic lake bottom muds. On the other hand, Schindler et al (1974) found no release of either N or P from the sediments of eutrophic Meretta Lake in the Canadian arctic despite high loadings of N and P to the lake from sewage; although bottom water dissolved oxygen was never completely depleted. Additionally, Schindler et al (1973) found no release of P from the anoxic bottom sediments of Lake 227, a Precambrian shield lake in northwestern Ontario, even following four years of artificial additions of nutrients to the lake.

It has been suggested (Blanton 1973; Burns and Ross 1972) that the late summer and autumn erosion of the thermoclines of thermally stratified lakes is an important factor contributing to late season phytoplankton pulses in lakes demonstrating significant accumulations of nutrients in their hypolimnia. In contrast, a study of the shallow, homothermous waters of the Upper Bay of Quinte (Wright, D., In prep.[1]) revealed that P release from aerobic bottom sediments was restricted mainly to physical processes and that soluble reactive P increased only slightly in surface waters following turbulent mixing by wind. Concurrently with Wright's study, a limnological investigation of the deep basin ($Z_{max.}$ = 33 m; Figure 1) of Stony Lake was undertaken in 1971 as a component of the "Kawartha Lakes Water Management Study" to determine the magnitude and significance of changes in nutrient concentrations and associated physico-chemical phenomena related to thermal stratification and the development of anoxic bottom waters. Particular attention was given to seasonal distribution of chlorophyll a in the euphotic zone of the lake realizing that entrainment of nutrient enriched bottom water into the euphotic zone during late summer and autumn would likely contribute to increases in chlorophyll a.

[1]M.Sc. Thesis Dept. of Zoology, University of Guelph.

METHODS

An outline of field and laboratory methods as well as details of lake morphometry, hydrology and external nutrient loadings are given in Vol III, Chapters 1 and 7.

During most of the ice-free period, sampling and field measurements were carried out on each week day.

RESULTS AND DISCUSSION

Water Temperature, Heat Content and Stability

The water column of the deep basin of Stony Lake had begun to stratify thermally by the second week of May when the intensive investigations were begun and by the last week of May, a well developed thermocline was in evidence (Figure 2a). By this time also, the centre of gravity of the water column lay 1.18 mm lower than under the (assumed) 4°C winter homotherm, giving rise to a stability of 365.8 g-cm/cm^2 (Figure 3). Over the ice-free period of the study, a maximum epilimnetic temperature (at 1m) of 24°C was recorded on the 8th of July, while maximum recorded temperature at 1m above bottom was 8.5°C on the 16th of June. A rapid increase in the stability of the water column between the 20th of July and 6th of August of 1171.8 g-cm/cm^2 corresponded to a surface water temperature increase of 5.1°C brought about by rising air temperatures during the same period (Figure 3). The maximum heat content of 246 metric ton-cal/m^2, calculated for early August, means the average rate of heating of the water column was approximately 155 g-cal/cm^2/day. The rate of heat increases of the deep basin of Stony Lake is therefore in good agreement with the rate (160 g-cal/cm^2/day) cited by Hutchinson (1957, p.493) for Lake Lodoga of approximately the same latitude. The rate of increase of heat content was not constant, however, and sharp losses in heat content, most likely as a result of atmospheric cooling of the surface waters of the lake, came about during the third week of June and the second week of July (Figure 3).

After its development in mid-May, the lower limit of the metalimnion remained at about 10 m depth until the third week of August (two weeks after maximum heat content of the water column was attained) when the thermocline began to fall; by the last week of October it lay between 13 and 17 m (Figure 2[a]). The average rate of fall of the thermocline during late summer and autumn was therefore about 10.7 cm/day, resulting in entrainment of approximately 1.36×10^7 m^3/day of hypolimnetic and metalimnetic water into the metalimnion and epilimnion, respectively. No attempt was made to budget heat losses, however, back-radiation from the epilimnetic waters to the atmosphere and eddy diffusion caused by density increases in the surface water no doubt contributed to the erosion and lowering of the thermocline at this time of the year. Near homothermous temperatures existed from surface to bottom by the 9th of November (Figure 2[a]).

The maximum stability of 2771.4 g-cm/cm^2 during the second week of September for the waters of the deep basin of Stony Lake agrees well with those recorded for ELA lakes of similar depth (Schindler 1972). It would seem, therefore, that the added fetch given to the prevailing northwesterly winds from the extensive areas of shallower waters of the lake is not a serious deterrent to the establishment of very stable thermal stratification in the deep basin of the lake. Heat content of the water column of the deep basin may in fact be increased during warm windy weather as a result of rapidly heated water in the littoral areas of the lake being dispersed over the whole lake surface and displacing or mixing with the epilimnetic waters of the deep basin. For these reasons, the marked fluctuations observed in heat content during summer (Figure 3) were probably greater than those expected if the deep basin were self-contained or isolated from the extensive littoral areas of the main lake. In this regard, it is also noteworthy that the decline in heat content from September to November is much more uniform than the increase observed between June and August (Figure 3) despite marked fluctuations in abient air temperature and is probably related to the moderating influence of the heat stored in shallow water sediments during periods of rapidly declining air temperatures.

Dissolved Oxygen, and Free Carbon Dioxide

Owing to the proximity of the bottom sediments and associated reductive processes, the rate of depletion of dissolved oxygen at 30 m was somewhat greater (0.10 mg/l/day) than at 14 m and 21 m where the depletion rate was 0.06 mg/l/day (Figures 2^b, 4 and 5). From these data, a hyperbolic rate of depletion with depth was assumed, yielding a dissolved oxygen depletion rate of 0.15 mg/l/day at 33 m. The hypolimnetic areal oxygen depletion rate was then calculated by summing the absolute depletions in strata beneath the metalimnion (Table 1). The 742 kg of dissolved oxygen lost per day is equivalent to about 580 mg/m^2/day.

Areal hypolimnetic dissolved oxygen depletion rates have been used by Mortimer and Hutchinson as an index of the trophic state of lakes (Hutchinson 1957, p.644). Hutchinson's upper limit for oligotrophy is 170 mg/m^2/day and lower limit for eutrophy is 330 mg/m^2/day while Mortimer suggests limits of 250 and 550 mg/m^2 day, for oligotrophy and eutrophy, respectively. The areal dissolved oxygen depletion rate in the central basin hypolimnion of Lake Erie is about 390 mg/m^2/day (Burns and Ross 1972) and hence falls within the criteria suggested by Hutchinson for eutrophic lakes and by Mortimer for mesotrophic lakes. It is noteworthy that the rate of depletion of dissolved oxygen in Stony Lake's hypolimnion (580 mg/m^2/day) exceeds the lower limits for eutrophy set out by both Mortimer and Hutchinson, yet the lake does not exhibit other classical signs of eutrophy such as algal blooms and poor water transparency (see below).

Carbon dioxide analyses on samples from 30 m were not regular but samples were also analyzed for CO_2 from 29 m and 31 m. If concentrations at all three depths are plotted, more confidence is to be had from the straight line rate curve established for May, June and July (Figure 6) than if sporadic data from one depth only are plotted. It remains difficult to establish a well defined rate of increase in the bottom waters during August, September and October as the data are widely scattered. The same is true of CO_2 data collected at 14 m and 21 m (Figure 5 and 7). The rate of increase of CO_2 during early summer at 30 m (0.11 mg/l/day) accounts for 80% of the dissolved oxygen depletion at this depth.

TABLE 1: Hypolimnetic dissolved oxygen depletion rates in the deep basin of Stony Lake during the period of thermal stratification of 1971.

Depth (m)	Water Vol.(m^3)	D.O. depletion rate (mg/l/day)	Absolute D.O. depletion (kg/day)
14 - 20	5.62×10^6	0.06	338
20 - 25	3.80×10^6	0.06	228
25 - 30	1.67×10^6	0.08	134
30 - 33	3.50×10^5	0.12	42
		TOTAL	742

Similarly at 14 m and 21 m, the rate of increase of CO_2 (0.07 mg/l/day) accounts for 83% of the dissolved oxygen depletion at these depths. This means that at both 14 m and 21 m and as well at 30 m, 17% and 20%, respectively of the depleted dissolved oxygen was lost to processes other than CO_2 evolution. In the Central Basin of Lake Erie, the increase in hypolimnetic carbon dioxide was accounted for by 87% of the dissolved oxygen depletion or, 13% of the oxygen depleted was lost to processes other than CO_2 evolution (Burns and Ross 1972). It is probable that in Stony Lake, as in Lake Erie, substantial amounts of dissolved oxygen were consumed by the oxidation of iron sulphide. Other processes causing depletion of dissolved oxygen include the biochemical oxidation of reduced nitrogen compounds (see below) and the formation of water from the oxidation of organic matter. Li (1973) found the rate of oxidation of organic carbon to be accounted for completely by the rate of decrease of dissolved oxygen at depths below 60 m in Lake Zurich; but above 20 m (still below the metalimnion) found dissolved oxygen replenishment by diffusion from the surface waters to be substantial. It is therefore possible that the lower rate at depletion of 14 m and 21 m in Stony Lake (compared to the rate at 30 m) was in part attributed to replenishment by diffusion. However, because the rate of CO_2 accumulation was proportionately lower in the upper hypolimnion (at 14 m and 21 m), diffusion between the upper and lower hypolimnion of both CO_2 and dissolved oxygen was likely much more important in Stony Lake than diffusion across the metalimnion.

Mineral Constituents

The eastern basin of Stony Lake contains moderately hard water, undoubtedly a consequence of land drainage from local areas of sedimentary limestone. Alkalinity of euphotic zone waters was inversely related to standing stock of phytoplankton (chlorophyll a; see below) with lowest values (60 - 65 mg/l as $CaCO_3$) found during the chlorophyll a maximum in late May and early June and highest values (70 - 72 mg/l) found during the latter part of June (Figure 8[a]) when chlorophyll a concentrations decreased to less than 1 µg/l (Figure 15). The implication being, that with high standing stocks of phytoplankton, photosynthetic assimilation of free carbon dioxide (undetectable in the euphotic zone during early June; Figure 9[a]) and bicarbonate ion lead to higher pH (as high as 8.7 on June 14; Figure 9[b]) and to precipitation of calcium carbonate. Lowest pH values of 6.7 were found in the bottom waters of the hypolimnion during September and October and accompanied the large accumulations of free carbon dioxide (Figure 9[a]).

Specific conductance was fairly uniform with depth throughout most of the ice-free period (Figure 8[b]) ranging from about 150 to 275 μmhos/cm, with the relatively high values again indicating moderately hard water. Considerable seasonal fluctuation was evident (Figure 8[b]) but a trend to generally higher conductivity towards late summer probably reflects the results of evaporative concentration, accumulations of inorganic carbon in the hypolimnion and inputs of less dilute land drainage water.

Nutrients

Seasonal trends in total P, soluble reactive P and Fe in hypolimnetic water (samples collected 1 - 2 m above bottom) were not evident (Figures 10 and 11). Three or four large peaks in concentrations of total P, Fe and Kjeldahl-N found in bottom water samples during the ice-free period most likely represent entrapment of bottom sediment in the sampler and do not indicate release of dissolved substances from the bottom sediments into the overlying water. A slight trend to decreasing Kjeldahl-N concentrations from June until August (Figure 12) is reflected in a slight decrease in ammonia-N of from 30 to 40 μg/l in late June to concentrations of about 10 μg/l in July and August (Figure 13) and, in turn, coincides with an increase in nitrate-nitrogen during the same period. During this period, it is likely that ammonia was nitrified as rapidly as it was released from decomposing organic material on the lake bottom. The estimated rate of increase of nitrate-N of 2.25 μgN/l/day between June 1 and July 28 (Figure 14) corresponds with a dissolved oxygen requirement of 7.73 μg O/l/day (3.9 μg O_2/l/day). Therefore, in addition to the 80% of the dissolved oxygen depletion accounted for by CO_2 evolution in the bottom waters (given above), 4% was depleted by nitrification processes.

Bottom water ammonia-N concentrations rose sharply in late September and October after depletion of bottom water dissolved oxygen and coincided with decreasing nitrate-N concentrations, owing undoubtedly to both the ammonification of organic matter and the reduction of nitrate (Figures 13 and 14). No seasonal trends were noted in the upper hypolimnion at sampling depths of 14-16 m and it is likely that significant accumulations of ammonia-N were restricted to only the deeper depths (>15m) because maximum concentrations at 1 - 2 m above bottom were moderately low, even by autumn.

The most important P-sorbing constituent of lake sediments is believed (Shukla et al 1971) to be a gel complex of hydrated iron oxide which contains small amounts of aluminium oxide, silicon hydroxide and organic matter. It is highly significant that neither P nor Fe accumulated in the hypolimnion of Stony Lake (Figures 10 and 11). The classical ferric phosphate reduction reaction at the sediment-water interface is therefore not an important reaction in the anoxic hypolimnion of Stony Lake as it apparently is in Lake Erie's Central Basin (Burns and Ross 1972). P released from organic matter settling out of the trophogenic zone was likely precipitated as some inorganic-organic complex and not as ferric phosphate. Richards (1965) model of organic decomposition would indicate that 1 μg P is released with every 150 μg CO_2. On this basis therefore, the observed increase in CO_2 between June and September in Stony Lake's hypolimnion (30 m) should have coincided with an increase in P of 66 μg/l, while in fact no accumulation was observed (Figure 10). On the other hand, Burns' and Ross' data (1972) for Lake Erie's Central Basin showed good agreement with Richards' model with anoxic generation of 99 μg CO_2/l corresponding with the accumulation of 1 μ g P/l.

The seasonal distribution of chlorophyll a was well defined with an early summer peak in early June (to 6.1 μg/l). A steady decline between early and late June (to a low of 0.5 μg/l) was accompanied by greatly improved water clarity (Figure 15). Throughout most of July and August, chlorophyll a concentrations ranged between 2 and 3 μg/l. One moderately high concentration of 7.1 μg/l was found on July 28. Because no accumulations of P were found in the hypolimnion and only small accumulations of ammonia materialized in the bottom waters, late summer entrainment of hypolimnetic water into the euphotic zone would not be expected to contribute to increases in suspended chlorophyll a. In fact, the autumn chlorophyll a concentrations were the lowest of the ice-free period (Figure 15) and were accompanied by excellent water clarity (Secchi disc readings exceeding 8 m).

It is not known if the relatively high chlorophyll a concentrations of spring and early summer were stimulated mainly by nutrients supplied to the euphotic zone from the bottom waters of the lake during spring "turnover". Observations on other shield lakes suggest that dissolved oxygen depletion in Stony Lake's bottom waters during the period of winter ice cover is unlikely to be more severe than during the summer, and consequently, nutrient accumulations in the bottom waters during the period of ice cover were probably only small. It follows that the bulk of the nutrients for the spring growth of phytoplankton in the euphotic zone of the deep basin most likely originated from melting snow, rainfall and land drainage. The decline of the springtime standing stock of phytoplankton may have been brought about by depletion of inorganic nitrogen from a peak of 264 μg/l on May 21 to undetectable levels (< 10μg NH_3-N and NO_3-N/l) on June 8 (Figure 16). Euphotic zone iron concentrations also decreased dramatically from a peak of 0.30 mg/l soon after ice-melt to less than 0.05 mg/l by the end of May (Figure 17). Total and soluble reactive P on the other hand showed great day-to-day fluctuations but with no evidence of seasonal trends (Figure 18) that might be linked with the well defined seasonal distribution of chlorophyll a.

If N depletion was in fact the main cause of the collapse of the spring phytoplankton population, then some concern should relate to the hypolimnetic ammonia-N regeneration observed in the late summer. Although late summer accumulations were small and apparently restricted to the near-bottom waters, it is probable that similar accumulations of ammonia-N do result by late winter under ice cover. More extensive accumulations of bottom water ammonia-N would therefore contribute to a magnification of the spring phytoplankton growths and ultimately lead to more severe dissolved oxygen depletions in the bottom waters during both the ice-on and the ice-free periods. It follows then that control of artificial inputs of nutrients and organic matter to Stony Lake are desirable if satisfactory surface water quality of the lake is to be maintained.

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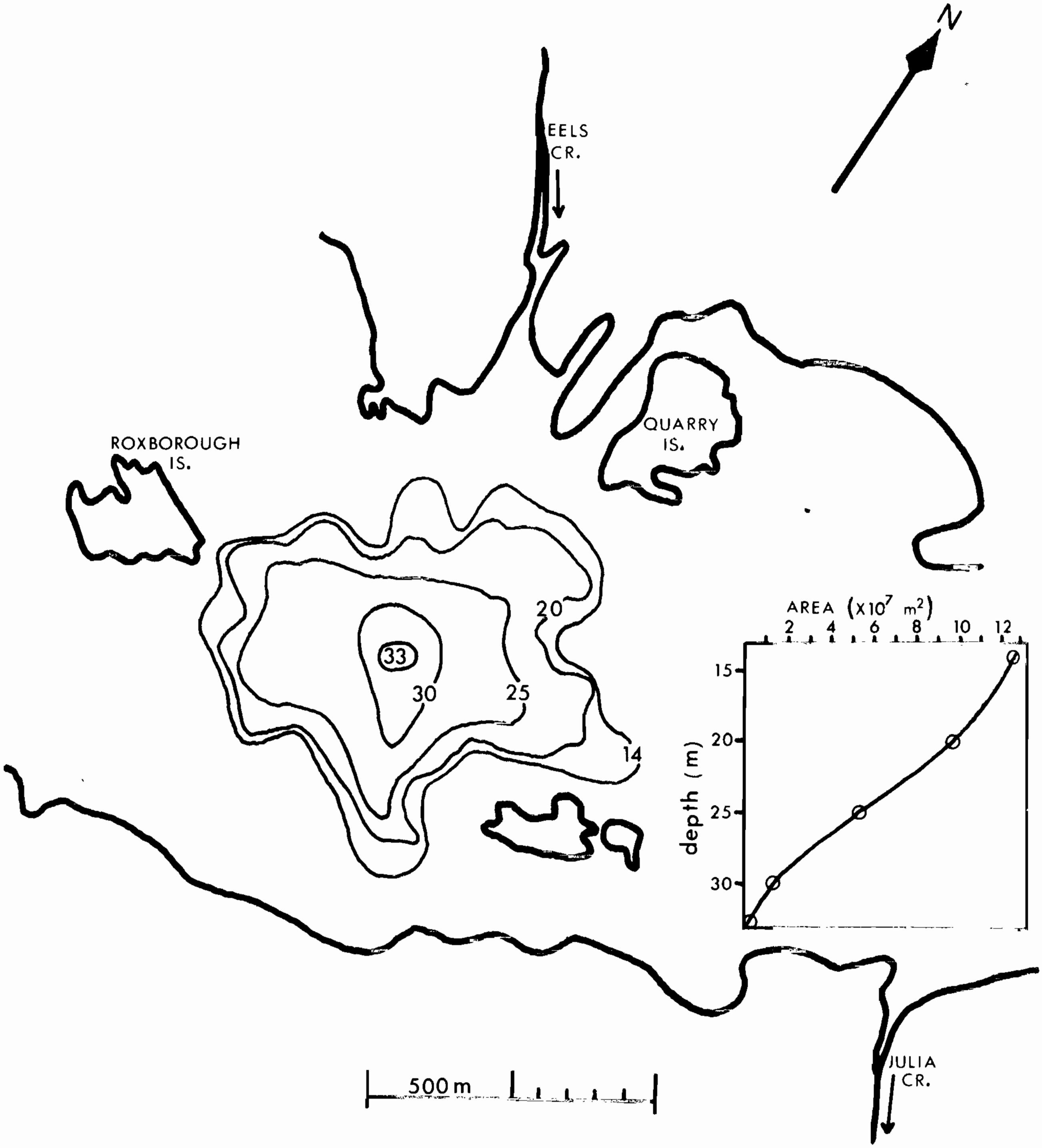

Figure 1: Bathylithic map and hypsograph of the hypolimnion of Stony Lake's deep eastern basin.

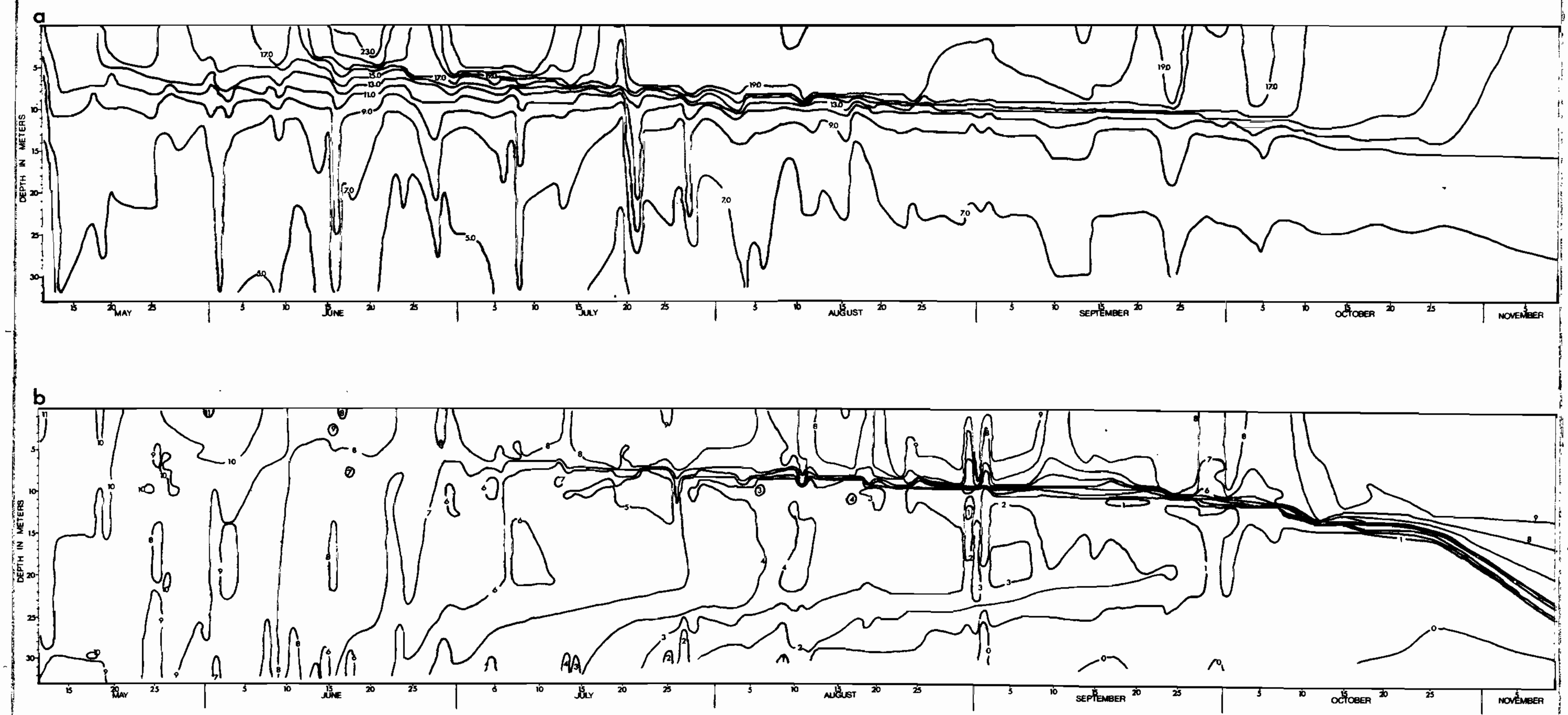

Figure 2: Seasonal isotherms (a) and dissolved oxygen (mg/l) isopleths (b) of the deep basin of Stony Lake.

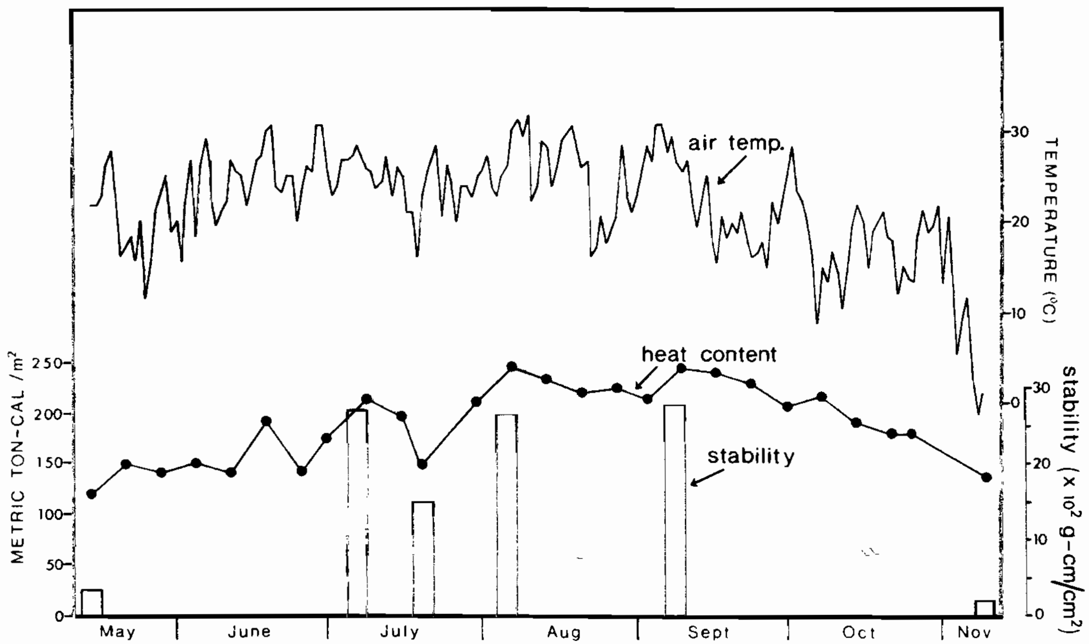

Figure 3: Mean daily air temperature (recorded at Trent University, Peterborough) and selected stability and heat content data for the water column of the deep basin of Stony Lake during the ice-free period of 1971.

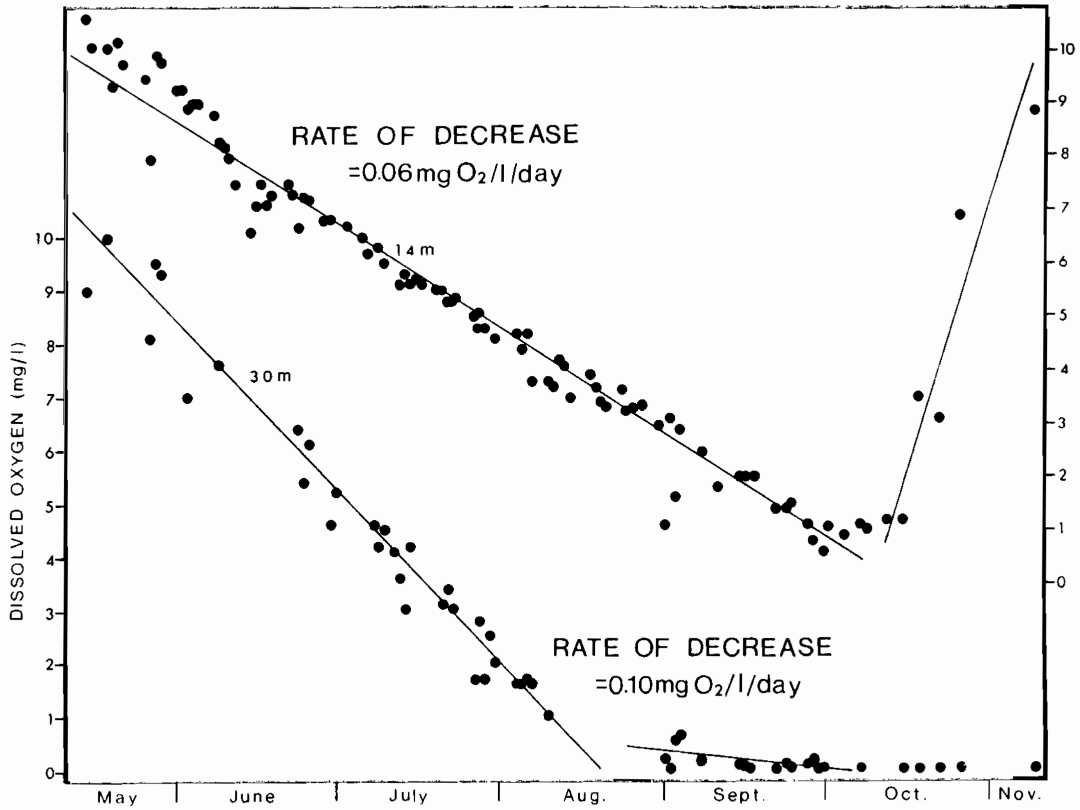

Figure 4: Hypolimnetic dissolved oxygen depletion rate at 14 m and 30 m in the deep basin of Stony Lake.

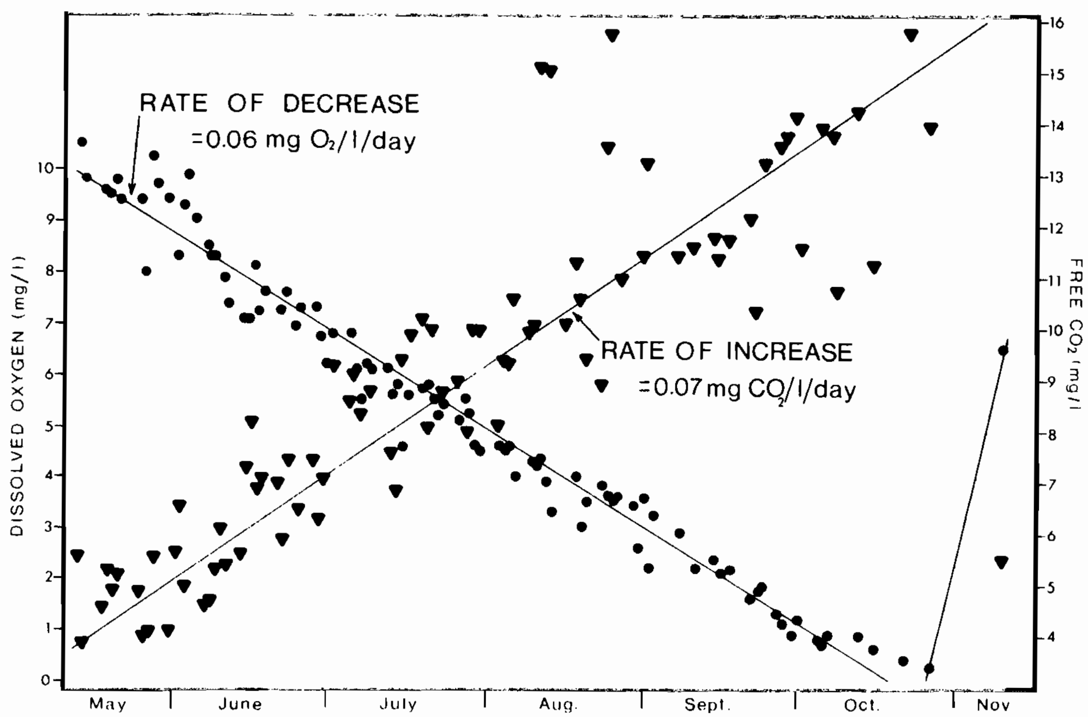

Figure 5: Hypolimnetic dissolved oxygen depletion rate and rate of increase of free carbon dioxide at 21 m in the deep basin of Stony Lake.

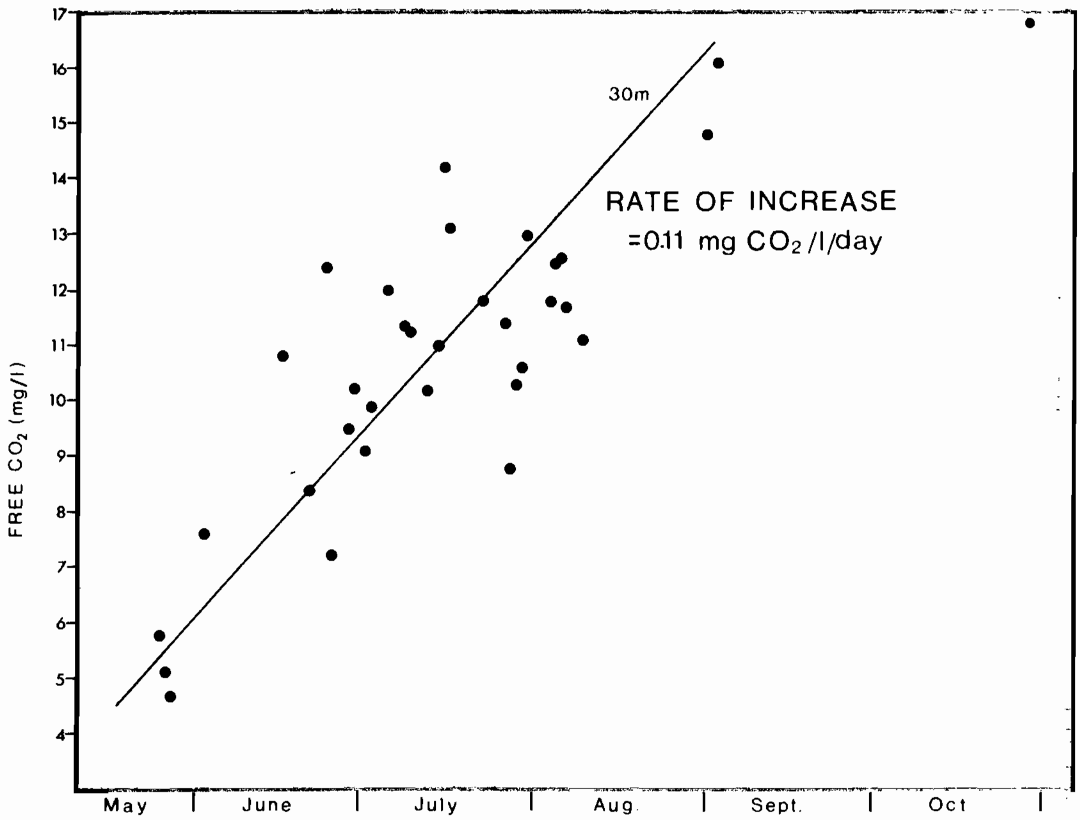

Figure 6: Rate of increase of free carbon dioxide at 30 m in the eastern basin of Stony Lake.

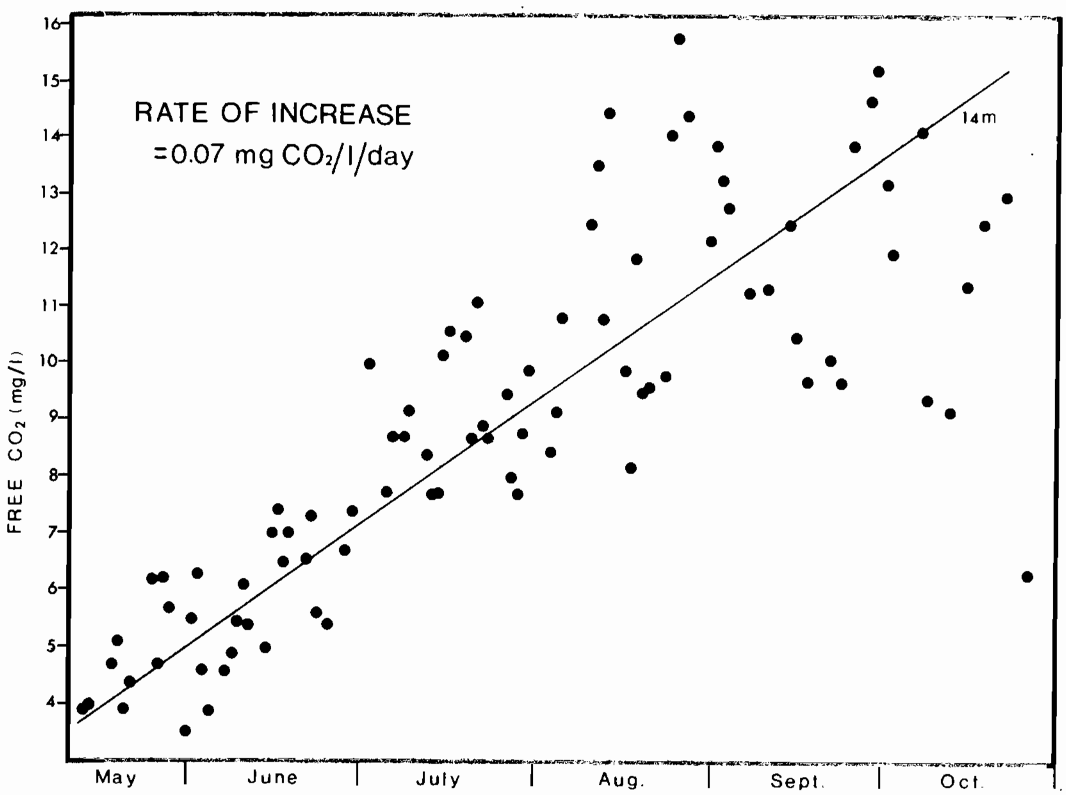

Figure 7: Rate of increase of free carbon dioxide at 14 m in the eastern basin of Stony Lake.

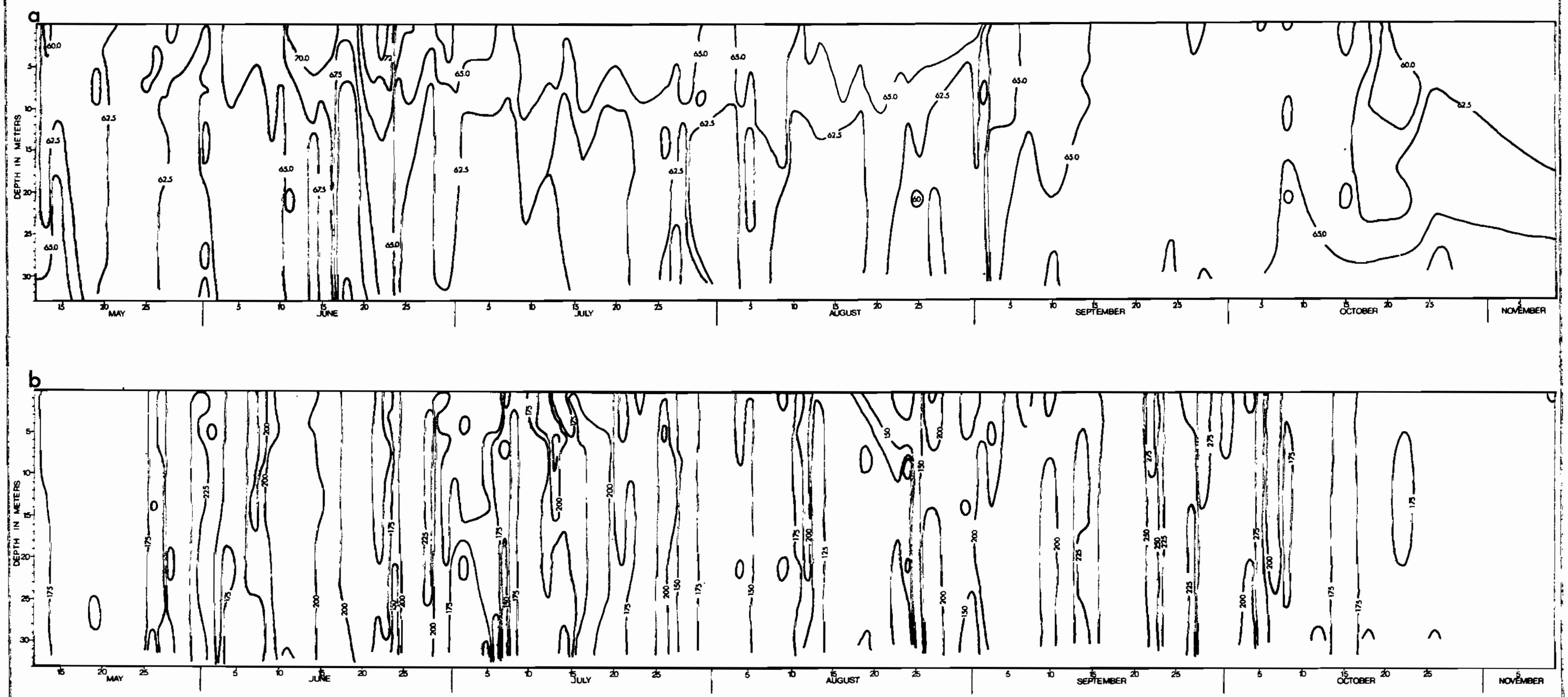

Figure 8: Seasonal isopleths of alkalinity (a) as mg/l $CaCO_3$ and specific conductance (b) in µmhos/cm at 25 C, in the deep basin of Stony Lake.

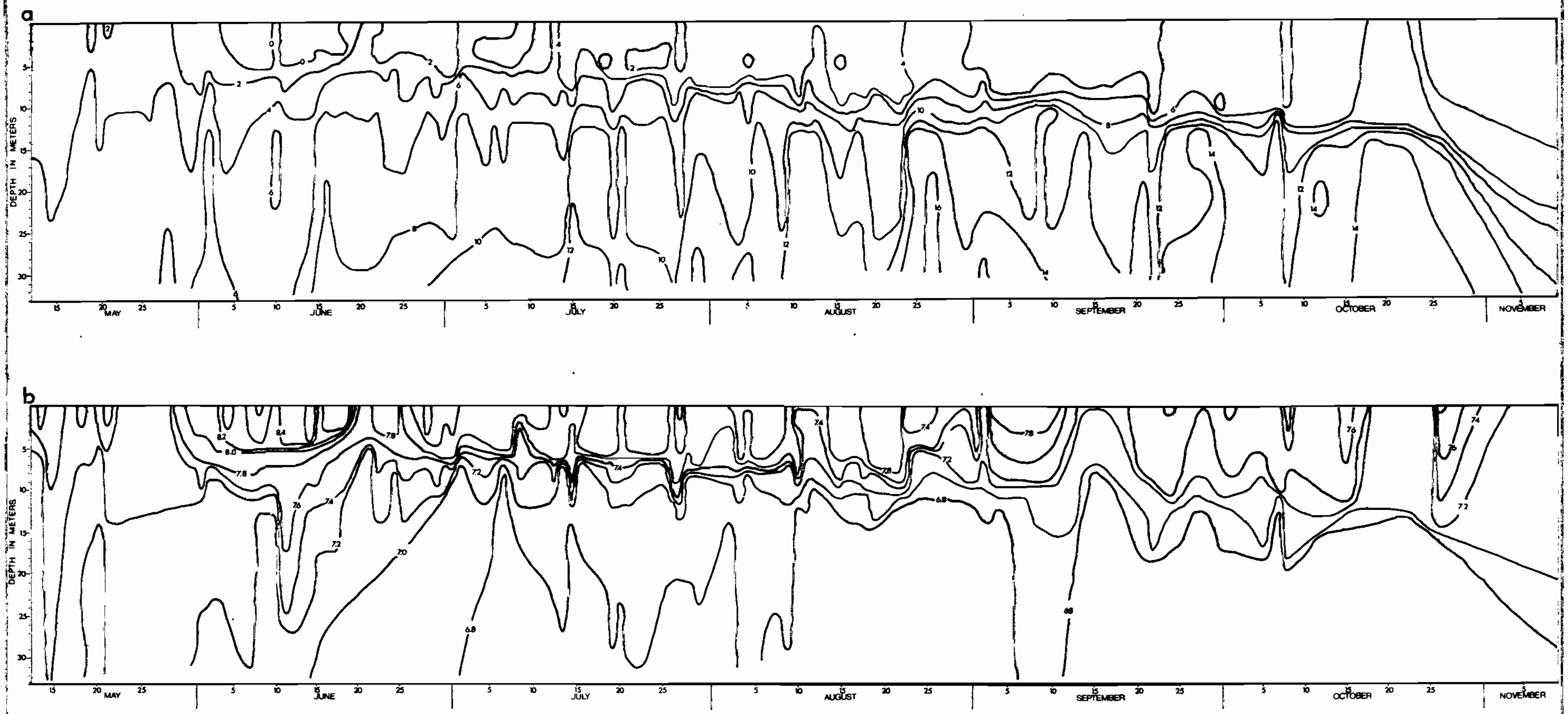

Figure 9: Seasonal isopleths of free carbon dioxide (a) in mg/l and of pH (b) in the deep basin of Stony Lake.

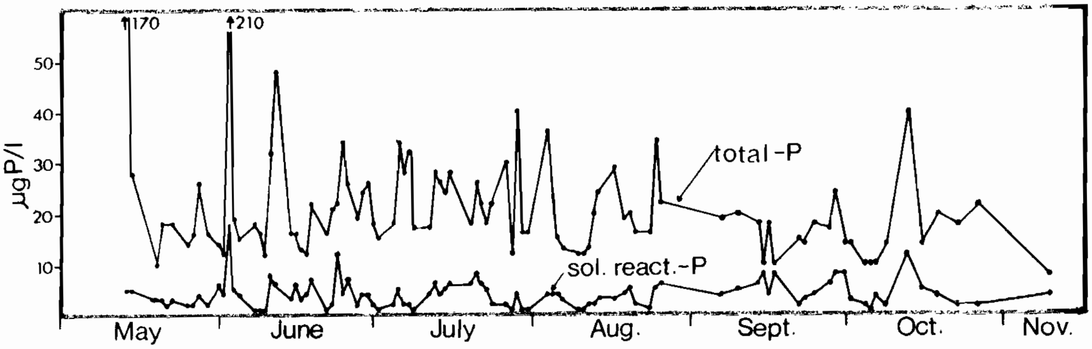

Figure 10: Seasonal distribution of total and soluble reactive phosphorus in samples collected 1 - 2 m above bottom in the deep basin of Stony Lake during the ice-free period of 1971.

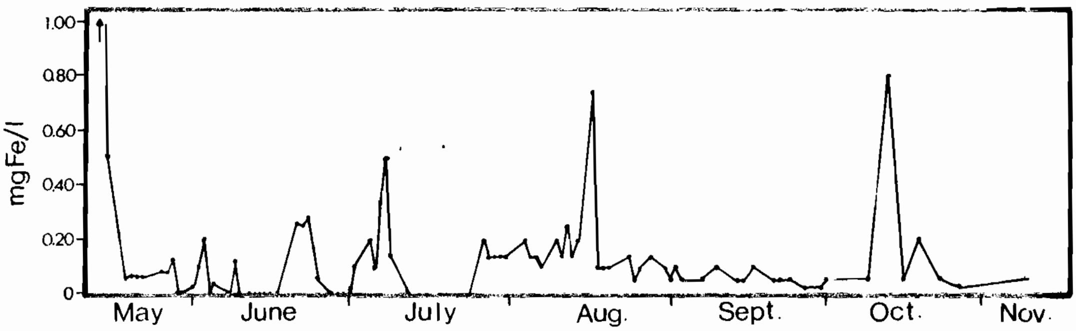

Figure 11: Seasonal distribution of total iron in samples collected 1 - 2 m above bottom in the deep basin of Stony Lake during the ice-free period of 1971.

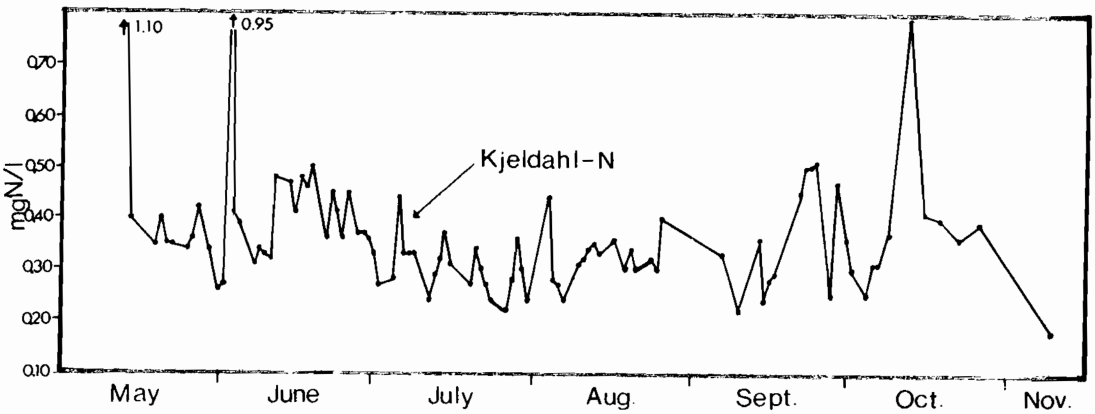

Figure 12: Seasonal distribution of total Kjeldahl-N in samples collected 1 - 2 m above bottom in the deep basin of Stony Lake during the ice-free period of 1971.

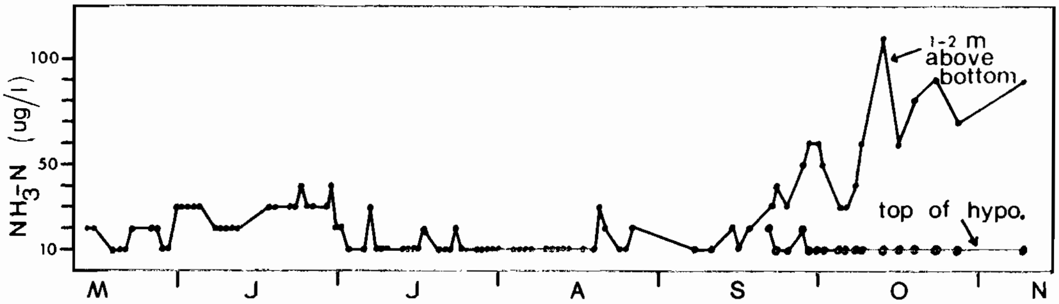

Figure 13: Seasonal distribution of ammonia-N in the hypolimnion of the deep basin of Stony Lake at 1 - 2 m above bottom. For comparison, some results from the top of the hypolimnion (14 - 16 m depth) collected during the autumn are also shown.

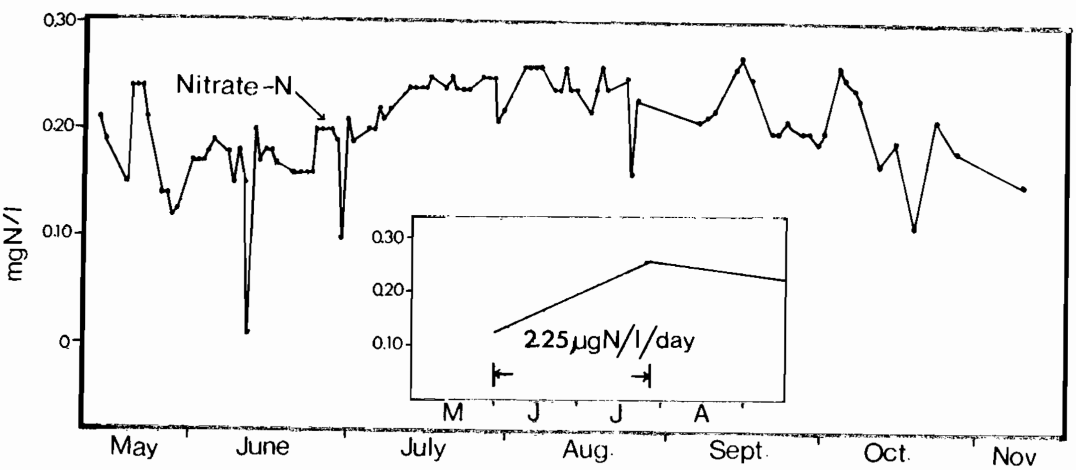

Figure 14: Seasonal distribution of nitrate-N in samples collected 1 - 2 m above bottom in the deep basin of Stony Lake. Insert shows the estimated rate of increase of nitrate nitrogen between June 1 and July 28.

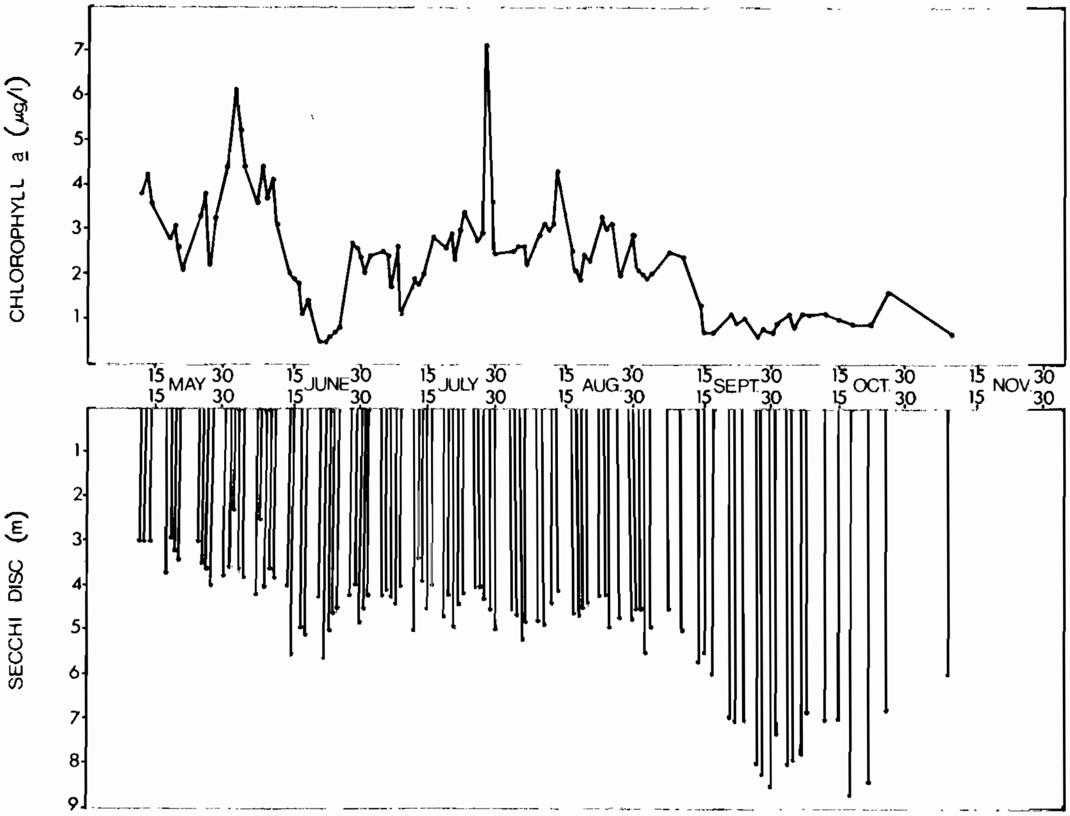

Figure 15: Seasonal distributions of chlorophyll a and of Secchi disc visibilities in the euphotic zone of the deep basin of Stony Lake during the ice-free period of 1971.

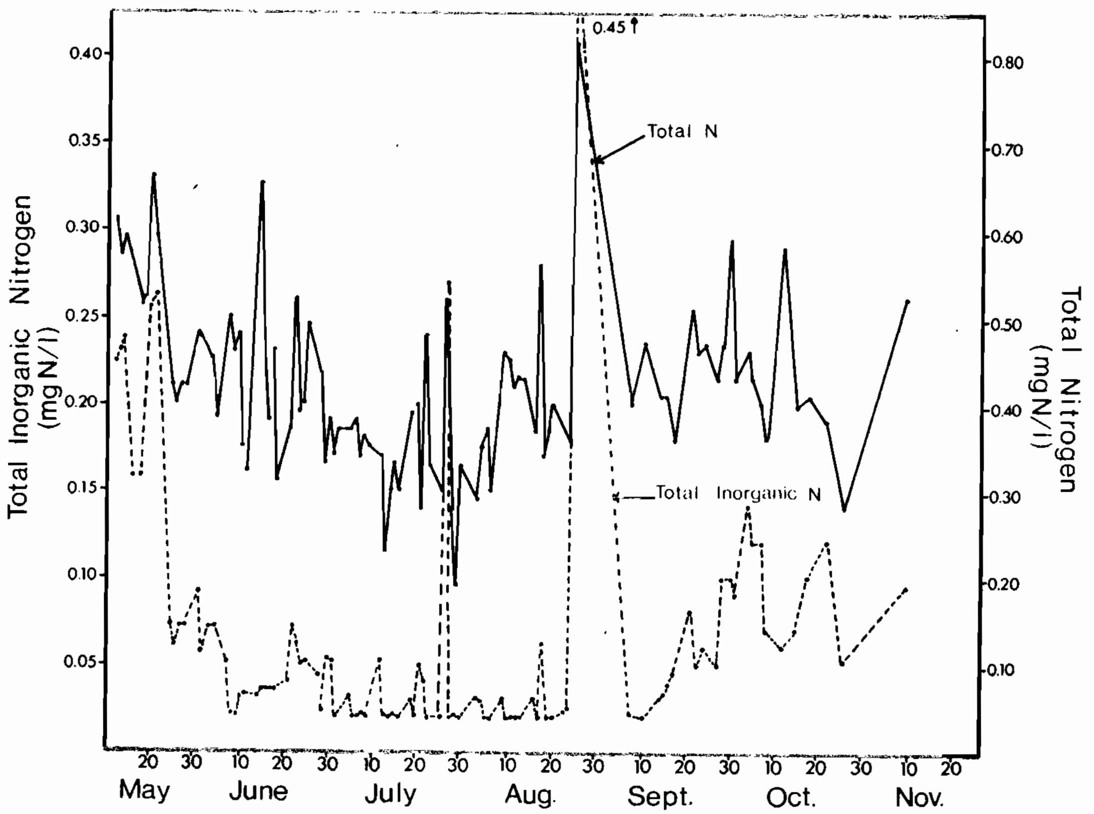

Figure 16: Seasonal distribution of total nitrogen (total Kjeldahl -N+NO_3^--N+NO_2^--N) and total inorganic nitrogen (NH_3-N+NO_3^--N+NO_2^--N) in the euphotic zone of the deep basin of Stony Lake during the ice-free period of 1971.

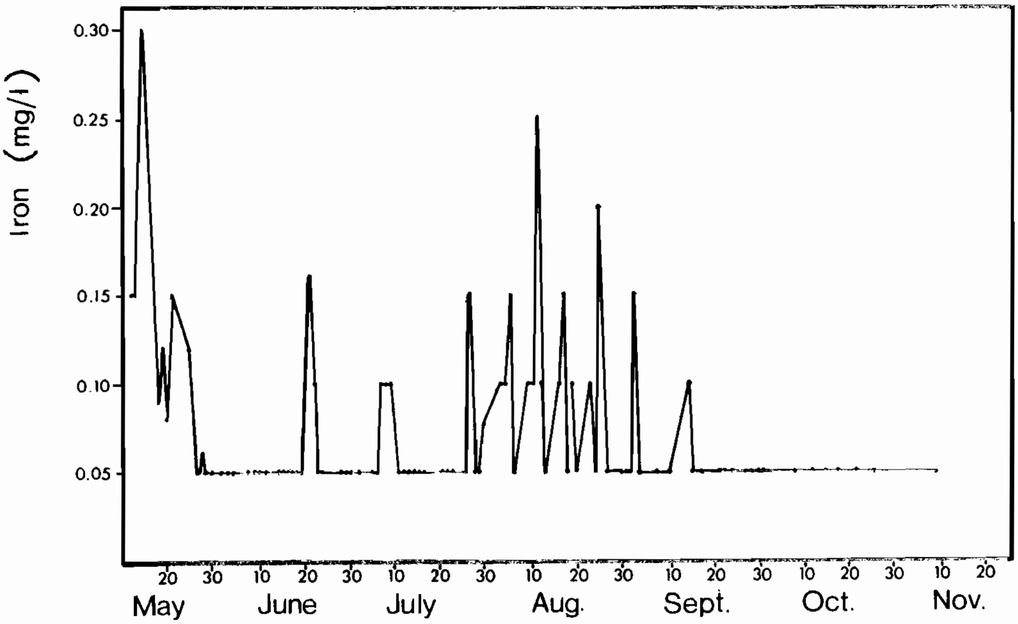

Figure 17: Seasonal distribution of total iron in the euphotic zone of Stony Lake during the ice-free period of 1971.

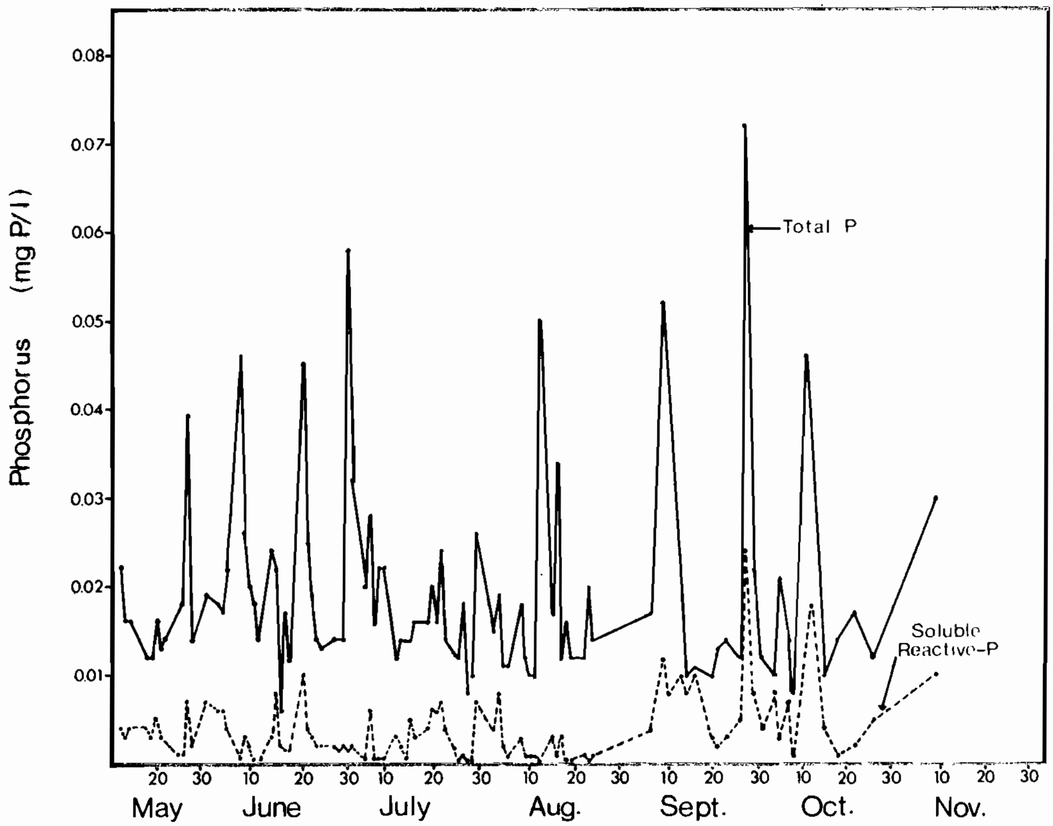

Figure 18: Seasonal distribution of total and soluble reactive phosphorus in the euphotic zone of Stony Lake during the ice-free period of 1971.

APPENDIX 'A'

LIST OF TABLES

TABLE 1. Minimum, maximum and mean values for temperature (°C), dissolved oxygen (ppm), pH, CO_2 (mg/l), alkalinity (mg/l) and conductivity (μmhos/cm³ at 25°C) in the Kawartha Lakes in 1972 and 1976.

Station	Sample Depth	Temperature (°C) range	Temperature (°C) mean	Dissolved Oxygen (ppm) range	Dissolved Oxygen (ppm) mean	pH range	pH mean	CO_2 (mg/l) range	CO_2 (mg/l) mean	Alkalinity (mg/l) range	Alkalinity (mg/l) mean	Conductivity (μmhos/cm³) range	Conductivity (μmhos/cm³) mean
1972													
B-1	1m	12.7-24.0	19.3	7.5-9.7	8.2	6.8-7.9	7.45	0.5-4.8	1.96	24-35	28.9		
	5.8m	10.1-22.8	18.0	6.7-9.8	7.9	6.8-7.8	7.37	1.0-4.7	2.12	26-36	29.1		
B-2	1m	11.2-23.5	18.3	7.6-11.4	8.6	7.3-7.9	7.69	0.6-3.3	1.74	36-45	42.2		
	10.9m	8.1-19.0	15.8	5.7-9.8	7.5	6.8-7.9	7.40	1.1-5.9	3.01	35-46	43.6		
B-3	1m	11.7-23.0	18.2	7.4-10.6	8.5	7.2-7.9	7.70	0.8-5.2	1.91	42-45	43.6		
	2.5m	11.0-22.0	17.9	7.4-10.6	8.6	6.8-7.9	7.59	0.8-7.0	2.60	34-45	42.4		
1976													
B-1	1m	7.8-24.0	17.3	7.9-10.8	8.5	7.4-8.0	7.75	0.5-2.0	1.1	23-38	30	71-103	85
	6.0m	7.8-21.7	16.8	7.2-10.5	8.4	7.4-7.9	7.67	0.5-2.4	1.4	22-38	29	72-103	85
B-2	1m	8.4-22.0	16.7	7.6-11.8	8.6	7.8-8.0	7.9	0.7-1.2	1.0	38-47	43	103-120	112
	8.9m	8.4-20.4	15.5	4.4-10.7	8.0	7.7-7.9	7.8	0.9-5.3	2.1	38-56	45	103-123	114
B-3	1m	6.3-22.5	16.5	7.5-12.5	8.7	7.8-8.0	7.89	0.8-1.1	1.0	41-48	45	105-123	115
	3.0m	6.3-22.5	16.5	7.8-11.3	9.1	7.8-8.0	7.87	0.88-1.2	1.0	41-48	44	111-114	112
1972													
Ca-4	1m	14.0-23.6	19.6	7.6-10.2	8.3	7.2-8.0	7.6	0.9-3.5	2.2	38.0-47.5	44.4		
	10.3m	9.8-17.1	14.5	1.4-8.9	5.5	6.9-7.7	7.2	2.4-7.8	5.1	38.5-47.0	44.3		
Ca-5	1m	14.8-23.0	18.9	7.3-10.6	8.2	6.8-7.9	7.4	0.9-7.0	3.1	33.5-45.5	43.1		
	14.9m	8.9-17.9	13.6	0.3-9.4	4.5	6.7-7.7	7.1	1.1-11.0	7.0	30.5-49.0	43.1		
Ca-6	1m	13.8-23.0	18.5	7.2-11.0	8.3	7.2-7.9	7.5	1.1-4.6	2.9	43.5-49.0	45.2		
	10.2m	9.0-18.3	14.5	1.2-8.9	5.7	6.7-7.8	7.2	0.9-10.3	4.4	40.0-46.5	43.6		
1976													
Ca-5	1.0	9.0-22.0	16.6	7.9-10.7	8.7	7.7 -8.1	7.8	0.6-1.8	1.2	42-49	46	113-123	115
	12.3	9.0-15.8	12.9	0.5-10.6	6.0	7.0 -7.9	7.5	0.9-7.04	3.3	43-51	46	109-131	118

Table 1 (continued)

Station	Sample Depth	Temperature (°C) range	Temperature (°C) mean	Dissolved Oxygen (ppm) range	Dissolved Oxygen (ppm) mean	pH range	pH mean	CO_2 (mg/l) range	CO_2 (mg/l) mean	Alkalinity (mg/l) range	Alkalinity (mg/l) mean	Conductivity (µmhos/cm^3) range	Conductivity (µmhos/cm^3) mean
1972													
S-7	1 metre	16-24	19.2	7.4-11.6	8.8	7.2-8.2	7.8	.13-5.9	2.2	43.0-50.5	48.8		
	5.5m	11.5-22.5	17.5	4.8-11.0	7.8	7.1-8.2	7.6	0.26-7.3	3.0	45.5-60.0	50.9		
S-8	1.0m	13.6-23.0	18.6	7.4-13.2	8.8	7.6-8.6	8.0	0-4.5	1.8	58.5-65.3	61.0		
	10.1m	9.9-19.8	16.4	0-8.3	5.1	6.8-8.4	7.5	0-10.9	5.0	53.5-69.0	62.0		
S-9	1.0m	15.8-23.3	18.9	7.4-12.2	8.6	7.4-8.6	8.0	0-3.1	1.2	56.0-121	66.0		
	2.6m	12.0-22.0	17.9	6.6-9.9	8.1	7.2-8.0	7.6	0-4.5	2.1	44.5-65.5	58.5		
S-10	1.0m	15.0-23.0	19.0	7.2-11.6	8.4	7.5-8.3	8.0	0-2.4	1.0	57.5-64.5	61.5		
	7.2m	9.9-22.3	17.4	6.3-8.5	7.3	7.2-8.1	7.7	0.4-9.2	2.5	59.5-66.0	62.0		
S-11	1.0m	13.9-25.1	19.1	7.4-10.2	8.4	7.6-8.5	8.1	0-2.6	1.0	61.0-72.5	64.7		
	3.4m	12.0-22.0	18.3	6.0-10.5	8.0	7.3-8.4	8.0	0-4.0	1.2	62.0-70.5	65.5		
1976													
S-7	1.0	8.7-22.7	16.8	7.0-10.4	8.4	7.8 -8.1	8.0	.7-2.0	1.3	50-67	56	122-164	142
	5.1	8.7-21.5	16.3	7.3-9.4	8.4	7.9 -8.0	8.0	1.1-1.6	1.2	52-69	59	138-166	150
S-8	1.0	9.2-21.0	16.8	6.9-9.9	8.2	7.9-8.7	8.1	0-1.8	1.0	63-72	68	156-181	169
	9.1	9.2-21.0	16.0	2.1-9.1	6.5	7.6-8.6	8.0	0-4.7	1.6	62-80	70	155-185	171
S-9	1.0	8.5-21.3	16.5	6.6-10.2	8.3	7.8-8.7	8.3	0-2.5	0.7	67-106	89	185-264	222
S-10	1.0	9.5-22.0	16.9	7.2-9.9	8.0	7.9-8.8	8.2	0-1.8	1.0	63-79	70	164-184	176
	7.3	9.5-21.5	16.8	6.6-9.1	7.8	7.9-8.9	8.2	0-2.2	1.3	63-78	70	163-183	176

Table 1 (continued)

Station	Sample Depth	Temperature (°C) range	Temperature (°C) mean	Dissolved Oxygen (ppm) range	Dissolved Oxygen (ppm) mean	pH range	pH mean	CO_2 (mg/1) range	CO_2 (mg/1) mean	Alkalinity (mg/1) range	Alkalinity (mg/1) mean	Conductivity (µmhos/cm^3) range	Conductivity (µmhos/cm^3) mean
1972													
S-12	1.0m	14.8-22.5	19.2	7.4-11.1	8.9	8.2-8.6	8.4	0-1.0	0.2	119-133	127		
S-13	1.0m	14.8-22.2	18.8	7.8-10.9	8.7	8.0-8.6	8.4	0-2.0	0.3	117-138	129		
	5.7m	14.0-20.6	17.6	4.3-9.0	7.2	7.7-8.5	8.2	0-5.6	1.3	127-138	131		
S-14	1.0m	14.8-21.6	18.8	5.9-10.8	8.3	8.0-8.6	8.3	0-2.7	.85	129-151	140		
S-15	1.0m	14.8-22.0	18.9	6.7-11.3	8.4	8.0-8.6	8.3	0-2.5	1.0	126-146	138		
1976													
S-13	1.0	5.2-21.9	14.8	7.1-11.1	9.0	8.1-8.6	8.4	0-1.4	0.3	115-135	125	280-326	304
	4.8	5.5-21.7	14.6	7.3-11.1	9.1	8.2-8.5	8.4	0-0.4	0.1	122-136	127	283-322	300
S-15	1.0 1.7	5.0-21.8	14.7	7.0-11.5	9.1	8.0-8.6	8.4	0-1.0	0.2	132-142	138	305-345	327
1972													
P-16	1.0m	15.0-24.8	19.2	7.2-10.4	8.0	6.9-8.4	7.9	0-9.8	2.4	60-74	69.8		
	10.9m	8.4-18.7	14.8	0.7-8.5	4.9	6.7-8.1	7.3	2.3-11.8	6.0	67-80	71.7		
P-17	1.0m	17.8-25.8	21.3	6.7-9.4	7.9	7.3-8.5	7.8	0-5.7	2.6	65-72	70.2		
	14.0m	10.2-18.8	12.2	0-6.6	2.3	7.0-7.6	7.3	1.9-10.7	8.0	68-107	86.5		
P-20	1.0m	15.2-24.8	19.2	7.0-9.2	8.2	7.8-8.2	8.1	0-2.4	.64	70-74	72.3		
	3.0m	15.2-22.3	18.2	6.7-9.2	7.7	6.3-8.7	7.9	0-7.0	2.1	71-74	72.9		
1976													
P-16	1.0	10.2-21.0	17.0	7.0-10.3	8.4	8.0-8.7	8.2	0-1.32	0.9	69-77	75	160-185	179
	9.8	10.0-19.0	14.6	0.3-10.3	5.7	7.4-8.6	7.9	0-5.54	3.2	69-83	76	166-200	185
P-17	1.0	10.5-22.5	17.5	7.4-10.2	8.5	7.9-8.3	8.1	0-4.4	1.3	64-79	74	138-218	182
	14.0	10.0-18.0	13.5	0.1-10.2	4.9	7.4-8.5	7.7	0-7.3	3.7	66-104	80	158-209	184
P-20	1.0	8.2-22.3	16.9	7.0-10.9	8.6	7.93-8.50	8.20	0-1.14	0.6	68-79	75	157-192	183
	3.0	8.2-22.3	16.8	7.7-10.8	8.8	7.93-8.45	8.18	0-1.58	0.6	74-85	79	190-192	191

Table 1 (continued)

Station	Sample Depth	Temperature (°C) range	Temperature (°C) mean	Dissolved Oxygen (ppm) range	Dissolved Oxygen (ppm) mean	pH range	pH mean	CO_2 (mg/l) range	CO_2 (mg/l) mean	Alkalinity (mg/l) range	Alkalinity (mg/l) mean	Conductivity (µmhos/cm³) range	Conductivity (µmhos/cm³) mean
1972													
P-18	1.0m	16.8-26.0	21.2	5.9-8.8	7.5	6.9-7.8	7.5	1.2-7.5	3.6	58-71	66		
	6.8m	6.9-16.0	10.6	0.3-10.0	3.1	6.5-7.1	6.8	7.0-21.5	11.6	41-86	64		
P-19	1.0m	17.7-24.9	20.6	6.9-9.8	8.0	7.6-8.3	7.9	0-4.0	1.8	73-88	84		
	8.5m	10.2-18.0	12.5	0-7.9	2.1	7.0-8.0	7.3	1.1-16.4	9.9	82-112	96		
P-21	1.0m	15.0-26.7	20.2	6.3-9.1	8.0	7.9-8.6	8.2	0-5.5	1.2	73-162	125		
1976													
P-18	1.0	8.5-23.5	17.6	7.0-9.1	8.1	7.8-8.0	7.9	1.2-3.0	1.7	57-74	68	130-168	153
	6.6	8.5-20.4	12.7	0.5-9.2	4.6	7.3-7.9	7.6	1.2-5.6	3.4	50-74	64	129-165	149
P-21	1.0	6.5-23.0	16.8	7.4-12.0	8.9	8.3-8.8	8.5	0	0	96-158	116	170-305	231
1972													
B-22	1.0m	16.8-24.0	19.6	6.5-8.3	7.9	7.5-8.5	8.0	0-3.7	1.5	43-77	70		
B-23	1.0m	17.0-24.5	19.7	6.5-9.4	8.4	7.4-8.5	7.9	0-5.4	1.4	70-78	76		

Table 1 (continued)

Station	Sample Depth	Temperature (°C) range	Temperature (°C) mean	Dissolved Oxygen (ppm) range	Dissolved Oxygen (ppm) mean	pH range	pH mean	CO_2 (mg/l) range	CO_2 (mg/l) mean	Alkalinity (mg/l) range	Alkalinity (mg/l) mean	Conductivity (µmhos/cm³) range	Conductivity (µmhos/cm³) mean
1976													
B-22	1.0	7.9-22.5	17.0	7.5-10.9	8.9	8.1-8.6	8.4	0-0.9	0.2	69-85	80	188-200	194
B-23	1.0	7.6-22.5	16.9	7.9-10.0	8.6	8.3-8.8	8.4	0-0.2	0.01	71-80	76	168-197	187
	3.9	7.6-22.5	16.7	7.8-11.5	9.2	8.3-8.8	8.5	0	0	72-83	79	186-202	193
1972													
B-24	1.0m	17.1-24.7	19.7	6.4-8.8	7.7	7.6-8.3	7.9	0-5.5	2.1	67-79	73		
	13.4m	12.2-19.0	15.4	0-8.5	4.4	7.0-8.1	7.5	0.6-9.6	5.9	66-79	74		
B-25	1.0m	16.8-24.1	19.7	7.5-9.9	8.4	7.7-8.4	8.1	0-5.2	1.9	56-79	71		
	7.1m	11.2-19.0	17.1	4.0-8.6	6.7	6.2-8.3	7.7	0-12.1	3.8	58-76	71		
B-26	1.0m	17.8-24.3	19.9	7.1-8.7	7.7	7.4-8.3	7.9	0-5.0	1.9	68-76	73		
	19.9m	16.1-24.3	19.2	0.3-8.3	6.2	7.6-8.1	7.7	0.5-6.7	2.9	67-85	75		
1976													
B-24	1.0	8.0-22.7	16.8	7.8-10.4	8.7	8.1-8.4	8.3	0-0.9	0.2	68-81	73	152-186	173
	11.8	8.0-20.5	14.4	0.3-10.6	4.7	7.6-8.5	7.9	0-1.1	2.2	65-88	76	158-197	177

Table 1 (continued)

Station	Sample Depth	Temperature (°C) range	Temperature (°C) mean	Dissolved Oxygen (ppm) range	Dissolved Oxygen (ppm) mean	pH range	pH mean	CO_2 (mg/l) range	CO_2 (mg/l) mean	Alkalinity (mg/l) range	Alkalinity (mg/l) mean	Conductivity (µmhos/cm^3) range	Conductivity (µmhos/cm^3) mean
1972													
S-27	1.0m	18.5-24.3	20.8	8.0-8.9	8.4	7.4-8.4	7.9	0-5.2	1.7	61-77	71		
	15.7m	10.0-13.8	12.0	0-8.7	3.0	6.8-7.9	7.3	2.3-12.1	6.9	67-95	78		
S-105	1.0m	18.0-23.7	19.4	7.0-10.0	8.3	7.6-8.2	7.8	0.4-2.9	1.3	50-65	59		
	31.0m	4.0-8.0	5.5	0.2-8.0	2.6	6.8-7.2	7.0	5.8-12.5	9.4	59-67	65		
1976													
S-27	1.0	8.7-22.5	17.3	7.2-11.0	8.6	7.9-8.3	8.1	0-1.6	0.7	70-77	74	159-184	174
	20.1	8.7-20.3	10.3	0.5-10.6	2.9	7.3-8.1	7.7	0.4-2.3	3.7	69-92	79	164-194	181
S-105	1.0	10.5-22.5	17.2	8.0-9.9	8.7	7.8-8.1	8.0	0.6-3.7	1.4	58-63	60	141-155	148
	28.8	7.9-9.0	8.4	0.3-8.7	2.8	7.1-7.5	7.3	2.8-6.8	4.4	60-74	65	143-155	155
1972													
C-28	1.0m	17.9-23.8	19.8	7.0-9.6	8.2	7.4-8.2	7.9	0.4-4.2	1.5	68-77	72		
	7.3m	12.4-20.1	17.6	3.5-10.6	7.5	7.1-8.1	7.7	0.4-6.2	2.8	68-75	71		
C-29	1.0m	17.9-23.1	19.5	7.6-8.5	8.3	7.4-8.2	8.0	0.3-4.1	1.4	68-76	71		
	10.2m	10.1-18.8	16.1	1.4-8.1	5.6	7.2-8.2	7.6	0.4-5.5	3.2	68-76	72		
1976													
C-29	1.0	10.3-22.8	17.4	7.7-9.8	8.7	7.8-8.5	8.1	0-1.5	0.9	70-74	72	158-180	173
	9.8	10.5-20.5	15.3	2.1-9.8	7.0	7.4-8.2	7.9	0.4-3.8	2.2	69-76	72	158-183	175

Table 1 (continued)

Station	Sample Depth	Temperature (°C) range	Temperature (°C) mean	Dissolved Oxygen (ppm) range	Dissolved Oxygen (ppm) mean	pH range	pH mean	CO_2 (mg/l) range	CO_2 (mg/l) mean	Alkalinity (mg/l) range	Alkalinity (mg/l) mean	Conductivity (µmhos/cm^3) range	Conductivity (µmhos/cm^3) mean
1972													
K-1	1.0m	16.0-22.9	20.0	8.3-9.7	8.8	7.6-8.5	8.2	0-3.3	0.7	71-77	74		
	6.2m	16.0-22.6	19.2	7.8-8.9	8.4	8.0-8.4	8.2	0-0.9	0.4	71-79	74		
K-2	1.0m	16.1-23.0	19.7	8.0-9.0	8.5	7.6-8.4	8.1	0-4.4	1.2	69-76	73		
	8.3m	16.1-22.6	19.0	6.0-8.7	7.6	7.6-8.3	8.0	0-3.7	1.4	70-76	73		
K-3	1.0m	18.5-23.0	20.2	8.0-9.0	8.5	7.2-8.3	7.9	0.4-7.6	1.6	68-76	73		
	5.1m	18.5-23.0	20.0	7.9-9.0	8.3	7.6-8.3	8.0	0-3.6	1.0	69-76	73		
K-4	1.0m	16.0-22.6	19.8	7.9-9.8	8.7	7.6-8.5	8.2	0-4.8	0.9	70-76	73		
1976													
K-2	1.0	9.8-22.4	17.1	7.9-10.6	9.1	7.8-8.5	8.1	0-2.5	1.0	71-76	73	146-180	171
	7.1	9.8-21.2	16.6	7.4-10.4	8.8	7.7-8.4	8.1	0-1.6	0.9	70-76	73	166-181	175

Table 1 (continued)

Station	Sample Depth	Temperature (°C) range	Temperature (°C) mean	Dissolved Oxygen (ppm) range	Dissolved Oxygen (ppm) mean	pH range	pH mean	CO_2 (mg/l) range	CO_2 (mg/l) mean	Alkalinity (mg/l) range	Alkalinity (mg/l) mean	Conductivity (μmhos/cm^3) range	Conductivity (μmhos/cm^3) mean
1972													
R-33	1.0m	14.1-22.8	19.7	7.8-8.9	8.5	7.9-8.8	8.5	0-3.1	0.7	74-95	82		
R-34	1.0m	14.1-23.1	20.3	7.6-9.0	8.2	8.0-8.6	8.3	0-7.3	1.0	75-87	82		
R-35	1.0m	14.1-23.5	20.1	7.5-8.9	8.3	8.0-9.0	8.3	0-3.8	1.2	78-87	83		
	5.4m	14.1-22.9	19.5	4.8-8.6	7.1	7.6-8.8	8.2	0-4.1	1.7	78-92	84		
R-36	1.0m	14.2-23.5	20.2	7.1-9.3	8.4	8.0-9.0	8.4	0-1.4	0.6	78-98	86		
	4.2m	14.1-23.0	20.0	6.4-10.2	8.2	8.0-9.0	8.4	0-1.8	0.8	78-99	85		
1976													
R-33	1.0	6.7-21.6	16.6	6.3-11.8	9.1	8.2-8.9	8.6	0-1.0	0.2	74-104	90	171-225	201
	2.7	6.7-21.5	16.5										
R-34	1.0	6.7-22.9	17.0	7.8-11.4	9.3	8.2-8.8	8.5	0	0	74-90	84	173-215	199
	2.4	6.7-22.5	16.9										
R-35	1.0	7.0-23.0	17.2	7.4-11.5	9.4	8.4-9.1	8.7	0	0	82-123	94	185-215	200
	5.1	7.0-22.8	16.8	6.8-10.5	8.3	8.1-8.7	8.5	0	0	81-96	89	186-215	203

1972													
Q-42	1.0m	19.2-22.7	20.8	5.7-8.7	7.7	7.4-8.2	7.8	0.3-5.9	2.2	91-108	99		

TABLE 2. Means and ranges for hardness (mg/l), iron (mg/l Fe), silica (mg/l SiO_2), inorganic carbon (mg/lC), chlorophyll a (ppb) and secchi disc (m) in the Kawartha Lakes in 1972 and 1976.

Station	Sample Depth	Hardness (mg/l) range	Hardness (mg/l) mean	Iron range	Iron mean	SiO_2 range	SiO_2 mean	Carbon (mgC/l) range	Carbon (mgC/l) mean	Chloro a (ppb) range	Chloro a (ppb) mean	Secchi Disc m range	Secchi Disc m mean
1972													
B-1	comp.	33-56	45	.05-.10	.07	.03-2.4	2.0	4-8	7.2	1.0-3.0	2.96	3.0-4.9	3.9
B-2	comp.	56-66	60	.05-.05	.05	1.3-3.6	2.6	4-12	8.3				
	11.9m	58-76	65	.05-.10	.07	2.4-3.2	2.9	4-9	7.8	1.1-3.3	1.87	3.5-5.4	4.8
B-3	comp.	55-80	64	.02-.04	.04	2.2-3.2	2.7	4.5-9	7.8	1.0-3.5	2.21	2.8-5.0	3.3
1976													
B-1	comp.	31-80	38	.02-.11	.07	1.1-1.5	1.3			1.6-2.6	2.0	2.9-4.5	3.6
	5.9	32-80	44	.04-.09	.06	1.0-1.6	1.4						
B-2	comp.	49-96	60	.01-.09	.05	1.3-2.1	1.7			1.2-3.0	1.9	3.3-5.5	4.4
	8.9	48-97	61	.06-0.5	.16	1.5-2.0	1.8						
B-3	comp.	49-97	60	.01-.07	.04	1.2-2.0	1.6			1.4-3.6	2.6	2.8-4.0	3.4
1972													
Ca-4	comp.	56-74	64	.10-.15	.11	2.0-3.2	2.8	7-10	8.6	1.0-3.3	2.2	2.8-7.7	4.0
	10.3m	57-88	69	.10-.15	.12	2.0-4.4	3.4	7-11.5	9.2				
Ca-5	comp.	56-66	62	.10-.15	.12	2.7-3.6	3.0	7-10	8.1	0.8-6.6	2.8	2.8-5.6	3.7
	14.9m	60-68	62	.10-.45	.23	2.9-5.0	4.2	7.5-13	9.9				
Ca-6	comp.	58-66	61	.05-.15	.11	0.4-3.5	2.6	7-10	8.7	0.8-3.6	2.6	2.8-5.6	3.7
	10.2m	58-62	60	.10-.15	.12	0.3-4.7	3.5	7.5-10	8.8				
1976													
Ca-5	comp.	52-64	56	.06-.09	.07	1.2-1.9	1.6			1.0-3.0	1.9	2.6-4.5	3.7
	12.3	52-63	57	.06-.48	.15	1.4-2.4	1.8						

Table 2 (continued)

Station	Sample Depth	Hardness (mg/l) range	Hardness (mg/l) mean	Iron range	Iron mean	SiO_2 range	SiO_2 mean	Carbon (mgC/l) range	Carbon (mgC/l) mean	Chloro a (ppb) range	Chloro a (ppb) mean	Secchi Disc m range	Secchi Disc m mean
1972													
S-7	comp.	60-78	67	.05-.40	.14	.34-3.0	2.1	7.5-12	9.4	2.1-8.6	4.9	2.3-3.0	2.4
	5.5m	70-76	69	.10-.30	.18	.25-3.8	2.4	8-24	15.5				
S-8	comp.	74-88	79	.05-.15	.06	0.6-2.8	1.8	9.1-15.0	11.2	2.8-16.0	9.1	1.8-3.4	2.3
	10.1m	69-84	80	.10-.50	.21	0.2-4.4	3.2	9.0-15	11.6				
S-9	comp.	70-148	90	.05-.15	.09	0.4-2.7	1.7	9-21	12.7	2.6-16.0	8.3	0.9-2.5	2.0
S-10	comp.	76-92	82	.05-.10	.08	0.3-3.0	2.1	9.5-15	11.6	2.0-18.0	12.3	1.4-3.3	2.3
	7.2m	76-104	84	.05-.15	.09	0.2-4.8	2.7	7.5-15	11.7				
S-11	comp.	78-98	83	.05-.15	.09	0.2-13.5	3.6	7.4-15	11.6	1.5-20.0	7.4	1.2-4.3	2.5
1976													
S-7	comp.	58-86	68	.06-.13	.11	1.2-1.9	1.6			2.4-6.5	4.6	1.9-3.0	2.1
	5.1												
S-8	comp.	75-93	84	.04-.14	.09	.50-2.1	1.4			1.9-13.0	8.3	1.5-2.8	2.3
	9.1	75-93	84	.05-.20	.11	.35-2.2	1.5						
S-9	comp.	79-126	107	.05-.18	.10	.10-2.1	1.0			1.9-22.0	13.2	0.8-2.3	1.4
	2.1												
S-10	comp.	75-98	87	.04-.11	.07	.25-1.5	1.3			1.9-13.0	8.2	1.5-3.3	2.4
	7.3												

Table 2 (continued)

Station	Sample Depth	Hardness (mg/l)		Iron		SiO_2		Carbon (mgC/l)		Chloro a (ppb)		Secchi Disc m	
		range	mean	range	mean	range	mean	range	mean	range	mean	range	mean
1972													
S-12	comp.	142-156	151	<.05-.10	.06	1.2-5.4	3.4	23-28	25.0	3.8-27.0	13.2	0.5-0.9	0.7
S-13	comp.	142-156	150	<0.05-.15	.08	1.2-5.3	3.5	22-29	24.8	5.6-41.0	19.2	0.5-1.0	0.8
	5.7m	142-162	152	0.05-.15	.08	1.2-5.1	3.3	17-39	26.8				
S-14	comp.	150-172	162	0.05-.25	.11	.8-6.4	3.9	19-29	25.5	9-27	15.5	0.5-1.1	0.8
S-15	comp.	148-182	163	<.05-.10	.06	1.1-6.4	3.8	20-34	26.4	4.2-41.0	16.6	0.6-1.2	0.9
1976													
S-13	comp.	137-158	149	.05-.13	.08	.25-1.6	1.1			8.3-15.0	14.2	0.5-1.0	.07
	4.8	137-154	149	.03-.08	.05	0.5-1.6	1.2						
S-15	comp.	101-169	148	.04-0.9	.25	0.2-3.2	1.5			8.5-22.0	14.3	0.6-1.0	0.8
	1.7												

Table 2 (continued)

Station	Sample Depth	Hardness (mg/l) range	Hardness (mg/l) mean	Iron range	Iron mean	SiO_2 range	SiO_2 mean	Carbon (mgC/l) range	Carbon (mgC/l) mean	Chloro *a* (ppb) range	Chloro *a* (ppb) mean	Secchi Disc m range	Secchi Disc m mean
1972													
P-16	comp.	86-104	92	.05-.10	.08	0.9-13.5	3.9	8.5-17	13.4	2.3-10.0	5.5	1.6-4.4	2.7
	10.9m	90-96	92	.10-.30	.13	3.0-13.5	5.9	10.5-20	15.3				
P-17	comp.	86-102	94	.05-.15	.09	1.3-3.4	2.6	8.5-16	13.0	1.3-9.8	4.6	2.5-4.1	3.3
	14.0m	90-118	102	.10-3.0	1.1	2.2-10.1	6.1	9-26	17.5				
P-20	comp.	86-102	92	.05-.15	0.8	0.9-3.6	2.3	9-18	14.4	1.8-10.0	5.0	1.5-3.3	2.5
1976													
P-16	comp.	85-96	89	.02-.10	.06	0.2-1.7	1.1			4.5-9.2	6.7	2.0-3.0	2.6
	9.8	80-92	88	.04-.76	.24	0.2-2.9	1.8						
P-17	comp.	82-93	88	.03-.10	.07	0.5-2.2	1.1			2.3-10.0	4.6	2.6-3.5	3.0
	14.0	82-96	87	.08-1.5	.54	0.8-4.7	2.1						
P-20	comp.	77-98	87	.05-.14	.11	0.1-2.5	1.4			5.5-8.8	6.8	1.1-2.9	1.9
	3.0												

Table 2 (continued)

Station	Sample Depth	Hardness (mg/l) range	Hardness (mg/l) mean	Iron range	Iron mean	SiO_2 range	SiO_2 mean	Carbon (mgC/l) range	Carbon (mgC/l) mean	Chloro a (ppb) range	Chloro a (ppb) mean	Secchi Disc m range	Secchi Disc m mean
1972													
P-18	comp.	78-86	80	.30-3.4	.77	1.9-2.8	2.4	8.5-22	14.2	2.0-5.0	3.4	1.7-2.3	2.1
	6.8m	78-138	98	.35-1.8	.84	3.2-4.7	3.7	9.1-19	13.7				
P-19	comp.	88-108	102	.05-.15	.09	1.2-2.4	1.7	10.5-22.0	16.0	2.2-8.2	4.2	2.5-4.3	3.5
	8.5m	112-128	116	<.05-1.5	.57	1.1-4.1	3.3	12-29	20.5				
1976													
P-18	comp.	71-84	78	.11-.40	.22	0.5-1.7	1.2			3.9-6.4	5.4	1.5-2.5	1.9
	6.6	70-81	75	.13-.90	.45	0.8-1.7	1.3						
1972													
P-21	comp.	122-178	154	<0.5-0.5	.05	0.1-4.6	2.7	21-31	24.8	0.8-3.7	2.4	1.4-2.0	1.6
1976													
P-21	comp.	109-172	131	.02-.09	.06	0.3-1.5	0.8			3.0-6.4	3.9	1.2-1.5	1.3(btm)
1972													
B-22	comp.	92-106	95	<.01-.10	.04	0.6-3.3	2.4	10-18	14.3	2.5-6.4	4.0	1.7-3.0	2.3
B-23	comp.	92-110	100	<.05-.10	.07	0.6-3.6	2.4	10.5-19.0	13.9	2.0-6.3	4.3	1.7-3.3	2.5
1976													
B-22	comp.	81-104	92	.02-.20	.04	0.3-2.3	1.3			4.3-7.6	5.9	1.8-2.9	2.4
B-23	comp.	83-96	91	.03-.08	.04	0.1-2.3	1.4			3.8-9.1	6.7	1.8-2.5	2.1

Table 2 (continued)

Station	Sample Depth	Hardness (mg/l) range	Hardness (mg/l) mean	Iron range	Iron mean	SiO_2 range	SiO_2 mean	Carbon (mgC/l) range	Carbon (mgC/l) mean	Chloro *a*- (ppb) range	Chloro *a*- (ppb) mean	Secchi Disc m range	Secchi Disc m mean
1972													
B-24	comp.	86-104	94	<.05-.10	.07	1.9-2.7	2.3	11.5-17	13.6	3.5-7.6	5.3	2.0-3.3	2.4
	13.4m	88-102	96	<.05-.25	.11	1.6-4.1	2.8	13-24.5	16.8				
B-25	comp.	86-104	96	<.05-.10	.06	1.2-2.9	2.1	12-17	14.0	1.8-6.8	4.0	2.0-4.7	2.9
	7.1m	86-114	97	<.05-.15	.08	1.3-2.7	1.9	11-17	13.8				
B-26	comp.	86-110	98	<.05-.10	.07	1.3-3.9	2.3	12-17	13.8	2.6-8.0	4.9	1.9-3.8	2.6
	19.9m	92-106	97	<.05-.20	.10	1.2-4.5	2.5	8-20	13.8				
1976													
B-24	comp.	79-92	86	.03-.08	.05	0.2-2.0	1.1			5.6-10.0	7.0	1.8-2.8	2.2
	11.8	79-90	86	.04-.46	.22	0.2-1.7	0.9						
1972													
S-27	comp.	88-112	95	<.05-.15	.08	1.3-2.7	2.1	8-16	12.8	1.6-7.6	4.7	1.7-3.3	2.5
	15.7m	80-100	92	.05-2.6	.54	1.7-7.1	5.1	11.5-20	15.8				
1976													
S-27	comp.	75-88	85	.03-.06	.05	.15-2.2	1.1			3.2-9.7	5.7	1.9-3.0	2.3
	20.1	86-88	86	.09-2.2	.88	.50-2.3	1.4						

Table 2 (continued)

Station	Sample Depth	Hardness (mg/l) range	Hardness (mg/l) mean	Iron range	Iron mean	SiO_2 range	SiO_2 mean	Carbon (mgC/l) range	Carbon (mgC/l) mean	Chloro a (ppb) range	Chloro a (ppb) mean	Secchi Disc m range	Secchi Disc m mean
1972													
S-105	comp.	66-88	80	<.05-.15	.09	1.6-2.8	2.4	9.5-14	11.7	1.0-4.9	2.8	2.8-4.9	3.7
	31.0m	78-90	83	.10-.15	.12	3.9-5.3	4.8	11-19	14.7				
1976													
S-105	comp.	63-76	70	.03-.04	.03	0.9-1.4	1.1			2.2-7.5	3.9	3.5-4.5	4.3
	28.8	70-75	73	.02-.57	.13	1.7-2.7	2.2						
1972													
C-28	comp.	80-104	90	<.05-.10	.06	1.7-2.6	2.1	12-15	13.2	3.1-9.0	5.6	2.1-3.0	2.7
	7.3m	83-106	91	.05-.15	.08	1.7-3.9	2.6	12.5-15	14.0				
C-29	comp.	83-92	89	<.05-.10	.07	1.4-2.8	2.2	11-15	13.0	2.2-7.2	4.6	2.1-4.3	2.9
	10.2m	83-102	94	.05-.15	.08	2.0-3.6	2.9	12-16	13.4				
1976													
C-29	comp.	77-88	83	.01-.06	.04	0.4-2.5	1.3			2.2-9.6	5.7	2.0-6.0	3.5
	9.8	77-86	83	.02-.43	.15	0.5-2.6	1.6						

Station	Sample Depth	Hardness (mg/l) range	Hardness (mg/l) mean	Iron range	Iron mean	SiO_2 range	SiO_2 mean	Carbon (mgC/l) range	Carbon (mgC/l) mean	Chloro a- (ppb) range	Chloro a- (ppb) mean	Secchi Disc m range	Secchi Disc m mean
1972													
K-1	comp.	83-94	88	<.05-.10	.06	1.8-2.9	2.2	12-15	14.3	1.3-7.0	4.2	2.0-4.3	2.9
K-2	comp.	83-100	93	<.05-.50	.12	1.8-2.7	2.2	13-15	13.8	1.2-8.6	4.1	2.2-6.3	3.3
	8.3m	92-102	94	<.05-.50	.16	1.9-2.7	2.2	13-15	13.8				
K-3	comp.	83-102	91	<.05-.10	.06	1.7-2.9	2.2	11-15	13.3	1.1-8.0	3.5	2.3-6.0	3.3
K-4	comp.	83-96	89	<.05-.05	.05	2.3-2.9	2.7	12-16	14.5	1.0-6.8	4.4	1.7-2.1	2.0
1976													
K-2	comp.	80-87	83	.03-.06	.05	0.6-2.2	1.3			3.3-27.0	9.1	1.9-3.0	2.5
	7.1	78-86	83	.02-.13	.07	0.5-2.3	1.4						
1972													
R-33	comp.	92-96	96	<.05-.25	.13	0.5-5.8	2.2	11-19	15.0	1.3-16.0	8.5	1.0-2.6	1.6
R-34	comp.	96-100	98	<.05-.10	.08	1.0-4.4	2.1	12-17	14.3	1.7-17.0	9.7	1.4-2.1	1.8
R-35	comp.	96-108	102	<.05-.15	.09	0.5-6.4	2.3	12-17	14.9	2.3-27.0	10.1	1.2-2.8	1.8
	5.4m	94-112	102	.05-90	.24	0.6-6.2	3.0	13-17	15.7				
R-36	comp.	94-106	100	<.05-.20	.10	0.7-6.4	2.4	12-19	15.8	1.8-21.0	7.5	1.2-2.5	1.8
	4.2m	94-114	103	.10-.25	.17	0.6-7.0	2.0	12-17	15.4				
1976													
R-33	comp.	85-109	98	.08-.20	.29	0.2-1.6	0.6			5.3-46.0	19.7	0.7-2.0	1.2
R-34	comp.	86-109	100	.07-.20	.14	0.2-1.3	1.0			4.4-40.0	17.3	1.2-2.0	1.5
R-35	comp.	93-111	99	.04-.12	.09	0.2-1.5	0.7			9.6-27.0	18.8	0.5-2.0	1.3
1972													
Q-42	comp.	108-124	115	.05-.15	.12	0.5-5.2	2.9	14-22	18.0	2.7-49.0	14.4	1.0-1.5	1.2

... (as mg/l P) and nitrogen (free ammonia, TKN

TABLE 3. Minimum, maximum and mean values for total phosphorus (as mg/l P) and nitrogen (free ammonia, TKN, NO_2, NO_3 as mg/l N) in the Kawartha Lakes in 1972 and 1976.

		Total Phosphorus (mgP/l)		Nitrogen (mgN/l)							
				NH_3		TKN		NO_2		NO_3	
Station	Sample Depth	range	mean	range	mean	range	mean	range	mean	range	mean
1972											
B-1	comp.	.012-.031	.017	.01-.05	.03	.25-.36	.31	.001-.004	.003	<.01-.12	.07
B-2	comp.	.008-.024	.017	.01-.04	.02	.26-.38	.32	.001-.004	.002	<.01-.12	.02
	10.9m	.010-.026	.017	.02-.12	.06	.33-.97	.59	.001-.004	.003	<.01-.14	.03
B-3	comp.	.009-.024	.015	<.01-.07	.02	.27-.39	.33	<.001-.004	.003	<.01-.08	.02
1976											
B-1	comp.	.006-.016	.010	<.01-.07	.02	.20-.28	.25	<.001-.002	.001	<.01-.08	.02
	5.9	.004-.018	.011	<.01-.02	.01	.17-.36	.26	<.001-.001	.001	<.01-.01	.01
B-2	comp.	.006-.92	.009	<.01-.04	.02	.15-.31	.23	<.001-.003	.002	<.01-.08	.02
	8.9	.007-.013	.010	<.01-.02	.01	.21-.37	.26	<.001-.001	.001	<.01-.02	.01
B-3	comp.	.005-.024	.011	<.01-.05	.01	.18-.33	.26	<.001-.002	.001	<.01-.01	.01
1972											
Ca-4	comp.	.012-.022	.014	.01-.10	.04	.29-.40	.33	.003-.004	.004	<.01-.14	.04
	10.3m	.011-.037	.020	.01-.64	.14	.31-1.2	.58	.003-.005	.003	.02-.16	.09
Ca-5	comp.	.009-.023	.016	.02-.03	.02	.33-.41	.37	.002-.004	.004	<.01-.10	.03
	14.9m	.009-.052	.023	.01-.11	.05	.32-.1.6	.61	.002-.009	.005	.02-.14	.07
Ca-6	comp.	.016-.023	.018	.01-.19	.05	.34-.54	.42	.001-.005	.004	<.01-.10	.03
	10.2m	.014-.031	.022	.01-.09	.04	.33-.91	.49	.002-.004	.004	<.01-.14	.07
1976											
Ca-5	comp.	.006-.011	.009	<.01-.03	.02	.12-.31	.26	.001-.002	.002	<.01-.08	.02
	12.3	.007-.045	.015	<.01-.04	.02	.10-.44	.30	.001-.027	.008	.01-.13	.05

TABLE 3 - Continued

Station	Sample Depth	Total Phosphorus (mgP/l) range	Total Phosphorus (mgP/l) mean	Nitrogen (mgN/l) NH_3 range	NH_3 mean	TKN range	TKN mean	NO_2 range	NO_2 mean	NO_3 range	NO_3 mean
1972											
S-7	comp.	.012-.039	.022	<.01-.08	.04	.34-.69	.50	.003-.004	.004	<.01-.04	.02
	5.5m	.017-.026	.022	.01-.07	.04	.51-1.0	.66	.003-.004	.003	<.01-.05	.02
S-8	comp.	.017-.040	.029	<.01-.18	.05	.45-.80	.58	.002-.005	.003	<.01-.09	.02
	10.1m	.034-.046	.040	<.01-.24	.09	.55-.92	.70	.002-.004	.003	<.01-.20	.03
S-9	comp.	.018-.038	.030	<.01-.08	.03	.43-.75	.59	.001-.004	.003	<.01-.01	.01
S-10	comp.	.010-.055	.030	<.01-.06	.02	.40-.67	.55	.002-.006	.003	<.01-.08	.02
	7.2m	.016-.042	.030	<.01-.04	.03	.38-.96	.55	.001-.005	.004	<.01-.24	.04
S-11	comp.	.014-.041	.026	<.01-.10	.02	.41-.87	.58	.001-.006	.003	<.01-.15	.01
1976											
S-7	comp.	.004-.034	.018	.01-.06	.03	.20-.45	.36	.001-.002	.002	<.01-.07	.02
S-8	comp.	.012-.036	.021	.01-.10	.04	.10-.53	.39	.001-.002	.002	<.01-.01	<.01
	9.1m	.019-.072	.032	.01-.28	.08	.47-.79	.55	.001-.003	.002	<.01-.01	<.01
S-9	comp.	.017-.084	.041	.01-.08	.03	.45-.90	.70	.001-.004	.002	<.01-.01	<.01
S-10	comp.	.012-.034	.025	.01-.06	.03	.42-.57	.46	.001-.002	.002	<.01-.01	<.01
1972											
S-12	comp.	.027-.068	.041	<.01-.30	.06	.92-1.4	1.1	.002-.010	.003	<.01-.15	.01
S-13	comp.	.026-.050	.035	<.01-.03	.01	.59-1.3	.95	.001-.007	.003	<.01-.09	.02
	5.7m	.033-.086	.050	.02-.37	.12	.97-1.8	1.4	.001-.008	.003	<.01-.15	.03
S-14	comp.	.032-.038	.043	<.01-1.1	.17	.73-2.0	1.20	.002-.003	.002	<.01-.01	.01
S-15	1.0m	.034-.065	.042	<.01-.16	.05	.74-1.3	1.0	.002-.003	.002	<.01-.01	.01

TABLE 3 - Continued

Station	Sample Depth	Total Phosphorus (mgP/l) range	Total Phosphorus (mgP/l) mean	Nitrogen (mgN/l) NH3 range	NH3 mean	TKN range	TKN mean	NO2 range	NO2 mean	NO3 range	NO3 mean
1976											
S-13	comp.	.025-.079	.043	<.01-.33	.10	.74-1.98	1.18	.001-.004	.002	<.01	<.01
	4.8m	.027-.048	.037	<.01-.16	.05	.92-1.78	1.16	.001-.003	.002	<.01	<.01
S-15	comp.	.027-.066	.047	<.01-.06	.03	.86-1.32	1.00	.001-.002	.002	<.01-.10	.03
1972											
P-16	comp.	.017-.031	.026	.01-.04	.02	.43-.75	.54	.002-.006	.004	<.01-.17	.04
	10.9m	.012-.120	.040	.01-.30	.12	.41-1.2	.82	.004-.012	.007	<.01-.21	.06
P-17	comp.	.013-.058	.030	.01-.18	.06	.43-.80	.57	.004-.008	.005	<.01-.17	.04
	14.0	.008-1.100	.272	.04-1.1	.43	.37-2.0	1.1	.004-.006	.005	<.01-.21	.06
P-20	comp.	.014-.035	.023	.01-.08	.03	.41-.90	.57	.002-.005	.004	<.01-.11	.03
1976											
P-16	comp.	.014-.035	.022	<.01-.07	.04	.39-.61	.68	.001-.003	.002	<.01-.01	<.01
	9.8m	.015-.128	.068	<.01-.31	.15	.39-.93	.68	.001-.004	.002	<.01-.01	.01
P-17	comp.	.015-.039	.024	<.01-.07	.04	.39-.54	.44	.001-.003	.002	<.01-.08	.02
	14.0m	.02 -.198	.075	<.01-.17	.21	.42-.94	.66	.001-.004	.003	<.01-.08	.02
P-20	comp.	.010-.030	.022	<.01-.06	.03	.27-.61	.48	.001-.003	.002	<.01	<.01
1972											
P-18	comp.	.004-.030	.022	<.01-.60	.11	.56-1.2	.78	.003-.006	.005	<.01-.04	.01
	6.8m	.021-.042	.033	.08-.44	.20	.64-1.4	1.03	.005-.008	.007	<.01-.13	.03
P-19	comp.	.016-.029	.020	.01-.15	.07	.40-.87	.51	.002-.005	.003	<.01-.03	.01
	8.5m	.014-.034	.025	.12-.69	.46	.61-1.3	1.0	.002-.005	.004	<.01-.07	.02
1976											
P-18	comp.	.013-.028	.020	.01-.05	.03	.46-.66	.55	.001-.003	.002	<.01	<.01
	6.6m	.022-.034	.027	.01-.29	.13	.46-.82	.66	.002-.005	.003	<.01-.01	<.01

TABLE 3 - Continued

Station	Sample Depth	Total Phosphorus (mgP/l)		Nitrogen (mgN/l)							
				NH3		TKN		NO2		NO3	
		range	mean	range	mean	range	mean	range	mean	range	mean
1972											
P-21	comp.	.017-.032	.025	<.01-.12	.03	.52-.86	.68	.002-.004	.003	<.01-<.01	.01
1976											
P-21	comp.	.015-.036	.027	<.01-.04	.02	.54-1.0	.75	.001-.003	.002	<.01	<.01
1972											
B-22	comp.	.015-.034	.024	<.01-.04	.02	.44-.69	.52	.003-.005	.004	<.01-.09	.03
B-23	comp.	.017-.026	.022	<.01-.05	.02	.39-.66	.49	.003-.006	.005	<.01-.09	.04
1976											
B-22	comp.	.014-.031	.019	<.01-.04	.02	.41-.47	.45	<.001-.003	.001	<.01	<.01
B-23	comp.	.015-.036	.025	<.01-.05	.02	.44-.50	.48	<.001-.003	.002	<.01	<.01
1972											
B-24	comp.	.012-.030	.022	.01-.09	.05	.37-.72	.54	.001-.010	.004	<.01-.12	.03
	13.4m	.010-.054	.028	.04-.35	.13	.46-1.3	.81	.002-.007	.004	<.01-.18	.04
B-25	comp.	.010-.032	.023	<.01-.08	.02	.39-.66	.49	.001-.006	.004	<.01-.15	.03
	7.1m	.021-.056	.031	.02-.18	.08	.46-.90	.68	.001-.006	.004	<.01-.03	.01
B-26	comp.	<.001-.031	.020	<.01-.08	.03	.37-.70	.51	.001-.006	.003	<.01-.13	.03
	19.9m	.016-.039	.023	.02-.09	.04	.46-1.3	.71	.001-.005	.003	<.01-.13	.03
1976											
B-24	comp.	.010-.029	.022	<.01-.04	.02	.09-.52	.42	.001-.003	.002	<.01	<.01
	11.8m	.016-.050	.023	.01-.50	.21	.34-1.44	.94	.001-.003	.002	<.01-.01	<.01

TABLE 3 - Continued

Station	Sample Depth	Total Phosphorus (mgP/1)		Nitrogen (mgN/1)							
				NH_3		TKN		NO_2		NO_3	
		range	mean	range	mean	range	mean	range	mean	range	mean
1972											
S-27	comp.	.020-.026	.024	<.01-.14	.05	.39-.66	.49	.002-.006	.004	<.01-.11	.03
	15.7m	.009-.310	.083	.01-1.0	.37	.45-2.1	.95	.002-.029	.009	<.01-.15	.06
1976											
S-27	comp.	.013-.025	.020	<.01-.05	.03	.38-.54	.46	.001-.003	.002	<.01-.01	<.01
	20.1m	.024-.238	.107	.03-.89	.19	.38-1.29	1.02	.002-.003	.003	<.01-.04	.01
1972											
S-105	comp.	.012-.017	.014	<.01-.25	.07	.33-.64	.45	.002-.006	.004	.01-.03	.02
	31.0m	.010-.024	.018	<.01-.17	.04	.29-.54	.39	.002-.006	.004	.12-.28	.21
1976											
S-105	comp.	.005-.014	.010	<.01-.10	.03	.24-.38	.32	.001-.007	.003	<.01-.07	.02
	28.8	.002-.026	.010	<.01-.19	.07	.25-.50	.38	.001-.016	.005	.04-.27	.14
1972											
C-28	comp.	.014-.032	.022	<.01-.07	.03	.35-.65	.47	.001-.005	.004	<.01-.15	.03
	7.3m	.013-.030	.022	.02-.11	.06	.370.92	.58	.002-.006	.004	<.01-.04	.02
C-29	comp.	.011-.032	.025	<.01-.07	.03	.37-.56	.45	.001-.006	.004	<.01-.15	.04
	10.2m	.008-.035	.026	.01-.08	.05	.31-.86	.55	.002-.006	.004	<.01-.20	.04
1976											
C-29	comp.	.012-.022	.015	<.01-.07	.04	.29-.43	.37	.001-.003	.002	<.01-.04	.01
	9.8m	.010-.027	.017	<.01-.28	.10	.37-.82	.55	.001-.003	.002	<.01-.04	.01

TABLE 3 - Continued

Station	Sample Depth	Total Phosphorus (mgP/l) range	Total Phosphorus (mgP/l) mean	Nitrogen (mgN/l) NH$_3$ range	NH$_3$ mean	TKN range	TKN mean	NO$_2$ range	NO$_2$ mean	NO$_3$ range	NO$_3$ mean
1972											
K-1	comp.	.020-.043	.026	<.01-.88	.03	.32-.60	.46	.001-.005	.003	<.01-.07	.03
K-2	comp.	.013-.032	.020	<.01-.03	.02	.22-.72	.44	.001-.005	.003	<.01-.07	.03
	8.3m	.020-.036	.027	.01-.07	.04	.32-.75	.61	.002-.005	.003	<.01-.08	.03
K-3	comp.	.020-.062	.032	<.01-.11	.04	.44-.62	.51	.002-.005	.004	<.01-.07	.03
K-4	comp.	.016-.150	.041	<.01-.17	.05	.30-1.1	.72	.001-.010	.005	<.01-.09	.04
1976											
K-2	comp.	.014-.023	.019	<.01-.04	.03	.38-.51	.49	.001-.004	.002	<.01-.03	.01
	7.1m	.015-.022	.017	.01-.08	.05	.39-.68	.55	.001-.005	.002	<.01-.03	.01
1972											
R-33	comp.	.031-.092	.069	.01-.04	.02	.68-1.2	.84	.002-.004	.003	<.01-.02	.02
R-34	comp.	.025-.081	.050	<.01-.34	.08	.01-.75	.56	.001-.005	.003	<.01-.02	.01
R-35	comp.	.021-.085	.055	<.01-.27	.07	.44-1.3	.80	.002-.012	.004	<.01-.11	.03
	5.4m	.033-.078	.059	.01-.14	.05	.41-1.4	.78	.002-.004	.003	<.01-.01	.01
R-36	comp.	.032-.076	.049	<.01-.15	.05	.53-.93	.72	.001-.003	.002	<.01-.01	.01
	4.2m	.038-.099	.066	.02-.36	.10	.74-2.2	1.15	.002-.004	.003	<.01- .01	.01
1976											
R-33	comp.	.048-.090	.066	<.01-.29	.05	.54-1.02	.79	.001-.002	.001	<.01	<.01
R-34	comp.	.017-.049	.037	<.01-.06	.03	.50-.77	.61	.001-.004	.002	<.01-.06	.02
R-35	comp.	.030-.056	.043	<.01-.08	.02	.51-.98	.73	.001	.001	<.01	<.01
1972											
Q-42	comp.	.029-.069	.050	.01-.03	.02	.50-.81	.69	.003-.012	.006	<.01-.07	.02

TABLE 4: Mean values for the prominent ions (mg/l) found in the Kawartha Lakes in 1972.

Station	Sample Depth	Ca^{++}	Na^{++}	Mg^{++}	K^{+}	CL^{-}	$SO_4^{=}$
B-1	composite	13.0	1.0	2.8	.36	2.6	11.4
B-2	composite	20.8	1.0	2.0	.36	3.4	12.0
	10.9m	21.5	1.6	2.0	.50	3.5	12.0
B-3	composite	20.8	1.0	2.8	.36	3.4	12.4
Ca-4	composite	21.4	1.0	2.4	.32	3.2	11.4
	10.3m	23.0	1.5	3.0	.40	3.5	13.0
Ca-5	composite	21.0	1.2	2.4	.40	3.0	12.2
	14.9m	21.8	1.2	2.0	.40	3.6	12.2
Ca-6	composite	21.2	1.2	2.0	.36	3.6	12.2
	10.2m	21.3	1.5	2.0	.36	4.3	12.8
S-7	composite	23.2	1.4	2.0	.48	4.2	12.0
S-8	composite	27.2	2.2	2.8	.54	5.2	13.2
	10.1m	28.0	2.6	2.2	.68	5.2	13.2
S-9	composite	29.8	2.6	3.4	.64	5.0	14.4
S-10	composite	28.6	2.2	2.6	.62	5.2	14.0
	7.2m	28.5	2.3	3.0	.58	4.8	14.4
S-11	composite	29.6	1.8	2.4	.52	5.2	14.6

TABLE 4: Mean values for the prominent ions (mg/l) found in the Kawartha Lakes in 1972.

Station	Sample Depth	Ca^{++}	Na^{++}	Mg^{++}	K^{+}	CL^{-}	$SO_4^{=}$
S-12	composite	49	4.4	7.2	1.0	9.2	15.2
S-13	composite	49.2	4.0	6.6	1.1	9.2	18.0
	5.7m	52.4	4.0	5.2	1.2	9.2	17.6
S-14	composite	54.8	4.6	6.0	0.8	11.0	18.2
S-15	composite	53.4	4.4	7.6	1.1	10.8	18.0
P-16	composite	31.0	2.2	4.2	.48	5.2	15.2
	10.9m	31.6	2.4	3.2	.72	5.0	14.0
P-17	composite	34.2	2.0	3.6	.52	4.8	14.2
	14.0m	34.8	2.4	3.8	.78	4.8	12.8
P-20	composite	31.6	1.8	3.4	.40	4.4	14.8
P-18	composite	26.0	1.2	3.6	.38	3.4	11.6
	6.8m	32.0	1.2	4.4	.44	3.4	12.2
P-19	composite	35.6	2.4	3.0	.20	7.4	12.2
	8.5m	41.0	2.8	3.0	.50	8.8	11.3
P-21	composite	49.2	2.6	7.0	.28	5.0	16.6
B-22	composite	32.2	2.0	3.2	.38	4.8	15.4
B-23	composite	34.4	2.2	3.4	.52	4.4	13.0

TABLE 4 : Mean values for the prominent ions (mg/l) found in the Kawartha Lakes in 1972.

Station	Sample Depth	Ca^{++}	Na^{++}	Mg^{++}	K^{+}	CL^{-}	$SO_4^{=}$
B-24	composite	31.8	2.2	3.2	.42	4.6	12.8
	13.4m	32.4	1.8	3.4	.52	4.4	12.4
B-25	composite	32.2	2.0	3.8	.44	4.2	12.8
	7.1m	34.0	2.0	3.0	.30	4.7	13.3
B-26	composite	33.4	1.8	3.2	.40	4.0	12.2
	19.9m	34.0	1.8	3.0	.50	5.0	12.6
S-27	composite	33.6	2.0	2.6	.38	4.6	12.6
	15.7m	31.0	2.0	3.4	.56	4.6	12.2
S-105	composite	26.2	1.2	3.2	.36	3.0	12.0
	31.0m	28.8	1.4	2.2	.52	3.8	12.4
C-28	composite	30.0	1.8	3.6	.38	4.4	13.0
	7.3m	31.4	1.8	3.2	.40	4.6	13.8
C-29	composite	31.0	2.0	2.8	.46	4.8	14.0
	10.2m	30.8	2.0	4.0	.54	4.6	13.2

TABLE 4 : Mean values for the prominent ions (mg/l) found in the Kawartha Lakes in 1972.

Station	Sample Depth	Ca^{++}	Na^{++}	Mg^{++}	K^{+}	CL^{-}	$SO_4^{=}$
K-1	composite	31.6	2.6	2.0	.42	5.0	13.0
K-2	composite	31.6	2.4	3.2	.42	4.6	13.2
	8.3m	32.5	2.3	3.0	.80	4.8	14.0
K-3	composite	31.8	2.8	2.8	.68	4.4	12.8
K-4	composite	32.0	1.4	1.6	.48	5.0	13.3
R-33	composite	33.7	2.7	2.3	.70	6.3	12.0
R-34	composite	34.8	2.5	2.3	.58	6.3	11.8
R-35	composite	35.0	3.0	2.8	.73	5.8	13.3
	5.4m	35.8	3.0	2.8	.75	5.8	13.3
R-36	composite	35.3	3.0	2.5	.75	5.8	13.3
	4.2m	33.8	2.8	4.3	.75	6.5	12.8
Q-42	composite	40.0	4.0	3.3	.85	6.3	13.3

TABLE 5: Mean values for Calcium (mg/l), Magnesium (mg/l) and Chloride (mg/l) in the Kawartha Lakes in 1976.

Station	Sample Depth	Ca^{++}	Mg^{++}	Cl^{-}
B-1	comp.	13	1.9	2.2
	bottom	12	2.0	2.2
B-2	comp.	18	2.2	2.5
	bottom	18	2.3	2.5
B-3	comp.	18	2.2	2.5
Ca-5	comp.	19	2.2	2.8
	bottom	19	2.1	2.8
S-7	comp.	23	2.7	3.7
S-8	comp.	28	3.1	4.5
	bottom	28	3.1	4.7
S-9	comp.	36	4.1	5.7
S-10	comp.	29	3.1	4.7
S-13	comp.	49	6.1	9.8
	bottom	49	6.3	9.8
S-15	comp.	49	6.0	13.5
P-16	comp.	30	3.1	4.4
	bottom	30	3.1	4.3
P-17	comp.	30	3.1	4.3
	bottom	30	3.1	4.1
P-20	comp.	30	3.1	4.4

TABLE 5. Mean values for Calcium (mg/l), Magnesium (mg/l) and Chloride (mg/l) in the Kawartha Lakes in 1976.

Station	Sample Depth	Ca^{++}	Mg^{++}	Cl^{-}
P-18	comp.	26	3.0	3.4
	bottom	25	2.9	3.0
P-21	comp.	39	8.3	4.6
B-22	comp.	31	3.4	4.4
B-23	comp.	31	3.3	4.4
B-24	comp.	30	3.1	4.2
	bottom	30	2.7	4.2
S-27	comp.	29	3.0	4.1
	bottom	30	2.7	4.0
S-105	comp.	25	2.2	2.7
	bottom	26	2.2	2.7
C-29	comp.	29	2.8	4.0
	bottom	29	2.8	4.0
K-2	comp.	29	2.9	4.0
	bottom	29	2.9	4.0
R-33	comp.	33	3.7	5.5
R-34	comp.	35	3.4	5.3
R-35	comp.	34	3.4	5.4