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WEED HARVEST AND LAKE NUTRIENT DYNAMICS

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WEED HARVEST AND LAKE NUTRIENT DYNAMICS

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ABSTRACT

After more than 60 years of cultural eutrophication Lake Sallie supports dense growths of phytoplankton and rooted vegetation. Its major water mass has the chemical character imparted by photosynthesis at all seasons, and chemical effects of decomposition are rather localized. Phytoplankton dominance alternates among diatoms, blue-green, and green algae, in that order of abundance. Prior to operation of a weed harvester, attached plants grew densely over 34% of the bottom area. The bulk of nitrogen and phosphorus is usually contained in the water mass, with noticeably smaller amounts in upper bottom sediments and biota. The fish population, less than one half the mass of weeds, contained considerable more N and P than weeds in 1971. Harvest in 1970 evidently reduced weed density in 1971, and increased the cost per unit of nutrients removed. Nitrogen and phosphorus removed in weeds were insignificant when compared with annual waste-water effluent contributions to the lake. Cost of phosphorus removal by weed harvest was \$61 and \$199 per pound in 1970 and '71, respectively; nitrogen cost \$8 and \$21 and carbon \$0.64 and \$1.62 per pound for the same two years.

This report was submitted in fulfillment of Project Number 16010 DFI under the sponsorship of the Water Quality Office, Environmental Protection Agency.

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FINDINGS AND CONCLUSIONS

1. Cultural enrichment of Lake Sallie has produced a highly photosynthetic lake rich in phytoplankton and attached vegetation.

2. The chemical character of the major water mass is normally that imparted by photosynthesis, since the rate of decomposition has been too low to alter upper waters greatly even under ice and snow.

3. Phytoplankton is not dominated by any major group, but its composition usually varies with season with one of four groups predominating. Greatest densities (55,000,000+ per 1) have been achieved by diatoms; blue-green algae have attained more than 6,000,000 units per 1. Other ranking groups (green algae and Cryptophyceae) have been much less numerous.

4. The major nutrient source is the Pelican River which receives the waste water effluents from Detroit Lakes. A progressive downlake decrease in nutrients is usually evident between the inlet and outlet of this river, but some variation has occurred.

5. The bulk of nitrogen and phosphorus is usually contained in the water mass (quantities for weeds the exceptional year are based on approximations) with considerably lesser amounts in upper sediment layers and bodies of organisms. The fish population, although less in mass, has had more contained nutrients than the rooted plant assemblage.

6. After one year's harvest, density of weeds was about 1/4 as great the following year and phytoplankton density and photosynthesis increased.

7. Weed removal plus the annual controlled fish harvest took out insignificant amounts of nitrogen and phosphorus with respect to amounts brought in annually by the Pelican River.

8. Cost of nutrient removal by weed harvest increased with declining weed density, e.g., phosphorus from $16 and $199 per pound from 1970 to 1971.

9. Weed harvest can exert little control on phytoplankton unless it removes more nutrients than are annually contributed from outside sources, and may actually expedite phytoplankton development if this condition is not met.

10. Since most nitrogen and phosphorus usually occur in the water mass they could be expected to decline soon following significant reduction of nutrients in wastewater entering the Pelican River.

RECOMMENDATIONS

1. In view of its cost and inefficiency, weed harvest is not recommended as a method for lowering nutrient supplies in a lake receiving cultural enrichment. Unless it can remove more than a year's increment of nutrients from outside sources, it will be inconsequential or even detrimental to alleviation of undesirable phytoplankton growth. It could be applied to hasten recovery of an eutrophied lake whose nutrient source has been significantly curtailed, but annual outside contributions would have to be low and many weeds in harvestable situations.

2. Harvesting evidently interferes with weed growth and renewal, and operation during a second year may be expected to remove much fewer weeds; thus a few years may need elapse before the method may be economically reapplied to an originally justifiable situation, i.e., where it could remove more than 1 year's nutrient increment. Justification may be determined from annual nutrient load entering the lake, standing harvestable weed crop, and weed nutrient concentration.

3. In order to reach most weeds it would be desirable to have harvesters capable of operating in 2 feet of water.

4. Removal of weeds and fish may hasten "de-eutrophication" after elimination of nutrient inflow, but the latter appears to be a mandatory first step for any real success.

5. Where the presence of weeds poses problems, cutting and removal can apparently bring about improvement for at least one growing season following the harvest year.

INTRODUCTION

Eutrophication is a term somewhat loosely applied today to both natural aging of lakes and nutrient and organic matter enrichment of all water bodies. Enrichment is frequently augmented by man, which has led to coinage of the term, "cultural eutrophication", and evidence has been presented that suggests it began in the Bronze Age in Europe (Hasler, 1947). Zürichsee in Switzerland exhibited gradual increases in phosphorus, nitrogen, and chloride from 1888 to 1916, during which time cyprinids replaced coregonid fishes, blue-green algae succeeded diatoms as dominant phytoplankters, and oxygen was reduced in deep water (Minder, 1926, '38, '43). Some other European lakes have had similar histories (Hasler, 1947). Cultural enrichment has also affected a number of North American lakes, but few of them were studied before they posed problems. The Yahara River lakes near Madison, Wisconsin; Lake Sebasticook, Maine; and Lake Washington near Seattle have probably received as much attention as any (U.S. DHEW, 1969; Hasler, 1947, Sawyer, 1947; Edmondson 1961, '66, '68).

It has been proposed (Livermore, 1954) that nutrient content of lakes may be reduced by removing large quantities of aquatic plants. Weed harvest has generally been concerned with clearing lakes and canals for recreation and navigation (e.g. Blanchard, 1965), but some attention has been given to water weeds as livestock feed (Bailey, 1965; Lange, 1965). Yount (1964) and Yount and Crossman (1970) suggested that aquatic plant harvest was one of the more promising solutions for reducing lake productivity.

In 1968 the National Eutrophication Research Program, Federal Water Quality Administration, funded a study on Lake Sallie, Minnesota of the effects of large scale weed harvest on lake nutrient content. A research grant was awarded to the University of North Dakota to determine the basic limnological nature of this lake and varied effects of weed removal. This article, largely based on data appearing in Peterson (1971) and Smith (1972), comprises the final report on this project.

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STUDY AREA

Lake Sallie (Fig. 1) has received nutrients supplied by wastewaters from the city of Detroit Lakes, Minnesota (1970 population nearly 7,000) for more than 60 years (Larson, 1961). Waters enriched by these wastes, which are now treated by settling, biofiltration, aeration, a stabilization pond, and flow through a peat bed, in that order, follow a somewhat circuitous route into Lake Sallie, that requires passage through 2 other lakes (Fig. 2). This city also experimented with lime precipitation and spray irrigation as means of nutrient removal, but abandoned the first after facilities proved inadequate and the second when data collection arrangements failed. Civil suit brought against the city in 1951 by lake property owners was dismissed for lack of evidence, but the city is now under orders from the Minnesota Pollution Control Agency to reduce nutrients, especially phosphorus, to noncritical levels. One hundred and sixty eight cottages along the shores of Lake Sallie, occupied for varying periods during the year, discharge wastes to individual septic tanks usually situated in ground areas draining to the lake.

Lake Sallie is part of the Pelican River lake chain in northwestern Minnesota, which is contributory to the Ottertail River and the Red River of the North. The topography of the Pelican River watershed was primarily determined by Wisconsin glaciation during the Pleistocene Epoch, which sent at least 4 lobes of its ice sheet into Minnesota. The Wadena lobe, which moved into the area from the Northwest, and the Des Moines lobe, advancing along the Red River Valley, were chiefly involved in formation of this watershed. The Wadena lobe formed the hilly region (Fergus Falls Moraine) to the east, and as it retreated, the Des Moines lobe, moving east from the Red River Valley, overrode this moraine and carried till with it. Withdrawal of the latter lobe added to deposits on the Fergus Falls Moraine and formed outwash areas to either side of it (Fig. 3). This hilly, glacial overlap region is known as the Alexandria Morainic Complex (Wright, 1962). Melting of buried blocks of ice formed the lakes (kettle basins) as the glaciers retreated.

A thick layer of glacial drift now lies within the Pelican River watershed (Fig. 3). Outwash gravel forms the central area, with till on either side. Glacial drift exceeds 91 m in thickness in the general area, and outwash deposits vary from 1 to 24 m or more in thickness (Allison, 1932). Watershed soils range from well drained, medium textured sandy loam developed from calcareous, buff colored glacial till on the east to dark-colored coarse to medium textured material, formed from outwash near the center, to well drained dark soil produced from calcareous galcial till on the west (Reedstrom and Carlson, 1969).

About 45% of the Pelican River Watershed is used for agriculture (small grains, hay, and pasture), water and marsh areas comprise 29%, forests 23%, and urban and residential areas 3%.

Lake Sallie is kidney-shaped with its long axis lying northeast to southwest (Fig. 1). The area lying north of its indentation (hilus) has a somewhat irregular bottom formed by depressions and elevations, while that south of the hilus is practically flat below the shoreline slopes. The deepest area in the lake lies between these two distinctive areas, east of the indentation. The Pelican River enters through Muskrat Lake, which was formed by a dam, with weirs for water level control, across the river inlet. Lake Sallie has the following dimensions:

Area - 5.30 km^2 (1309.6 acres)
Length, total - 3.32 km (2.06 mi.)
Width, Maximum - 2.01 km (1.25 mi.)
Depth, Maximum - 16.5 m (55 ft.)
Depth, mean - 6.35 m (20,86 ft.)
Volume - 33.7 x $10^6 m^3$ (1.18 x 10^9 $ft.^3$)
Shoreline, length - 9.5 km (5.9 mi.)
Shore development - 0.65

Area and volume have the following magnitudes at the listed depths:

Depth		Area		Volume		% of total
m	ft	m^2	ft^2	m^3	ft^3	
0 - 1.52	0- 5	5,300,000	57,145,472	8,069,397	284,930,408	23.94
1.52 - 3.05	5-10	4,460,000	47,998,712	6,776,281	239,270,482	20.11
3.05 - 4.57	10-15	3,410,000	36,708,996	5,183,360	183,024,441	15.37
4.57 - 6.09	15-20	3,020,000	32,545,043	4,595,619	162,271,306	13.64
6.09 - 9.14	20-30	2,660,000	28,659,848	8,093,996	285,798,998	24.02
9.14 - 12.19	30-40	290,000	3,101,187	875,824	30,925,345	2.60
12.19 - 15.24	40-50	30,000	331,026	93,486	3,300,990	0.28
15.24 - 16.50	50-55	10,000	87,112	12,299	434,277	0.04
			Totals:	33,700,262	1,189,956,247	100

At the beginning of this investigation Lake Sallie had luxuriant summer growths of rooted aquatic plants extending out to the 3 m (10 ft.) contour and some patches of Potamogeton praelongus extending out to 6 m (18 ft.). Weeds covered about 34% of the total bottom area.

The lake is situated in a transition zone between boreal forest and western prairie, and water quality is somewhat intermediate between that of the forest and prairie, leaning more toward that of the former, which is considered hard, whereas that of the prairie region is classed as alkaline (Moyle, 1945, '56; Allison, 1932). This region has rather warm summers and cold winters. Over the period 1946-60 mean daily minimum temperatures occuring in January averaged -15.1°C (4.9°F) and mean daily maximums recorded in July averaged 21.2°C (70.1°F). During this time average annual precipitation was 49.86 cm (23.57 in.). Evaporation exceeds precipitation by about 25.4 cm(10") per year. About 68% of the annual precipitation occurs from May through September. Depth of winter snowfall varies, as does thickness of ice on the lake, depending upon precipitation, wind, and temperature patterns. In 1968-69 ice was unsafe for walking on a large central area, but in subsequent winters it has become thick enough to permit foot and vehicle travel to all parts.

It was assumed that knowledge of major limnological characteristics prior to and following weed harvest in this lake with a long history of enrichment would indicate environmental consequences of weed removal as well as its efficiency in reducing nutrients.

MATERIALS AND METHODS

The basic plan was to determine major limnological characteristics of the lake, then harvest weeds and ascertain what changes were brought about. Amounts of nutrients removed in weeds would also be ascertained. Details follow:

Sampling

Sampling was carried out at the 21 sites shown in Figure 4, with frequency varying from daily to semi-weekly to weekly in summer and from weekly to biweekly in winter. Postponements were caused by unsafe ice in early and late winter, and occasionally by adverse winter weather. The surface was included at all sites and varied depths down to 16 m at selected sites in the limnetic zone, in order to monitor depth and duration of thermal stratification and its chemical and biological effects.

Physical Features

Temperature and light penetration were routinely measured, the former with a thermistor thermometer and the latter with a submarine relative irradiance meter with green, red, and blue filters. Measurements were made during open water seasons and under ice. Discharge in and out of the lake was recorded by the U.S. Geological Survey, St. Paul, Minnesota, and weather data were obtained from Radio Station KDLM, 4.5 kilometers (2.8 miles) NE of Lake Sallie. Solar radiation was monitored in 1971 with a pyranograph.

Chemical Features

Samples were taken with a Kemmerer Sampler (plastic) and transferred to iced chests in summer and heated ones in winter for transport to a lakeside laboratory for immediate performance of the following analyses: carbonate and bicarbonate alkalinity, total, calcium and magnesium hardness, ammonia, nitrite, and nitrate nitrogen, total phosphorus, orthophosphate, and oxygen. Oxygen was also measured in the field by dragging a galvanic cell probe along a series of transects extending across and up and down the lake. All analyses except total P and NO_3 were according to Standard Methods, 12th edition (A.P.H.A., 1965). Total phosphorus was according to Krawczyk (1969), and NO_3 to Strickland and Parsons (1965).

Aquatic macrophytes were prepared for analysis by drying and milling to pass a 60 mesh screen. Nitrogen and carbon were determined with a hydrogen-nitrogen-carbon gas analyzer and total phosphorus with the one solution ascorbic acid technique (Strickland and Parsons, 1965), with persulfate digestion. Sediment samples were air dried and anlyses were performed on the materials fine enough to pass through a 60 mesh screen. Total nitrogen was determined by the modified micro-Kjeldahl method of Koch and McMeekin (1924) for some sediment samples. Phosphorus was extracted with 0.6NHcl, and, after filtering and dilution, tested with standard reagents. Twenty eight samples of 11 species of macrophytes had Ca, Mg, Na, K, Co, Cu, Fe, Mn, No, and Zn measured. Periphyton was normally included with macrophytes. Ca, Al, and Fe of some sediment samples were determined by the method of Chang and Jackson (1957). Nutrient analyses of fish flesh were performed on dried samples of ground whole fishes, using the same methods described for plants.

Sediment samples to a depth of 15 cm (6") were taken with an Ekman dredge and air dried and graded with sieves prior to analysis. Aquatic macrophytes were collected by hand prior to weed harvest, but after this process was underway 0.024 cubic meter (1 cu. ft.) samples were picked off the harvester apron, dried, grated through 6.35 mm (1/4") hardware cloth, and portions of them analyzed. These samples contained periphyton, snails, insects, crustaceans, and small fishe in addition to weeds, and represented all materials removed by the harvestor.

Biological Features

Weed areas were mapped prior to harvest by collecting along a large number of transects extending across weed beds perpendicular to shore. Dominant species were noted for each area. Plankton was collected in several regions, but most sampling was confined to the deepest lake area where samples were vertically spaced at 2 m intervals in the euphotic zone and at varying depths in the aphotic. Samples of 4 l were concentrated to 200 ml by settling. Counts were made in Sedgewick - Rafter cells, using the strip method for common forms and counting the whole cell for rare organisms. Plankton units were 1 ocular grid (.49 sq. mm) for large irregular colonies, 100 micron lengths for filamentous algae, individual colonies for such organisms as *Pediastrum* and *Crucigenia*, and individuals for single celled algae and zooplankters.

Primary production by plankton, net and gross, was measured by oxygen change in light and dark bottles filled with water from varied depths in the euphotic and aphotic zones and returned to these depths for incubation, which was for 2 hour periods, except during colder seasons with low plankton densities, when it was 6 hours. Results were converted to mg C fixed/cu.m/hr. Primary production by macrophytes and their investing periphyton was arrived at by isolating an area of lake bottom and its vegetation in a large cylinder of clear vinyl film and noting changes in pH, free CO_2, and alkalinity at frequent intervals (usually 2 hours) in the enclosed water.

Light and dark bottles were filled and suspended inside the cylinder to estimate changes attributable to phytoplankton. Calculation was as follows:

$$CVP = A \text{ or } B \times 0.27 - CP$$

where

CVP = Carbon fixed by vascular plants and their periphyton (mg/m^3)
A = free CO_2 used (mg/m^3)
B = Carbonate increase + total alkalinity decrease (mg/m^3) x 0.44
CP = Carbon fixed by plankton (mg/m^3)

At the end of incubation a volume of water was taken from the cylinder for membrane filtration and determination of plankton dry weight, and all attached vegetation was removed from the cylinder to ascertain its dry weight.

Weed Harvesting

Weeds were removed with a mechanical cutting, loading and unloading maching (Marine Scavenger Model 258-II) manufactured by Aquatic Controls Co. This unit has a capacity of 11.363 kg (25,000 lbs.) per hour, a pay load of 3.636 Kg (8,000 lbs.), a draft of 41-61 cm (16-24 inches), and can cut to a depth of 1.52 m (5 feet). Minimum practical working depth is about a meter (3.28 ft.). The lake was divided into 9 harvest areas (Fig. 6), and loads removed from each were recorded. Twenty nine harvester loads were weighted wet, and 0.024 m^3 (one cubic foot) samples removed from them were weighed wet, dried, and reweighed. Wet harvester load weights divided by wet weights of 0.024 m^3 samples allowed computation of number of cubic units per load (m^3 or ft^3). Wet and dry weights of 0.024 m^3 samples were then applied to harvester loads to determine total wet and dry weights removed from each area and the lake. This size samples were taken from many harvester loads that were not weighed. Nutrient loads per harvest area and lake were computed from their concentration in dried samples.

The weed harvester was also used in mapping macrophyte distribution and determination of standing crop. A standard length of line, floated and marked at set intervals was used to guide the harvester over a known area 2.4 x 91 meters (8 x 300'); and any species changes with distance along each cutting transect could be referred to the nearest line marker. Chemical sampling sites are shown in Figure 4, locations of oxygen transects in Figure 5, and weed harvest areas in Figure 6.

DISCUSSION

Climatological Features

Climate during the period of this study differed somewhat from norms established over 1946-60. Average January and July temperatures were slightly lower than these norms. Total annual precipitation was below normal in 1969 and '70 but above it in 1971. Months with greatest precipitation were July 1969, June 1970, and September 1971 (Table 1).

Physical Features

Ice Cover

Ice cover endured from around mid November until Mid April each winter. Ice became covered with snow that varied from 40 (1968-69) to 12 (1969-70) to 5 inches (1970-71). There was some drifting during the last winter giving 24.5 cm (10 inches) of snow in some areas. Heavy snowfall occuring during early freezing in 1968 reduced ice thickness to as little as 15.24 cm (6 inches) on central lake areas, and produced an opaque spongy ice except near shore. Ice formed during subsequent winters was clear and firm and varied from 61-91 cm (24 to 36 inches) in thickness. Noticeable surface flooding of ice occured in March 1971.

Temperature

Water temperature responded rather quickly to seasonal air temperature change, and there were generally distinct differences between temperatures of surface and deeper waters in summer and winter (Figures 7 and 8). Thermal stratification (summer stagnation) endured continually from mid July until September 1969, when the thermocline varied from 5 to 8 m in depth. In 1970 a thermocline that became established June 6 disappeared 20 days later and did not recur. In 1971 a thermocline was present in early May, again on June 3, to June 10, then again from June 15 until July 21, and finally from August 12 to August 20. Its position and thickness during these periods appear in Figure 9. Winter stagnation was well developed each year (Figures 7 and 8).

Light and Light Transmission

Solar energy was recorded, with a few interruptions, from June 8 to December 23, 1971. Mean daily values in langleys were: June, 477; July, 559; August, 502; September, 348; October 187; November 132; and December, 103. The maximum daily value, 708 langleys, occurred July 5, and the minimum, 42 langleys, December 1. Surface light intensity (total) varied from 402 to 7,153 foot candles at times of light penetration measurements. Total light intensities (as % of surface irradiation) at depths of 1 and 3 m varied during open water seasons over the 3 year period (Figure 10), and no light was observed to penetrate ice cover, even the minimum (around 24.5 cm or 10 in.) considered safe for observers. Light penetration during open water seasons was commonly restricted by trubidity due to plankton growth, especially blue-green algae near the surface. The 1% level of incident radiation usually occurred at 3 to 3.5 m, but in autumn sometimes reached 8.5 m. Very faint light was sometimes detected at 10 m. Penetration of green, blue, and red wave lengths varied over the seasons, with green and red usually with greater intensity and range (Figure 11). Red was sometimes noticeably stronger than green near the surface, but green usually accounted for most light intensity at depths of 2 m and greater.

Sediment

Shoal areas, which comprise about 45% of the bottom area, are largely sand, and deeper areas are largely covered with silt and clay, having a gyttja consistency when wet (Figure 12). Bars of cobble sized rocks and sand extend out from shore in some areas.

Chemical Features

Lake Water

Hydrogen Ion Concentration

Surface waters of the limnetic area of Lake Sallie had pH values well above 8.0 at all seasons during open water and under ice and snow cover (Figure 13). Deeper water pH fell below 8.0 during summer and winter stagnation but rose above 8.0 during periods of full circulation. Littoral areas, especially those affected by ground and surface inflow, e.g. the Pelican River, Fox and Monson Lake discharges, and Station 9 often had pH below 8.0; but at times had the highest pH recorded (up to 9.7). Low values occurred in winter when anaerobic or nearly anaerobic waters built up in these areas, and high values in summer with accelerated photosynthesis responding to inflow nutrients. Surface pH in the limnetic zone rarely exceeded 9.0, reaching 9.2 on a few occasions in 1969.

These pH data indicate a virtual isolation of most upper waters from areas with greatest decomposition over most of the year, widespread effects of photosynthesis in upper waters, and relatively minor water volume (in littoral areas and in a few deep pockets) undergoing pronounced changes due to decomposition. Persistence of high pH in the absence or near absence of photosynthesis under ice and snow further attests to the general low level of decomposition. Upon a few occasions a minor pH increase (0.1 pH) occurred in water in contact with the ice cover, and it is assumed that these elevations were due to photosynthesis since they were usually accompanied by slight increases in carbonate and oxygen. Winter sampling occurred at weekly and biweekly intervals, and although no light penetration through ice was recorded, it could have occurred between sampling dates. There was usually a slight progressive decline in surface water pH with time under ice cover in the limnetic zone, with a few interruptions occasioned by rare periods of photosynthesis.

Alkalinity

Carbonate

As may be inferred from the above account of pH, carbonate occurred in surface waters of the limnetic zone at all seasons, was absent from deeper waters during summer and winter stagnation, and from some littoral areas at intervals. Its concentration reached 100 mg/l (as $CaCO_3$) in Muskrat Lake discharges and attained 48 mg/l in the limnetic zone. It increased slightly under ice cover when pH and oxygen changes indicated photosynthesis, as would be expected.

Bicarbonate

This ion had its minimum recorded concentration in surface waters of the limnetic zone when photosynthesis was most pronounced and achieved its maxima for this zone in deeper waters during winter stagnation. The most recorded in the limnetic zone was 230 mg/l during winter, but Stations 9 and 21 in the littoral zone and Station 1 in Muskrat Lake discharge often exhibited higher values under ice. The highest recorded value was 428 mg/l at Station 9 in January 1971. That area appeared to receive considerable ground water during winter, or this water was more isolated there under ice. During open water seasons photosynthesis was noted to reduce bicarbonate to 124 mg/l in surface water of the limnetic zone. In most waters this much bicarbonate would provide sufficient CO_2 for photosynthesis and there seems no reason to suspect that it would be limiting in Lake Sallie.

Hardness

Total hardness varied above and below total alkalinity in concentration suggesting that at times cations other than those contributing hardness were combined with carbonate and bicarbonate. From October 1968 until June 1969 hardness continually exceeded alkalinity in surface water of the limnetic zone, but this was not true for the remainder of that growing season, nor for the 1969-70 winter, nor for the 1970 open water period. In autumn of 1970 and early in the 1970-71 winter hardness overshadowed alkalinity in upper limnetic water, but alkalinity pulled even in late December and went ahead in early January. Hardness came to the fore again in early February and was thereafter greater than alkalinity until early June 1971, when it fell slightly below. It became dominant again in late June and remained so through December 31, 1971. The hardness maximum recorded in surface limnetic water during 1970-71 was 225 mg/l, whereas that of alkalinity was 206 mg/l. Minimums during the same period were 167 hardness and 149 for alkalinity. Alkalinity exceeded hardness by as much as 8 mg/l, but hardness was greater then alkalinity by as much as 25 mg/1.

Hardness and alkalinity were rather uniform from surface to bottom during periods of complete circulation, but both changed with depth during times of stagnation. The usual tendency then was to increase with depth, and this appeared generally true when upper- and lowermost waters were compared, but there were several occasions when intermediate waters were lower than those above and below; and there were 2 periods during the 1969-70 winter when lenses of harder water appeared to flow through the limnetic zone at a depth of 2 meters. When they disappeared no hardness increase was noted at 4 or 6 meters, and it is assumed that they moved out of the sampled area (Station 4) laterally. Inflow of the Pelican River has at times exhibited hardness concentrations very near those of these lenses, and it seems reasonable that its discharge may pass through the lake as an interflow when ice cover stills wind driven circulation. With one exception, which may have resulted from an analytical error, hardness and alkalinity augmentation occurred in surface water under ice cover and likely represented retention of freeze-out in the upper, lighter water.

Both hardness and alkalinity varied in different regions of the littoral zone, especially when mixing into lake water was slowed by ice cover. Ranges on three occasions in late winter at 12 alongshore stations in mg/1 were:

Date	Total Alkalinity	Total Hardness
3/15/69	198 - 242	210 - 250
2/06/70	196 - 326	215 - 323
3/07/70	182 - 408	196 - 372

Highest values occurred at Station 9, where concentration diminished rapidly with distance from shore. Maximum concentrations recorded there were 428 mg/1 alkalinity and 431 mg/1 hardness in January 1971. Concentration at most shoreline stations decreased abruptly when wind driven circulation returned with ice melt. Areas most dominated by inflowing water (e.g. Station 1 at the Pelican River inlet) tended to remain more mineralized than the lake, but they were reduced to the general limnetic level by strong winds. Hardness and alkalinity were generally most concentrated during the winter and most dilute during open water seasons in surface and deeper waters (Table 2).

Calcium and Magnesium

In limnetic water calcium (as $CaCO_3$) varied from slightly less than 60 to almost 100 mg/1 (Table 2). Greatest concentrations noted were in deep water during times of stagnation. Magnesium exhibited a similar pattern of variation, but its range was noticeably higher, from 108 to 147 mg/l in 1970-71. Littoral stations attained greater concentrations of both ions under ice cover, and at times in some of those areas calcium attained greater concentrations than magnesium. These occurrences suggest that ground water entering this lake system is normal for this general area in having more calcium than magnesium, and this has been confirmed by analyses of well water in 1972. Preponderance of magnesium in a lake fed by such ground water indicated photosynthesis overshadowing decomposition in magnitude and placing the more soluble $MgCO_3$ in a more favorable position than $CaCO_3$ to recombine with CO_2. This condition has been noted in other eutrophic lakes in this general area. Both ions increased when CO_2 appeared in bottom water at Station 4, but magnesium to a greater extent.

Oxygen

Level of oxygen in Lake Sallie was frequently determined by photosynthesis and respiration. During open water seasons the entire lake surface commonly exhibited oxygen pulses with concentration declining to near zero in the early morning hours and building up to supersaturated values by early afternoon. Greatest concentration (as % saturation) was usually produced by macrophytes and attached algae in the littoral zone (out to 3 m depth), and, as would be expected, lowest concentrations also frequently occurred in this area. Stratification in summer and winter frequently occasioned oxygen depletion in deeper waters, but oxygen was always found in surface water, even under heaviest ice and snow cover. In fact, photosynthetic production of oxygen occurred at intervals under ice cover, at one time giving an increase of about 3 mg/l between sampling dates, although light measurement consistently indicated no penetration through the ice. Carbonate alkalinity and pH increase accompanied oxygen elevations, and there seems no doubt that photosynthesis was operative at those times. Since photosynthesis occurred between visits it is assumed that light penetrated ice at times that were missed by the sampling schedule (Table 2).

Biochemical Oxygen Demand

Maxima of this parameter appeared to normally characterize early spring, late summer, and autumn in the limnetic zone, but peaks occurred at other times in Pelican River inflow (Figure 14). Increases and decreases in BOD were rather closely associated with those of plankton, and it would appear that suspended organisms and their detritus were major contributors to BOD in the largest lake area.

Nitrogen

Ammonia

This form of nitrogen was consistently present in all areas and depths sampled in Lake Sallie. In the limnetic zone it was most concentrated in deeper waters during summer and winter stagnation (up to

2.6 mg/l in summer and to 1.5 mg/l in winter). Greater concentration in upper waters (1.25 mg/l) occurred during periods of full circulation when maxima attained in bottom waters during stratification were reduced. Surface concentration varied in different lake regions. Highest values (slightly above 4.0 mg/l) were observed at Station 9 under ice cover, which suggests that inflow there was contaminated, but concentrations above the general lake level were also noted at Stations 1, 12, 19, and 21. These ammonia values were induced by inflowing surface and ground water. That entering at Station 1 represented by far the greatest volume, and was considered most influential on the character of the lake. Concentration in the limnetic zone was nearly always greater than 0.1 and usually more than 0.2 mg/l (Table 2).

Nitrite

Nitrite was usually, but not invariably, found in samples from all areas, depths, and dates. It disappeared in August 1969 from all sampled areas, and was missing at times in summer from some stations. Its concentration was generally well below 0.01 mg/l at all depths during open water seasons, but it increased to 0.1 at Stations 1 and 4 for a short period in September, 1970. With stratification maximums (up to 0.1 mg/l in March 1970) occurred at intermediate depths (6 to 8 m) under ice and at intermediate or maximum depth with open water, when increases rarely occurred below stable thermoclines (Table 2).

Nitrate

Nitrate was most concentrated at all depths under ice cover, when the maximum observed concentration (0.34 mg/l) occurred in surface water at 3 stations. Vertically in the limnetic zone, it attained peak values at 6 and 8 m during winter of 1969-70, but during the 1970-71 winter its maximum was at 14 m. Inflow via the Pelican River generally had higher nitrate concentration than that leaving the lake. Nitrate was rarely absent from surface water, but zero values there were noted during all seasons except under ice cover (Table 2).

Phosphorus

Available phosphorus (PO_4) generally was most concentrated in deeper waters of the limnetic zone, especially during periods of stratification (the 9.2 mg/l maximum was in the hypolimnion in 1969), but it tended to disappear from surface waters during the growing season, although this occurred infrequently in 1969. It varied markedly in surface water at Station 1, where maximum values (4.8 mg/l) occurred, but it reached comparable levels in other littoral areas (Stations 9, 10, and 12) under ice cover. Its maximum for the limnetic zone surface (1.4 mg/l) occurred in September 1969. Surface values there were usually less than 0.20 mg/l. Orothophosphate was consistently higher in inflowing than in outflowing water, declining to zero in the latter for about 30 consecutive days in July and August 1971. Surface water concentrations were higher in 1969 than in 1970 and 1971.

Total phosphorus occurrence and variation generally paralleled those of PO_4, but its concentration was substantially higher. It increased with depth, declined from winter maxima during the growing season, and was almost always more concentrated in inflowing than in outflowing water. Its level was also greater in 1969 than in 1970 and 1971.

Miscellaneous Water Chemical Features

Sulfate, analyzed infrequently, had generally low levels (6.0 - 7.5 mg/l), but was about 3 times as concentrated (20.5 - 27.5 mg/l) in inlet and outlet. Reasons for increase at the outlet are unknown. Conductivity, measured only once during summer stagnation, showed an increase with depth (320 umhos at 9 m) and was greatest in surface water in Stations 1 and 9, which was not amazing considering greater mineral content at those stations. Hydrogen sulfide measured at 1 m intervals down to 15 m at Station 4 on July 8, 1971, occurred only at 8 m and below, increasing from 0.1 at 8 m to 5 mg/l at 15 m.

The Pelican River above Muskrat Lake usually had more orthophosphate, ammonia, and nitrate nitrogen than this lake's discharge, but total P was more frequently greater in the discharge. Evidently a significant share of the PO_4 entering Muskrat Lake was incorporated into organic matter before reaching Lake Sallie. Analyses of the Pelican River above and below where it receives the ditch from St. Clair (see Figure 2) confirmed high nutrient content of drainage receiving Detroit Lakes waste water effluent.

Rainwater collected near Station 1 in September and October 1971 was acidic (pH 3.8-4.2), at times contained PO_4 (0.25 mg/l) and always bore nitrogen (NH_3-N, .05-.75; NO_2-N, .004-.006; NO_3-N, .054-.426 mg/l). Ice and snow from atop the lake in November and December 1971 had .38-.52 mg/l PO_4 and .053-.414 mg/l NO_3-N. Concentrations in the ice were considerably greater than those in surface water on dates of collection. Reasons for this increase are only speculative at this time.

Samples taken through ice in the littoral zone in the winters of 1968-1969 and 1969-1970 disclosed a lack of oxygen at Station 9. A transect run perpendicular to shore there in March 1970 showed an oxygenless condition out to about 90 m from shore, but a rapid increase to 6.28 mg/l at 105 m. The anaerobic zone also extended alongshore for about 100 m on either side of Station 9.

Sediments

Nitrogen and phosphorus were considerably lower in sediments in shallow than in deeper lake areas. Nitrogen was about 4 times as concentrated under 5.5 m than under 1 m or less of water, although C:N ratios were little changed. Total P was about 3.5 times more concentrated under deeper water, largely in calcium and iron combinations, with the latter more prevalent. Aluminum P was significantly less common, but was also greater under deeper water. Calcium phosphorus was 12 times as great as the water soluble fraction. In 1970-71 sediment analysis was restricted to total N and total P, but increases with water depth were still apparent (Tables 3, 4, and 5).

Aquatic Macrophytes

Analyses of upper, middle, and lower one thirds (including roots) of 8 species of rooted plants collected in September 1968 showed rather uniform concentrations of most elements measured (P, N, C, H, Ca, Mg, Na, K, Co, Cu, Fe, Mn, Mo, and Zn) throughout the plant, although they varied in different species. P was greater in upper sections of *Myriophyllum exalbescens* and *Vallisneria americana*; calcium was most concentrated in *Potamogeton Richardsonii* and *Elodea canadensis*, and the upper two thirds of *Vallisneria*; and sodium was highest in the root sections of the four species whose lower 1/3 was analyzed (*Scirpus validus*, *Myriophyllum*, *Potamogeton pectinatus*, and *P. Richardsonii*) (Tables 6 and 7).

Weed Harvester Catches

Organisms gathered by the weed harvester included aquatic macrophytes plus periphyton and any animals living in the vegetation. Carbon content of this assemblage was rather uniform throughout the lake weed beds in 1970 and 1971, as were nitrogen and phosphorous in 1971. However, in 1970 P was 2.4 times as concentrated in Area 1 than in areas 8 and 9 and exhibited a gradual decrease around the lake counterclockwise from Station 1. Nitrogen was more concentrated in Areas 1 and 2 in 1970. Ranges in ppm per dry weight of weeds were as follows: 1970. P, 1,900 - 4,500; N, 21,000 - 29,900; C, 277,000 - 370,000. 1971. P, 2,200 - 3,450; N, 18,300 - 32,000; C, 294,000 - 336,000 (Table 7).

Fish

Ten species of fish were analyzed in toto for P, N, and C. Sunfishes (3 species) had higher levels of P than perch, walleye, pike, white sucker, or bullheads (3 species). Range among these species was 0.49 - 0.85% wet weight. Nitrogen (range 1.83 - 2.61% wet wt.) and carbon (range 7.91 - 9.97% wet wt.) showed no marked relationship to fish species.

Plankton

Plankton, including detritus, was analyzed only for phosphorus. P tended to be more concentrated in plankton from the upper 2 m of the limnetic zone, but at times was about as concentrated in spspended matter from deepest water. It varied from place to place in samples from surface water, once achieving 47,000 ppm per dry weight at Station 12. Plankton from the limnetic zone had markedly lower P concentrations in fall than in summer, but seasonal trends were much less marked in the littoral zone.

Biological Features

Plankton

Qualitative Features

Collections made over the three year period yielded 188 plankton organisms that are listed in the appendix. Green algae, largely chlorococcales, accounted for the largest number of species (59); diatoms had 38, blue-green algae 25, ciliate protozoans 21, and rotifers 19 species. Less numerous groups, copepods (3), cladocerans (7), suctorians (2), amoeboid protozoans (4), dinoflagellates (3), cryptophyceans (1), euglenophytes (3), chrysophytes (1), xanthophytes (1), and identifiable bacteria (1), gave 26 species.

Seasonal Occurrence

Seasonal patterns were usually considerably modified by location in the lake, and sometimes were unstable during periods with changing dominant groups. In the limnetic zone, as exemplified by Station 4, the general tendency appeared to be dominance by diatoms in spring giving way to blue-greens in summer to diatoms again in autumn and early winter and to green algae (*Chlamydomonas*) and/or pyrrophytes (*Cryptomonas*) in winter. However, this was by no means a fixed order of succession. For example, *Microcystis* (a blue-green) replaced *Chlamydomonas* as the dominant plankter in surface water in February 1971, but was replaced by the latter in March. *Chlamydomonas* did not loose dominance in deeper water. In June 1971, dominance changed from *Stephanodiscus* (a diatom) to *Microcystis*, back to *Stephanodiscus*, and then to the blue-greens *Anabaena* and *Aphanizomenon*. Blue-greens, with *Gomphosphaeria* and *Oscillatoria* entering dominant ranks in August and September, were thereafter most prevalent until late September when they were replaced for about 10 days by the diatoms *Melosira* and *Stephanodiscus*. *Aphanizomenon* regained dominance in surface water on October 1, and was only slightly less numerous than *Stephanodiscus* at 2 m, but it was "ousted" for good by the latter on October 9. This diatom gave way to *Chlamydomonas* on December 11, and eleven days later this green alga was joined by *Cryptomonas*, which had also appeared in dominant ranks with *Aphanizomenon* in surface water on October 1. Vacillating dominance between blue-greens and diatoms in late spring and early fall suggests that competition between them is rather finely balanced and that swings to either side may be occasioned by minor environmental changes. In August 1969 a dense *Aphanizomenon* population was severely reduced by applications of copper sulfate along the southeast shore, and, when effects of this algicide wore off, Aphanizomenon was replaced in dominance by Melosira, which achieved even greater concentrations. Melosira was gradually replaced by Stephanodiscus, which became dominant in mid-October. This application of algicide resulted in diatoms assuming dominance about 2 months earlier than they did in succeeding years (Figure 15).

Variation in Surface Water

Plankton composition, even with regard only to major groups, exhibited considerable variation at any time in both littoral and limnetic zones. In August 1969 blue-greens comprised 90% of the population at Station 1, 10% at Station 2, 5% at Station 4, 2% at Station 8, and 20% at Station 11. For the same period diatoms were 2% at Station 1, 40% at Station 2, 85% at Station 4, 38% at Station 8, and 40% at Station 11. Greens ranged from 1 - 30% of the populations at these stations, and other groups from 4 to 30%. In June 1970 (1 series of samples) composition was as follows: Station 1, 42% blue-greens, 58% diatoms; Station 2, 35% blue-greens, 63% diatoms, others 2%; Station 4, 72% blue-greens, 23% diatoms, 2% greens, 2% dinoflagellates, and 1% others; Station 8, 25% blue-greens, 65% diatoms, 3% greens, 5% dinoflagellates, and 2% others; and Station 11, 80% blue-greens, 18% diatoms, and 2% others. Hence, seasonal dominance varied with location, and neither littoral nor limnetic zone exhibited any general uniformity.

Variation with Depth

Frequently the group dominant at the surface was also prevalent all the way down to 10 m, although with as much as 30% variation in degree of dominance. On other occasions dominance changed to another group at an intermediate depth and back to the surface dominant in deepest water. In August 1969 diatoms formed from 90 - 98% of the population down to 3 m, 2% at 5 m (where blue-greens amounted to 98%), 98% at 7 m, and 95% at 5 m. Zooplankters were concentrated in deeper water at times, and Coleps was often conspicuous in these build-ups. In September 1969 diatoms were dominant and varied from 52% of the population at 2 m to 80% at 8 m. Blue-greens, second in abundnace, varied from 10 to 25% of the populations having both minimum and maximum values at intermediate depths. Greens had 2% of the population in deepest water and 15% at 2 m; dinoflagellates ranged from 0 - 15% of the populations at varied depths, being most numerous at 4 m; and zooplankters varied from 1 - 18% with most numbers in deepest water. In summer of 1970 blue-greens were dominant at all depths, but they were replaced at all levels except 1 m by diatoms in October.

At the generic level variation was often rather marked during periods of dominance by one of the larger groups. For example, on July 5, 1971, Aphanizomenon, dominant in upper water, was replaced by another blue-green, Gomphosphaeria, at 6 m, and by Gomphosphaeria and

Coleosphaerium, still another blue-green, at 8 m. Generic variation within a major group also occurred in different littoral and limnetic regions.

Quantitative Features

Concentration in samples from the limnetic zome varied from more than 55,000,000 to 12,000 units per 1. Seasonal influences, insofar as these may be determined from only 3 years records, appear to result in spring, summer, and autumn maxima, with winter, late spring, and late summer minima. Diatoms have been largely responsible for the spring and fall elevations and blue-greens for the major summer growth, but diatoms replaced blue-greens in summer of 1969 following an application of algicide. Green algae exhibited about 5 peaks per year, three in summer and one each in spring and winter. They achieved dominance only in winter, but they were more numerous than diatoms during summer, except in 1969. The greatest concentration observed, 55,114,200 units per liter occurred at 6 m in the limnetic zone during a spring diatom maximum, and diatoms comprised 99.7% of the total population. Diatoms were also dominant in surface and near surface waters, but their concentrations were somewhat less, being 50,657,500 per 1 at the surface and 42,802,600 at 2 m. Greater concentration at 6 m may have been due to settling. The highest observed summer concentration when blue-greens were dominant was slightly more than 6,000,000 per 1. Phytoplankters were several times as concentrated in spring of 1971 than during either preceeding year, but summer densities were comparable to those of 1969 and 1970 (Figures 16, 17, and 18).

Lake Sallie, although with a long history of cultural eutrophication, was not dominated by blue-green phytoplankton except on a seasonal basis, and this seasonal dominance did not appear very firm, but rather finely balanced against incursion by diatoms. Green aglae, even when dominant, never attained numbers near those reached by diatoms and blue-greens at their peaks.

Attached Vegetation

Chara sp. grew on the bottom and *Cladophora* sp. and *Gleotrichia natans* (Hed.) Rab. were attached to aquatic flowering plants. Star duckweed (*Lemna Trisulca* L.) grew both free floating and attached to other vegetation, but other duckweeds (*Lemna minor* L., *Spirodela Polyrhiza* (L.) *Schleid*., and *Wolffia columbiana* Karst.) were all surface floaters. Macrophytes observed were:

Najas flexilis (Willd.) Rostk. & Schmidt
Potamogeton amplifolius Tuckerm.
P. crispus L.
P. filiformis var. *Macounii* Marong.
P. pectinatus L.
P. praelongus Wulf.

P. Richardsonii (Benn.) Rydb.
Ruppia maritima L.
Alisma gramineum var. Geyeri (Torr.) Sam.
Scirpus actus Muhl.
Heteranthera dubia (Jacq.) MacM.
Elodea canadensis Michx.
Vallisneria americana Michx.
Ceratophyllum demersum L.
Myriophyllum exalbescens Fern.
Nuphar variegatum Engelm.
Nymphaea tuberosa Paine

These macrophytes covered about 34% of the total lake area, all above the 3 m contour except Potamogeton praelongus which grew down to 6 m (Figure 19). In 1969 and '70 Myriophyllum and Potamogeton pectinatus tended to predominate, especially the former, in the northern half of the lake and along the south shore. Scirpus beds have been prominent along the eastern and northern shores and in a smaller area on the west just north of the hilus. Littoral areas in other lake regions were largely covered by a mixture of Ruppia, Potamogeton Richardsonii, Vallisneria, and Ceratophyllum, in which other species were widely scattered. Duckweeds were most conspicuous in shallow areas, especially near Scirpus beds. Gleotrichia first appeared epiphytic on macrophytes and later became free floating. It and Nostoc became very abundant on the bottom in late fall.

Weed distribution in 1971 was quite similar to that noted in '69 and '70, but all species, except Scirpus, which was not harvested, were noticeably less abundant. Potamogeton pectinatus was more prominent in weed harvester hauls and growth was most luxuriant in Areas 3, 5, and 5, whereas in 1970 it had been greatest in Area 2 followed closely in Area 3.

Standing Crop

Standing Crop of aquatic flowering plants and their epiphytes, based on weed harvester hauls from known areas in July and August 1971, was estimated at 119,599 kilograms dry weight for all weed bearing areas (34% of the total lake area). This figure includes roots which had harvesting tests indicated were 13% dry weight of the portion usually taken by the harvester. Average dry weight of harvester hauls was 58.8 g/sq. m. The 1970 harvest was 2.9 times as great as that of 1971 for comparable harvester effort.

Primary Production

By Phytoplankton

Two hour exposure periods were adopted as standard for light and dark bottle tests, and duplicate sets indicated this gave a precision of ± 10 mg C fixed/m^3/hr.

Nutrient concentrations declined along the course of the Pelican River inflow into Lake Sallie, and this was also true of the rate of primary production upon some, but not all occasions. It was often greater at Station 4 in the limnetic zone than at Station 1 or in Muskrat Lake. Variation among stations in the limnetic zone appeared to be normal.

Most measurements were made at Station 4 near the heart of the limnetic zone. Surface water there showed maxima in late summer or early fall each year, but summer and fall activity varied noticeably over 1969-'71. Average values for the euphotic zone gave a three-year pattern that resembled that for surface water, but generally had sharper and fewer peaks. In 1969 and '71, means for the euphotic zone maxima were comparable with highest rates developed in surface water, but the average value was much below that of the surface in 1970 (Figures 20 and 21). Surface productivity showed a progressive increase from 1969 through 1971 with respect to total amount of carbon fixed per growing season. These upper waters accounted for 68% of production at Station 4 over the three-year period. Net production was greater and respiration less in 1971 than in '69 or '70 in both surface water and throughout the euphotic zone (Figures 22 and 23).

Productivity varied with depth in the euphotic zone (Figure 24) and with time of the day (Figure 25) for which no pattern appeared consistent. There was also no definite relationship with intenstiy or amount of light on either a daily or a seasonal basis, but photosynthetic efficienty (mg C fixed per solar radiation unit) was greatest in late afternoon and in early September and during most of October when solar energy was noticeably below values occurring in July and August (Figure 26).

By Attached Vegetation

Measurements within the plastic cylinder chiefly if not exclusively represent the activity of flowering plants, largely Myriophyllum, and phytoplankton, as very few attached algae were ever enclosed. Depth of sampling and bottle suspension inside the cylinder was 10 cm. Net productivity attributable to the rooted plants (total for the cylinder minus that for the light bottle suspended inside) ranged from -338 to 780 mg C/m^3/hr and that attributable to plankton from -119 to 503 mg C/m^3/hr. On a net productivity per gram of dry weight basis phytoplankton greatly outstripped the rooted vegetation, but dry weight of the rooted vegetation included many more parts, roots, fibers, etc., that are not photosynthetic. It is likely that rates for attached vegetation would have been higher had attached algae been enclosed with other plants. Thermal and oxygen stratification usually developed within the cylinder. Light intensity declined markedly with depth inside the cylinder, usually being less than 5% of surface values at 1 m (Table 8).

Nutrient Removal

By Weed Harvester

As mentioned previously, the weed harvester removed algae, invertebrates, and fishes with aquatic flowering plants. Total wet weight of these organisms removed was greater for each area except No. 5 in 1970 and 3.8 times greater for the entire lake as shown in the following table:

Kg (wet weight) of Weeds Removed

Area	1970	1971
1	97,853	6,578
2	138,119	1,928
3	105,351	31,477
4	5,770	1,850
5	19,856	54,711
6	47,430	14,520
7	673	0
8	3,336	0
9	9,616	0
Total	428,034	111,064

Dry weight of weeds removed amounted to 30,371 kg (66,816 lbs.) in 1970 and 10,366 kg (22,805 lbs.) in 1971. Kilograms of nutrients taken out with weeds were as follows:

	1970	1971
Phosphorus	100	26
Nitrogen	721	248
Carbon	10,699	3,219

Mean percentages of nutrients in dried weeds were:

	1970	1971
P	0.27	0.265
N	2.34	2.46
C	32.25	30.73

In 1970 weeds from Areas 1 and 2 (near the Pelican River inlet) had noticeably higher percentages of phosphorus and nitrogen than those from areas farther down lake. This was not true for P in 1971 when quantities available to the harvester in Areas 1 and 2 amounted to but a small fraction of the mass removed in 1970, but weeds from Area 1 still had the maximum nitrogen concentration. In the 6 most productive areas (1970) nitrogen ranged from 3 to 10 times the concentration of P, and C varied from 64 - 155 times as great as P; in 1971 N was 4.5 to 10 times as great as P and C from 72 - 132 times.

Removed in Fish

Commercial and sport fishermen took out 76,530 kg of fish (mostly bullheads) in 1969-70, and 39,129 kg in 1970-71. Mean concentrations of P, N, and C in tested specimens were 0.53, 2.01, and 9.25%, respectively, which would indicate that quantities removed were:

	1969-70	1970-71
P	406 kg	207 kg
N	1,591 kg	786 kg
C	7,109 kg	3,619 kg

Thus, 76,530 kg wet weight of fush contained slightly more than 4 times as much P, more than twice as much N, and slightly more than 2/3 as much C as 428,034 kg, wet weight, of weeds in 1970. In 1971, 39,120 kg wet weight of fish gave almost 10 times the amount of P, 3.15 times the quantity of N, and slightly more C than 111,064 kg, wet weight, of weeds.

Costs per pound of nutrient removal by weed harvester were:

	1970	1971
P	$61.19	$198.92
N	$ 8.24	$ 21.04
C	$ 0.64	$ 1.62

Costs include operation, maintenance, trucking of weeds to points outside the drainage basin, and harvester depreciation. Increased per unit costs in 1971 reflect lower weed density.

Water and Nutrient Budgets

Surface water enters Lake Sallie via the Pelican River (major source) and outlets from Fox and Monson Lakes, and exits only via the Pelican River. Ground water inflow apparently exceeds seepage from the lake, as surface outlow always exceeded inflow from the river and lakes. Quantities of water and nutrients entering and leaving in surface flow appear below.

		Water Years		
		1968-69	1969-70	1970-71
Water	Inflow m^3	20,197,256	17,858,188	17,849,207
	Outflow m^3	22,716,382	19,087,138	20,807,164
Phosphorus	Inflow kg	10,140*	7,470**	15,643**
	Outflow kg	5,810*	2,510**	7,758**
Nitrogen[1]	Inflow kg	11,650	5,594	10,567
	Outflow kg	9,720	2,640	7,217

* Soluble P
** Total P
1 $NH_3 - N + NO_2 - N + NO_3 - N$

Soluble P only was measured in 1968-69. In subsequent years the mean ratio of soluble P to total P was 1:1.7, and, if this may be applied to the 1968-69 water year, total P entering then would exceed 17,000 kg and that leaving around 9,900 kg. Both P and N declined noticeably in 1969-70, but recovered substantially in 1970-71. P and N content of Lake Sallie water was, in kilograms:

	1968-69	1969-70	1970-71
P	2,270*	9,690**	16,513**
N	24,740	5,070	21,231

* Soluble P
** Total P

Mean quantities contained in the upper 15 cm (6") of sediments in 1968, '69, and '70, in kilograms, were 73 P and 748 N, whereas in 1971 they were 89 and 738 kilograms, respectively. Total volume of sediments to this depth is about 795,000 m^3. Estimates of total wet weight of fishes (Olson, 1971, '72) and quantities of P, N, and C tied up in them, all in kg, follow:

	1969	1970	1971
Fish	347,545	212,090	594,740
P	1,980	1,220	3,152
N	7,210	4,270	11,594
C	30,340	18,006	55,013

The 1971 standing crop of aquatic flowering plants and organisms gathered with them by the harvester, plus roots and lower stems not taken by the harvester, has been estimated as 119,520 kilograms, dry weight. This figure is based on a mean standing crop of 66.4 g/sq. m., dry weight, over an area of 1,800,000 sq. m. (34% of the total lake area). Since percentages of P, N, and C in dried weeds were .30, 2.35, and 30.87, respectively, total nutreint content of weeds and associated organisms in 1971 was 358 kg P, 3810 kg N, and 36,920 kg C.

Nitrogen and phosphorus budgets (Table 9) indicate that harvest of fish and weeds to the extent possible with present equipment and practices did not offset yearly gains via surface inflow. Removal of all fish and weeds would make an inroad on previously accumulated N, but would not equal any annual P increment recorded to date. With the exception of 1969-70 much more N and P were contained in the water mass than in bodies of organisms and sediments combined, and concentration of these two elements would be subject to rather rapid reduction if their discharge in wastewater to the Pelican River was curtailed.

Effects of Weed Harvest

Two years of weed harvest did not alter the basic chemical nature of the water mass nor the general pattern of nutrient dynamics in the water. One year's harvest greatly reduced weed concentration in affected areas and occasioned some change in dominant forms. Denser plankton concentration occurred the first year following harvest, the amount of carbon fixed by phytoplankton increased, and the ratio of planktonic respiration to photosynthesis decreased. These latter developments suggest that weeds compete with phytoplankton, and, that weed removal should not be expected to aid phytoplankton control unless it depletes nutrient supplies beyond annual increments.

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FIGURES

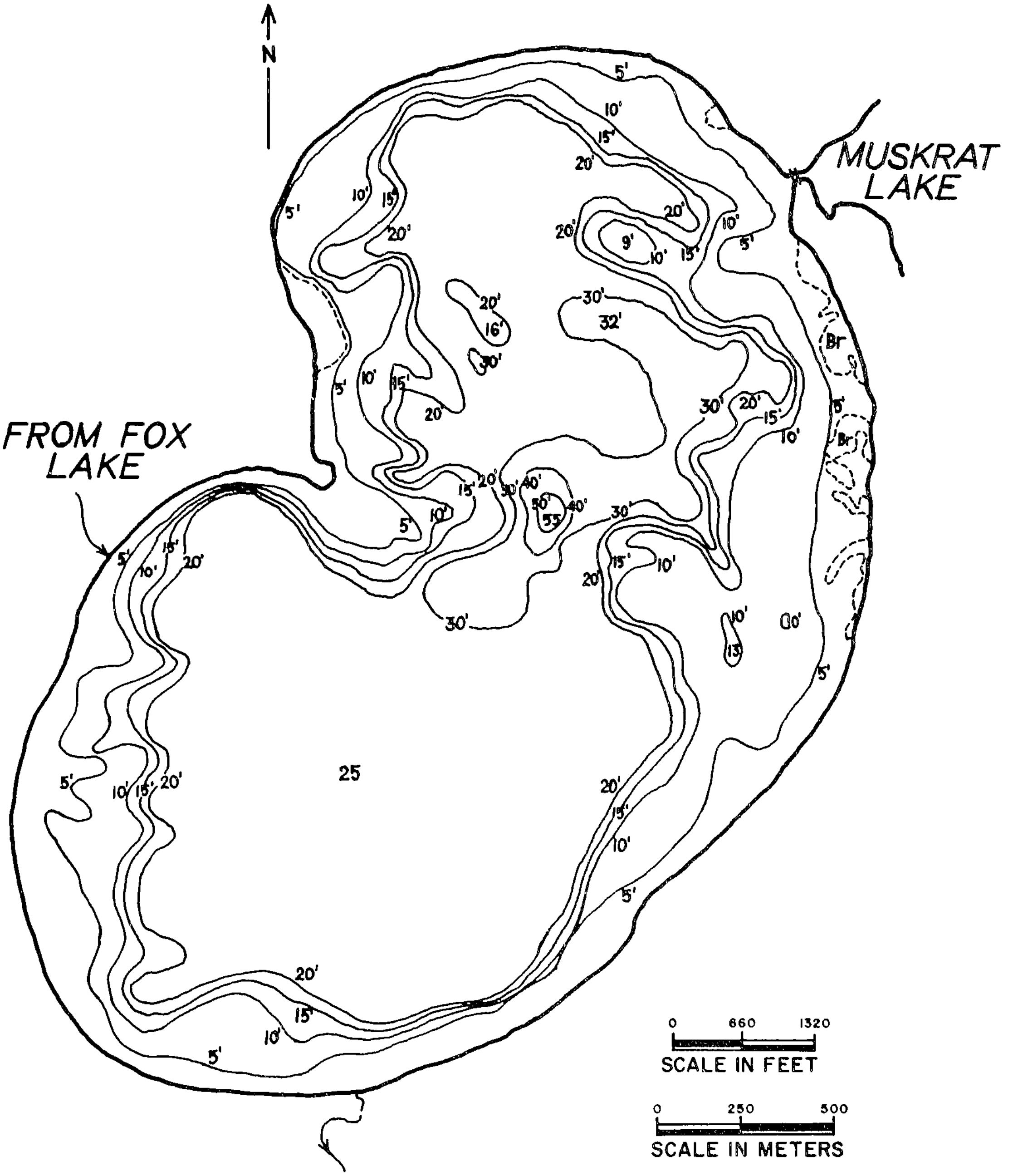

FIGURE 1. BATHYMETRIC MAP OF LAKE SALLIE, MINNESOTA.

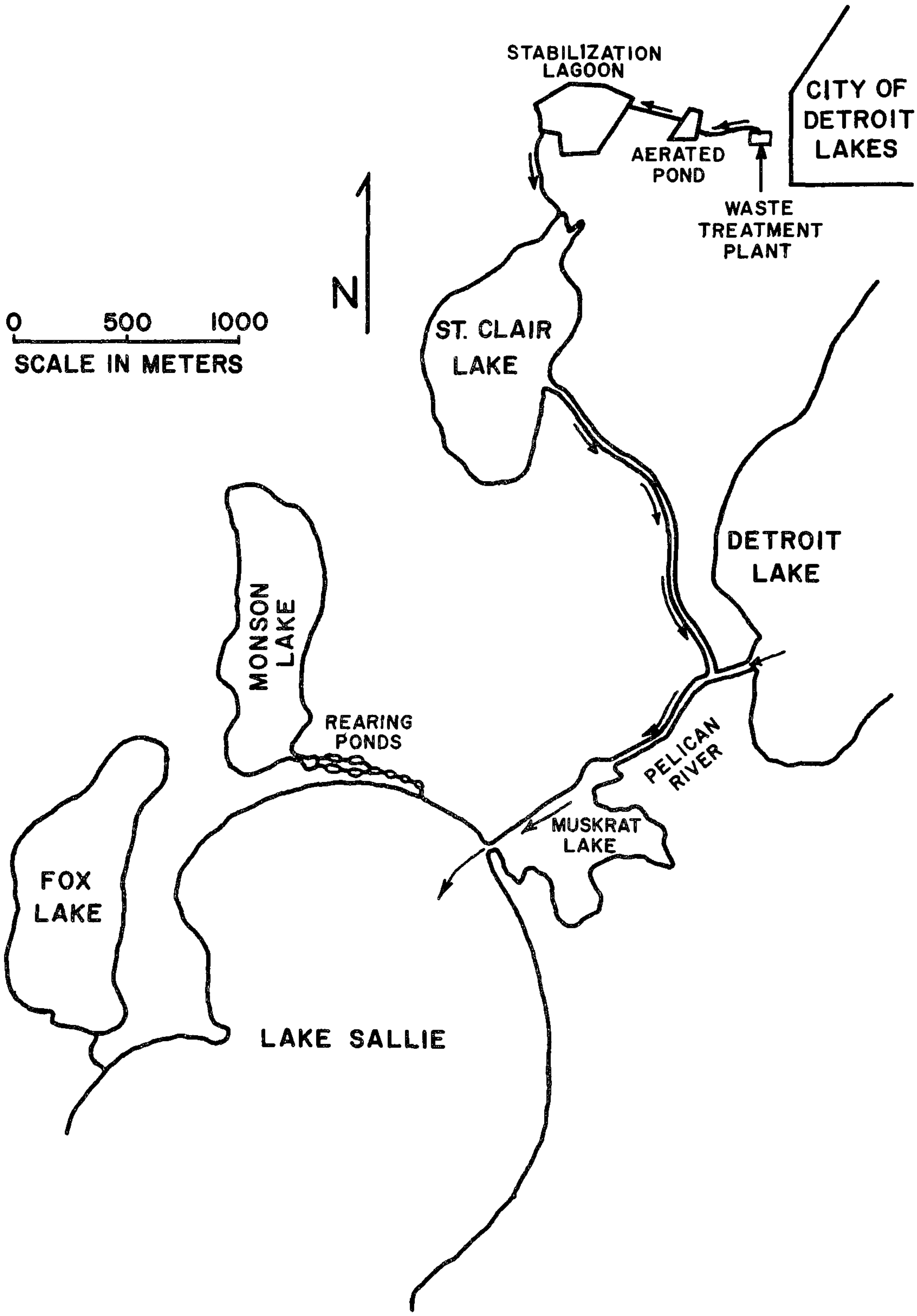

FIGURE 2.
FLOW ROUTE OF WASTEWATER EFFLUENT FROM DETROIT LAKES TO LAKE SALLIE.

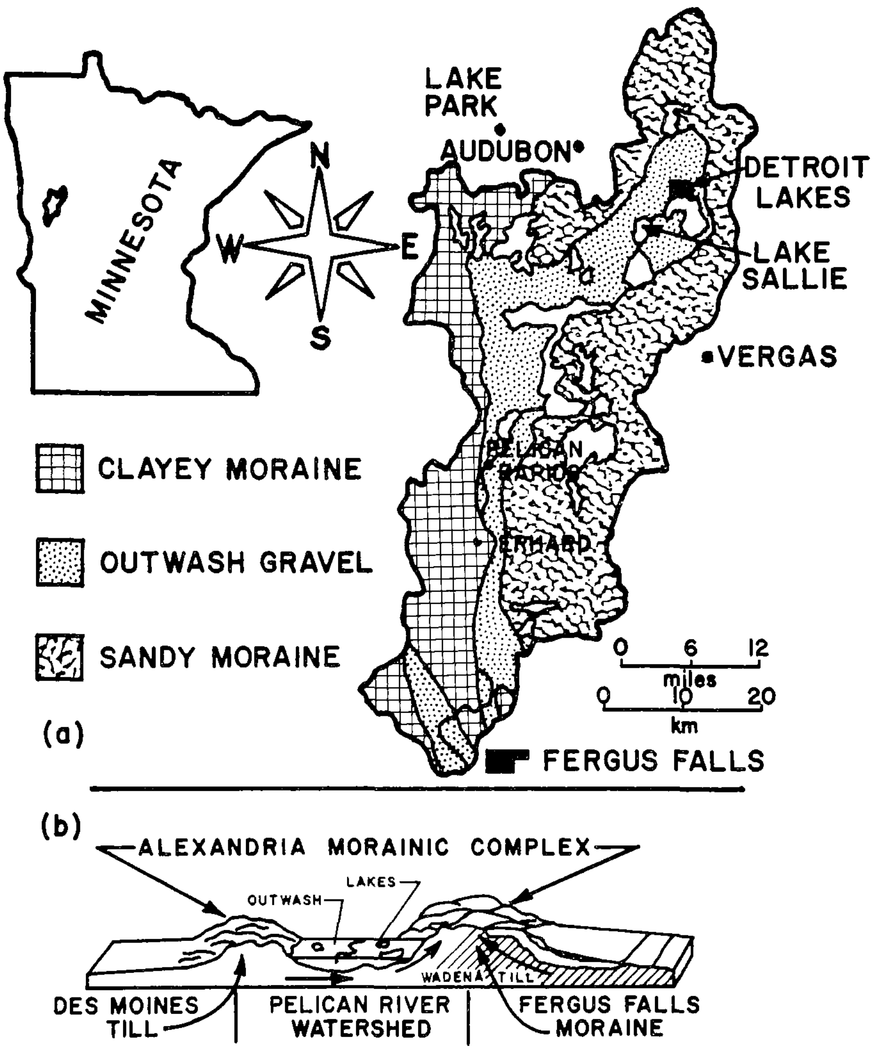

FIGURE 3. GLACIAL DEPOSITS IN THE PELICAN RIVER WATERSHED (A) TOPOGRAPHIC (B) CROSS-SECTIONAL. (REDRAWN FROM ALLISON, 1932)

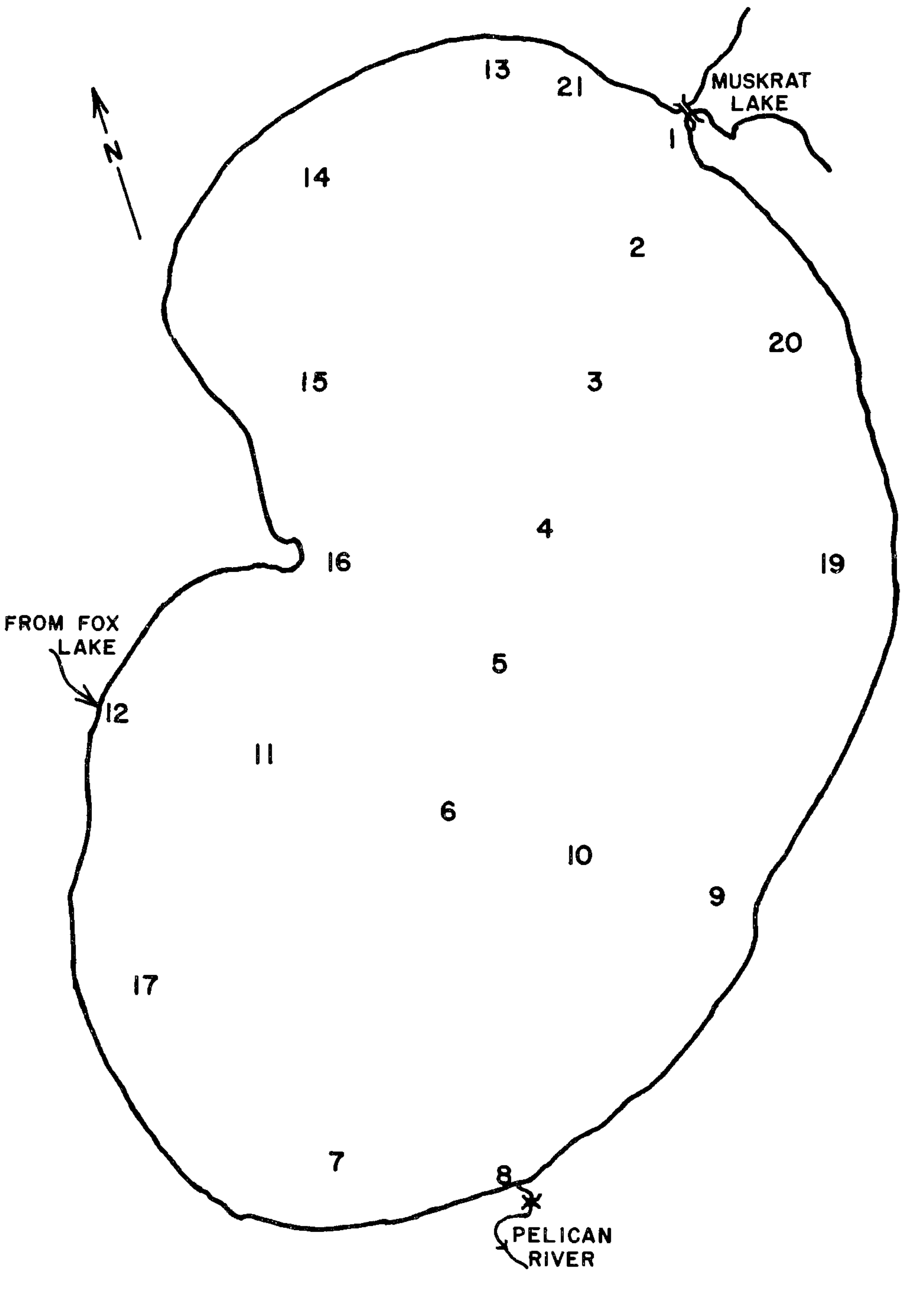

FIGURE 4. LAKE SALLIE SAMPLING STATIONS

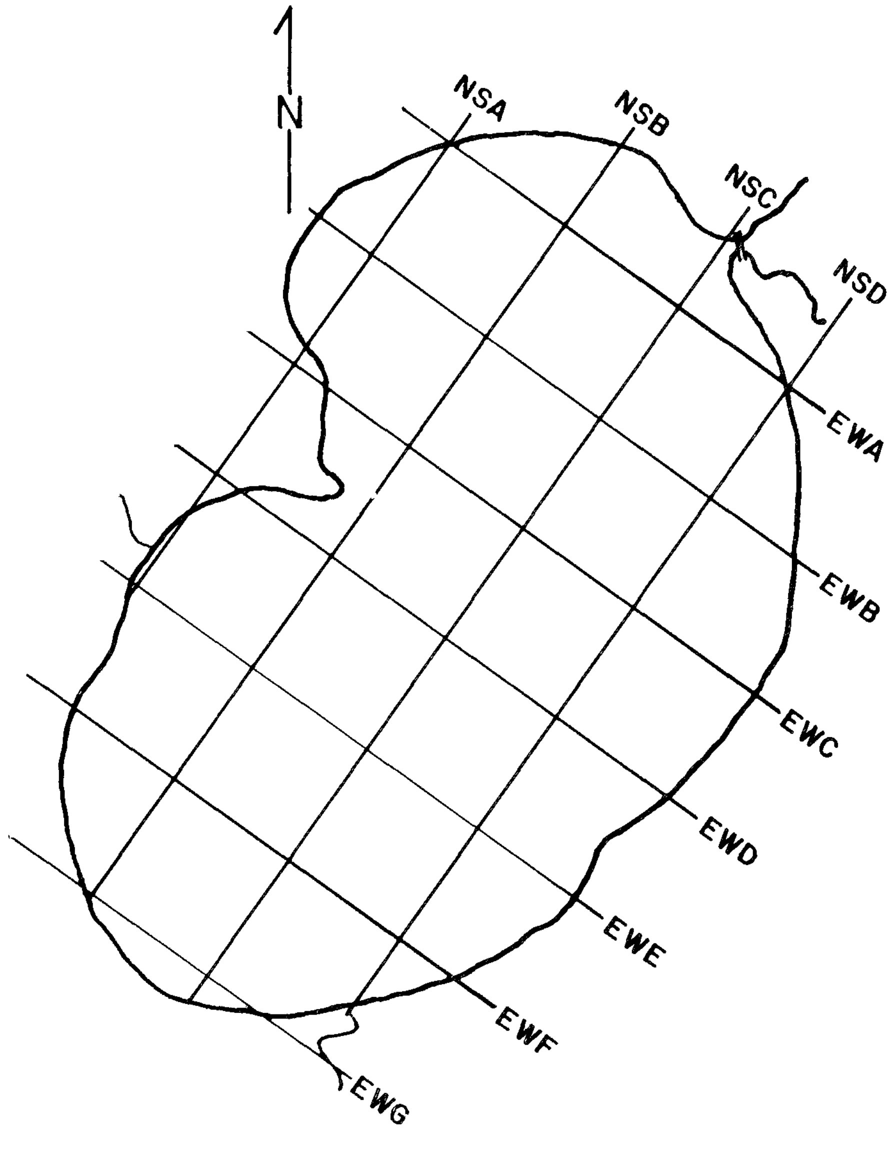

FIGURE 5. TRANSECTS FOR TOWING OXYGEN PROBE

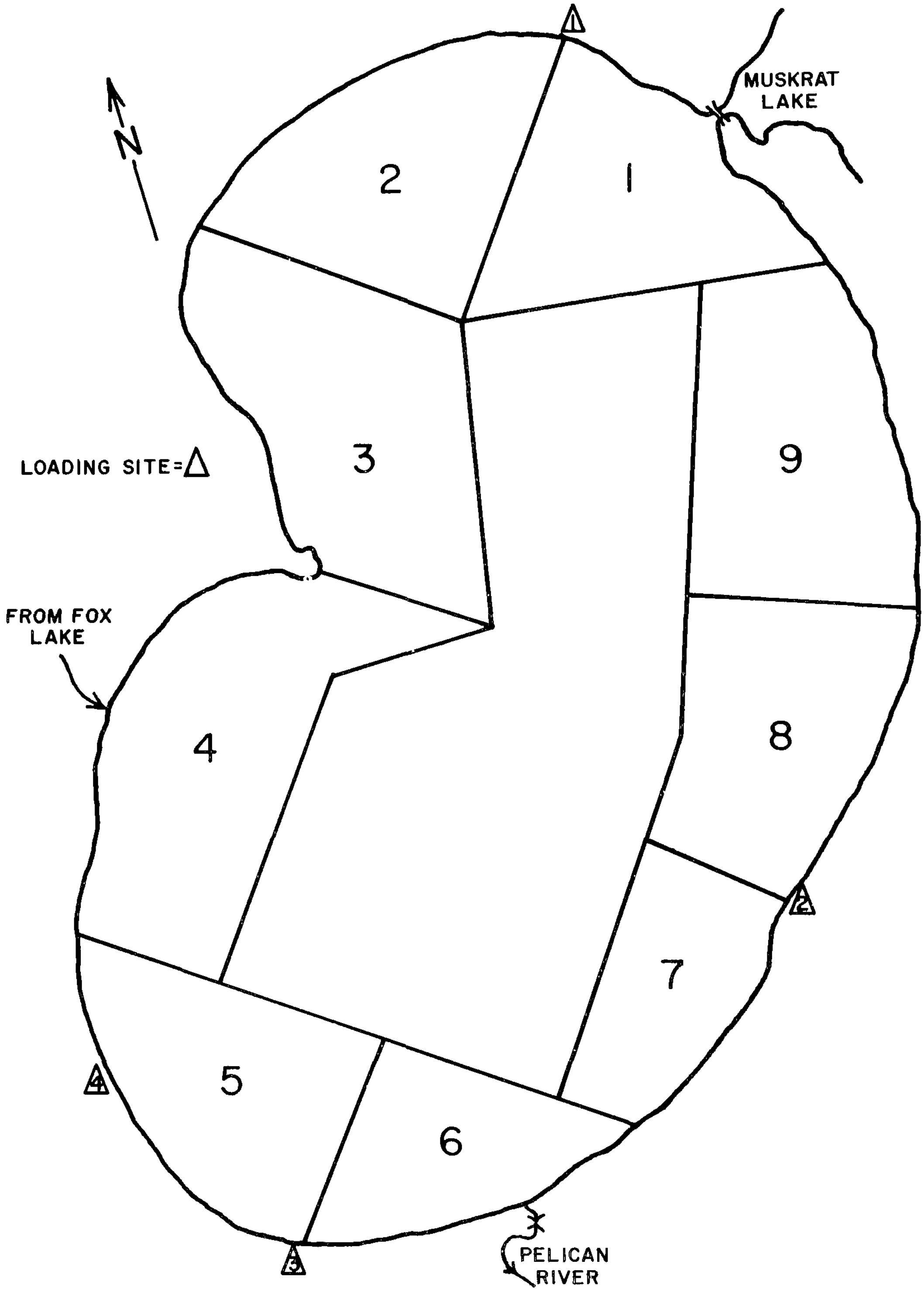

FIGURE 6. WEED HARVEST AREAS IN LAKE SALLIE

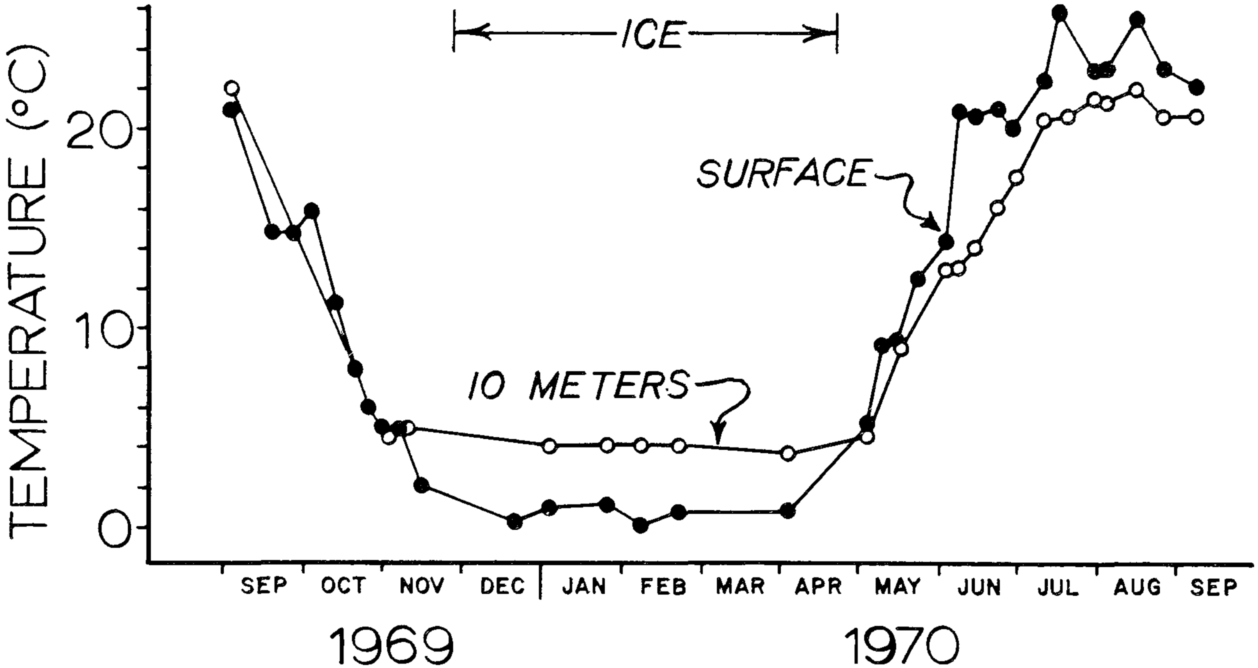

FIGURE 7. TEMPERATURE VARIATION AT SURFACE AND 10 METERS

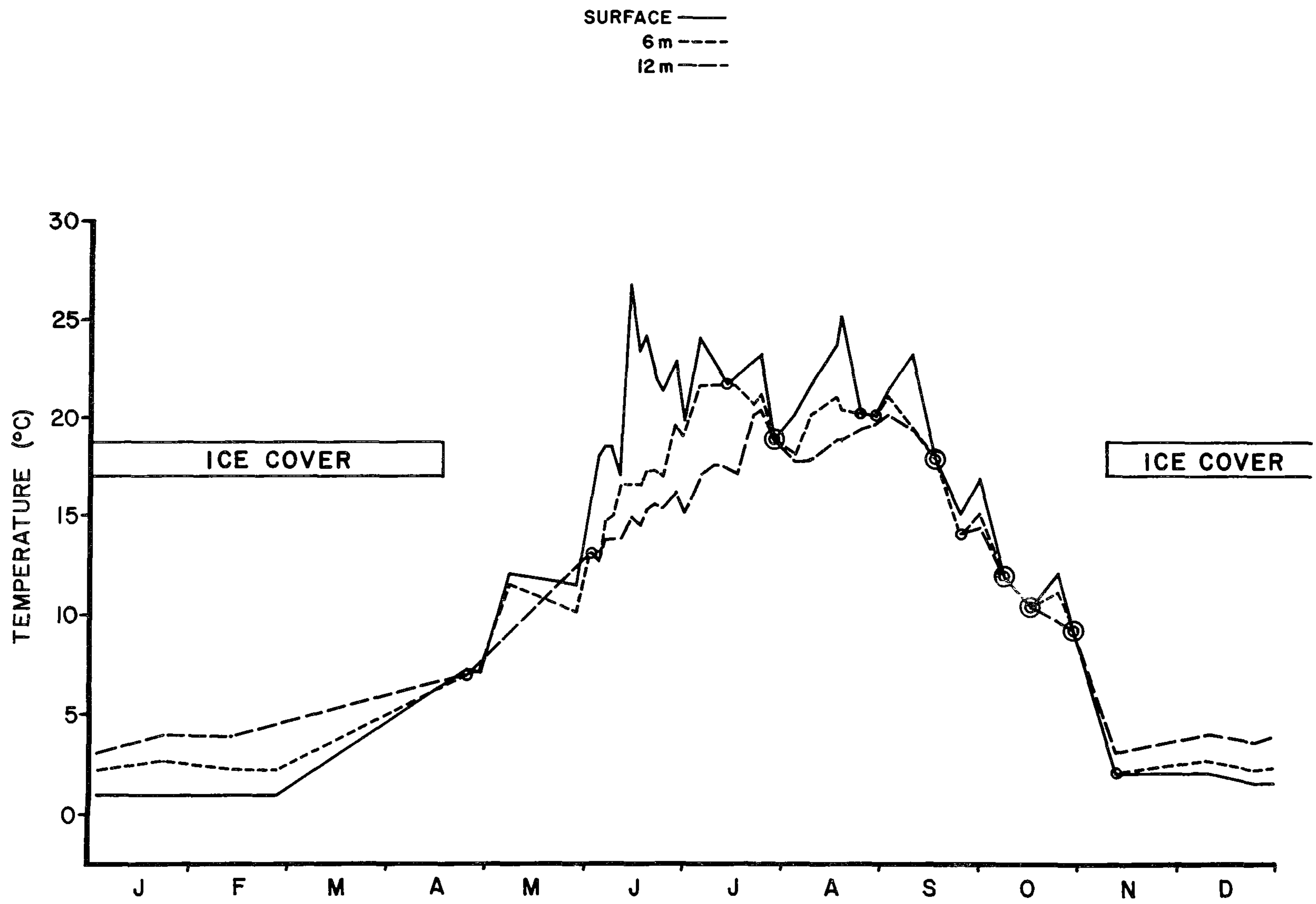

FIGURE 8. TEMPERATURE VARIATION WITH DEPTH, 1971

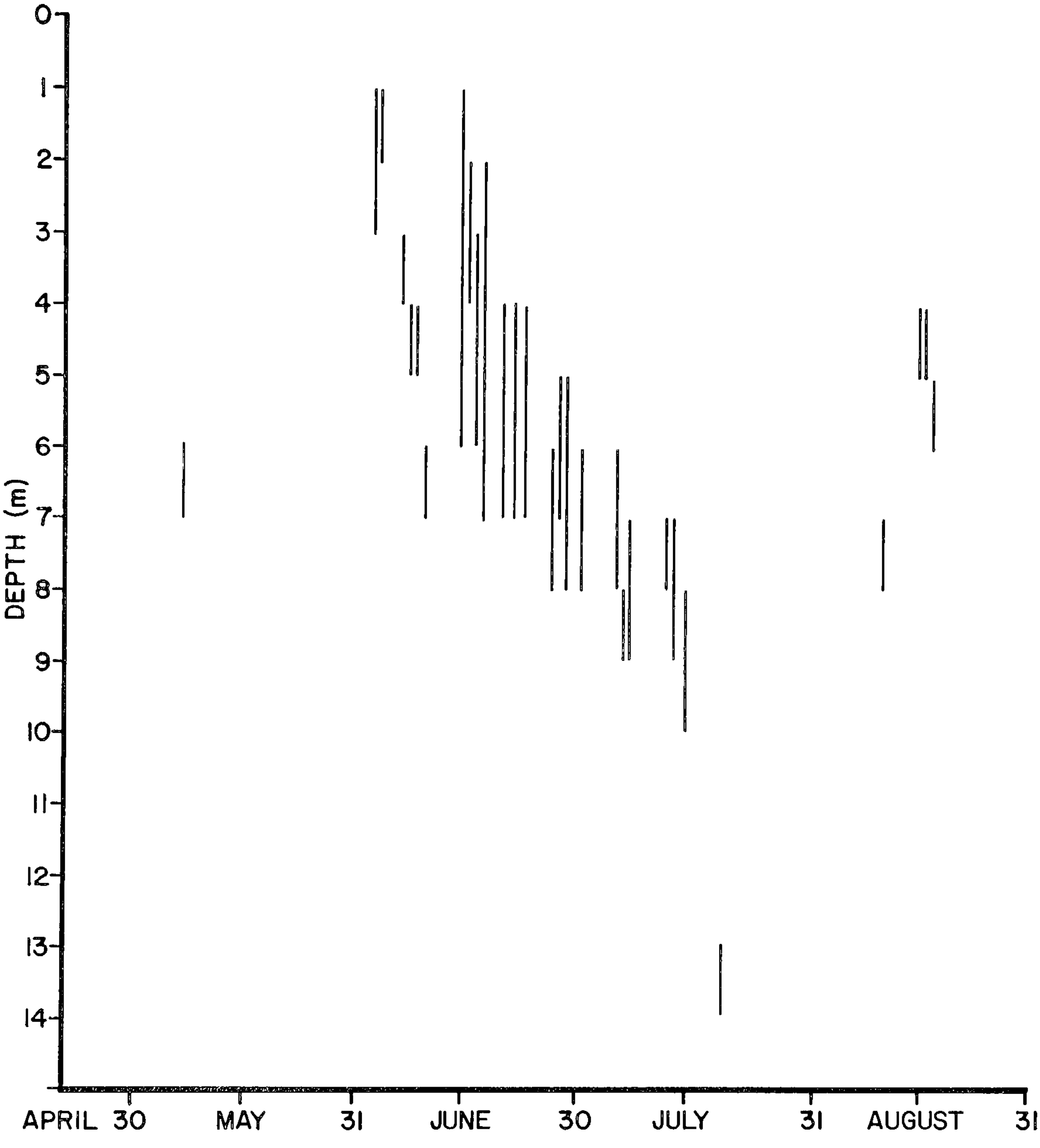

FIGURE 9. POSITION AND THICKNESS OF THERMOCLINE DURING OPEN WATER SEASON, 1971, IN LAKE SALLIE

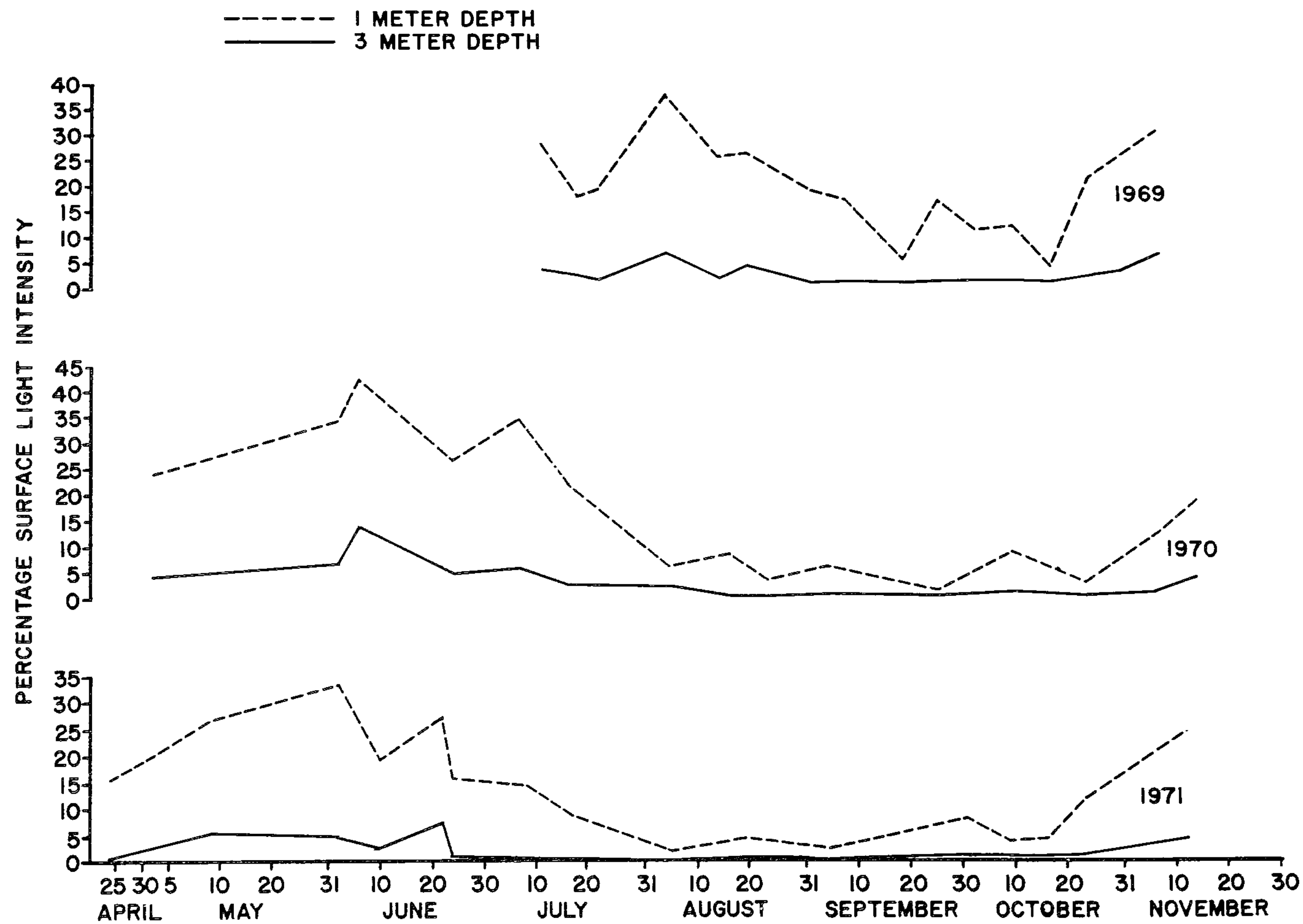

FIGURE 10. ANNUAL VARIATION IN LIGHT INTENSITY AT 1 AND 3 M.

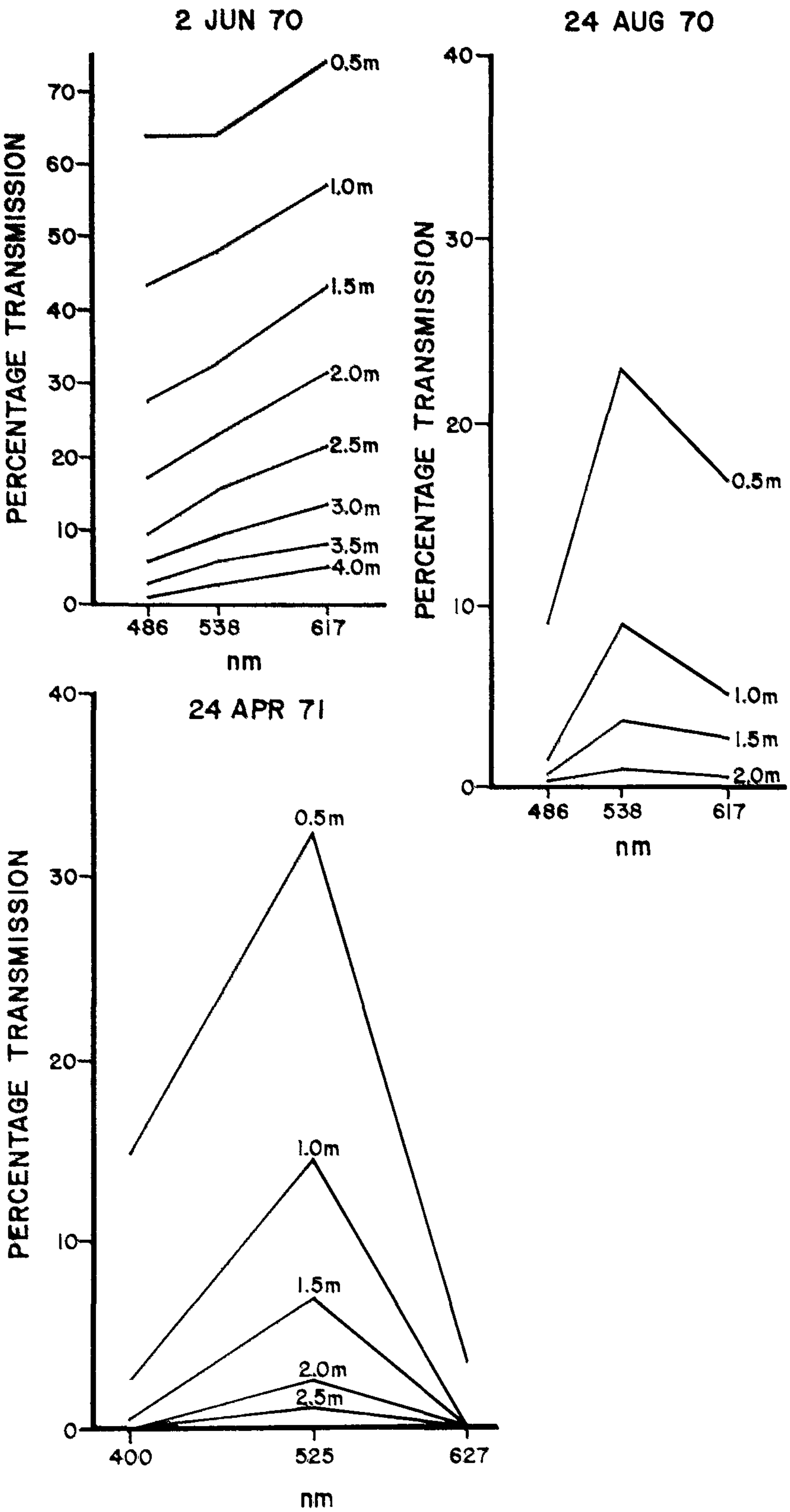

FIGURE 11. SEASONAL CHANGES IN WAVE LENGTH PENETRATION

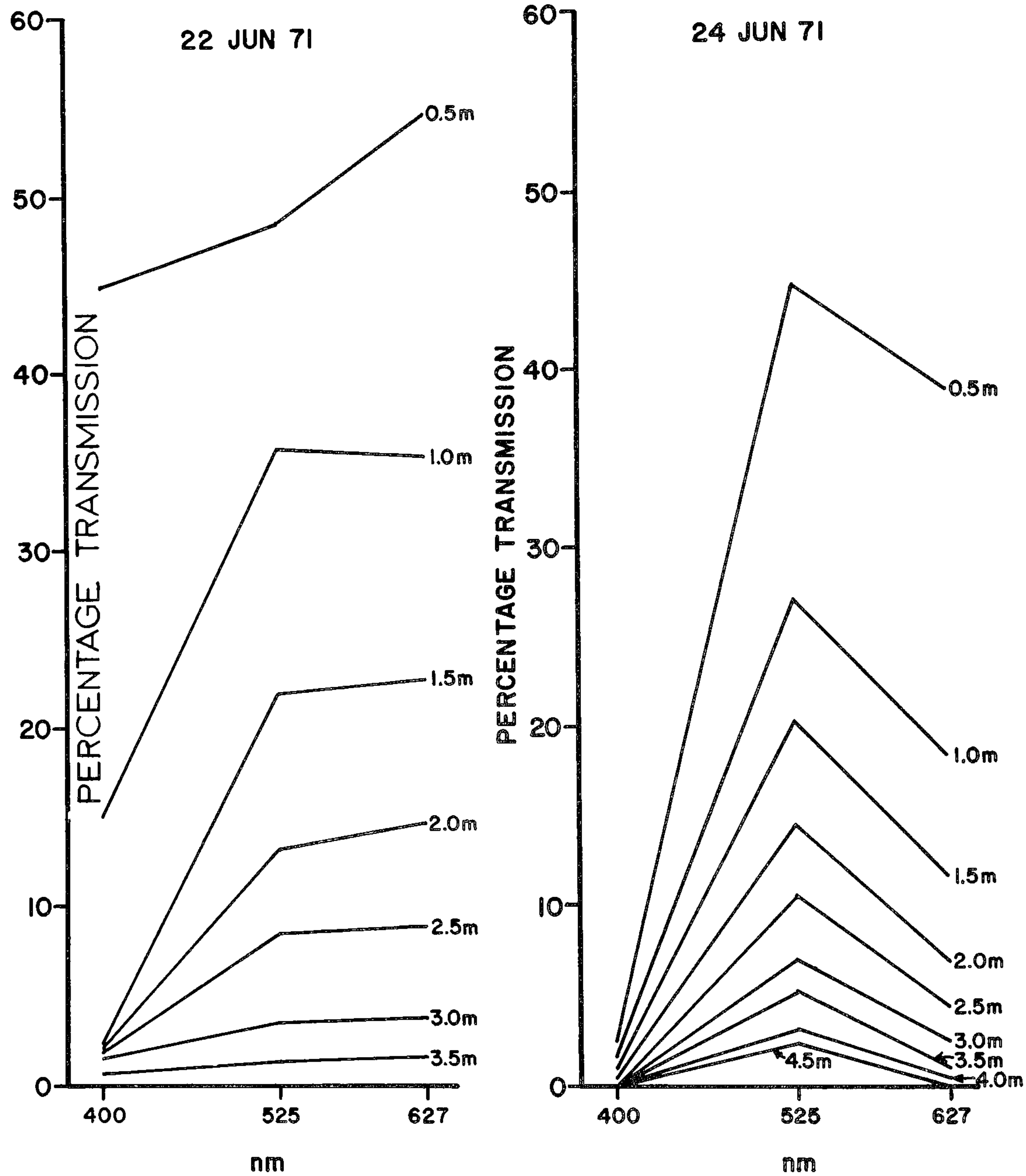

FIGURE 11. CONTINUED

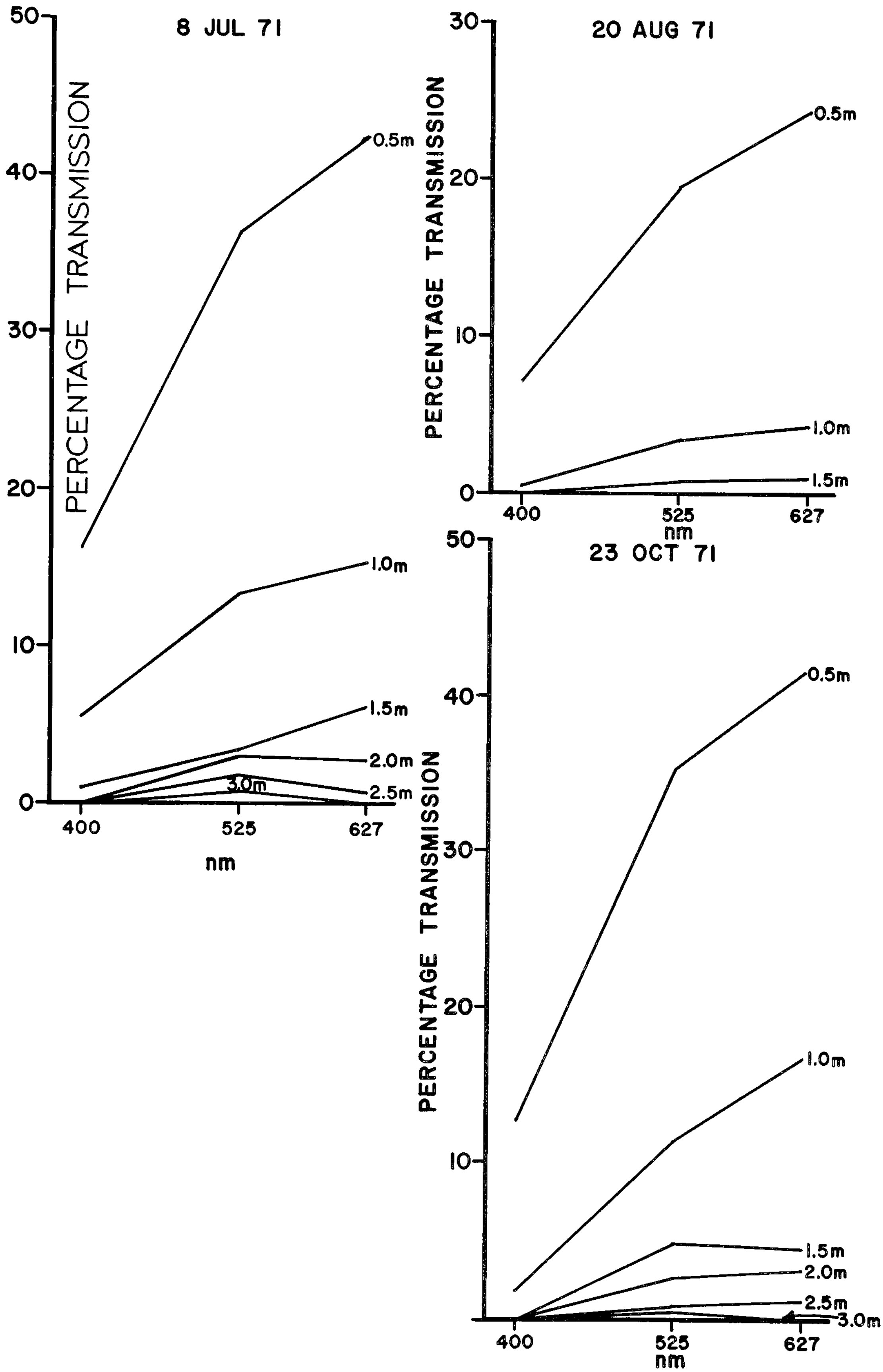

FIGURE 11. CONTINUED

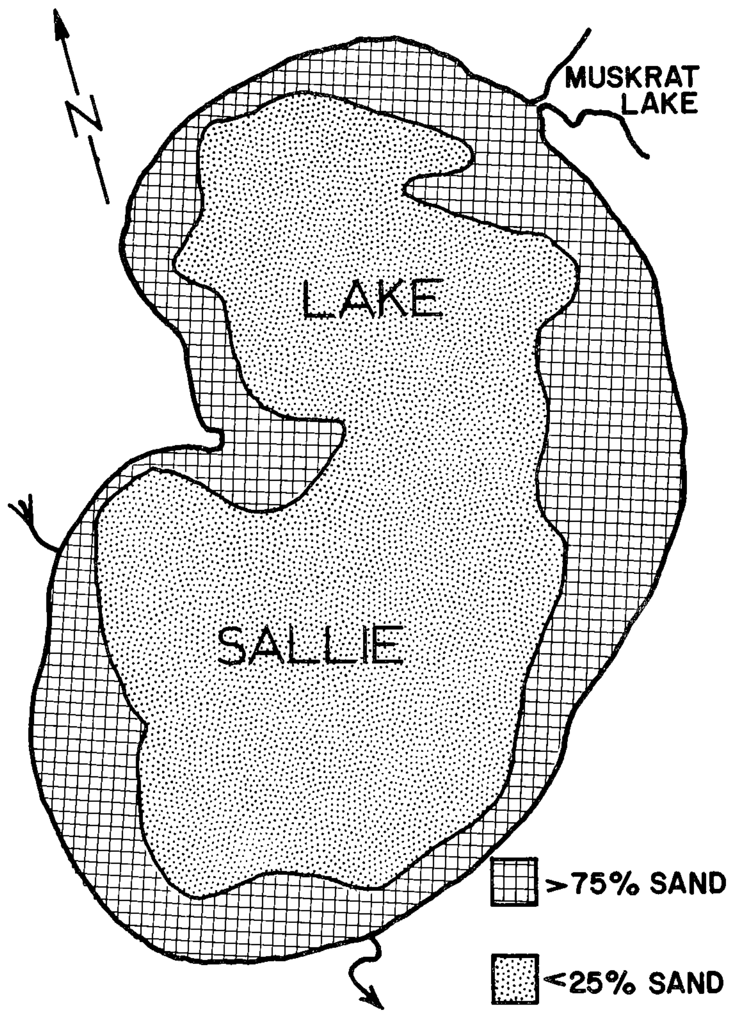

FIGURE 12. DISTRIBUTION OF SAND IN LAKE SALLIE SEDIMENTS

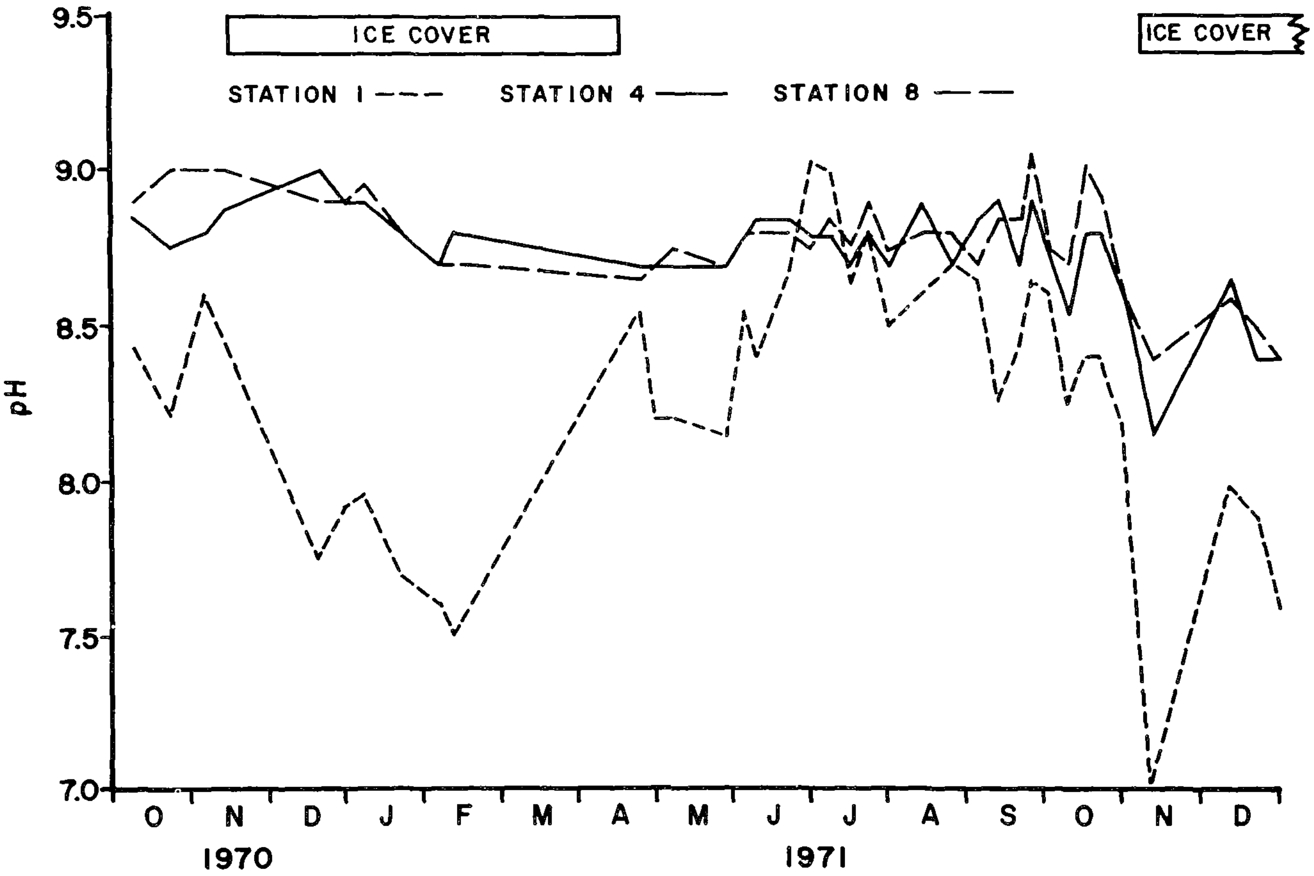

FIGURE 13. VARIATION IN SURFACE WATER pH AT 3 LAKE SALLIE SITES

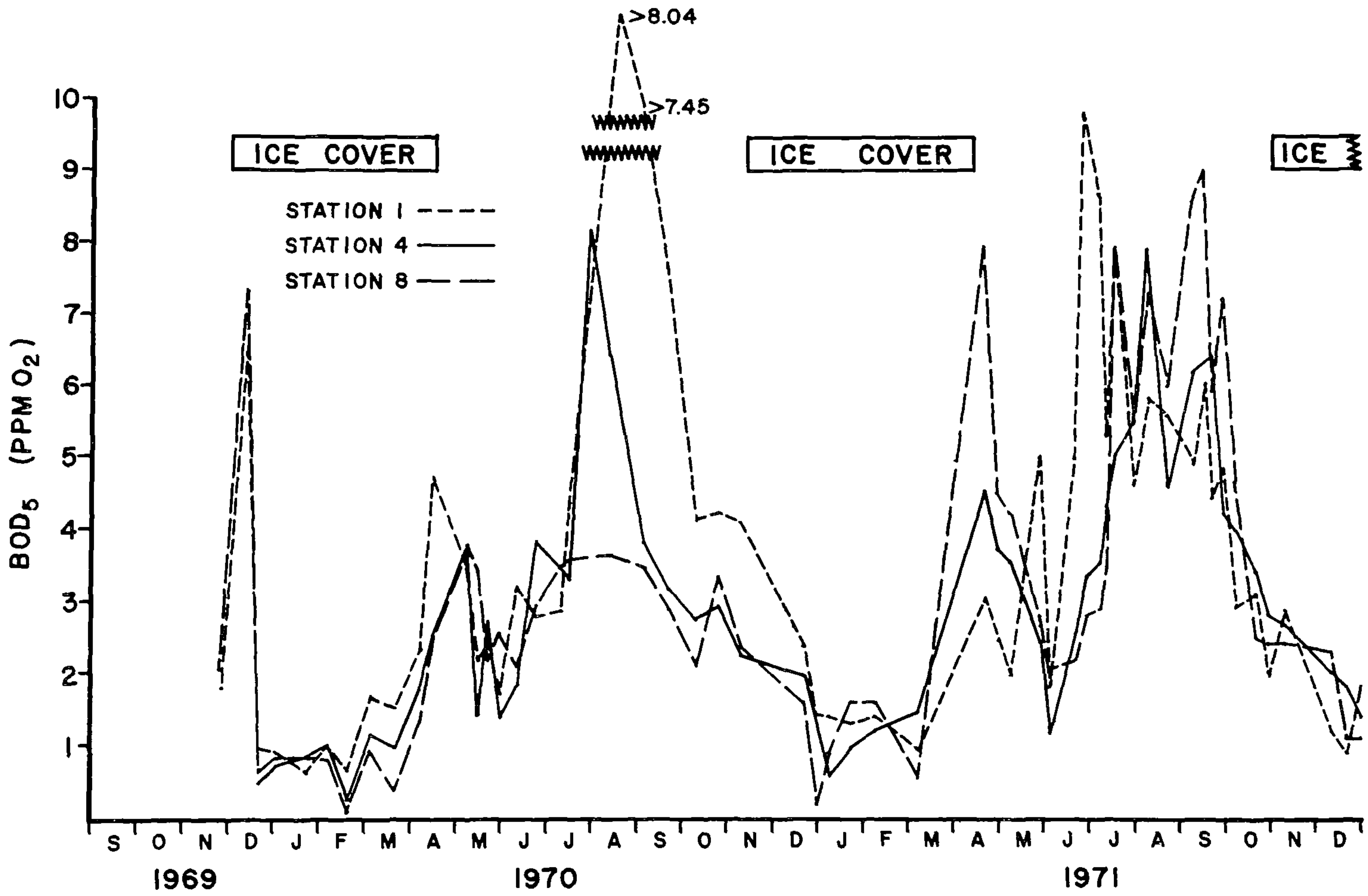

FIGURE 14. BOD VARIATION AT 3 LAKE SALLIE STATIONS

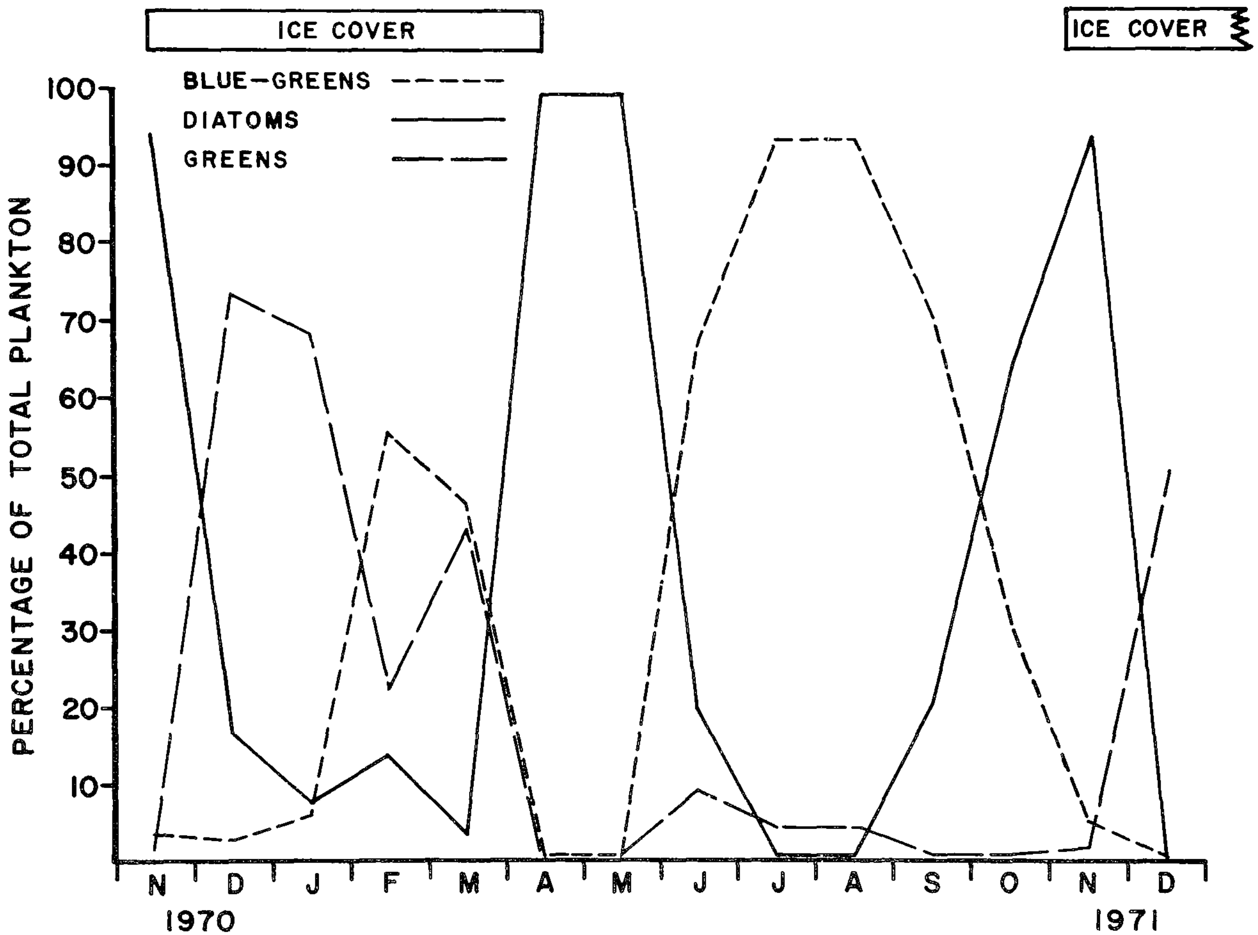

FIGURE 15. MEAN MONTHLY PERCENTAGES OF MAJOR PHYTOPLANKTON GROUPS IN SURFACE WATER, STATION 4

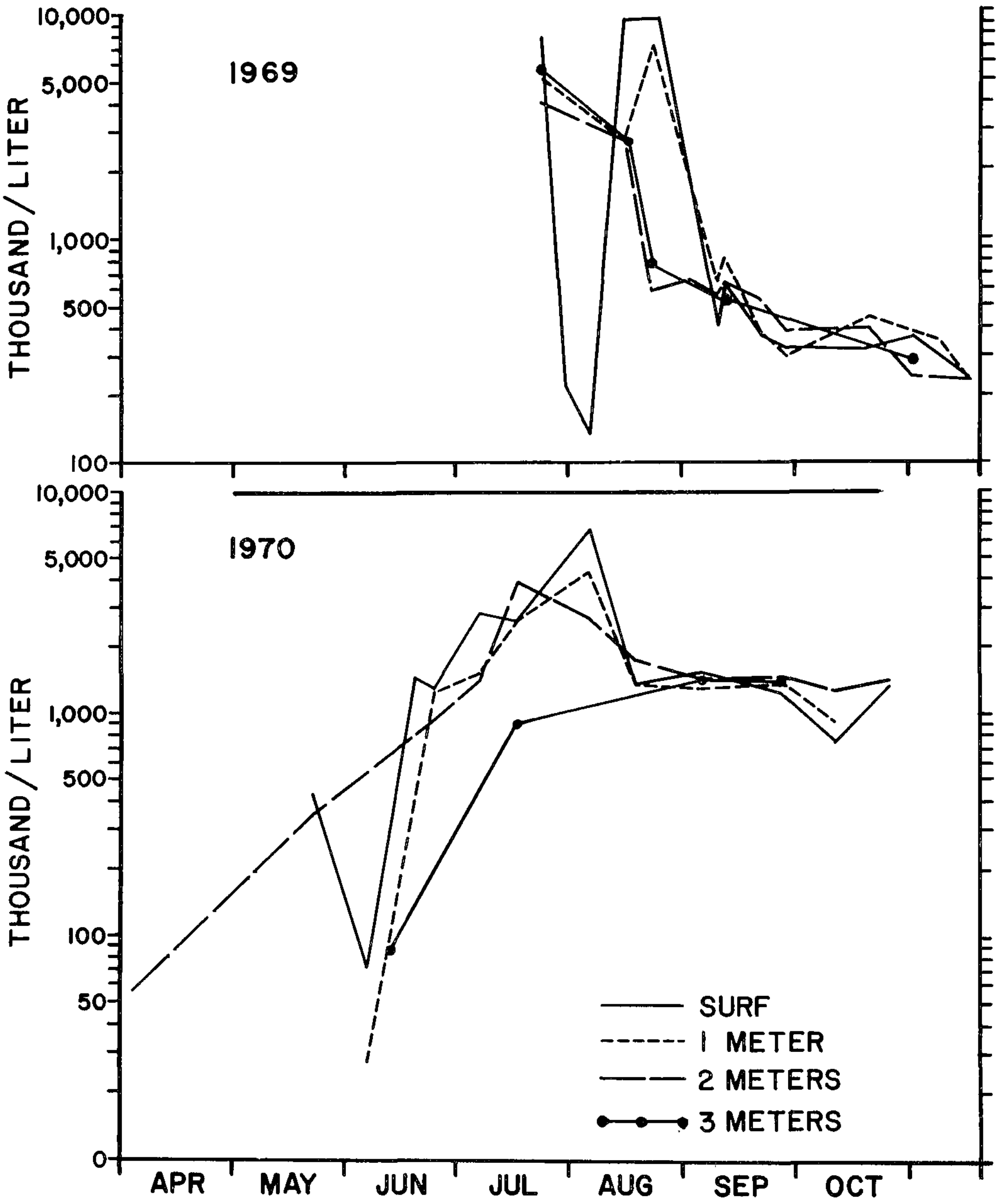

FIGURE 16. VARIATION IN LIMNETIC PHYTOPLANKTON CONCENTRATION AT DIFFERENT DEPTHS

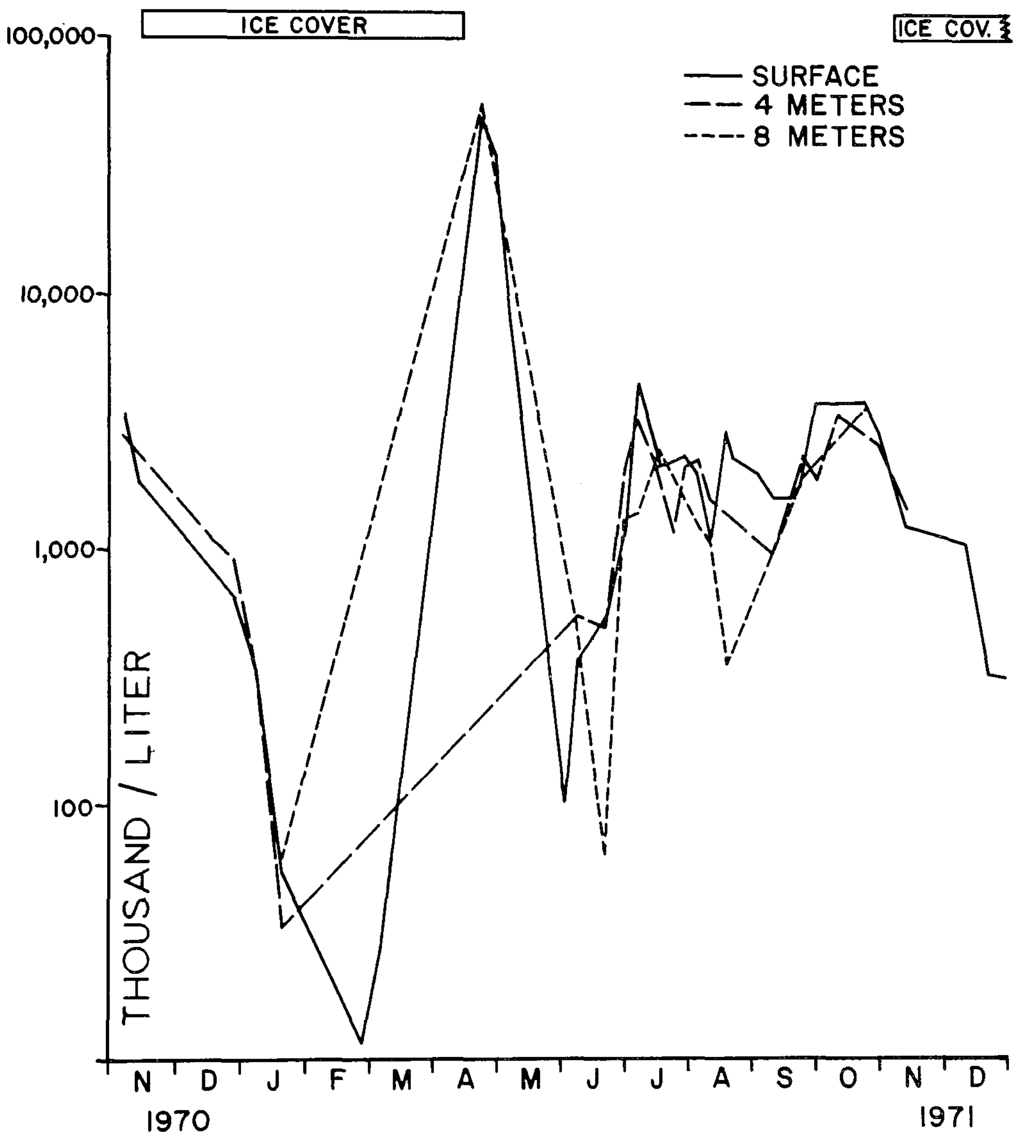

FIGURE 16. CONTINUED

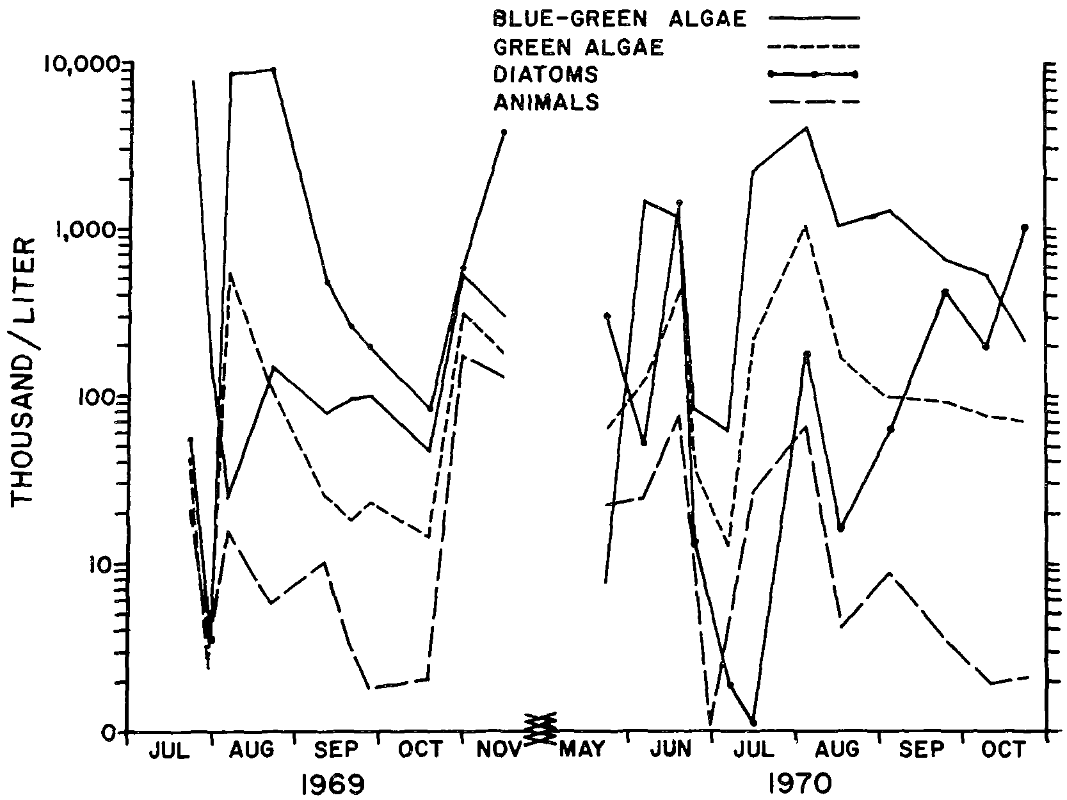

FIGURE 17. VARIATION IN CONCENTRATION OF MAJOR PLANKTON GROUPS IN SURFACE WATER

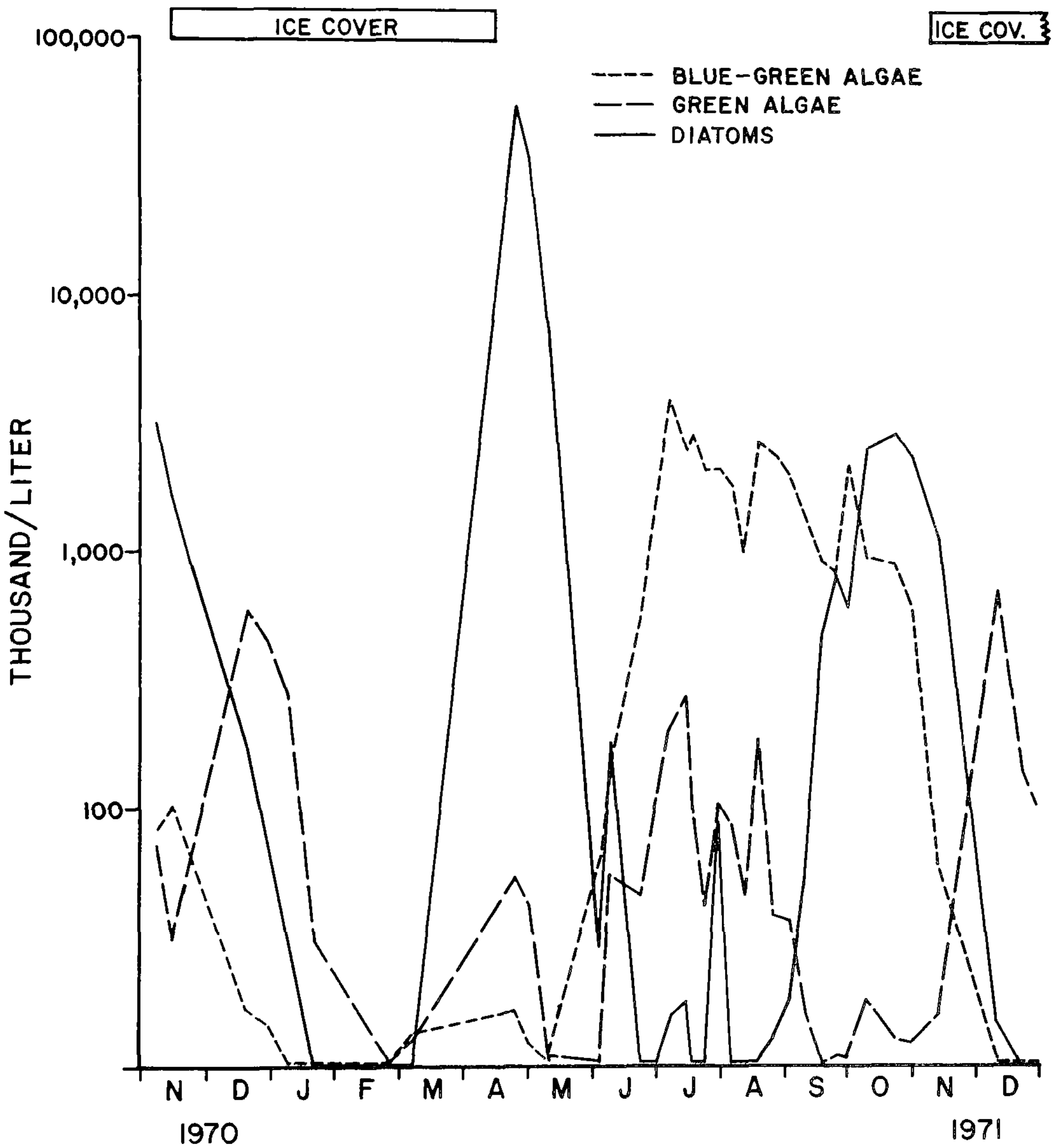

FIGURE 18. SEASONAL SUCCESSION IN CONCENTRATION OF MAJOR PHYTOPLANKTON GROUPS IN SURFACE WATER AT STATION 4.

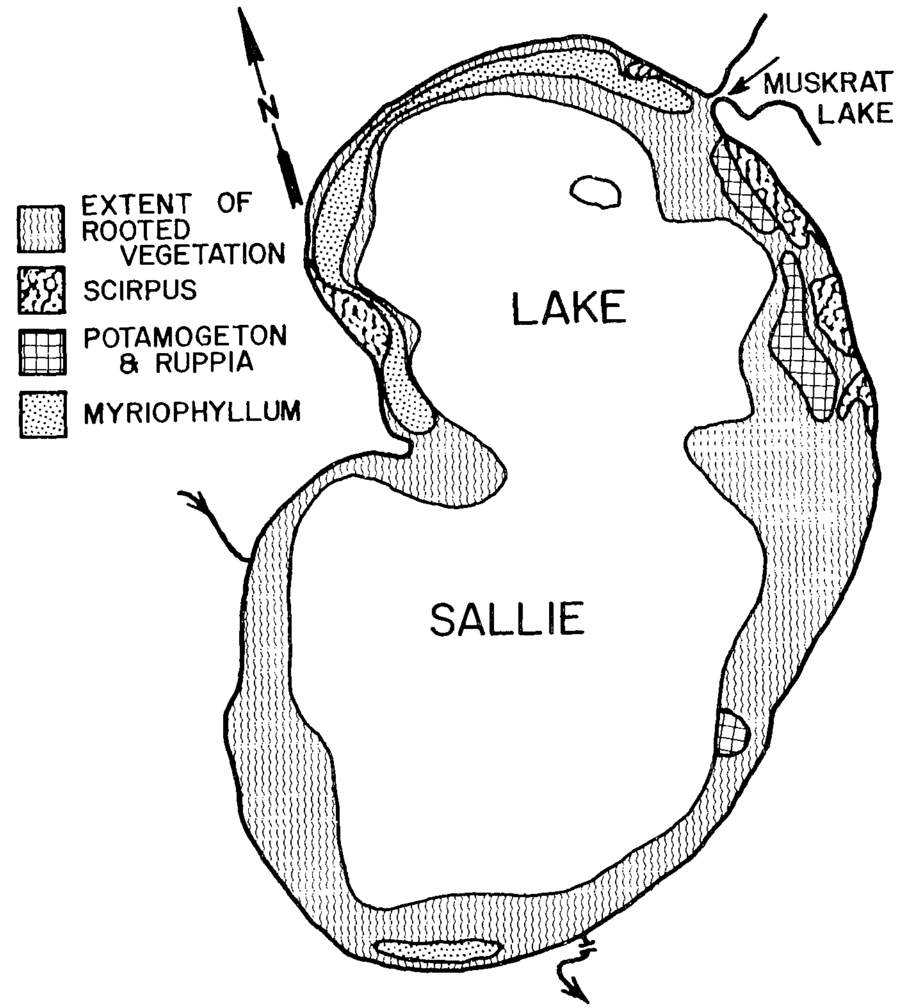

FIGURE 19. AREAS WITH ROOTED VEGETATION

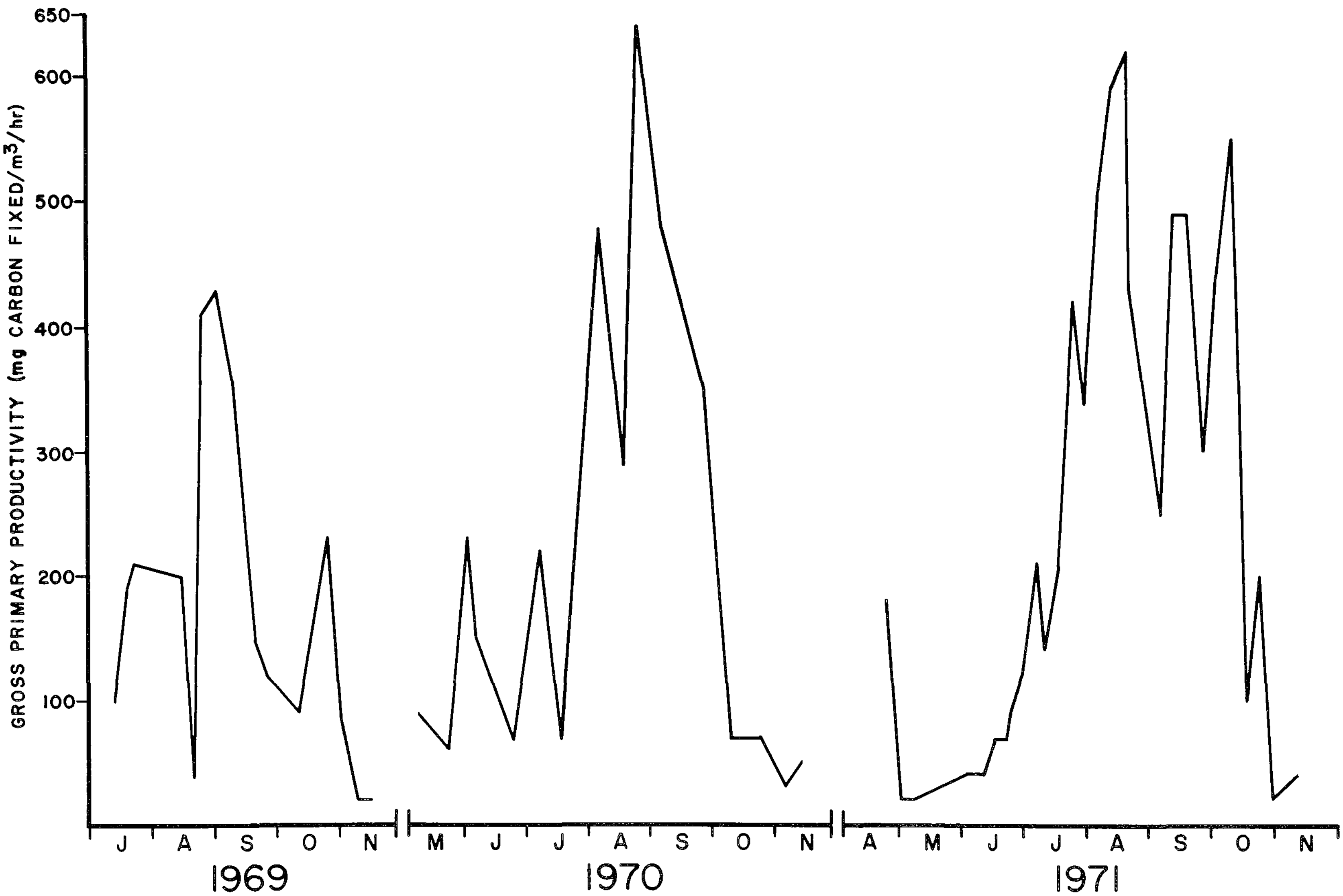

FIGURE 20. GROSS PRIMARY PRODUCTION IN LIMNETIC SURFACE WATER (STATION 4)

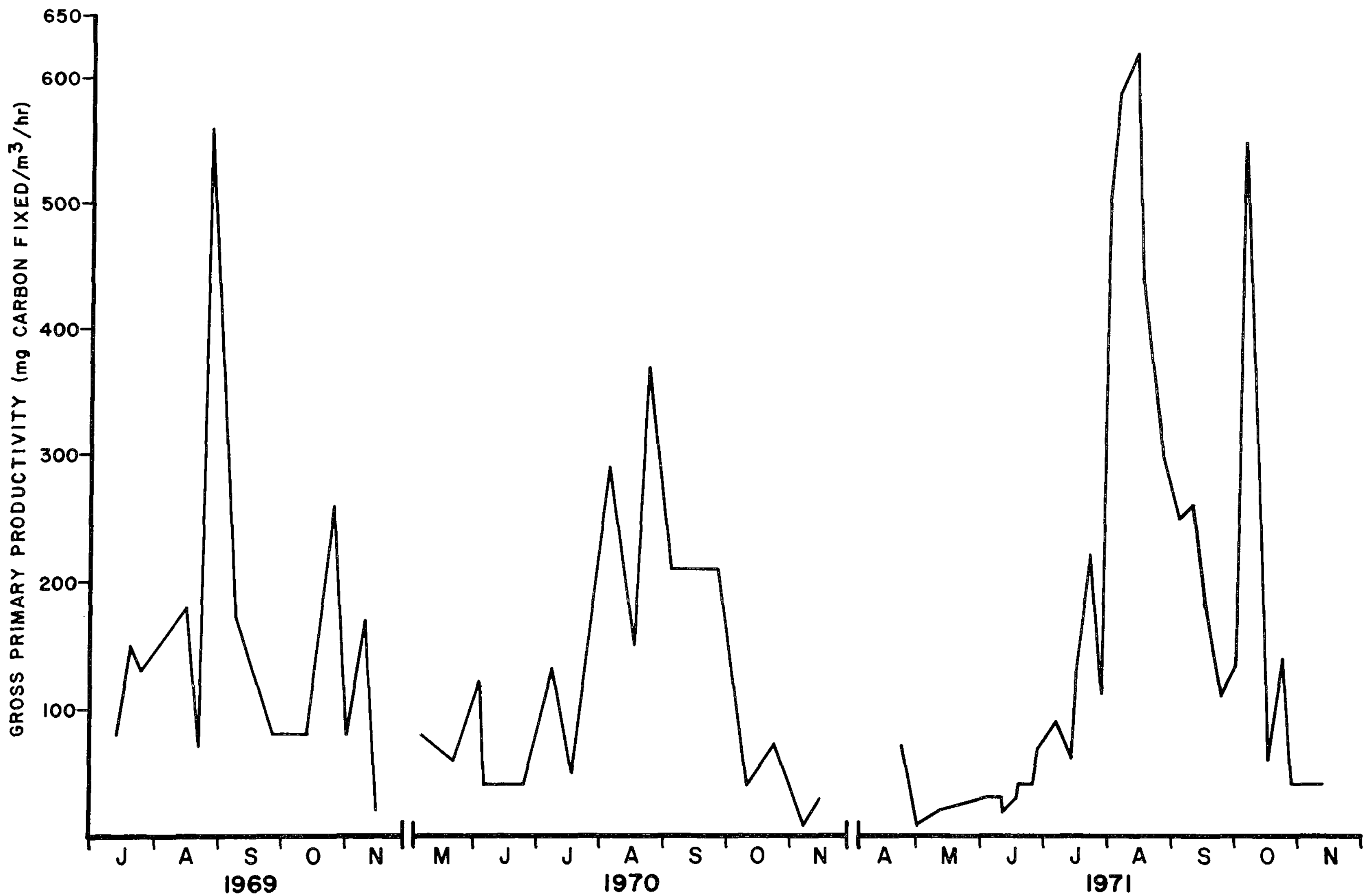

FIGURE 21. AVERAGE GROSS PRIMARY PRODUCTION IN THE LIMNETIC PHOTIC ZONE (STATION 4)

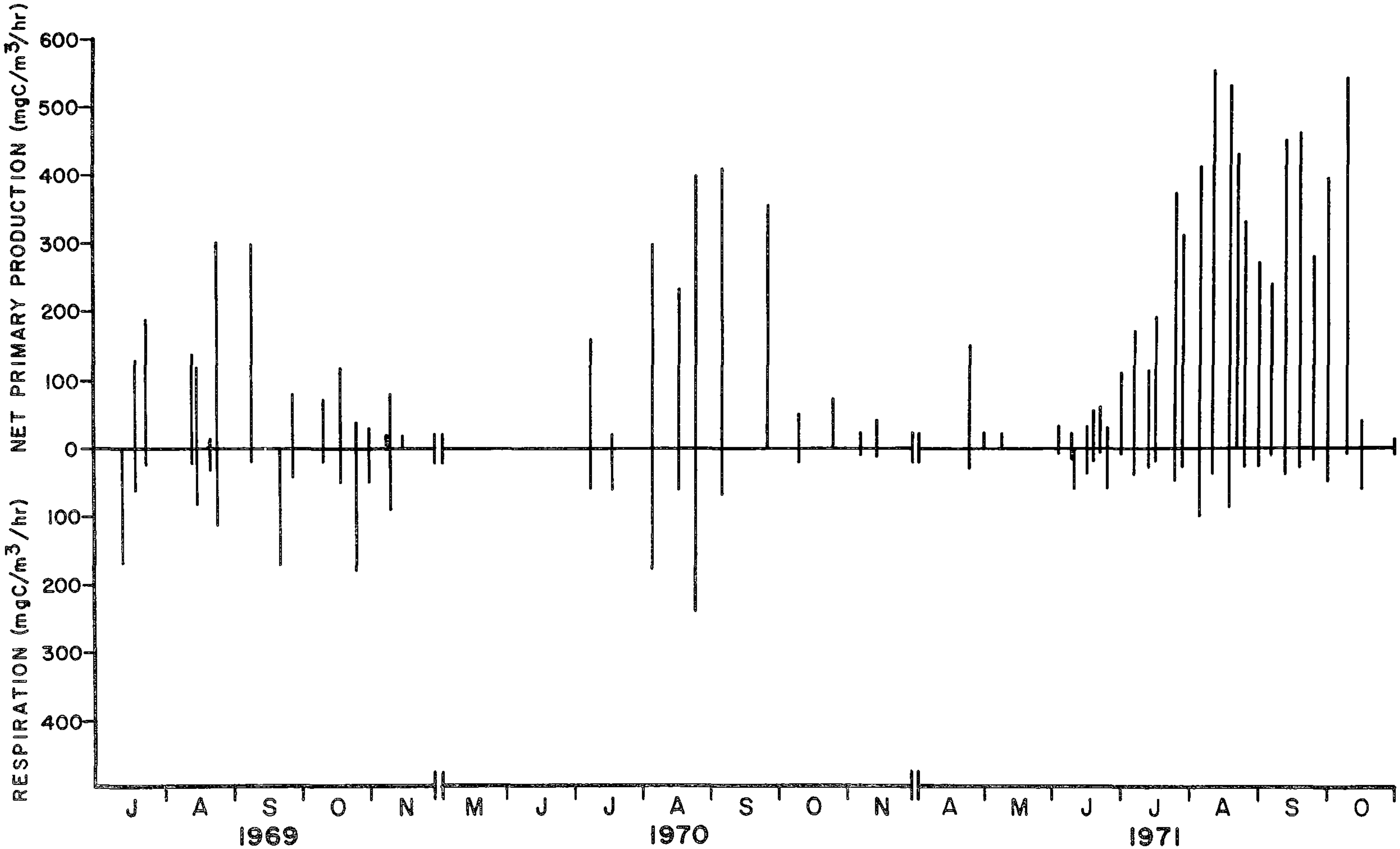

FIGURE 22. NET PRIMARY PRODUCTION AND RESPIRATION RATES IN SURFACE WATER AT STATION 4

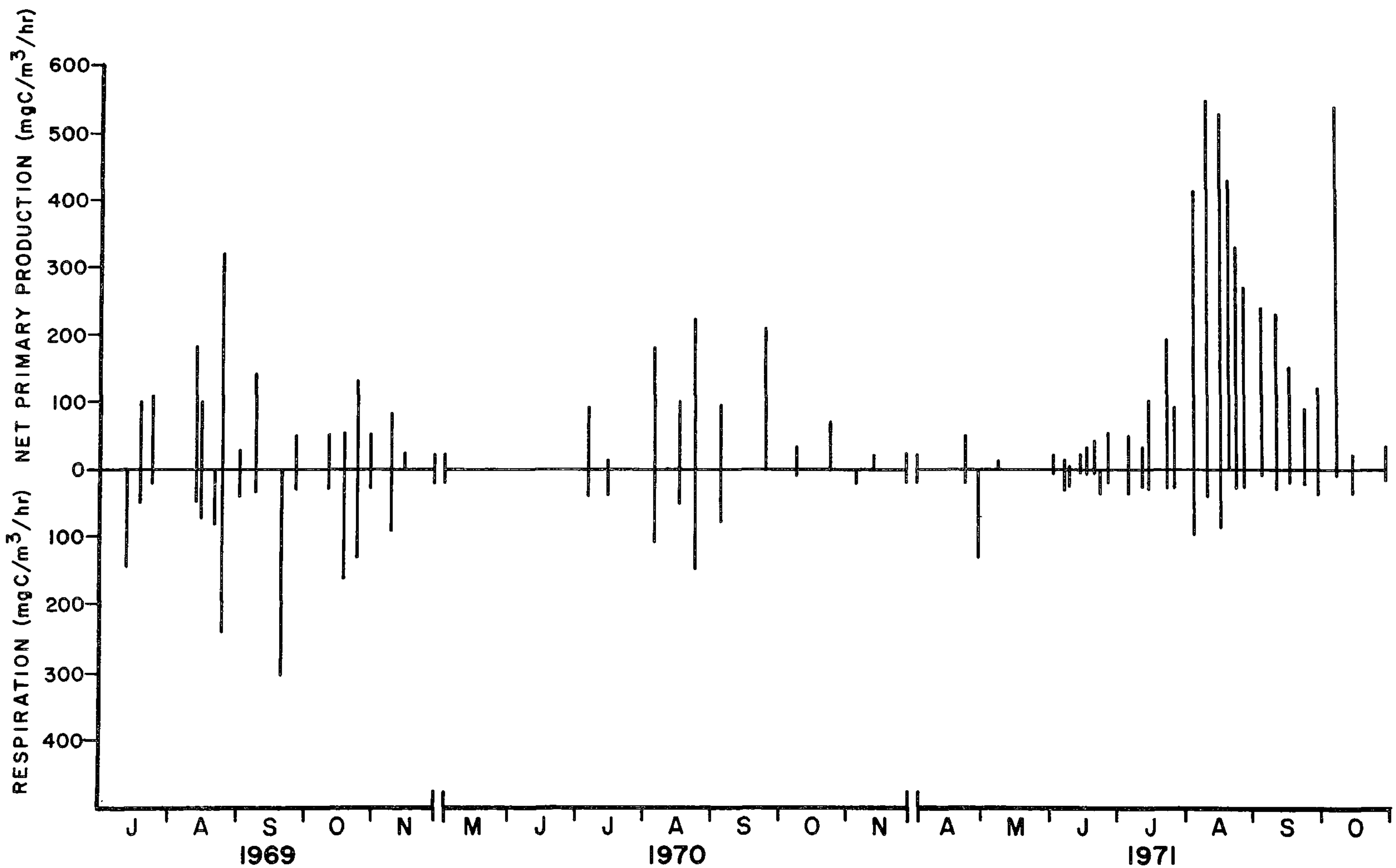

FIGURE 23. NET PRIMARY PRODUCTION AND RESPIRATION RATES WITHIN THE PHOTIC ZONE AT STATION 4

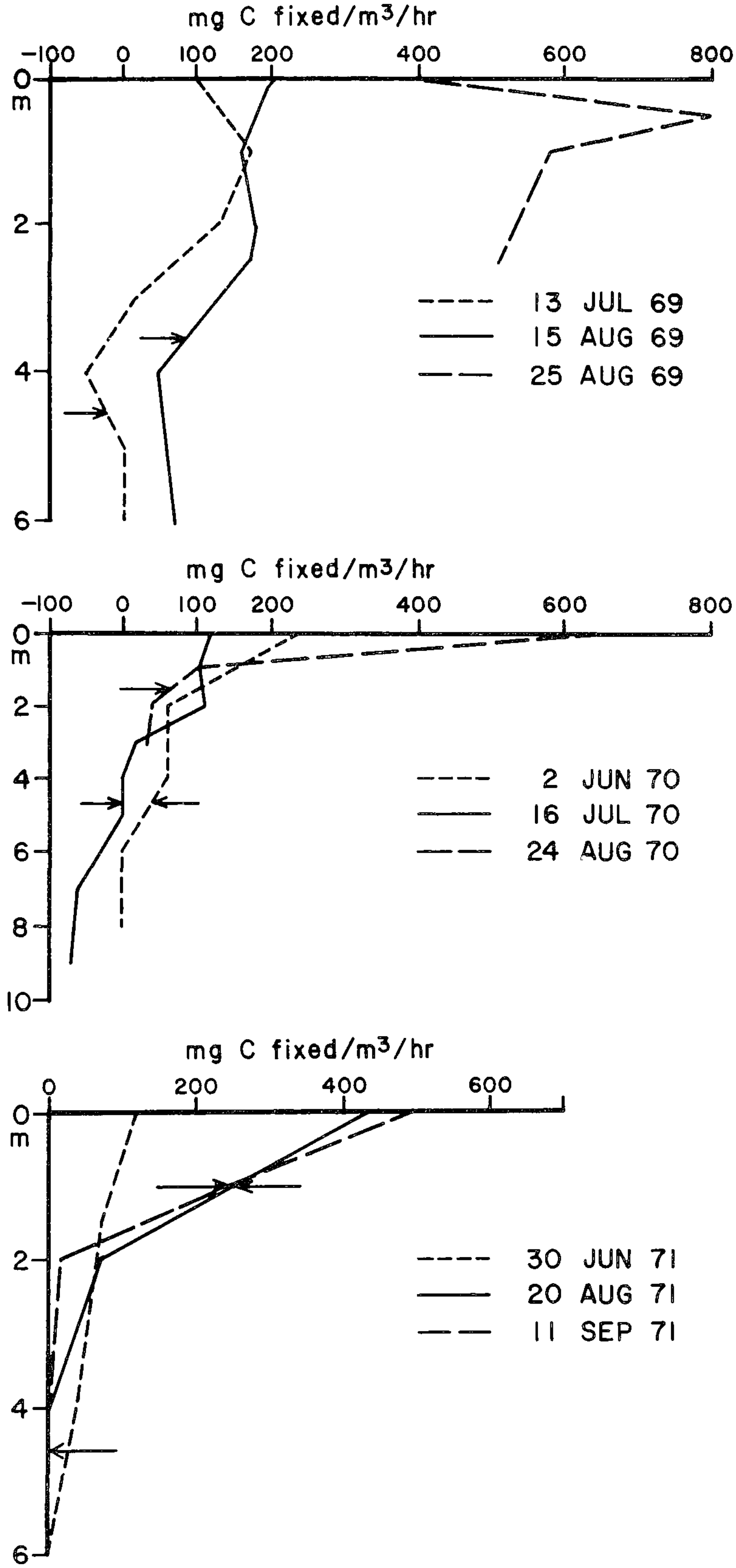

FIGURE 24. VERTICAL VARIATION IN GROSS PRIMARY PRODUCTION ON SELECTED DATES AT STATION 4

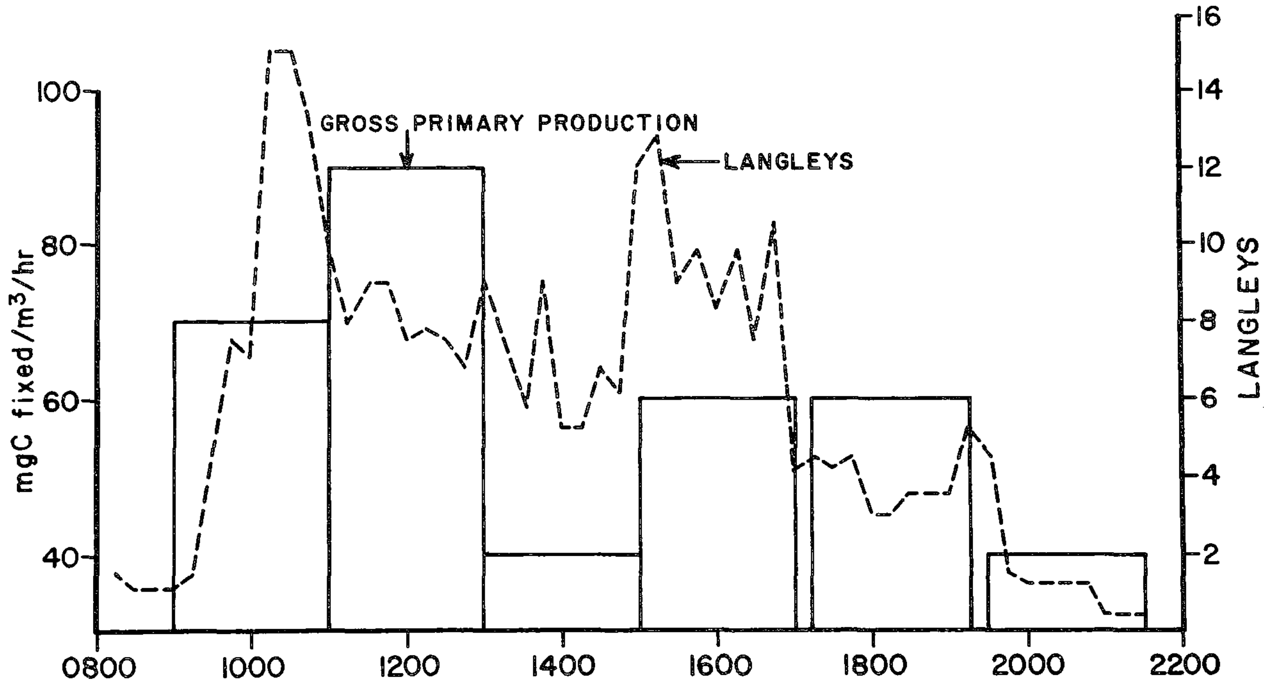

FIGURE 25. VARIATION IN INCIDENT SOLAR RADIATION (LANGLEYS) AND HOURLY CHANGE IN PRIMARY PRODUCTION RATE AT STATION 4, JUNE 24, 1971

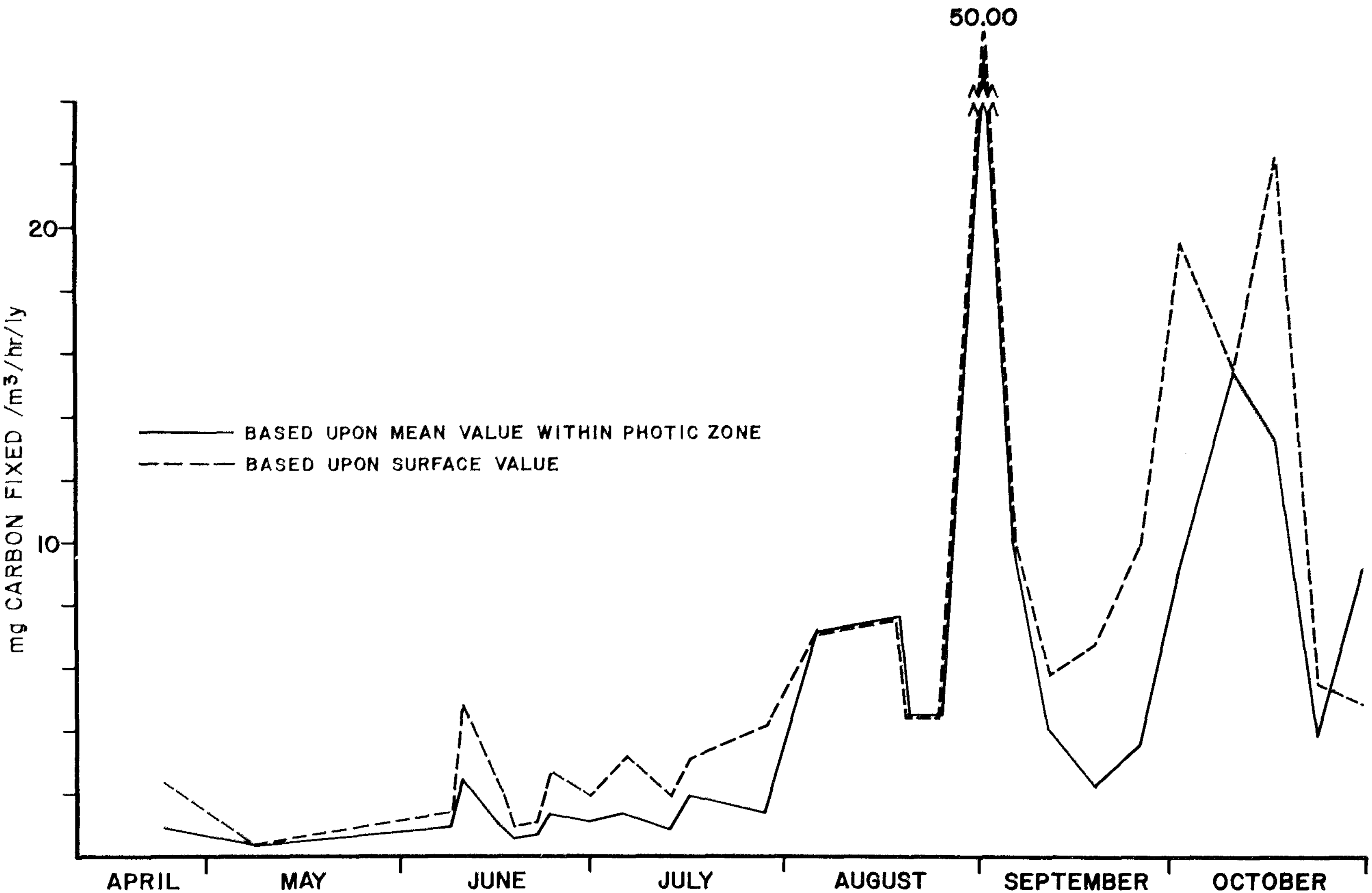

FIGURE 26. PHOTOSYNTHETIC EFFICIENCY AT STATION 4 DURING 1971

TABLES

TABLE 1

MEAN TEMPERATURE AND PRECIPITATION RECORDED
AT DETROIT LAKES, MINNESOTA

	1946-1960[a]		1969[b]		1970[b]		1971[b]		1969-1971	
Month	Mean Temp. (°C)	Mean Precip. (cm)	Mean Temp. (°C)	Precip. (cm)	Mean Temp. (°C)	Precip. (cm)	Mean Temp. (°C)	Precip. (cm)	Mean Temp. (°C)	Precip. (cm)
January	-15.1	1.80	-18.3	4.17	-16.5	0.41	-18.7	1.88	-17.8	2.15
February	-12.9	1.73	-10.5	2.01	-13.7	0.66	-11.9	2.34	-12.0	1.67
March	- 5.5	2.51	- 8.8	0.30	- 8.7	2.34	- 6.3	1.83	- 7.9	1.49
April	4.5	5.13	8.1	2.74	3.8	7.29	6.9	2.13	6.3	4.05
May	12.2	7.59	12.4	5.61	11.2	4.63	10.8	4.01	11.5	4.75
June	17.7	9.63	13.6	-	18.6	13.72	18.5	13.44	16.9	13.58
July	21.2	9.09	19.1	11.10	20.8	3.94	17.5	11.48	19.1	8.84
August	19.7	9.53	21.1	2.11	19.2	0.69	18.1	6.96	19.5	3.25
September	13.9	4.98	14.1	5.97	14.3	6.88	14.2	17.07	14.2	9.97
October	7.4	3.48	9.5	7.42	6.6	5.92	8.6	11.43	8.2	8.26
November	3.1	2.49	- 1.7	4.53	3.7	1.07	- 2.2	3.05	- 0.1	2.27
December	-11.2	1.80	- 8.9	2.69	-12.4	1.98	-11.1	0.64	-10.8	1.77
Total		59.76		51.34		49.53		66.22		62.05

[a]Modified from D. C. Reedstrom and R. A. Carlson, 1969, A biological survey of the Pelican River watershed, Becker, Clay, and Ottertail Counties, Minn. Dept. Conserv. Special Publ. No. 65.

[b]U.S. Dept. of Commerce, Climatological data.

TABLE 2

VERTICAL VARIATION IN WATER CHEMISTRY AT STATION 4, LAKE SALLIE, MINNESOTA (Concentrations, except pH, in ppm)

Date	Depth (m)	pH	CO_3 Alk.	HCO_3 Alk.	Total Hardness	Ca++
1970						
10 October	0	8.85	40	126	166.6	58.8
	2	8.80	40	136	166.6	58.8
	5	8.80	40	136	166.6	58.8
	8	8.90	36	140	186.2	58.8
	11	8.90	40	138	176.4	58.8
23 October	0	8.75	32	142	186.2	68.6
	4	8.75	32	142	186.2	58.8
	8	8.75	32	142	186.2	58.8
	12	8.75	32	142	186.2	58.8
6 November	0	8.80	36	137	186.2	58.8
	3	8.80	34	140	176.4	58.8
	6	8.80	34	140	176.4	58.8
	9	8.80	34	138	176.4	58.8
13 November	0	8.85	40	134	186.2	58.8
	4	8.85	40	134	186.2	58.8
	8	8.85	40	134	186.2	58.8
19 December	0	9.00	44	142	196.0	58.8
	2	8.90	48	140	186.2	58.8
	4	8.90	48	140	186.2	58.8
	6	8.90	44	146	186.2	58.8
	8	8.60	24	178	196.0	68.6
	12	8.25	8	227	225.4	78.4
29 December	0	8.90	44	150	196.0	58.8
	4	8.90	44	146	196.0	58.8
	8	8.30	12	193	196.0	68.6
1971						
7 January	0	9.00	44	160	196.0	68.6
	2	8.90	40	154	186.2	58.8
	4	8.85	40	155	186.2	58.8

TABLE 2--Continued

Mg++	O_2	Ortho PO_4	Total PO_4	NH_3-N	NO_2-N	NO_3-N	Temp. °C
107.8	8.62	0.18	0.76	0.09	0.006	0.020	9.0
107.8	8.62	0.25	1.28	0.10	0.004	0.008	9.0
107.8	8.53	0.25	0.76	0.10	0.006	0.009	9.0
107.8	8.53	0.12	1.00	0.40	0.004	0.013	9.0
117.6	8.82	0.25	1.00	0.11	0.006	0.011	9.0
117.6	10.00	0.12	0.62	0.15	0.008	0.007	9.0
127.4	9.90	0.18	1.14	0.15	0.008	0.009	9.0
127.4	9.90	0.12	0.76	0.12	0.006	0.009	9.0
127.4	9.11	0.12	0.76	0.10	0.006	0.011	9.0
127.4	12.40	0.12	0.76	0.92	0.010	0.007	5.5
117.6	12.40	0.25	0.76	0.97	0.008	0.009	5.5
117.6	12.30	0.12	0.50	0.92	0.008	0.004	5.5
117.6	12.20	0.12	0.50	0.79	0.010	0.005	5.5
127.4	13.20	0	0.50	0.48	0.012	0	3.5
127.4	13.20	0.11	0.36	0.38	0.010	0.007	3.5
127.4	13.20	0.11	0.36	0.37	0.008	0.004	3.5
137.2	16.07	0	0.24	0.25	0.008	0.010	0
127.4	14.31	0	0.12	0.49	0.006	0.006	1.0
127.4	14.31	0	0.12	0.12	0.008	0.010	1.0
127.4	13.56	0	0.24	0.20	0.006	0.009	1.0
127.4	9.99	0	0.24	0.49	0.006	0.011	2.0
147.0	6.47	0.06	0.50	0.38	0.015	0.020	2.5
137.2	15.48	0.05	0.10	0.27	0.008	0.004	1.0
137.2	14.99	0	0.24	0.25	0.004	0.004	2.0
127.4	6.66	0	0.24	0.32	0.006	0.009	3.0
127.4	15.20	0.18	0.24	0.23	0.006	0.011	1.0
127.4	15.10	0.05	0.24	0.18	0.008	0.009	2.0
127.4	13.10	0	0.24	0.20	0.008	0.009	2.0

TABLE 2--Continued

Date	Depth (m)	pH	CO_3 Alk.	HCO_3 Alk.	Total Hardness	Ca++
	6	8.80	36	164	186.2	58.8
	8	8.05	0	220	215.6	78.4
	10	7.90	0	230	225.4	78.4
	12	7.60	0	228	230.3	88.2
22 January	0	8.80	40	156	196.0	68.6
	2	8.80	44	153	196.0	68.6
	4	8.80	40	156	196.0	68.6
	6	8.70	32	168	205.8	68.6
	8	8.10	4	218	235.2	88.2
	10	7.80	0	230	254.8	98.0
6 February	0	8.70	36	170	215.6	68.6
	2	8.80	40	168	215.6	68.6
	4	8.55	28	185	225.4	68.6
	6	8.10	6	225	235.2	78.4
	8	8.40	18	199	225.4	68.6
	10	7.80	0	237	245.0	88.2
11 February	0	8.80	48	156	205.8	68.6
	2	8.75	36	164	205.8	68.6
	6	8.70	32	172	215.6	68.6
	8	7.80	8	200	235.2	78.4
	12	8.20	0	232	254.8	88.2
	14	7.50	0	254	254.8	98.0
23 April	0	8.70	34	157	205.8	68.6
	2	8.70	32	150	205.8	68.6
	4	8.65	34	157	205.8	68.6
	8	8.65	34	157	205.8	68.6
	10	8.60	32	160	205.8	68.6
	14	8.60	32	160	205.8	68.6
30 April	0	8.70	38	152	215.6	88.2
	2	8.65	34	153	215.6	88.2
	4	8.65	34	157	215.6	88.2
	8	8.65	34	157	215.6	88.2
7 May	0	8.70	34	155	210.7	68.6
	2	8.70	34	155	210.7	68.6
	4	8.70	34	155	210.7	68.6
	8	8.70	34	155	210.7	68.6
28 May	0	8.70	32	155	205.8	68.6
	4	8.70	32	155	205.8	68.6

TABLE 2--Continued

Mg^{++}	O_2	Ortho PO_4	Total PO_4	NH_3-N	NO_2-N	NO_3-N	Temp. °C
127.4	12.00	0	0.22	0.20	0.006	0.006	2.5
137.2	5.70	0.32	0.24	0.28	0.012	0.014	2.5
147.0	4.20	0.12	0.50	0.30	0.008	0.014	3.0
142.1	2.60	0.25	0.76	0.37	0.008	0.014	3.0
127.4	14.90	0.25	0.38	-	0.008	-	1.0
127.4	15.10	0.18	0.24	-	0.012	0	2.0
127.4	13.60	0.63	0.24	-	0.017	-	2.0
137.2	11.80	0.25	0.38	-	0.012	-	3.0
147.0	5.90	0.18	1.02	-	0.030	-	3.0
156.8	2.00	0.18	0.62	-	0.35	-	3.5
147.0	13.33	0.12	0.38	0.16	0.023	0.011	0.0
147.0	12.84	0	0.24	0.16	0.026	0.008	2.0
156.8	11.47	0	0.24	0.23	0.030	0.011	1.5
156.8	6.27	0.38	0.64	0.55	0.026	0.015	2.0
156.8	8.82	0.25	0.50	0.40	0.028	0.011	3.0
156.8	3.43	0.25	0.64	0.46	0.026	0.035	3.0
137.2	14.00	0.12	0.10	0.20	0.019	0.009	1.0
137.2	12.50	0.19	0.28	0.22	0.024	0.004	2.0
147.0	11.20	0.25	0.28	0.26	0.024	0.011	2.5
156.8	6.60	0.38	0.76	0.28	0.024	0.050	3.0
166.6	5.00	0.38	0.76	0.32	0.028	0.058	4.0
156.8	0	0.25	1.02	0.20	0.021	0.109	4.0
137.2	13.90	0.06	0.30	0.40	0.004	0.004	7.5
137.2	13.90	0.06	0.30	0.31	0.008	0	7.0
137.2	13.90	0.12	0.50	0.36	0.006	0.002	7.0
137.2	13.90	0.06	0.30	0.44	0.004	0.007	7.0
137.2	13.72	0.06	0.30	0.28	0.004	0.007	7.0
137.2	13.72	0.12	0.50	-	0.006	0.005	7.0
127.4	12.25	0	0.24	1.15	0.004	0.004	7.0
127.4	12.54	0	0.24	1.28	0.004	0.004	7.5
127.4	12.44	0	0.24	1.28	0.004	0.004	7.5
127.4	12.44	0.06	0.36	1.41	0.004	0.004	7.5
142.1	12.00	0.05	0.24	0.48	0.001	0.007	12.0
142.1	12.00	0.05	0.10	0.59	0.004	0.004	12.0
142.1	12.00	0	0.10	0.43	0.004	0.004	11.5
142.1	12.00	0.05	0.24	0.39	0.004	0.004	9.5
137.2	11.60	0	0.24	0.15	0.001	0.007	11.5
137.2	11.80	0	0.10	0.19	0.004	0.004	10.5

TABLE 2--Continued

Date	Depth (m)	pH	CO_3 Alk.	HCO_3 Alk.	Total Hardness	Ca++
	8	8.50	24	165	225.4	68.6
	12	8.40	16	177	225.4	78.4
4 June	0	8.80	40	152	210.7	83.3
	2	8.80	40	152	205.8	73.5
	6	8.60	28	164	196.0	73.5
	10	8.40	16	179	196.0	68.6
9 June	0	8.85	36	154	186.2	78.4
	2	8.85	38	155	196.0	73.5
	6	8.65	28	167	196.0	78.4
	8	8.35	12	184	196.0	68.6
21 June	0	8.75	32	150	176.4	68.6
	2	8.70	28	154	176.4	68.6
	4	8.70	28	157	176.4	68.6
	8	8.20	4	192	196.0	78.4
	12	7.90	0	202	196.0	83.3
29 June	0	8.80	32	148	186.2	78.4
	2	8.80	36	144	181.3	63.7
	4	8.80	36	144	186.2	68.6
	6	8.70	28	157	186.2	68.6
	8	7.80	0	202	205.8	78.4
	10	7.75	0	206	200.9	78.4
7 July	0	8.80	32	145	176.4	63.7
	2	8.80	32	145	176.4	58.8
	4	8.80	32	144	176.4	58.8
	8	8.05	2	187	186.2	68.6
	10	7.80	0	200	200.9	73.5
	14	7.70	0	205	200.9	73.5
14 July	0	8.70	28	136	176.4	58.8
	2	8.70	28	135	176.4	63.7
	6	8.70	28	138	176.4	63.7
	8	7.90	0	176	186.2	68.6
	10	7.50	0	195	200.9	74.4
	14	7.40	0	200	205.8	83.3
22 July	0	8.80	30	135	176.4	63.7
	2	8.75	28	136	176.4	63.7
	4	8.75	26	137	176.4	68.6
	8	8.50	16	152	176.4	68.6
	12	8.30	10	160	181.3	68.6

TABLE 2--Continued

Mg++	O_2	Ortho PO_4	Total PO_4	NH_3-N	NO_2-N	NO_3-N	Temp. °C
156.8	9.20	0	0.24	0.27	0.004	0.004	10.0
147.0	7.20	0.05	0.64	0.27	0.004	0.006	10.0
127.4	11.10	0	0.24	0.38	0.004	0.004	18.0
132.3	11.70	0	0.10	0.27	0.004	0.004	15.0
122.5	8.80	0	0.24	0.25	0.001	0.007	13.0
127.4	4.80	0	0.50	0.33	0.004	0.004	13.0
107.8	10.00	0	0.24	0.32	0.001	0.005	17.0
122.5	10.20	0	0.36	0.33	0	0.006	17.0
117.6	6.20	0	0.24	0.40	0.001	0.005	14.0
127.4	3.40	0	0.24	0.40	0.004	0	14.0
107.8	8.90	0	0.36	0.36	0.004	0.004	22.5
107.8	8.60	0.12	0.24	0.36	0	0.008	22.5
107.8	8.00	0.05	0.50	0.31	0	0.008	22.0
117.6	1.40	0	0.24	0.48	0	0.012	16.0
112.7	0.10	0.12	0.24	1.18	0	0.012	15.5
107.8	9.70	0.05	0.24	0.28	0.004	0.002	22.0
117.6	9.60	0	0.24	0.28	0.004	0.002	22.0
117.6	9.60	0.12	0.12	0.31	0.004	0.002	22.0
117.6	5.90	0.05	0.24	0.33	0.001	0.007	20.0
127.4	0.20	0.19	0.24	0.74	0.004	0.002	16.0
122.5	0.10	0.12	0.50	0.82	0.001	0.005	16.0
112.7	8.10	0.12	0.24	0.36	0.001	0.007	23.0
117.6	8.20	0	0.50	0.37	0.001	0.009	23.0
117.6	7.70	0.12	0.36	0.39	0.001	0.007	22.5
117.6	1.40	0.18	0.36	0.77	0.001	0.007	19.0
127.4	0.20	0.32	0.50	1.08	0.017	0.008	18.0+
127.4	0	0.32	0.50	1.33	0.004	0.004	17.0
117.6	7.52	0.12	0.50	0.33	0.004	0.004	21.0
112.7	7.52	0.12	0.64	0.37	0.001	0.005	21.0
112.7	6.53	0.12	0.50	0.46	0	0.006	21.0
117.6	0.40	0.25	0.50	1.11	0.001	0.003	18.5
126.5	0	0.51	1.02	2.07	0	0.004	17.0
122.5	0	0.77	1.16	2.60	0	0.004	17.0
112.7	8.89	0	4.86	0.32	0.001	0.005	21.0
112.7	8.48	0	0.36	0.32	0.004	0.004	21.0
112.7	7.88	0	0.36	0.36	0.001	0.005	21.0
112.7	3.23	0.11	0.50	0.74	0.004	0,002	20.0
112.7	1.21	0.11	0.50	0.81	0.006	0.002	20.0

TABLE 2--Continued

Date	Depth (m)	pH	CO_3 Alk.	HCO_3 Alk.	Total Hardness	Ca++
	14	8.10	4	166	181.3	68.6
29 July	0	8.70	20	142	176.4	68.6
	2	8.65	20	142	176.4	68.6
	4	8.65	20	141	176.4	68.6
	8	8.65	20	143	176.4	68.6
	14	8.65	20	144	176.4	63.7
12 August	0	8.90	36	124	166.6	58.8
	2	8.90	34	127	166.6	58.8
	4	8.90	32	127	166.6	58.8
	8	8.60	18	147	176.4	58.8
	14	8.25	6	165	186.2	68.6
25 August	0	8.70	26	135	176.4	63.7
	6	8.70	26	133	176.4	58.8
	14	8.05	2	167	181.2	68.6
4 September	0	8.85	30	129	176.4	63.7
	2	8.85	30	129	176.4	58.8
	4	8.80	28	130	176.4	58.8
	8	8.70	24	136	176.4	58.8
	14	8.55	16	150	181.3	58.8
12 September	0	8.70	24	137	176.4	58.8
	8	8.70	24	138	176.4	58.8
	14	8.50	16	148	176.4	63.7
17 September	0	8.70	28	133	181.3	53.9
	8	8.70	28	132	176.4	58.8
	14	8.70	26	139	176.4	58.8
24 September	0	8.90	36	129	181.3	68.6
	2	8.85	34	131	181.3	68.6
	8	8.70	26	139	181.3	68.6
	14	8.70	26	141	186.2	68.6
1 October	0	8.70	28	137	181.3	73.5
	8	8.50	14	151	181.3	73.5
	14	8.30	4	156	181.3	73.5
8 October	0	8.55	16	146	186.2	73.5
	4	8.55	16	146	181.3	68.6
	8	8.55	16	147	181.3	68.6
	14	8.50	14	149	176.4	68.6
15 October	0	8.80	34	131	186.2	68.6
	8	8.80	34	131	186.2	68.6

TABLE 2--Continued

Mg++	O_2	Ortho PO_4	Total PO_4	NH_3-N	NO_2-N	NO_3-N	Temp. °C
112.7	0.20	0.11	0.50	1.00	0.006	0	20.0
107.8	7.33	0	0.36	0.31	0	0.007	18.0
107.8	7.33	0	0.50	0.33	0.001	0.003	18.0
107.8	7.23	0	0.50	0.33	0	0.004	18.0
107.8	7.13	0	0.50	0.31	0.001	0.005	18.0
112.7	7.13	0	0.50	0.31	0.001	0.005	18.0
107.8	8.90	0	0.50	0.15	0	0.012	20.5
107.8	8.80	0	0.36	0.25	0	0.21	20.5
107.8	8.80	0	0.50	0.22	0	0.017	20.5
117.6	3.30	0.05	0.50	0.56	0.004	0.024	19.0
117.6	0.20	0.52	0.64	0.95	0.004	0.015	18.0
112.7	6.60	0.11	0.50	0.54	0.004	0.017	20.0
117.6	6.40	0.11	0.50	0.54	0.002	0.015	20.0
112.6	0	0.60	0.92	1.69	0	0.012	19.0
112.7	8.12	0.25	0.92	0.32	0.002	0.019	21.0
117.6	7.92	0.05	0.64	0.33	0.004	0.017	21.0
117.6	7.72	0.25	0.92	0.38	0	0.021	21.0
117.6	6.14	0.14	0.64	0.45	0.003	0.025	20.0
122.5	2.48	0.32	0.64	0.94	0.003	0.018	20.0
117.6	6.70	0	0.59	0.42	0.005	0.005	19.0
117.6	6.60	0.19	0.64	0.43	0.004	0.006	19.0
112.7	3.70	0.26	0.52	0.67	0.006	0.011	19.0
127.4	7.80	0.12	0.64	0.26	0.004	0.011	17.0
117.6	7.70	0.12	0.78	0.39	0.004	0.008	17.0
117.6	6.00	0.25	0.92	0.50	0.004	0.008	17.0
112.7	10.60	0.09	0.64	0.01	0.002	0.017	15.0
112.7	10.00	0.09	0.64	0.01	0.002	0.013	14.5
112.7	6.80	0.09	0.64	0.01	0.002	0.019	14.0
117.6	7.10	0.12	0.92	0.01	0.004	0.020	14.0
107.8	9.50	0.05	0.64	0.18	0.005	0.020	17.0
107.8	5.60	0.05	0.78	0.35	0.004	0.026	15.0
107.8	2.70	0.36	0.64	0.47	0.004	0.033	14.0
112.7	9.29	0.12	0.64	0.23	0.005	0.012	12.0
112.7	9.29	0.12	0.64	0.25	0.004	0.013	12.0
112.7	9.09	0.12	0.64	0.25	0.004	0.013	12.0
107.8	8.99	0	0.52	0.19	0.004	0.013	12.0
117.6	11.40	0.12	0.28	0.13	0.004	0.013	10.0
117.6	10.30	0.05	0.50	0.13	0.002	0.015	10.0

TABLE 2--Continued

Date	Depth (m)	pH	CO_3 Alk.	HCO_3 Alk.	Total Hardness	Ca++
	14	8.75	32	132	186.2	68.6
22 October	0	8.80	34	129	176.4	58.8
	5	8.80	34	129	176.4	58.8
	10	8.55	20	144	176.4	68.6
29 October	0	8.60	20	146	186.2	68.6
	6	8.60	24	140	186.2	68.6
	13	8.60	24	140	186.2	68.6
12 November	0	8.15	6	162	196.0	68.6
	4	8.55	20	149	196.0	68.6
	8	8.25	8	156	186.2	78.4
	12	7.20	0	158	205.8	68.6
11 December	0	8.65	28	156	215.6	78.4
	5	8.50	20	164	215.6	78.4
	10	7.55	0	192	215.6	78.4
22 December	0	8.40	16	177	225.4	88.2
	5	8.30	16	182	207.7	88.2
	10	7.60	0	196	205.8	78.4
	14	7.50	0	205	215.6	88.2
31 December	0	8.40	18	187	225.4	88.2
	5	8.20	12	192	215.6	88.2
	10	7.50	0	202	205.8	88.2
	14	7.50	0	202	225.4	88.2

TABLE 2--Continued

Mg++	O_2	Ortho PO_4	Total PO_4	NH_3-N	NO_2-N	NO_3-N	Temp. °C
117.6	10.20	0	0.50	0.13	0.002	0.013	10.0
117.6	12.90	0.05	0.24	0.11	0.004	0.014	12.0
117.6	12.40	0	0.24	0.12	0.004	0.011	11.0
117.6	6.80	0	0.50	0.12	0.004	0.014	10.5
117.6	9.40	0	0.38	0.12	0	0.013	9.0
117.6	9.40	0.05	0.50	0.16	0.006	0.007	9.0
117.6	9.30	0	0.38	0.21	0.004	0.009	9.0
127.4	13.80	0	0.38	0.15	0.004	0.011	2.0
127.4	13.30	0.12	0.66	0.13	0.004	0.011	2.0
107.8	11.80	0.09	0.56	0.15	0.004	0.011	2.0
137.2	5.20	0.12	0.50	0.15	0.004	0.011	3.0
137.2	14.80	0.19	0.38	0.06	0.004	0.013	2.0
137.2	13.20	0.19	0.38	0.09	0.004	0.030	2.5
137.2	1.80	0.12	0.24	0.15	0.006	0.018	3.5
137.2	14.40	0.01	0.02	0.09	0.010	0.025	1.5
119.5	12.80	0.01	0.01	0.15	0.006	0.051	2.0
127.4	1.00	0	0.01	0.30	0.012	0.018	3.5
127.4	0.60	0	0.01	0.38	0.006	0.011	4.0
137.2	13.00	0.25	0.24	0.22	0.008	0.039	1.5
127.4	11.80	0.25	0.50	0.24	0.006	0.050	2.0
117.6	0.80	0.12	0.38	0.32	0	0.021	3.5
137.2	0.40	0.12	0.38	0.46	0	0.015	4.0

TABLE 3

NITROGEN, CARBON, AND PHOSPHORUS CONCENTRATION IN SEDIMENTS COLLECTED FROM SHALLOW[a] AND DEEP[b] WATER AREAS OF LAKE SALLIE, MINNESOTA

Date	Stations	Component: H_2O Sol. P mg/kg	Total P g/kg	Ca-P	Al-P mg/kg	Fe-P	Total N %	Carbon %
1968								
September 28	1, 2, 12	. .	0.72	125.90	0.09	6.93	0.64	5.16
	3, 4	. .	1.17	22.80	0.14	14.30	2.40	13.65
October 19	1, 2, 8, 9, 12	. .	0.43	. .	. .	. .	0.37	4.54
	3, 5, 6, 10, 11	. .	1.41	. .	. .	. .	1.40	14.86
November 2	1, 8, 9, 12	10.20	0.37	175.60	0.08	1.96	0.37	3.85
	3, 4, 5, 6, 10, 11	. .	1.49	. .	. .	. .	1.43	15.01
November 16	1, 2, 7	. .	0.80	. .	. .	. .	0.85	9.33
	4, 5, 6	. .	1.42	. .	. .	. .	1.40	14.73
1969								
February 7	1, 2, 8, 9	10.40	0.27	136.00	0.19	0.51	0.08	4.29
	3	30.40	1.43	407.00	0.20	9.51	. .	. .
April 26	1, 2, 8, 9, 12	20.54	0.30	150.00	0.03	3.66	0.18	4.49
	3, 4, 5, 6, 10, 11	45.82	1.25	349.20	0.07	6.17	1.25	16.97
June 6	1, 2, 8, 9, 12	13.52	0.32	206.50	0.04	3.56	0.47	5.21
	4, 5, 6, 10, 11	34.66	1.35	391.30	0.10	9.04	1.51	15.01
August 17	1, 2, 8, 12	13.17	0.27	125.67	. .	3.14	0.22	2.20
	3, 4	27.58	0.77	295.00	. .	6.19	0.85	9.88

TABLE 3--Continued

Date	Stations	H_2O Sol. P mg/kg	Total P g/kg	Ca-P	Al-P mg/kg	Fe-P	Total N %	Carbon %
September 28	1, 2, 8, 9	6.89	0.23	102.18	. .	0.86	0.40	2.19
	4, 5, 6	49.90	1.35	407.33	. .	8.94	1.42	15.16
November 15	1, 2, 12	12.00	0.25	124.33	. .	2.23	0.27	2.47
	3, 4	26.35	0.90	290.00	. .	5.94	0.86	8.90
1970								
January 25	1, 8, 9, 12	9.70	0.23	144.75	. .	1.29	0.20	2.91
	4	16.70	0.70	200.00	. .	6.38	0.80	9.88
May 22	1, 9, 12	7.32	0.25	175.33	. .	2.75	0.20	1.77
	4	52.40	1.46	492.00	. .	. .	1.40	15.30
July 10	1, 8, 9, 12	11.91	0.31	128.15	. .	2.64	0.25	2.69
	. .	. .	. .	. .	. .	. .	. .	. .

[a]Upper row of values per each date.

[b]Lower row of values per each date.

TABLE 4

ACID-SOLUBLE PHOSPHORUS (AS PO_4-P) OF AIR DRIED SEDIMENTS FROM LAKE SALLIE, MINNESOTA, EXPRESSED AS GRAMS PER KILOGRAM OF SEDIMENTS

	Station								
	1	3	4	6	7	8	9	12	21
	Depth (m)								
	0.5	9.0	16.5	7.5	1.0	0.5	0.5	0.3	0.3
7 November 1970	0.37	1.30	1.24	-	0.51	0.29	0.28	0.31	0.33
19 December 1970	-	-	1.22	-	-	0.24	0.23	0.42	0.41
18 March 1971	0.50	-	-	-	-	0.34	-	0.27	0.39
8 May 1971	0.14	-	1.63	1.57	-	0.15	0.30	0.38	0.31
25 June 1971	0.45	1.47	-	1.23	0.30	0.16	0.29	0.26	0.16
21 July 1971	1.33	1.28	1.75	1.16	0.35	1.57	0.42	0.29	0.21
30 October 1971	0.19	-	0.83	-	-	0.24	0.30	0.18	0.33
10 December 1971	-	-	-	-	-	0.19	0.26	0.30	0.52
31 December 1971	-	-	1.18	-	-	-	-	-	-

TABLE 5

TOTAL KJELDAHL NITROGEN, AS PERCENTAGE OF DRY WEIGHT
OF SEDIMENTS, LAKE SALLIE, MINNESOTA

	Station								
	1	3	4	6	7	8	9	12	21
	Depth (m)								
Date	0.5	9.0	16.5	7.5	1.0	0.5	0.5	0.3	0.3
7 November 1970	0.29	1.15	1.98	-	0.13	0.33	0.09	0.13	0.11
19 December 1970	-	-	1.23	-	-	0.18	0.07	0.21	0.17
18 March 1971	0.13	-	-	-	-	0.17	-	0.11	0.26
8 May 1971	0.06	-	1.30	1.28	-	0.10	0.08	0.11	0.12
25 June 1971	0.36	0.85	-	1.38	0.15	0.13	0.08	0.08	0.11
21 July 1971	0.88	1.13	0.80	2.00	0.17	0.55	0.12	0.08	0.10
30 October 1971	0.09	-	0.48	-	-	0.50	0.10	0.08	0.11
10 December 1971	-	-	-	-	-	0.11	0.11	0.09	0.11
31 December 1971	-	-	1.07	-	-	-	-	-	-

TABLE 6

CONCENTRATION OF CERTAIN ELEMENTS IN VARIOUS AQUATIC PLANTS FROM LAKE SALLIE, MINNESOTA, SEPTEMBER 16, 1968

	Plant Part 1/3			Concentration													
				%				mg/g									
Plant Description	Upper	Middle	Lower	P	N	C	H	Ca	Mg	Na	K	Co	Cu	Fe	Mn	Mo	Zn
Scirpus validus	x			0.19	2.6	39.8	5.8	2.0	1.6	0.46	6.0	0.008	0.019	0.142	0.350	0.105	0.046
		x		0.20	2.6	42.6	5.3	2.0	1.3	0.50	7.0	0.008	0.018	0.142	0.178	0.095	0.380
			x	0.20	2.1	44.1	6.0	1.6	2.2	1.00	7.0	0.006	0.022	0.094	0.051	0.065	0.440
Myriophyllum exalbescens	x			0.34	3.6	34.9	4.8	11.0	2.6	2.80	6.0	0.015	0.025	0.456	0.158	<0.065	0.105
		x		0.31	3.4	37.0	5.4	12.0	2.3	5.50	8.5	0.006	0.022	0.260	0.120	<0.065	0.048
			x	0.29	2.8	31.9	4.4	30.0	2.8	3.60	6.5	0.008	0.027	0.420	0.156	<0.065	0.030
Lemna trisulca	x	x	x	0.64	4.2	38.5	6.2	10.0	2.8	1.20	16.0	0.032	0.020	0.379	0.850	<0.065	0.070
Ceratophyllum demersum	x	x	x	0.48	3.4	37.4	6.0	3.2	5.1	1.40	12.0	0.036	0.042	0.427	0.860	<0.200	0.087
Nymphaea tuberosa		x		0.23	1.6	38.7	5.8	2.0	2.7	9.80	12.0	0.023	0.023	0.171	0.227	<0.065	0.029
	x			0.32	4.6	43.9	5.9	2.7	1.8	6.00	7.0	0.016	0.016	0.124	0.162	<0.065	0.065
Vallisneria americana	x	x		0.43	3.6	31.3	4.9	32.0	2.8	1.80	22.0	0.012	0.023	0.640	0.580	<0.065	0.029
			x	0.28	3.2	29.1	4.4	3.5	2.5	5.60	34.0	0.017	0.017	1.330	0.830	<0.065	0.028
Elodia canadensis	x	x	x	0.37	3.2	27.1	4.0	36.0	3.4	1.90	6.0	0.008	0.026	0.540	0.293	<0.065	0.055
Potamogeton pectinatus	x			0.30	2.5	35.7	5.7	12.0	2.8	3.80	10.0	0.008	0.015	0.172	0.118	<0.065	0.026
		x		0.27	2.3	39.5	5.5	4.2	2.4	4.20	10.0	0.014	0.012	0.180	0.094	<0.065	0.023
			x	0.25	2.3	38.9	5.2	2.8	1.7	5.20	12.0	0.026	0.021	1.660	0.105	<0.110	0.038

TABLE 6 --Continued

Plant Description	Plant Part 1/3: Upper	Middle	Lower	Concentration: % P	N	C	H	mg/g Ca	Mg	Na	K	Co	Cu	Fe	Mn	Mo	Zn
Potamogeton richardsonii	x			0.33	2.8	27.9	3.7	45.0	3.2	0.70	5.0	0.100	0.015	0.870	0.441	<0.065	0.026
		x		0.31	2.8	27.3	3.7	44.0	3.2	0.80	5.5	0.009	0.024	0.940	0.451	<0.065	0.026
			x	0.34	2.5	25.7	3.2	44.0	2.7	1.10	9.0	0.009	0.020	1.040	0.270	<0.065	0.034
Microcystis scum	N.A.[a]			0.72	8.1	43.0	6.2	3.9	2.0	0.60	3.5	0.018	0.023	0.780	0.223	<0.065	0.007
Periphyton removed from *Vallisneria*	N.A.			0.46	2.7	22.9	3.8	46.0	3.7	0.36	1.5	0.022	0.023	1.06	0.510	<0.065	0.090

[a]Not Applicable

TABLE 7

CHEMICAL ANALYSIS OF AQUATIC MACROPHYTES FROM SELECTED AREAS IN LAKE SALLIE, MINNESOTA

Date	Sample	Remarks	Total C g/kg	Total N g/kg	Total P g/kg
12 July 1971	Transect 3-1	Almost entirely *Potamogeton pectinatus*	336	18.3	2.25
20 July 1971	Transect 5-2	Mixture of *Ruppia maritima* and *P. pectinatus*	311	23.7	2.60
27 July 1971	Area 3	From 0.283 m^3 sample	294	21.0	2.135
30 July 1971	Transect 1-1	Mixture of *Myriophyllum exalbescens* and *P. pectinatus*	286	28.7	2.74
5 August 1971	Area 6	From 0.283 m^3 sample	250	24.0	2.54
10 August 1971	Transect 4-1	Mixture of *M. exalbescens* and *P. pectinatus*	305	23.7	2.295
10 August 1971	Transect 5-3	Mixture of *M. exalbescens* and *P. pectinatus*	315	21.3	2.165
16 August 1971	Transect 6-1	0-15 m from Pelican R., mostly *M. exalbescens*	307	25.3	2.515
16 August 1971	Transect 6-1	30-45 m from Pelican R., mostly *M. exalbescens*	305	25.0	3.02
16 August 1971	Transect 6-1	75-90 m from Pelican R., *M. exalbescens* and *P. pectinatus*	328	28.3	2.50
16 August 1971	Transect 6-1	90-105 m from Pelican R., mostly *P. pectinatus*	312	25.3	2.683

TABLE 8

PRIMARY PRODUCTIVITY OF SUBMERGED VASCULAR PLANTS AND ASSOCIATED PLANKTON, LAKE SALLIE, MINNESOTA

Date	Location	Time	Net Production				
			Total[a]	Rooted Plants[a]	Plank-ton[a]	Rooted Plants[b]	Plankton[b]
12 August 1970	A[c]	1100-1145	1187	780	407	-	-
		1145-1600	587	84	503	-	-
19 August 1971	B[d]	2230-0800	- 375	-375	0	-6.0	0
20 August 1971	B[d]	1100-1500	713	475	238	7.6	68.0
		1500-2030	250	216	43	3.5	12.3
		2030-1130	- 411	-388	- 24	-6.2	- 6.9
5 September 1971	C[e]	0715-0915	238	119	119	3.7	92.2
		0915-1215	475	158	317	5.0	245.7
		1215-1415	119	-119	238	3.7	184.5
		1415-1615	475	237	238	7.4	184.5
		1615-1815	0	0	0	0	0
10 September 1971	D[f]	1700-1900	- 119	0	-119	0	- 41.9

TABLE 8--*Continued*

Date	Location	Time	Total[a]	Rooted Plants[a]	Plankton[a]	Rooted Plants[b]	Plankton
			Net Production				
11 September 1971	D[f]	0700-0900	178	0	178	0	62.7
		0900-1200	911	594	317	15.2	111.6
		1200-1530	950	679	271	17.4	95.4

[a]mg $C/m^3/hr$.

[b]mg C/g dry weight/hr.

[c]250 m NW of Station 1. Enclosed *M. exalbescens*. Depth 1 m.

[d]On weed harvest transect 5-3. Enclosed *M. exalbescens* (19.0 g dry wt) and mixture of *P. pectinatus* and *R. maritima* (43.5 g combined dry wt). Dominant algae were *M. aeruginosa*, *A. spiroides* and *Lyngbya* sp. (17.5 mg/l dry wt). Depth 1 m.

[e]25 m NW of Station 1. Enclosed *M. exalbescens* (31.9 g dry wt). Dominant alga was *O. curviceps* (12.9 mg/l dry wt). Depth 0.5 m.

[f]On weed harvest transect 3-1. Enclosed *M. exalbescens* (22.7 g dry wt), *R. maritima* (9.0 g dry wt), and *P. pectinatus* (7.3 g dry wt). Dominant alga was *A. spiroides* (14.2 mg/l dry wt). Depth 1.1 m.

TABLE 9

WATER AND NITROGEN AND PHOSPHORUS BUDGETS IN LAKE SALLIE 1968-69 TO 1970-71

	WATER YEAR								
	1968-69			1969-70			1970-71		
	Total N kg	Total P kg	Water Flow m^3x10^6	Total N kg	Total P kg	Water Flow m^3x10^6	Total N kg	Total P kg	Water Flow m^3x10^6
A. In Lake Sallie									
Water	24,740	2,270*	-	5,070	9,690	-	21,231	16,513	-
Weeds	-	-	-	8,149**	1,038**	-	2,810	358	-
Fish	7,210	1,980	-	4,270	1,220	-	11,594	3,152	-
Sediment	1,014	95	-	748	73	-	738	89	-
Total	32,494	4,345	-	21,412	12,415	-	36,729	20,112	-
B. Input									
Pelican R.	11,360	10,020	18.96	5,590	7,060	16.77	10,568	15,169	16.88
Fox Lake	200	80	0.78	180	310	0.66	393	305	0.62
Monson L.	90	20	0.48	80	100	0.41	217	169	0.35
Total	11,650	10,140	20.22	5,850	7,470	17.84	11,178	15,643	17.85
C. Outflow	9,720	5,810	22.71	2,640	2,510	19.08	7,217	7,758	20.81
D. Net Gain or Loss (B-C) to Lake	1,930	4,330	-2.49	3,210	4,960	-1.24	3,961	7,885	-2.96
E. Removed by Harvest									
Fish	-	-	-	1,590	406	-	786	207	-
Weeds	-	-	-	721	100	-	248	26	-
Total	-	-	-	2,311	506	-	1,034	233	-

* Soluble P
**Approximation from 1971 standing crop data and 1970 harvest.

APPENDIX

LIST OF PLANKTERS OBSERVED 1968-71

Bacteria

Division Schizophyta

Class Schizomycetes

Sphaerotilus natans Kutz.

Algae

Division Chlorophyta

Class Chlorophyceae

Order Volvocales

Chlamydomonas sp. Ehr.
Eudorina elegans Ehr.
Gonium formosum Pasch
Pandorina morum (Mull.) Bory
Pleodorina californica Shaw
Volvox globator L.

Order Tetrasporales

Elakatothrix gelatinosa Wille
Ererella bornhomensis Conrad.
Gloeocystis gigas (Kutz.) Lag.
Gloeocystis major Ger. *ex* Lem.
Gloeocystis planctonica (W. and W.) Lem.
Sphaerocystis Schroeteri Chod.

Order Ulotrichales

Stichococcus bacillaris Naeg.

Order Chlorococcales

Actinastrum gracillimum Lag.
Ankistrodesmus falcatus (Corda) Ralfs
Characium gracilipes Lamb.
Characium limneticus Lem.
Chlorella ellipsoidea Gern.
Chlorella vulgaris Beyern.
Closteriopsis longissima Lemm.
Coelastrum microporum Naeg.
Crucigenia fenestrata Sch.
Crucigenia irregularis Wille
Crucigenia Lauterbornii Sch.
Crucigenia quadrata Mor.
Crucigenia rectangularis (A. Braun) Gay
Dictyosphaerium Ehrenbergianum Naeg.
Dictyosphaerium pulchellum Wood
Kirchneriella obesa (W. West) Schmid.
Lagerheimia ciliata G. M. Sm.
Lagerheimia citriformis (Snow) G. M. Sm.
Micractinium pusillum Fres.
Nephrocytium sp. Naeg.
Oocystis sp. Naeg.
Oocystis parva W. and W.
Pediastrum Boryanum (Turp.) Meneg.
Pediastrum duplex Meyen
Pediastrum simplex (Meyen) Lem.
Planktosphaeria gelatinosa G. M. Sm.
Quadrigula lacustris (Chod.) G. M. Sm.
Scenedesmus arcuatus Lem.
Scenedesmus bijuga (Turp.) Lag.
Scenedesmus dimorphus (Turp.) Kutz.
Scenedesmus guadricauda Chod.
Scenedesmus guadricauda var. longispina (Chod.) G. M. Sm.
Scenedesmus guadricauda var. maxima W. and W.
Schroderia Judayi G. M. Sm.
Selenastrum gracile Reinsch.
Tetradesmus wisconsinense G. M. Sm.
Tetraedron regulare Kutz.
Tetraedron arthrodesmiforme (G. S. West) Wolo.
Tetraedron pentaedricum W. and W.
Tetraedron sp. Kutz.
Tetrallantos Lagerheimii Teil.

Order Zygnematales

Closterium moniliforme (Bory) Ehr.

Cosmarium sp. Breb.
Staurastrum paradoxum Meyen
Mougeotia sp. (C. A. Ag.) Wittr.

Division Chrysophyta

Class Xanthophyceae

Order Heterococcales

Ophiocytium capitatum Woll.

Class Chrysophyceae

Order Chrysomonadales

Dinobryon divergens Imh.

Class Bacillariophyceae

Order Centrales

Melosira granulata (Ehr.) Ralfs
Stephanodiscus astraea (Ehr.) Grun.
Stephanodiscus astraea var. *minutula* (Kutz.) Grun.

Order Pennales

Amphiprora sp. Ehr.
Asterionella formosa Hass.
Cocconeis pediculus Ehr.
Cocconeis scutellum Ehr.
Cymatopleura solea (Breb.) W. Sm.
Cymbella cistula (Hemp.) Grun.
Cymbella lanceolata (Ehr.) v. Heur.
Cymbella prostata (Berk.) Cl.
Cymbella tumida (Breb.) v. Heur.
Cymbella sp. Ag.
Diatoma sp. DeCand.
Epithemia sorex Kutz.
Epithemia sp. Breb.
Epithemia turgida (Ehr.) Kutz.

Epithemia zebra (Ehr.) Kutz.
Eunotia sp. Ehr.
Fragillaria capucina Desm.
Fragillaria crotonensis Kitt.
Gomphonema acuminatum Ehr.
Gomphonema sp. Hust.
Gomphonema lanceolatum Ehr.
Gomphonema olivaceum (Lyng.) Kutz.
Gomphonema parvulum (Kutz.)
Navicula cuspidata Kutz.
Navicula sp. Bory
Nitzschia amphibia Grun.
Nitzschia sigmoidea (Ehr.) W. Sm.
Nitzschia sp. Hass.
Rhopalodia sp. O. Mull.
Stauroneis sp. Ehr.
Surirella sp. Turp.
Synedra rumpens Kutz.
Synedra ulna (Nitzsch.) Ehr.
Synedra sp. Ehr.

Division Euglenophyta

Order Euglenales

Euglena sp. Ehr.
Phacus sp. Duj.
Trachelomonas sp. Ehr.

Division Pyrrophyta

Class Dinophyceae

Order Peridiniales

Ceratium hirudinella (O. F. Mull.) Duj
Glenodinium berolinense (Lem.) Lindem.
Peridinium sp. Ehr.

Class Cryptophyceae

Cryptomonas sp. Ehr.

Division Cyanophyta

Class Myxophyceae

Order Chroococcales

Aphanocapsa sp. Naeg.
Aphanothece nidulans Naeg.
Chroococcus cispersus (Keissl.) Lem.
Chroococcus limneticus Lem.
Coelosphaerium dubium Grun.
Coelosphaerium Kützingianum Naeg.
Coelosphaerium Naegelianum Ung.
Dactylococcopsis Smithii Chod. and Chod.
Gomphosphaeria aponina Kutz.
Marssoniella elegans Lem.
Merismopedia punctata Meyen
Microcystis aeruginosa Kutz.
Microcystis flos-aquae (Wittr.) Kirch.

Order Hormogonales

Anabaena sp. Bory
Anabaena circinalis (Har.) Rab.
Anabaena spiroides Kleb.
Aphanizomenon flos-aquae (L.) Ralfs
Gleotrichia natans (Hed.) Rab.
Lyngbya sp. C. A. Ag.
Oscillatoria sp. Vauch.
Oscillatoria curviceps C. A. Ag.
Oscillatoria limosa (Roth) C. A. Ag.
Oscillatoria princeps Vauch.
Phormidium sp. Kutz.
Spirulina major Kutz.

Animals

Phylum Protozoa

Class Sarcodina

Order Testacea

Centropyxis aculeata (Ehr.) Stein
Difflugia sp. Lecl.
Difflugia lebes Pen.

Order Heliozoa

Actinosphaerium sp. Stein

Class Ciliata

Order Holotricha

Coleps sp. Nitz.
Cyclidium sp.
Didinium sp. Stein
Enchelys sp.
Frontonia sp. Ehr.
Lacrymaria sp. Ehr.
Prorodon sp. Ehr.
Saprophilus sp. Stokes
Trachelophullum sp. Clap. and Lach.

Order Spirotricha

Caenomorpha sp.
Codonella sp. Haeck.
Euplotes sp. Ehr.
Halteria sp. Duj.
Oxytricha sp. Ehr.
Strombidium sp. Clap. and Lach.
Strombilidium sp. Schew.
Stylonchia sp. Ehr.

Order Peritricha

Epistylis sp. Ehr.
Thuricola sp.
Vaginicola sp. Lam.
Vorticella sp. L.

Order Suctoria

Acineta sp. Ehr.
Tokophyra sp. Buts.

Phylum Nematoda

Nematode sp.

Phylum Gastrotricha

Class Chaetonotoidea

Chaetonotus sp. Ehr.

Phylum Rotifera

Class Bdelloidea

Order Bdelloida

Philodina sp. Ehr.

Class Monogononta

Order Ploima

Anuraeopsis sp. Laut.
Asplanchna priodonta Gosse
Brachionus sp. Pallas
Brachionus calyciflorus Ahl.
Cephalodella auriculata Bory de St. Vincent
Colurella sp. Bory do St. Vincent
Euchlanis sp. Ehr.
Keratella cochlearis (Gosse)
Keratella quadrata (Mull.)
Lecane sp. Nitz.
Monostyla sp. Ehr.
Polyarthra euryptera (Wierz.)
Polyarthra vulgaris Carl.
Synchaeta pectinata Ehr.
Trichocerca multicrinis Kell.
Trichocerca similis Ehr.

Order Flosculariaceae

Conochilus sp. Hlava
Filinia longiseta (Ehr.)
Sinantherina socialis (L.)

Phylum Tardigrada

Order Eutardigrada

Macrobiotus sp. Schultze

Phylum Arthropoda

Class Arachnida

Order Hydracarina

Larval mites

Class Crustacea

Order Cladocera

Alona affinis (Ley.)
Alona monocantha Sars
Bosmina longirostris (O. F. Mull.)
Ceriodaphnia sphaericus (O. F. Mull.)
Daphnia longiremis Sars
Simocephalus sp. Schød.

Order Podocopa

Ostracod sp.

Order Eucopepoda

Cyclops sp. O. F. Mull.
Diaptomus sp. Westw.
Nauplii

Miscellaneous

Division Chlorophyta

Volvocalean spores

Division Eumycophyta

Fungal spores

Division Tracheophyta

Pollen grains

Phylum Rotifera

Rotifer eggs

Phylum Annelida

Class Oligochaeta

Aeolosoma sp. (eggs)

Phylum Arthropoda

Class Crustacea

Order Cladocera

Ephippia

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16. Abstract After more than sixty years of cultural eutrophication Lake Sallie, Minnesota, supports dense growths of phytoplankton and rooted vegetation. Its major water mass has the chemical character imparted by photosynthesis at all seasons, and chemical effects of decomposition are rather localized. Phytoplankton dominance alternates among diatoms, blue-green, and green algae in that order of abundance. Prior to operation of a weed harvester, attached plants grew densely over 34% of the bottom area. The bulk of nitrogen and phosphorus is usually contained in the water mass, with noticeably smaller amounts in upper bottom sediments and biota. The fish population, less than one half the mass of weeds, contained considerable more N and P than weeds in 1971. Harvest in 1970 evidently reduced weed density in 1971, and increased the cost per unit of nutrients removed. Nitrogen and phosphorus removed in weeds were insignificant when compared with annual water borne waste effluent contributions to the lake. Cost of phosphorus removal by weed harvest was $61 and $199 per pound in 1970 and 1971, respectively; nitrogen cost $8 and $21 and carbon $0.64 and $1.62 per pound for the same two years.

17a. Descriptors

* Eutrophication, *Nutrients, Nutrient budgets, Water pollution, Nutrient distribution in lake water, sediments, biota Watershed pollution, *Weed harvest and Nutrient Removal

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