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PHYTOPLANKTON POPULATIONS IN RELATION TO TROPHIC LEVELS OF LAKES IN NEW HAMPSHIRE, U. S. A.

by

Gerhard K. Gruendling and Arthur C. Mathieson

Department of Botany

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ABSTRACT

The relationships between composition, periodicity and abundance of phytoplankton species and the trophic status of two New Hampshire lakes (Newfound and Winnisquam) were investigated. The lakes had vastly different concentrations of nitrate and phosphate and provided an excellent opportunity for a comparative study of the basic ecology and nutrient requirements of phytoplankton. They also provided an opportunity to test the usefulness of algal indicators and quotients for determining trophic status.

Regular collections (approximately fortnightly) were made at each lake from June 25, 1966 to November 10, 1967. Samples of phytoplankton were taken from six depths at three stations with a 4-liter Van Dorn water sampler. Samples were also taken for nutrient analyses of orthophosphate, nitrate nitrogen and silicon dioxide. Qualitative determinations were made from living material. The total number of phytoplankton cells were enumerated from fixed material under an inverted microscope.

The differences in the total standing crop at the two lakes were correlated with their differences in nutrient concentrations. Orthophosphate appeared to be the primary limiting factor of algal growth at the oligotrophic lake (Newfound), while light, temperature, and possible extracellular products were the primary limiting factors at the eutrophic lake (Winnisquam). The vertical distribution of the standing crop was a function of light penetration and the types of algal

populations. A discussion of the factors influencing the periodicity, abundance, and distribution of phytoplankton species at the two lakes is presented, and the results are compared with the findings of other workers.

The species composition at the lakes was dependent upon their trophic status. Dominant species were considered to be the best indicators of trophic levels and a list of possible indicators organisms is given. A summary of possible rare indicators is also included. It is suggested that the species composition, abundance and periodicity of phytoplankton should be considered when determining indicator organisms.

The phytoplankton quotients proposed by various authors were applied to the lakes. Most of the indices correctly designated the eutrophic lake, but not the oligotrophic lake. An evaluation of several phytoplankton quotients is given and a few suggestions are presented for improving phytoplankton quotients.

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INTRODUCTION

The present investigation was initiated in order to evaluate the relationships between composition, periodicity, and abundance of phytoplankton species and the trophic status of two New Hampshire lakes (Newfound and Winnisquam Lake). The lakes are similar in origin, geology, size, depth, altitude, and certain of their chemical and physical characteristics. However, they have vastly different concentrations of nitrate and phosphate, for Newfound Lake is oligotrophic while Winnisquam Lake is in the early stages of eutrophication. Winnisquam Lake was considered to be oligotrophic in 1936 (Newell, 1963), but since then the process of eutrophication has been accelerated by the liberation of treated sewage effluent into the lake. The two lakes provided an excellent opportunity for a comparative study of the basic ecology and nutrient requirements of phytoplankton populations.

It was also felt that the two lakes provided an opportunity to test the usage of algal indicators and quotients for determining trophic status - especially of soft-water lakes. Few North American workers have attempted to use algal indicators and quotients to evaluate the trophic levels of lakes (Palmer, 1957; Rawson, 1956), although a number of studies have been done on the effects of pollutants on algae in flowing waters (Lackey, 1938, 1941; Patrick, 1949, 1961, 1964). A detailed study of nutrient and phytoplankton relationships has never been undertaken in New Hampshire lakes.

METHODS

Regular collections (approximately fortnightly) were made at each lake from June 25, 1966 to November 10, 1967, except during December and January when ice conditions prevented access. Three stations were established at each lake (Fig. 1 & 2), and six samples (1, 3, 5, 10, 15, and 20 meters) were taken at each station with a 4-liter Van Dorn water sampler. Twenty-five ml subsamples were collected from each depths for phytoplankton enumeration. These were preserved with three drops of acid Lugol's solution. One liter subsamples were also taken from 1, 5, and 10 meter depths for nutrient analysis. The nutrient samples were placed in polypropylene bottles, refrigerated and later taken in the laboratory for analysis. Vertical hauls (20 meters in depth) were collected at each station with a # 25 plankton net, in order to concentrate living phytoplankton for identification. The collections were refrigerated and then taken to the laboratory for analysis. Light penetration was determined with a Whitney Model LMD-8A Underwater Light Meter. Temperatures were recorded with a standard mercury thermometer and a Whitney Model TC-5 Underwater Thermometer.

Living samples were used whenever possible for the identification of organisms. Nannoplankton were concentrated with a .45 micron millipore filter (living samples) and by sedimentation (fixed samples). The generic designations listed by Smith (1950) were used whenever possible. A variety of sources were consulted for specific identifications: Ahlstrom (1937); Eddy (1930); Huber-Pestalozzi (1938-1961); Patrick

and Reimer (1966); Prescott (1962); Smith (1920, 1924); Teiling (1967); West and West (1904-1912); and West, West, and Carter (1923). Voucher specimens have been deposited in the University of New Hampshire Herbarium.

The phytoplankton were enumerated according to the inverted microscope technique outlined by Lund, Kipling, and Le Cren (1958), using a Unitron Model Bi-4777 inverted microscope. A one ml unconcentrated sample was added to a sedimentation tube, it was allowed to settle for 18 hours, and then the phytoplankton were counted under 430X magnification. The total number of cells of each species per ml was counted.

Nutrient analyses were performed, whenever possible, immediately upon return to the laboratory. Otherwise the samples were immediately frozen and stored at -10 C until they were analyzed. The procedures outlined by the American Public Health Association (1965) were used, i.e., the stannous chloride method for orthophosphate, the phenoldisulfonic acid method for nitrate nitrogen, and the colorimetric heteropoly blue method for silica. All colorimetric analyses were determined with a Beckman DU-2 spectrophotometer.

reached their maxima somewhat later. In August, 1966, the surface temperatures decreased rapidly and by September 19, the upper 10 meters of the lake were isothermal. The fall overturn was completed by October 17 and at this time the water column was isothermal at 11.8 C. During February and March, 1967, the temperatures under the ice ranged from 0.5 - 2.0 C; a slight inverse stratification was evident. The lake was free of ice in early April and the spring overturn then occurred. Thereafter, the temperature of the water column increased rapidly and thermal stratification was evident in early June. After June the surface temperatures increased rapidly until a maximum of 25.0 C was recorded on August 1. During the summer period the temperatures at 10 meters ranged from 8.5 - 11.5 C; those at 15 meters ranged from 8.5 - 10.0 C. During the later summer and fall the temperature again decreased rapidly, and isothermal conditions were recorded in early November.

Figure 4 shows the seasonal variation of light penetration (1% of the surface light). Each point depicts the mean value recorded for all stations. In general, there was a correlation between the total standing crop and the depth of light penetration (compare Figures 4 & 5). Thus, as the total standing crop increased, the light penetration decreased, and vice versa. The light penetration was low during the spring of 1966, and a minimum transparency was recorded on August 24 (12 meters). The minimum corresponded with the maximum standing crop of the year. The transparency of the water then increased steadily until fall, at which time decreased light penetration was again recorded. During February, March, and early Arpil of 1967, the ice and snow

cover on the lake varied considerably. A maximum cover of 50 cm of ice and 45.7 cm of snow occurred on March 3. The maximum cover corresponded with the lowest light penetration (2.5 meters). During the ensuing two weeks, there was considerable melting, and the light penetration increased rapidly. The light penetration fluctuated throughout the summer and fall, in association with minor peaks of phytoplankton.

The seasonal levels of nutrients (orthophosphate, nitrate nitrogen, and silicon dioxide) at Newfound lake are shown graphically in Figures 6, 7, 8, respectively. Each point represents the mean value of the three stations.

The yearly mean orthophosphate values recorded were .011 mg/l at 1 meter, .011 mg/l at 5 meters, and .010 mg/l at 10 meters. During 1966 the maximum orthophosphate concentration (.020 mg/l) occurred on October, 3; smaller peaks were recorded in June and September. A minimum concentration (.002 mg/l) was found on November 23; other low values were recorded in August and late September. During 1967 the orthophosphate concentrations ranged from .032 mg/l (February 20) to .002 mg/l (May 5). Two lesser peaks occurred during June and November. Low values occurred during late March, April, July, and August. In general, the seasonal patterns of orthophosphate concentrations were similar at each depth.

The yearly mean nitrate nitrogen concentrations recorded were .057 mg/l at 1 meter, .052 mg/l at 5 meters, and .055 mg/l at 10 meters. During 1966, peaks occurred on June 25 (.064 mg/l) and on November 23 (.082 mg/l). A low of .019 mg/l was recorded on October 3. During 1967, the highest concentration (.097 mg/l) was recorded on February 20. After February there was a rapid decline to a low of .046 mg/l on May 5. The

summer concentrations fluctuated considerably and the lowest concentration (.044 mg/l) was recorded on November 10. The concentrations at the three depths showed similar seasonal patterns. Exceptions were recorded on November 23, 1966 and February 20, 1967.

The yearly mean silicon dioxide concentrations were .849 mg/l at 1 meter, .841 mg/l at 5 meters, and .770 mg/l at 10 meters. The concentrations during 1966 were lowest in the spring (.687 mg/l on June 25) and fall (.210 mg/l on November 23). The maximum concentration (2.120 mg/l) was recorded on August 24. The silicon dioxide concentrations fluctuated extensively during 1967. The winter concentrations were generally low, and ranged between .181 and .820 mg/l. The concentrations rose steadily throughout the spring and summer and a maximum of 2.095 mg/l was recorded on August 11. During 1966, concentrations of silicon dioxide were similar at the three depths, but they differed considerably during 1967. This was especially true during July and August, when the concentrations at 1 meter were much higher than the concentrations at 5 and 10 meters.

Species Composition

A total of 105 species of phytoplankton were identified at Newfound Lake. A complete list of the species and their seasonal periodicity is presented in Table 1. No particular group of algae dominated the phytoplankton from Newfound Lake. The largest number of species belonged to the Chlorophyceae (a total of 43) and 26 of these were desmids. The other major components of the total phytoplankton flora were as follows: Chrysophyceae (19 species), Bacillariophyceae

(13 species), Cyanophyceae (10 species), and Dinophyceae, (10 species).

The phytoplankton flora of Newfound Lake was characterized by having a large number of species that were present during the entire year. Thirty-six species were found in every collection; these were primarily members of the Desmidiaceae, Chrysophyceae, and Bacillariophyceae. The ephemeral species were chiefly species of the Chroococales, Chlorophyceae (exclusive of desmids), and Dinophyceae. In general, the summer and fall phytoplankton flora of Newfound Lake was composed of a large number of species of Cyanophyceae, Chrysophceae, and Desmidiaceae. The Chrysophyceae and Bacillariophyceae contributed the largest number of species during the winter and spring.

Seasonal Periodicity of Standing Crop

Figure 5 shows the seasonal periodicity of the total standing crop, while Figure 9 shows the major groups contributing to the total standing crop. Each point in these figures represents the mean of five collections (1, 3, 5, 10, and 15 meters). Thus, a general indication of the average standing crop within the photic zone is given. The mean monthly cell counts for the major species are depicted in Table 2.

The standing crop was higher during the summer of 1966 than in 1967. The total number of phytoplankton was low during June, 1966 (3.2×10^5 cells/l), but increased steadily to a peak of 12.7×10^5 cells/l on August 24. It then decreased slowly to 3.9×10^5 cells/l on October 3. After the fall overturn, the phytoplankton numbers then increased to a fall maximum of 5.7×10^5 cells/l on November 23. The lowest standing crop (1.2-2.0 cells/l) occurred during the winter of

1967. No significant increase was detected until early June. At this time, the cell numbers began to increase and a maximum of 6.9×10^5 cells/l was recorded on July 6; this was the highest value of 1967. The total population then fluctuated slightly during the summer, and reached a low of 2.9×10^5 cells/l on October 16. The population then increased again during November.

Members of the Cyanophyceae and Chrysophyceae were the major contributors to the standing crop at Newfound Lake (Fig. 9). In June, 1966, the numbers of Cyanophyceae increased steadily until a peak of 8.0×10^5 cells/l was reached on September 19. Gomphosphaeria lacustris and Aphanothece clathrata were the major contributors on this date. The cell numbers then decreased rapidly throughout the fall, but increased again in November, reaching a peak on November 23. The standing crop of Cyanophyceae was at a low level (.35-.53 cells/l) during the winter of 1967. The population started to increase during June and reached a peak of 4.0×10^5 cells/l on August 1. Gomphosphaeria lacustris was again the dominant species. The population then decreased throughout the fall and a final pulse occurred on November 10.

The Chrysophycean population at Newfound Lake can be characterized as having two pulses a year. One occurred in the summer, and the other occurred in late fall. Beginning in June, 1966, a rapid increase of Chrysosphaerella longispina, Dinobryon cylindricum, and D. bavaricum took place. A maximum of 3.7×10^5 cells/l of Chrysosphaerella longispina occurred on August 8. The seasonal maximum recorded for the Chrysophyceae (12.0×10^5 cells/l) occurred on August 24, when a sudden pulse of Uroglenopsis americana developed. After August 24, the stand-

ing crop of Chrysophyceae declined rapidly to the lowest point recorded of .03 x 10^5 cells/l on September 19. There was then a gradual increase in numbers, especially of Dinobryon cylindricum and D. bavaricum, until a maximum of 1.7 x 10^5 cells/l was reached on November 23. The standing crop during the winter of 1967 was dominated by Synura uvella. Population levels were very low from February through early June (ranging between .05 and .35 x 10^5 cells/l), but beginning in early June, 1967 there was a rapid increase. Uroglenopsis americana, Dinobryon bavaricum, and D. cylindricum again contributed to the maximum (4.8 x 10^5 cells/l) which occurred on July 6. Chrysosphaerella longispina was not as abundant in 1967 as in 1966. After July, there was a rapid decline in the standing crop until early fall; however, during this decline period there was a substantial increase in Dinobryon vanohoffenii and Synura uvella. The fall pulse of 1967 was not as great as that during 1966. A maximum of only .48 x 10^5 cells/l was recorded on October 16. The main contributors were Synura uvella, Dinobryon cylindricum, and D. divergens. In general, the populations of Chrysophyceae followed the same yearly trends throughout the study.

Members of the Bacillariophyceae were the third largest contributors to the total standing crop. In 1966, the standing crop increased through June and reached a peak of 2.3 x 10^5 cells/l on July 25. The major components were Asterionella formosa var. formosa and Rhizosolenia eriensis. The population then decreased steadily through September. Two pulses were recorded during the fall; one occurred during the breakdown of thermal stratification and the other followed the complete

overturn. The first pulse (.60 x 10^5 cells/1) occurred on October 3 and it was chiefly composed of Melosira islandica and Asterionella formosa var. formosa. The second maxima (.75 x 10^5 cells/1) of the same species occurred on November 23. The Bacillariophyceae were the major components of the winter population. The maximum standing crop (1.10 x 10^5 cells/1 occurred on April 21, 1967, immediately after the spring overturn. The population was dominated by Asterionella formosa var. formosa, A. formosa var. gracillima, and Melosira islandica. The numbers of diatoms decreased steadily through June, but thereafter increased. A maximum population of .91 x 10^5 cells/1 was recorded on July 21, and was primarily composed of Rhizosolenia eriensis. Instead of decreasing to a summer low, as during 1966, the standing crop of diatoms remained relatively high during the summer and fall. The high standing crop during the summer was primarily due to large numbers of Rhozosolenia eriensis and Asterionella formosa var. formosa. The only substantial increase of diatoms during the fall occurred on October 1, when Tabellaria fenestrata reached .25 x 10^5 cells/1.

Members of the Chlorophyceae did not contribute significantly to the total standing crop. Their standing crop remained relatively low throughout the year except for small pulses during June and July, 1966 (1.0 x 10^5 cells/1) and during June (.50 x 10^5 cells/1) and September, 1967 (.70 x 10^5 cells/1). The major contributors were Botryococcus braunii, Gloeocystis gigas, and Crucigenia rectangularis.

Members of the Cryptophyceae contributed less than the Chlorophyceae to the standing crop. The populations were low during the

summer and reached maximum levels in the fall - 1.1 x 10^5 cells/l on October 3, 1966 and 1.0 x 10^5 cells/l on November 10, 1967. Rhodomonas lacustris was the major component of the fall blooms. Cryptomonas ovata and C. marsonnii tended to reach smaller peaks during late summer.

The Dinophyceae, although conspicuous at times due to their large size, contributed very little to the total standing crop. Peridinium limbatum was the major contributor and it was most abundant in the early spring and late fall, with maximum concentrations of .03 x 10^5 cells/l. during the winter, substantial populations of dinoflagellates also occurred. Peridinium willei was the major contributor. Although the dinoflagellate populations were generally abundant during the spring and fall, the largest pulse occurred during the summer of 1967. On August 1 and August 11, Peridinium inconspictum was found in quantities of .07 and .06 cells/l, respectively.

Vertical Distribution of Standing Crop

Table 3 summarizes the vertical distribution of the standing crop at Newfound Lake. The bulk of the phytoplankton occurred at 3, 5, and 10 meters. All of the Cyanophyceae, except Anabaena flos-aquae, were most abundant between 5 and 10 meters. Anabaena flos-aquae the only filamentous blue-green alga of any significance at Newfound Lake, occurred throughout the summer in largest numbers at the surface.

The Chrysophyceae generally reached maximum standing crops at 5 and 10 meters. An exception to this was the occurrence of Dinobryon spp. in large numbers at the surface during June and July, 1966. However, during other peaks of Dinobryon spp. the algae did not occur at

the surface, but they reached their maximum numbers at 3, 5, and 10 meters. An interesting vertical distribution was noted in Mallomonas tonsurata var. alpina. During the period of ice cover, when light and temperatures were low, it reached maximum abundance at one meter. During the summer, it was found in maximum numbers at 10 and 15 meters, where the light and temperature regimes were lower than at the surface. During the late fall, it was again higher in the water column (3-5 meters). Such observations suggest that the vertical distribution is dependent upon certain critical temperature and/or light relationships.

The Bacillariophycean populations were usually most abundant at 5 and 10 meters - even during winter when the ice and snow cover was substantial. It was also noted, that as diatom populations declined, they tended to occur progressively deeper in the water column. This sinking was especially evident after peaks of Melosira islandica, Asterionella formosa var. formosa and Rhizosolenia eriensis. Rhizosolenia eriensis reached maximum numbers at one meter during the early summer. As the population began to decline the depth at which the maximum number of organisms was found increased, until the alga was almost completely absent from the photic zone. The same sequence occurred again during the summer of 1967. Melosira islandica was abundant near the surface only after the spring and fall overturns. Following the overturns, it sank quickly to greater depths. Asterionella formosa var. formosa, Cyclotella bodanica, and C. compta never developed maximum numbers near the surface, but usually reached a maximum at 5 and 10 meters.

During the ice free period the members of the Crytophyceae were evenly distributed throughout the photic zone. However, during the winter they were generally found closer to the surface, although large number of Rhodomonas lacustris and Crytomonas spp. were found still well below the point of light extinction. Most of the Dinophyceae were evenly distributed throughout the water, except for Peridinium inconspictum which was most abundant at 1 and 3 meters. Peridinium willei reached maximum numbers at 1 meter under the ice but after the ice had melted it tended to become more evenly distributed. The Chlorophyceae generally occurred in the surface waters and reached maximum quantities at 1 and 3 meters.

Occurrence of Reproductive Spores

Table 4 summarizes the reproductive spore periodicity of phytoplankton observed during the study. Spores were only found in three species. Akinetes were present on Anabaena flos-aquae throughout its growing season, except for November. No obvious correlations were evident between akinete production and environmental factors. Statospores were found on Dinobryon bavaricum during June and July, 1967 and on Dinobryon cylindricum during October and November, 1966 and June and July, 1967. In all cases, the formation of statospores occurred when the standing crops of Dinobryon spp. were at their peaks and when the orthophosphate concentrations were low (between .008 and .015 mg/l). No other correlations were evident between spore formation and other environmental factors.

Calculation of Phytoplankton Indices

An attempt was made to assess the trophic level of Newfound Lake by applying the phytoplankton quotients proposed by various authors. The Chlorophycean quotient suggested by Thunmark (1945), and the Myxophycean, Diatom, Euglenine, and Compound quotients developed by Nygaard (1949) were used. A summary of the index values and the suggested trophic status for Newfound Lake is found in Table 5. Calculations were based on yearly records of species, as well as distinct seasonal periods (i.e. summer and winter). Values for indices other than the Diatom index were not calculated for the winter, since Nygaard considered them applicable only to summer collections. A summary of the quotients and their interpretations is as follows:

QUOTIENT	OLIGOTROPHIC	EUTROPHIC
Chlorophycean = $\frac{\text{Chlorococcales}}{\text{Desmidieae}}$	< 1.0	> 1.0
Myxophycean = $\frac{\text{Myxophyceae}}{\text{Desmidieae}}$	< 0.4	$0.1 - 3.0$
Diatom = $\frac{\text{Centrales}}{\text{Pennales}}$	< 0.3	> 0.3
Euglenine = $\frac{\text{Euglenine}}{\text{Myxo. + Chlor.}}$	< 0.2	$0.0 - 1.0$
Compound = $\frac{\text{Myxo. + Chlor. + Cent. + Euglen.}}{\text{Desmidieae}}$	< 1.0	> 2.5

The results shown in Table 5 are conflicting and the designation of the trophic status of Newfound Lake depends upon the type of index used and the time for which it is calculated. The simple Chlorophycean index and the Euglenine index tend to classify the lake as oligotrophic. However, the Myxophycean, Diatom, and Compound indices place it as a mesotrophic or eutrophic lake. An interpretation of the significance of these results can be found in the discussion.

ECOLOGY OF PHYTOPLANKTON AT WINNISQUAM LAKE

Description of Area and Environmental Factors

Winnisquam Lake is located at approximate 43° 32' N latitude and 71° 31' W longitude. It is 1,725 hectares in area and has a maximum depth of 50 meters (Newell, 1963). The origin and basic morphometry are similar to that of Newfound Lake. The northern portion of the lake is underlain by medium to coarse grained biotite-quartz monzonite, while the bedrock in the southern portion is composed of micaceous quartzite and coarse grained mica schist (Billings, 1956).

Philip J. Sawyer (personal communication) has also studied the limnological characteristics of Winnisquam Lake. His data have shown that it is a soft-water lake. The pH ranged from 6.2-7.2, except during an extreme bloom of Aphanizomenon flos-aquae, when a value of 10.2 was recorded. Methyl orange alkalinity values ranged from 5.0 - 11.0 ppm. No phenolphthalein hardness was recorded except during bloom conditions. The oxygen values ranged from 100% saturation at the surface to complete oxygen depletion in the hypoliminion during the summer months. Total dissolved solids ranged from 55 - 75 ppm.

The seasonal cycle of temperature at Winnisquam Lake was similar to that at Newfound Lake (compare Figs. 3 & 10). The maximum summer surface temperatures at Winnisquam Lake ranged between 23.0 and 25.0 C, and after the summer there was a steady decrease in temperatures until the fall overturn. During the winter of 1967 the temperatures under the ice showed an inverse stratification similar to that in Newfound Lake. The spring overturn occurred during April, and relatively isothermal conditions existed until early June. Thereafter, the summer stratification began to develop. The maximum summer surface temperatures were reached later in 1967 than in 1966. In addition, the complete overturn in the fall of 1967 did not occur until much later.

Figure 4 illustrates the seasonal variation of light penetration at Winnisquam Lake. Because the total standing crop at Winnisquam Lake was much greater than at Newfound Lake, the light penetration at Winnisquam Lake was reduced. During 1966, the light penetration ranged from 7.0 to 10.0 meters, depending on seasonal variations of the standing crop. The maximum ice (60.0 cm) and snow cover (22.8 cm) at Winnisquam Lake was recorded on March 3, and at this time the 1% light level ranged between 4.2 and 5.8 meters. During April, the ice cover had just disappeared and the maximum spring standing crop was recorded. The light penetration reached its lowest value (3.2 meters) at this time. The occurrence of a large amount of particulate matter also contributed to the low transparency. Summer transparencies were comparable to the previous summer. During the fall, the light penetration decreased drastically, corresponding to the time of the fall phytoplankton bloom.

Figures 11 - 13 summarize the seasonal values of nutrients (orthophosphate, nitrate nitrogen, and silicon dioxide) at Winnisquam Lake. The mean orthophosphate values were .035 mg/l at 1 meter, .036 mg/l at 5 meters, and .051 mg/l at 10 meters. During 1966 the orthophosphate concentrations ranged from .124 mg/l on September 12 to .019 mg/l on September 28. In 1967 the values ranged from maxima of .079 mg/l (September 6) and .076 mg/l (April 17) to minima of .012 mg/l (August 1) and .015 mg/l (March 3). At 1, 5, and 10 meters there were similar seasonal trends and only slight differences were evident at the depths sampled.

The mean nitrate nitrogen concentrations were .087 mg/l at 1 meter, .096 mg/l at 5 meters, and .122 mg/l at 10 meters. During 1966 they ranged from .201 mg/l (June 25) to .012 mg/l (September 12). In 1967, maxima of approximately .210 mg/l occurred from March through early April and in September. The minimum values (approximately .030 mg/l) occurred from late June through August. The nitrate concentrations at the three sampling depths showed a similar pattern, except during September, 1967, when the amount at 10 meters rose to .205 mg/l. The concentrations at 10 meters were very high throughout September, but decreased again by October 16.

The mean silicon dioxide concentrations recorded during the study were .286 mg/l meter, .274 mg/l at 5 meters, and .266 mg/l at 10 meters. During June, July, and August, 1966 the values ranged from .160 to .220 mg/l. They decreased to a low of .030 mg/l on September 28, but they rose again during late fall. The maximum silicon dioxide concentration recorded during 1967 was .520 mg/l on March 3. After March the concen-

trations decreased and eventually leveled off during June, July, and August. A late fall peak (.400 mg/l) was recorded on November 3. The silicon dioxide concentrations recorded at different depths were quite variable, probably reflecting differences in utilization at the particular depths.

Species Composition

One hundred and forty-three species of algae were identified from the plankton at Winnisquam Lake, Several species, however, were considered transitory members in the open water - e.g. some of the filamentous green algae (Mougeotia, Oedogonium, and Spirogyra), certain species of Oscillatoria, and the diatom Cymbella. Table 6 summarizes all of the species found and their periodicity of occurrence.

The green algae contributed the most species to the phytoplankton at Winnisquam Lake - e.g. ninety-three species were members of the Chlorophyceae. There were 32 desmid species found. Other major contributing groups were the Bacillariophyceae (14 species), Chrysophyceae (13 species), and Cyanophyceae (10 species). The lake also had a large number of ephemeral species; they contributed to the marked fluctuations in the species composition throughout the year. Only 21 species were present in all of the 29 collections made during the study. These persistent species included a few members from all of the algal classes present. The majority of the ephemeral species were members of the Chlorophyceae. In general, the summer phytoplankton flora of Winnisquam Lake was composed of a large number of species of Chlorophyceae and filamentous Cyanophyceae. In the spring and fall, the Bacillariophyceae,

Chrysophyceae, and Chlorophyceae (mainly desmids), contributed the largest number of species. Diatoms were the major components of the winter flora.

Seasonal Periodicity of Standing Crop

Figure 14 summarizes the total standing crop at Winnisquam Lake, while Figure 15 shows the major components of the total phytoplankton. Each point on Figures 14 and 15 represents the mean value of four depths (1, 3, 5, and 10 meters) and three stations, i.e. 12 collections. The mean monthly cell counts for the major species contributing to the standing crop are also depicted in Table 7.

The total standing crop was much higher during 1967 than in 1966; in some cases the difference was as great as 1.0×10^7 cells/l. Large populations of algae, chiefly blue-green, occurred during July and August, 1966. A maximum of 2.2×10^6 cells/l was found on August 8. The populations then decreased to their lowest points ($.7 \times 10^6$ cells/l) during August and September. A second pulse (1.7×10^6 cells/l) was recorded after the fall overturn; it was primarily composed of blue-green algae and diatoms. The fall pulse was then followed by a gradual decline in the standing crop.

During February and March of 1967, the standing crop (mainly diatoms) was at its lowest point (between .45 and $.55 \times 10^6$ cells/l). A rapid increase in the phytoplankton numbers of all algal groups occurred after the spring overturn. By April 29, a maximum of 9.0×10^6 cells/l was found. A rapid decline in numbers then ensued and a summer low of 1.3×10^6 cells/l was recorded on June 2. Although the cell counts

recorded on June 2 were relatively low for 1967, they were still higher than most of the 1966 records. The standing crop increased rapidly throughout the summer and fall and reached a maximum of 1.7×10^8 cells/l on September 29. At this date, most of the standing crop consisted of Aphanizomenon flos-aquae and it remained very high until the study was terminated in November.

The Cyanophyceae and Chlorophyceae were the major phytoplankton components at Winnisquam Lake. A blue-green maximum of 1.5×10^6 cells/l (chiefly Anabaena flos-aquae) was recorded on August 8, 1966, and a smaller peak of $.68 \times 10^6$ cells/l (mostly Aphanizomenon flos-aquae) occurred in October 12. During February and March of 1967 a substantial population of Oscillatoria limnetica developed under the ice. Their cell numbers increased rapidly after the spring overturn and a peak of 3.6×10^6 cells/l was recorded on April 29. A peak of 3.2×10^6 cells/l occurred on July 6, 1967; it consisted mostly of Anabaena flos-aquae and Aphanizomenon flos-aquae. The final pulse began in early August an a maximum of 1.7×10^6 cells/l was recorded on September 29 (almost entirely Aphanizomenon flos-aquae).

The Chlorophyceae were another major group contributing to the total standing crop at Winnisquam Lake. One major peak (1.5×10^6 cells/l) was observed on July 18, 1966; it was composed chiefly of Gloeocystis vesiculosa and Eudorina elegans. The populations then leveled off during the rest of the summer and fall, and cell counts of $.3 - .5 \times 10^6$ cells/l were recorded. This late summer and fall population also had Dictyosphaerium pulchellum, Staurastrum pingue, and

Schroederia judayi as important contributors. The green algal populations were at their lowest point during February and March, 1967. After the spring overturn their cell numbers increased drastically and a maximum of 2.1 x 10^6 cells/l was found on April 29. Almost all of the material at this time was Ankistrodesmus falcatus var. mirabilis. The standing crop then gradually decreased until a second pulse occurred during July and August. The summer maximum of 1.6 x 10^6 cells/l was observed on August 1; it was primarily composed of Dictyosphaerium pulchellum and Gloeocystis vesiculosa. The population of green algae then decreased rapidly to a low level which was maintained until the termination of the study.

The members of the Bacillariphyceae contributed significantly to the winter, spring and late fall standing crop. During the summer of 1966, the populations were generally low until August. At this time, there was an increase in Tabellaria fenestrata var. fenestrata and a peak of approximately .13 x 10^6 cells/l was found from September 12 to October 12. The maximum diatom standing crop (.64 x 10^6 cells/l) occurred on November 23, and it consisted chiefly of Fragilaria crotonensis, Asterionella formosa var. formosa, and Melosira italica.

The winter diatom populations were somewhat lower than those recorded during the fall and they were primarily composed of Melosira italica, Asterionella formosa var. formosa, and A. formosa var. gracillima. The diatom population increased during April and it reached a peak of 2.3 x 10^6 cells/l)on April 29. The total population then decreased to an early summer low; however, Synedra ulna reached its maximum standing crop (.18 x 10^6 cells/l) on May 11. The standing crop

recorded during the summer of 1967 was different from that of 1966. Peaks of Fragilaria crotonensis were observed on July 21 (.35 x 10^6 cells/1) and on August 1 (.22 x 10^6 cells/1). There was then a steady decline in the diatom population and no significant fall diatom pulse occurred.

The Chrysophyceae contributed insignificantly to the total standing crop at Winnisquam Lake. Synura uvella and Dinobryon spp. were the most important individuals of the class. Small peaks were recorded in June and July of 1966, and a high of .22 x 10^6 cells/1 was found on October 12, Synura uvella contributed .19 x 10^6 cells/1 to this peak. During 1967, the populations were even lower than in 1966. Peaks of of Synura uvella were recorded on August 1 (.10 x 10^6 cells/1) and on August 11 (.12 x 10^6 cells/1). The populations of Chrysophyceae were scarcely detectable during the fall of 1967.

The Cryptophyceae were at their peak during the spring overturn. The major contributors were Rhodomonas lacustris and Cryptomonas ovata; although other species of Cryptomonas were evident at the time. Their standing crop was fairly uniform throughout 1966 except for a small peak of .24 x 10^6 cells/1 which was recorded on October 12. The population was very low during the winter of 1967, but a rapid increase of Rhodomonas lacustris occurred immediately after the ice melted. The population reached a plateau of about .80 x 10^6 cells/1 on April 29, and it remained at this level throughout May. There was then a rapid decline in the Cryptophycean population and it remained at a low level until the end of the study.

Only one species of the Dinophyceae, Ceratium hirundinella, was consistently found in the cell counts, but several other ephemeral were also recorded. The largest population of Dinophyceae was found on September 12 (.024 x 10^6 cells/1) and on September 28 (.048 x 10^6 cells/1). The standing crop recorded during 1967 was never as high as that observed in 1966.

Effects of Copper Sulphate Treatment on The Standing Crop

The natural sequence of development at Winnisquam Lake was altered on July 21, 1967 when 0.5 ppm. of copper sulphate were added by the New Hampshire Water Supply and Pollution Control Commission, to control a bloom of Anabaena flos-aquae and Aphanizomenon flos-aquae. Collections made before and on the day of application revealed that the blue-green algal populations had reached their peak of 3.2 x 10^6 cells/1 on July 6, and they were decreasing at the time of application. In contrast, the populations of Chlorophyceae, Bacillariophyceae, and Cryptophyceae were increasing before the application. Our records indicated that the total standing crop increased from 3.5 x 10^6 cells/1 on July 21 to 3.8 x 10^6 cells/1 on August 1. Several species decreased in numbers, but certain green algal populations continued to increase. The most striking example was Distyosphaerium pulchellum which increased from .27 x 10^6 cells/1 to 1.03 x 10^6 cells/1. Gloeocystis vesiculosa also increased (from .39 x 10^6 to .51 x 10^6 cells/1). The diatom and cryptomonad populations decreased. The blue-green populations decreased slightly and 1.8 x 10^6 cells/1 were recorded on August 1. However, the standing

crop of Aphanizomenon flos-aquae then began to increase and a maximum of 1.7×10^8 cells/l was recorded on September 29. This was the highest value recorded for a phytoplankton population during the study. The population of Aphanizomenon flos-aquae remained very high until the termination of the study. During the same period all of the other algal groups eventually decreased in abundance, and the normal fall pulsatation did not occur.

Vertical Distribution of Standing Crop

Table 8 summarizes the vertical distribution of the standing crop at Winnisquam Lake. In contrast to the vertical distribution at Newfound, the largest portion of the standing crop at Winnisquam Lake occurred in the upper five meters. A large percentage of the phytoplankton occurred below 5 meters when populations were declining and sinking out of the photic zone. The vertical distributions of the standing crop also depended upon the periodicity of major phytoplankton groups. When there was a large population of blue-green algae the largest number of organisms usually occurred near the surface, but when diatoms were dominant the maximum numbers occurred lower in the water column.

Although the largest numbers of Cyanophyceae usually occurred at 1, 3, and 5 meters, at times they were observed in abundance at lower depths. For example, Oscillatoria limnetica showed a conspicuous seasonal difference in its vertical distribution. During late February and early March large populations were present in the upper three meters. By the end of March it had settled to 10 and 15 meters - even though it was still increasing in numbers. With the onset of the spring overturn, a

large portion of the population was brought to the surface where it increased rapidly. The standing crop of Oscillatoria limnetica then decreased, sank to lower depths and finally disappeared from the photic zone. The large bloom of Aphanizomenon flos-aquae, which occurred during the fall of 1967, did not appear to react in the same manner. On September 6 it was found in very large numbers at 1, 3, and 5 meters. During late September and October some of the population moved to 10 meters, with the decline and eventual decomposition of the alga occurring in the upper 10 meters.

The members of the Chlorophyceae were more evenly distributed within the upper ten meters than the Cyanophyceae. However, when large blooms of blue-green algae were found at the surface, the maximum vertical distribution of the green algae was reduced. An interesting vertical distribution was found in Closteriopsis longissima. During the ice-free periods, it was always confined to the 15 and 20 meter samples, and it was often found in relatively large numbers well below the 1% surface light level. The only time it was found higher in the water column (5 meters) was during February under the ice. Such observations imply that low light and/or low temperature are critical in determining its distribution. Staurastrum pingue also appeared to reach maximum numbers at greater depths than most green algae. Although it was found near the surface, its maximum population densities usually occurred at 10 meters.

During times of peak numbers the members of the Bacillariophyceae showed a maximum numbers of cells at 5 and 10 meters. When they began to decline they slowly sank. A striking example of this was Melosira italica. During September, 1966 it was present in substantial

quantities and at lower depths (15 and 20 meters). The alga was evenly distributed throughout the water column after the fall overturn; it was also at this point that peak numbers were reached. The population began to sink after the ice cover had formed and by March 20, it was confined again to 15 and 20 meters. With the onset of the spring overturn the alga again appeared in large numbers throughout the water column, and it was at this time that the maximum densities were reached. The population steadily settled out of the photic zone during the spring and summer. It was difficult to assess whether other diatoms showed this type of movement.

Members of the Cryptophyceae occurred mainly in the surface waters. The largest portions of their standing crop usually occurred above 5 meters. However, during the spring and fall overturns they tended to become more uniformly distributed.

It was difficult to distinguish any distributional pattern for members of the Chrysophyceae and Dinophyceae since their standing crop was very low and they were very sporadic in occurrence. During peak populations, Synura uvella tended to reach maximum numbers at 5 and 10 meters.

Occurrence of Reproductive Spores

Table 4 summarizes the reproductive periodicity of six species of phytoplankton at Winnisquam Lake. Akinetes were almost always found during the summer on Anabaena flos-aquae, Anabaena Scheremetievi, and Gloeotrichia echinulata. No correlation was evident between akinete formation and environmental factors. Akinetes were found on

Aphanizomenon flos-aquae from September through November, 1967. The akinetes first appeared when the standing crop of this alga had reached its highest level during the study. Dinobryon cylindricum formed statospores in April, May and early June of 1967. These dates were somewhat earlier than those recorded for this species at Newfound Lake. However, as at Newfound Lake, the statospores were produced during the peak of the standing crop. The nutrient levels were also decreasing, but they were not as low as those recorded at Newfound Lake. There was another peak of Dinobryon cylindricum at Winnisquam Lake during June and July, 1966, but there was no formation of statospores. Auxospores were found on Melosira italica during the peak of the standing crop (April 29, 1967), and they were present until early June when many of the spores were germinating. Auxospore formation occurred only on the smallest filaments, i.e. those ranging from 3.2 to 5.6 microns in diameter.

Calculation of Phytoplankton Quotients

The phytoplankton quotients proposed by Thunmark (1945) and Nygaard (1949) were also applied to Winnisquam Lake. A summary of the values and the proposed trophic status is given in Table 9. The Myxophycean and Euglenine indices classified the lake as oligotrophic. However, the Chlorophycean, Compound, and Diatom indices placed it as a mesotrophic or eutrophic lake. The index values were quite variable and depended on the algal groups employed and the time of year the data were obtained.

DISCUSSION

The differences in the total standing crop at the two lakes can be correlated with their differences in nutrient concentrations. Phosphate appears to be the most important limiting factor for algal growth at Newfound Lake. Hutchinson (1967) stated that phosphate is the limiting factor in many unproductive lakes. The primary factors limiting growth at Winnisquam Lake are probably light, temperature, and possibly extracellular substances; nutrients are usually not limiting. According to Lund (1965), the phosphate concentration in artificially enriched lakes is so high, that it may play a lesser role in controlling phytoplankton populations. Steeman-Nielsen (1955) has proposed that if a lake is very rich in nutrient, light may be the main limiting factor, especially in the fall. In New Hampshire lakes, temperature appears to control the initiation and cessation of growth of certain algal populations.

The total standing crop at Newfound Lake reached higher levels during the summer of 1966 than in 1967. The higher standing crop was correlated with slightly higher levels of phosphate in the surface waters during 1966. In contrast, the standing crop at Winnisquam Lake was higher during the summer and fall of 1967 than in 1966. The higher standing crop was correlated with increased nitrate and phosphate concentrations. Apparently the nutrients were liberated by many of the algae after the lake had been treated with copper sulfate.

A large standing crop (mainly diatoms) was developed during the spring at Winnisquam Lake; this is typical of temperate lakes. High concentrations of nutrients were present during the winter, and after the

light increased, the algal populations increased rapidly. The maximum standing crop (mainly Chrysophyceae) at Newfound Lake did not occur during the spring, but developed during early summer. There was a definite uptake of phosphate and nitrate by the phytoplankton during the winter and spring. However, a long lag period then occurred until the proper light and/or temperature requirements were reached for these organisms. These differing maxima may, perhaps, be explained in terms of differing species compositions at the two lakes.

The vertical distribution of the standing crop was chiefly a function of light penetration and the types of algal populations present. Since the standing crop at Winnisquam Lake was large and primarily composed of blue-green algae, the light penetration was reduced. Thus, the largest percentage of organisms occurred in the upper five meters. There also appeared to be little light inhibition of algal growth at the lake surface. At Newfound Lake, light inhibition appeared to occur near the surface, since very low cell numbers were recorded from the one meter samples. The transparency at this lake was much greater and a large percentage of organisms occurred lower in the water column. Suppression of the actively growing zone could have had an effect on the development of the standing crop, since many of the algae had to grow at lower temperatures.

Pearsall (1932) observed that diatom populations in English Lakes were limited by silicon concentrations below .500 mg/1. In contrast, the silicon concentrations at Winnisquam Lake were seldom more than .500 mg/1, but diatom populations were extensive and increased even when the silicon levels were below .100 mg/1. Lund (1949, 1950) found that if

other nutrients were not limiting, diatom populations would continue to increase. Such may be the case at Winnisquam Lake where phosphate and nitrate levels were very high. Jorgensen (1957) found that the lower limits for diatom growth were between .03 - .04 mg/l silicon; these are similar to the lower limits observed at Winnisquam Lake. The silicon concentrations at Newfound Lake were very high, and except for brief periods during the winter, they were always well above .500 mg/l. However, large diatom populations were never recorded and this was probably due to the low phosphate concentrations.

Specific diatom populations had different factors controlling their growth. Peaks of Asterionella formosa occurred at Winnisquam Lake shortly after maximum nitrate and silicon concentrations. However, the phosphate concentrations preceding the population peaks were generally low. A possible explanation has been presented by Mackereth (1953). He found in culture that there was a rapid uptake of phosphate by Asterionella formosa before any appreciable growth in the population was detected. At Newfound Lake, this same alga showed a similar pattern. Decreases in populations at both lakes were associated with decreases in nutrients. In addition, parasitism by chytrid fungi, as suggested by Canter and Lund (1948), possibly contributed to the decreases in the populations.

Maxima of Tabellaria fenestrata were usually reached later in the spring and earlier in the fall than most of the other diatoms. The populations at both lakes initiated growth when the phosphate and nitrate concentrations were low. In the two New Hampshire lakes, it

appears that Tabellaria fenestrata had a preference for lower nutrient concentrations than other diatoms.

Another factor that contributed to the seasonal diatom fluctuations was the sinking phenomenon studied extensively by Lund (1954, 1955). He found that Melosira italica subsp. subartica was brought to the surface during the spring and fall overturns, reached peak development, and then quickly sank out of the photic zone when less turbulent conditions occurred. Melosira italica at Winnisquam Lake and Melosira islandica at Newfound Lake also followed this type of pattern. Fragilaria crotonensis did not show the same development, since large numbers occurred during the summer stratification period.

Lund (1965) stated that lakes with low phosphorus content should have a large Chrysophyte population. At Newfound Lake, Dinobryon cylindricum, D. Bavaricum, D. vanhoeffenii, Chrysosphaerella longispina, and Uroglenopsis americana began development in early summer, when the phosphate concentrations were low. At Winnisquam Lake, Synura uvella increased when the phosphate and nitrate concentrations were low, while Dinobryon cylindricum did not increase substantially until after the vernal maximum. Hutchinson (1944) found similar results for Dinobryon divergens in Linsey Pond, Connecticut. He and other works (Bamforth, 1958; Rodhe, 1948; and Lund, 1965) have shown that the increase in Chrysophyceae standing crop was associated with low phosphate concentrations.

The Cyanophyceae populations at the two lakes were floristically distinct. Members of the Chroococcales were abundant at Newfound Lake and reached peak numbers during the summer. They initiated growth when

the surface temperatures increased and their maximum standing crop was recorded when the temperatures were between 15.0 and 20.0 C. No apparent correlations were noted between nutrient concentrations and the initiation of peak numbers. The Cyanophyceae populations at Winnisquam Lake also reached maximum numbers in the summer, although Oscillatoria limnetica increased greatly under the ice. A number of workers, including Eberly (1967) have found large quantities of Oscillatoria spp. at low light intensities and temperatures. The larger standing crop of Oscillatoria limnetica in April, October, and November indicates that optimum growth conditions are not restricted to the winter months.

Hammer (1964) studied lakes in Saskatchewan, Canada and found that blooms of Anabaena flos-aquae usually appeared one or two weeks after phosphate peaks and when the water temperatures were between 15.0 and 20.0 C. Similar results were recorded at Winnisquam Lake, except that temperatures were higher (22.0 - 25.0 C) and the blooms occurred later in the season. Hammer (1964) also found that blooms of Aphanizomenon flos-aquae developed after the Anabaena flos-aquae blooms. Aphanizomenon was rarely present until the temperatures reached 20.0 C and most blooms appeared at temperatures of 22.5 - 26.5 C. The alga appeared also to be influenced directly by the phosphate concentrations. During the fall of 1966, Aphanizomenon flos-aquae initiated its growth at Winnisquam Lake approximately two weeks after high phosphate concentrations were recorded. The surface water temperatures ranged between 12.0 and 21.0 C. The population decline was correlated with a decrease in temperature. The alga was present throughout the winter and began to increase again during the early spring. However, substantial numbers

were not recorded until the surface water temperatures had reached 20.0 C. Peak numbers were recorded when the temperatures ranged between 21.0 and 22.0 C. The initial growth was again associated with high concentrations of phosphate.

Aphanizomenon flos-aquae decreased slightly after the lake was treated with copper sulphate and then it increased to very high numbers. Copper sulphate treatment killed most of the Anabaena flos-aquae population and certain of the green algal populations. As a result, large amounts of nutrients were released into the surface waters. A very large peak of Aphanizomenon flos-aquae occurred after five to six weeks and few other algae were present. The low standing crop of other organisms could have been due to the shading effect of the large blue-green algal population. However, more probably it was due to an antagonistic substance released by Aphanizomenon. The abundance of Aphanizomenon appeared to restrict the occurrence of a diatom pulse in the fall of 1967. Lefevre (1964) has reviewed the subject of extracellular products of algae and he has stated that Aphanizomenon flos-aquae releases substances which inhibit the growth of other algae. Shortly after Aphanizomenon began to decrease at Winnisquam Lake, other algae again began to increase.

The Chlorophyceae were more abundant at Winnisquam Lake than at Newfound Lake. Peaks of Ankistrodesmus falcatus var. mirabilis, Dictyosphaerium pulchellum, and Eudorina elegans occurred shortly after high phosphate and nitrate concentrations were recorded. The very large populations of Dictyosphaerium pulchellum occurred immediately after the copper sulphate treatment. The highest nitrate concentrations

were recorded during the winter at Winnisquam Lake. As the ice disappeared and light intensity increased, Ankistrodesmus falcatus var. mirabilis reached its maximum standing crop.

Lackey (1938, 1941) found that Cryptomonas ovata, Cryptomonas erosa, and Rhodomonas lacustris were inhibited by high concentrations of sewage. All three species were found in substantial quantities at both lakes. The initiation of their peaks could not be correlated with low nutrient levels. During the summer, Cryptomonas ovata and Rhodomonas lacustris developed peak numbers when the phosphate levels were low; but in the spring and fall, the initiation of pulses were associated with high nutrients. It is not possible to make exact comparisons with those of Lackey, since he did not include quantitative nutrient data.

The species composition of the two lakes was quite different and it is presumed to be dependent upon the trophic levels of the lakes. Seventy-three species were found exclusively at Winnisquam Lake. Of these, the dominant species were Aphanizomenon flos-aquae, Gleoetrichia echinulata, Oscillatoria limnetica, Ankistrodesmus falcatus var. mirabilis, Eudorina elegans, Gloeocystis vesiculosa, Scenedesmus spp., Schroederia judayi, Staurastrum pingue, Staurastrum johnsonii, and Melosira italica. Forty-two species were found exclusively at Newfound Lake, of which the dominants were Aphanothece clathrata, Gloeothece linearis, Merismopedia punctata, Merismopedia tenuissima, Cosmarium bioculatum, Staurastrum pentacerum, Staurodesmus bulnheimii, Staurodesmus cuspidatus var. curvatus, Dinobryon vanhoeffenii, Mallomonas tonsurata var. alpina, Cyclotella bodanica, Melosira islandica, Peridinium inconspictum, and

Peridinium willei. One-hundred and thirty-three species were common to both lakes. Of these, Anabaena flos-aquae and Dictyosphaerium pulchellum are generally considered to be eutrophic species, but they were also found in very small quantities at Newfound Lake. The following species were abundant at Newfound Lake, but were found in abundance at Winnisquam Lake only during periods of low nutrients: Dinobryon bavaricum, D. cylindricum, Chrysosphaerella longispina, Synura uvella, Uroglenopsis americana, Gloeobotrys limnetica, and Rhizosolenia eriensis.

Two points must be considered when indicator organisms are selected. First, species which are found exclusively in a particular environment should be considered. Secondly, species that are dominant in a particular trophic situation should also be considered - even though they are found in other situations. For example, Hutchinson (1967) has reviewed most of the literature on indicator organisms and has pointed out that a number of workers have considered Dinobryon cylindricum var. palustre and Dinobryon bavaricum var. vanhoeffenii (D. vanhoeffenii in this study) as oligotrophic species. Dinobryon spp. can be considered oligotrophic indicators in New Hampshire lakes, even though Dinobryon cylindricum was found in the eutrophic situation. More detailed information about other New Hampshire lakes would be required to verify the possible indicators mentioned above, although most of the organisms suggested have also been proposed by several European workers (Brook, 1968 ; Jarnefelt, 1952; Nygaard, 1949; Round and Brook, 1959; Teiling, 1955; and Thunmark, 1945). However, there was some disagreement with the findings of other authors. Jarnefelt (1956) found one eutrophic lake in Finland which was dominated by Cosmarium bioculatum. In New

Hampshire the alga was found only in the oligotrophic lake. Rawson (1956) considered Asterionella formosa as an oligotrophic species in Saskatchewan lakes,although most European workers consider it to be associated with higher trophic levels. In both New Hampshire lakes it was relatively abundant at all times of the year, but it was usually associated with high nutrient levels. Lackey (1941) considered Cryptomonas ovata and Rhodomonas lacustris as oligotrophic indicators in rivers. However, these organisms showed a preference for higher nutrient levels in the lakes studied in New Hampshire. Round and Brook (1959) found that Dictyosphaerium pulchellum showed a preference for oligotrophic lakes in Ireland. In New Hampshire the alga was most abundant in the eutrophic lake.

Rawson (1956) has suggested that the rarer species would be more indicative of trophic status than the dominant species. If Rawson's assumption is correct, the species that are present for extended periods would probably be the best ones to use as indicators. Taking this into account, possible rare indicator organisms at Newfound Lake would then be Dinobryon crenulatum, D. suecium, Mallomonas pseudocoronata, Diceras phaseolus, and Peridinium wisconsiense, while at Winnisquam Lake they could be Closteriopsis longissima, Kirchneriella lunaris, Kirchneriella obesa var. aperta, Schroederia setigera, and Synura adamsii. However, the designation of these species as indicators is highly speculative, and many more lakes would have to be investigated in order to obtain an accurate assessment of their usefulness.

The phytoplankton quotients proposed by Thunmark (1945) and Nygaard (1949), which give equal value to dominant are rare organisms, were

applied to the New Hampshire lakes. Most of the indices calculated, correctly designated Winnisquam Lake as eutrophic. However, they gave a very poor characterization of Newfound Lake. It has been shown (Tables 5 and 9) that the simple Chlorophycean quotient of Thunmark was the only one that adequately described the trophic status of both lakes. It was reliable because the Chlorococcalean populations had many more species at Winnisquam Lake than at Newfound Lake. The Diatom Index did not give an accurate determination of trophic status because the species of diatoms were similar at both lakes. The Myxophycean Index was not accurate because the numbers of species of blue-green algae at the two lakes was comparable. The Euglenine Index was not applicable, since there were very few members of this group in the eutrophic lake (two species of Colacium and one Euglena.) The Compound Index was also erroneous, for many of the above reasons. In addition, the emphasis upon desmids in the Compound Quotient gave an inaccurate determination of the trophic status of Newfound Lake. Nygaard assumed that many species of desmids were restricted to oligotrophic waters, but in New Hampshire, a larger number of species of desmids were found in the eutrophic situation. Hutchinson (1967) has stated that "the prevalence of a large number of desmids is probably directly determined by low calcium rather than by deficiency of nitrogen and phosphorus"; this might explain the similarity in the number of desmid species at the two lakes. Calcium was present only as calcium bicarbonate in both lakes except during peak blooms at Winnisquam.

Data collected in this study suggest that species composition, abundance, and periodicity should be taken into account when determin-

ing the usefulness of indicators. Species of diatoms could not be used as indicators in the two New Hampshire lakes (with the possible exception of Melosira italica and M. islandica) because most of the same species occur at both lakes. However, with information about their abundance and periodicity, some indication of trophic status at the lakes can be determined. Dinobryon spp. and other species of Chrysophyceae appear to be good oligotrophic indicators, since they occurred in abundance at Newfound Lake and were rare at Winnisquam Lake. The Cyanophyceae populations were distinct at the two lakes and in this case could be used as indicators. Winnisquam Lake was dominated by filamentous blue-green algae, which are generally considered to be eutrophic indicators. Even though Anabaena flos-aquae occurred in small quantities at Newfound Lake, this should not eliminate it as a eutrophic indicator. The blue-green population at Newfound Lake was primarily composed of members of the Chroococcales. Certain members of the Chroococcales might be used as oligotrophic indicators, but more work must be done to determine their trophic requirements. The Chlorococcales as a whole, appear to be good indicators of eutrophic situations, because a large number of species occurred at Winnisquam Lake while very few species were found at Newfound Lake. The present study concludes that members of the Cryptophyceae can not be used satisfactorily as indicators.

Although it is difficult to draw definite conclusions from a study of two lakes, the detailed nutrient and phytoplankton data has led to the following suggestions. It is felt that Nygaard definitely improved the quotient concept by developing the Compound Quotient. However, as Hutchinson (1957) and Rawson (1956) have suggested, it is unfortunate

that he based the entire denominator on one group of organisms (desmids). If other groups could be added to the denominator, the index would probably become more reliable for New Hampshire lakes. In particular, the number of species of Chrysophyceae could be added. Also, the separation of the Centrales into its eutrophic (Stephanodiscus, Melosira, etc.) and oligotrophic (Cyclotella, etc.) components may be advantageous. Another suggestion would be to integrate the abundance of organisms with the number of species in determining the phytoplankton index. Quantitative measurement could be calculated as relative abundance of species in the particular lake, or as absolute numbers of organisms. Thus, differences in standing crop would be considered. Jarnefelt (1956) has developed a quotient based on a quantitative approach and it worked well in Finnish Lakes. However, his quotient can not be used until a large number of lakes from a particular area have been investigated, and thus it was not applied in New Hampshire.

SUMMARY

The relationships between composition, periodicity, and abundance of phytoplankton species and the trophic status of two lakes in New Hampshire were investigated. Newfound Lake is oligotrophic, while Winnisquam Lake is eutrophic. During the study the following conclusions were reached:

1) The differences in the total standing crop at the two lakes were correlated with their differences in nutrient concentrations. Orthophosphate appeared to be the primary limiting factor of algal growth at Newfound Lake, while light, temperature, and possibly extracellular products were the primary limiting factors at Winnisquam Lake.

2) A large vernal maximum, typical for temperate lakes, was recorded at Winnisquam Lake. Newfound Lake has no vernal peak and the maximum phytoplankton development was delayed until early summer. The differing maxima may be explained in terms of differing species composition at the two lakes.

3) The vertical distribution of the standing crop was a function of light penetration and the types of algal populations. The maximum standing crop at Winnisquam Lake occurred higher in the water column than at Newfound Lake. Light inhibition of algal growth appeared to occur near the surface at Newfound Lake.

4) A discussion of the factors influencing the periodicity, abundance, and distribution of phytoplankton species at the two lakes is presented, and the results are compared with findings of other authors.

5) The species composition appeared to be dependent upon the trophic levels of the lakes. Dominant species were considered to be the best indicators of trophic status and a list of possible indicator organisms is given. A summary of possible rare indicators is also included.

6) The phytoplankton quotients proposed by Thunmark and Nygaard were applied to the lakes. Most of the indices correctly designated Winnisquam Lake as eutrophic, but incorrectly characterized Newfound Lake. Thunmark's Chlorophycean Quotient was the only quotient that adequately described both lakes. An evaluation of the phytoplankton quotients is given.

7) It is suggested that the species composition, abundance, and periodicity of phytoplankton should be considered when determining indicator organisms. A few other suggestions are given for improving phytoplankton quotients.

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Table 1

Seasonal Occurrence of Phytoplankton - Newfound Lake

	1966						1967									
CYANOPHYCEAE	J	J	A	S	O	N	F	M	A	M	J	J	A	S	O	N
Anabaena flos-aque (Lyngb.) De Breb.		X	X	X	X	X						X	X	X	X	X
Aphanothece Clathrata G. S. West	X	X	X	X	X	X						X	X	X	X	X
Chroococcus limneticus Lemm.	X	X	X	X	X	X						X	X	X	X	X
Chroococcus minimus (Keissl.) Lemm.			X	X	X	X						X	X	X	X	X
Gloeothece linearis Naegeli	X	X	X	X	X	X						X	X	X	X	X
Gomphosphaeria aponina var. delicatula Virieux	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Gomphosphaeria lacustris Chodat	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Gomphosphaeria lacustris var. compacta Lemm.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Merismopedia punctata Meyen	X	X	X	X	X	X					X	X	X	X	X	X
Merismopedia tenuissima Lemm.	X	X	X	X	X	X						X	X	X	X	X
CHLOROPHYCEAE																
Ankistrodesmus falcatus var. acicularis (Braun) G. S. West		X	X	X	X							X	X	X		
Botryococcus braunii Kuetzing	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Botryococcus protuberans var. minor G. M. Smith	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Closterium parvulum Naegeli											X					
Closterium kuetzingii De Breb.		X				X	X				X					
Coelastrum microporum Naegeli	X	X							X	X	X	X				
Cosmarium bioculatum De Breb.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Cosmarium contractum var. papillatum W. & G. S. West	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Cosmarium punctulatum De Breb.		X	X	X	X	X						X	X	X	X	X
Crucigenia rectangularis (Braun) Gay	X	X	X	X	X	X	X	X				X	X	X	X	X
Desmidium swartzii C. A. Agardh.											X					

Table 1 - continued

	1966						1967									
	J	J	A	S	O	N	F	M	A	M	J	J	A	S	O	N
Dictyosphaerium pulchellum Wood	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Elakatothrix viridis (Snow) Printz	X	X	X	X	X	X	X	X			X	X	X	X	X	
Euastrum didelta (Turp.) Ralfs.															X	X
Euastrum pulchellum De Breb.	X	X	X	X	X	X					X	X	X	X	X	X
Gloeocystis gigas (Kuetz.) Lagerheim	X	X	X	X	X							X	X	X	X	
Gonatozygon monotaenium De Bary				X												
Gonatozygon pilosum Wolle			X	X												
Gymnozyga moniliformis Ehr.														X		
Hyalotheca dissiliens (Smith) De Breb.		X	X		X	X					X	X	X		X	
Nephrocytium limneticum (Smith) Smith			X	X	X									X	X	
Oocystis borgei Snow	X	X	X	X			X			X	X	X	X	X	X	X
Pediastrum boryanum (Turp.) Meneghini	X	X									X	X				
Pediastrum boryanum var. longicorne Raciborski					X											
Pediastrum simplex var. duodenarium (Bailey) Rabenh.											X					
Quadrigula closterioides (Bohlin) Printz	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Scenedesmus serratus (Corda) Bohlin	X	X	X	X	X	X					X	X	X	X	X	X
Sphaerocystis schroeteri Chodat		X	X									X	X			
Spondylosium planum (Wolle) W. & G. S. West				X											X	X
Staurastrum ankyroides Wolle				X												
Staurastrum arctiscon (Ehr.) Lund.				X												
Staurastrum limneticum var. cornutum G. M. Smith			X	X	X								X	X	X	X
Staurastrum pentacerum (Wolle) Smith	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Staurodesmus bulnheimii (Racib.) Brook														X		
Staurodesmus cuspidatus (West) Teiling	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Staurodesmus extensus (Borge) Teiling	X	X	X	X	X	X	X				X	X	X	X	X	X
Staurodesmus incus var. ralfsii (West) Teiling							X	X	X	X	X					

Table 1 - continued

	1966 J	J	A	S	O	N	1967 F	M	A	M	J	J	A	S	O	N
Staurodesmus mamillatus (Nordst.) Teil.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Staurodesmus megacanthus (Lund.) Thunm.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Staurodesmus subtriangularis (Borge) Teil.			X	X	X	X	X	X			X	X	X	X	X	X
Stylosphaeridium stipitatum (Bachm.) Geitler & Gimesi		X	X	X	X							X	X	X		
Tetraedron limneticum Borge													X			
Xanthidium antilopaeum var. polymazum Nordst.					X											
EUGLENOPHYCEAE																
Colacium arbuscula Stein	X	X	X	X	X	X			X	X	X	X	X	X	X	X
Colacium vesiculosum Ehrenberg		X	X	X	X	X	X	X		X	X	X	X	X	X	X
XANTHOPHYCEAE																
Gloeobotrys limneticus (Smith) Pascher				X	X	X							X	X	X	X
Ophiocytium capitatum Wolle					X	X								X	X	X
CHRYSOPHYCEAE																
Chrysophaerella longispina Lauterborn	X	X	X	X	X	X					X	X	X	X	X	X
Diceras phaseolus Fott	X	X			X						X			X	X	
Dinobryon bavaricum Imhof	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Dinobryon crenulatum W. & G. S. West	X	X			X	X				X	X			X	X	X
Dinobryon cylindricum Imhof	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Dinobryon divergens Imhof	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Dinobryon sertularia Ehrenberg	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Dinobryon suecicum Lemm.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Dinobryon vanhoeffenii (Krieg.) Bachm.		X	X	X	X	X					X	X	X	X	X	X
Epipyxis tabellariae (Lemm.) Smith					X	X									X	X
Epipyxis utriculus Ehrenberg			X	X	X	X							X	X	X	

Table 1 - continued

	1966 J	J	A	S	O	N	1967 F	M	A	M	J	J	A	S	O	N
Mallomonas acaroides Perty					X	X									X	X
Mallomonas fastigata Zach.			X	X	X	X						X	X	X	X	X
Mallomonas producta (Zach.) Iwanoff		X	X	X								X	X	X	X	
Mallomonas pseudocoronata Prescott	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Mallomonas tonsurata var. alpina (Pasch. & Ruttn) Krieger	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Mallomonas sp.					X	X									X	X
Synura uvella Ehrenberg	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Uroglenopsis americana (Calkins) Lemm.	X	X	X	X								X	X	X	X	X
BACILLARIOPHYCEAE																
Asterionella formosa Hass.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Asterionella formosa var. gracillima (Hantz.) Grun.							X	X	X	X						
Cyclotella bodanica Eulenst.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Cyclotella comta (E.) Kg.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Cyclotella glomerata Bachm.					X		X	X	X	X	X			X	X	X
Fragilaria capucina Desm.		X	X	X	X	X	X				X	X	X	X	X	X
Fragilaria crotonensis Kitton	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Melosira distans (E.) Kg.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Melosira islandica O. Muller	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Rhizosolenia eriensis H. L. Smith	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Synedra ulna (Nitz.) Ehr.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Tabellaria fenestrata (Lyngb.) Kuetz.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Tabellaria flocculosa (Roth) Kuetz.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
DINOPHYCEAE																
Ceratium hirundinella (Muell.) Dujardin	X	X	X	X	X	X					X	X	X	X	X	X
Gonyaulax palustris Lemm.							X	X	X	X	X					
Gymnodinium fuscum (Ehrenb.) Stein	X				X	X	X	X	X	X	X	X		X	X	X

Table 1 - continued

	1966						1967									
	J	J	A	S	O	N	F	M	A	M	J	J	A	S	O	N
Gymnodinium palustre Schilling							X	X	X							
Gymnodinium sp.							X	X								
Peridinium cinctum (Muell.) Ehren.					X	X							X	X	X	X
Peridinium inconspicuum Lemm.		X	X	X	X							X	X	X	X	
Peridinium limbatum (Stokes) Lemm.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Peridinium willei Huitfeld-Kaas	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Peridinium wisconsinense Eddy		X	X	X	X							X	X	X	X	
CRYPTOPHYCEAE																
Cryptomonas erosa Ehren.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Cryptomonas erosa var. reflexa Marsson							X	X	X		X					
Cryptomonas marssonii Skuja				X	X	X							X	X		X
Cryptomonas ovata Ehren.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Rhodomonas lacustris Pascher & Ruttner	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Table 2

Summary of Major Phytoplankton Components (1 x 10^5 cells/l

Newfound Lake

	1966 J	J	A	S	O	N	1967 F	M	A	M	J	J	A	S	O	N
Aphanothece clathrata	.15	.07	1.65	2.32	.55	.05	-	-	-	-	-	-	.05	.08	.17	-
Gloeothece linearis	.30	.18	.41	.11	.26	.04	-	-	-	-	.04	.06	.05	.06	.31	.60
Gomphosphaeria lacustris	.97	1.60	2.80	3.35	1.62	1.15	.40	.32	.37	.37	.49	1.55	3.27	2.32	1.35	1.95
Merismopedia tenuissima	-	1.13	.26	.70	.11	.03	-	-	-	-	-	.07	.05	.11	.28	.12
Botryococcus braunii	.12	.14	.09	.08	.04	.21	.16	.20	.10	.08	.07	.25	.09	.04	.03	.01
Crucigenia rectangularis	.02	.05	.05	.04	.03	.02	-	-	-	.01	.03	.04	.01	.03	.05	.03
Gloeocystis gigas	.14	.20	.09	.07	.01	-	-	-	-	-	.05	.12	.03	.23	.02	-
Chrysosphaerella longispina	.06	1.15	2.56	.07	.01	.21	-	-	-	-	-	.02	.11	.04	.01	.26
Dinobryon bavaricum	.02	.47	.11	.07	.27	.25	.04	.01	.01	.04	1.47	1.24	.19	.01	.01	.01
Dinobryon cylindricum	.10	.26	.02	.02	.15	.79	.04	.01	.01	.01	.23	.59	.19	.02	.06	.04
Dinobryon vanhoeffenii	-	.11	.09	.01	-	-	-	-	-	-	-	.19	.32	.02	-	-
Synura uvella	-	-	-	-	-	.06	.15	.08	.11	.12	.03	-	.13	.04	.13	.02
Uroglenopsis americana	-	-	7.12	1.00	.08	-	-	-	-	-	-	1.15	.16	.08	-	-
Asterionella formosa	.16	.95	.32	.03	.14	.11	.45	.33	.46	.29	.04	.03	.22	.72	.08	.01
Cyclotella bodanica	.19	.11	.12	.04	.02	.06	.01	.01	.01	-	-	.03	.06	.09	.02	.02
Melosira	.02	.05	.04	.04	.24	.20	.20	.11	.46	.39	.05	.05	.04	.03	.02	.08
Rhizosolenia eriensis	.03	.58	.38	.06	.02	.01	.01	.01	.02	.04	.02	.53	.40	.06	.01	.01
Tabellaria fenestrata	.01	.01	.11	.12	.07	.03	-	-	.01	.08	.02	.01	.03	.02	.20	.09
Cryptomonas ovata	.02	.09	.23	.19	.14	.09	.07	.07	.04	.04	.02	.15	.09	.11	.06	.11
Rhodomonas lacustris	.01	.02	.02	.08	.57	.91	.21	.10	.26	.16	.02	.02	.06	.19	.34	.89

Table 3

Vertical Distribution of Phytoplankton - Percent of Total Standing Crop

Newfound Lake

	1966 J	J	A	S	O	N	1967 F	M	A	M	J	J	A	S	O	N
1 meter	19	15	14	19	11	13	11	11	17	13	48	21	6	13	17	11
3 meters	26	19	25	20	12	17	15	23	27	16	25	21	8	12	22	19
5 meters	27	34	28	22	16	17	32	31	12	23	16	25	15	19	20	27
10 meters	18	26	27	20	25	18	32	22	14	17	7	22	38	34	19	22
15 meters	9	5	4	9	23	20	10	13	15	16	3	10	21	21	21	13
20 meters	1	1	2	10	13	15	-	-	15	15	1	1	12	1	2	8

Table 4

Summary of Reproductive Spore Periodicity

Organism	Reproductive Spore	1966 J	J	A	S	O	N	1967 F	M	A	M	J	J	A	S	O	N
NEWFOUND LAKE																	
Anabaena flos-aquae	akinete		X	X	X	X							X	X	X	X	
Dinobryon bavaricum	statospore											X	X				
Dinobryon cylindricum	statospore					X	X					X	X				
WINNISQUAM LAKE																	
Anabaena flos-aquae	akinete		X	X	X	X	X					X	X	X	X		
Anabaena scheremetievi	akinete					X	X							X	X		
Aphanizomenon flos-aquae	akinete														X	X	X
Gloeotrichia echinulata	akinete		X	X	X								X	X			
Dinobryon cylindricum	statospore								X	X	X						
Melosira	auxospore								X	X	X						

Table 5

Summary of Phytoplankton Indices and Proposed Trophic Status

Newfound Lake

	Yearly	Summer	Winter	Trophic Status
Chlorophycean Index	.46	.24 - .94	-	oligotrophic
Myxophycean Index	.46	.46 - 1.00	-	eutrophic
Diatom Index	.85	.85 - 1.20	1.00	eutrophic
Euglenophyta Index	.03	.03 - .05	-	oligotrophic
Compound Index	1.20	.96 - 2.55	-	meso-eutrophic

Table 6

Seasonal Occurrence of Phytoplankton - Winnisquam Lake

	1966						1967									
CYANOPHYCEAE	J	J	A	S	O	N	F	M	A	M	J	J	A	S	O	N
Anabaena flos-aquae (Lyngb.) De Breb.	X	X	X	X	X	X				X	X	X	X	X		
Anabaena scheremetievi Elenkin					X	X							X	X		
Aphanizomenon flos-aquae (L.) Ralfs	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Gloeotrichia echinulata (J. E. Smith) Rich.		X	X	X								X	X			
Gomphosphaeria aponina var. delicatula Virieux	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Gomphosphaeria lacustris var. compacta Lemm.				X	X	X							X	X	X	X
Oscillatoria granulata Gardner	X	X	X	X	X					X	X	X	X	X		
Oscillatoria limnetica Lemm.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Spirulina laxa G. M. Smith		X	X									X	X	X		
Tolypothrix lanata Wartmann			X	X	X	X							X	X		
CHLOROPHYCEAE																
Ankistrodesmus falcatus (Corda) Ralfs		X	X	X							X	X	X	X		
Ankistrodesmus falcatus var. acicularis (A. Braun) G. S. West			X	X							X	X	X			
Ankistrodesmus falcatus var. mirabilis (West & West) G. S. West	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Botryococcus braunii Keutzing	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Botryococcus protuberans var. minor G. M. Smith							X	X	X	X	X					
Characium curvatum G. M. Smith		X	X	X									X	X		
Characium gracilipes Lambert			X	X									X	X		
Characium limneticum Lemm.		X	X	X								X	X	X		
Chlorangium stentorinum (Ehren.) Stein		X	X										X			
Closteriopsis longissima Lemm.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Table 6 Continued

	1966 J	J	A	S	O	N	F	M	A	M	J	J	A	S	O	N
Closterium acerosum (Shrank) Ehren.				X		X					X					
Closterium dianae Ehren.								X	X	X	X	X	X			
Closterium kuetzingii De Breb.	X	X				X			X	X						
Closterium moniliferum (Bory) Ehren.											X	X				
Closterium parvulum Naegeli																
Coelastrum microporum Naegeli	X	X	X	X	X	X					X	X	X	X	X	X
Cosmarium contractum var. papillatum W. & G. S. West	X	X	X	X	X	X					X	X	X	X	X	X
Cosmarium punctulatum De Breb.			X	X	X								X	X	X	X
Crucigenia rectangularis (Braun) Gay				X	X	X						X	X			
Desmidium baileyi (Ralfs) Nordst.		X	X											X	X	
Desmidium Swartzii C. A. Agardh.			X													X
Dictyosphaerium ehrenbergianum Naegeli				X	X									X	X	X
Dictyosphaerium pulchellum Wood	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X
Dimorphococcus lunatus A. Braun					X	X								X	X	X
Elakatothrix gelatinosa Wille	X	X	X	X	X	X					X	X	X	X		
Elakatothrix viridis (Snow) Printz		X	X	X	X	X	X	X				X	X	X	X	X
Eudorina elegans Ehren.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Gloeocystis ampla (Kuetz.) Lagerheim			X	X	X							X	X			
Gloeocystis gigas (Kuetz.) Lagerheim	X	X	X	X	X	X					X	X	X	X	X	X
Gloeocystis vesiculosa Naegeli		X	X	X	X	X						X	X	X	X	
Gonatozygon aculeatum Hastings			X	X												
Gonatozygon monotaenium De Bary													X			
Hyalotheca dissiliens (Smith) De Breb.				X	X	X								X		
Kirchneriella contorta (Schmidle) Bohl.																X
Kirchneriella lunaris (Kirch.) Moebius		X	X	X	X	X						X	X	X	X	X
Kirchneriella lunaris var. dianae Bohl.			X										X			
Kirchneriella obesa var. aperta (Teil.) Brunnthaler	X	X	X	X	X	X	X	X			X	X	X	X	X	X

Table 6 - continued

	1966						1967									
	J	J	A	S	O	N	F	M	A	M	J	J	A	S	O	N
Micrasterias radiata Hass.				X												
Micrasterias radiosa (Lyngbye) Agardh													X			
Mougeotia spp. (sterile)	X	X							X	X	X	X	X			
Nephrocytium ecdysiscepanum W. West																
Nephrocytium limneticum (Smith) Smith	X	X	X	X	X	X					X	X	X	X	X	X
Nephrocytium lunatum W. West			X	X	X							X	X	X		
Oedogonium spp. (sterile)	X	X	X	X	X					X	X	X	X	X		
Oocystis borgei Snow	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Oocystis elliptica W. West			X	X												
Oocystis lacustris Chodat					X	X										
Oocystis parva West & West		X	X	X								X	X			
Pediastrum araneosum (Racib.) Smith				X										X		
Pediastrum boryanum (Turp.) Meneghini	X	X	X	X	X	X			X	X	X	X	X	X	X	X
Pediastrum duplex Meyen	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Pediastrum duplex																
var. clathratum (Braun) Lagerheim	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X
Pediastrum duplex																
f. gracilimum West & West		X	X	X	X	X						X	X	X	X	X
Pediastrum tetras (Ehrenb.) Ralfs												X	X			
Pediastrum tetras																
var. tetraodon (Corda) Rabenhorst		X	X	X								X	X	X	X	X
Pleurotaenium trabecula (Ehrenb.) Naeg.			X			X										
Quadrigula closterioides (Bohlin) Printz	X	X	X	X	X	X					X	X	X	X	X	X
Quadrigula lacustris (Chodat) Smith			X	X	X							X	X	X		
Scenedesmus abundans (Kirch.) Chodat		X	X										X			
Scenedesmus acutiformis Schroeder												X				
Scenedesmus arcuatus																
var. platydisca Smith	X	X	X	X	X	X					X	X	X	X	X	X
Scenedesmus bijuga (Turp. Lagerheim		X	X									X				
Scenedesmus brasiliensis Bohlin	X	X	X	X	X						X	X	X	X	X	X

Table 6 - continued

	1966 J	J	A	S	O	N	1967 F	M	A	M	J	J	A	S	O	N
Scenedesmus dimorphus (Turp.) Kuetz.	X	X	X	X	X	X					X	X	X	X	X	X
Scenedesmus opoliensis Richter															X	X
Scenedesmus quadricauda (Turp.) De Breb.	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X
Scenedesums quadricauda var. parvus Smith			X	X									X			
Scenedesmus quadricauda var. westii Smith			X	X									X	X	X	
Schroederia judayi Smith	X	X	X	X	X	X					X	X	X	X	X	
Schroederia setigera (Schroed.) Lemm.	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X
Sorastrum spinulosum Naegeli				X									X	X	X	
Spaerocystis schroeteri Chodat	X	X	X	X	X				X	X	X	X	X	X		
Spirogyra spp. (sterile)	X	X	X	X	X	X			X	X	X	X	X	X		
Spondylosium planum (Wolle) W. & G. S. West	X	X	X	X							X	X	X	X	X	X
Staurastrum anatinum var. longibrachiatum W. & G. S. West			X	X	X	X		X	X	X	X	X	X	X	X	X
Staurastrum arctiscon (Ehren.) Lund											X					
Staurastrum cingulum (W. & G. S. West) Smith				X	X	X	X	X				X	X	X		
Staurastrum johnsonii W. & G. S. West	X	X	X	X	X	X	X	X			X	X	X	X	X	X
Staurastrum limneticum var. cornutum Smith			X	X	X	X							X	X		
Staurastrum manfeldtii Delp.			X	X	X	X										
Staurastrum pilosum Archer					X	X					X	X	X	X	X	
Staurastrum pingue Teiling	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Staurastrum pseudopelagicum W.& G.S. West	X	X	X	X	X	X					X	X	X	X		
Staurastrum vestitum Ralfs				X	X									X		
Staurodesmus dickiei (Ralfs) Lillier.										X	X					
Staurodesmus extensus (Borge) Teiling			X	X	X										X	X
Staurodesmus incus var. ralfsii (West) Teiling							X	X	X	X	X	X	X			
Staurodesmus mamillatus (Nordst.) Teil.		X	X	X	X							X	X	X	X	X

Table 6 - continued

	1966						1967									
	J	J	A	S	O	N	F	M	A	M	J	J	A	S	O	N
Staurodesmus megacanthus (Lund.) Thunm.	X	X	X	X					X	X	X	X	X	X	X	X
Staurodesmus subtriangularis (Borge) Teil.	X	X	X	X	X	X	X			X	X	X	X	X	X	X
Ulothrix subconstricta G. S. West	X	X	X	X	X	X					X	X	X	X	X	
Ulothrix tenerrima Kuetz.	X	X	X	X	X	X			X	X	X	X	X	X		
Ulothrix variabilis Kuetz.		X	X								X	X	X			
Xanthidium antilopaeum (De Breb) Kuetz.		X			X	X								X	X	X
EUGLENOPHYCEAE																
Colacium arbuscula Stein		X	X								X	X	X			
Colacium vesiculosum Ehren.			X	X	X	X	X	X	X	X	X	X	X			
Euglena spirogyra Ehren.			X													
XANTHOPHYCEAE																
Gloeobotrys limneticus (Smith) Pascher				X	X							X	X			
Stipitococcus capense Prescott		X	X	X								X	X			
CHRYSOPHYCEAE																
Chrysococcus sp.							X	X	X							
Chrysosphaerella longispina Lauterborn				X	X	X								X	X	X
Dinobryon bavaricum Imhof	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Dinobryon cylindricum Imhof	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Dinobryon divergens Imhof	X	X	X	X	X	X					X	X	X	X	X	X
Dinobryon sertularia Ehren.	X	X	X	X	X			X	X	X	X	X	X	X	X	X
Epipyxis tabellariae (Lemm.) Smith								X	X	X						
Mallomonas elegans Lemm.								X	X	X						
Mallomonas fastigata Zach.		X	X	X	X	X					X	X	X	X		
Mallomonas producta (Zach.) Iwanoff	X	X	X				X	X	X	X	X	X	X			
Synura adamisii Smith	X	X	X	X	X	X				X	X	X	X	X	X	X
Synura uvella Ehren.	X	X	X	X	X	X			X	X	X	X	X	X	X	X
Uroglenopsis americana (Calkins) Lemm.										X	X	X	X			

Table 6 - continued

	1966						1967									
	J	J	A	S	O	N	F	M	A	M	J	J	A	S	O	N
BACILLARIOPHYCEAE																
Asterionella formosa Hass.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Asterionella formosa var. gracillima (Hantz.) Grun.							X	X	X							
Cyclotella comta (E.) Kg.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Cyclotella stelligera Cleve & Grun.				X	X	X								X	X	
Cymbella ventricosa									X	X						
Fragilaria capucina Desm.								X	X	X	X					
Fragilaria crotonensis Kitton	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Melosira distans (E.) Kg.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Melosira italica (E.) Kg.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Meridion circulare var. constrictum (Ralfs) V. H.									X	X						
Rhizosolenia eriensis H. L. Smith	X						X	X	X	X	X					
Synedra ulna (Nitz.) Ehr.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Tabellaria fenestrata (Lyngb.) Kuetz.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Tabellaria flocculosa (Roth) Kuetz.									X	X	X					
DINOPHYCEAE																
Ceratium hirundinella (Muell.) Dujardin	X	X	X	X	X	X				X	X	X	X	X	X	X
Glenodinium aciculiferum (Lemm.) Lindem.								X	X	X	X					
Gymnodinium sp.								X	X	X	X					
Peridinium cinctum (Muell.) Ehren.	X	X			X	X	X	X	X	X	X	X		X	X	X
Peridinium limbatum (Stokes) Lemm.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
CRYPTOPHYCEAE																
Cryptomonas marssonii Skuja			X	X	X	X						X	X	X	X	X
Cryptomonas ovata Ehren.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Rhodomonas lacustris Pascher & Ruttner	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Table 7

Summary of Major Phytoplankton Components (1 x 10^5 cells/l)

Winnisquam Lake

	1966 J	J	A	S	O	N	1967 F	M	A	M	J	J	A	S	O	N
Anabaena flos-aquae	.03	1.92	5.33	.10	.01	-	-	-	-	-	.02	7.41	.16	.01	-	-
Aphanizomenon flos-aquae	-	-	.02	.58	5.03	.70	.17	.10	3.10	4.08	9.88	18.20	28.50	*	**	49.10
Oscillatoria limnetica	-	-	-	-	-	.01	.46	2.19	25.30	20.04	19.30	1.69	3.13	1.19	22.70	59.00
Ankistrodesmus falcatus var. mirabilis	.68	.02	.01	.01	.01	-	.18	.22	15.17	12.09	1.01	.21	.14	.03	.01	.01
Dictyosphaerium pulchellum	.42	.13	.49	2.30	.31	.02	-	-	-	.87	1.02	1.46	8.75	1.52	.22	.75
Eudorina elegans	.13	.52	.60	.29	.68	.22	-	-	.03	.05	.09	.15	.12	.07	.01	-
Gloeocystis vesiculosa	3.77	12.50	1.32	.53	1.58	.78	-	-	-	-	.18	2.01	3.06	1.25	.18	.18
Schroederia judayi	.03	.03	.10	.46	.31	.28	-	-	.01	.12	.11	.05	.01	.01	-	-
Staurastrum pingue	.02	.09	.12	.04	.43	.76	-	-	-	-	.05	.03	.02	.02	.01	-
Dinobryon cylindricum	.25	.38	.05	.02	.02	.03	-	-	.12	.12	.18	.02	.02	-	-	-
Synura uvella	.71	.66	.09	.02	1.02	.04	-	-	-	-	.02	.19	1.08	.14	-	-
Asterionella formosa	.06	.07	.21	.20	.38	1.72	.44	.24	3.50	.72	.76	.05	.04	.02	.01	.04
Fragilaria crotonensis	.01	.01	.11	.15	.76	2.74	.06	.05	.37	.29	.13	3.50	1.47	.06	.01	.08
Melosira	.05	.05	.16	.61	.92	.98	3.24	2.10	10.05	8.90	.21	.05	.05	.03	.02	.17
Synedra ulna	.01	.02	.01	.01	.02	.09	.15	.12	.33	1.85	1.54	.47	.04	.01	.01	.02
Tabellaria fenestrata	.01	.01	.27	1.18	.64	.31	.01	.01	.10	.40	.80	.12	.11	.08	.08	.30
Cryptomonas ovata	.39	.32	.35	.38	.97	.41	.08	.02	.08	.89	.42	.47	.13	.12	.05	.28
Rhodomonas lacustris	1.17	.42	.54	.47	.77	.32	.04	.03	4.81	6.28	6.54	.43	.08	.04	.01	.02

* 1.37 x 10^8 cells/l
** 1.05 x 10^8 cells/l

Table 8

Vertical Distribution of Phytoplankton - Percent of Total Standing Crop

Winnisquam Lake

	1966 J	J	A	S	O	N	1967 F	M	A	M	J	J	A	S	O	N
1 meter	26	27	47	26	25	16	5	20	21	23	39	45	28	31	28	38
3 meters	24	32	23	21	20	18	11	16	19	20	26	37	33	30	28	26
5 meters	23	28	18	18	21	15	37	17	18	19	19	12	19	32	23	18
10 meters	15	10	7	17	21	23	20	16	16	16	9	4	15	6	19	15
15 meters	8	2	3	9	7	15	18	16	15	11	5	1	4	1	1	2
20 meters	4	1	2	9	6	12	9	15	11	11	2	1	1	1	1	1

Table 9

Summary of Phytoplankton Indices and Proposed Trophic Status

Winnisquam Lake

	Yearly	Summer	Winter	Trophic Status
Chlorophycean Index	1.42	1.24 - 2.13	-	eutrophic
Myxophycean Index	.33	.27 - .50	-	oligo-mesotrophic
Diatom Index	.55	.44 - 1.00	.80 - 1.00	eutrophic
Euglenophyta Index	.03	.03 - .04	-	oligotrophic
Compound Index	2.00	1.60 - 2.90	-	meso-eutrophic

EXPLANATION OF PLATES (1-15)

Figure 1 - Map of Newfound Lake, New Hampshire

Figure 2 - Map of Winnisquam Lake, New Hampshire

Figure 3 - Seasonal Temperature Variations-Newfound Lake

Figure 4 - Seasonal Variations in Light Penetration-1% Level

Figure 5 - Total Phytoplankton-Newfound Lake

Figure 6 - Orthophosphate-Newfound Lake

Figure 7 - Nitrate Nitrogen-Newfound Lake

Figure 8 - Silicon Dioxide-Newfound Lake

Figure 9 - Major Phytoplankton Components-Newfound Lake

Figure 10 - Seasonal Temperature Variations-Winnisquam Lake

Figure 11 - Orthophosphate-Winnisquam Lake

Figure 12 - Nitrate Nitrogen-Winnisquam Lake

Figure 13 -- Silicon Dioxide-Winnisquam Lake

Figure 14 - Total Phytoplankton-Winnisquam Lake

Figure 15 - Major Phytoplankton Components-Winnisquam Lake

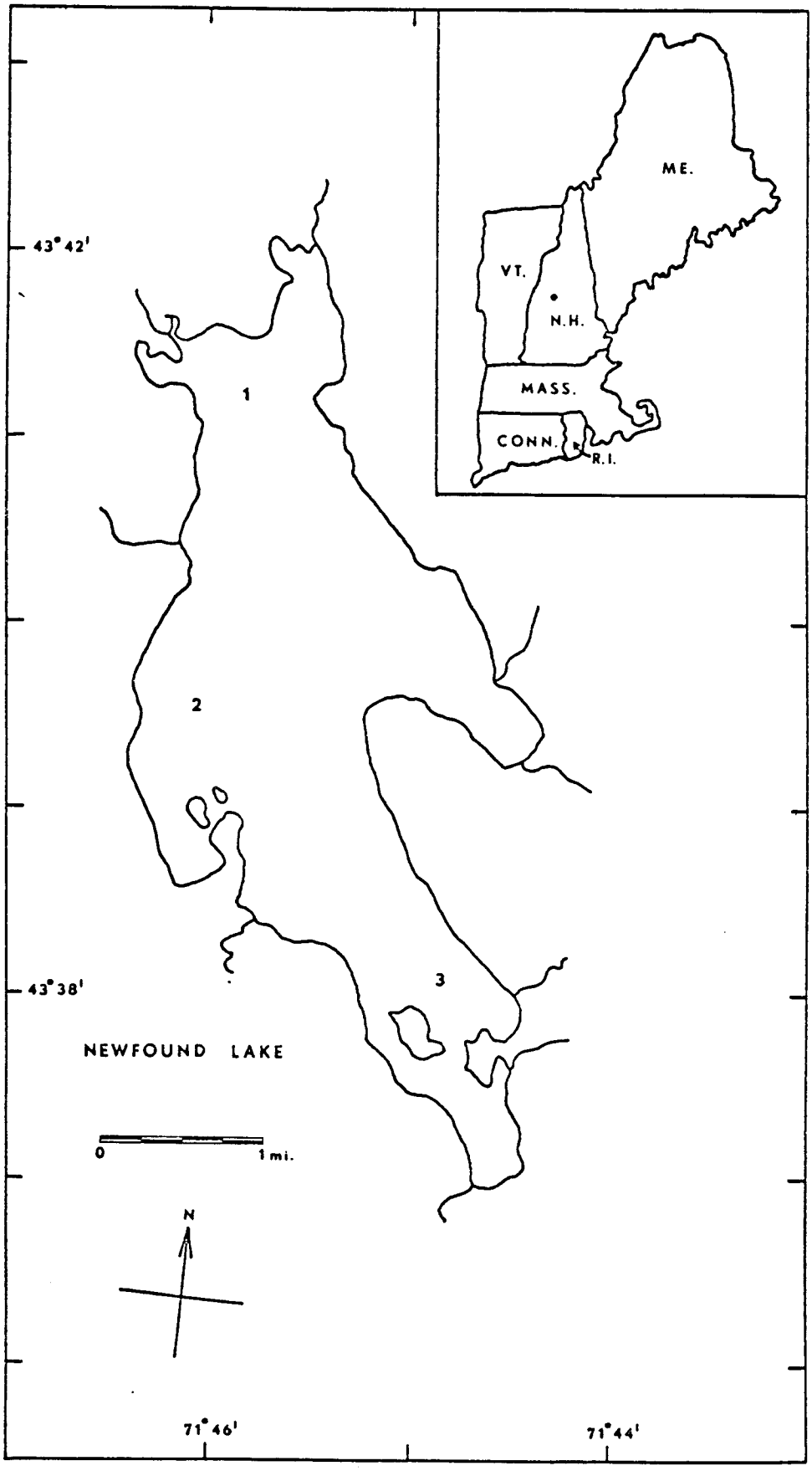
ME.
VT.
N.H.
MASS.
CONN.
R.I.
43°42'
43°38'
1
2
3
NEWFOUND LAKE
0
1 mi.
N
71°46'
71°44'

Figure 1

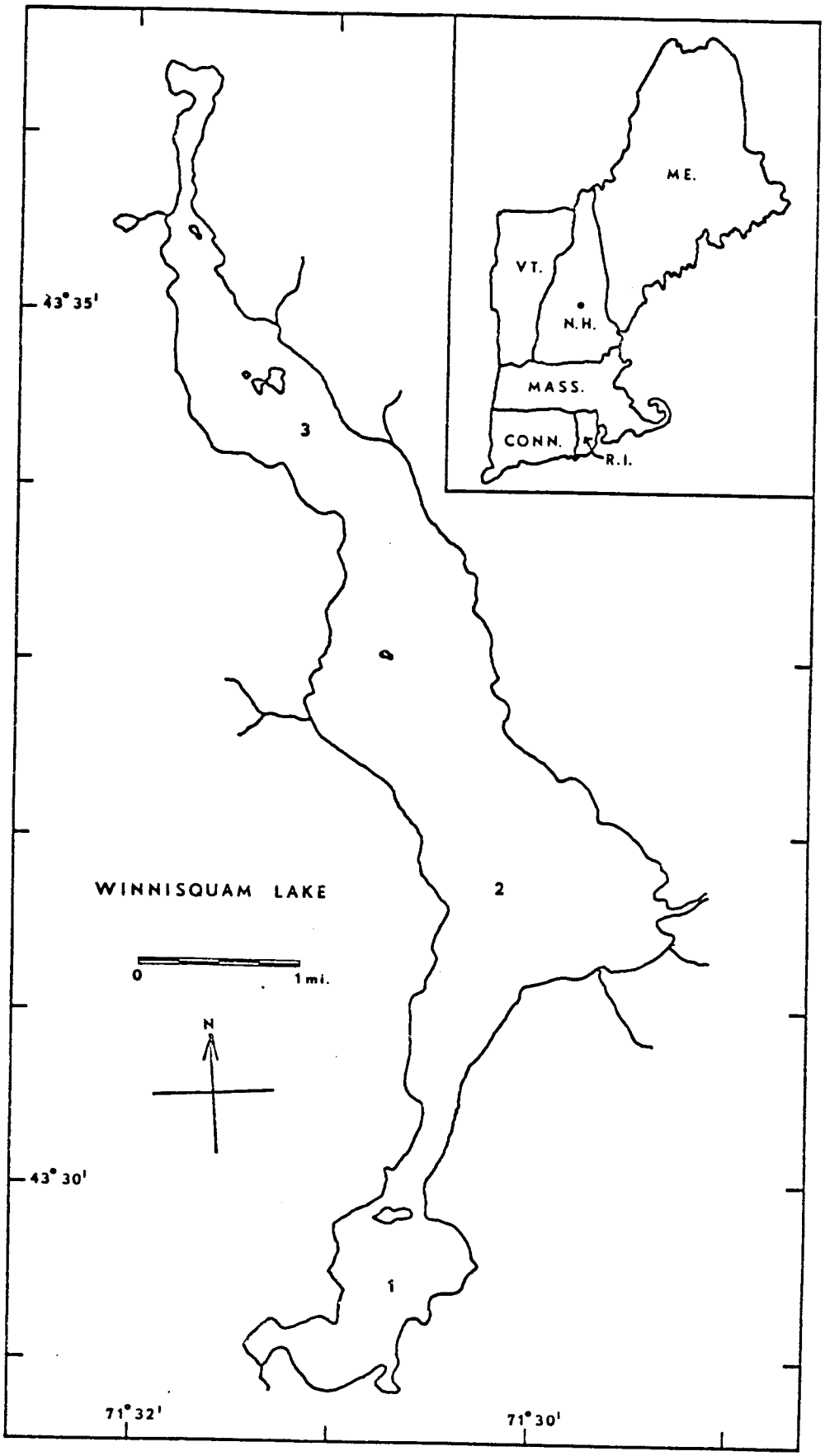
ME.
VT.
N.H.
MASS.
CONN.
R.I.
43° 35'
43° 30'
71° 32'
71° 30'
3
2
1
WINNISQUAM LAKE
0
1 mi.
N

Figure 2

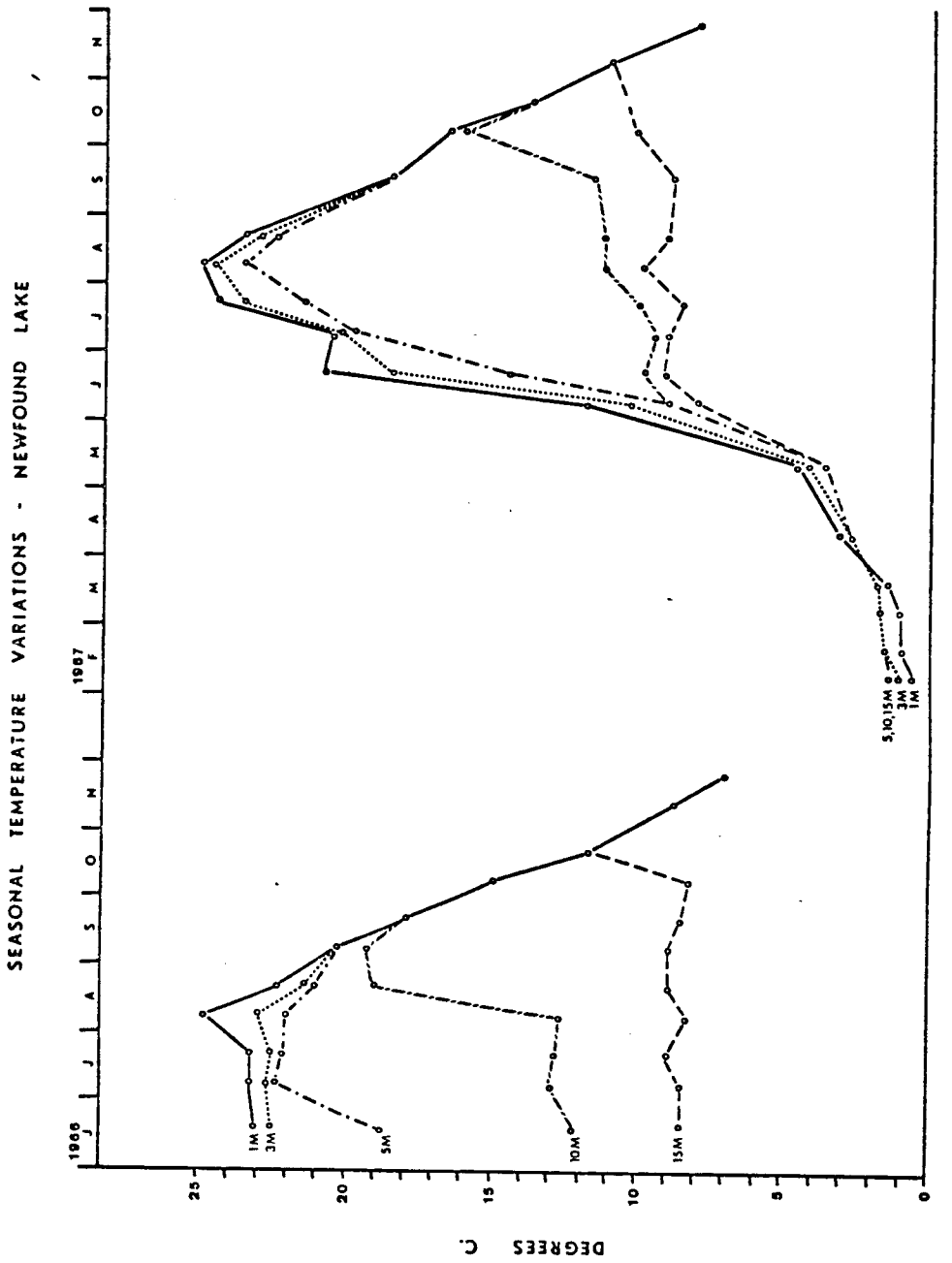
SEASONAL TEMPERATURE VARIATIONS - NEWFOUND LAKE
1966
J
J
A
S
O
N
1967
F
M
A
M
J
J
A
S
O
N
DEGREES C.
25
20
15
10
5
0
1M
3M
5M
10M
15M
5,10,15M
3M
1M

Figure 3

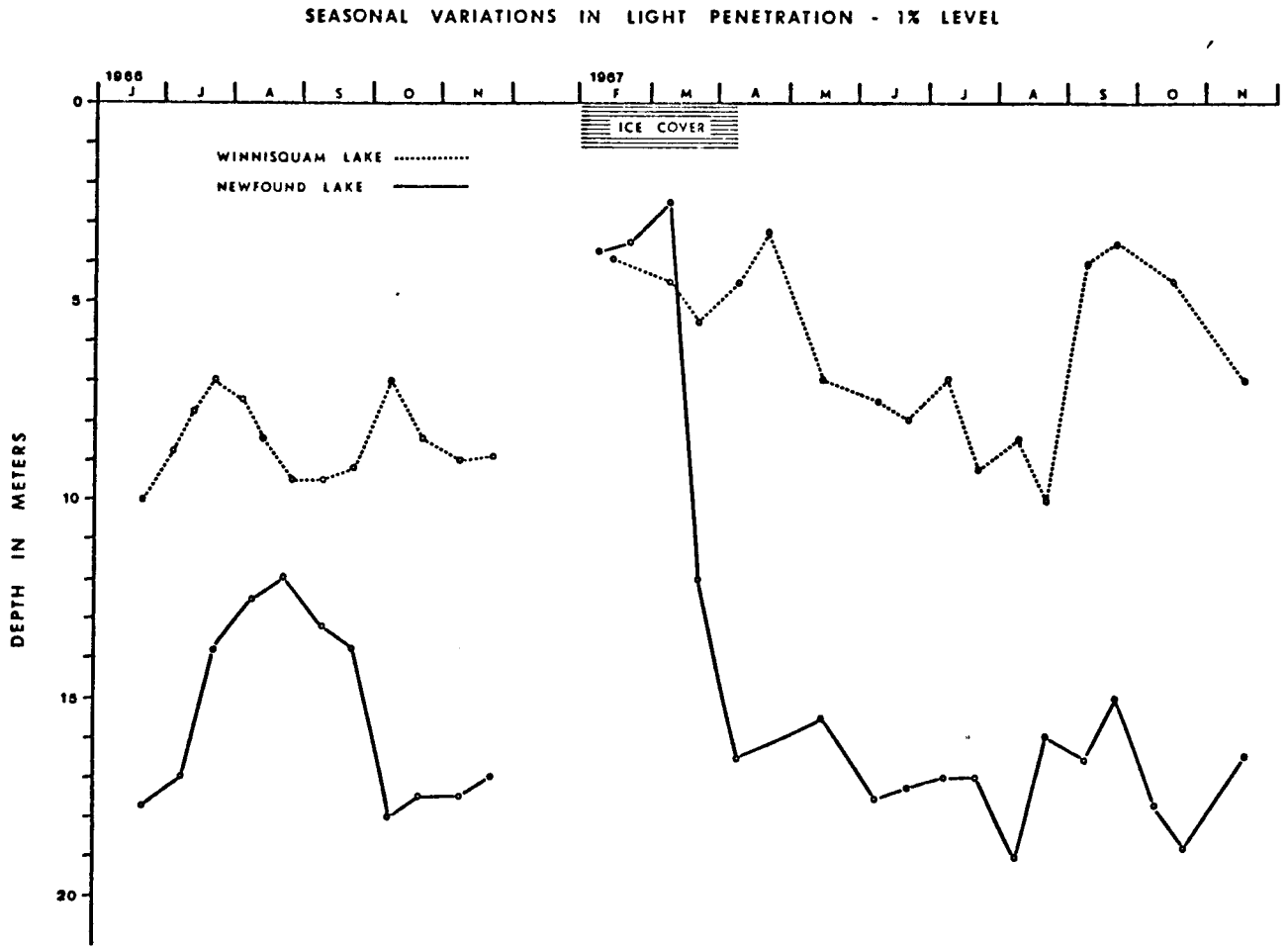
SEASONAL VARIATIONS IN LIGHT PENETRATION - 1% LEVEL
1966
J
J
A
S
O
N
1967
F
M
A
M
J
J
A
S
O
N
ICE COVER
WINNISQUAM LAKE
NEWFOUND LAKE
DEPTH IN METERS
0
5
10
15
20

Figure 4

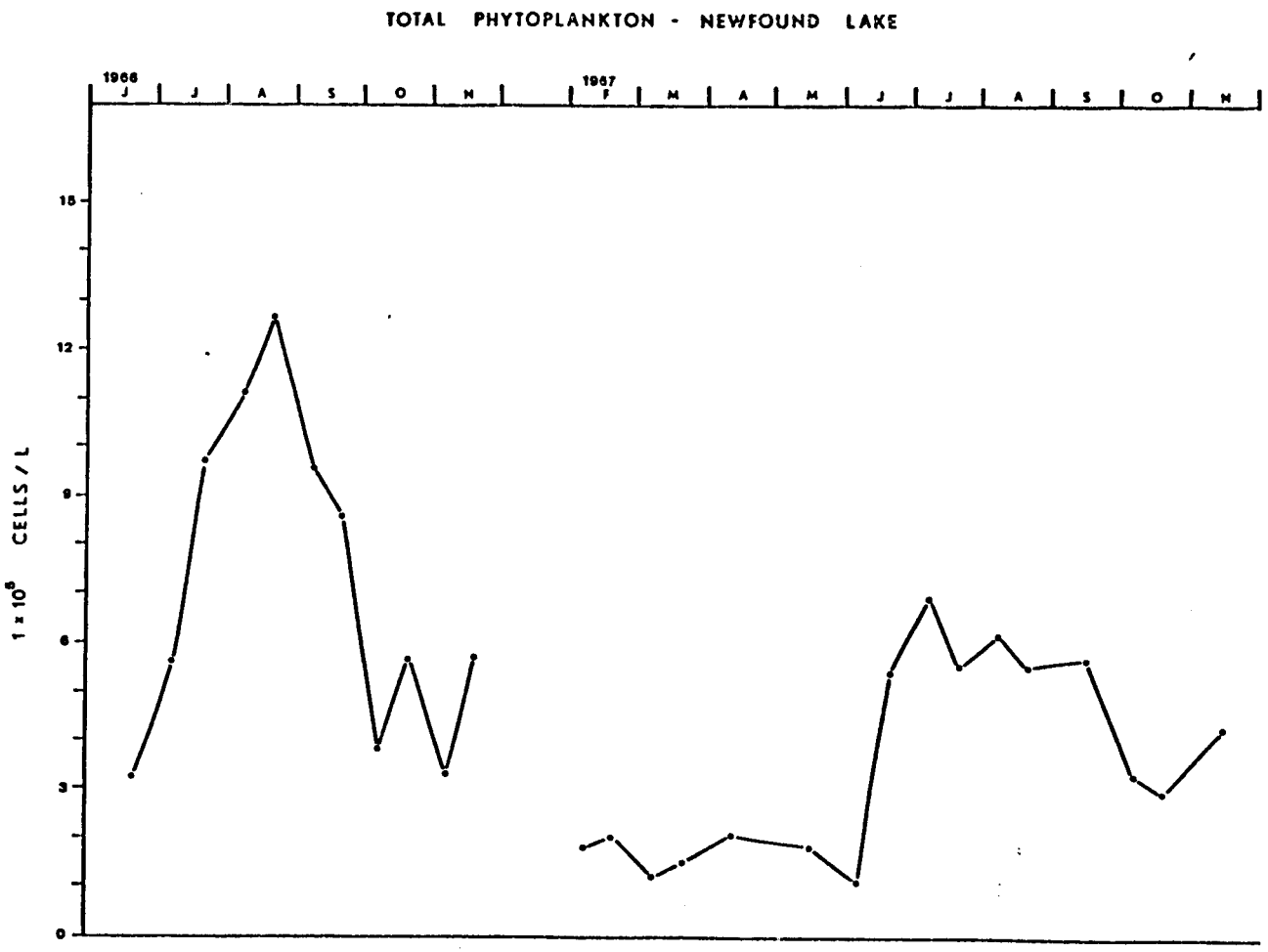
TOTAL PHYTOPLANKTON - NEWFOUND LAKE
1966
J
J
A
S
O
N
1967
F
M
A
M
J
J
A
S
O
N
15
12
9
6
3
0
1 x 10⁶ CELLS / L

Figure 5

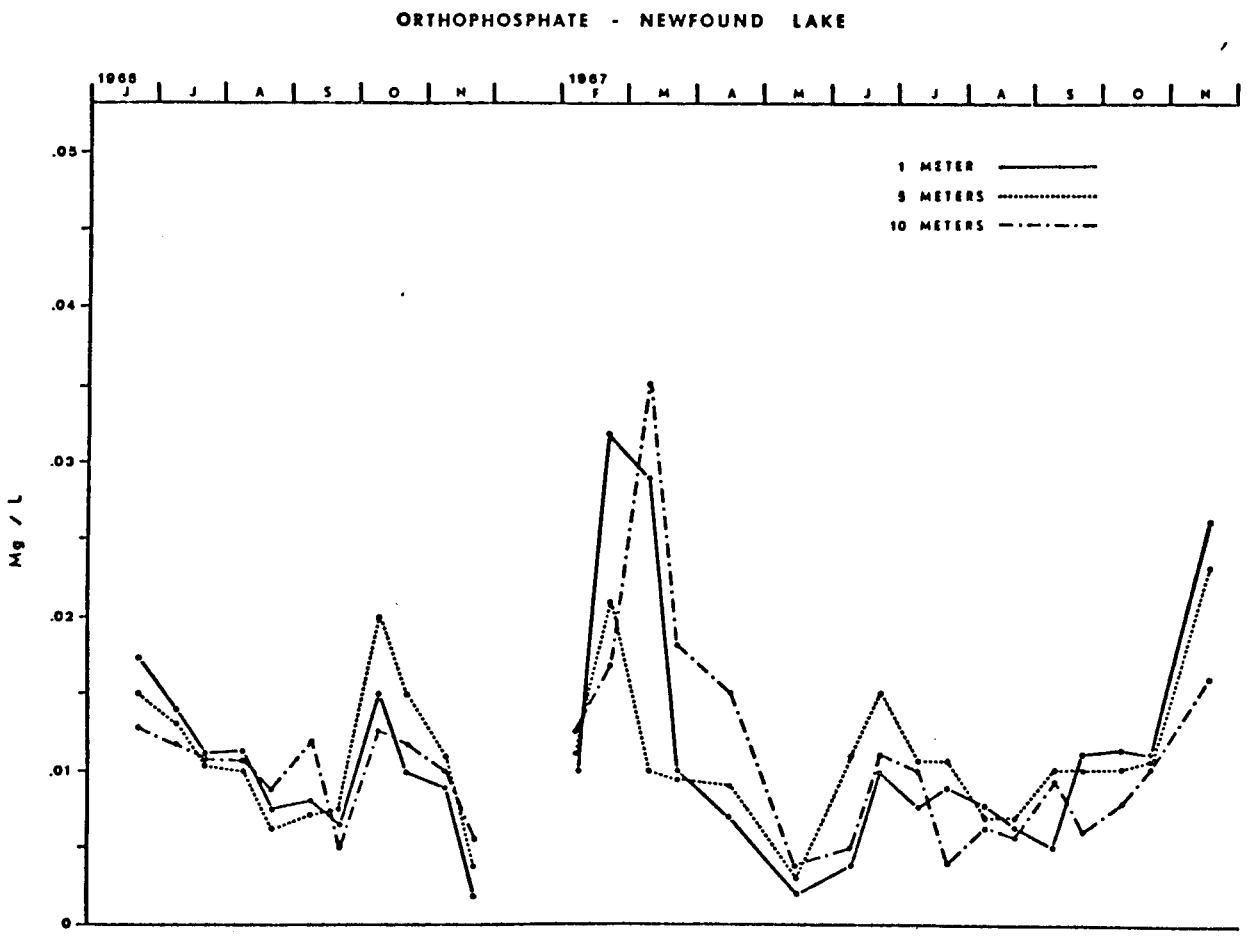
ORTHOPHOSPHATE - NEWFOUND LAKE
1966
J
J
A
S
O
N
1967
F
M
A
M
J
J
A
S
O
N
.05
.04
.03
.02
.01
0
Mg / L
1 METER
5 METERS
10 METERS

Figure 6

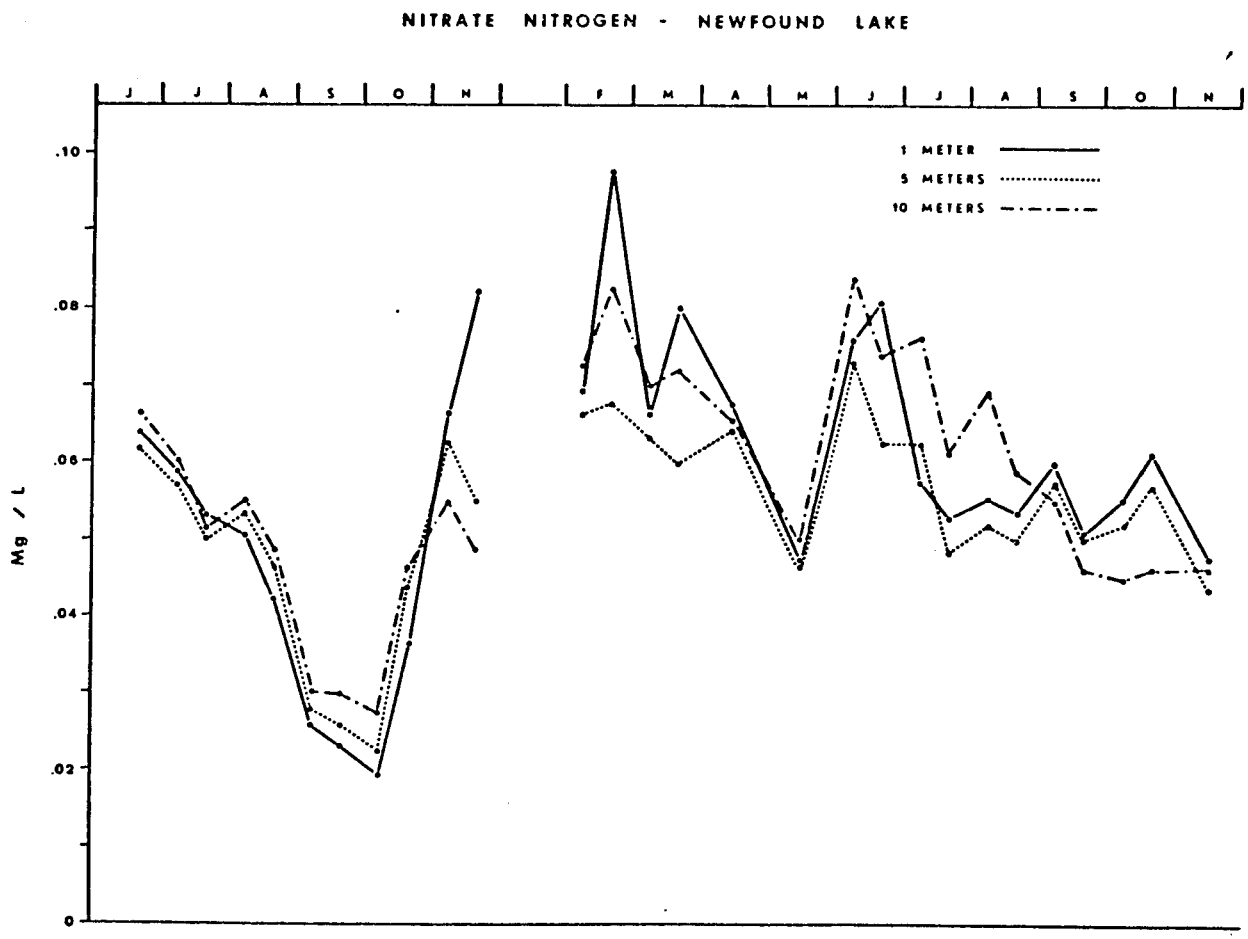
NITRATE NITROGEN - NEWFOUND LAKE
J J A S O N F M A M J J A S O N
1 METER
5 METERS
10 METERS
.10
.08
.06
.04
.02
0
Mg / l

Figure 7

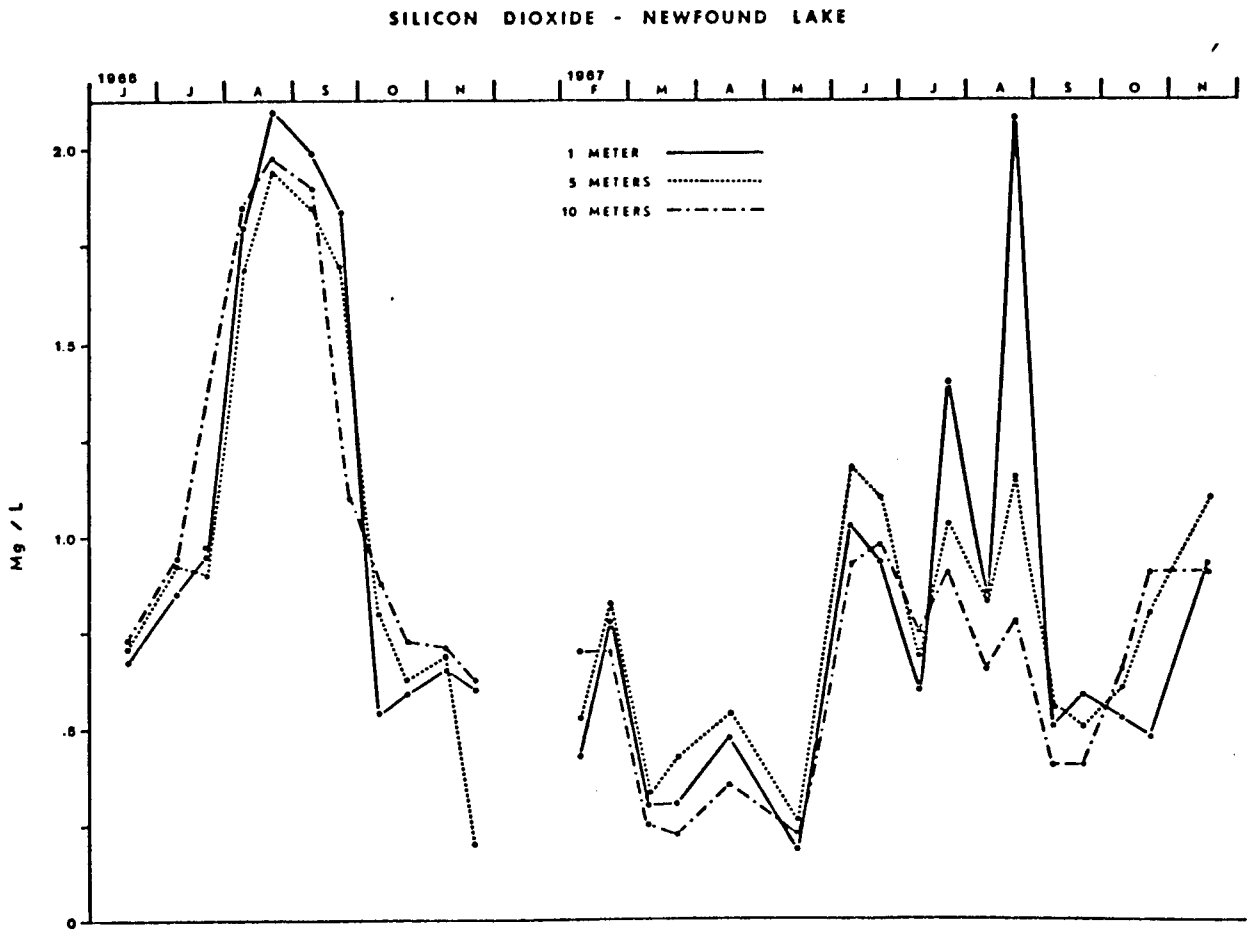
SILICON DIOXIDE - NEWFOUND LAKE
1966
J
J
A
S
O
N
1967
F
M
A
M
J
J
A
S
O
N
1 METER
5 METERS
10 METERS
Mg / L
2.0
1.5
1.0
.8
0

Figure 8

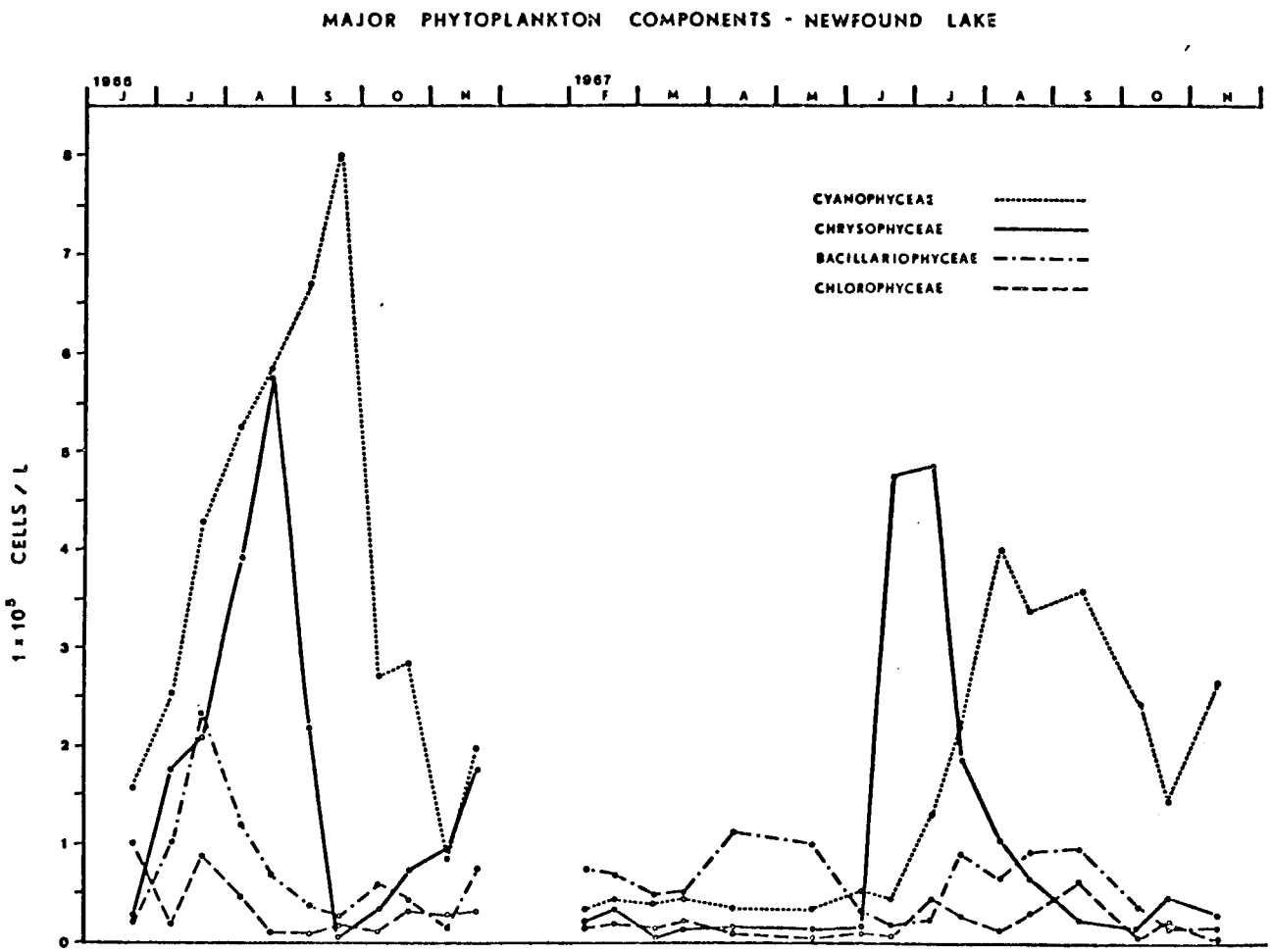
MAJOR PHYTOPLANKTON COMPONENTS - NEWFOUND LAKE
1966
J J A S O N
1967
F M A M J J A S O N
1 x 10³ CELLS / L
0 1 2 3 4 5 6 7 8
CYANOPHYCEAE
CHRYSOPHYCEAE
BACILLARIOPHYCEAE
CHLOROPHYCEAE

Figure 9

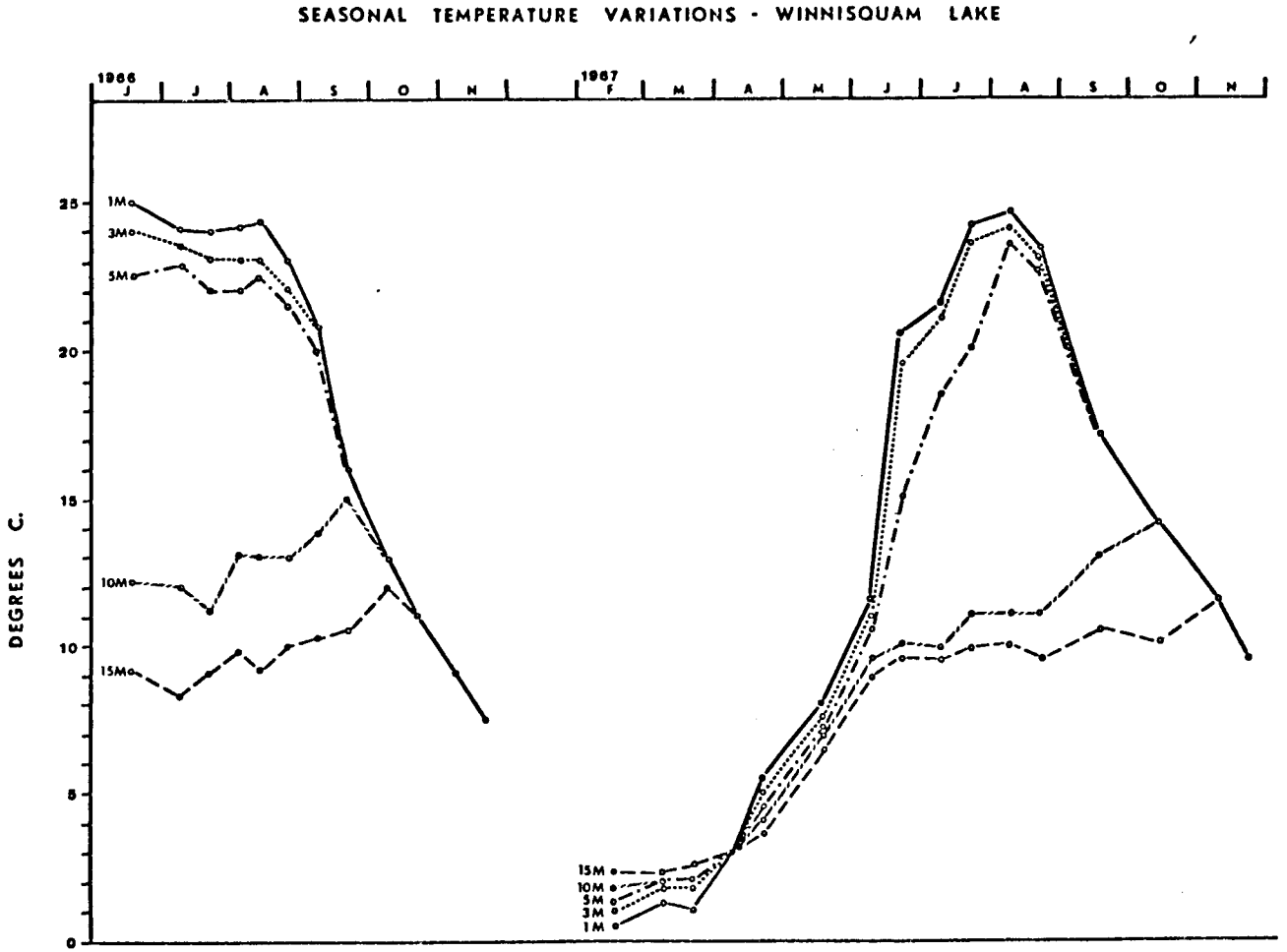
SEASONAL TEMPERATURE VARIATIONS - WINNISQUAM LAKE
1966
J
J
A
S
O
N
1967
F
M
A
M
J
J
A
S
O
N
DEGREES C.
0
5
10
15
20
25
1M
3M
5M
10M
15M
15M
10M
5M
3M
1M

Figure 10

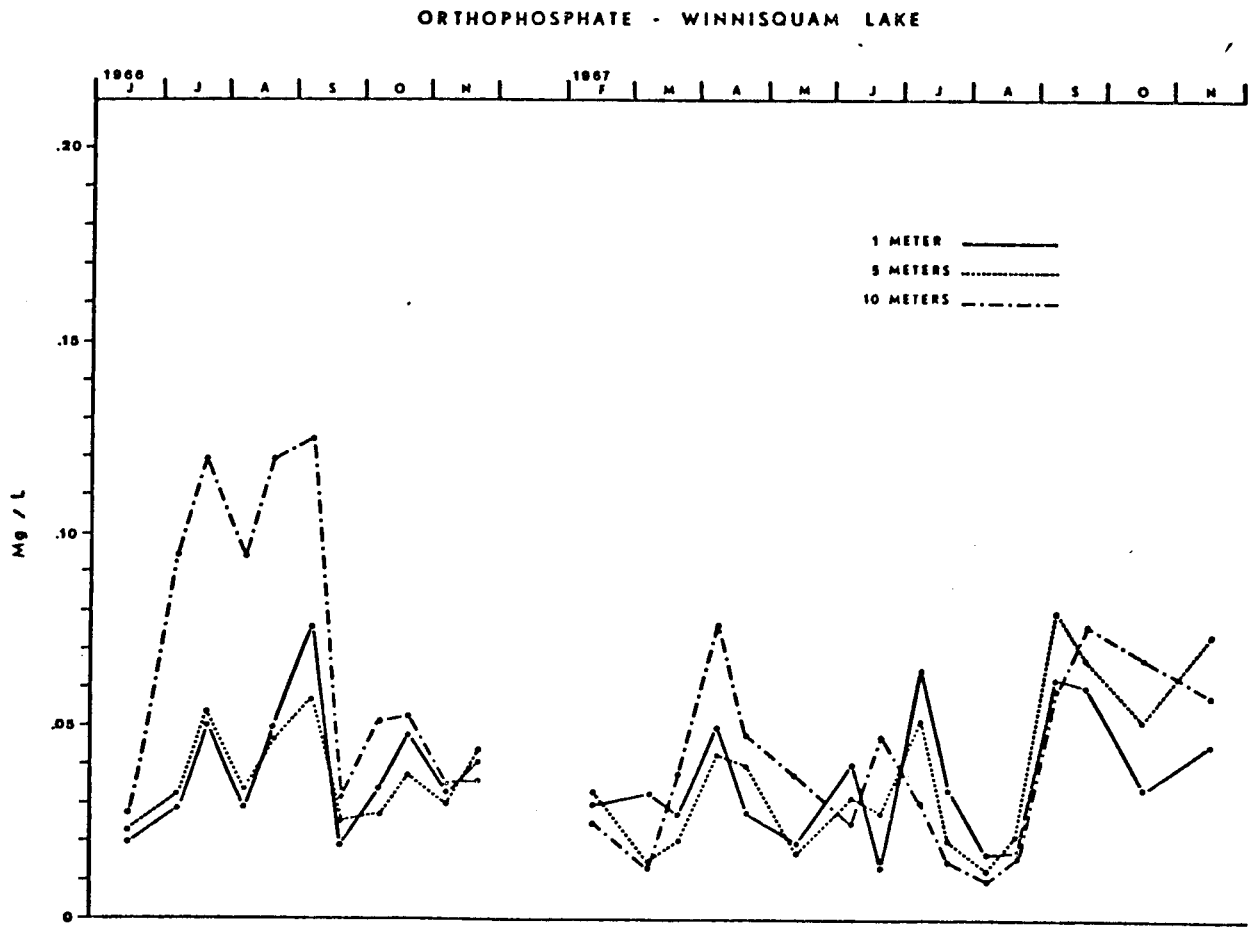
ORTHOPHOSPHATE - WINNISQUAM LAKE
1966
J
J
A
S
O
N
1967
F
M
A
M
J
J
A
S
O
N
.20
.15
.10
.05
0
Mg / L
1 METER
5 METERS
10 METERS

Figure 11

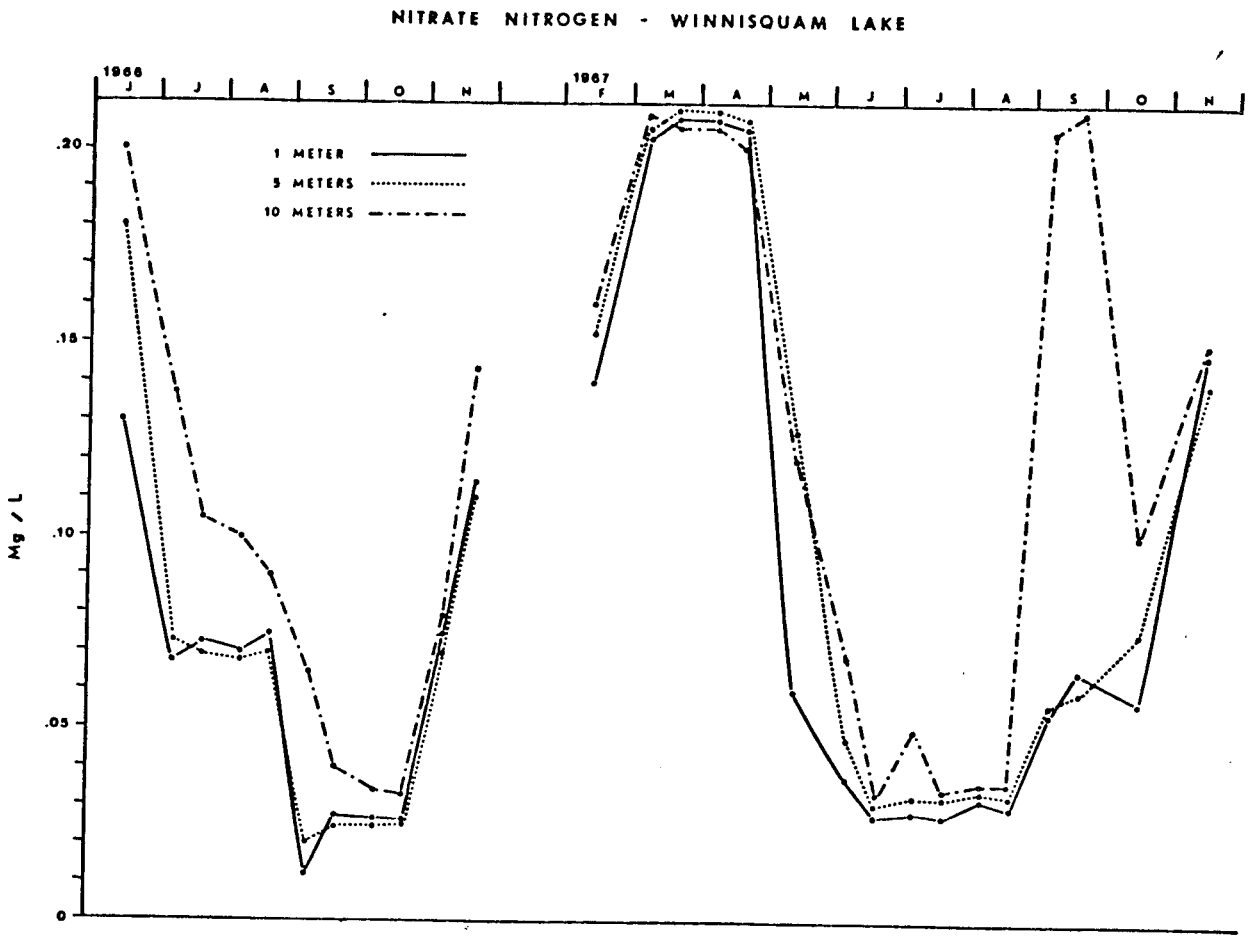
NITRATE NITROGEN - WINNISQUAM LAKE
1966
J
J
A
S
O
N
1967
F
M
A
M
J
J
A
S
O
N
1 METER
5 METERS
10 METERS
.20
.15
.10
.05
0
Mg / L

Figure 12

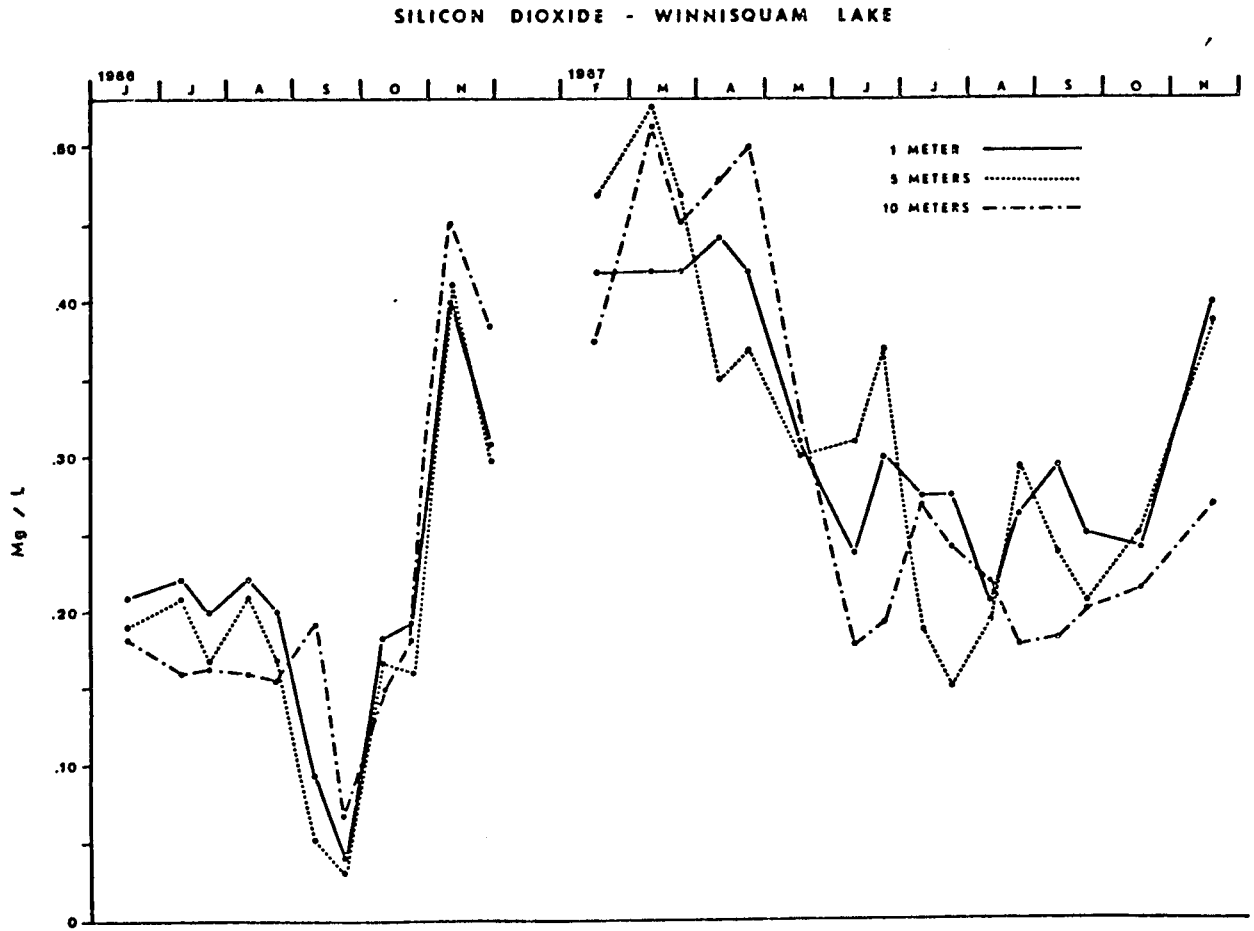
SILICON DIOXIDE - WINNISQUAM LAKE
1966
J
J
A
S
O
N
1967
F
M
A
M
J
J
A
S
O
N
.80
.40
.30
.20
.10
0
Mg / L
1 METER
5 METERS
10 METERS

Figure 13

TOTAL PHYTOPLANKTON - WINNISQUAM LAKE

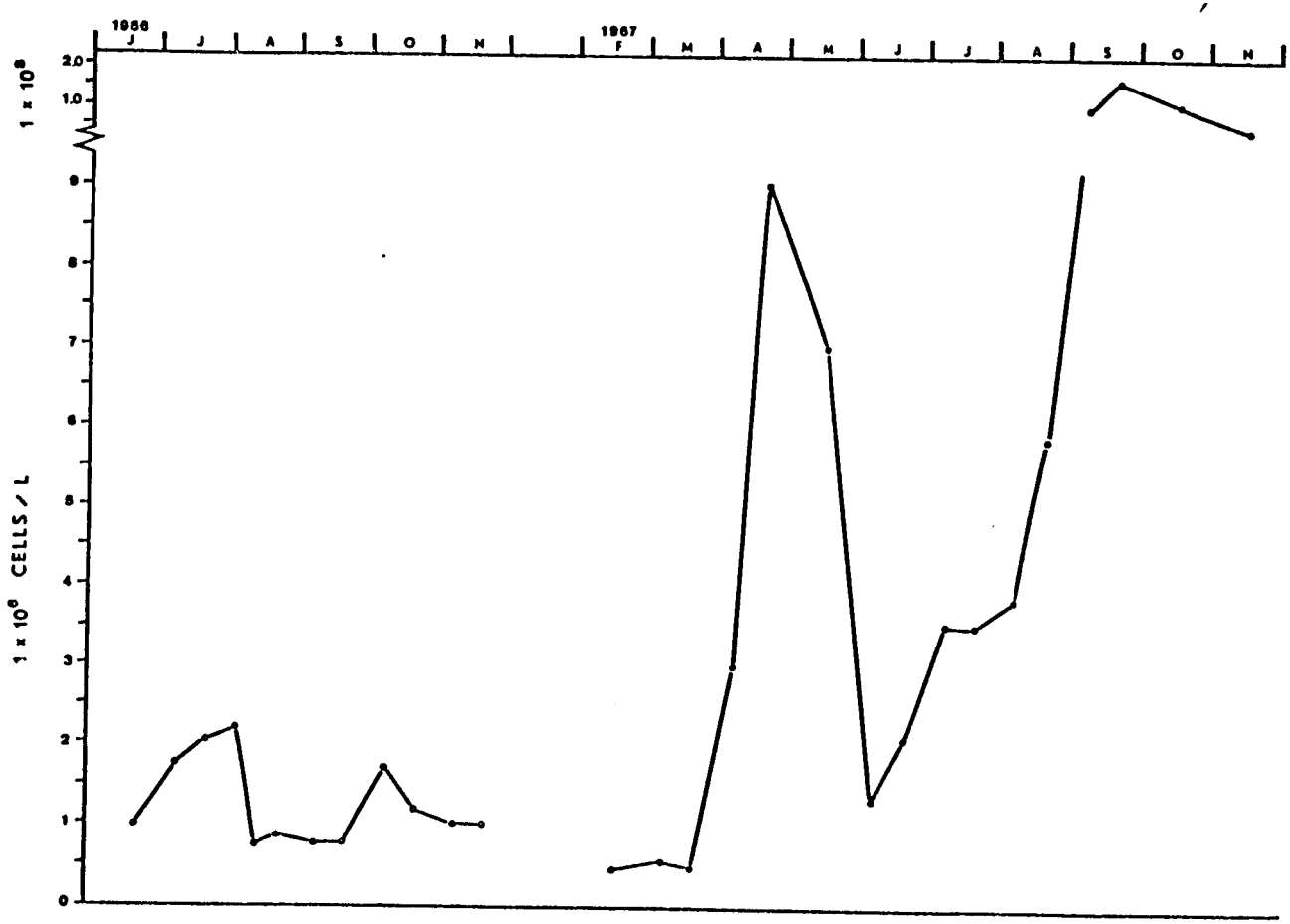

Figure 14

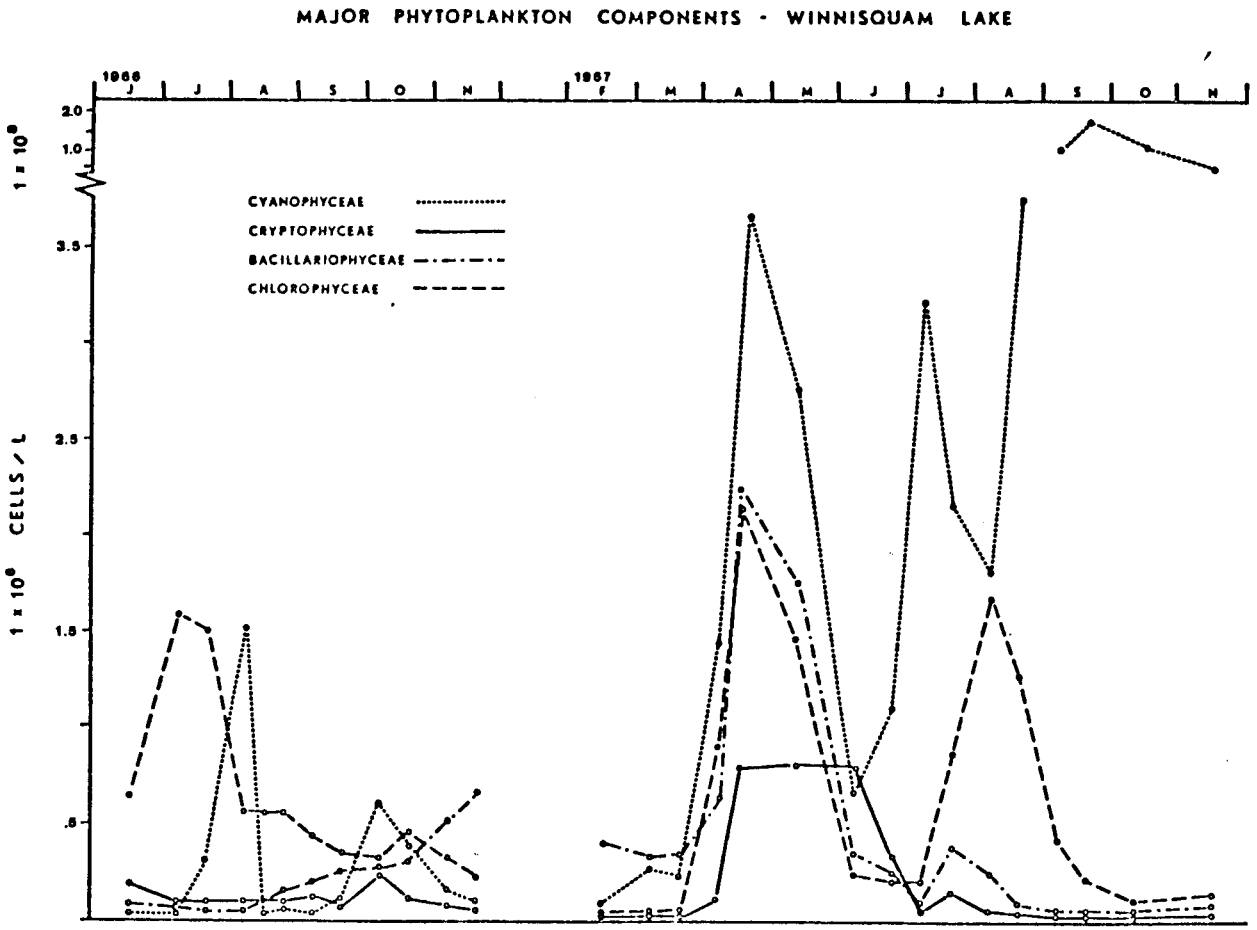
MAJOR PHYTOPLANKTON COMPONENTS - WINNISQUAM LAKE
1966
J
J
A
S
O
N
1967
F
M
A
M
J
J
A
S
O
N
2.0
1.0
3.5
2.5
1.5
1 x 10⁶
1 x 10⁶ CELLS / L
CYANOPHYCEAE
CRYPTOPHYCEAE
BACILLARIOPHYCEAE
CHLOROPHYCEAE

Figure 15