**Butler University Botanical Studies**

Volume 4 *Butler University Botanical Studies* Article 7

# A quantitative study of the phytoplankton of Lake Michigan collected in the vicinity of Evanston, Illinois

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# Butler University Botanical Studies

## (1929-1964)

*Edited by*

**Ray C. Friesner**

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# A QUANTITATIVE STUDY OF THE PHYTOPLANKTON OF LAKE MICHIGAN COLLECTED IN THE VICINITY OF EVANSTON, ILLINOIS[1]

*By* WILLIAM ALLEN DAILY

There have been but few papers published in which a quantitative study of the phytoplankton of Lake Michigan was considered. A study of this nature was therefore undertaken, using the Sedgwick-Rafter method.

A brief summary of the quantitative and qualitative studies which have been published on Lake Michigan includes the following: Briggs (1872) and Thomas and Chase (1887) presented lists of Diatomaceæ found in Lake Michigan. Later in 1896, reports were published by Ward, Thompson, and Kofoid which contained phytoplanktonts and some protozoans, as well. Other reports by Kofoid (1896) and Jennings (1896) dealt with the Rotatoria.

In 1927, Eddy published a list of both phytoplankton and zoöplankton of Lake Michigan and their relative abundance and seasonal variation. He writes: "There appeared to be a fairly constant and uniform phytoplankton throughout the year, although the zoöplankton showed some response to seasonal conditions. Diatoms predominate at all times and constitute the majority of the organisms of the plankton, the same species being conspicuous in all collections examined." His conclusions were based upon two series of collections made from Lake Michigan in 1887-1888 and 1926-1927, of which the former were made by the silk-net and filter-paper method. All of these were surface tows near the shore and were collected at Chicago, Illinois; Sawyer, Michigan; Michigan City, Indiana; and Indiana Dunes State Park.

Baylis and Gerstein (1929) list both zoöplanktonts and phytoplanktonts found in the lake water of the Chicago water supply. They found that in a two-year study of Lake Michigan the peak of plankton periodicity was in May 1927 and again in September 1928. In 1927 a second but lesser peak came in October. Temperature and sunlight readings were included, but no attempt was made to correlate these

[1]A portion of the work done on a thesis in partial fulfillment of the requirements for the Master of Science Degree in Northwestern University. The pages of Butler University Botanical Studies are open to all Butler University alumni.

with the periodicity of the plankton. Samples were collected five times a week at first, but later only three times.

Ahlstrom (1936) published a detailed report on the deep water and inshore plankton of Lake Michigan at Evanston; Crustacea were excluded. All collections were made by the silk-net method. Burkholder (1929) found that there is an autumn maximum of diatoms in Lake Erie. Gottschall and Jennings (1933) found that diatoms were the most abundant group of phytoplankton in Lake Erie and that they occurred in two peaks of abundance, one in the spring and one in the fall. They did not find the Chlorophyceæ and the Myxophyceæ abundant. Tiffany (1938) reports a definite autumnal maximum of Myxophyceæ in the west end of Lake Erie.

West and West (1913), in a study of English lakes, report that the greatest amount of phytoplankton is found in late summer and autumn, during the autumnal decline in temperature.

Inasmuch as phytoplankton is affected by various ecological factors, several of these have been considered in this paper, *e. g.*, temperature, turbidity, hydrogen-ion concentration, bacteria, and sunlight. It is generally assumed by most writers that temperature plays the leading role in algal and especially diatom periodicity, provided other factors do not limit the growth of the plants. Allen (1920) published an exhaustive analysis of the plankton of the San Joaquin River in California. He found the diatoms dominating the phytoplankton and concluded that temperature is the principal factor determining the plankton periodicity. Also he points out that the river shows a plankton maximum in the autumn. Eddy (1930) states that the rate of fresh-water plankton reproduction and consequently the abundance at different seasons in the same body of water varies directly with the temperature. Roach (1932) reports in his study on river plankton, that the phytoplankton varies in direct ratio with the temperature. Coffing (1937) states that temperature seems to be a primary factor influencing production in canal phytoplankton.

Pearsall (1923), on the other hand, does not believe that temperature plays the leading role in diatom periodicity, but that deficiencies of oxygen, nitrates, silica, or calcium are usually the limiting factors. He points out that floods influence the amount of these dissolved substances in the water. Later, Pearsall (1932) writes that diatoms occur in winter and spring when nitrates, phosphates, and silica are in abundance, and that the green algæ occur in the summer when nitrates and phosphates are low.

The subject of turbidity in relation to seasonal abundance of phytoplankton has received little attention from limnologists and algologists. Eddy (1930), however, regards turbidity as an important factor in reducing light and hindering the development and movements of many planktonts. He suggests that conditions must be such as to reduce this turbidity to proper value before plankton production can be heavy.

Hydrogen-ion concentration has received much attention in the past, but now is considered more of an index of a general environmental condition than a controlling factor in determining the periodicity of phytoplankton. Gottschall and Jennings (1933), in their study of Lake Erie, found that pH varied with the free carbon dioxide content. The lowest recorded pH was 7.6 and the highest 8.4. The pH value of the water studied by Eddy (1930) generally ranged from 7.8 in summer to 6.6 in winter, but the fluctuations were not always seasonal.

Altbough a number of papers have dealt with lake bacteria, few of these have considered their seasonal abundance in relation to that of phytoplankton. Recently, Henrici (1938) has reported on a periodical distribntion of bacteria in relation to the periodical distribution of plankton. It was found that the numbers of bacteria followed closely the curve for total plankton, with a distinct lag. He conclndes that the production of organic matter by plankton organisms is an important factor in determining the number of bacteria in the water.

According to Welch (1935), other workers studying the annual distribution of bacteria have found either one maximum and one minimnm which do not necessarily occur at the same time in different years, or two maxima and two minima, the maxima occurring in the spring and autumn and the minima during the two stagnation periods.

## METHODS

A weekly quantitative study of the phytoplankton of Lake Michigan at Evanston, Illinois, was made over a period of one year, May 1937 to May 1938. Several ecological factors were studied in conjunction with the seasonal periodicity of the phytoplankton, *e. g.*, temperature, turbidity, hydrogen-ion concentration, bacteria, and sunlight.

Essentially, tbe Sedgwick-Rafter procedure was used in this stndy: (1) collection of lake water samples; (2) filtration and concentration; (3) examination and enumeration; (4) calculation of the number of phytoplankton organisms per ml.

## Collection

Collection of two duplicate samples each week was made over a period of one year beginning May 9, 1937, and terminating May 3, 1938.[1] These collections were taken from the end of a breakwater which extends 65 meters into the lake, and which is situated on the Northwestern University campus. The water is 2 meters deep at the point of collection, but this fluctuates with the weather conditions. One one-half gallon Mason jar was fastened in an improvised "holder" at the end of a pole, and was then plunged beneath the surface of the water, not exceeding 3 decimeters. The collected water was poured into a second jar and the first was refilled. In several instances, openings were made in the ice to obtain samples, and once, because of inclement weather, a sample was taken only a few yards from the shore.

## Filtration and Concentration

Samples were brought immediately into the laboratory and 1000 ml from each jar were poured into separate graduated cylinders. In several cases, only 500 ml and once 700 ml were filtered because of high turbidity. These were then emptied slowly into two filter funnels of 500 ml capacity. Each of these was fitted with a one-hole rubber stopper with a U-tube inserted. 13-19 mm of 60-120-mesh filter sand were separated from the tube and stopper by a 200-mesh silk bolting cloth disc about 12 mm in diameter. A filter pump was used at all times to diminish the time of filtration, which was usually about three hours. This was deemed necessary because of the high turbidity which occurred in most of the samples. The inner surface of the funnels was washed down occasionally with distilled water to remove organisms and debris. The surface of the sand was intermittently broken by use of a fine needle fastened in the end of a glass tube. This was done in order to hasten filtration.

Following filtration, the sand and residue were washed directly into a small bottle by means of 10 ml of Transeau's preservative.[2] The bottles were immediately corked and sealed with paraffin for future study.

## Examination and Enumeration

The usual procedure outlined by Whipple (26) was followed in the examination and enumeration of the phytoplankton. The Whipple ocular-micrometer was calibrated so that, with a 16 mm objective and a 10X

[1]Collections were not made the weeks of May 23-29, 1937, and December 26-January 1, 1938

[2]Six parts water, 3 parts 95 percent ethyl alcohol, 1 part formalin.

ocular, any observed field of the counting chamber was exactly 1 sq mm. The counting chamber was 1 ml in capacity. In the enumeration, ten fields were counted in each sample. The ten fields were taken at random, attempting to distribute them equidistantly over the slide.

In counting the organisms, each planktont, regardless of the number of component cells, was counted as a unit. Rhizosolenia, Scenedesmus, Dinobryon, filaments of Fragilaria, Tabellaria, aud Melosira were respectively counted as units. Likewise, a single cell of a colony or filament was counted as a unit if found separated from the original aggregate. As suggested by Todd and Sanford (22) for blood corpuscle enumeration, cells which touched the lower and right sides of each square were counted as if within the squares.

Genera and species are listed in those forms which can be definitely recognized with a 16 mm objective; however, it was impossible to identify correctly some genera and species with such magnification. Species were listed only when identification was comparatively certain. It was made a practice to examine, previous to the counting process, the duplicate concentrated sample and a net collection which was made the same day as the concentrated sample. This permitted checking of any unidentified species which might appear.

## Calculation

The following formula was used in calculating the number of organisms per ml (Standard Methods of Water Analysis, 1936):

$$\frac{\text{No. of fields in a 1 ml counting cell 1 mm deep}}{\text{No. of fields counted}} \times \frac{\text{ml of concentrate}}{\text{ml of water filtered}} = \text{the multiplier}$$

thus:

$$\frac{1000}{10} \times \frac{10}{1000} = 1$$

The total number of organisms found in 10 fields in this case then equals the number of organisms in 1 ml of unconcentrated lake water.

## Temperature

Temperature of the sample was taken immediately upon entering the laboratory with a minimal error, since the laboratory is only 175 feet from the lake shore, and since the sample bottle used for the reading was allowed to remain submerged in the lake for a few minutes to assume the water temperature. Data for the period of May 1 to September 22, 1937, were secured from the Filtration Plant.

### Other Factors

Turhidity was determined by use of staudards prepared by the Evanston Filtration Plant according to Government Regulations. The standards ranged from 2 parts per million of fuller's earth to 50 parts per million and were prepared in glass-stoppered bottles. There were numerous times when the turbidity exceeded 50 and these were recorded as 50 plus. All standards were thoroughly shaken before comparing with the lake water of the same volume and contained in the same kind of bottle. Data for the period of May 1 to September 13, 1937, were secured from the Filtration Plant, whose standards were prepared in the same manner as those used in this study.

Hydrogen-ion concentration was determined with a LaMotte colorimetric outfit. Readings are recorded from the Filtration Plant from the period May 1 to Septemher 6, 1937. Their determinations were made by using glass colorimetric standards.

Since the Filtration Plant also ran bacterial counts, an attempt has been made to see what correlation, if any, could be made between plankton and hacterial seasonal growth. The plate method was used for determining the number of bacteria in the water. Each plate contained 1 ml of lake water in 10 ml of nutrient.[1] Incubation was for 24 hours at 37° C. Each colony found was counted as one and considered as developing from one bacterium.

The total number of hours of sunshine per month was obtained from the United States Weather Bureau, Chicago, Illinois, through the kindness of the Water Purification Division of the City of Chicago.

## THE EVANSTON WATER FILTRATION PLANT

The Evanston Water Filtration Plant is situated about three-fourths miles north from the station where the collections for this study were made. The information on raw lake water is computed from samples which are taken directly from the intake pipe line, which extends 1,684 meters into the lake. It is 30 inches in diameter and covered with a wire

[1]Nutrient was composed of agar, peptone, and beef extract.

grill having openings in it 2 inches square. An average of ten million gallons of water flow through the pipe every 24 hours.

Immediately the question arises as to the advisability of using in this paper data which were recorded at the above plant. The correlation between the records of the Filtration Plant and those of the author are given in table I.

## TABLE I

COMPARISON OF DATA OF PRESENT STUDY WITH DATA FROM FILTRATION PLANT

| | pH | | Temperature | | Turbidity | |
|---|---|---|---|---|---|---|
| | Filtration Plant | Present Study | Filtration Plant | Present Study | Filtration Plant | Present Study |
| October | 7.6 | 7.8 | 15 | 17.3 | 8 | |
| | 7.6 | 7.8 | 13 | 11.5 | 30 | |
| | 7.6 | 7.8 | 11 | 10 | 8 | 15 |
| | 7.6 | 7.8 | 9 | 8.4 | 4 | 15 |
| November | 7.4 | 7.8 | 9 | 6.6 | 6 | 20 |
| | 7.8 | 7.8 | 8 | 8.2 | 6 | 10 |
| | 8.0 | 7.8 | 5.5 | 3.4 | 6 | 15 |
| | 7.6 | 7.8 | 4.5 | 1.5 | 6 | 30 |
| December | 7.4 | 7.8 | .5 | .1 | 8 | 15 |
| | 7.6 | 7.8 | 0. | 0. | 10 | 10 |
| | 7.4 | 7.6 | 0. | 0. | 6 | 15 |
| | 7.8 | | | | | |
| January | 7.6 | 7.6 | .5 | .1 | 6 | 6 |
| | 7.6 | 7.6 | .5 | .2 | 2 | 6 |
| | 7.6 | 7.6 | 1. | .2 | 4 | 15 |
| | 7.6 | 7.8 | .5 | 0. | 15 | 50+ |
| February | 7.6 | 7.6 | .5 | .5 | 8 | 15 |
| | 7.6 | 7.8 | 2.0 | 1.8 | 20 | 50+ |
| | 7.6 | 7.8 | 1.5 | .9 | 20 | 30 |
| | 7.8 | 7.6 | 1. | 1.1 | 20 | 50+ |

## RESULTS AND OBSERVATIONS

In the 49 weekly samples taken from Lake Michigan, 43 genera representing 5 classes were recorded. Of these, 20 forms were determined to species. The classes were in order of numerical abundance, Bacillariophyceæ, Chrysophyceæ, Myxophyceæ, Chlorophyceæ, and Dinophyceæ. There was a maximum of 3,688 organisms per cc the week of June 4, 1937, and a minimum of 152 per cc the week of March 9, 1938. The maximal monthly average production of total phytoplankton occurred in June, and the minimal production in March.

The total phytoplankton (graph 5) showed two peaks of abundance, the first and greater in June 1937 and the second and lesser in October 1937, besides considerable weekly variation in number. These peaks correspond quite favorably with those found by Baylis and Gerstein (3) on Lake Michigan. The diatoms dominated the phytoplankton at all times, both in number and species. This is very similar to what Gottschall and Jennings (9) found in Lake Erie. The curve for diatoms (graph 6) conforms almost exactly with that of total phytoplankton.

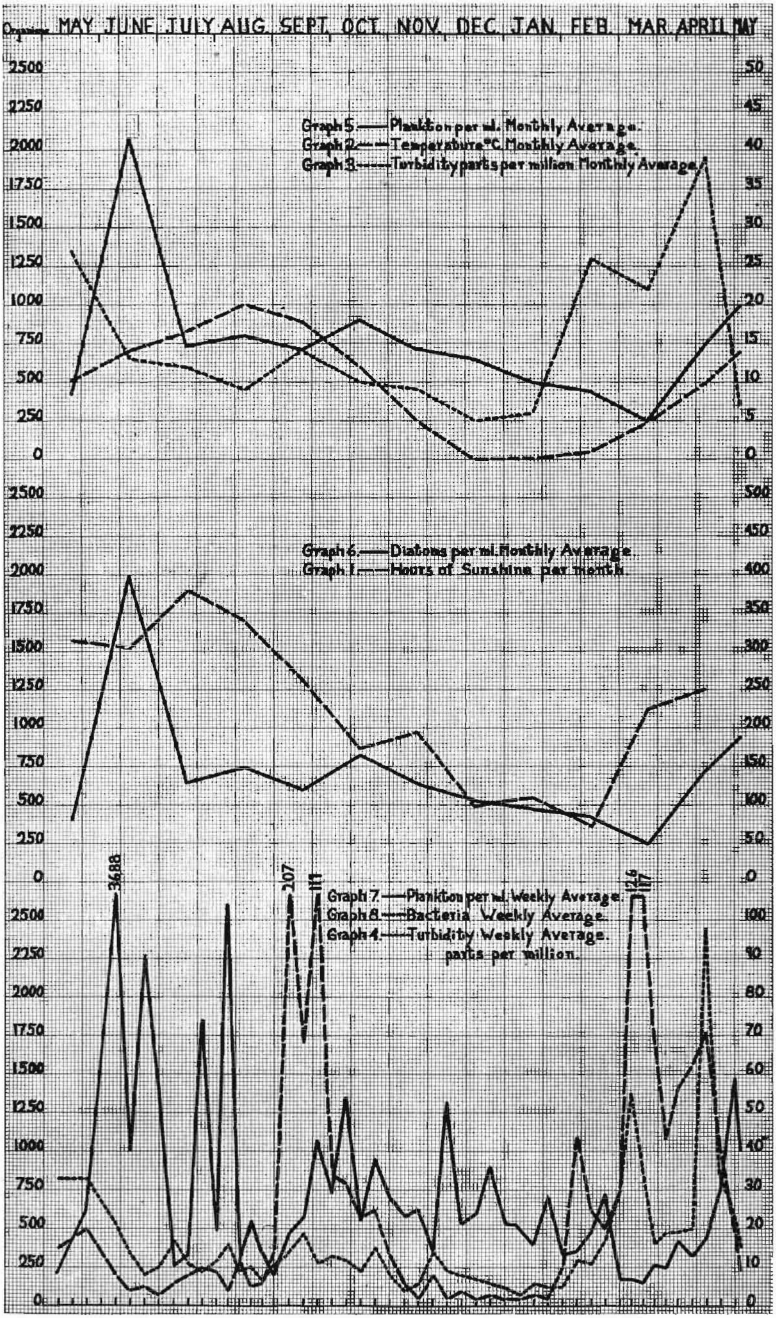
The maxima in June and October are attributable mainly to Synedra, which was the most abundant diatom of the Bacillariophyceæ (table III) and was greatest numerically of all pbytoplanktonts in June and again in October. Eddy's statement (8) that "seasonal variation in constituent species were noticeably lacking, the dominant diatoms running almost uniformly through the collection——," is not borne out by this paper. It is noteworthy, however, that these maxima were augmented by pulses of the dominant diatoms which were Asterionella, Fragilaria, Melosira, Synedra, and Tabellaria. Three other diatoms which were present throughout the year and nearly as abundant as the dominant group might be classed as "codominants." They are Cyclotella, Navicula, and Rhizosolenia.

### BACILLARIOPHYCEÆ

Each of the phytoplanktonts displayed its own pulse throughout the year. This was especially noticeable among genera in which more than one species were studied (table II). Among the dominant genera and species of diatoms at least one distinct pulse and sometimes more than one was found each month from June until December. The order Pennales (see classification list) led the Centrales in number and species at all times.

During the spring of 1937 the peaks of abundance of the dominant genera of diatoms occurred in the following order: Melosira in May, Asterionella and Synedra in June, and Fragilaria and Tabellaria in July. Gottschall and Jennings (9) found a somewhat similar succession in Lake Erie, with the exception that they found Tabellaria at the end of May.

Fragilaria and Tabellaria were both dominant diatoms, following Synedra in numerical abundance, and exhibited summer and autumnal seasonal maxima. The species of Fragilaria and Tabellaria showed uniformity to a rather bigh degree in their periods of abundance, but varied numerically (tahle II). It is noteworthy and demonstrated by Fragilaria that species of a genus are usually much unlike in number at the same



Organisms
MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC. JAN. FEB. MAR. APRIL MAY
Graph 5. —— Plankton per ml. Monthly Average.
Graph 2. — — Temperature °C. Monthly Average.
Graph 3. ------ Turbidity parts per million Monthly Average.
Graph 6. —— Diatoms per ml. Monthly Average.
Graph 1. — — Hours of Sunshine per month.
Graph 7. —— Plankton per ml. Weekly Average.
Graph 8. — — Bacteria Weekly Average.
Graph 4. —— Turbidity Weekly Average. parts per million.
3688
207
111
126
117

## TABLE II

### Diatom Genera and Species — Monthly Average

| | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Asterionella | 24 | 87 | 29 | 9 | 9 | 46 | 91 | 134 | 49 | 17 | 50 | 250 | 117 |
| Fragilaria crotonensis | 5 | 35 | 80 | 57 | 46 | 143 | 197 | 105 | 35 | 16 | 17 | 30 | 21 |
| Fragilaria sp. | 1 | 24 | 79 | 37 | 23 | 50 | 64 | 57 | 23 | 17 | 18 | 34 | 12 |
| Fragilaria—Total | 6 | 59 | 159 | 94 | 69 | 193 | 261 | 162 | 58 | 33 | 35 | 64 | 33 |
| Melosira | 77 | 58 | 18 | 12 | 10 | 20 | 5 | 5 | 5 | 10 | 51 | 208 | 173 |
| Synedra ulna | 6 | 21 | 4 | 3 | 4 | 10 | 9 | 6 | 5 | 17 | 10 | 12 | 0 |
| Synedra sp. | 261 | 1627 | 269 | 459 | 383 | 423 | 146 | 98 | 285 | 315 | 45 | 74 | 257 |
| Synedra—Total | 267 | 1648 | 273 | 462 | 387 | 433 | 155 | 104 | 290 | 332 | 55 | 86 | 257 |
| Tabellaria flocculosa | 4 | 9 | 51 | 21 | 8 | 18 | 15 | 6 | 5 | 2 | 2 | 6 | 11 |
| Tabellaria fenestrata | 8 | 20 | 64 | 48 | 23 | 38 | 27 | 24 | 8 | 6 | 8 | 16 | 24 |
| Tabellaria—Total | 12 | 29 | 115 | 69 | 31 | 56 | 42 | 30 | 13 | 8 | 10 | 22 | 35 |
| Cyclotella | 8 | 21 | 21 | 24 | 35 | 27 | 23 | 35 | 19 | 8 | 24 | 33 | 19 |
| Rhizosolenia | 1 | 25 | 23 | 13 | 6 | 12 | 32 | 25 | 17 | 11 | 9 | 51 | 294 |

weekly interval throughout the year. Tabellaria never dominated the diatoms numerically in any collection. Melosira was most abundant in the spring and fall months of 1937, and Asterionella was greatest in the spring and winter months, being dominant in only 3 weekly collections. Rhizosolenia was rather evenly distributed seasonally; however, there was a distinct spring maximum in 1938 and a slight winter increase (table II).

Cyclotella and Navicula, both codominants, exhibited similar spring and early fall periods of greatest abundance, which occurred in June and September respectively. The remainder of the diatoms were found in sparse numbers and occurred sporadically.

### Chrysophyceæ

Three genera of the Chrysophyceæ (table III) were observed during the study, and all belonged to the same order, Chrysomonodales. One specimen each of Mallomonas and Chrysosphaerella were recorded. Dinobryon was found in all months except May 1937 and April 1938. It was at its peak in July, and this was followed by another lesser pulse in November. Baylis and Gerstein (3) report, "Dinobryon, and perhaps most animal organisms, usually have their peaks in the summer or fall."

### Myxophyceæ

The Myxophyceæ appeared to have two periods of abundance, the higher in September and the lower in June. This appears to follow the

## TABLE III

### Phytoplankton Classes — Monthly Average

| | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bacillariophyceæ | 403 | 2000 | 653 | 738 | 607 | 829 | 639 | 528 | 472 | 431 | 243 | 731 | 936 |
| Myxophyceæ | 14 | 57 | 17 | 22 | 83 | 31 | 26 | 6 | 2 | 2 | 2 | 12 | 48 |
| Chlorophyceæ | 1 | 8 | 2 | 2 | 4 | 6 | 4 | 5 | 5 | 0 | 4 | 8 | 15 |
| Chrysophyceæ | 0 | 19 | 66 | 38 | 20 | 20 | 62 | 41 | 15 | 1 | 1 | 0 | 0 |
| Dinophyceæ | 0 | 0 | 0 | 3 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

autumnal maxima of lake blue-greens, reported by the Wests (25), Whipple (26), and Gottschall and Jennings (9). Tiffany (19) reports a definite autumnal maximum of Myxophyceæ in the west end of Lake Erie. The order Hormogonales, represented by Anabæna, Lyngbya, and Oscillatoria in this study, was the outstanding group of the class, with Lyngbya being the dominant form. The Chroöcoccales, represented mainly by Cœlosphærium and Microcystis, were frequently present, but in few numbers. It is interesting to note (table III) that the blue-greens were almost as abundant numerically as the Chrysophyceæ, of which Dinobryon is outstanding.

### Chlorophyceæ

Chlorophyceæ, represented mainly by Ankistrodesmus and Scenedesmus of the order Chlorococcales, was never abundant in the samples. The periods of amplitude occurred in June, October, and April; however, when the figures are low and comparatively alike, reasonable conclusions concerning seasonal growth cannot be made with certainty.

### Dinophyceæ

Ceratium and Peridinium represented the class Dinophyceæ. Ceratium was present, 2 organisms per cc during August and one organism during September and October. Peridinium appeared only in August, one specimen having been observed. Gottschall and Jennings (9) only report Ceratium and Peridinium for Lake Erie and never very abundant.

### Ecological Factors

It is thought that no one factor alone could be responsible for seasonal periodicity of plankton, and that a great number of known and perhaps unknown factors are necessary. It is important, however, in bodies of water such as Lake Michigan, to study each factor as far as possible and determine what influence that factor may have on the periodicity of one or all organisms.

Obviously, the two "turnovers" of the lake have much to do with the spring and autumnal maxima of phytoplankton, by increasing the turbidity and thereby increasing the necessary gases and mineral salts, mainly oxygen, carbon dioxide, silicates, calcium, nitrates, and phosphates which are essential for optimum growth. Turbidity, monthly average, is shown in graph 3. Turbidity displayed two maxima, which were caused by the annual spring and fall lake turnovers. There were weekly fluctuations, however, which are mainly attributable to the weather conditions, such as storms and wind. Slight waves will cause an increase in turbidity near the shore. It appears from this study that the increase of turbidity during the month likewise influences phytoplankton pulses. From weekly studies (graphs 4 and 7), it was difficult to ascertain the exact relation between turbidity and plankton pulses; however, the increases in turbidity appear to precede the plankton pulses. The information here tends to lean toward Pearsall's (15) idea that temperature does not play a leading role in diatom periodicity, but, instead, the view that deficiency of oxygen, nitrates, silica, or calcium is usually the factor limiting diatom periodicity. Although temperature is important in optimum growth of most phytoplanktonts, it does not seem to be of prime importance as a controlling factor in diatom periodicity.

The highest temperature recorded was 21° C., which was reached August 1, 1937, and the lowest was 0° C., which occurred several times in December and once in February. Phytoplankton abundance and growth in the earliest spring seems to follow the rise in temperature rather closely (graphs 2 and 5). However, neither of the major plankton peaks occur near the temperature high. The average temperature in June, when the diatoms were at the period of greatest amplitude, was 7° C. lower than the highest temperature recorded. When the peak in October occurred, the temperature was 11.8° C. and was steadily declining at the time.

It is noticeable that the June and October phytoplankton maxima occur at approximately the same average temperature. However, it should be noted that the major weekly peaks occurred in a range from 1.5 to 21° C, so that no particular degree of temperature within this range may be designated as an optimum.

No correlation could be found between hydrogen-ion concentration and the seasonal periodicity of the phytoplankton. The pH varied from pH 7.4 to 8.0 throughout the year, pH 8.0 occurring ten days in November 1937, and again, once only, on April 27, 1938. The rapid increase in phytoplankton at this time, and the few weeks preceding, might account for the reading of pH 8.0 on the basis of $CO_2$ utilization in photosynthesis. The author's pH recordings do not show a reading below 7.6.

The greatest number of hours of sunlight (graph 1) occurred in July 1937, and the least number in February 1938. The hours of sunlight appear to have an important correlation with the spring maximum of plankton, but can hardly be held accountable for the October and November increase of plankton.

Bacteria showed two major peaks of abundance throughout the year. The maximum occurred in September and the minimum in December. The September maximal and also the minimal pulses of bacteria between May and October appear to be in direct correlation with the plankton pulses, and generally follow the plankton pulses with a lag (graphs 8 and 7). It does not appear likely that the September peak could be attributable to the fall turnover of the lake, since it precedes the turnover. We may assume then, perhaps, as does Henrici (10), that the product of phytoplankton decay "is an important factor in determining the number of bacteria."

## SUMMARY AND CONCLUSIONS

1. This study revealed a marked periodicity both of the total phytoplankton, and of the classes, genera, and species of the algæ.

2. The classes in order of numerical abundance for the year were, Bacillariophyceæ, Chrysophyceæ, Myxophyceæ, Chlorophyceæ, and Dinophyceæ.

3. The total phytoplankton showed considerable weekly variation, and it exhibited a spring and autumn maximum, which occurred respectively in June and October. Both of the maxima were attributable to diatoms, and especially to Synedra.

4. The maximal monthly average production of total phytoplankton occurred in June. The minimal monthly average production occurred in March.

5. The maxima of total phytoplankton were augmented by pulses of each of the dominant diatoms, which were Asterionella, Fragilaria,

Melosira, Synedra, and Tabellaria. Codominants were Cyclotella, Navicula, and Rhizosolenia.

6. Each of the phytoplanktonts displayed its own pulses throughout the year. Likewise, species of the same genus were usually much unlike in numbers at the same weekly intervals throughout the year.

7. The peaks of abundance of the dominant genera of diatoms occurred in the following order: Melosira in May, Asterionella and Synedra in June, and Fragilaria and Tabellaria in July.

8. The curve for diatoms conforms almost exactly with that of total phytoplankton.

9. Among the dominant genera and species of diatoms from June until December, there was at least one distinct pulse and sometimes more than one in each month.

10. The order Pennales led the Centrales in number and species at all times.

11. The class Chrysophyceæ was second in abundauce to the Bacillariophyceæ, and the order Chrysomonodales, which contains Dinobryon, was most abundant.

12. The Myxophyceæ appeared to have two periods of abundance, the higher in September and the lower in June. The order Hormogonales, represented chiefly by Lyngbya, was the outstanding group.

13. Chlorophyceæ, represented mainly by Ankistrodesmus of the order Chlorococcales, and Dinophyceæ, represented by Ceratium and Peridinium, were never abundant in the samples.

14. Hydrogen-ion concentration appears to have little, if any, appreciable effect on seasonal periodicity of the phytoplankton. Hydrogen-ion concentration varies from 7.4 to 8.0 throughout the year.

15. Although temperature is important in optimum growth of most phytoplanktonts, it does not seem to be of prime importance as a controlling factor in diatom periodicity.

16. Turbidity, caused by lake turnovers in the spring and fall, and by storm and wind between periods of turnovers, seems to exert a very important influence on seasonal growth and pulses.

17. Hours of sunlight appear to have an important correlation with the spring maximum of plankton, but hardly can be held accountable for the October and November increase of plankton.

18. The September maximum and also the minimal pulses of bacteria between May and October appear to be in direct correlation with the plankton pulses and generally follow these plankton pulses with a lag.

## A SYSTEMATIC LIST OF THE PHYTOPLANKTON

Bacillariophyceæ

Order Centrales

Cyclotella glomerata Bachmann

Cyclotella melosiroides (Kirchner) Lemmermann

Cyclotella

Melosira

Rhizosolenia

Stephanodiscus

Order Pennales

Amphiprora ornata Bailey

Amphora ovalis Kütz.

Asterionella

Cocconeis

Cymatopleura solea (Breb.) W. Smith

Cymatopleura elliptica (Breb.) W. Smith

Cymbella

Diatoma

Fragilaria crotonensis Kitton

Fragilaria

Gomphonema

Gyrosigma

Navicula

Nitzschia

Pinnularia

Surirella ovata Kütz.

Synedra radians Kütz.

Synedra ulna (Nitzscb.) Ehr.

Synedra

Tabellaria flocculosa (Roth) Kütz.

Tabellaria fenestrata Kütz.

Chrysophyceæ

Order Chrysomonodales

Chrysosphærella longispina Lauterb.

Chrysosphaerella longispina Lauterb.

Dinobryon

Mallomonas

- Myxophyceæ
  - Order Chroöcoccales
    - Aphanocapsa
    - Chroöcoccus
    - Cœlosphærium
    - Gomphosphæria lacustris Chod.
    - Microcystis æruginosa Kütz.
    - Microcystis
  - Order Hormogonales
    - Anabæna
    - Lyngbya
    - Oscillatoria
- Chlorophyceæ
  - Order Chlorococcales
    - Ankistrodesmus
    - *Cœlastrum cambricum Arch.
    - Dictyosphærium pulchellum Wood
    - Golenkinia
    - Oöcystis
    - Pediastrum
    - Scenedesmus
  - Order Desmidiales
    - Closterium
  - Order Tetrasporales
    - *Glœocystis planctonica (W. & G. S. West) Lemmermann
    - Sphærocystis Schroeteri Chod.
  - Order Zygnematales
    - *Spondylosium pygmaeum (Cooke) W. West
- Dinophyceæ
    - Ceratium hirundinella (O. F. M.) Schrank
    - Peridinium

*New species for Lake Michigan.

## ACKNOWLEDGMENTS

The writer expresses his sincere gratitude to Dr. L. H. Tiffany, under whose direction this research was carried out, for aid in identification and for generous critical suggestions in preparing the manuscript. The writer is indebted to E. S. Ford for aid in the early part of the investigation and for making the weekly plankton collections and filtrations from June 4 to September 15, 1937.

Thanks are expressed to Dr. Glenn C. Couch, of the Oklahoma University Department of Botany, for aid in identification of diatoms and for helpful suggestions; to Horace Frye, assistant superintendent of the Evanston Water Department, for preparing the turbidity standards, for aid in securing literature, and for permitting use of scientific data which were recorded at the Filtration Plant; and to Dr. R. C. Friesner for the use of laboratory and equipment in the Butler University Department of Botany for identification of phytoplankton during the summer months of 1937.

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