THE ANNUAL DISTRIBUTION AND STRATIFICATION OF PHYTOPLANKTON AT AURORA LAKE, PORTAGE COUNTY, OHIO[1, 2]

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ABSTRACT

A 13-month study of a hard-water lake in northeast Ohio has provided a quantitative and qualitative record of the seasonal changes of the phytoplankton. Maximum production occurred during the summer and winter periods. The summer pulse was dominated by the cyanophyte species: *Microcystis aeruginosa*, *Anabaena spiroides*, *A. circinalis*, and *Aphanizomenon flos-aquae*. The dominants of the winter pulse were the diatoms *Fragilaria crotonensis* and *Asterionella formosa*, which formed separate peaks under an ice cover in December and January, respectively. The January development extended into March with the highest concentrations for the year being reached at approximately 1,400,000 cells per liter. The Chlorophyta were represented by 34 species, but quantitatively were of minor importance. The Pyrrophyta were uncommon and were represented by only 3 species. Periods of maximum and minimum phytoplankton development correspond closely in duration and magnitude at the surface and at one meter, with a slight tendency for pulses at two meters to lag behind. Vertical distribution indicated that the cyanophyte species, *Phacus* sp., and *Fragilaria crotonensis* were more numerous in the upper layers, whereas *Asterionella formosa*, *Synedra* sp., *Closterium* sp., and *Melosira granulata* occurred in greater numbers in the lower strata. *Microcystis aeruginosa* was noted to change its level of greatest concentration with the seasons.

The periodic changes in the concentration and composition of phytoplankton follows a bimodal pattern in the majority of north temperate lakes. The classical pattern consists of spring and fall maxima, with corresponding low periods of development during the summer and winter. In Ohio lakes, such bimodal patterns have been reported by Tressler et al. (1940), Kraatz (1940, 1941), Chandler (1942), Davis (1962), Palmer (1962), Ward and Seibert (1963), and others. Growth patterns of phytoplankton that differed from the usual spring and fall pulse formation are described, among others, by Pennak (1949), and Willén (1961, 1962). Numerous investigators have attempted to correlate the algal pulses and their population growth with specific ecological conditions of the environment. These dynamic factors would include the climatic phenomena of the habitat and the physical and chemical nature of the water (Pearsall, 1932; Findenegg, 1943; Rodhe, 1948; McCombie, 1953).

Phytoplankton studies in Ohio have been predominantly directed to investigations of Lake Erie, lakes of central Ohio, or to the small ponds and reservoirs that exist in the state. With the exception of Lake Erie, there is a minmal amount of information concerning the composition and seasonal fluctuations of phytoplankton in northern Ohio lakes.

The present investigation was made to study and attempt to explain the composition of phytoplankton in Aurora Lake, Ohio, and determine the seasonal distribution and vertical stratification for the major algal groups and dominant algal species. The period of study lasted thirteen months, from March, 1959, to March, 1960.

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LAKE CHARACTERISTICS

Aurora Lake is located approximately 20 miles south of Lake Erie in the northwest corner of Portage County, Ohio. The lake rests on glacial fill covering a preglacial valley that formerly drained westward and parallel to the present location of Lake Erie (Scranton & Lamb, 1932). The hydroseral succession pattern has been influenced greatly by man during the past 100 years by repeated attempts to drain the lake or dam the single outlet (Aldrich, 1943). At the present time, the lake covers an area of approximately 200 hectares and possesses a maximum depth of 6 m. The major source of water for Aurora Lake is precipitation and springs in the sandstone walls of the original glacial valleys (Cushing et al., 1931).

A dense rooted vegetation, lakeward from the shore, encircles the lake and is composed primarily of *Ceratophyllum dermersum*, *Cabomba caroliniana*, *Myriophyllum spicatum*, *Elodea canadensis*, and *Potamogeton* sp. This development of rooted plants ends abruptly at a depth of approximately 2 m. *Nymphaea advena* could also be found along the entire littoral margin.

Random bottom samples were obtained. The deposits were sapropel in character revealing high concentrations of organic deposits of autochthonous origin. A fine black muck, containing abundant remains of diatoms, was common in all the deposits of the central lake area. The detritus in the samples was in an advanced stage of decomposition.

PROCEDURES

During a 3-month preliminary investigation, water samples were taken from twelve established stations. Three of the twelve stations were selected as the collecting sites (one limnetic, two littoral) for the principal study from March, 1959, to March, 1960. A row boat was used to gain access to all stations, except during the period of ice cover. The water samples were taken on 38 sampling dates at the surface, and at depths of 1 m and 2 m with a 1 liter Kemmerer water sampler. In each case 250 ml were stored in glass bottles and fixed with an I_2-KI-acetic acid solution. The settling method was followed as outlined by Welch (1948). Aliquots were placed in a Sedgwick-Rafter cell and numerical counts were based on number of cells per liter, with the exception of a few colonial forms where estimates were referred to by units, each representing a mature colony.

At each sampling level, a pH reading of the water was made at once by colorimetric determination, using Fisher short range alkacid test papers. Temperatures were recorded at the same time with a Negretti and Zamba mercury reversing thermometer. The procedures used in the chemical analysis of the lake water were those presented by Faber et al. (1955).

PHYSICAL AND CHEMICAL CONDITIONS

The climate of northeastern Ohio is typically continental, with Lake Erie exerting a strong modifying influence upon the surrounding area. The large air masses that cross Lake Erie in winter produce extensive cloudiness, snow, and temperature variations. A permanent ice cover on Aurora Lake was established during this investigation on January 29, 1959, and remained through April, 1960. The winter samples were taken through openings cut into the ice. Special care was taken to minimize the water turbulence caused by the break-through.

Water temperatures ranged from a winter low of O C to 28.4 C on August 28. From March 18 to May 20, there was little difference in the temperature of the depths measured. Distinct thermoclines occurred frequently between May 28 and October 26. Inverse temperature relationships were found in the winter months beginning November 7 and continuing to March 26.

The shallow nature of Aurora Lake provided conditions that were conducive to fluctuations of pH values. The range during the year lay between 4.0 and 6.5. These pH readings were similar to those that have been found in dystrophic and bog lakes (Prescott, 1939; Hansen, 1962). General sources for hydrogen ions contributing to the acidity include decay products from the soils in the surrounding drainage area and ionization products of carbonic acid, humic acid, and other sources in the lake water.

As shown in table 1, there was an excess of the basic minerals that are essential for the development and maintenance of phytoplankton populations (Rodhe, 1948; McCombie, 1953). There were present relatively high concentrations of calcium, silica, and magnesium, similar to those of other north-temperate, hard-

TABLE 1

Results of water analysis at Aurora Lake on July 10, 1959

	ppm
Calcium (Ca^{++})	19.0
Magnesium (Mg^{++})	4.9
Total iron	1.0
Silicon (as SiO_2)	38.0
Chlorides (Cl^-)	11.0
Fluorides (F^-)	0.01
Sulfates ($SO_4^{=}$)	14.8
Ammonia (NH_3)	0.35
Nitrates (NO_3^-)	0.44
Phosphates ($PO_4^{\equiv}$)	0.01
Total solids	168.0
Dissolved solids	118.0
Total hardness	67.4

water lakes in advanced eutrophic stages (Wade, 1949). The literature contains considerable disagreement as to the role of specific nutrients and climatic conditions for the development of phytoplankton (Pennak, 1949; Rodhe, 1948), and the present results do not greatly clarify the issue.

PHYTOPLANKTON

Forty-nine major species of phytoplankton were identified, with an additional twenty forms identified to genera. No attempt to make a complete taxonomic analysis of the algae of the lake was made. The Chlorophyta were represented by 34 colonial, filamentous, and unicellular forms; this was the largest number of species in any algal phylum. However, their quantitative value was of relatively minor significance. The Chrysophyta, Cyanophyta, and Euglenophyta were represented by numerous species, but only a few species in each group produced large pulses. The most prominent sub-group of Chrysophyta was the Bacillariophyceae which produced the major winter pulse. The Pyrrophyta were rare.

STRATIFICATION OF PHYTOPLANKTON

The seasonal distribution of total phytoplankton at the surface and at 1 m depth was similar for the three collecting stations (fig. 1). Throughout the year, major algal pulses and their subsequent periods of decline corresponded closely in their duration and magnitude for these levels. There were considerable fluctuations in the algal concentrations, however, at the 2 m depth. The settling of plankters from the upper levels may have been a factor in the tendency shown by the pulses at two meters to increase their numbers after the phytoplankton development of the upper strata.

Surface

With a few exceptions, the algal concentration at the littoral stations was generally higher than that in open water. In the littoral and limnetic regions, the Cyanophyta occurred in the largest numbers at the surface, *Anabaena circinalis*, *A. spiroides*, *Microcystis aeruginosa*, and *Aphanizomenon flos-aqua* dominating. Several euglenophyte forms (*Euglena*, *Trachelomonas*, and *Phacus* species) were found consistently. The Chlorophyta were richest in species, but the biomass was low, with pulse patterns that were similar at all levels and stations tested. The lowest surface count of agal forms at all the stations occurred March 18 to

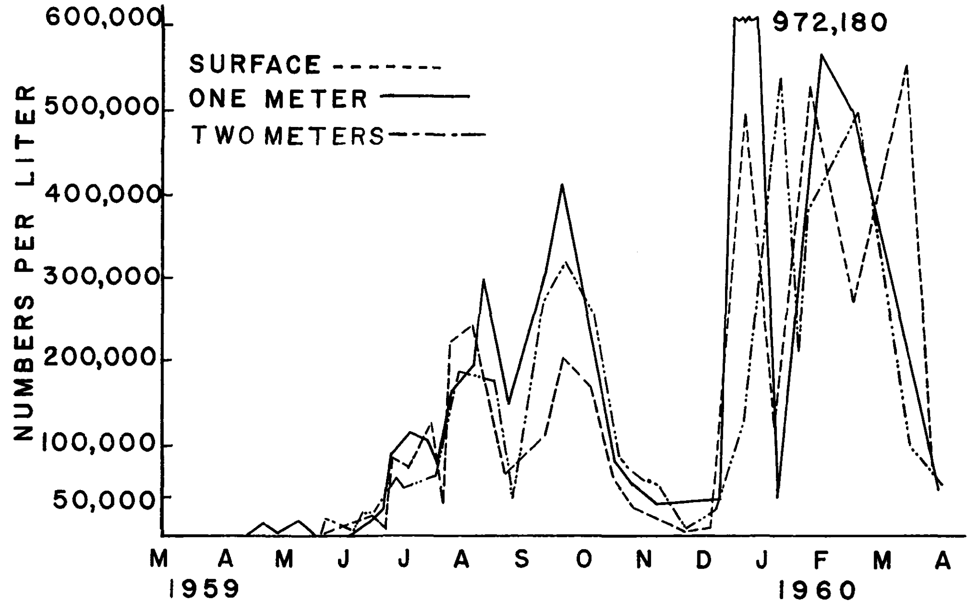

FIGURE 1. Seasonal distribution of phytoplankton at the surface, 1 m, and 2 m, at littoral Station A.

June 8 and on November 21 when cell numbers barely exceeded 4600 cells per liter (fig. 2). Maximum development took place in early August (mostly Cyanophyta) and again under a 25-cm ice cover during the winter months, when the pulse was expressed by three separate peaks extending from December 20 to March 15. These latter high numbers were due primarily to the diatoms *Fragilaria crotonensis* and *Asterionella formosa*.

One Meter

The species of Cyanophyta and Chlorophyta that were most abundant in the surface samples also dominated the phytoplankton at 1 m. Four of the five major pulses (two in later summer and three in winter) that took place during the year at the surface also occurred at 1 m (fig. 3). These were all comparable as to the time of occurrence, but the average concentration of total phytoplankton at one meter exceeded the numbers at surface throughout the year.

During April, a light pulse developed when the acidity of the littoral region was the highest recorded for the year (pH 4). Of highest numerical concentration were *Chlamydomonas* sp., *Scenedesmus acuminatus*, *Pediastrum tetras*, and *Asterionella formosa*.

The limnetic station possessed slightly higher concentrations of phytoplankton at 1 m than the littoral area during the summer and winter pulses.

Two Meters

Diatoms were found in greatest numbers at this level throughout the study period. The most abundant species were *Melosira granulata* in the summer, with *Asterionella formosa* and *Fragilaria crotonensis* predominant during the winter months.

The winter pulse began December 6, decreased rapidly in January, then rose

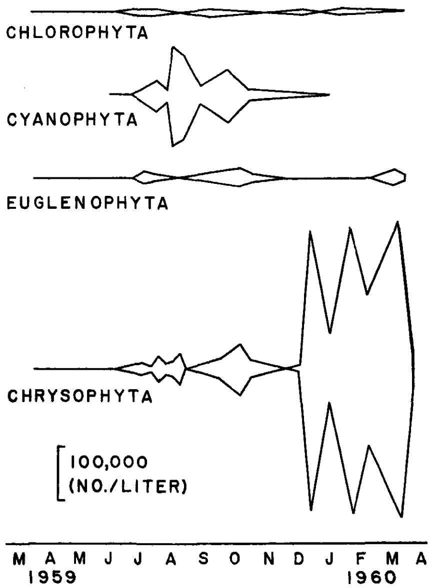

FIGURE 2

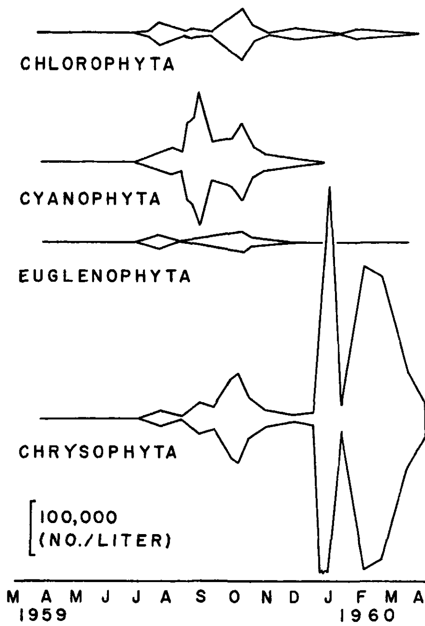

FIGURE 3

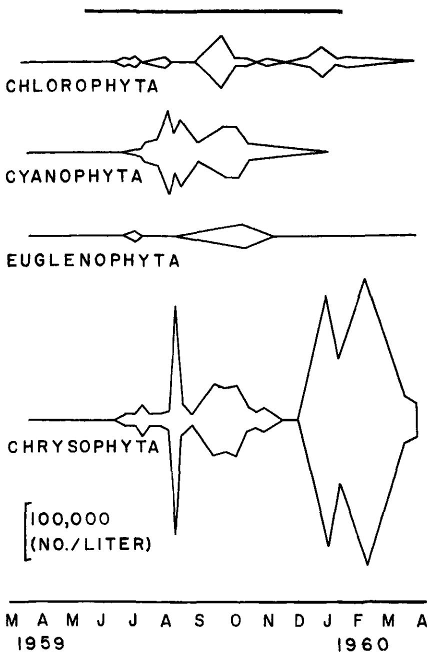

FIGURE 4

FIGURE 2. Seasonal distribution of the major phytoplankton phyla at the surface, at Aurora Lake.

FIGURE 3. Seasonal distribution of the major phytoplankton phyla at 1 m, at Aurora Lake.

FIGURE 4. Seasonal distribution of the major phytoplankton phyla at 2 m, at Aurora Lake.

to its maximum peak, which extended from February 6 (1,386,000 cells/liter) into March (fig. 4). This winter development occurred under an ice cover (25 cm). The Chlorophyta and Euglenophyta were found at greatest concentration in the littoral regions, in contrast to the members of the Chrysophyta which were more abundant at the limnetic station.

SEASONAL DISTRIBUTION OF PHYTOPLANKTON

The maximum and minimum of the phytoplankton at Aurora Lake did not follow the classical pattern during the year of study. There occurred an extended summer pulse that diminished in early October; this was followed by a winter pulse composed of two extensive peaks that occurred December 20 and February 6 (fig. 5). The periods of minimum development were in the spring months and in November.

The more important species are reviewed below according to their respective phyla.

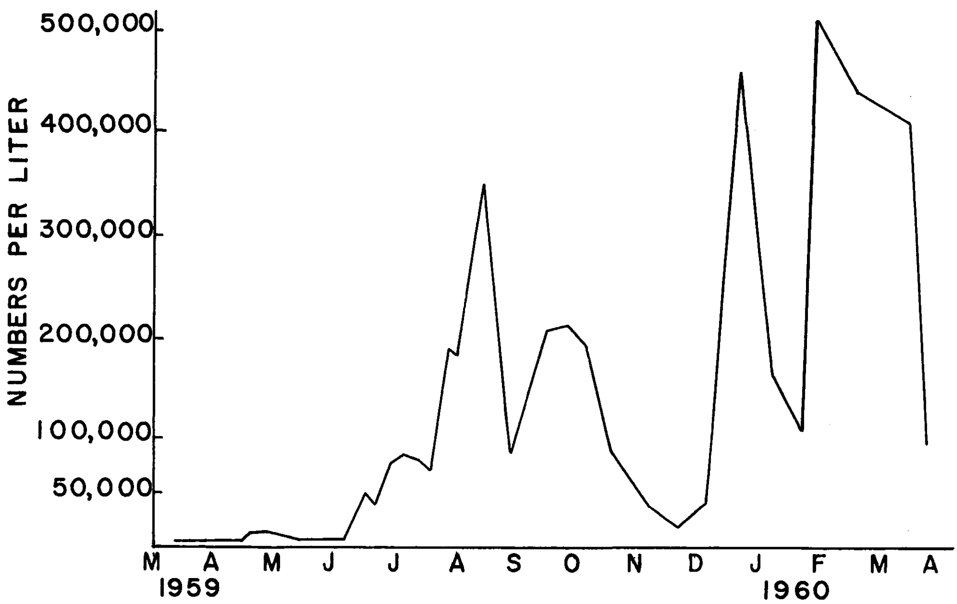

FIGURE 5. Seasonal distribution of phytoplankton based on averages at the surface, 1 m, and 2 m, at the three collecting stations.

Chrysophyta

The Chrysophyta had their minimum development in spring and late fall. The concentrations of these algae were large during the summer and early fall, but their maximum production occurred during the winter months. The Chrysophyta were the dominant winter algae that were represented primarily by diatom species.

The absence of a spring diatom pulse differed from the "typical" distribution pattern of Chrysophyta (Kraatz, 1941; Niessen, 1956). This could have been the result of adverse conditions that existed at this time, such as the high acidity or low oxygen levels. A bimodal spring and winter distribution was reported by Hutchinson (1944), Davis (1954), and Pierce (1947). Davis reported that the diatoms constituted nearly 100 per cent of the phytoplankton during spring and winter in the Cleveland Harbor area of Lake Erie. In contrast to these reports, low diatom concentrations during the winter have been reported in a variety of lakes by several investigators (Maucha, 1932; Kurasawa & Shiraishi, 1954; Castenholz, 1960).

Asterionella formosa Hass. occurred at all stations throughout the period of investigation, producing moderate pulses August 5 and September 20 and a major development in January 29 through February 19 under ice cover (fig. 6). The average temperature during those pulses was above 20 C for the summer and below 2 C during the winter peak. The summer distribution of this species was comparable to results reported by McCombie (1953) in a three-year study of the Algonquin Park Lakes where he found this genus favoring temperatures from 14 to 21 C. The winter development for this species at Aurora Lake was considerably below this temperature range. However, this species has been classified as a cold-water type with various physiological races reported in warmer waters (Tinbergen, 1948). The light intensities are reduced under a snow-covered ice layer; thus, the major pulse at Aurora Lake was composed of a form that was favored by low temperatures and low light requirements. Spring and autumn peaks were reported by Wade (1949), Kurasawa & Shiraishi (1954), and Willén (1961). Pennak (1949) and Kokke (1958) noted a single spring pulse and Davis (1954) a dominant winter and a larger autumn pulse, while Tucker (1957) reported a single November peak. Greatest concentrations of *Asterionella formosa* usually occurred at 1 or 2 m.

Fragilaria crotonensis Kitt. The usual distribution pattern of this species (fig. 6) was correlated with temperature. There were low concentrations from March 18 through October 8, but this was followed by a December 20 maximum. The temperature of Aurora Lake during the winter pulse was below 3 C for the entire period. The *Fragilaria* distribution differs also from that reported by Kurasawa and Shiraishi (1954), Tucker (1957) and Kraatz (1941), who found the concentration was rather uniform during the year, with minor peaks occurring sporadically. Wade (1949) and Davis (1954) found pulses during the spring and fall, while Pennak (1949) reported the species as dominant during June. In the present study, a higher concentration of this species prevailed at the surface and at 1 m.

Melosira granulata (Ehr.) Ralfs developed pulses July 6, August 12, October 8, October 26, and December 20. The concentrations never became very large, but the population maintained sufficient size to be considered as a prominent species from late June to the following spring. The only period of low concentration occurred in the spring of 1959 and early winter. These results approached a bimodal distribution, with late spring and fall maxima that were similar to the results reported by Wade (1949), Tucker (1957), and Willén (1961). The species was not the dominant chrysophyte in the lake, whereas in the investigations by Rawson (1960) and Davis (1954) it was the most important form present. The vertical distribution of *Melosira* was fairly uniform at the three depths measured, although there was a slight tendency for a larger concentration to occur at 2 m.

Synedra sp. attained maximum density during the winter months. At other times, the concentrations were relatively low, but the genus was well represented in many samples (fig. 7). The winter pulse attained a maximum density of slightly over 60,000 cells per liter on January 3, at the 2-m level. This seasonal distribution was different at Douglas Lake (Tucker, 1957), where *Synedra* developed a fall peak. Castenholz (1960) found *Synedra* the commonest algal form in the spring and winter plankton, while Kraatz (1941) noted development of this genus throughout the year, with peaks in spring and fall. Kurasawa and Shiraishi (1954) found it at Lake Suwa in all seasons except winter, while Phillips and Whitford (1959) found a single spring pulse in four North Carolina ponds.

Dinobyron sp. was found in large concentrations during the winter months often at temperatures below 4 C; it occurred in scattered samples throughout the year in lesser quantities (fig. 8). Surface concentrations reached a high of over 161,700 cells per liter on March 15, in the littoral region. Davis (1954) reported regular observations of this plankter during July and August, then greatly reduced numbers after October in the Cleveland Harbor area of Lake Erie. Kraatz (1941) found the genus erratic in its seasonal distribution, but maximum development took place in April. Spring and fall pulses were reported by Willén (1959), Pennak

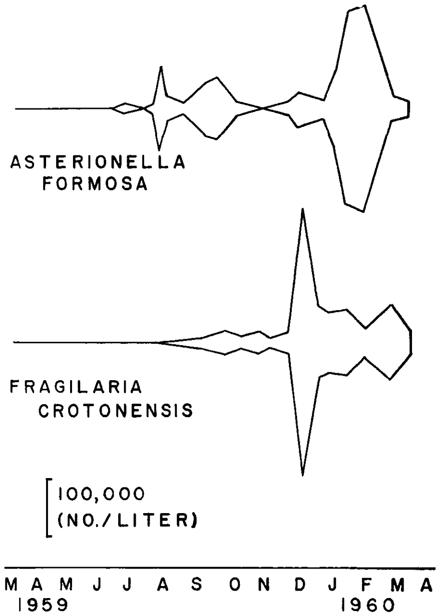

FIGURE 6

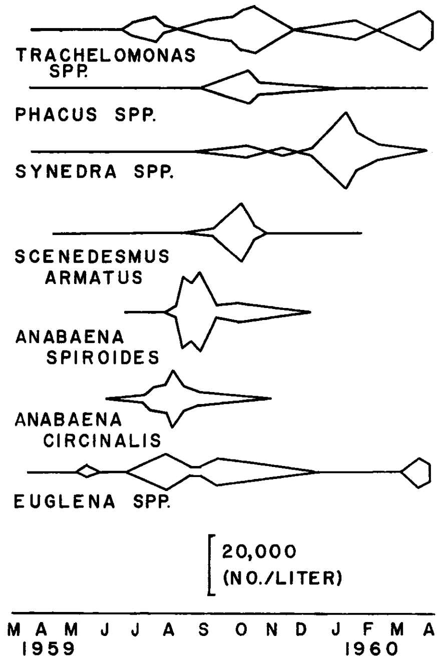

FIGURE 7

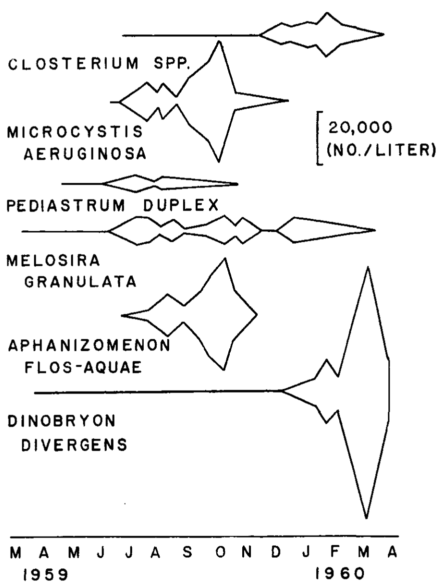

FIGURE 8

FIGURE 6. Average seasonal distribution of *Asterionella formosa* and *Fragilaria crotonensis* at Aurora Lake.

FIGURE 7. Average seasonal distribution of major phytoplankton at Aurora Lake.

FIGURE 8. Average seasonal distribution of major phytoplankton at Aurora Lake.

(1949), and McCombie (1953). Whitford (1960) considered the genus as favored by high light intensities and low temperatures, while Tucker (1957) correlated development with the overturn taking place in spring and fall. At Aurora Lake, *Dinobryon* was primarily a winter plankter, developing at low temperatures, reduced light intensities, and beneath an ice cover.

Cyanophyta

The Cyanophyta of Aurora Lake developed a single pulse, which began June 8 and reached maximum concentration August 12. Similar patterns of a single summer pulse were found in lake studies by Hutchinson (1944), Kraatz (1941), Chandler (1942), Wade (1949), and others. Pennak (1949) found that the numbers decreased rapidly with falling temperatures, but low concentrations prevailed during the winter in seven Colorado lakes.

This group dominated the summer algae at Aurora Lake. There was a positive relationship between its development and the rise in temperature. Conversely, the population density decreased as the temperature became lower in the fall.

Microcystis aeruginosa Kuetz. emend. Elenkin was the most important species during the summer pulse at Aurora Lake (fig. 8), reaching a concentration of over 40,000 colonies per liter September 18. The appearance of this species in other lakes has been associated with hard-water conditions that are similar to Aurora Lake (Prescott, 1951; Dineen, 1953). Its development corresponds to that found in lake studies by Willén (1959), Wade (1949), Tryon and Jackson (1952), and Davis (1954). Kurasawa and Shiraishi (1954) noted higher surface concentrations in the summer than during the autumn. The development at Aurora Lake indicated a similar distribution, with larger concentrations extending to the 1 m depth during the summer. In the autumn, total concentrations dropped rapidly and the distribution became relatively uniform at the various depths.

Anabaena circinalis Rabenhorst attained its summer maximum on July 13, and as this species decreased in number, *Anabaena spiroides* Klebahn became more prevalent, reaching its peak August 12 (fig. 7). Both species gradually decreased with lower temperatures. The temperatures at the time of this development were between 24 and 26 C, which is comparable, but considerably higher than temperature data obtained by McCombie (1953) in the Algonquin Park Lakes, where the pulse development of this genus did not take place at temperatures below 17 C.

The seasonal distribution patterns at Aurora Lake for this genus were similar to periodicities reported in lakes by Wade (1949), Tressler et al. (1940), Kraatz (1941), Chandler (1942), and Phillips and Whitford (1959). A three-year study by Willén (1961) revealed maxima during the summer at Lake Södra Vixen. Willén correlated abundance with the nutritional level of the water and the seasonal turnover period to the development of this genus. There was a tendency for the genus to be stratified in its distribution, with larger numbers more prevalent at the surface and at 1 m.

Aphanizomenon flos-aquae (L.) Ralfs had a bimodal period of sustained development from July 24 to November 7; it developed major pulses August 5 and October 8 (fig. 8). Prescott (1951) considered this form a common inhabitant of hard-water lakes, not favored by low pH conditions such as those that prevailed at Aurora Lake. The summer population increase at Aurora Lake was correlated with the rising pH of the water, but the species was scarce at other times. Other studies have indicated spring or summer blooms (Kraatz, 1941; Wade, 1949; Dineen, 1953; Davis, 1954) in the lakes that were less acidic.

Chlorophyta

The Chlorophyta species never reached large concentrations. However, the phylum produced a moderate pulse September 20. Chlorophyta have been reported elsewhere as more productive during the summer period (Tressler et al., 1940; Chandler, 1942; Rodhe, 1948; Willén, 1959) and may produce extensive maxima at this time (Pennak, 1946, 1949; Kurasawa and Shiraishi, 1954; and others). The Chlorophyta contained more species than the other algal categories during the year. Although never reaching dominant status, they maintained their population density both under cold and warm temperature conditions, indicating a somewhat eurythermal group.

The Desmidiaceae were relatively scarce throughout the year. This group is found predominantly in acid soft-water lakes in water between pH 5 and pH 6, and often in shallow and poorly aerated water (Pearsall, 1932; Smith, 1950; Niessen, 1956). Prescott (1948) stated that they are commonly found as components of the plankton in non-calcareous lakes rich in organic matter. Although the majority of the above conditions existed at Aurora Lake, the calcareous nature of the water may have been the reason for the poor development of desmids. The desmids had an irregular distribution throughout the year, with prominent species, *Cosmarium protractum*, *C. punctulatum* and *Staurastrum natator*, found in greater concentrations at the two-meter depth than at the higher levels. The most abundant genus of the desmids was *Closterium*; it showed a small pulse that continued from December 6 to February 6 (fig. 8). There was a gradual increase accompanying the drop in water temperatures that continued into January.

Scenedesmus armatus (Chod.) G. M. Smith was found throughout the year in low concentrations, with the major development occurring September 22 (fig. 7). *Pediastrum duplex* Meyer was found exclusively between April and October. During this time cell concentrations were low, with the exception of a large surface pulse on June 25, in open water.

Euglenophyta

Throughout the year the euglenoids were subordinate to the major phyla, but they gave evidence of a slight pulse September 20. The group was most frequently found in shallow water of less than 2 m in depth, where distinct variations were noted in the periodicity of each genus in these investigations (fig. 7).

Euglena sp. Each of the three stations possessed a different pulse pattern for *Euglena*. They were found on all sampling dates with the exception of February 19, but greatest numbers extended from April to November. At the littoral station off the northwest bank, the *Euglena* occurred throughout the year with spring and fall pulses. Off the opposite shore, the phytoplankton of the littoral station maintained an abundant concentration of *Euglena* all year, with maximum numbers (over 66,000 cells per liter) developing July 23. Although the limnetic station possessed an earlier and greater spring development, its fall pulse was more subdued in comparison with either littoral station. The somewhat erratic pattern of *Euglena* distribution in Aurora Lake may be misleading due to the differing pulse patterns of several species, reaching their peak at different periods and occurring in different concentrations at the three stations.

The distribution of *Phacus* showed low concentrations from March 18 to September 16, with a small pulse on September 17. The genus was absent between January 17 and March 26. The shallow and swamp-like nature of some areas of Aurora Lake are similar to conditions listed by Prescott (1951) as favorable for the development of *Phacus*. There was a tendency for this genus to occupy the surface waters. *Trachelomonas* was a typical constituent of all plankton samples, but was more abundant during the fall and winter. *Trachelomonas* had an average fall pulse September 17 that was larger and more extensive than that of *Euglena*. The numbers were rather consistent throughout the year.

Pyrrophyta

This algal group was insignificant in its over-all contributions to the phytoplankton composition of Aurora Lake. There were only three species, occurring in scattered samples from September 22 to March 15. These forms were not found at Aurora Lake until the fall and winter seasons, with *Peridinium cinctum* (Muell.) Ehrenberg and *Peridinium* sp. predominating in this group. The concentrations were always low and no pulse pattern was noted during this period. The genus was found in low concentrations in correlation with a low pH level by Tucker (1957). *Ceratium hirundinella* (Muell.) Dujardin was found only once, on September 22, in the littoral region. Prescott (1951) stated that *Ceratium hirundinella* occurred more abundantly in hard-water than in soft-water lakes. Kraatz (1941) found the species prominent through the year, with peaks in June and August. Pulses were found by Willén (1959, 1961a) and Wade (1949) in June, July, and August, while Tucker (1957) and Chandler (1940) noticed that larger numbers followed each overturn period.

DISCUSSION

The characteristics of shallow Aurora Lake include the following: an extensive littoral region of submerged vegetation and organic deposits along the lake bottom, with considerable amounts of dissolved organic matter in suspension. The lake lacks a cold hypolimnion during the summer months, and the natural presence of warm-water fish (perch) is common. The above conditions and the rich chrysophyte-cyanophyte population are indices of advanced stages of eutrophication.

The phytoplankton at Aurora Lake was the expression of several dominant algae, developing in sequence. The physical and chemical conditions that provided the optimum conditions for any one of these algal species undoubtedly were different for other species. The summer pulse was composed of two peaks, each dominated by different species of the cyanophyta, occurring at different temperature and pH levels, and presumably in water of changing chemical composition. The winter pulse presented a similar situation where the two peaks were dominated by two different diatoms that were prolific under different physical and presumed chemical conditions. There must have existed a dynamic interplay of physical and chemical factors that favored or hindered the metabolism of the various algal species. These changing factors resulted inevitably in conditions that influenced seasonal and successional patterns of development.

The influence of temperature on phytoplankton development includes numerous indirect effects resulting from the seasonal circulatory movements of the water masses, as well as the direct response of the phytoplankton population to temperature variations. The summer pulse at Aurora Lake was composed of two peaks, occurring at the end of August and in early September. During the first summer peak, there was correlation between the composition and development of phytoplankton and rising water temperatures of the lake. The population subsided during warm temperatures so that the period of lowest cell concentrations, between two summer growths, occurred at the time of the highest water temperatures (28.4 C), recorded for the year. After this period of low concentration, the second phytoplankton peak developed, and subsided with the gradually falling water temperature. In contrast, two extensive developments of diatom species were noted during the winter months beneath a cover of ice.

There was a gradual increase in the pH (4.5 to 6.0) of Aurora Lake, correlated with the rise in temperature and with the development of the total summer phytoplankton. The pH values dropped with the lower temperatures of autumn preceding the decline of the second summer peak. There was also a slight increase in the pH during the winter pulse. The fluctuation of water pH is mainly influenced by photosynthetic and respiratory activities, with the major source of CO_2 in the respiratory activities of the biota.

The pH of Aurora Lake is below the ranges commonly found in oligotrophic and eutrophic lakes (Kraatz, 1941; Tucker, 1957), where typical readings lie between pH 6.0 and pH 9.8. The pH of Aurora Lake is similar to dystrophic and bog lakes; however, the algal composition is mainly eutrophic. The development of these algae may indicate a tolerance, or species variation, to this pH condition.

The seasonal distribution of phytoplankton in Aurora Lake differed from the patterns in northern Ohio lakes reported by Tressler et al. (1940), Kraatz (1941), Chandler (1942), Davis (1962), and others.

Every natural lake is unique in its character and ecological traits. The individuality of each lake is the product of numerous realtionships that will not always produce a stereotyped response to a given stimulus or environmental condition. This is especially true of small, shallow lakes in advanced eutrophic states. This type of lake may deviate from the classical patterns that first were established in the larger lakes. It is difficult to select a single factor as the cause of certain maximum or minimum periods. In fact, lakes containing different biota, with different physical and chemical characteristics, would not be expected to respond in a similar manner to the same stimulus.

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