EFFECTS OF FERTILIZATION AND AERATION ON THE ECOLOGY OF PONDS

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ABSTRACT

EFFECTS OF FERTILIZATION AND AERATION
ON THE ECOLOGY OF PONDS

By

Howard Alan Simonin

Two farm ponds were fertilized, one (Pond C) with both phosphates and nitrates to approximate a secondary sewage effluent, and the other (Pond D) only with nitrates. Each pond was divided into two sections by a black plastic divider, and half of each pond was aerated. We expected that as a result of fertilization, the plant community would increase and result in increased demands on the dissolved oxygen in the system. In an unaerated situation we expected that dissolved oxygen levels would drop to critical levels at night, due to the increased plant respiration. In the aerated system, however, an adequate dissolved oxygen level would be maintained.

The project was divided into two phases, with aeration continuing throughout the summer. During the first phase, the ponds were fertilized once, and the biological and chemical changes were monitored. During the second phase, high nutrient concentrations were maintained by fertilizing every fourth day. Again, the chemical and biological changes which occurred were measured.

The dissolved oxygen concentrations in pond C were continuously monitored and showed little difference between the aerated and unaerated sections. Supersaturated conditions occurred during the day, and the

lowest recorded value at night was 5.7 mg/l. Greater fluctuations in the diurnal dissolved oxygen curve were noted as a result of continued fertilization of pond C with nitrates and phosphates.

The ortho-phosphate and nitrate concentrations decreased rapidly, shortly after fertilization. Pond D, which showed relatively little increase in plant growth, exhibited a rapid nitrate decline, similar to that of pond C. The plant community of pond C increased as a result of fertilization with nitrates and phosphates, and as a result the concentrations of these nutrients declined rapidly. The rapid decline of phosphate was due most likely to a combination of factors including bacterial activity, adsorption, uptake by plants, and precipitation with Ca^{++}.

The phytoplankton in both sections of both ponds C and D responded similarly to fertilization. Increases in the absorbance of plant pigments at 665 nm were noted approximately seven days after fertilization. During the second phase of the project, this value remained at a high level.

A definite increase in periphyton was noted in pond C as a response to fertilization with nitrates and phosphates. The periphyton colonization rates of the aerated section C1 were significantly greater than those of unaerated C2. This was thought to be due to the aeration system bringing CO_2 into the system and acting as an additional carbon source.

Filamentous algae became very abundant in pond C by the end of the summer, but not in pond D. Oedogonium was the dominant alga and appeared first along the aeration hose in section C1. This was attributed to the carbon dioxide being brought into the system by aeration.

The macrophyte Najas flexilis in pond D died as a result of fertilization with nitrate fertilizer, whereas populations in pond C remained relatively healthy. Different species of macrophytes in pond C behaved differently over the summer period. Whether the responses were due to the fertilization or to normal seasonal changes could not be determined.

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Howard Alan Simonin

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INTRODUCTION

The effects that our society has had on the natural world are many. In regard to aquatic environments, perhaps the most important of these concerns the process of eutrophication. The adding of nutrients to our lakes and streams and the resulting increases in plant growth have lead to problems of every sort and dimension. The complexity of the various relations and interactions involved in the aquatic environment make dealing with these problems difficult. It is this same complexity, however, which helps to maintain the stability of the natural ecosystem.

The many factors which affect the growth of aquatic plants are an integral part of eutrophication. Even though a lake may be rich in nutrients, it may not be able to support a large plant population because certain of these conditions are not met. Some of the physical factors involved include temperature, light, depth of the water, suitable substrate, percent littoral zone, and the degree of circulation. Chemical factors would include dissolved oxygen levels, pH, presence or absence of toxicants, concentrations of essential nutrients, and carbon dioxide concentrations. These factors are of course not the only ones involved, but they do help to show the interactions involved in the eutrophication process.

Oxygen is one of the most critical components in regard to life in the aquatic environment. When abundant dissolved oxygen (D.O.) is present, and other conditions are adequate, then a diverse biota can exist. However, when this oxygen is not present, then most forms of aquatic life cannot survive, and the anaerobic forms become dominant. Eutrophication is exemplified by abundant plant growth, and this increased biomass in the system results in increased demands on the oxygen balance. Edwards and Owens (1965) have summarized much of the work concerning the effects of plants on the oxygen balance of rivers. Owens, Knowles, and Clark (1969) showed that at high plant densities and low light intensities the average dissolved oxygen concentration decreased to about 1 mg/l. With low plant densities and low light intensity, however, the average dissolved oxygen level remained at about 6 mg/l.

The overall effect of plant life in the water results in a diurnal change in oxygen concentration. During the daylight hours, the plants photosynthesize and release oxygen, therefore increasing the D.O. of the water. At night, however, oxygen production stops, and the D.O. of the water decreases, due to the respiration of the biotic community. In a eutrophic environment with its abundant plant growth, we would expect both greater demands and greater fluctuations in the oxygen balance than in a less eutrophic environment.

The problem of nutrient concentrations and the limiting nutrient concept have been the topic of many discussions. Whether or not a certain nutrient is present in adequate supply or not is critical to the growth of a plant. Part of the discussion concerns the fact that different species of plants, both algae and macrophytes, may require nutrients in different quantities. This variation in species requirements results in certain species being present when conditions are not adequate for others. This also is shown by seasonal changes in plant communities.

It is generally accepted that phosphorus is the nutrient most frequently limiting plant growth in freshwater environments. There are of course lakes in which one of the micro-nutrients such as molybdenum, cobalt, manganese, or iron may be limiting to plant growth (Goldman, 1972), but this is not saying that these are phosphorus-rich lakes. Cultural eutrophication in lakes has often resulted when, by man's activity, the input of phosphorus to a lake increased, perhaps by sewage effluents or by agricultural or urban drainage.

When the demand for a limiting nutrient such as phosphorus is met by an increase in the supply, then plant growth increases. This growth would then, however, become limited by other factors in the environment, such as light, temperature, or other nutrients. Carbon is an important nutrient in the growth of plants and is oftentimes in great demand. When the phosphorus and nitrate concentrations in the water are increased, this nutrient may very well become limiting to many of the plants. In fact, Kerr et al. (1972) suggest that the phosphorus and nitrogen stimulation of algal growth may be indirect and mediated by the availability of carbon dioxide. King (1970) and Kuentzel (1969) have presented arguments that carbon and not phosphorus is the nutrient most important in limiting algal growth.

Innumerable methods have been developed for controlling or treating the problems of eutrophication. The tremendous variety in methods is in part a reflection of the tremendous variety in aquatic environments. Biological, chemical, and mechanical schemes have been applied to different situations.

One of the methods used in water treatment is aeration. Aeration of sewage and wastewater has been common practice to reduce the biochemical oxygen demand. By bubbling air through the water column, oxygen is made more available to the biota of the system. One of its uses in farm ponds is to reduce the chance of a winterkill by creating an oxygen supply adequate for fish. Aeration systems also have been used in the management of larger bodies of water (Symons, 1969).

In eutrophic lakes and reservoirs which stratify during the summer months, very low dissolved oxygen levels may occur in the hypolimnion. This puts a stress on the deep water aquatic life and may force fish into warmer shallow waters and result in the death of other aerobic organisms. Another problem resulting from the reducing conditions in the hypolimnion is that nutrients formerly trapped in the sediments are now released to the water, and may become available to plant growth when the lake overturns in the fall.

Aeration is often used to destratify reservoirs or lakes where eutrophication problems arise. This destratification theoretically results in a homothermal condition with oxygen present at all depths, and the nutrients remaining locked in the sediments. Symons (1969) has reported some of this work in regard to reservoirs. Leach and Harlin (1970) studied the effects of induced aeration on a small mountain reservoir which was used as a rainbow trout lake. In a study quite similar to the one reported here, Malueg et al. (1973) recorded the effects of induced aeration on stratification and eutrophication processes in an Oregon farm pond.

Fast (1971) reported the results of two aeration projects. In one, the hypolimnion of a eutrophic lake was aerated while thermal stratification was maintained. In the other study, an oligotrophic lake was aerated and destratified. In both of these projects the aeration resulted in changes in the oxygen and temperature regimes of the lakes, and consequently changes in the animal and plant populations were observed.

Whereas the aeration research discussed above was concerned with a stratified environment, the work reported in this paper is concerned with aeration of a shallow, unstratified environment. The shallow nature of the study ponds meant that plant growth was possible even at the deepest point. Littoral communities of this nature are characteristically rich in both plant and animal life.

In a typical eutrophic pond we would expect several changes in the environment to occur as a result of the plant activity. As a result of photosynthesis during daylight hours, the amount of CO_2 and bicarbonate in the water would be expected to decrease. Because of its relationship to the hydronium ion concentration, this decrease in CO_2 and bicarbonate would coincide with a rise in the pH of the water. In ponds with dense plant populations the pH may rise above 10, where it may have adverse effects on the biota of the system.

As was discussed previously, a second environmental change resulting from an increase in plant populations is an increase in the fluctuations of dissolved oxygen. A condition of abundant plants would result in higher daytime dissolved oxygen levels, and lower nighttime levels. In very eutrophic situations these low D.O. levels at night may greatly stress the biota of the system. In fact, it is not uncommon that after a period of hot, calm, cloudy days, where photosynthesis is low, the level of dissolved oxygen at night may drop to critical levels. At such levels intolerant animal life dies and a summerkill results.

An objective in managing a eutrophic pond environment would be to eliminate or decrease the possibility of adverse effects from pH and oxygen changes. Aeration was thought to be a reasonable method of eliminating the high pH and low dissolved oxygen levels. By bubbling air through the water column, a certain amount of CO_2 would be added. This would act to balance some of the CO_2 removed by plants and would in effect decrease the possibility of a high pH. The oxygen being added to the water by aeration would then eliminate the chance of oxygen depletion occurring at night.

The research reported in this paper was focused on the effects of fertilization and artificial aeration on the plant communities of two small ponds. As a result of fertilization, the plant community was expected to increase, and the dissolved oxygen concentrations at night were expected to drop to levels that would be critical to the pond biota. In an aerated system, however, these oxygen deficiencies would be eliminated.

DESCRIPTION OF STUDY AREA

This study was carried out during the summer of 1971 at the Water Quality Laboratory of the Lake City Agricultural Experiment Station. The experiment station is run by Michigan State University and is located about two miles south of Lake City, Michigan in Missaukee County.

The Department of Fisheries and Wildlife maintains the Water Quality Laboratory which includes four experimental ponds and adequate laboratory facilities. A 2.6 hectare (6.5 acre) reservoir formed by the damming of Mosquito Creek is the water source for the ponds. The outlets of the ponds connect with the downstream section of Mosquito Creek. The four ponds are designated A, B, C, and D from west to east. Only ponds C and D were used in this study.

Both study ponds were divided into two sections by a large black plastic divider. This resulted in two ecologically similar but separate units, where the effects of aeration or no aeration could be determined. The plastic divider was supported by a rope running the length of each pond and by posts driven into the pond bottom. The bottom of the wall was sealed with the sediments by extending the excess plastic along the pond bottom and weighting it down with rocks and gravel. The dividing walls in both ponds C and D were set up to give an inlet and outlet for each section. Chicken wire was used to cover the inlet and outlet areas to keep the fish populations of each section from mixing.

A relatively static condition was maintained during the summer, with a small inflow and outflow being unavoidable. Figure 1 shows the layout of the ponds and the pond sections.

The surface area of pond C was 0.07 hectare (0.17 acre) and of pond D was 0.07 hectare (0.18 acre). Both ponds were quite shallow, having an average depth of 1.1 meters (3.5 feet) and a maximum depth of 1.5 meters (5 feet). The volumes of water in the pond sections were as follows:

C1	-	349,800	liters
C2	-	386,000	"
D1	-	363,000	"
D2	-	416,300	"

Sections C1 and D1 were the aerated sections.

Figure 1. A map of the Lake City ponds C and D.

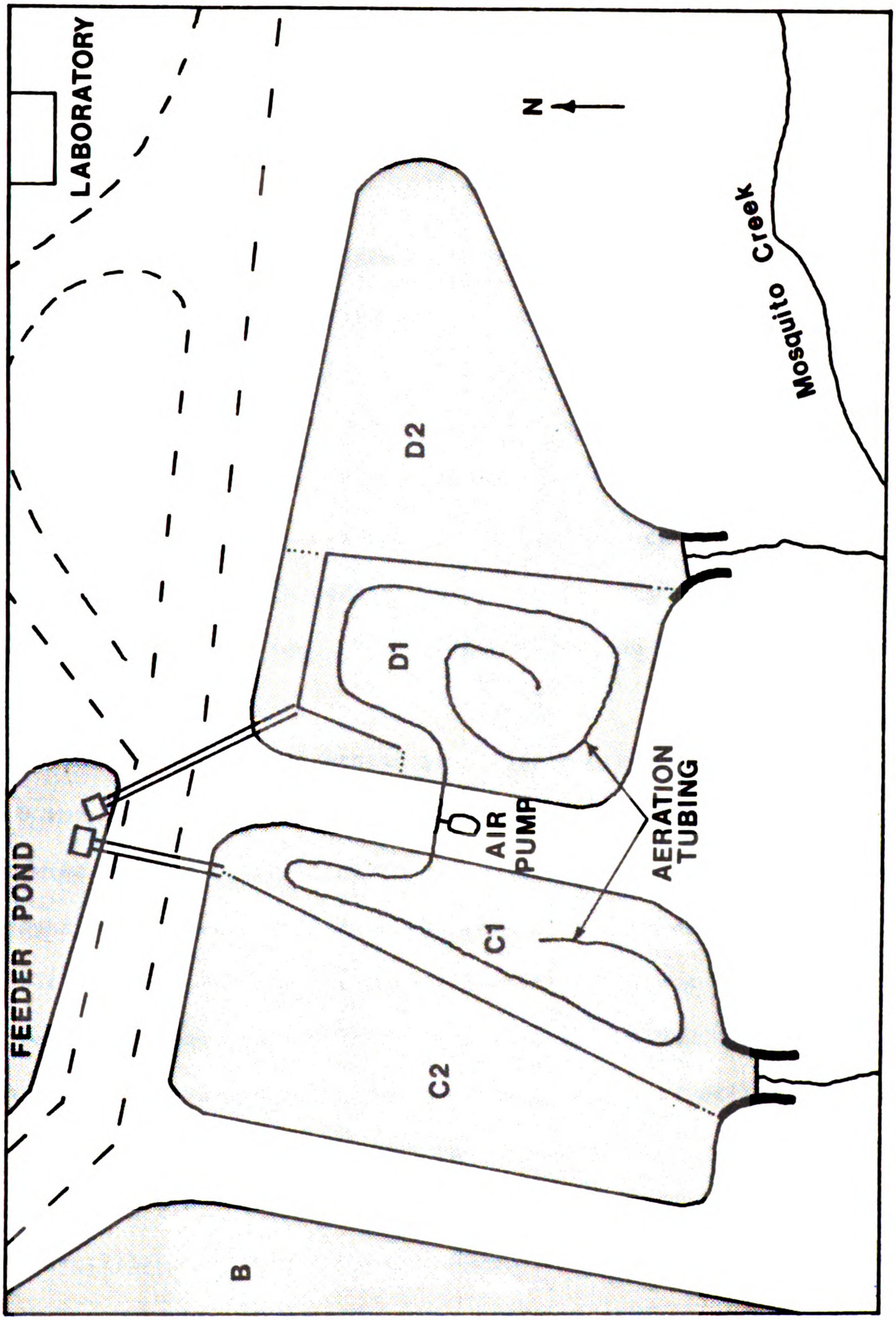
LABORATORY
N
Mosquito Creek
D2
D1
FEEDER POND
AIR PUMP
AERATION TUBING
C1
C2
B

Figure 1

TECHNIQUES AND MEASUREMENTS

Pond Fertilization

The increase in nutrients in ponds C and D was carried out in two phases. During the first part of the summer, the ponds were fertilized once, and the declines in phosphate and nitrate concentrations were measured, along with the effects of this fertilization on the biotic community. During the second phase of the project, which began at the end of August, the ponds were fertilized every fourth day. During this phase, high concentrations of phosphate and nitrate were maintained in the system. Again, the effects on the biotic community were measured.

The levels of nutrients in pond C were brought up to 6 mg/l PO_4 as P and 15 mg/l NO_3 as N. The nitrate concentration of pond D was likewise brought up to 15 mg/l, but this pond was not fertilized with phosphates. These nutrient levels were chosen in order to approximate levels found in secondary sewage effluent. This was done because we wanted to approximate expected conditions at the MSU Water Quality Project. In this project secondary sewage effluent will flow through a series of four ponds (Ball and Tanner, 1972).

The nitrate levels of ponds C and D were measured the day before each fertilization. From these values, and the known volumes of each pond, it could be determined how much fertilizer had to be added in order to bring the nitrate concentration to 15 mg/l. The nitrate form used was KNO_3 and was 33.3 percent by weight of the powdered fertilizer.

The phosphate fertilizer was 46 percent available P_2O_5 and is referred to as triple superphosphate. The phosphate levels in the ponds were measured the day before application of the fertilizer, as was done with the nitrates. The ambient phosphate level and volume of each pond section were then used to calculate the amount of phosphate fertilizer to be added. As was mentioned before, only pond C was fertilized with phosphates.

In order to increase the mixing of the powdered fertilizer with the water, the fertilizer was first dissolved in buckets of pond water on the shore. This solution was then sprayed over the pond from the back of a rowboat, using a hand pump. The boat was then rowed around the pond until the fertilizer appeared evenly distributed.

During the first phase of the project, the ponds were fertilized with nitrates on July 23, and with phosphates on July 24. During the second phase, the ponds were fertilized on August 27 and 31, and September 4, 8, 12, and 16.

Aeration System

A one-half horsepower oil-less air compressor distributed by Hinde Engineering Co. was used as an air source for this project. The compressor was set up on the dike separating ponds C and D. From the compressor, tubing lead to a tee and from there to sections C1 and D1, the sections nearest the compressor (Figure 1). In each of these sections was 200 feet of Air-aqua aeration tubing. This tubing is weighted and has small air openings at frequent intervals.

According to Hinde Engineering Company, the compressor was supplying about 4 ft^3/min. There would therefore be 2 ft^3/min of air being supplied to each of the aerated sections C1 and D1. The compressor was run continuously from July 15 until September 20, except for repairs and replacing the compressor itself on September 5.

A summary of the various pond treatments is shown in Table 1.

Physical and Chemical Parameters

Temperature

Water temperature was measured daily using Taylor maximum-minimum thermometers, which were left in pond sections C1 and D2. Temperature readings were recorded at 9:00 A.M. daily, therefore giving the previous day's high and nighttime low. Air temperature, rainfall, and general weather conditions were recorded at the weather station of the Lake City Agricultural Experiment Station.

Dissolved Oxygen

Since the level of dissolved oxygen in the ponds was a critical part of this project, a continuous sensor was used to record the diurnal oxygen curves. On August 13, a submersible electric pump was placed in pond Section C2. The pump was inside a wire basket designed to keep fish and debris from clogging the intake. Water was pumped from

Table 1. Summary of the various treatments used on the four pond sections.

Pond Section	PO_4 Fertilizer	NO_3 Fertilizer	Aeration
C1	X	X	X
C2	X	X	
D1		X	X
D2		X	

a depth of about 0.8 meter into the lab and into a large plexiglass cylinder where the oxygen probe was suspended. The water was then returned to the pond section through a plastic hose.

The oxygen levels were measured with a Beckman Model 777 dissolved oxygen meter, which was calibrated daily during the morning hours. The dissolved oxygen meter was connected to a Sargent recorder, which ran continuously.

In order to also monitor the diurnal oxygen curve of pond section C1, the submersible pump unit was moved to section C1 on September 1. On September 9 the unit was returned to section C2. Because of the relatively small response to fertilization shown in pond D, a continuous monitor of the dissolved oxygen was not made.

Chemical measurements of dissolved oxygen were made before and after the monitoring system was set up, and to calibrate the D.O. meter. These measurements were made by using the azide modification of the Winkler method (American Public Health Association et al., 1971), however, phenylarsene oxide was used in place of sodium thiosulfate.

pH

Measurement of hydrogen ion activity was made several times during the project after a Beckman pH meter was set up on August 17. The pH levels before and after fertilization were particularly watched.

Phosphate Concentrations

The measurement of orthophosphate in both sections of ponds C and D was made at regular intervals. The stannous chloride method as described by _Standard Methods for the Examination of Water and Wastewater_ (APHA et al., 1971) was used for these determinations. This is a photometric method and involved measuring the color development at 690 nm on a Beckman Model B spectrophotometer.

The water samples were not filtered or digested, so the measurements of orthophosphate include the total dissolved and suspended orthophosphate. A preliminary acid hydrolysis step was included during several measurements. By boiling the sample with acid, the condensed polyphosphates are converted to orthophosphates which can then be measured with the stannous chloride test. This additional step in the analysis resulted in orthophosphate values only slightly greater than those obtained without the hydrolysis. It was therefore decided to eliminate this step in subsequent determinations.

After the initial fertilization of the ponds on July 23 and 24, water samples were taken every two hours from pond C, and phosphate determinations were made as soon as possible. This was done to monitor any rapid decline in orthophosphate concentration in the water. From July 26 to August 2 phosphorus determinations were made daily, to monitor the changing concentrations in the water. After this period, the rate of change in orthophosphate concentration had decreased, and measurements were made every third or fourth day.

During the second phase of the project, which began on August 26, the phosphate concentrations in both sections of ponds C and D were determined every fourth day. These values then were used to determine how much phosphate fertilizer was to be added the next day in order to bring the concentration in the pond back up to 6 mg/l PO_4 as P.

Nitrate Concentrations

The brucine method for determining nitrate nitrogen (APHA et al., 1971) was used in this study. The reaction between nitrate and brucine produces a yellow color, which was then measured at 410 nm on a Beckman Model B spectrophotometer. Nitrate nitrogen is the main form of nitrogen in most natural bodies of water, and since the fertilizer added was in the nitrate form, a measure of this constituent was necessary to examine the change in concentration over a given time period.

Following the initial fertilization of ponds C and D, determinations of nitrate were made every three days. Several pieces of data were lost, however, when we encountered problems with the hot water bath on July 30 and August 2. During the second phase of the project, the nitrate concentrations were determined for both sections of ponds C and D every fourth day. As with the phosphate, these values were used to determine how much nitrate fertilizer should be added to each section to bring the concentration up to 15 mg/l NO_3 as N.

Biological Parameters

Phytoplankton

The phytoplankton standing crop in each section of ponds C and D was measured spectrophotometrically by a method modified from Talling (1969). A 250 ml water sample was filtered on an HA 0.45 μ Millipore filter. This filter was then placed in a mortar and ground for 2 minutes in about 2 ml of 90% acetone. The mixture was then diluted to 10 ml and centrifuged for 5 minutes, after which the optical density was determined at 665 nm on a Beckman Model B spectrophotometer. It was hoped that by using a background reading at 750 nm and also readings for each sample after acidification, we would be able to arrive at a value for chlorophyll a. However, because the phytoplankton populations were very low, only relative values could be obtained. These values are the optical densities of each sample at 665 nm.

During the first phase of the project, phytoplankton samples were taken daily, and later every second day. During the second phase, phytoplankton determinations were made every third day.

A qualitative sample to determine the species present in the phytoplankton was made at the end of the summer by passing buckets of water through a plankton net. The abundant filamentous algae in pond C eliminated the possiblilty of towing the net behind the boat. These samples were preserved in alcohol and identified later in the laboratory.

Periphyton

The term periphyton as used in this study includes both epiphytic and epilithic algae. In his discussion of this community, Ruttner (1963) uses the term aufwuchs, which includes both plants and animals living attached to a substrate. The term periphyton is more restrictive and is a more accurate description of the community being measured in this part of the project.

To measure the response of periphyton to the conditions in the ponds, artificial substrates were used. These substrates were left in the pond for a given period of time and then removed. The amount of periphyton colonization which had occurred was then measured spectrophotometrically and the amount of chlorophyll *a* per unit area was determined.

The artificial substrates used were plexiglass plates having an exposed surface area of 140 cm^2. The substrates were mounted horizontally in the water on a cross bar 0.5 meter below the water surface. This was held up by a metal post driven into the pond bottom. Eight substrates were used in each series in each of the four pond sections. During the first phase of the project, these periphyton substrates were left in the water for five days. Upon collecting the colonized substrates, clean substrates were started. During the second phase of the project, the substrates were replaced every four days.

At the end of each exposure period the periphyton was scraped from two of the substrates and preserved in 95% alcohol for later identification. The other six substrates were each placed in a plastic bag and frozen. This freezing procedure not only allowed for later analysis at a convenient time, but also served to help rupture the algal cells and release the plant pigments.

After allowing the sample to thaw, the periphyton was scraped from the plate into a mortar. The plate and scraper were rinsed with 90% acetone, and the material was ground for two minutes. The volume of the extract was then brought up to 20 ml, and a subsample was then centrifuged for five minutes. Next, the absorbance of the sample was determined at 665 nm and 750 nm on a Beckman Model B spectrophotometer. The sample was then acidified with 0.1 ml 4N HCl, recentrifuged and measured again at 665 nm and 750 nm. The values at 750 nm are used to correct for background absorption by materials other than plant pigments. The acidification step is to correct for the presence of non-photosynthetic plant pigments. The chlorophyll a per square meter was then determined as explained by Standard Methods (APHA et al., 1971).

Macrophytes

The measurement of primary production of the higher aquatic plants has always created problems to the aquatic biologist. Wetzel (1965) and Westlake (1969) have discussed these factors and the methods of dealing with them. Depth of the water, sediment type, amount of periphyton covering the macrophyte, and the diversity of the plant community all affect the methods of measuring the primary production.

In this study only the primary production of the submerged aquatic vegetation was measured. Emergent vegetation and floating leaved macrophytes were present in some of the pond sections, but not abundant enough to accurately determine production rates.

As explained by Westlake (1969), the primary production rate can be determined from the change in biomass. This method does have several deficiencies, however, in that loss of biomass due to dying or decaying vegetation may balance the gain in biomass due to the growth of young plants. Also, different plant species may have their greatest growth rate at different times of the year. Therefore, the measurements of the biomass of a plant community should be made during the main growing season and flowering period of the species being measured, and not during the time period when parts of the plant decay and drop off.

Another factor to be considered is the amount of plant biomass in the sediments as roots, rhizomes, or various anchoring devices. This is particularly important when dealing with emergent vegetation and plants having large rhizomes. When determining the amount of biomass per unit area, as in primary production studies, it is important that this underground biomass is included.

One method used to determine the change in biomass of the macrophyte community was to harvest and dry representative samples. One means of harvesting used was to place a 10 cm X 10 cm wooden square over the plant community and then remove all the plant material within the square. This was done at a depth of about 0.7 meter using a mask and snorkel. The sample was then carefully washed to remove detritus and periphytic algae. Edwards and Owens (1965) showed that the weight of epiphytic algae may be on the same order of magnitude as the weight of the macrophytes. Washing of the plants proved to be a time consuming job and limited the number of samples that could be processed.

Whereas the wooden squares were used in the sampling of relatively small plants in shallow water, a 15.2 cm X 15.2 cm Ekman dredge was used for sampling in the deeper water. Again, the samples were washed to remove detritus and periphyton. The washed plants were then placed in white enamel pans and dried for 18 hours at 80C. The dried plants were then placed in sealed, air tight plastic bags for transport to East Lansing where they were weighed.

Sampling was done three times during the summer: before fertilization, at the end of the first phase, and at the end of the second phase. As was mentioned, the process of washing the samples limited the number that could be collected in a reasonable time.

A second method used to monitor any changes in the macrophyte community was to periodically examine quadrats in each of the pond sections. Three 0.5 m X 0.5 m quadrats were established in each of the four pond sections and were marked by a wooden stake at each of the corners. Observations and measurement of plants in the quadrats were made every two weeks throughout the project, using a mask and snorkel.

By using a quadrat technique, it was possible to measure the change in height of the plants, and also to observe the colonization and growth of new plants in the quadrat. This was done by visually dividing the quadrat into 16 equal units and then from each unit recording the species and height of the tallest plant. From these data, which represent only the tallest plants in the sections, an average value for each species was determined. Also, the percentage of the 16 units where a given species was tallest was determined. Sections which were barren or covered with filamentous algae were recorded as such.

The quadrat method does not measure the primary production or biomass of an area, but it is a very useful tool in monitoring the community structure and the ecological changes which occur over a period of time.

Specimens of the various plant species found in the Lake City ponds were collected and pressed about midway through the summer. These were later identified to species.

Zooplankton

Zooplankton samples were taken four times during the project, at four week intervals. A light trap used at night was the method of sampling. The trap consisted of an amber light mounted in a small jar under a wooden float. Under the light was a funnel leading to a collecting chamber. One trap was set out in each of the four pond sections from 9:00 P.M. until 10:00 P.M. The samples were then preserved in 95% ethanol for later measurement and identification.

Baylor and Smith (1953) and Ervin (1969) have shown that light traps used for zooplankton sampling are very effective and deserve further study. Both found that yellow light attracted cladocerans, copepods, water mites, ostracods, and various aquatic insects. Since the light source may result in different responses or rates of response among various organisms, the light trap is most likely best used as a qualitative sampling method. Assuming that these different responses and rates of response are generally constant, we may still use the data collected to make approximate comparisons between ponds.

The biomass of each sample was measured volumetrically in a graduated cylinder. Then, one milliliter subsamples were examined in a Sedgwick-Rafter counting cell, and the percent composition of organisms by count was determined.

Fish

The effects of fertilization and aeration on the fish life in the ponds were not determined. However, since fish play an important role in the aquatic environment, an attempt was made to have equal numbers and types of fish on each side of the plastic divider. Fish from ponds C and D were not mixed, however. To keep the fish from mixing between the two sections of each pond, chicken wire extended from the end of the plastic divider to the shore.

The fish species found in the Lake City ponds included golden shiners, *Notemigonus crysoleucas*; pumpkinseed sunfish, *Lepomis gibbosus*; green sunfish, *L. cyanellus*; largemouth bass, *Micropterus salmoides*; yellow perch, *Perca flavescens*; and brown bullheads, *Ictalurus nebulosus*.

RESULTS AND DISCUSSION

Physical and Chemical Parameters

Temperature and Weather Conditions

Findings in regard to temperature showed that ponds C and D did not differ appreciably. The maximum water temperature recorded during the time of this study was 29C (85F) while the minimum temperature was 16C (61F). The average diurnal change from nighttime low to afternoon high was 3.6C (6.4F). Figure 2 shows the daily maximum and minimum air and water temperatures for the summer of 1971.

June proved to be the warmest month of the summer, with July and August being colder than average. The summer months were fairly dry in relation to previous years. Only August had more precipitation than normal.

Dissolved Oxygen

Fish kills have occasionally been observed during the summer months in ponds or shallow lakes with abundant plant growth. These summerkills have been observed to occur after a period of several days with warm temperatures, cloudy skies and little or no wind. Bennett (1962) records that under these weather conditions, the dissolved

Figure 2. The daily maximum and minimum air and water temperatures for the summer of 1971.
(--- maximum and minimum water temperature, —— maximum and minimum air temperature)

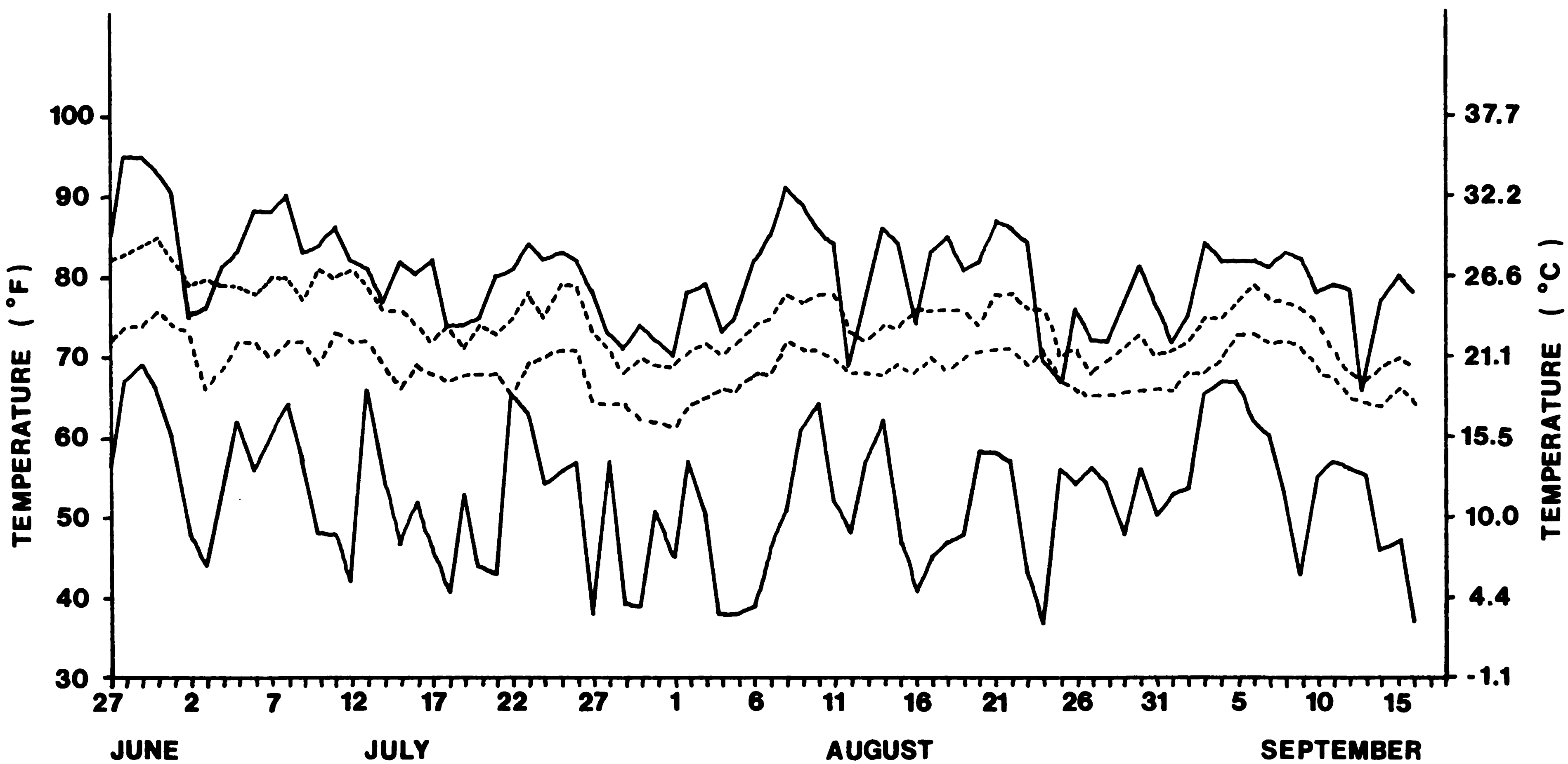
TEMPERATURE (°F)
100
90
80
70
60
50
40
30
TEMPERATURE (°C)
37.7
32.2
26.6
21.1
15.5
10.0
4.4
-1.1
27
2
7
12
17
22
27
1
6
11
16
21
26
31
5
10
15
JUNE
JULY
AUGUST
SEPTEMBER

Figure 2

oxygen normally abundant in the daytime, may become completely used up during calm, hot nights. High water temperatures, darkness, and rapid organic decay of shallow weed-filled ponds are also thought to contribute to the occurrence of summerkills.

Considering the nutrient rich shallow nature of the ponds in this study, it was expected that dissolved oxygen levels would drop to fairly low levels during the night. Filamentous algal mats floating on the pond surface would also tend to block sunlight and decrease the amount of oxygen produced during daylight hours. These low oxygen levels were expected to create an unfavorable environment for the animal life of the pond.

Conditions during the summer of 1971, however, did not result in low dissolved oxygen levels. The lowest recorded value was 5.7 mg/l oxygen on August 15 in pond C1. Figures 3 and 4 show the changes which occurred in dissolved oxygen levels over a one day period and over the entire summer period. Considerable fluctuations can be seen between the daytime and nighttime levels, but it is not likely that animal life was stressed by any of the low levels.

Figure 4 shows clearly that the diurnal fluctuations of dissolved oxygen in pond section C1 during September were greater than the fluctuations in C2 during August. It should be pointed out that a large amplitude of fluctuation also was observed in section C2 during September. The greater fluctuations are not due to the aeration of C1, but to the continued fertilization of the pond. The greater fluctuation in diurnal oxygen concentrations is a characteristic of eutrophic conditions. It is interesting to speculate that if a high nutrient

Figure 3. The change in dissolved oxygen concentration observed in pond section C1 on September 4, 1971.

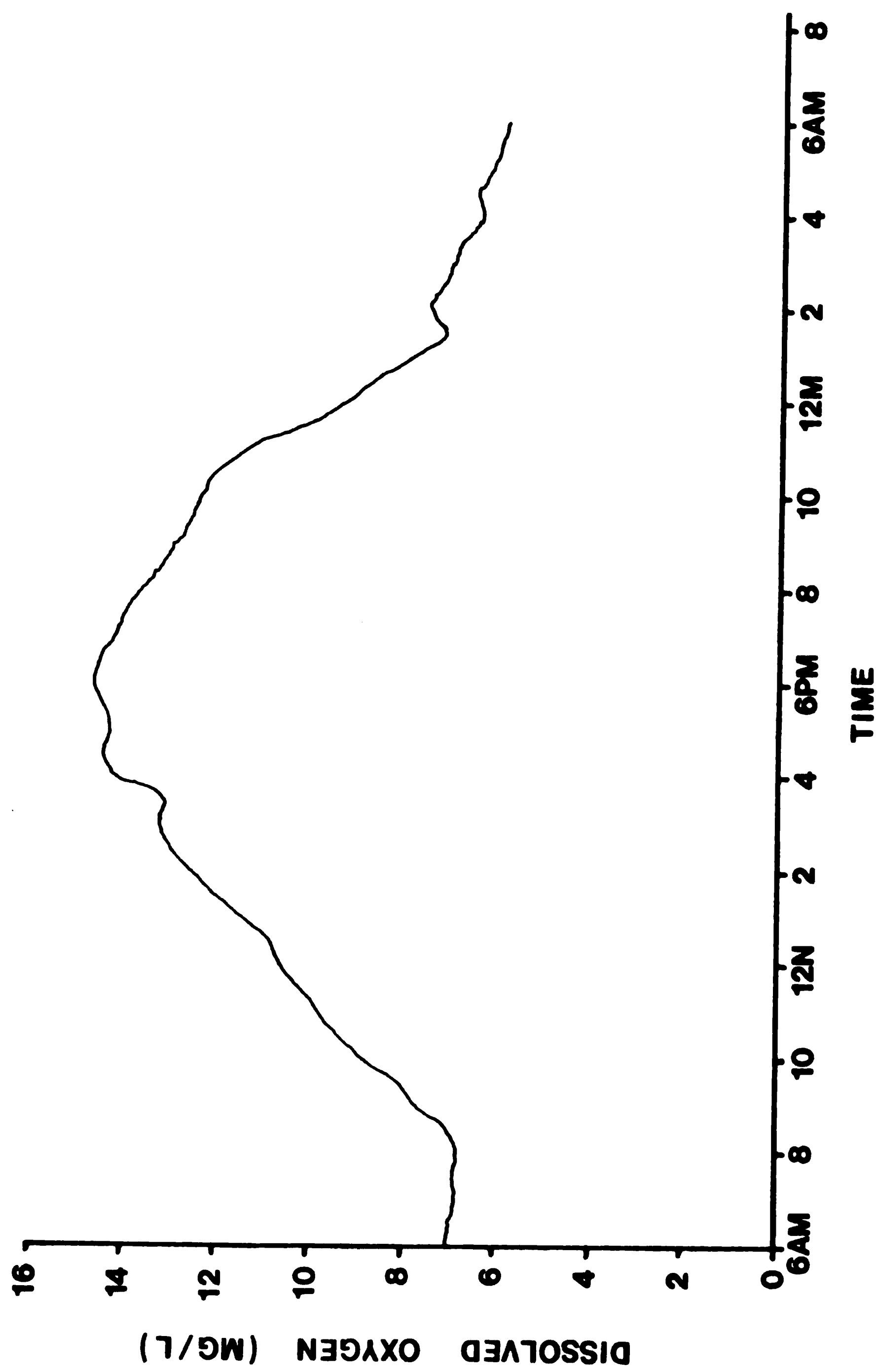
DISSOLVED OXYGEN (MG/L)
0
2
4
6
8
10
12
14
16
6AM
8
10
12N
2
4
6PM
8
10
12M
2
4
6AM
8
TIME

Figure 3

Figure 4. The changes in dissolved oxygen concentrations observed in pond C during the summer of 1971.
(—— C2, --- C1)

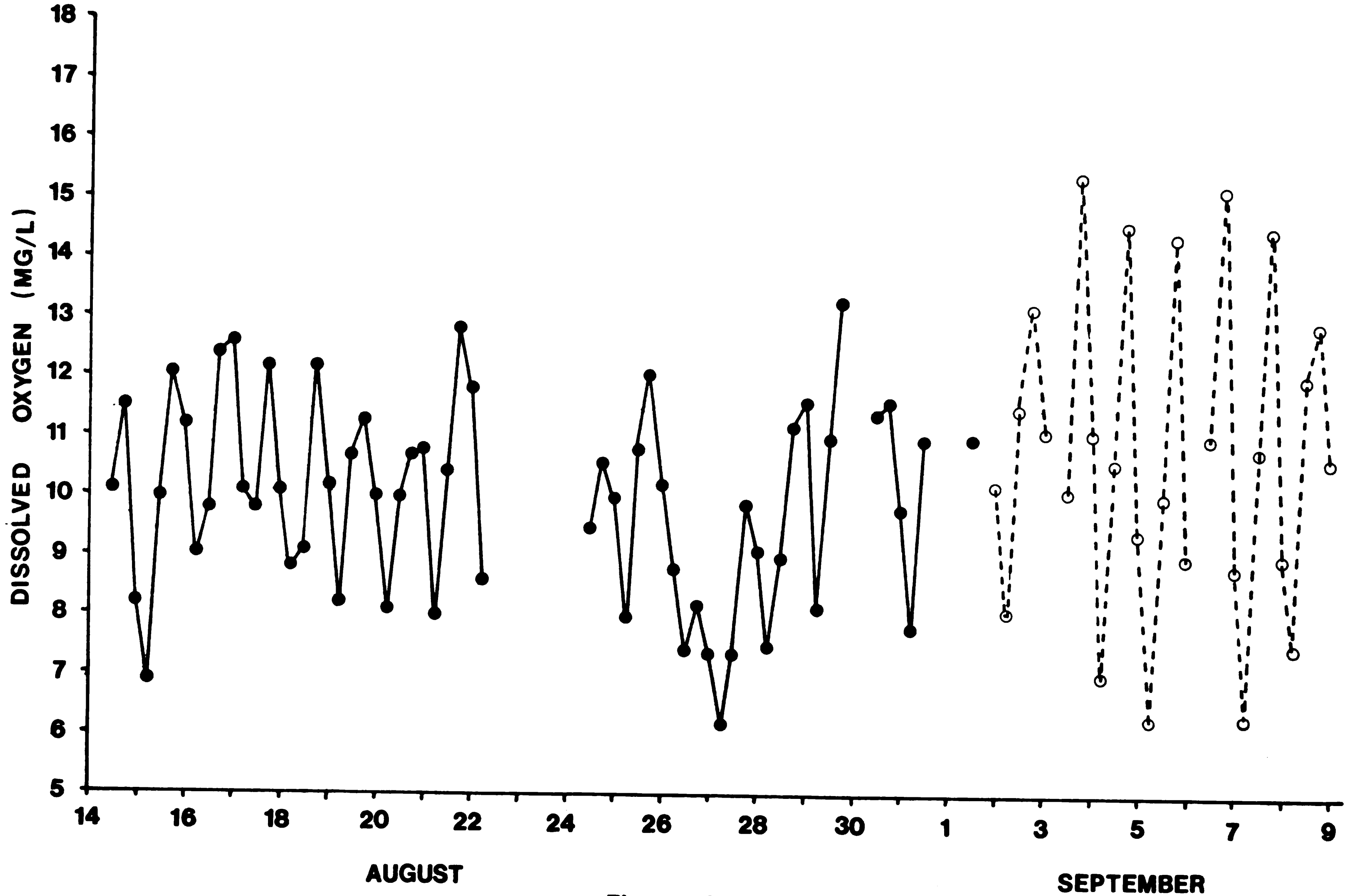
DISSOLVED OXYGEN (MG/L)
18
17
16
15
14
13
12
11
10
9
8
7
6
5
14
16
18
20
22
24
26
28
30
1
3
5
7
9
AUGUST
SEPTEMBER

Figure 4

level had been maintained from the beginning of the project, perhaps greater fluctuations in diurnal D.O. curves would have occurred.

Since the concentration of dissolved oxygen in the water was usually quite high, the efficiency in adding more oxygen to the system was very low. It also appeared that the aeration system was not reducing the supersaturated conditions as it had been expected to do. It is possible that a larger aeration system may be necessary under conditions like these. In deeper water, or water with a lower D.O. level, the efficiency of an aeration system would increase.

As is discussed later, the plant production in pond C was much greater than that in pond D. This was attributed to the abundant supply of phosphorus. As a result of this more productive plant community in pond C, the daytime oxygen levels were also higher than in pond D. Table 2 shows the dissolved oxygen concentrations for one pre-fertilization date and three post-fertilization dates.

pH

The water in the Lake City ponds has been found in other studies to be relatively hard and alkaline, with total alkalinity values ranging between 55 and 75 ppm (Sohacki et al, 1969). The normal pH of the ponds ranges from 8.0 to 9.0 during the summer months. The range of pH values in pond C during the summer of 1971 was from 6.9 to 9.2.

Abundant plant growth in a pond environment has a definite effect on the water pH. During the process of photosynthesis, plants often use up all the free CO_2 in the pond and much of the bicarbonate,

Table 2. Dissolved oxygen (mg/liter) recorded for Lake City ponds C and D during the summer of 1971.

Pond Section	Date 7/6	7/29	7/31	8/4
C1	9.99	12.68	11.71	17.12
C2		12.98	14.57	16.90
D1	10.25	9.45	8.85	11.38
D2		9.50	9.03	11.65

resulting in a rise in pH (Bennett, 1962). Free CO_2 is returned to the system at night due to respiration, resulting in a diurnal change in pH values.

A definite drop in pH values was observed following fertilization with phosphorus. This fertilizer was in a phosphoric acid form. Before fertilization of C2 on August 28, the pH was 7.7 and after fertilization this value had dropped to 6.9. A pH value of 7.7 was recorded the next day again and it appears that the adding of this acid had no long lasting effects on the pH of the pond. Similar results were found in section C2 on August 31 with a drop in pH from 8.0 to 7.4. On September 16, the pH of section C1 dropped from 8.8 to 8.3 following fertilization.

Phosphorus Concentrations and Uptake by Plants

The concentration of orthophosphate in both ponds C and D prior to fertilization was less than 0.003 mg/l PO_4 as P. This is a fairly common level for natural bodies of water. Following fertilization of sections C1 and C2, the uptake of phosphorus was rapid (Figure 5). Rigler (1956) and Hepher (1958) have shown that phosphorus may be rapidly taken up by various components of the aquatic community. This rapid uptake and the process of mixing the fertilizer with the pond water make it very difficult to determine when to measure the phosphorus concentration. As is shown in Figure 5, measurements taken every two hours after fertilization on July 27 showed variations from 4.0 to 6.8 mg/l PO_4.

Figure 5. Phosphorus concentrations observed in Lake City pond C during the summer of 1971.
(—— C1 (aerated), --- C2 (unaerated), circled points indicate theoretical values)

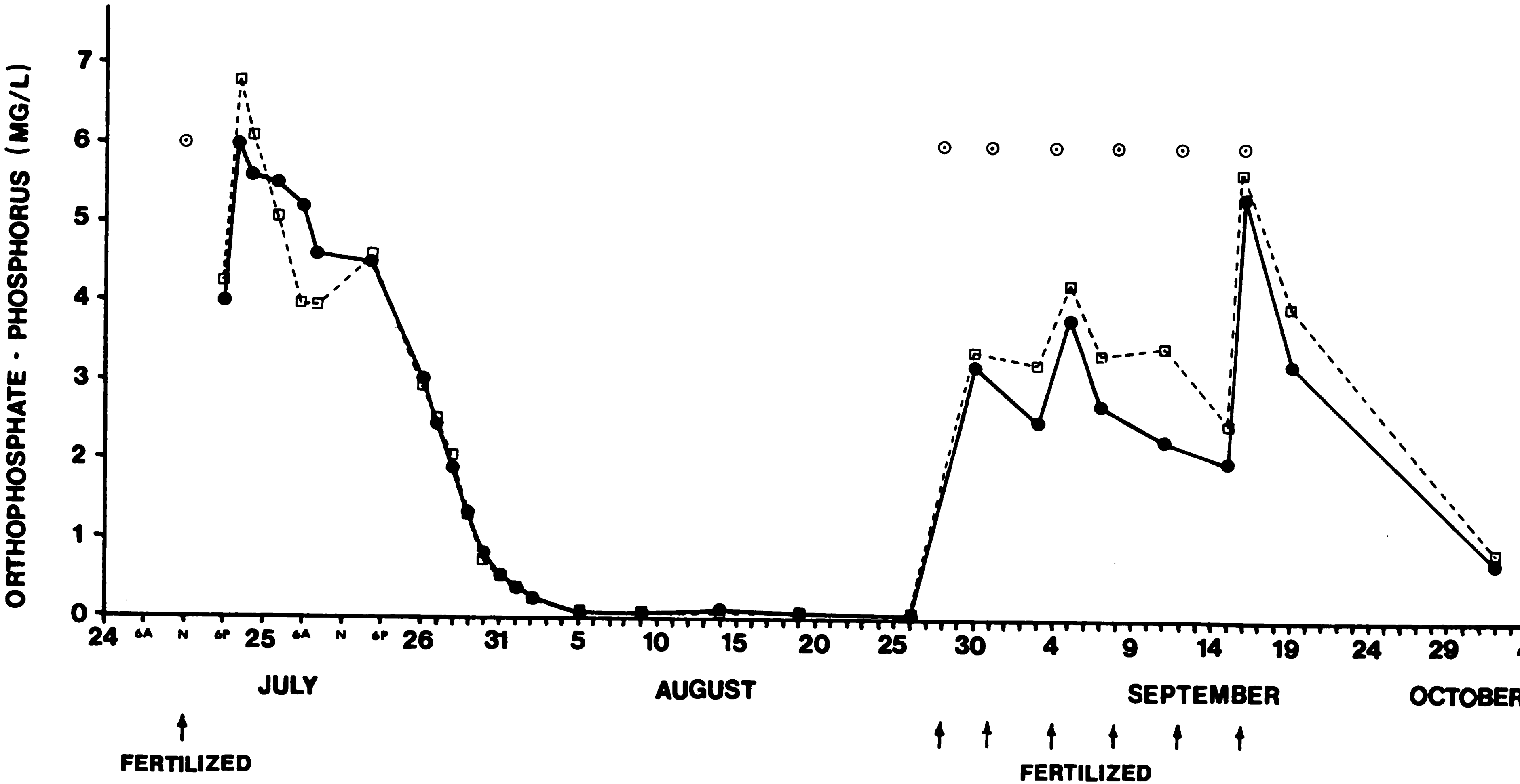
ORTHOPHOSPHATE - PHOSPHORUS (MG/L)
0
1
2
3
4
5
6
7
24
6A
N
6P
25
6A
N
6P
26
31
5
10
15
20
25
30
4
9
14
19
24
29
4
JULY
AUGUST
SEPTEMBER
OCTOBER
FERTILIZED
FERTILIZED

Figure 5

The values of orthophosphate concentrations obtained during the second half of the project are connected by lines in Figure 5. Between each of the measurements, however, the actual concentration was theoretically increased to 6 mg/l PO_4. Measurements on September 16 show that the actual values were fairly close to the theoretical values after fertilization.

Also shown in Figure 5 is the fact that sections C1 and C2 behaved similarly in regard to change in phosphorus concentration. One difference which could be pointed out, however, is that during the second phase of the project, C1 values were consistently below C2 values. As is discussed later, the periphyton community of C1 was more abundant than that of C2, and if we assume that this community is taking up much of the phosphate, this would explain the difference in concentrations. Periphyton communities may be very important in eutrophic situations and this explanation would seem reasonable.

In looking at the overall effects of fertilization with phosphorus on pond C as compared with pond D, it appears that phosphorus is the major factor limiting plant growth in these ponds. Pond D, which received only nitrate fertilizer, showed relatively little increase in plant activity.

Many environmental and physiological factors may influence the uptake of phosphorus by plants. Gerloff (1969) has reported two zones in regard to algal growth and phosphorus concentration in the water. A phosphorus deficient condition is indicated when the concentration of phosphorus in the plant tissue is below a specific critical level. In this deficient zone, plant growth is directly dependent on the phosphorus concentration in the water. The algae of the Lake City ponds were most likely in this phosphorus deficient zone prior to fertilization.

Gerloff (1969) defines the critical level as the concentration of phosphorus in the tissue which is just inadequate for maximum growth. If the algal tissue contains more than this critical concentration, it is in a luxury consumption zone. In this condition phosphorus is taken up by the plant and stored in the algal cells. As Gerloff (1969) points out, however, this luxury consumption is not associated with increases in yield. In this zone growth remains at a constant maximum.

Light is one of the major environmental factors which may influence the uptake of phosphorus by plants. Kuhl (1962) found that in most cases the uptake of phosphorus is increased by light. He reported research done with the diatom *Nitzschia*, and the green algae *Chlorella*, *Ankistrodesmus*, *Hydrodictyon*, and *Scenedesmus*. Azad and Borchardt (1968), however found that whereas *Chlorella* had a rapid uptake during darkness, *Scenedesmus* had no measurable uptake during darkness. Mackereth (1953) reported that the uptake of phosphorus by *Asterionella* cells occurred at the same rate independent of light or dark. In regard to macrophytes, light was found to increase the overall uptake of phosphorus by *Elodea densa* (Jeschke and Simonis, 1965).

The role of bacteria in the phosphorus balance of ponds is also important. The effect of bacteria is to reduce the rate of exchange of phosphorus with the plants and to hold most of the phosphorus in the water column (Phillips, 1964). Bacteria also are known to take up phosphorus more rapidly than either the algae or aquatic plants.

The adsorption of phosphorus onto surfaces may be a very important consideration in shallow ponds, where there is a large bottom area to water volume ratio. The presence of macrophytes also increases the surface area and sites where phosphorus could become adsorbed. Harter (1968) and Fitzgerald (1970) report that lake sediments are capable of adsorbing large amounts of phosphorus from the water. Some of this phosphorus is tightly bound, but the remainder is loosely bonded and may be released to the water at a later time. Hepher (1958) reports that in alkaline water with a high calcium content, most of the phosphorus fertilizer added to ponds is precipitated as $Ca_3(PO_4)_2$. An increase in pH also results in more phosphate being precipitated.

Nitrate Concentrations

Nitrogen can be found in several common forms in aquatic environments, NH_4^+, NO_2^-, and NO_3^- being the most common. Most plants can use any of these three forms as a source of nitrogen for proteins (McCarty et al., 1970). In natural waters nitrate is the most common form and is the product of the oxidation of NH_4^+ and NO_2^-.

The fertilizer added to both ponds C and D was in nitrate form so was readily available to plants in the water. Chemical determinations likewise were made only of the nitrate levels. Nitrate is quite soluble in water and is relatively non-reactive chemically, under natural water conditions. The major factor influencing the nitrate concentration is biological action, including incorporation into organic matter.

Figure 6 shows the nitrate concentrations observed during the summer of 1971 in ponds C and D. As with phosphorus, the nitrate was taken out of the water quite rapidly. Even in pond D, the concentration went down rapidly. Lines have been drawn in Figure 6 connecting the measured nitrate concentrations. However, as was the case with phosphorus, the nitrate concentrations were theoretically increased to 15 mg/l between each measurement during the second half of the summer. A measurement of nitrate in C1 on September 17 showed that following fertilization the actual concentration was fairly close to the theoretical value.

Since the plant populations of pond D did not appear to respond significantly to the fertilization, the rapid decrease in nitrate concentration could possibly have been due to bacterial action. The same mechanism appears to have been operating in both ponds. Kerr et al. (1972) found that bacterial populations increased within 12 hours after fertilization with N, P, and KCl. They also report that the relative availability of organic carbon and CO_2 could regulate the total bacterial density and the molecular form of nitrogen present in the water. It would therefore seem possible that bacteria were reducing NO_3-N to another form such as NH_4-N. This, however, requires anaerobic conditions, which were not observed in the ponds.

Because of the increased primary production in both sections of pond C, the nitrate nitrogen was removed from the water faster than in pond D. This is shown for both phases of the project. As was noted also in regard to phosphate concentrations, the nitrate values of section C1 were consistently lower than those of C2. This was attributed to the more abundant periphytic and filamentous algae in section C1.

Figure 6. Nitrate concentrations observed in Lake City ponds C and D during the summer of 1971. (—— C1, --- D1, circled points indicate theoretical values)

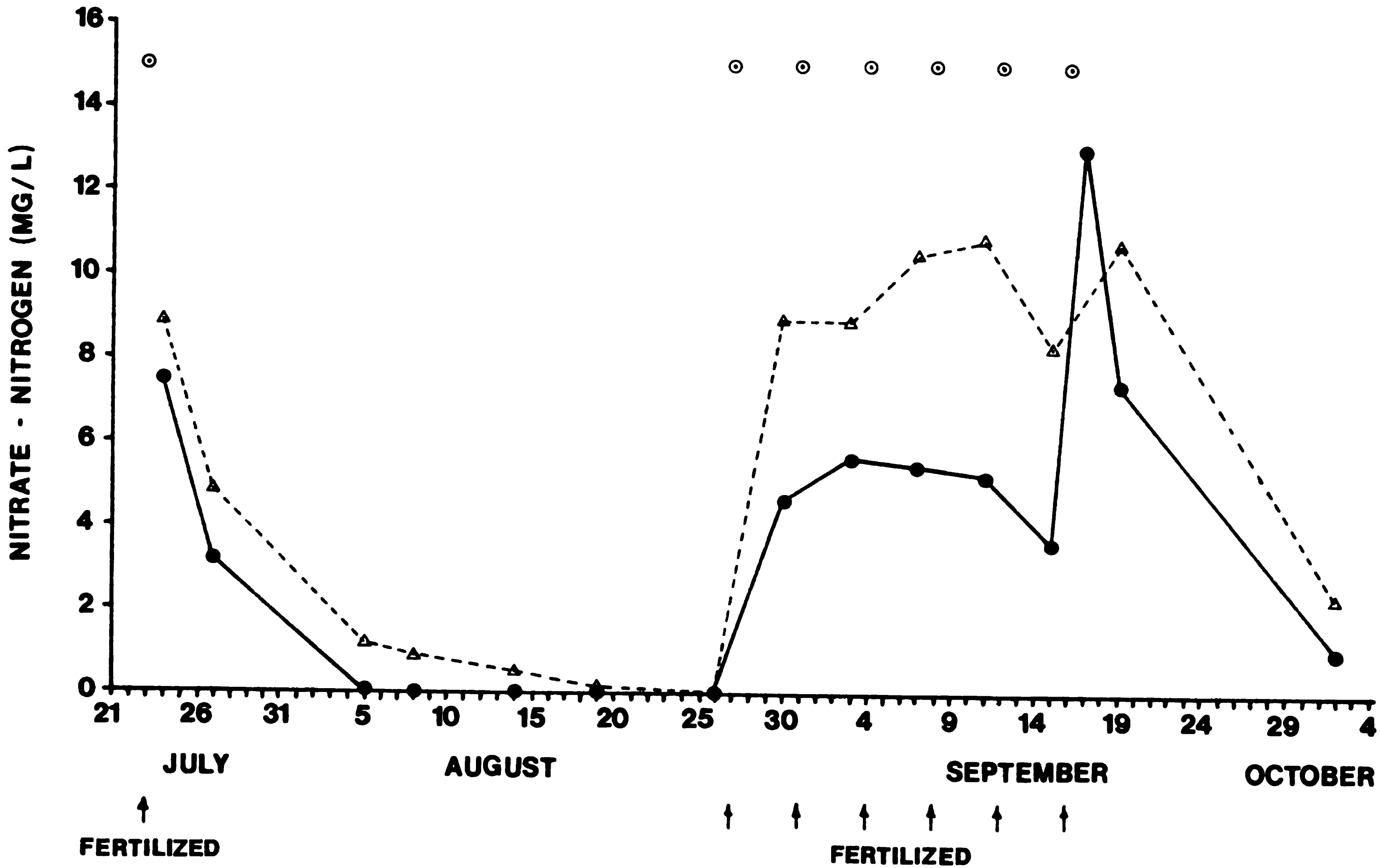
NITRATE - NITROGEN (MG/L)
16
14
12
10
8
6
4
2
0
21
26
31
5
10
15
20
25
30
4
9
14
19
24
29
4
JULY
AUGUST
SEPTEMBER
OCTOBER
FERTILIZED
FERTILIZED

Figure 6

Nitrogen is often present in relatively low amounts in natural systems. The pre-fertilization nitrate concentration for pond C was 0.025 mg/l and for pond D 0.011 mg/l. If phosphate alone had been added to pond C with no nitrate, it is likely that nitrate would have become the limiting factor for plant growth. In situations like this, nitrogen fixing blue-green algae may become the dominant algal form (Provasoli, 1969).

As was reported concerning phosphorus uptake by plants, the uptake of nitrate also is dependent on light. Light was found to stimulate the uptake of nitrate by Chlorella and Ankistrodesmus (Morris and Ahmed, 1969) and also by a Ceratophyllum - periphyton community (Toetz, 1971). The assimilation of NH_4^+, however, was found by Toetz to occur both during the day and at night.

Zooplankton

Most zooplankton are primary consumers and in the absence of predators would be expected to increase in population size in relation to increases in food supplies. Brooks (1969) and Hall et al. (1970) have shown, however, that the presence of predators in the system has a definite effect on the size and composition of the zooplankton population. Both researchers report that fish predation had the effect of removing the larger zooplankters. This results in the smaller zooplankton, such as Bosmina, rotifers and small crustaceans increasing in abundance. Hall et al. (1970) report that there is an interaction of nutrients and predation in regulating the zooplankton population. Although increased nutrients tend to increase the zooplankton biomass, predation by fish at least partly balances this increase by eliminating the larger zooplankters.

Various species of zooplankton may react in different ways to increases in primary production. Increases in macrophytes in shallow ponds, for example, would most likely lead to increases in Chydorus populations, since this cladoceran is a weed dweller and is more benthic in habit. Brooks (1969) discusses the possibility of using Bosmina as an indicator of enriched environments. As a lake is enriched, Bosmina coregoni longispina has been observed to be replaced by Bosmina longirostris. Observations of zooplankton in the Lake City ponds showed that Bosmina coregoni was the only member of this genus present. It was a major component of the zooplankton even at the end of the summer.

In using a light trap for sampling zooplankton, the limitations of this technique must be remembered. Members of the zooplankton community, for example, swim at different rates and would be expected to be sampled differently. Also, different organisms collected by the traps are known to prefer certain habitats in the littoral community, some being more benthic than others. Another complication in the use of light traps is that light would travel a considerable distance in a clear pond, but it would not reach out as far in a phytoplankton rich pond. In the clear pond, then we would be sampling a larger area than in the phytoplankton rich pond. Although we would expect a greater zooplankton biomass in the phytoplankton rich pond, our results may not reflect the true situation. Caution must be observed in the interpretation of results obtained with light traps.

Table 3 and Figure 7 show the fluctuations in species composition that the zooplankton were observed to undergo. Definite correlations or trends are difficult to find in the data. Various species of zooplankton undergo seasonal cycles in regard to population size, and two neighboring ponds, otherwise quite similar, may be a week out of sequence with each other (Hall, personal communication). If this is the case, then samples taken once a month may find a certain species blooming in one pond but only fairly common in the other pond. Attributing such differences to different environmental parameters may be quite incorrect.

The volumes of the various samples are recorded in Table 2 and show a range of 0.4 to 34.8 ml. The largest sample by volume was taken in pond C2 on September 14 and was over 90% *Cypridopsis* (Ostracoda). A sample taken on August 18 in pond D2 measured 9.3 ml and was about 90% *Bosmina coregoni*.

Primary Production

Phytoplankton

The primary productivity of the phytoplankton in ponds C and D remained at fairly low levels throughout the summer of 1971. Even though nutrient levels in pond C were high, the water remained clear. During the summer of 1970, Massey (personal communication) fertilized the Lake City ponds A, B, and C at various levels: A - 5 mg/l both phosphates and nitrates, B - 2.5 mg/l both phosphates and nitrates, and C - 1.25 mg/l both phosphates and nitrates. He found that in pond A,

Table 3. Percent composition by number of invertebrates collected by light traps from the four Lake City pond sections during the summer of 1971.

	volume	*Keratella*	*Bosmina coregoni*	*Daphnia*	Chydoridae	*Polyphemus*	Calanoid copepods	Cyclopoid copepods	Ostracoda	Hydracarina	Baetidae	Leptoceridae	*Chaoborus*	Tendipedidae
Pond C1														
6/26	4.0	1.90	64.64	1.14	10.27	-	0.38	6.84	4.18	9.51	0.76	-	-	0.38
7/25	0.7	-	90.70	-	2.95	-	-	0.78	1.24	2.95	0.31	-	-	1.09
8/18	4.4	-	8.37	23.19	24.71	-	0.38	6.08	34.22	1.52	0.38	-	1.14	-
9/14	3.4	-	77.37	0.35	0.46	-	-	-	21.36	0.35	0.12	-	-	-
Pond C2														
6/26	4.0	1.90	64.64	1.14	10.27	-	0.38	6.84	4.18	9.51	0.76	-	-	0.38
7/25	1.2	0.51	38.78	-	4.08	-	-	16.84	8.67	22.96	2.55	0.51	0.51	4.59
8/18	4.0	-	3.36	4.03	78.15	-	-	1.85	9.92	1.85	0.17	-	0.34	0.34
9/14	34.8	-	7.29	0.27	0.54	-	-	0.13	91.77	-	-	-	-	-
Pond D1														
6/26	4.2	-	67.57	0.98	2.70	-	6.39	1.47	16.71	2.95	0.49	-	-	0.74
7/25	0.4	-	8.33	-	1.67	-	1.67	23.33	28.33	31.67	-	-	-	5.00
8/18	0.8	4.92	57.38	1.64	5.74	-	1.64	6.56	8.20	6.56	0.82	-	1.64	4.92
9/14	0.5	-	32.14	44.64	-	-	-	8.93	10.71	3.57	-	-	-	-
Pond D2														
6/26	4.2	-	67.57	0.98	2.70	-	6.39	1.47	16.71	2.95	0.49	-	-	0.74
7/25	0.7	-	1.12	-	0.37	-	-	0.37	92.19	5.58	-	-	-	0.37
8/18	9.3	-	90.61	1.78	2.91	0.81	0.16	-	2.10	1.29	-	-	0.16	0.16
9/14	1.0	-	90.32	0.87	3.32	-	-	-	5.35	-	-	-	-	0.14

Figure 7. Percent composition by number of invertebrates collected by light traps from the four Lake City pond sections during the summer of 1971.

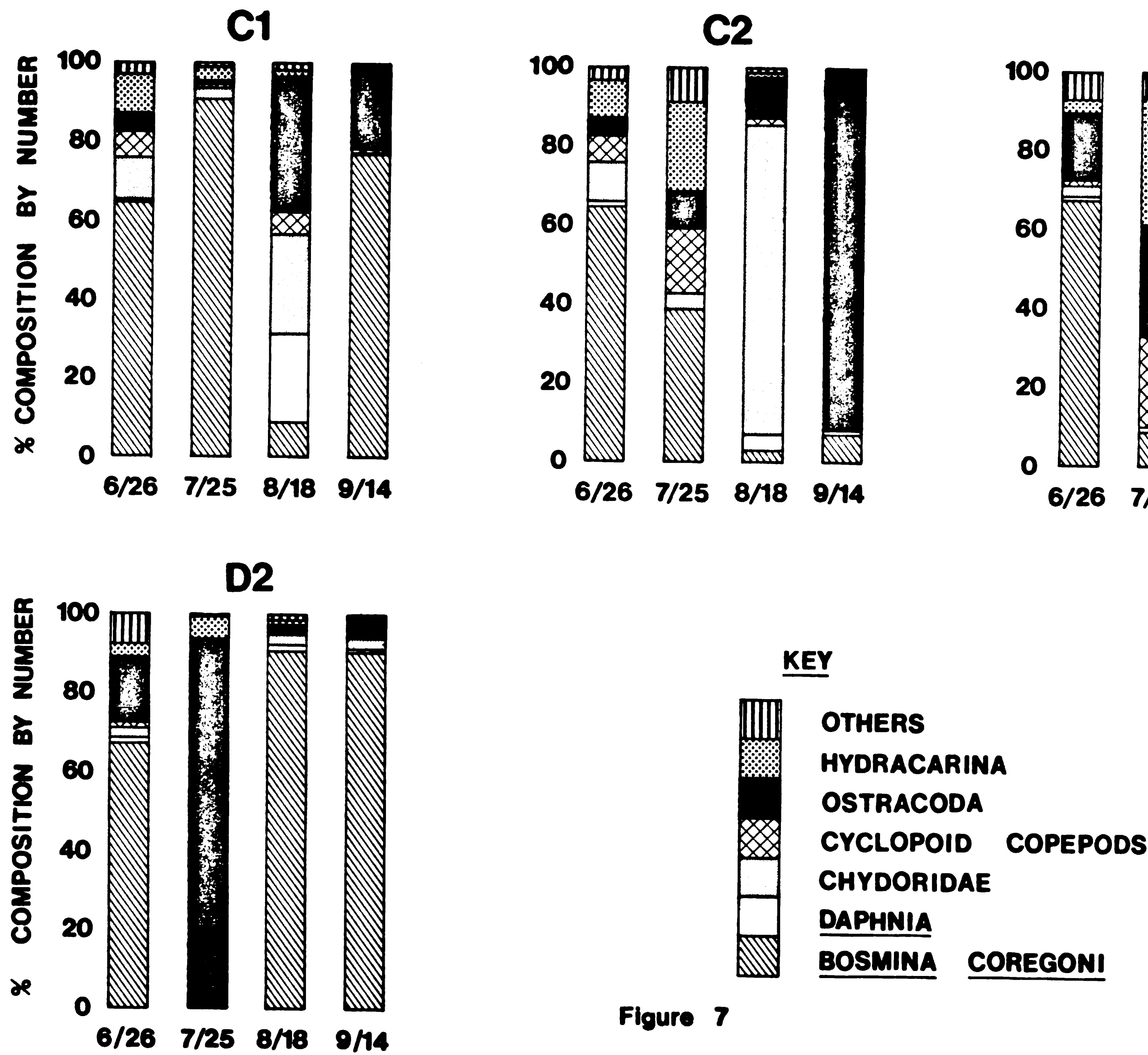
C1
C2
D1
D2
% COMPOSITION BY NUMBER
100
80
60
40
20
0
6/26
7/25
8/18
9/14
KEY
OTHERS
HYDRACARINA
OSTRACODA
CYCLOPOID COPEPODS
CHYDORIDAE
DAPHNIA
BOSMINA COREGONI

Figure 7

which he fertilized daily, large phytoplankton blooms resulted in a pea-soup character. Pond B was observed to have both large phytoplankton and filamentous algal blooms. Since large filamentous blooms were also observed in 1971 in pond C, this pond appears to have responded similarly under different nutrient concentrations.

A small, but significant increase in the plankton community of both ponds was observed about seven days after fertilization, both during the first phase, and initiation of the second phase of the project (Figure 8). This increase was much more pronounced in the second phase, when high nutrient concentrations were maintained. It would seem possible that some interactions, perhaps involving bacteria, could release essential micro-nutrients and result in this delayed response to fertilization. Kerr et al. (1972) found that following fertilization with nitrogen, phosphorus and potassium, the bacterial population increased within 12 hours, whereas the algal population increased 36-48 hours after fertilization. The bacteria appear to be able to more rapidly utilize the added nutrients, and the consequences of this action remain in question.

Even though pond D was fertilized only with nitrates, the phytoplankton community responded in the same manner as the community of pond C. Evidently the fertilization with nitrogen created a chain of events which in seven days lead to a stimulation of the phytoplankton. It is not possible to say what effect the added phosphorus in pond C had on this sequence.

An extensive dieoff of the macrophyte *Najas* was observed in pond D during the second week of August. Figure 8b shows that a slight increase in the phytoplankton population of pond D also occurred during

Figure 8a. Phytoplankton abundance in Lake City pond C during the summer of 1971 as indicated by the relative absorbance at 665 nm of extracted plant pigments.

Figure 8b. Phytoplankton abundance in Lake City pond D during the summer of 1971 as indicated by the relative absorbance at 665 nm of extracted plant pigments.

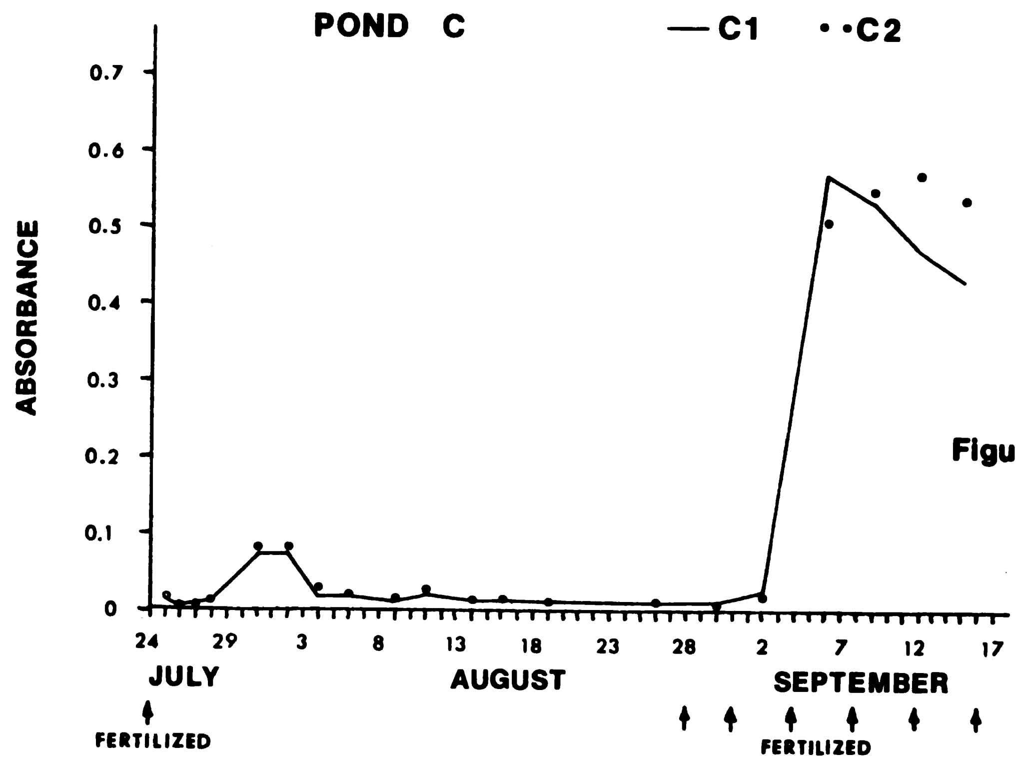

Figure 8a

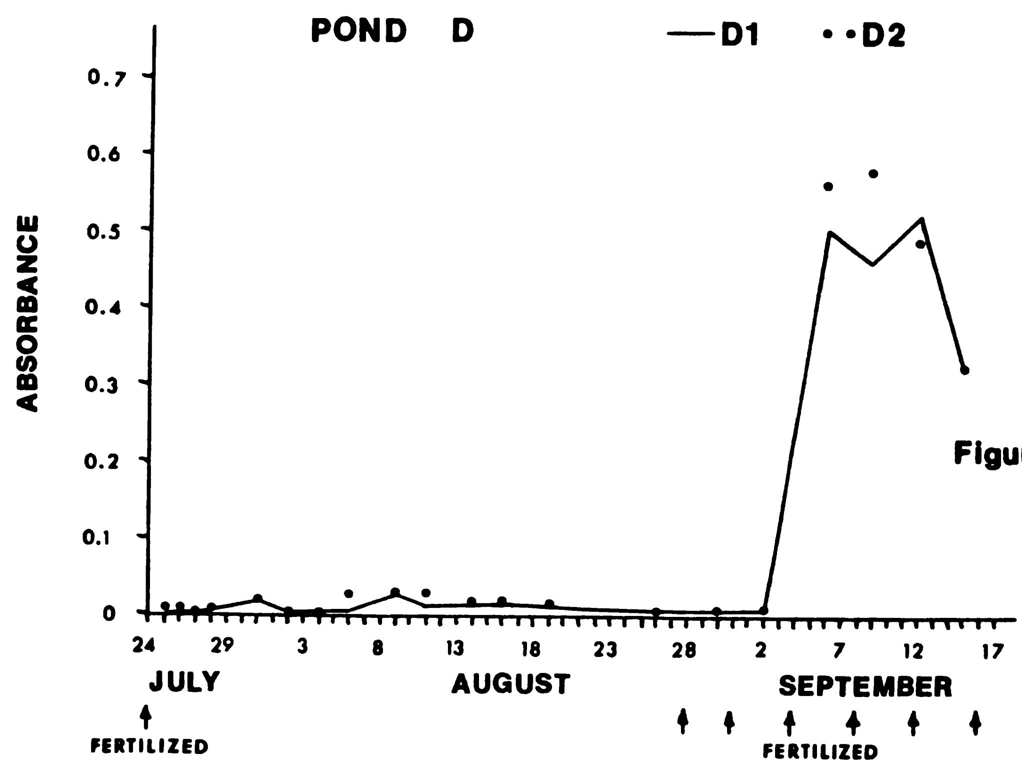

Figure 8b

this period. It would seem logical to assume that this dieoff of Najas resulted in nutrients being released to the water which were then available for plant growth. Boyd (1970) reports that aquatic macrophytes decompose rapidly, and a large quantity of the nutrients in the plants is returned to the environment during the first few days of decay.

It must be noted that the chlorophyll extraction technique used in this study would include chlorophyll extracted from autotrophic bacteria in the water. If an increase in autotrophic bacteria occurred as a result of fertilization, the resulting increase in chlorophyll extracted could be falsely interpretted as an increase in phytoplankton.

The genera of phytoplankton algae found in the ponds on September 16 are given in Table 4. This list undoubtedly does not include all of the genera present at that time, and is presented only to show the approximate composition of the phytoplankton.

Filamentous algae present a major problem to the limnologist attempting to measure primary production in a pond. It is difficult to measure accurately as phytoplankton or periphyton, although it can be considered part of both communities. In nutrient rich habitats it often grows epiphytically, extending in long strands into the water column. These strands may then break off and float to the surface forming large cotton candy like mats.

In pond C1 filamentous algae were first observed during the first week of August growing along most of the aeration hose (Figure 9). The algae were identified as Oedogonium, Spirogyra, Zygnema, Mougeotia, and Ulothrix, with Oedogonium becoming more dominant as the summer progressed. Since nitrogen and phosphorus were present in adequate

Table 4. The genera of phytoplankton observed in the Lake City ponds on September 16, 1971.

Pond C1		
	Microcystis	*Cosmarium*
	Lyngbya	*Closterium*
	Eudorina	*Staurastrum*
	Volvox	*Pediastrum*
	Oedogonium	*Rhizoclonium*
	Zygnema	*Ceratium*
	Spirogyra	
Pond C2		
	Microcystis	*Cosmarium*
	Lyngbya	*Closterium*
	Volvox	*Staurastrum*
	Oedogonium	*Pediastrum*
	Spirogyra	*Ceratium*
Pond D1		
	Microcystis	*Cosmarium*
	Lyngbya	*Staurastrum*
	Eudorina	*Pediastrum*
	Oedogonium	*Ceratium*
Pond D2		
	Microcystis	*Cosmarium*
	Merismopedia	*Staurastrum*
	Plectonema	*Pediastrum*
	Eudorina	*Ceratium*
	Oedogonium	

Figure 9. Photographs of pond section C1 showing filamentous algae growing along the aeration hose. Bubbles on the water surface indicate the aeration. The submerged macrophyte is Potamogeton berchtoldii Fieber.

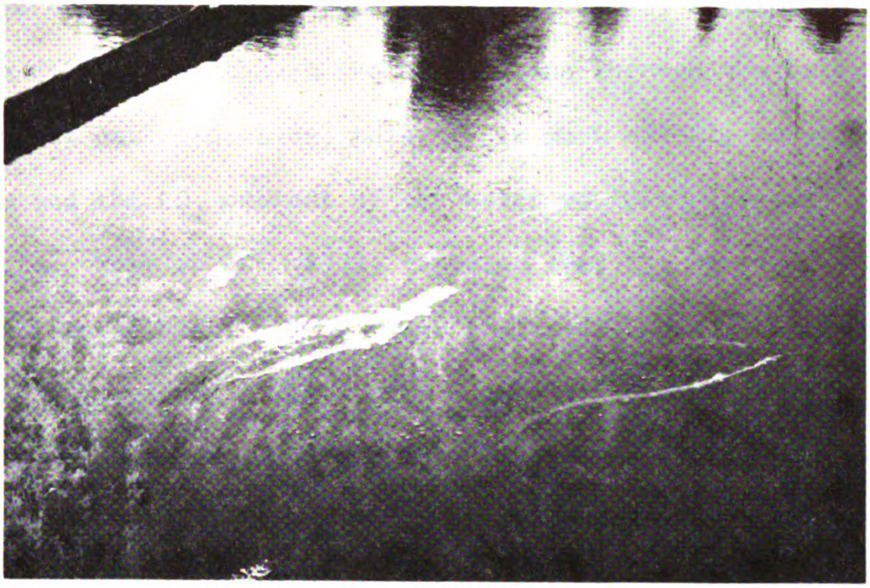

Figure 9a

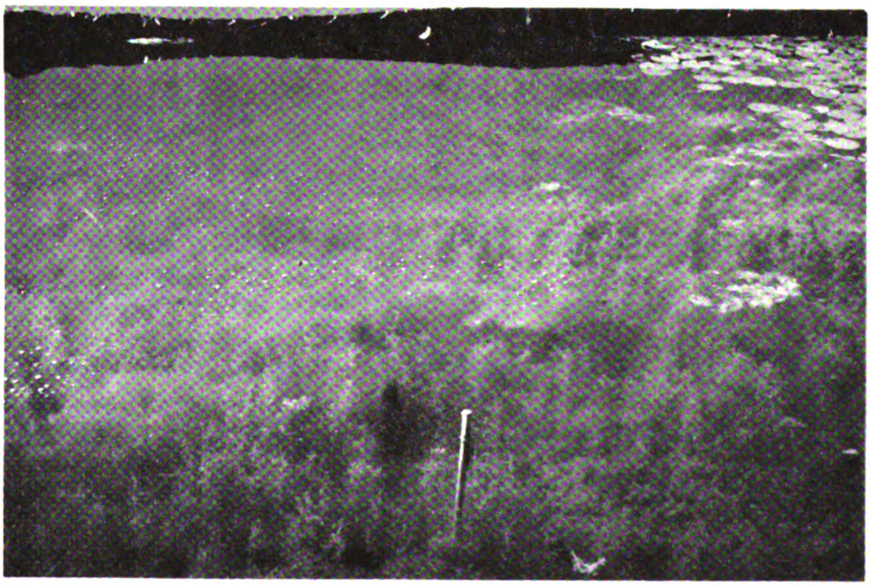

Figure 9b

supply, and were not limiting algal growth, the aeration was evidently contributing some factor to the pond which stimulated the growth of filamentous algae. This factor was most likely carbon, in the form of carbon dioxide. Although the air passing through the water column was only 0.03% carbon dioxide, this gas is more soluble in water than is oxygen and the CO_2 content of the water would be expected to increase slightly. Kerr et al. (1972) reported that the nitrogen and phosphorus stimulation of algal growth is an indirect one mediated by the increased availability of CO_2. They found that algal growth was stimulated by bubbling either air (0.03% CO_2) or 5% CO_2 in air through the water column. In another experiment these researchers found that more nitrogen and phosphorus were removed at night than during the day, which they attributed to a greater abundance of bicarbonate and carbon dioxide in the water at night.

The phosphorus - carbon controversy of which element is limiting aquatic plant growth continues (Likens, 1972). In regard to the filamentous algae in this study, a simplistic approach cannot be taken. Pond D1 was enriched with nitrogen and was aerated but showed no filamentous algae growth. Pond C2 was enriched with nitrogen and phosphorus and was not aerated, and showed filamentous algae growth several weeks after it appeared in pond C1. In pond C1 phosphorus and nitrogen were both present in adequate supply, and it appears that the aeration system was providing enough carbon dioxide to stimulate the growth of filamentous algae. Without the phosphorus in the system, the filamentous algae did not grow, and without the aeration, its growth was delayed.

Figure 10a. Photograph of pond C on August 30, 1971. Section C1 (aerated) is on the right of the divider, section C2 (unaerated) on the left.

Figure 10b. Photograph of pond C on September 6, 1971. Section C1 (aerated) is on the right of the divider, section C2 (unaerated) on the left.

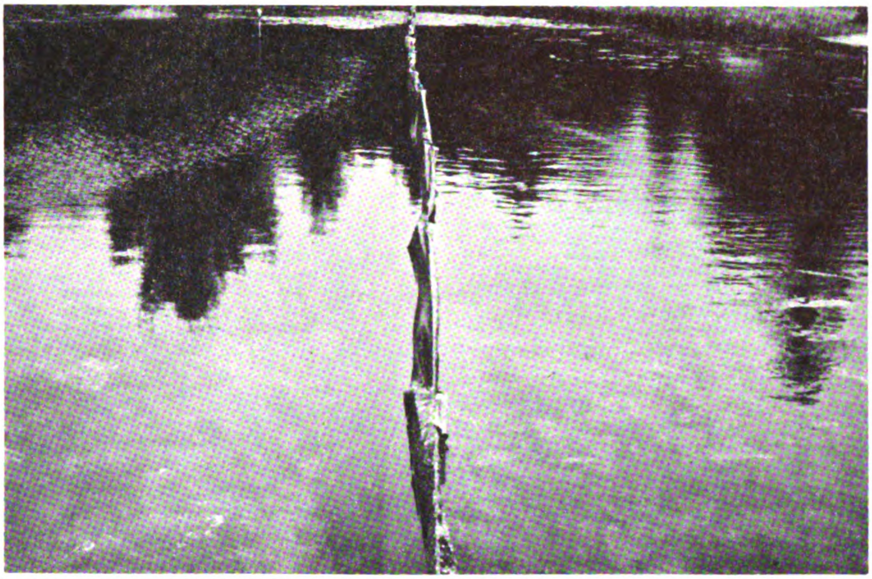

Figure 10a

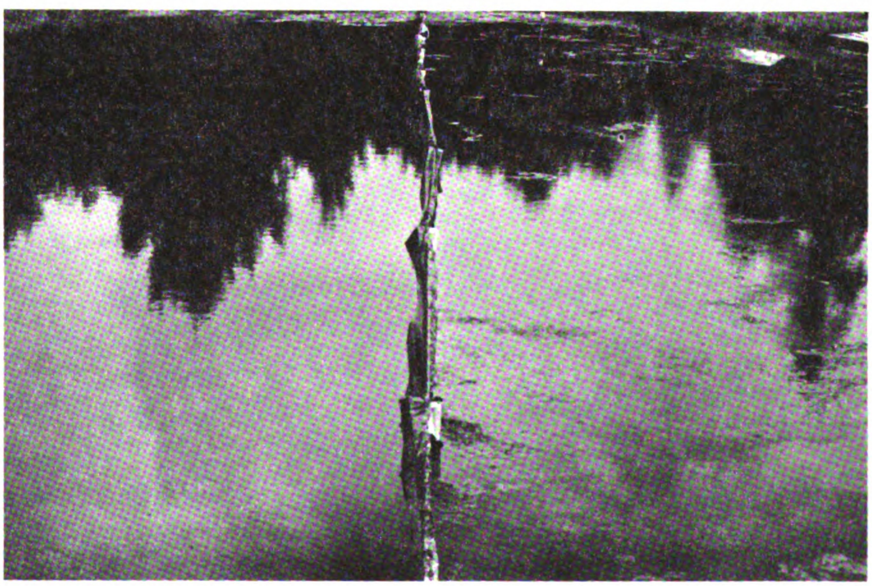

Figure 10b

Figure 11a. Photograph of pond C on September 13, 1971. Section C1 (aerated) is on the right of the divider, section C2 (unaerated) on the left.

Figure 11b. Photograph of pond C on September 20, 1971. Section C1 (aerated) is on the right of the divider, section C2 (unaerated) on the left.

Figure 11a

Figure 11b

Figures 10 and 11 show the changes which occurred in pond C during the second phase of the project, when high nutrient concentrations were maintained. The filamentous algae were seen first and became most abundant in section C1. The photograph taken on September 20 shows filamentous algae mixed with dead *Potamogeton berchtoldii* floating near the surface.

Periphyton

In shallow ponds, such as the ones used in this study, the periphytic algae play a major role in the primary production of the system. These algae may be found growing epilithically, epipelically and epiphytically. Epiphytic algae may interact with the host plant in ways both beneficial and harmful to that plant. Included in these interactions are competition for nutrients and shading of the host plant by the epiphytes. These interactions are discussed in greater detail in a later section.

Estimates of periphytic primary production in this study were made by measuring the amount of chlorophyll *a* found on artificial substrates after a given time period. Wetzel (1963) observed that considerable caution must be taken in interpreting estimates of primary production from pigment measurements of this type. Variables such as light and nutrient levels may affect the momentary concentrations of the pigments. Wilhm and Long (1969) found that at high nutrient levels the periphyton biomass and pigment concentration were high, but that net production was no greater than in communities of intermediate nutrient levels.

It must be noted that the techniques used in this study resulted in an estimate of the periphyton colonization rate and not an estimate of the standing crop. The periphyton substrates were left in the pond for either four or five days, and then were analyzed for periphyton colonization. To obtain an estimate of standing crop, a series of substrates would have had to be left in the pond for a considerable time, periodically removing several substrates for analysis. Although a single exposure period would not provide a measure of the rate of production of a well-established mat of periphyton (Kevern et al., 1966), the values obtained would still be useful in making comparisons within the same set of experiments. The colonization rates obtained would be an underestimation of the actual standing crop in the pond.

As was expected, pond C showed much greater periphyton growth than did pond D (significant at the 1% level, Analysis of Variance). Pond D periphyton showed a very slow colonization rate, often yielding amounts smaller than the sensitivity of the methods used. It was noted that the highest values recorded for pond section D1 occurred during the second week of August, following a large dieoff of the macrophyte *Najas*. Pond section D2 also showed periphyton amounts greater than had previously been observed. The periphyton colonization rates of pond sections D1 and D2 were not found to be significantly different at the 1% level.

The periphyton of pond C yielded some interesting data, with section C1 having significantly greater (5% level) periphyton colonization rates than section C2. Figure 12 shows that the values from C1 were greater than C2 throughout the project. Each data point in Figure 12 is the mean of six samples. Since both pond sections

Figure 12. Periphyton colonization rates for Lake City pond C as determined by chlorophyll a measurements. (—— C1 (aerated), --- C2 (unaerated))

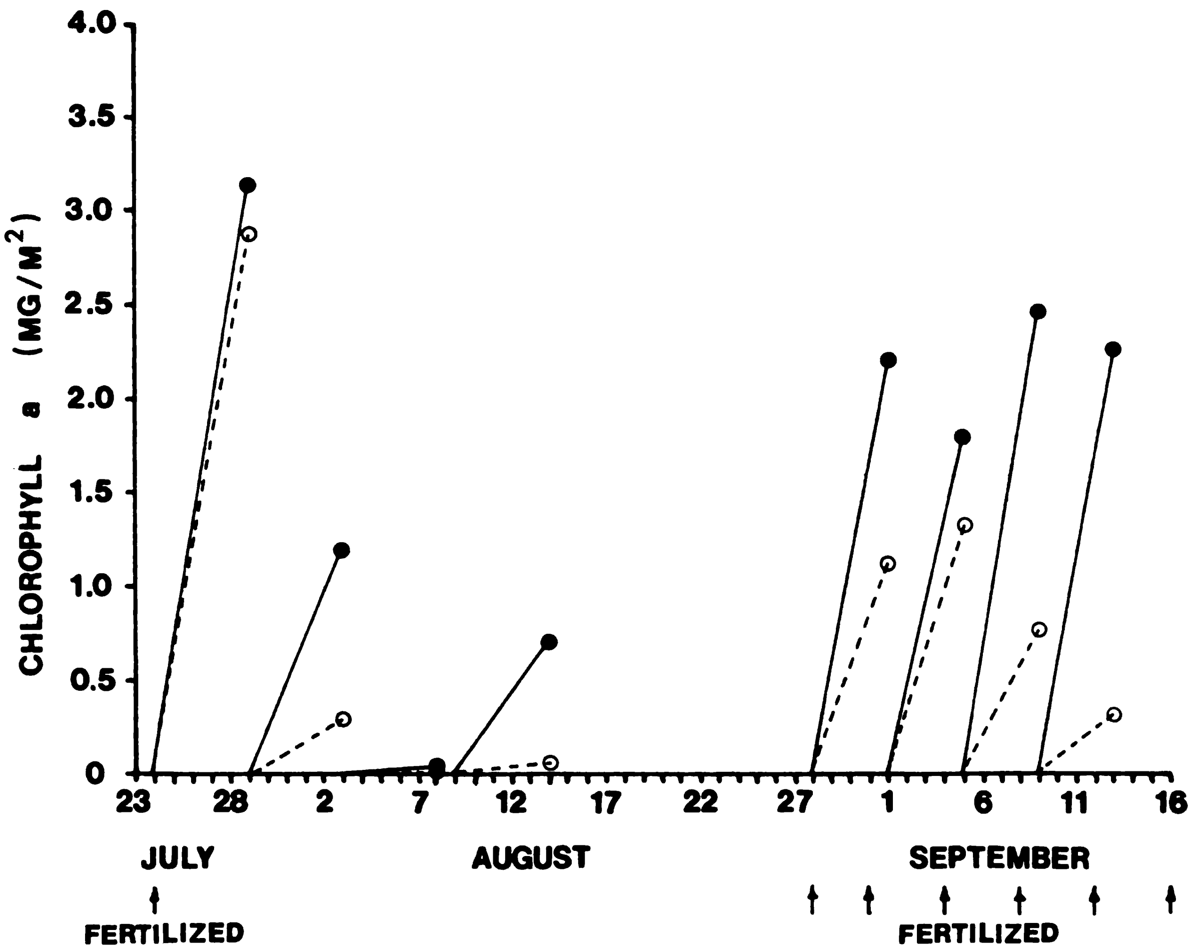
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
CHLOROPHYLL a (MG/M^2)
23
28
2
7
12
17
22
27
1
6
11
16
JULY
AUGUST
SEPTEMBER
FERTILIZED
FERTILIZED

Figure 12

received the same concentrations of fertilizer and other environmental parameters were similar, it would seem that the aeration of section C1 was stimulating periphytic growth. As was the case with the filamentous algae, the most likely consequence of aeration was the increase in available carbon.

It also can be seen from Figure 12 that the periphyton responded quite rapidly to fertilization, with no seven day lag period as was observed with the phytoplankton. The slopes of the lines in Figure 12 indicate the rate of colonization. This rate of colonization was relatively fast at the end of July, following fertilization, and then slowed down during August. Fertilization during the second phase of the project resulted again in an increased rate of colonization.

A gradual change in the species composition of the periphyton in pond C was observed over the summer. Whereas at the beginning of the summer, the periphyton community included numerous diatoms, by the end of the summer filamentous algae were most abundant, with the diatoms being more rare. Small filaments of *Oedogonium* including a basal hold-fast cell were most common. Single celled Chlorophyta, *Scenedesmus*, *Pleodorina*, *Cosmarium*, *Closterium*, and *Staurastrum* were present throughout the summer.

Macrophytes

The macrophyte communities in the Lake City ponds were quite extensive. Nearly all of the bottom area was covered with higher aquatic plant growth, and it was obvious that their presence was a major influence on the ecology of the ponds. Not only did these plants provide cover for fish, zooplankton, and aquatic insects, but they also contributed to the oxygen and carbon dioxide cycles of the pond. The nitrogen, phosphorus, and carbon cycles are intricately tied with the organic productivity of an aquatic system.

It was realized quite early in the study that the difference in macrophyte communities between ponds C and D was great, and that comparisons between the two communities would be difficult. Whereas pond C had a fairly diverse plant community, pond D was dominated by stands of *Potamogeton amplifolius*. This is a large *Potamogeton* with both submerged and floating leaves, and it occurred in stands which excluded the growth of other macrophytes. *Najas flexilis* occurred in the shallower water of pond D and *Elodea canadensis* was found in a very small patch near the west shoreline. The major plants of pond C were *N. flexilis* and *Chara* sp. occurring in the shallower water, and *Potamogeton berchtoldii* Fieber being found in the deeper water (0.7-1.5 meters deep). Water lilies, *Nymphaea odorata*, occurred at the north and southeast sides of the pond. Table 5 records the major aquatic plant species observed in the two ponds.

The aquatic environment places numerous limitations on plant growth. Depth of the water, for example, is known to be a key variable in determining the plant species present (Swindale and Curtis, 1957). Light limitation in deep water may be the major factor limiting macrophyte growth. Depth also places a limit on the plant biomass of submerged species. Submerged macrophytes are well adapted to the aquatic environment, but cannot extend much beyond the air-water interface.

Numerous problems were encountered in regard to sampling the macrophyte community. The periphyton attached to the leaves and stems

Table 5. The major aquatic plants observed in the Lake City ponds during the summer of 1971.

Pond C	Pond D
Chara sp.	*Potamogeton amplifolius*
Potamogeton natans	*Najas flexilis*
P. berchtoldii Fieber	*Elodea canadensis*
P. praelongus	
P. zosteriformis	
Najas flexilis	
Elodea canadensis	
Nymphaea odorata	
Myriophyllum sp	

of the macrophytes required a great deal of time to remove. As the summer progressed and filamentous algae became more abundant, the problem increased. The great variability between samples (range of 0 to 3.85 gm dry wt./dm^2) was also a problem in that it required a greater number of samples to be taken than time allowed. The dieoff of several species of plants towards the end of the summer increased this variability.

As a result of the above problems, the conclusions that can be drawn from my data are limited. It was interesting, however, that on September 7, section C2 had a significantly larger biomass of macrophytes than did section C1. One possible reason for this may have been due to a dieoff of *Potamogeton berchtoldii* Fieber, which occurred in section C1 before it occurred in C2. The greater amount of filamentous algae in C1 may have been responsible for this earlier dieoff.

Both sections of pond D showed an interesting occurrence during the second week of August, when the *Najas flexilis* population was found dead or dying. Plants were floating on the surface, and the bottom areas were becoming barren. Since the *Najas* of the other ponds were in good condition, it is logical to assume that this dieoff was in response to the fertilization with nitrate. The plants themselves appeared intact and as if they had been cut off at the mud-water interface. If the bacterial activity of the sediments was increased by the fertilization, then perhaps this could account for the dieoff. It is not known why a similar response was not observed in pond C.

Observations made of the quadrats set up in the ponds showed some very interesting trends. As a means of comparison, a relative abundance term was used. This term was obtained by multiplying the average of the recorded heights for each species, times the percentage of the 16 units per quadrat where the species was tallest. This was therefore a three-dimensional term obtained by multiplying a percent of area times height. Figure 13 shows the observed trends when relative abundance was plotted against time.

Whether or not the observed trends are a response to fertilization and/or aeration or to natural seasonal changes is not known. In both sections of pond C Chara was observed to decline in relative abundance throughout the summer. Forsberg (1964) reports that a high concentration of phosphorus in the water inhibits the growth of Chara, and that this sensitivity to phosphorus would explain the absence of Chara in very eutrophic waters. Since Chara is often observed under the ice during the winter and is present throughout the year, the decline in abundance to zero would appear to be more of a response to the high phosphorus levels than to a seasonal change.

Whereas the Najas flexilis of pond D died off during early August, the population in pond C first increased and then gradually declined to zero by the end of the summer. The abundance of Potamogeton berchtoldii Fieber increased through most of the project and was then observed to dieoff first in pond section C1. The population in section C2 was also beginning to decline by the last sampling date as is shown by Figure 13. A small quantity of Potamogeton praelongus in section C2 appeared quite constant throughout the project. The percent of barren bottom area did not increase considerably until the last sampling date. The percent of algae covered bottom area increased in section C1 during the first week of September, whereas that of C2 did not increase until the last sampling date.

Figure 13a. The observed relative abundance of macrophytes in Lake City pond section C1 during the summer of 1971. (—— *Najas flexilis*, ---- *Potamogeton berchtoldii* Fieber, -·-· *Chara* sp.)

Figure 13b. The observed relative abundance of macrophytes in Lake City pond section C2 during the summer of 1971. (—— *Najas flexilis*, ---- *Potamogeton berchtoldii* Fieber, -·-· *Chara* sp., ···· *Potamogeton praelongus*)

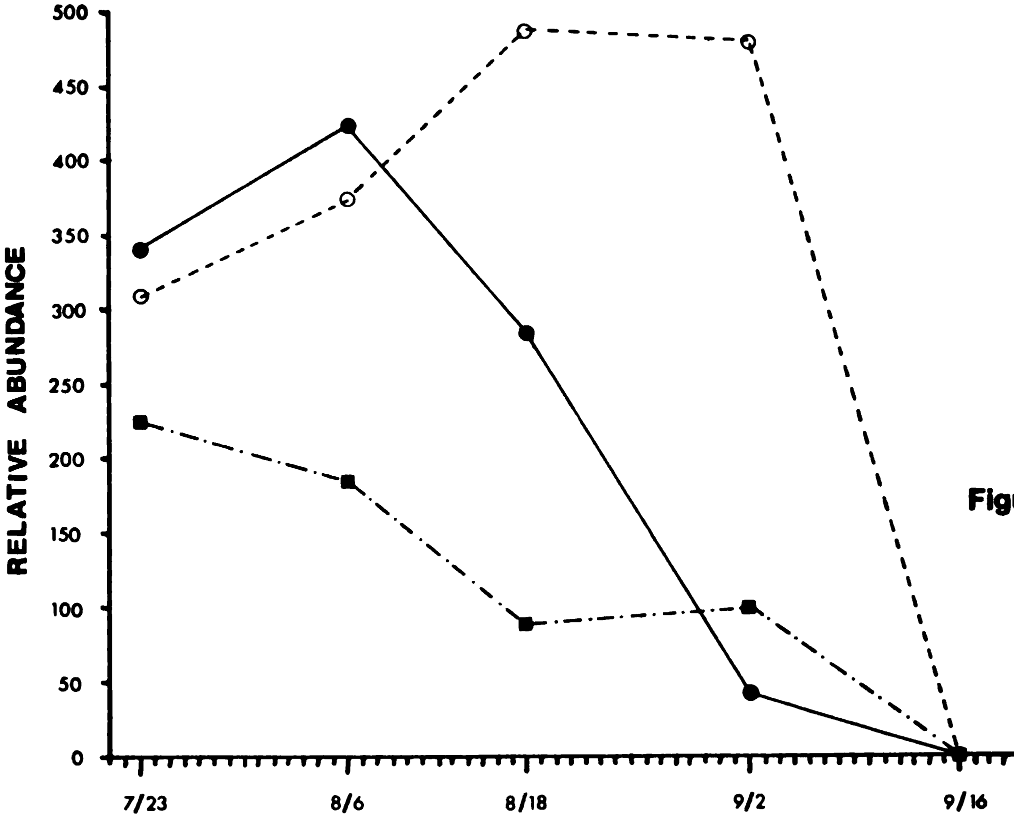

Figure 13a

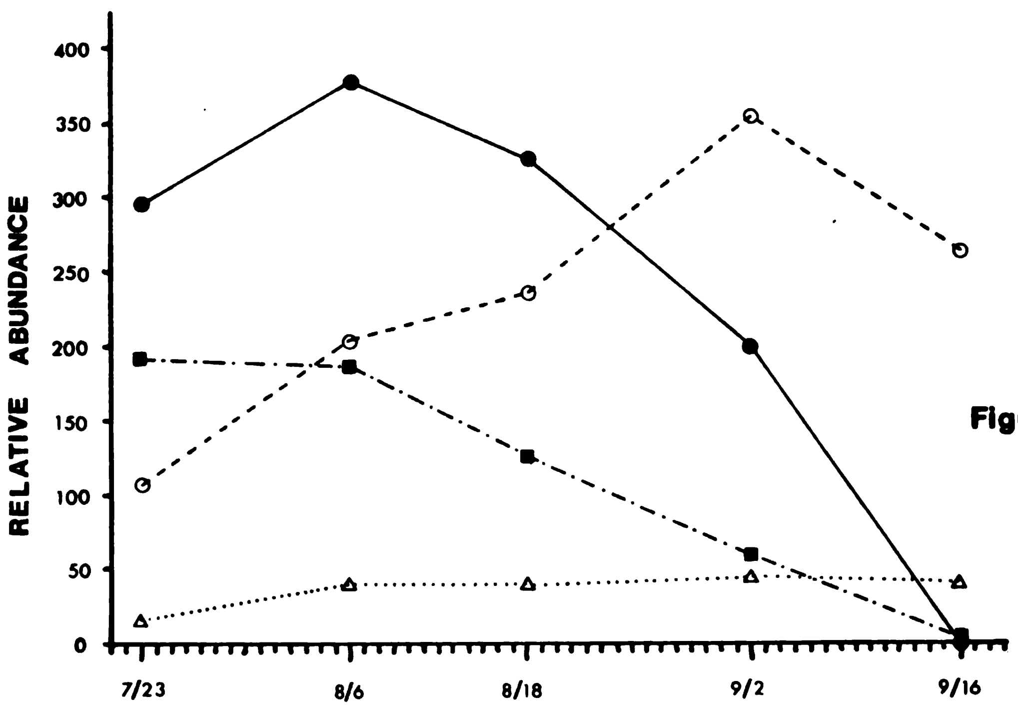

Figure 13b

The uptake of nutrients by higher aquatic plants is an important aspect of the eutrophication problem. Where phytoplankton must obtain all of their nutrients from the water, macrophytes may get their nutrients from either the sediments or the water. Some macrophytes have better developed root systems than others and are more efficient at taking nutrients from the sediments.

Several interesting studies have been made in regard to the uptake of phosphorus by aquatic plants. Bristow and Whitcombe (1971), for example, found that in Myriophyllum brasiliense, M. spicatum and Elodea densa most of the phosphorus present in the upper shoot had been absorbed by the root systems. In these plants the concentration of phosphorus in the water was relatively unimportant in relation to the growth of the plants and their uptake of phosphorus through the roots. These researchers found that Myriophyllum brasiliense grew equally well in nutrient rich or distilled water if the water exposed to the root section was a nutrient solution.

Other researchers have found similar results to those presented above. Martin, Bradford, and Kennedy (1970) showed that Najas sp. absorbed most of its phosphorus from the sediments. Nuphar sp. is also thought to take phosphorus up through its roots (Coffin et al., 1949). Elodea canadensis, Potamogeton sp., Myriophyllum sp., and Ludwigia palustris have been found to take up phosphorus through the root system and transport it to the stem and leaves (personal unpublished data).

Also of interest in the discussion of phosphorus and aquatic macrophytes is the adsorption of phosphorus onto surfaces. In a nutrient rich pond with abundant plant growth, such as pond C, this adsorption phenomenon may be considerable. It would seem to be of major importance to the periphytic algae. Some epiphyte-macrophyte interactions are discussed in the next section.

Macrophyte - Algal Interactions

There are numerous paths of interaction between macrophytes and the periphytic and planktonic algae. It has not been until fairly recently, however, that some of these interactions were actually identified. Hasler and Jones (1949) were one of the first to show that dense growths of macrophytes had a significant inhibiting effect on phytoplankton. The mechanism of this inhibiting effect has been the subject of much interesting research (Fitzgerald, 1969; Brandl et al., 1970; and others).

The occurrence of either phytoplankton or macrophyte communities at different nutrient levels in sewage ponds suggests that a nutritional interaction may exist. Competition for nutrients between species of algae has been observed (Fitzgerald, 1969). Mulligan and Baranowski (1969) report that submersed vascular aquatics have lower nutrient requirements than filamentous or planktonic algae. However, if the macrophytes are obtaining most of their nutrients from the sediments, then they are not competing with the algae for these same nutrients. Competition for carbon, however, may be of considerable importance and has been observed in stands of *Elodea canadensis*, where a decreased phytoplankton production was partly due to the decrease in CO_2 in the water due to its utilization by macrophytes (Brandl et al., 1970).

Competition for light and the shading of phytoplankton by macrophytes has also been reported. Straskraba and Pieczynska (1970) found light to be the dominant factor limiting photosynthesis of algae among stands of Phragmites, an emergent macrophyte. Similar results have been found in regard to submerged macrophytes. Brandl et al., (1970) did some very interesting research dealing with macrophyte - algal interactions and found a decrease in primary production of phytoplankton among stands of submerged macrophytes was caused by shading. Possible substances excreted by macrophytes inhibiting the growth of phytoplankton were not found by these researchers. Phytoplankton samples collected from the macrophyte stands and exposed to light increased in primary production.

Whereas Hasler and Jones (1949) found a lower abundance of phytoplankton among stands of macrophytes, Brandl et al. (1970) found a slight increase in abundance, but a very significant decrease in production rate when compared with open water phytoplankton. In an isolated marsh area Sloey (1969) found a decrease in phytoplankton abundance when compared to the open water algae. From the work of Brandl et al. (1970), it would appear that the decreased primary production may lead to a decrease in phytoplankton abundance when a macrophyte stand is isolated.

The shading of macrophytes by phytoplankton is also of importance to the overall production of ponds. A bloom of phytoplankton would severely limit light penetration and could result in the elimination of macrophytes. The depth of water in which macrophytes can grow is limited by the degree of light penetration.

A bloom of filamentous algae also would create unfavorable conditions for aquatic macrophytes. Not only could the algae limit the light penetration of the water, but they could accumulate epiphytically on the macrophytes in such amounts as to restrict other life processes of the plant. The filamentous algae of Lake City pond C were present in bloom proportions and were attached to macrophytes in such amounts as to completely cover them. When filamentous algae break loose from the bottom and form mats on the water surface, even macrophytes with floating leaves may become shaded.

Periphyton also interact with macrophytes in several ways. For example, the increased surface area created by the macrophytes is of critical importance to the epiphytic algae. Edwards and Owens (1965) found that in four shallow streams the surface area was increased 30 times by the presence of macrophytes. This increased surface area is also of importance to the epiphytic bacterial populations.

Fitzgerald (1969) found that when macrophytes were placed in nutrient rich water in the lab, the epiphytic algae increased tremendously, often obscurring any nutritional response of the macrophytes. He then observed that cultures of *Myriophyllum* sp., *Ceratophyllum* sp., *Lemna minor*, *Cladophora*, and *Pithophora oedogonium* will remain relatively free of epiphytes or competing phytoplankton if the cultures were nitrogen-limited. A phosphorus-limited medium with abundant nitrogen still resulted in epiphyte growth. This latter finding appears in conflict with the periphyton results from Lake City pond D, where abundant growth was not observed, although nitrate levels were high. As Fitzgerald points out, however, some type of bacterial interaction also may be involved in limiting algal growth.

Certain kinds of bacteria in the water may act as inhibitors to the growth of certain species of algae. Bacteria found in sewage effluent, for example, inhibited the growth of Microcystis; and Chlorella was unable to grow in aquaria where Pithophora was present (Fitzgerald, 1969). It was hypothesized by Fitzgerald that perhaps the filamentous green algae support a characteristic bacterial flora that inhibit the growth of epiphytes only when the filamentous algae are growing under nitrogen-limited conditions.

Allen (1971) has studied the nutritional interactions of the epiphytic bacteria and algae on macrophytes. He reports that dissolved organic matter released by macrophytes is rapidly taken up by the plant's epiphytic algae and bacteria. These algae and bacteria interact by each releasing respired CO_2 and excreted dissolved organic matter to the other. The epiphytic bacteria are also thought to release various growth factors and vitamins to the algae and to the surrounding water. Allen (1971) also mentions that well-developed macrophyte stands, with their nutritionally associated epiphytes are probably capable of using up a large portion of the dissolved organic materials present in some lakes. This event would deprive phytoplankton of these materials and most likely limit their abundance.

It is evident from the above discussion that the macrophyte - algal interaction question is considerably complex. The physical aspect of shading and the more complex nutritional relations both play major roles in determining the presence of certain forms of plant life. This subject continues to be an active area of research.

SUMMARY

Two farm ponds were fertilized, one (Pond C) with both phosphates and nitrates to approximate a secondary sewage effluent, and the other (Pond D) only with nitrates. Half of each pond was then aerated to determine if this would result in less chance of oxygen depletion in the aerated section. The responses of phytoplankton, periphyton, macrophytes, and zooplankton were measured.

The project was divided into two sections, the first being that the ponds were fertilized once and continuously aerated and the chemical and biotic changes monitored. During the second phase, the ponds were fertilized every four days to maintain high nutrient levels. Again aeration was continued and the various chemical and biotic changes observed.

In all cases the phosphate and nitrate concentrations in the water were observed to decline very rapidly. It is thought that the rapid decline in nitrate concentrations may have been due to bacterial activity. The rapid decline of phosphate concentrations was most likely due to a combination of factors including adsorption by the sediments, uptake by plants and precipitation with Ca^{++}. The concentrations of both nitrates and phosphates were consistently lower in aerated C1 than in unaerated C2, presumably because of the larger amount of plant growth in section C1 and the resulting greater uptake of nutrients.

The standing crop of phytoplankton was observed to increase slightly and then decline again during the first phase of the project. At continued high nutrient levels, the phytoplankton levels were observed to increase and remain at a relatively higher level. These increases in phytoplankton standing crop were noted to occur in both sections of both ponds C and D. In both phases of the project the increase in phytoplankton was delayed by approximately seven days. This occurrence was thought possibly to be due to bacterial activity.

The colonization rates of periphyton were observed to increase in response to fertilization with nitrogen and phosphorus, but not in response to an added nitrogen supply alone. The periphyton production of aerated section C1 was greater than that of unaerated section C2. This was thought to be due to the aeration system, which was acting as an additional source of carbon by bringing CO_2 into the water.

Filamentous algae became very abundant in pond C by the end of the summer. Its first appearance was along the aeration hose of section C1. This was attributed to the carbon dioxide being brought into the pond by aeration. Since filamentous algae were not observed in aerated section D1, it appears that the algae were phosphorus limited in pond D.

The macrophyte communities proved to be very difficult to accurately measure. A system of periodically recording the growth of plants in quadrats set up in the ponds showed that the different species of macrophytes behaved differently over the summer period. Whether the responses were due to the fertilization or to normal seasonal changes could not be determined.

The ecological interactions between macrophytes and algae have proved to be quite complex. The shading of macrophytes by algae or of algae by macrophytes can result in a dominance of one plant community or another. Nutritional interactions, some involving bacteria, have also been recorded. It is evident that some if not all of these interactions were operating in the Lake City ponds.

It would appear from the work reported here that aeration of shallow nutrient rich ponds may result in complex problems with algal growth. With a more powerful aeration system and conditions of oxygen deficiency in the ponds, it is possible that other factors may become important. Further research will hopefully answer some of these questions.

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