# COMMUNITY STRUCTURE OF PLANKTON

# IN CLEAR AND TURBID PONDS

By

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## PREFACE

This study of community structure of plankton in clear and turbid farm ponds was made to determine the effects of turbidity on the plankton, identify physicochemical factors affecting turbidity, and determine seasonal environmental changes.

Professor Troy C. Dorris served as major advisor. Drs. Roy W. Jones, William A. Drew, Jerry Wilhm, and Rudolph Miller served on the advisory committee and criticized the manuscript. Dr. Robert Morrison directed writing the computer program for population and diversity calculations. Bobby Gene Whiteside helped with field collections and with the computer program. Appreciation is expressed to Drs. C. Carroll, Dorothy V. Leake, and G. W. Prescott for aid in the identification of the phytoplankton and to Drs. T. Wayne Porter and Dale Toetz for help in the identification of zooplankton.

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CHAPTER I

# INTRODUCTION

Studies of the effects of turbidity on total numbers or volumes of plankton have produced conflicting results. Chandler (1942) found that pulses of phytoplankton in western Lake Erie occurred at times of low turbidity. Phytoplankton pulses followed increases in turbidity in Lake Michigan (Daily, 1938). In western Lake Erie the greatest numbers of phytoplankton occurred in waters of intermediate turbidity (Verduin, 1954). Harris and Silvey (1940) reported maximum net plankton volumes at times of high turbidity in two Texas lakes and at low turbidity in two others. Claffey (1955) found that plankton volume decreased with increase in turbidity in Oklahoma ponds and reservoirs.

Since turbidity affects water quality, it may be considered a form of pollution. Addition of suspended and settleable solids is one of the five physical and chemical effects of pollution (Hynes, 1963). Although eroded materials are not recognized as pollutants by the general public, they have been described as the most universal and perhaps the most important pollutant in America (Cottam and Tarzwell, 1960). The need for investigation of the effects of turbidity on aquatic organisms has been stated by Cottam and Tarzwell (Ibid.).

Species diversity is a useful parameter for determining the effects of pollutants on aquatic communities (Patrick, Hohn, and Wallace, 1954; Gaufin and Tarzwell, 1956; Wilhm and Dorris, 1966). Models for the distribution of individuals among species to yield diversity indices have been proposed by Margalef (1958), Patten (1962), and MacArthur (1965). Another measure of the diversity of the plankton community is pigment diversity, the ratio of the concentration of carotenoids and other pigments to that of chlorophyll a. Changes in pigment diversity and species diversity were found to be correlated during ecological succession in laboratory microcosms by Margalef (1961). Therefore, pigment diversity may be reduced by pollutants in a similar way to species diversity.

Since turbid ponds exist adjacent to clear ponds in central Oklahoma, it is possible to study the effects of turbidity on plankton communities. The turbidity is caused by negatively-charged montmorillonite clay particles of colloidal dimensions which remain suspended for long periods of time (Weiser, 1938). The literature concerning these suspended clay particles has been reviewed by Claffey (1955) and Keeton (1959).

The present study was undertaken to investigate the effects of turbidity on species diversity and pigment diversity of plankton communities in two turbid and two clear ponds.

## CHAPTER II

## DESCRIPTION OF AREA

The four ponds are located in Payne County, about 10 km from Stillwater, Oklahoma. The area is underlain with sedimentary rocks called "Permian Red Beds," The soils in the area are of the Vernon Loam type (U.S. Geol. Survey Prof. Paper, 1937). Since the area is a part of the mixed grass prairie and has a rolling terrain, much of the land area is used as pasture.

All of the ponds are artificial impoundments used primarily for watering livestock. The larger turbid pond is referred to as Big Muddy Pond and the smaller is called Little Muddy Pond. Likewise, the clear ponds are called Big Clear Pond and Little Clear Pond.

Little Muddy Pond is located in Range 2E, Township 20N, and Section 23. This pond is oval in form and located on a hillside (Fig. 1). It was built approximately in 1935 and was redredged in 1956. Little Muddy Pond has an area of 0.25 ha and a mean depth of about 0.5 m. This pond occasionally overflows. The drainage area is 6 ha of pasture land. The principle grasses on the drainage basin were *Andropogon saccharoides* SW., *A. scoparius* Michx., *Echinochloa crusgalli* (L.) Beaux., and *Aristida oligantha* Michx. Common forbs were *Ambrosia psilostachya* DC, and *Solanum eleagnifolium* Cav. A clump of *Salix* sp. was located below the dam.

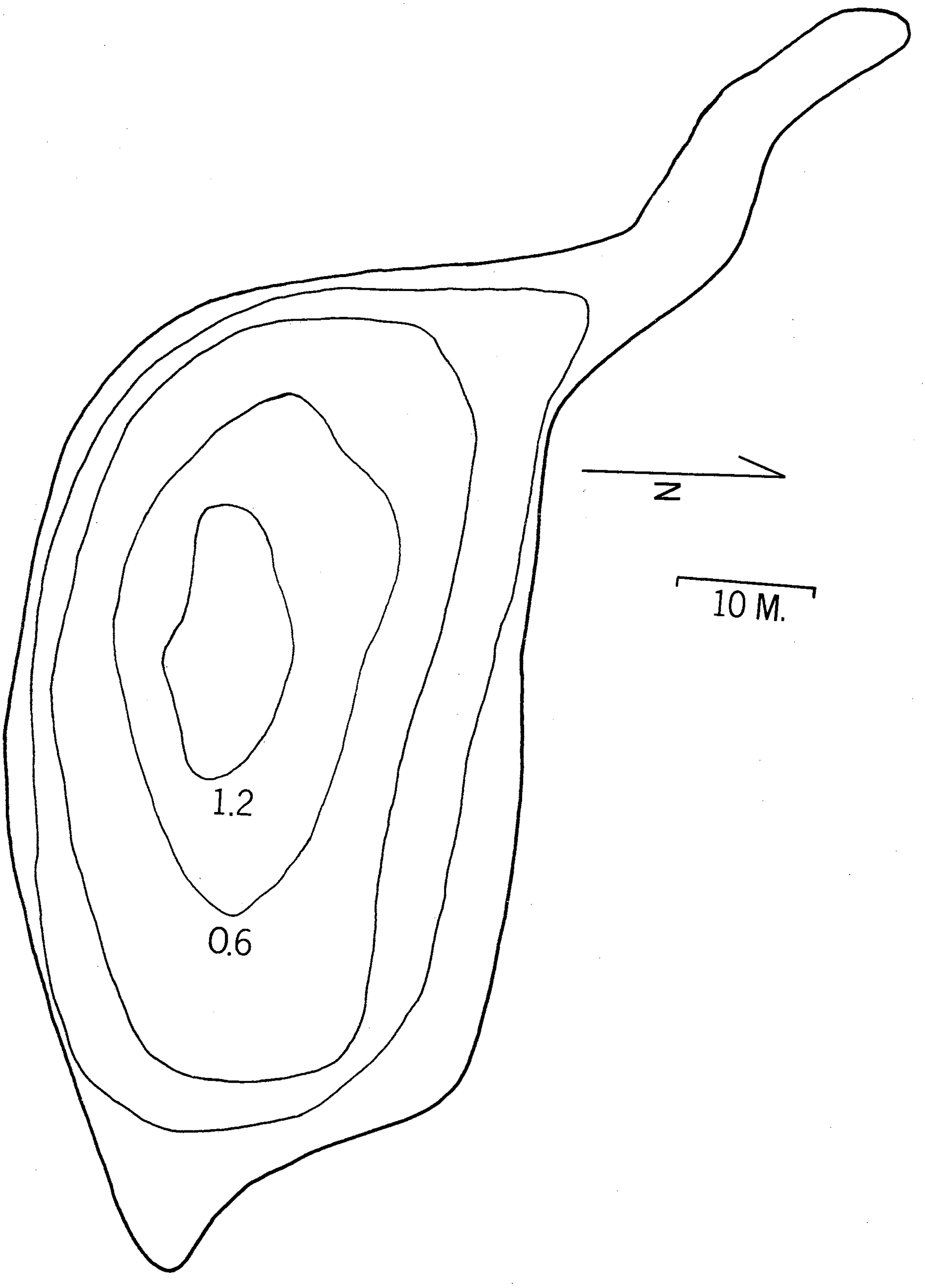


Figure 1. Contour Map of Little Muddy Pond. Depth Contours in Meters Below Normal Water Level.

Big Clear Pond is located about 300 m from Little Clear Pond (Fig. 2). This pond is located in a ravine and is partially protected from wind action by steep banks on two sides. The surface area is about 1.6 ha and the mean depth is about 0.8 m. Aquatic macrophytes abundant during the warm months include Potamogeton pectinatus L., P. nodosus Polret, Najas guadalupensis (Spreng.) Magnus, and Ceratophyllum demersum L. The drainage area is 11 ha of native range characterized by A. scoparius, Bouteloua curtipendula (Michx.) Torr., Solidago sp., Ambrosia sp., and Bouteloua gracilis (Willd. ex HBK.) Lag. ex Griffiths. Near the pond banks are a few individuals of Ulmus, Salix, and Tamarix.

Little Clear Pond is located about 322 m south of Little Muddy Pond (Fig. 3). Little Clear Pond has a long, narrow shape and lies in a ravine. It was built approximately in 1940, rebuilt in 1956, and the dam was raised in 1963. The surface area is normally 0.3 ha, and the mean depth is slightly more than 0.6 m. Potamogeton spp. and N. guadalupensis become abundant in the summer months. The drainage area is 11 ha of well-covered range composed mostly of A. scoparius, Sorghastrum nutans (L.) Nash, Bouteloua hirsuta Lag., and A. gerardi Vitman.

Big Muddy Pond is located in Section 26, Township 20N, and Range 2E. It is about 1.6 km south of the other three ponds. Big Muddy Pond is irregular in outline (Fig. 4). It was built approximately in 1930. At spillway level the area was nearly 2.8 ha, but normally the pond covered less than 2 ha. Mean depth was normally 5.4 m. The water level fluctuated more than in the other ponds. The

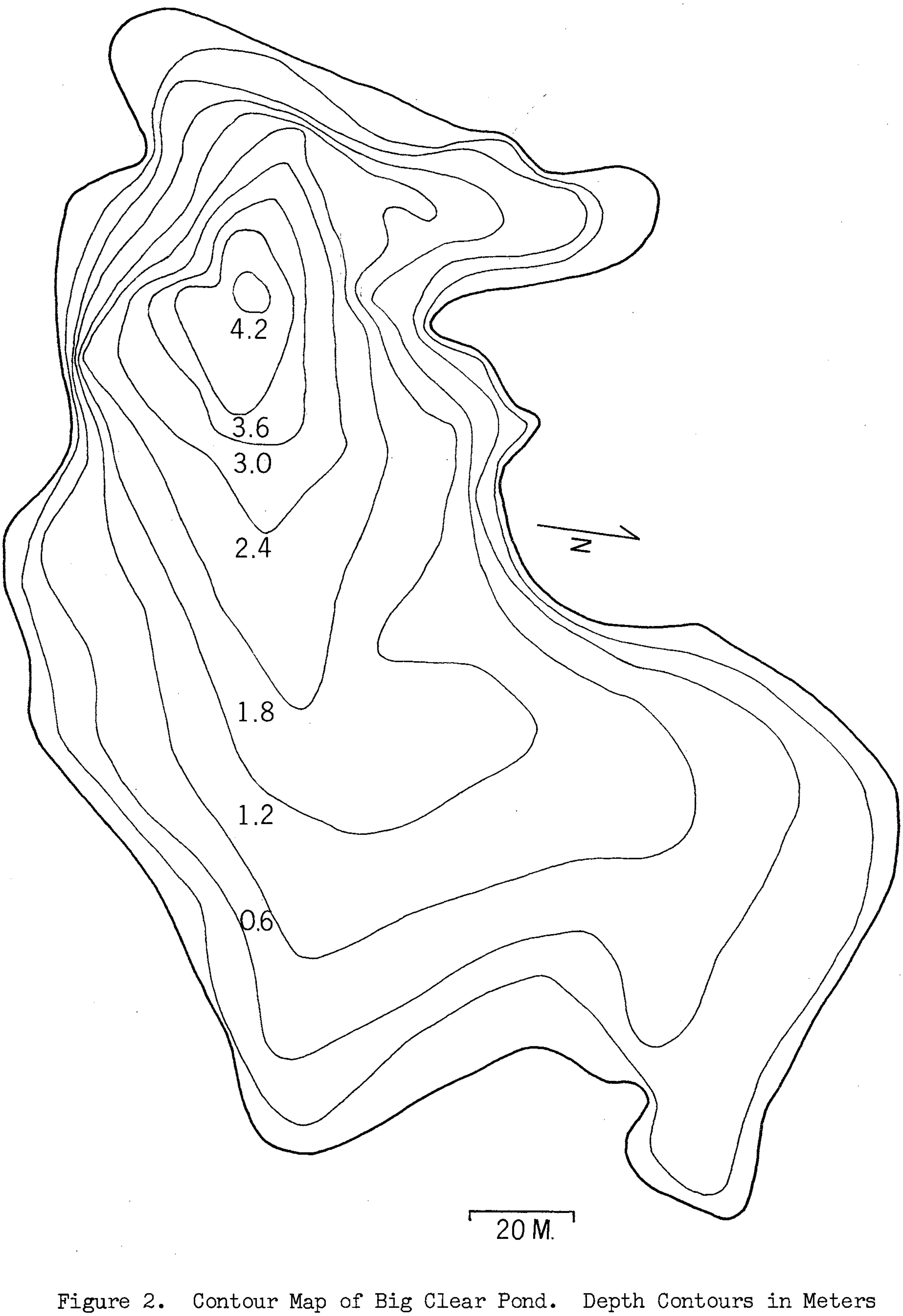


Figure 2. Contour Map of Big Clear Pond. Depth Contours in Meters Below Normal Water Level.

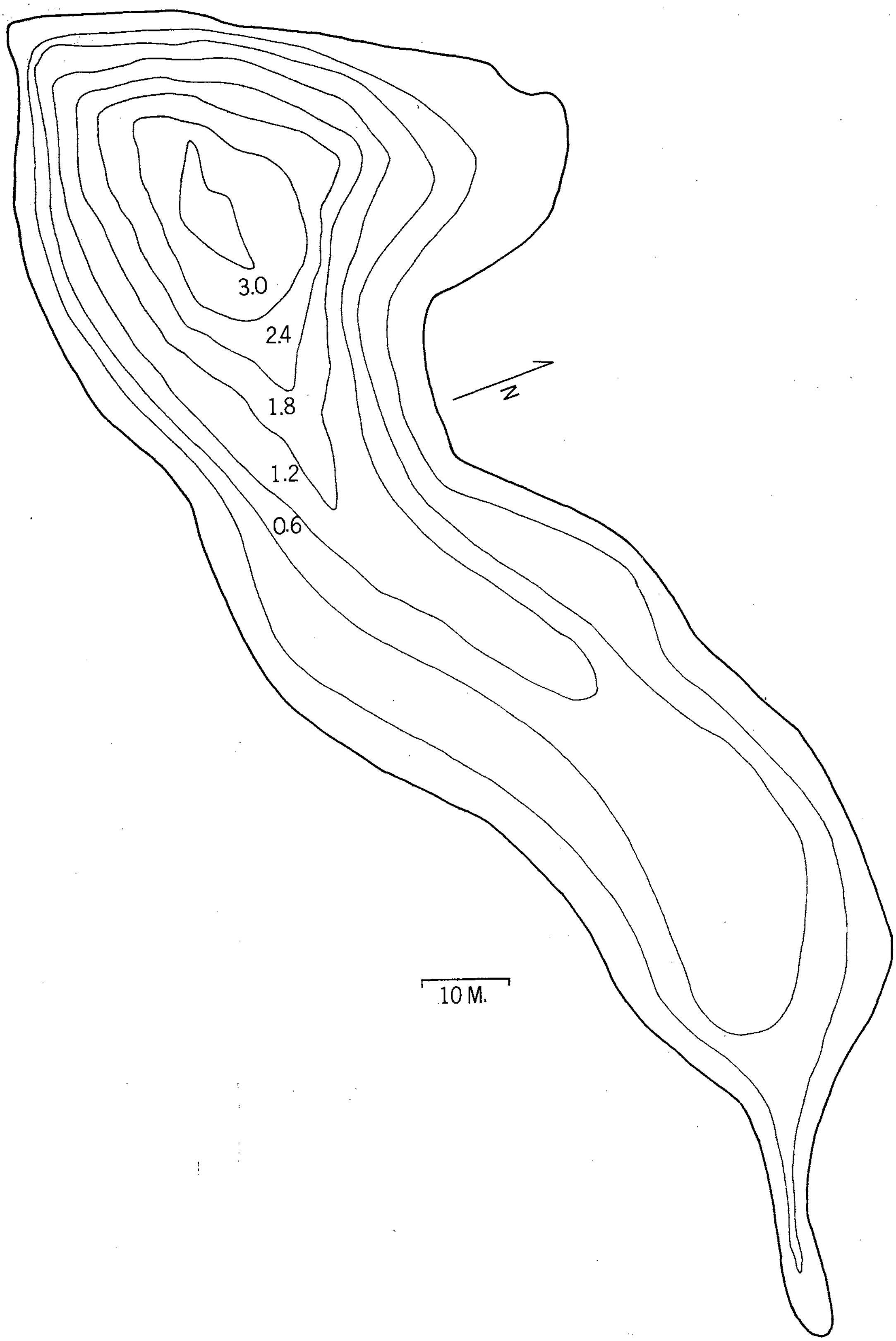


Figure 3. Contour Map of Little Clear Pond. Depth Contours in Meters Below Normal Water Level.

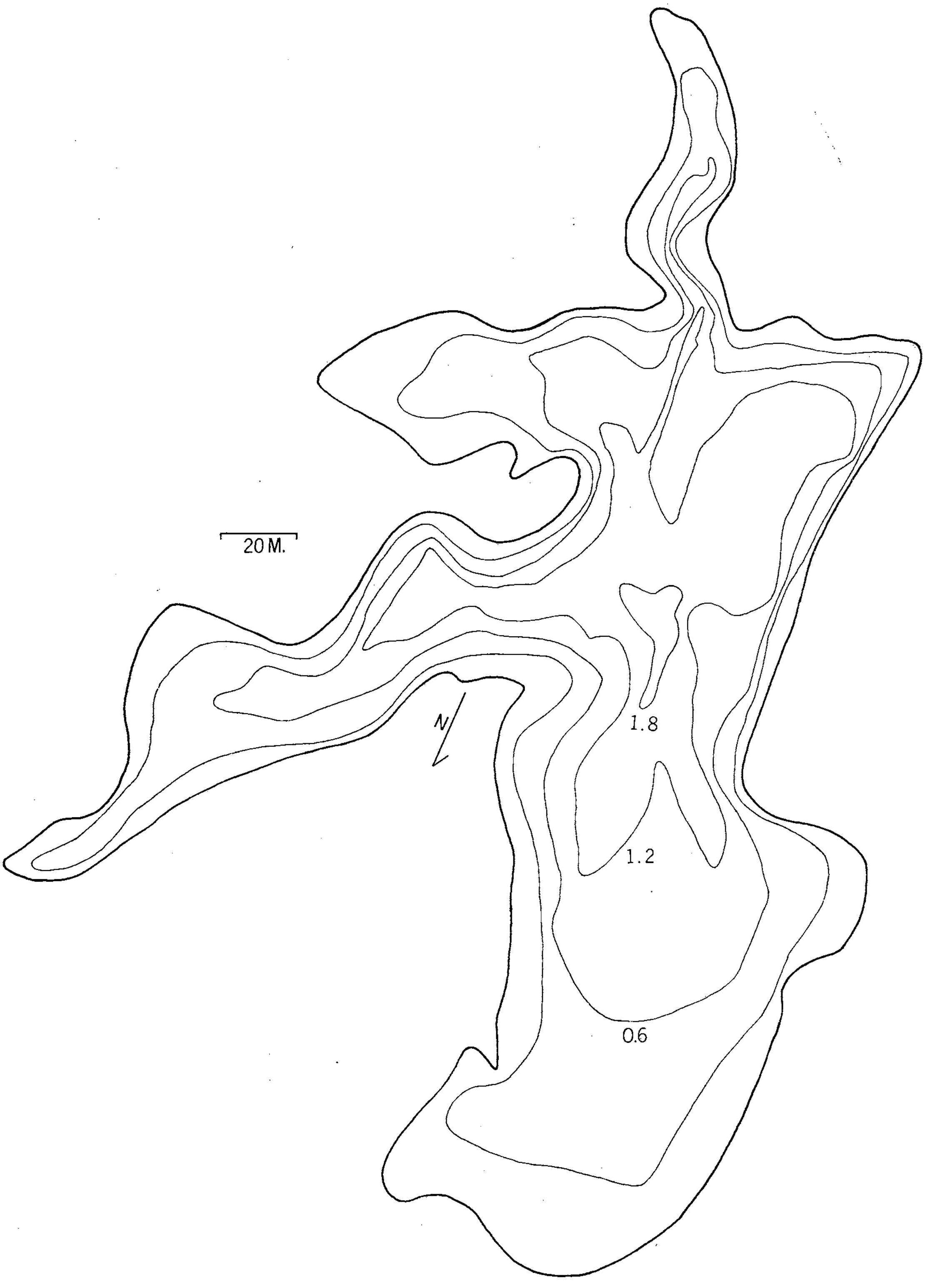


Figure 4. Contour Map of Big Muddy Pond. Depth Contours in Meters Below Normal Water Level.

drainage area was over 76 ha of overgrazed range, dominated by *A. scoparius* and *B. hirsuta*.

## Morphometry

The morphometry of the ponds is shown in Table I. The normal volume of Big Clear Pond was slightly larger than Big Muddy Pond. Big Clear Pond had less surface area, but had greater mean depth. Big Muddy Pond had twice the shoreline of Big Clear Pond.

Each large pond was at least five times greater in normal area and volume than either of the small ponds. Little Clear Pond was greater than Little Muddy Pond in volume, surface area, mean depth, and length of shoreline.

The clear ponds remained at levels farther below the spillway because the turbid ponds had a greater drainage area/spillway volume ratio. Since the clear ponds lost less water over the spillway, materials brought into the ponds by seepage or runoff water became concentrated by evaporation.

TABLE I

DIMENSIONS OF THE PONDS

| Pond | Normal Water Level | | | | |
|---|---|---|---|---|---|
| | Volume (m$^3$) | Surface Area (ha) | Mean Depth (ha) | Length of Shoreline (m) | Drainage Area (ha) |
| Little Muddy | 598.3 | 0.172 | 0.45 | 146.3 | 6.1 |
| Big Muddy | 11,252.0 | 1.987 | 0.56 | 1207.0 | 77.5 |
| Little Clear | 1,983.5 | 0.295 | 0.66 | 326.1 | 11.6 |
| Big Clear | 12,505.2 | 1.586 | 0.77 | 624.8 | 11.3 |

| Pond | Spillway Level | | |
|---|---|---|---|
| | Volume (m$^3$) | Surface Area (ha) | Mean Distance from Water Level to Spillway (cm) |
| Little Muddy | 1,541.9 | 0.3 | 41.9 |
| Big Muddy | 18.169.5 | 2.8 | 8.7 |
| Little Clear | 4,872.5 | 0.6 | 72.5 |
| Big Clear | 24,670.0 | 2.3 | 90.5 |

## CHAPTER III

## METHODS

Plankton collections and physicochemical measurements were made on each pond every 2 weeks alternately from September 1964 to October 1965. Water level of each pond was measured by a permanent gauge. Rainfall data were obtained from the records of the Oklahoma State University Weather Station, approximately 10 km from the ponds. The drainage area of each pond was estimated from aerial photographs and field observations. Water temperature was taken with a mercury field thermometer and a reversing thermometer. Hydrogen ion concentration was measured with a Hellige pH comparator. Depth of light penetration was determined with a submarine photometer or a Secchi disk. Phenolphthalein and methyl orange alkalinity were measured by titration with 0.02 N sulfuric acid. Primary productivity and community respiration were estimated from light-dark bottles incubated for 24 hours.

Water samples were tested for turbidity with a Bausch and Lomb Spectronic 20 Colorimeter at 450 mμ and for conductivity with an Industrial Instruments Wheatstone Bridge. Dissolved and suspended solids were determined from dried filtered and unfiltered 50 ml water samples fired at 500 C. Photosynthetic pigments were prepared by filtration of samples through 5.0 μ and 0.45 μ Millipore filters and extraction of the residue in 90% acetone. The pigments of winter samples were measured in a Bausch and Lomb Spectronic 20. More detailed analysis of the plankton pigments was made during the summer months by the use of a Perkin-Elmer recording spectrophotometer.

An estimate of summer plankton biomass was attempted by a modification of the methods of Curl and Sandberg (1961). The biomass from 1 liter of pond water was concentrated in a Foerst plankton centrifuge. The concentrate was transferred into a vial containing sodium succinate and a buffer solution. A solution of 2(p iodophenyl)-2-(p nitrophenyl)-5-phenyl-tetrazolium chloride (INT) was added to every vial except for blanks and incubated for one hour at 30 C. Concentration of formazan produced by the succinic dehydrogenase of the plankton cells was measured at 490 mμ with a Bausch and Lomb Spectronic 20.

Two phytoplankton samples were taken from the windward side, 2 from the center, and 2 from the lee side of the large ponds. Three samples were taken from the small ponds with the same orientation to wind direction. From each sample, 200 ml were concentrated to 10 ml by a Foerst plankton centrifuge. The phytoplankton was examined in a Palmer cell under a microscope with 430x magnification. The phytoplankton present in 40 Whipple-disc fields was counted from each sample. Zooplankton in 10 liters of water were concentrated to 10 ml with a Foerst plankton centrifuge. From this concentrate, 2 ml were examined in Sedgewick-Rafter slides under a microscope with a 100x magnification.

The indices used to estimate community structure were community diversity (d), diversity per individual ($\bar{d}$), maximum diversity ($d_{max}$), minimum diversity ($d_{min}$), and redundancy ($r$), computed by the following equations derived from Patten (1962) [$H$, $\bar{H}$, $m$, and $N$ were changed to $d$, $\bar{d}$, $s$, and $n$]:

$$d = \sum_{i=1}^{s} n_i \log_2 \frac{n_i}{n}$$

$$\bar{d} = \sum_{i=1}^{s} \frac{n_i}{n} \log_2 \frac{n_i}{n}$$

$$d_{max} = \log_2 n! - s \log_2 (n/s)!$$

$$d_{min} = \log_2 n! - \log_2 [n - (s-1)]!$$

$$r = \frac{d_{max} - d}{d_{max} - d_{min}}$$

Where $n$ is total number of individuals, $n_i$ is number of individuals of species $i$ and $s$ is the number of species per unit volume.

Statistical analysis of the data was accomplished by the method of significant differences (Ostle, 1963) and by coefficient of correlation. Computations were made with an IBM 7040 data processing computer.

# CHAPTER IV

# PHYSICOCHEMICAL CONDITIONS

## Rainfall and Water Levels

Precipitation was irregular, with largest amounts in November, May, June, and September (Fig. 5). Less than 2.5 cm of precipitation was received in October, December, January, and February. Total precipitation during the year of study was 79.8 cm.

Pond water levels were affected by rainfall in various ways (Fig. 5). Water levels of the small ponds raised after rainfall except during late fall and winter when the soil was dry and the amount of runoff was probably small. The levels of the large ponds raised to a lesser degree in response to rainfall. The water level of Big Clear Pond was stabilized in part by seepage springs near the periphery.

Big Muddy Pond overflowed in September, March, and April, but the other ponds did not reach spillway level during the study. The ponds which did not overflow decreased in volume generally from September 1964 to September 1965. Levels of all ponds decreased sharply in late summer during the period of high temperature and maximum evaporation. In September, 16 cm of rain in 4 days raised all pond levels. Since fall rains were effective in raising water levels after late summer decreases, precipitation in this season may be the major influence in the water economy of these ponds.

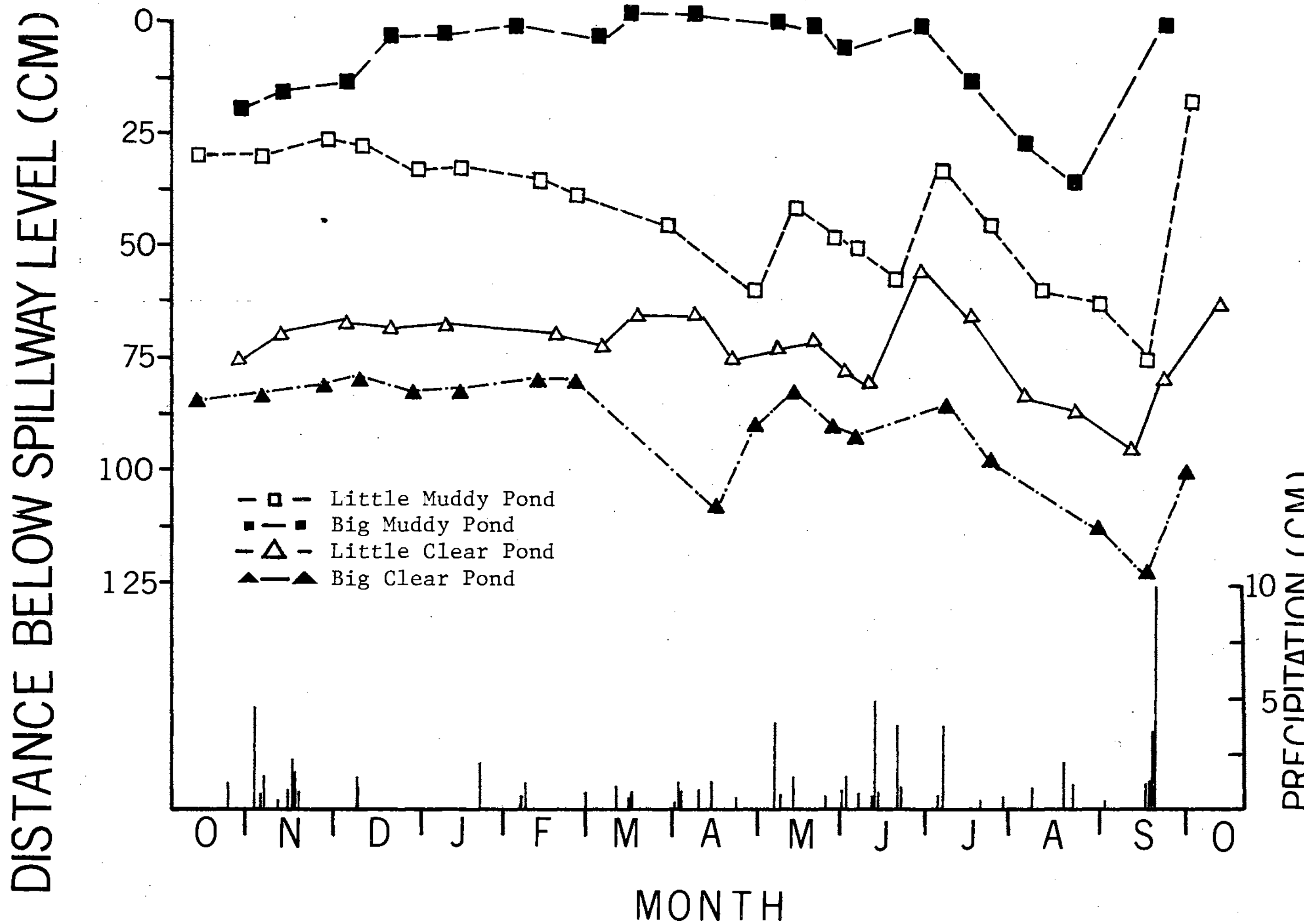


Figure 5. Water Levels of Ponds and Precipitation.

Temperature

The observed temperatures of the ponds ranged from 0 to 32 C during the year (Fig. 6). The temperature of each pond fell rapidly from November to December, fluctuated at a low level during the winter months and increased rapidly from March to April. After April, temperatures increased at a slower rate until late July and then began to decrease slowly. Because of the extreme changes at the first of December and the first of April and less variable conditions between these dates, data of other parameters were divided into a cold season from December through March and a warm season consisting of the remaining months.

Annual mean temperatures among ponds were similar (Table II). Big Muddy Pond had the highest mean temperature during the warm season and Little Muddy Pond had the highest temperature during the cold season. Since turbid water absorbs more heat at the surface than clear water, a higher surface temperature in the turbid ponds was expected. Butler (1963) found a sharp temperature gradient in a small turbid pond, which indicated that most heat was absorbed at the surface. A comparable temperature gradient was not detected in this study. Since the mean annual temperatures were similar for all ponds, it was concluded that the clear ponds absorbed as much heat throughout their depths and at their bottoms as the muddy ponds absorbed at their surfaces. Since dark bodies lose heat by radiation faster than clear bodies, turbid ponds may lose heat more rapidly than clear ponds during cool nights.

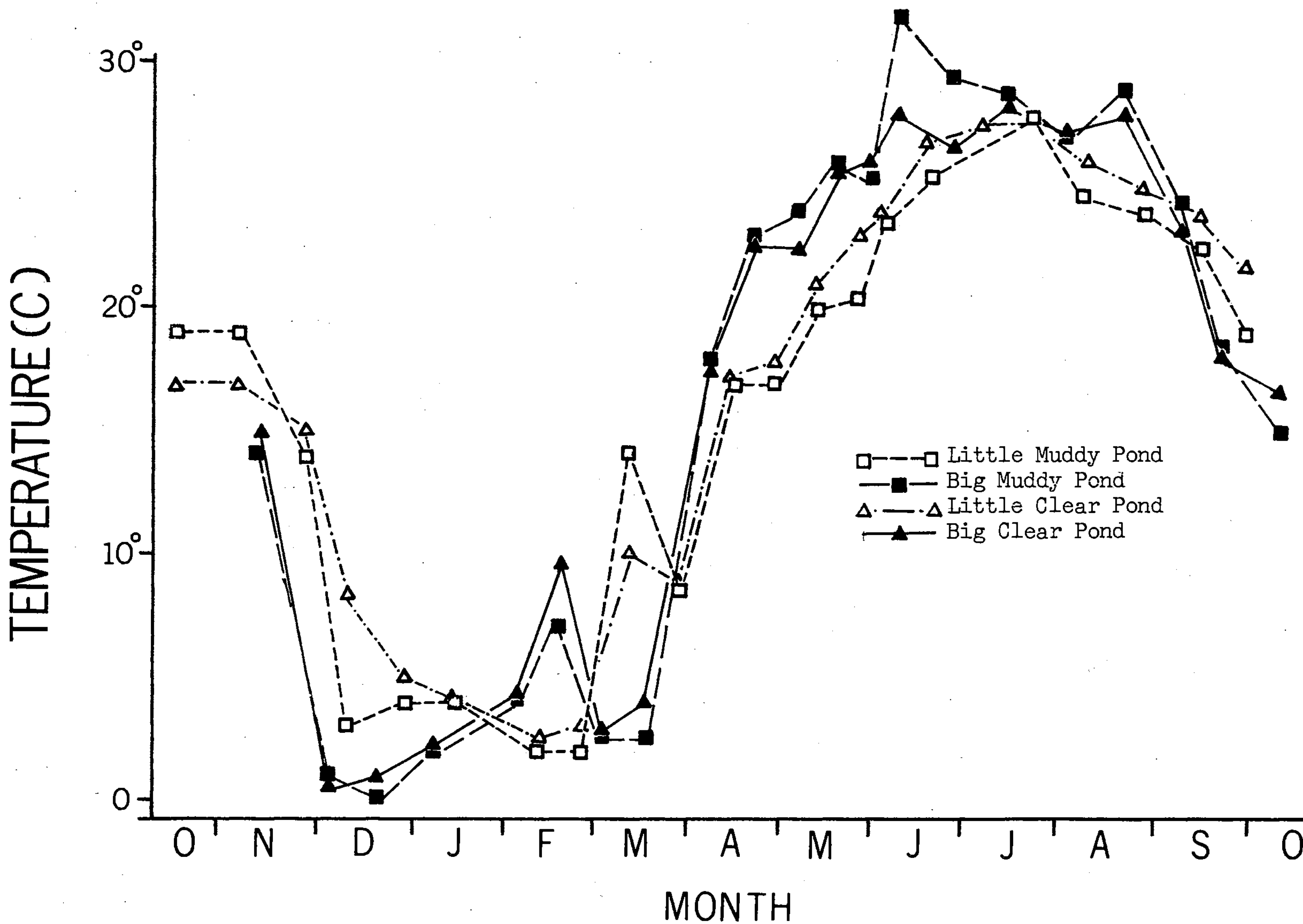


Figure 6. Surface Temperatures.

TABLE II

PHYSICOCHEMICAL FACTORS

| | Conductivity (μmhos) | pH | Carbonate (ppm) | Bicarbonate (ppm) | Surface Temperature (C) |
|---|---|---|---|---|---|
| **Annual Means** | | | | | |
| Little Muddy | 243 | 8.0 | 1.9 | 85.9 | 16.8 |
| Big Muddy | 361 | 8.1 | 0.6 | 122.5 | 16.9 |
| Little Clear | 380 | 8.5 | 30.1 | 106.8 | 16.7 |
| Big Clear | 570 | 8.8 | 83.9 | 146.8 | 17.0 |
| **Cool Season Means** | | | | | |
| Little Muddy | 209 | 8.1 | 0.0 | 71.2 | 5.4 |
| Big Muddy | 330 | 8.2 | 0.0 | 119.0 | 2.7 |
| Little Clear | 337 | 8.3 | 6.3 | 136.3 | 3.4 |
| Big Clear | 563 | 8.4 | 5.5 | 239.5 | 5.2 |
| **Warm Season Means** | | | | | |
| Little Muddy | 257 | 8.0 | 2.5 | 90.8 | 21.3 |
| Big Muddy | 375 | 8.0 | 0.8 | 123.5 | 23.9 |
| Little Clear | 379 | 8.6 | 35.5 | 100.0 | 23.3 |
| Big Clear | 579 | 8.9 | 110.0 | 115.9 | 21.4 |

## Conductivity

Conductivity appeared to be inversely related to water level. An overall correlation of 0.65 existed between conductivity and distance of water level below spillway. Increased conductivity during spring and late summer appeared to be related to reduced rainfall and concentration by evaporation (Fig. 7). Mean annual conductivity was highest in Big Clear Pond and lowest in Little Muddy Pond in all seasons. Conductivity was similar in Little Clear Pond and Big Muddy Pond. Spring increases in the clear ponds were probably caused by an increase in bicarbonate content.

## Hydrogen Ion Concentration and Alkalinity

The pH was similar in all ponds during the cool season with the clear ponds having a slightly higher pH than the turbid ponds (Table II and Fig. 8). All ponds had a relatively low pH in November. The clear ponds were relatively stable through the winter and spring, indicating a larger buffer capacity due to bicarbonate which was present in high concentrations. Ruttner (1953) has shown that the buffering of water is dependent upon its bicarbonate content. The pH increased from 8.4 to 9.4 within 10 days in early June in the clear ponds. The pH in Little Clear Pond remained at this level for 4 weeks and then decreased to 8.6. In Big Clear Pond pH increased to 9.6 and remained at this point for longer than 2 months.

Bicarbonate in the clear ponds increased generally through the spring to a level much higher than in the turbid ponds (Fig. 9). In

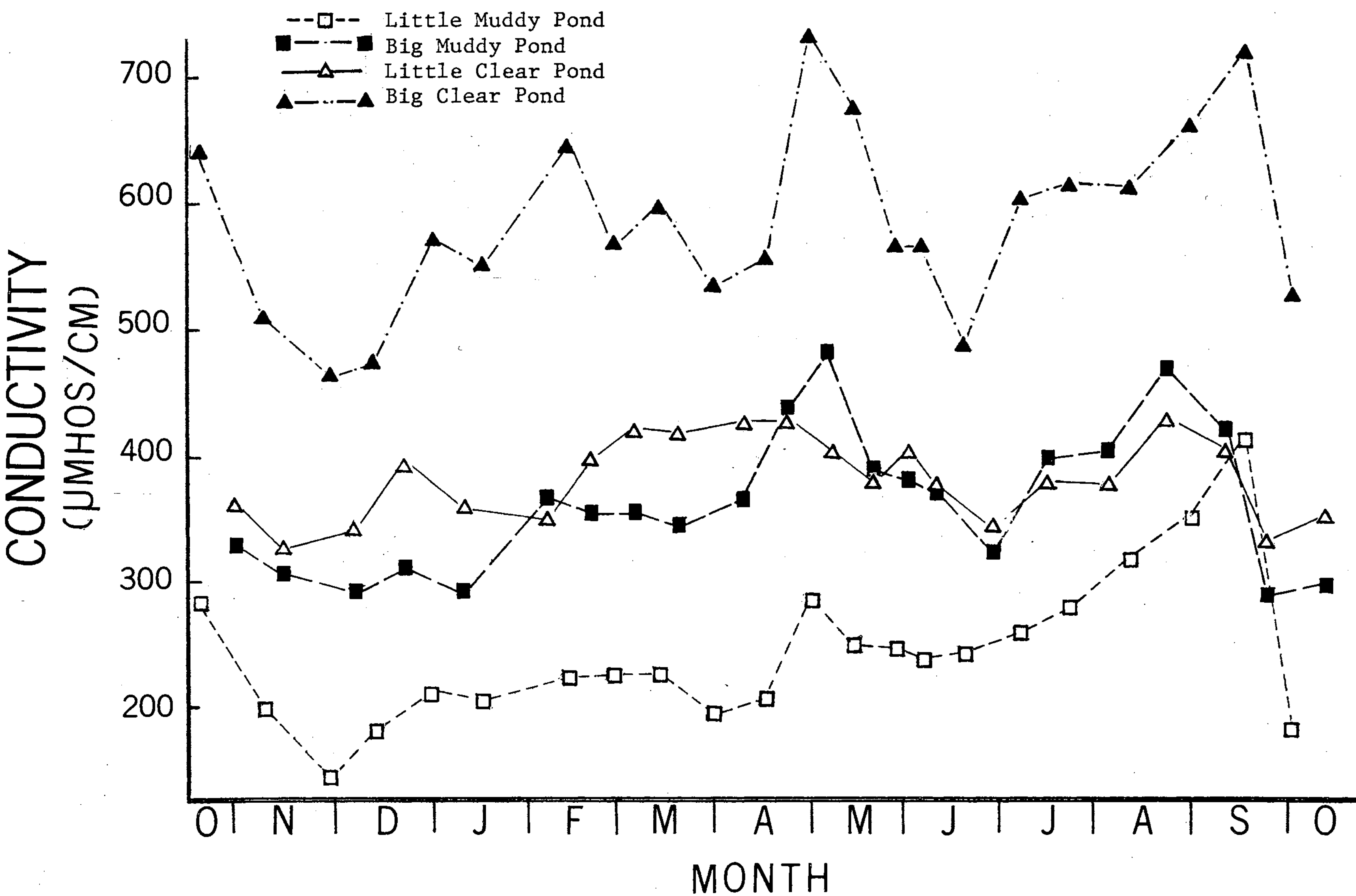


Figure 7. Annual Variation of Conductivity.

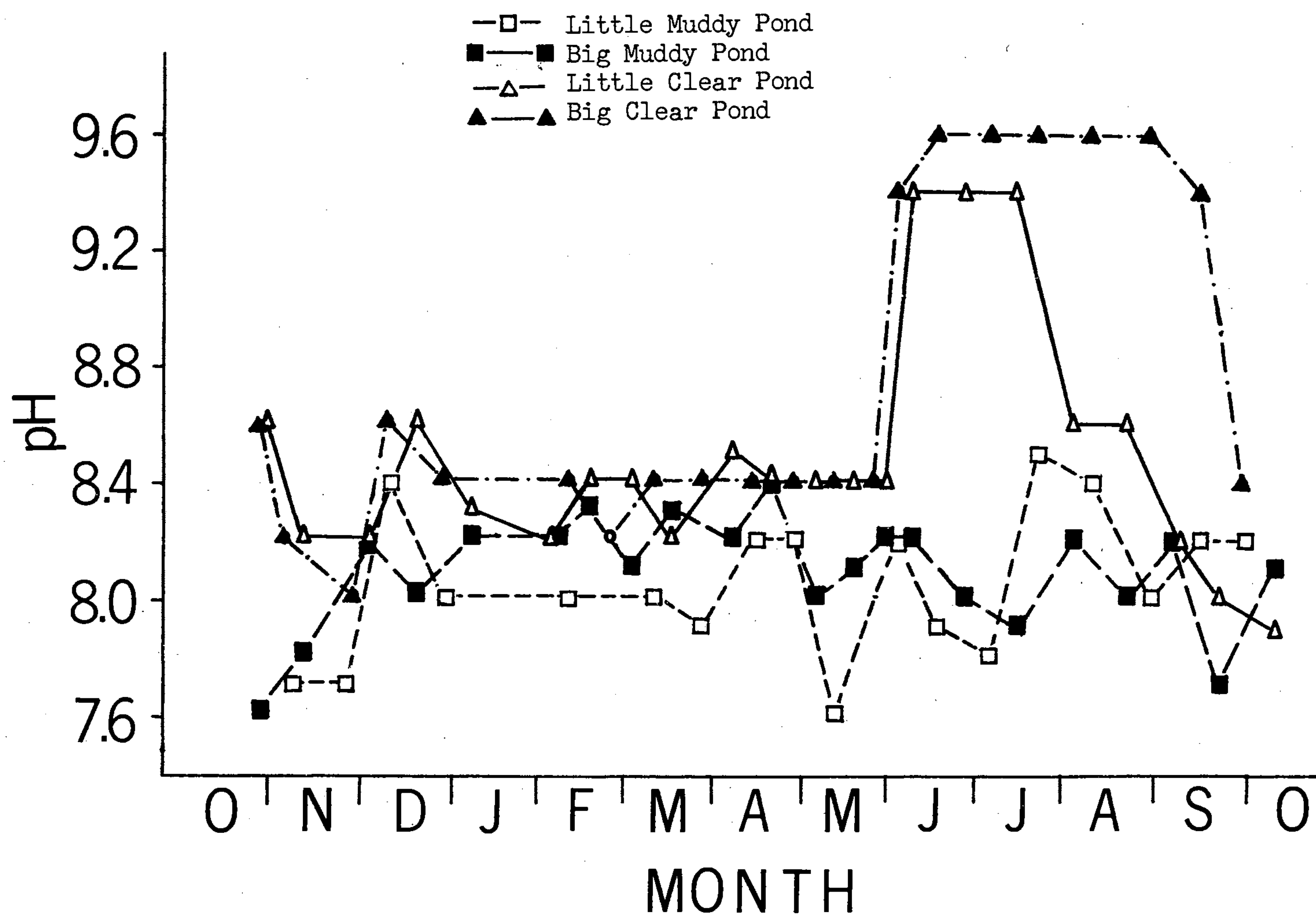


Figure 8. Annual Variation of Hydrogen Ion Concentration.

early summer the bicarbonate decreased as the carbonate and pH increased. Carbonate concentration was greatest in Big Clear Pond with a maximum of 164 ppm in June. Little Clear Pond held a maximum of nearly 80 ppm of carbonate. Maximum carbonate concentration was 20 ppm in Little Muddy Pond and about 5 ppm in Big Muddy Pond. The muddy ponds contained carbonate for less than 6 weeks. The clear ponds had carbonate present for more than 24 weeks, and carbonate was still present in Big Clear Pond when the study was terminated.

As carbonate and pH decreased in the late summer, the bicarbonate content increased in all ponds. Bicarbonate decreased sharply in all ponds except Big Clear Pond in the fall.

Many aquatic plants can use bicarbonate as a carbon source for photosynthesis when carbon dioxide is absent (Ruttner, 1953). In the process carbonate and hydroxyl ions are formed:

$$2\,HCO_3^- \longrightarrow CO_2 + CO_3^= + H_2O$$

$$CO_3^= + H_2O \longrightarrow HCO_3^- + OH^-$$

The hydroxyl ions raise the pH and may form hydroxides of calcium, magnesium, iron, and other cations.

Photosynthetic processes explain the spectacular increase in pH, reduction in bicarbonate, and increase in carbonate in the clear ponds during the summer months (Figs. 8 and 9). Aquatic macrophytes were dominating the clear ponds at this time and appear to be responsible. Changes in pH, bicarbonate and carbonate in Big Muddy Pond in early August may have been caused by a dense bed of *Chara* sp. Comparable changes in Little Muddy Pond in August can perhaps be explained by the high rate of photosynthesis by phytoplankton in late July.

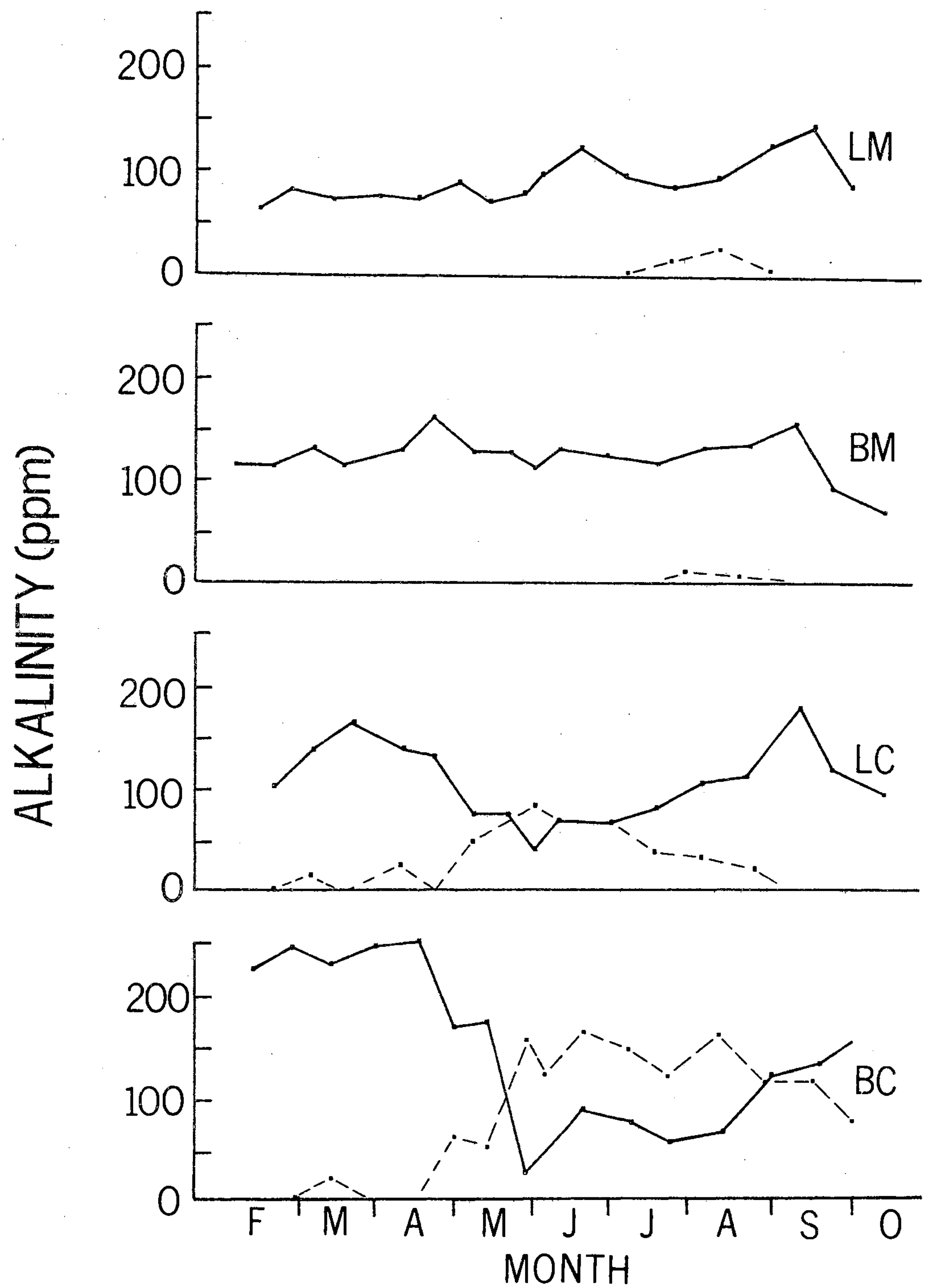


Figure 9. Annual Variation in Bicarbonate (——) and Carbonate (•——). LM = Little Muddy Pond, BM = Big Muddy Pond, LC = Little Clear Pond, BC = Big Clear Pond.

## Dissolved Mineral Concentration

Water from each pond was tested for nitrogen and phosphorus in August (Table III). The clear ponds contained lowest concentrations of total phosphorus, possibly because of greater use and precipitation of this nutrient by aquatic macrophytes. Little Muddy Pond and Big Clear Pond contained higher concentrations of total nitrogen than Little Clear Pond or Big Muddy Pond.

An analysis in February indicated low amounts of nitrate and ortho-phosphate. The sulphate content of all ponds was high. Magnesium was more abundant in the clear ponds and the ratio of magnesium to calcium was greater in the clear ponds also.

## Solids and Turbidity

Mean annual total solids was greatest in Little Muddy Pond, intermediate in Big Clear Pond, and least in Big Muddy Pond and Little Clear Pond (Table IV). Little Muddy Pond contained more suspended than dissolved solids; the reverse was true of the other ponds. Mean annual suspended solids were higher in the turbid ponds than in the clear ponds. Total dissolved solids was highest in Big Clear Pond.

Mean total dissolved solids were directly related to mean conductivity (Fig. 10). The inverse relationship between mean total organic solids and mean turbidity is shown in Fig. 11. Higher total organic solids in the clear ponds probably resulted from greater primary productivity by algae and macrophytes. Organic solids may have been produced not only from the decay of the plants, but also from the organic material which aquatic plants normally release (Fogg, 1965).

TABLE III

CHEMICAL ANALYSIS OF POND WATER

| Pond | pH | Total Nitrogen (ppm) | Total Phosphate (ppm) |
|---|---|---|---|
| August 10, 1965* | | | |
| Little Muddy | 8.3 | 4.00 | 2.8 |
| Big Muddy | 8.3 | 1.25 | 3.6 |
| Little Clear | 8.5 | 1.75 | 0.66 |
| Big Clear | 9.8 | 4.50 | 1.72 |

| Pond | Ca Hardness as $CaCO_3$ (ppm) | Mg Hardness as $CaCO_3$ (ppm) | Sulfate as $NaSO_4$ (ppm) | Ortho-P as $PO_4$ (ppm) | Total Iron (ppm) | Nitrate as $NO_3^{--}$ (ppm) |
|---|---|---|---|---|---|---|
| February 15, 1965+ | | | | | | |
| Little Muddy | 48.0 | 28.0 | 36.0 | 0.0 | 0.3 | 2.0 |
| Big Muddy | 72.0 | 40.0 | 57.0 | 0.0 | 0.1 | 0.0 |
| Little Clear | 63.0 | 45.0 | 45.0 | 0.0 | 0.0 | 0.0 |
| Big Clear | 56.0 | 62.0 | 45.0 | 0.1 | 0.1 | 0.0 |

*Analysis by Dr. V. G. Heller of the Oklahoma State University Chemistry Department
+Analysis by Commercial Chemical Laboratory

TABLE IV

MEAN ANNUAL SOLIDS, TURBIDITY AND SECCHI DISK READINGS

| Pond | TS (ppm) | TDS (ppm) | TSS (ppm) | TOS (ppm) | DOS (ppm) | SOS (ppm) | TIS (ppm) | DIS (ppm) | SIS (ppm) | TU | SDR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Little Muddy | 413 | 166 | 246 | 46 | 40 | 15 | 360 | 126 | 230 | 263 | 12.7 |
| Big Muddy | 274 | 230 | 43 | 62 | 58 | 35 | 212 | 189 | 51 | 116 | 14.2 |
| Little Clear | 263 | 231 | 36 | 71 | 65 | 10 | 214 | 183 | 36 | 21 | 120.4 |
| Big Clear | 386 | 394 | 27 | 71 | 64 | 15 | 315 | 292 | 70 | 23 | 115.3 |

Legend:
TS = Total solids
TDS = Total dissolved solids
TSS = Total suspended solids
TOS = Total organic solids
DOS = Dissolved organic solids
SOS = Suspended organic solids
TIS = Total inorganic solids
DIS = Dissolved inorganic solids
SIS = Suspended inorganic solids
TU = Turbidity units
SDR = Secchi disk readings

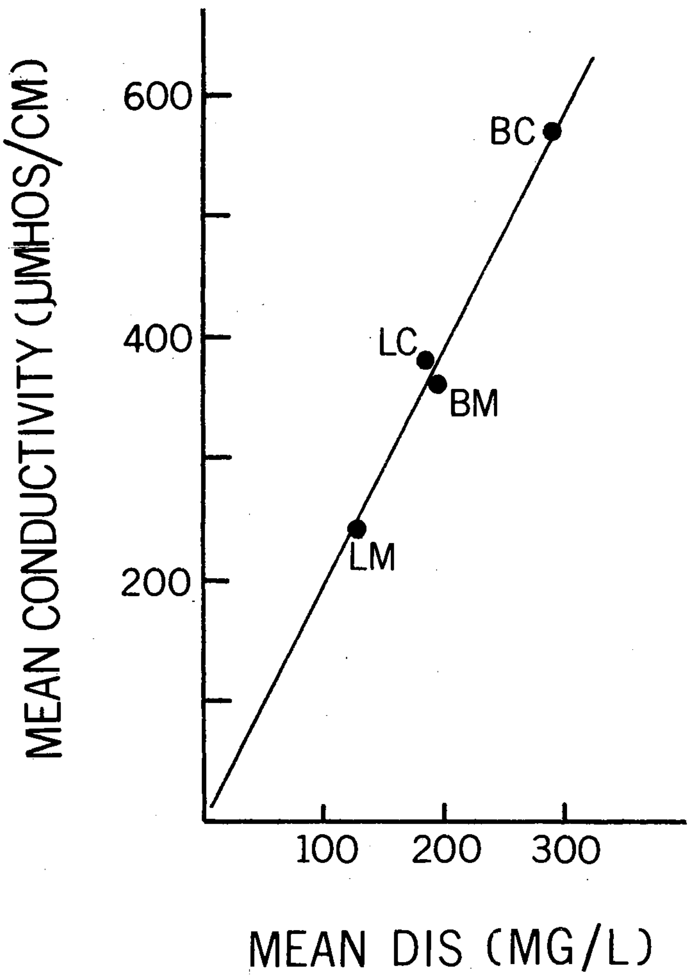


Figure 10. Comparison of Mean Dissolved Inorganic Solids with Mean Conductivity.
LM = Little Muddy Pond
BM = Big Muddy Pond
LC = Little Clear Pond
BC = Big Clear Pond

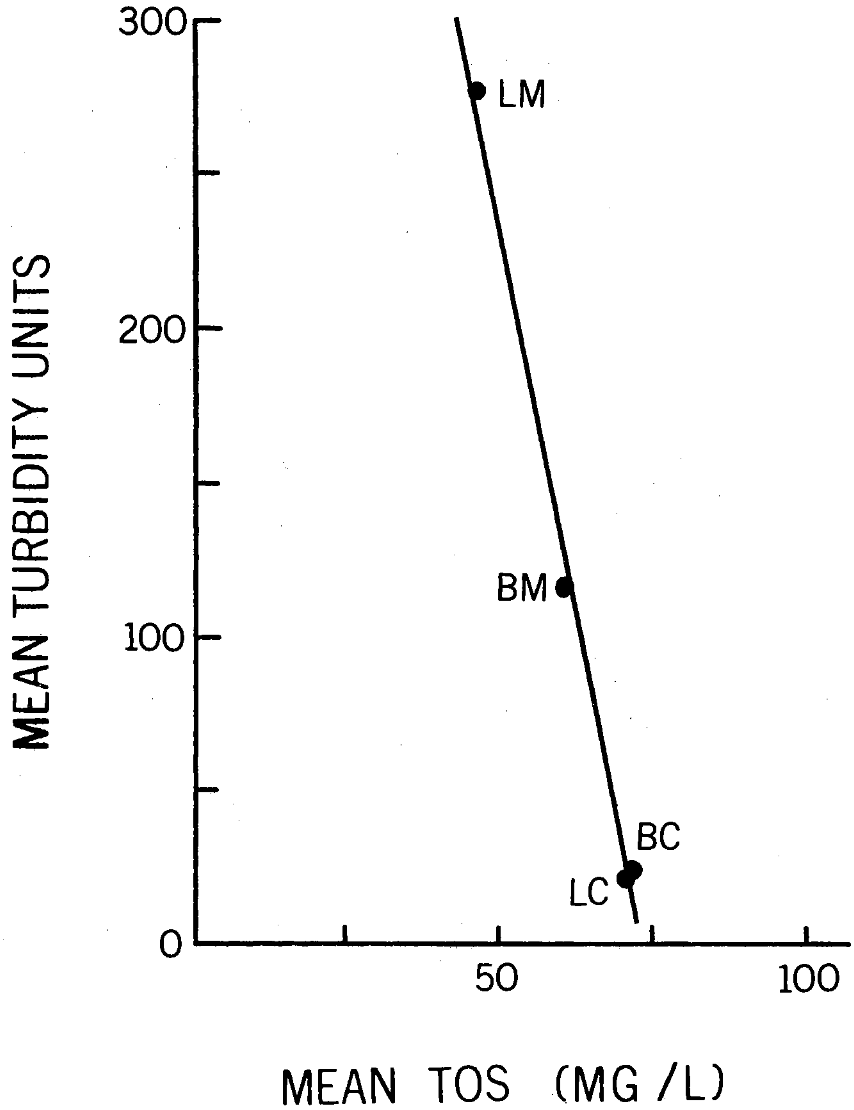


Figure 11. Comparison of Mean Turbidity with Mean Total Organic Solids. LM = Little Muddy Pond, BM = Big Muddy Pond, LC = Little Clear Pond, BC = Big Clear Pond.

Dissolved organic solids were present in greater concentrations in the clear ponds. Higher dissolved organic solids content in the more alkaline clear ponds is in agreement with Tucker (1958).

Average turbidity and Secchi disk readings are shown in Table IV. The annual changes in turbidity are shown as per cent light transmission (Fig. 12). Transparency remained high in the clear ponds except for a small decrease during February in Big Clear Pond. Little Muddy Pond was turbid except for a marked decrease in late summer. In Big Muddy Pond transparency increased generally through the fall and winter months and decreased in early summer. Transparency increased in the late summer.

Turbidity appeared to be reduced by conductivity (Fig. 13). The effective line indicates the maximum turbidity in a pond when the conductivity is known. The effective line was simply drawn to point out this relationship. The correlation coefficient of conductivity with per cent light transmission was 0.72 which was significantly different from zero at the 95% level of confidence.

Since conductivity is a measure of all ions and since the turbid particles are precipitated by cations only (Irwin and Stevenson, 1951), conductivity probably is related only because cations increase and decrease in the same general proportion as all ions. Since conductivity is related to dilution and concentration, turbidity should be reduced by concentration of the water due to evaporation and be increased by loss of electrolytes due to overflow. The clear ponds had overflowed few times in the past 10 years.

The effects of conductivity upon turbidity can be explained because turbid particles are in a stable colloidal dispersion

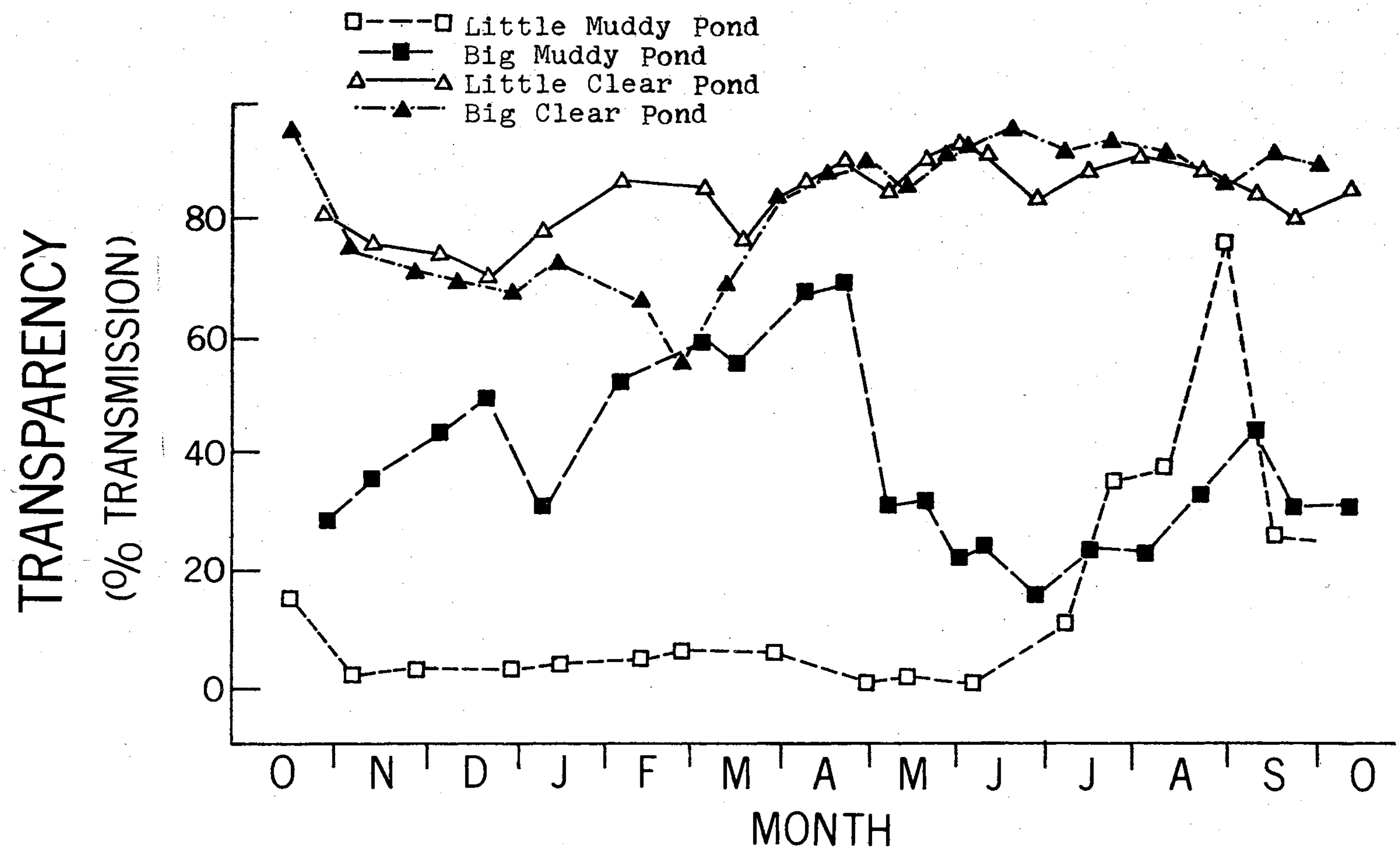


Figure 12. Annual Variation in Light Transmission.

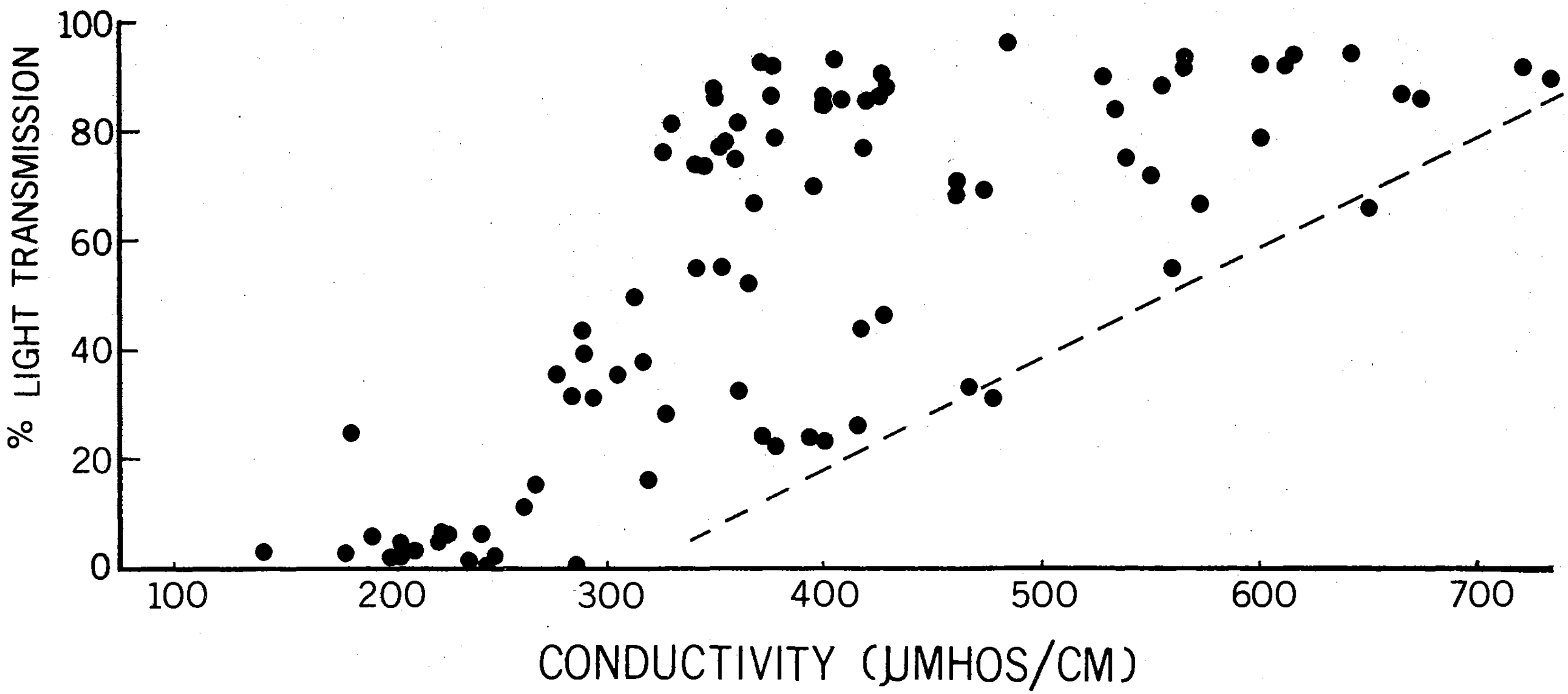


Figure 13. Comparison of Conductivity with Light Transmission.

· one sample
-- effective line (level of conductivity sufficient to cause per cent transmission to remain above this line).

(Sawyer, 1960). Stability of turbid particles depends upon the electrical charge which they possess. This charge is gained by the adsorption of ions from the surrounding medium which form a close layer around the particle. Ions of opposite charge are arranged diffusely around the inner layer. The magnitude of the charge is known as the Zeta Potential. The Zeta Potential acts as a repelling force in opposition to the interparticle attractive Van der Waals force. If the Zeta Potential is stronger than the Van der Waals force, the particles remain as a hydrophilic colloid. If the Zeta Potential is reduced, the particles will coalesce and precipitate.

The Zeta Potential may be reduced by addition of electrolytes which act in two ways. Monovalent ions reduce the thickness of the zone of influence. Multivalent cations enter the zone of influence and neutralize the charge of the colloid.

Irwin and Stevenson (1951) reported bacterial respiration of organic matter produced carbonic acid and hydrogen ions from the carbonic acid caused turbid particles to flocculate. The hydrogen ions acted by reducing the zone of influence and the Zeta Potential. It has been demonstrated that acidity precipitates turbid particles but the ponds in this study were alkaline throughout the year and it seems doubtful that pH was ever low enough to clear these ponds. In a laboratory experiment, passing pure $CO_2$ through muddy water did not clarify it even though the pH was reduced from 7.6 to 5.3 and the water was left undistrubed for 48 hours.

Reduction of turbidity by multivalent cations has been described by Keeton (1959), Mathis (1965), and Harrel and Dorris (1968). In these cases, turbidity appeared to be reduced as the conductivity increased. Data from the ponds do not agree entirely with this proposed mechanism. If conductivity alone was the critical factor, Little Clear Pond and Big Muddy Pond should have been similar in turbidity, since their conductivities were similar. Some other mechanism dependent upon pH and photosynthesis appears to be involved.

Turbidity was inversely related to pH, since a progressive decrease in turbidity occurred at increasing pH levels (Fig. 14). The correlation of pH with light transmission was 0.62 which was significantly different from zero at the 95% confidence level. Turbid particles were flocculated at high pH levels in laboratory experiments (Fig. 15). Water from Little Muddy Pond was divided into equal portions. Each portion was adjusted to a predetermined pH and allowed to stand for 24 hours. The turbidity was then measured as percent light transmission.

The effect of increased pH may be explained by the action of hydroxides of multivalent cations upon the negatively-charged turbid particles. Although cations can combine directly with turbid particles to reduce the Zeta Potential, the cations probably are added slowly in nature and are more likely to combine with hydroxyl ions to form a hydroxide.

$$Fe^{3+} + 3\ OH^{-} \longrightarrow Fe\ (OH)_3$$

This hydroxide is colloidal and adsorbs cations to form a positively charged sol, which neutralizes the charge on negative colloids, such as turbid particles, permitting them to agglomerate. The hydroxide sol itself is neutralized and precipitated by sulfate ions and other negative ions. While precipitating, the hydroxide sol may collect and remove more turbid particles.

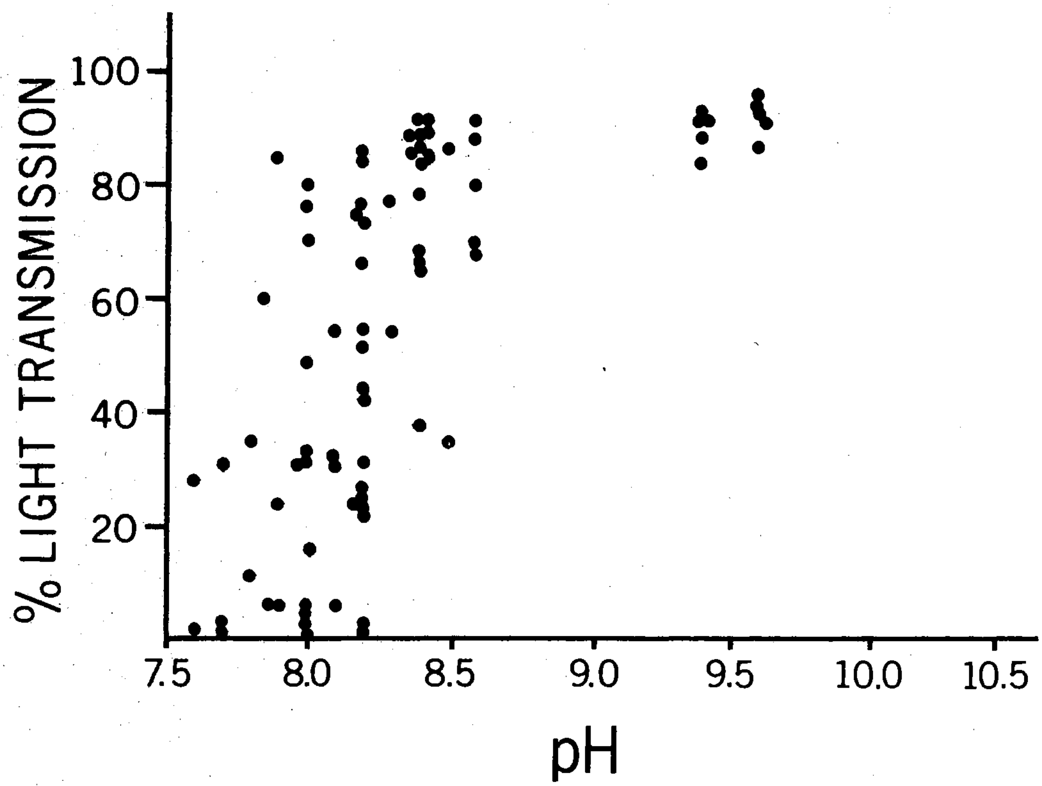


Figure 14. Comparison of pH with Light Transmission.

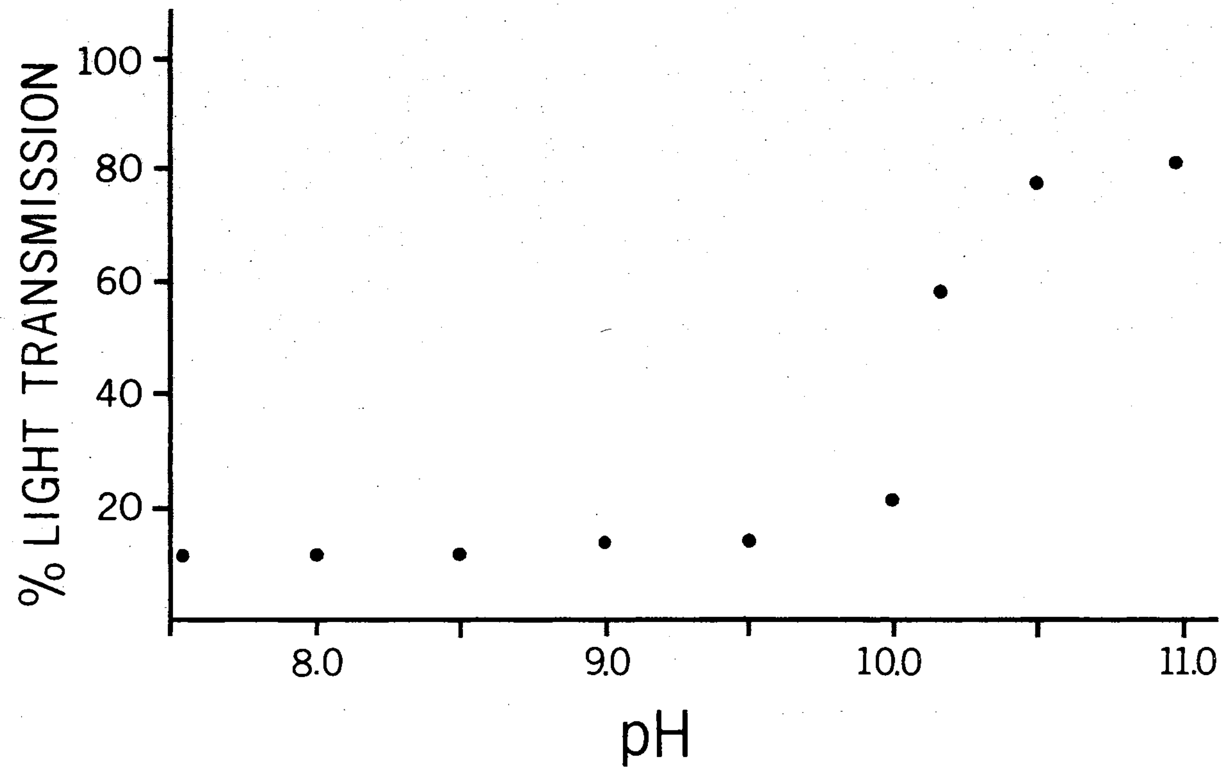


Figure 15. Light Transmission After Adjustment in pH.

Since hydroxyl ions are produced abundantly by the photosynthetic uptake of bicarbonate, this process may be instrumental in precipitating turbid particles. Laboratory experiments with turbid water indicated that formation of magnesium, manganese, cupric, and ferric hydroxide caused rapid agglomeration. The effects of high pH and hydroxide are confirmed by the seasonal changes in turbidity. Transparency increased sharply in Little Muddy Pond during July and August when carbonate was present and pH was above normal. Big Muddy Pond cleared to a lesser extent during August when carbonate was present.

During the fall of 1966, Big Muddy Pond became as clear as the clear ponds. An analysis of the major ions in the ponds was made at this time to check for changes in water chemistry (Table V). Presence of carbonate and a pH of 8.2 indicated that Big Muddy Pond may have been cleared by hydroxides produced by photosynthesis. *Chara* sp. was growing in the shallow margins of Big Muddy Pond and may have been responsible for clearing the water.

Turbidity retards the growth of aquatic macrophytes. Thus, no hydroxyl ions are produced by photosynthesis and the turbid particles are not agglomerated by insoluble hydroxides. Initial turbidity would seem to depend upon the amount of clay entering the pond, pH, organic matter, and available cations.

Three mechanisms exist for precipitating turbid particles in Oklahoma ponds. One method involves flocculation by hydrogen ions and organic materials (Irwin and Stevenson, 1951). Another method is the salting out process described by Keeton (1959) and Mathis (1965). These mechanisms operate on the principle of disturbing the ionic repulsive charges on the clay particles by addition of cations. The

TABLE V

CHEMICAL ANALYSES OF POND WATER SAMPLED DURING PERIOD OF LOW TURBIDITY IN BIG MUDDY POND*

| Pond | Chloride (ppm) | Sulfate (ppm) | Carbonate (ppm) | Bicarbonate (ppm) | Nitrate (ppm) |
|---|---|---|---|---|---|
| Little Muddy | 35.70 | 44.00 | 0.00 | 298.00 | 0.84 |
| Big Muddy | 53.60 | 30.00 | 7.45 | 179.30 | 0.16 |
| Little Clear | 35.70 | 30.00 | 0.00 | 239.10 | 0.24 |
| Big Clear | 89.30 | 10.00 | 14.70 | 388.60 | 0.56 |
| **Pond** | **Calcium (ppm)** | **Magnesium (ppm)** | **Sodium (ppm)** | **Iron (ppm)** | |
| Little Muddy | 23.00 | 8.00 | 14.50 | 4.50 | |
| Big Muddy | 29.00 | 17.00 | 20.00 | 0.50 | |
| Little Clear | 25.00 | 15.00 | 51.00 | 0.50 | |
| Big Clear | 16.00 | 21.00 | 130.00 | 0.50 | |

*Analysis by Soils Laboratory, Oklahoma State University third method is the formation of insoluble hydroxides and carbonates which appeared to operate in the present study and presumes an accessory "scavenging" action by insoluble hydroxides of multivalent cations which are produced in quantity by bicarbonate-consuming photosynthesis.

CHAPTER V

# COMMUNITY STRUCTURE OF PHYTOPLANKTON

## Numbers of Individuals and Species

Annual fluctuation of total numbers of phytoplankton, exclusive of microcells, is illustrated in Figures 16-19. The classical bimodal model of phytoplankton with spring and fall maxima was modified. The variance from the bimodal pattern may have been caused by sampling of nannoplankton as well as net plankton. Patten, Mulford, and Warinner (1963) have shown that the annual cycle of total phytoplankton abundance is quite different from the classical bimodal pattern described for net plankton forms. Large numbers were observed in fall, midwinter, and midsummer. The fall maxima probably were due to enrichment caused by runoff water. The algae responsible for these blooms were blue-green algae, including *Microcystis*, *Aphanizomenon*, and *Raphidiopsis*.

A sharp decrease occurred in December during and after the time ponds were covered with ice. Whether the populations were actually reduced or whether they sank to the bottom in the absence of the usual turbulence was not determined.

Later, diatoms and blue-green algae increased following a rapid drop in temperature. This increase may have been due to recirculation of nutrients from lower levels of the ponds. Planktonic algae

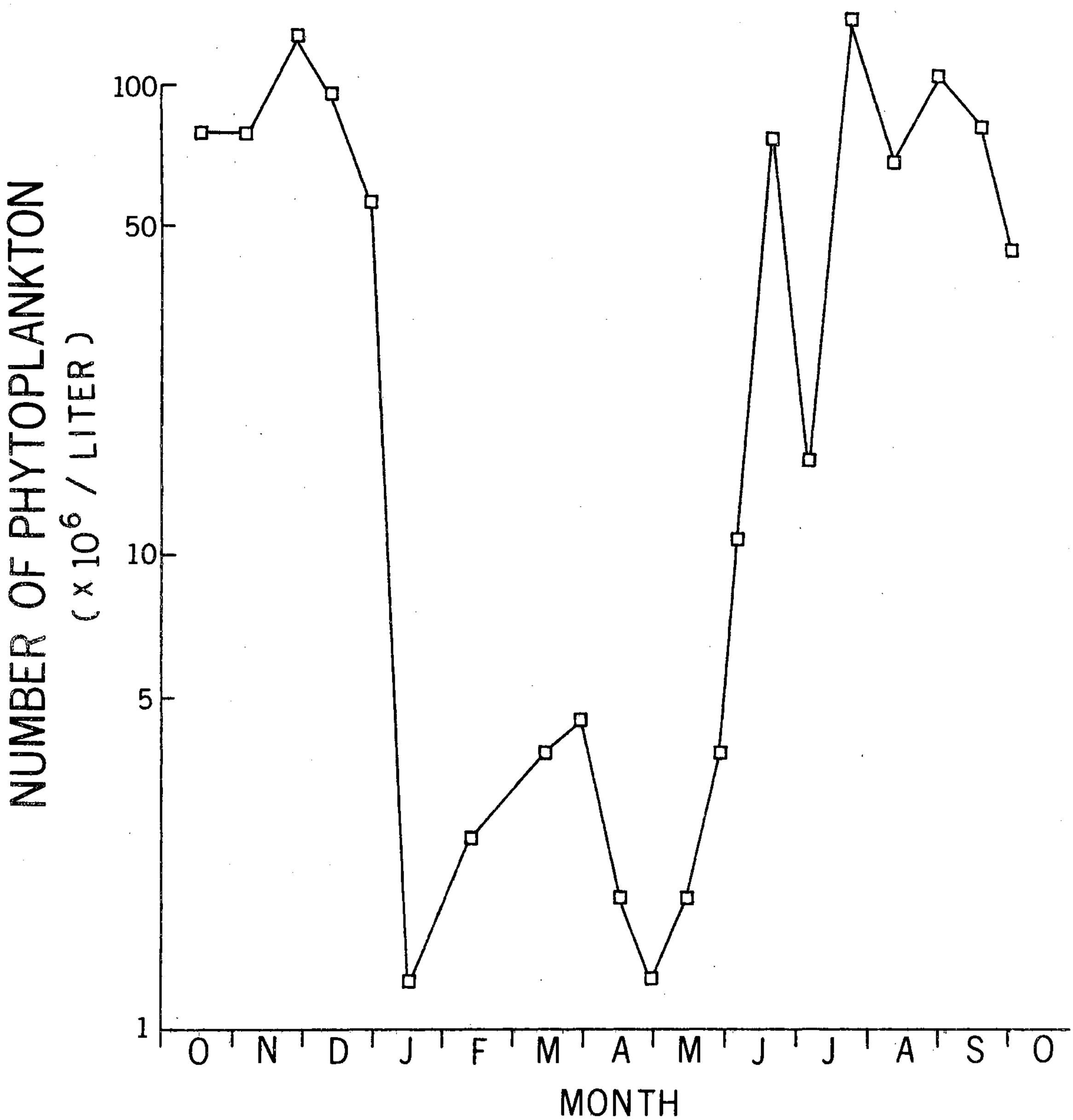


Figure 16. Annual Variation of Total Numbers of Phytoplankton in Little Muddy Pond.

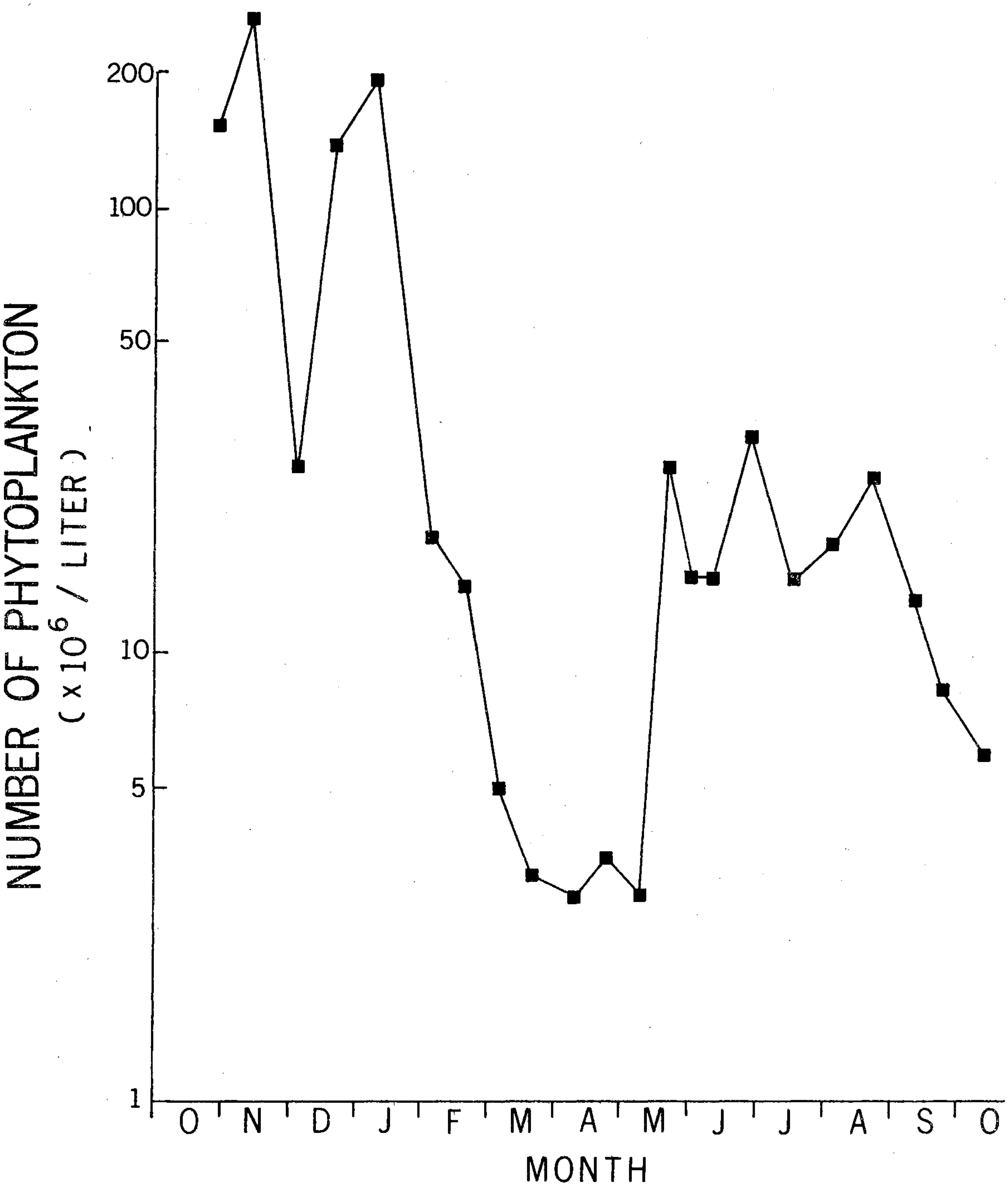


Figure 17. Annual Variation of Total Numbers of Phytoplankton in Big Muddy Pond.

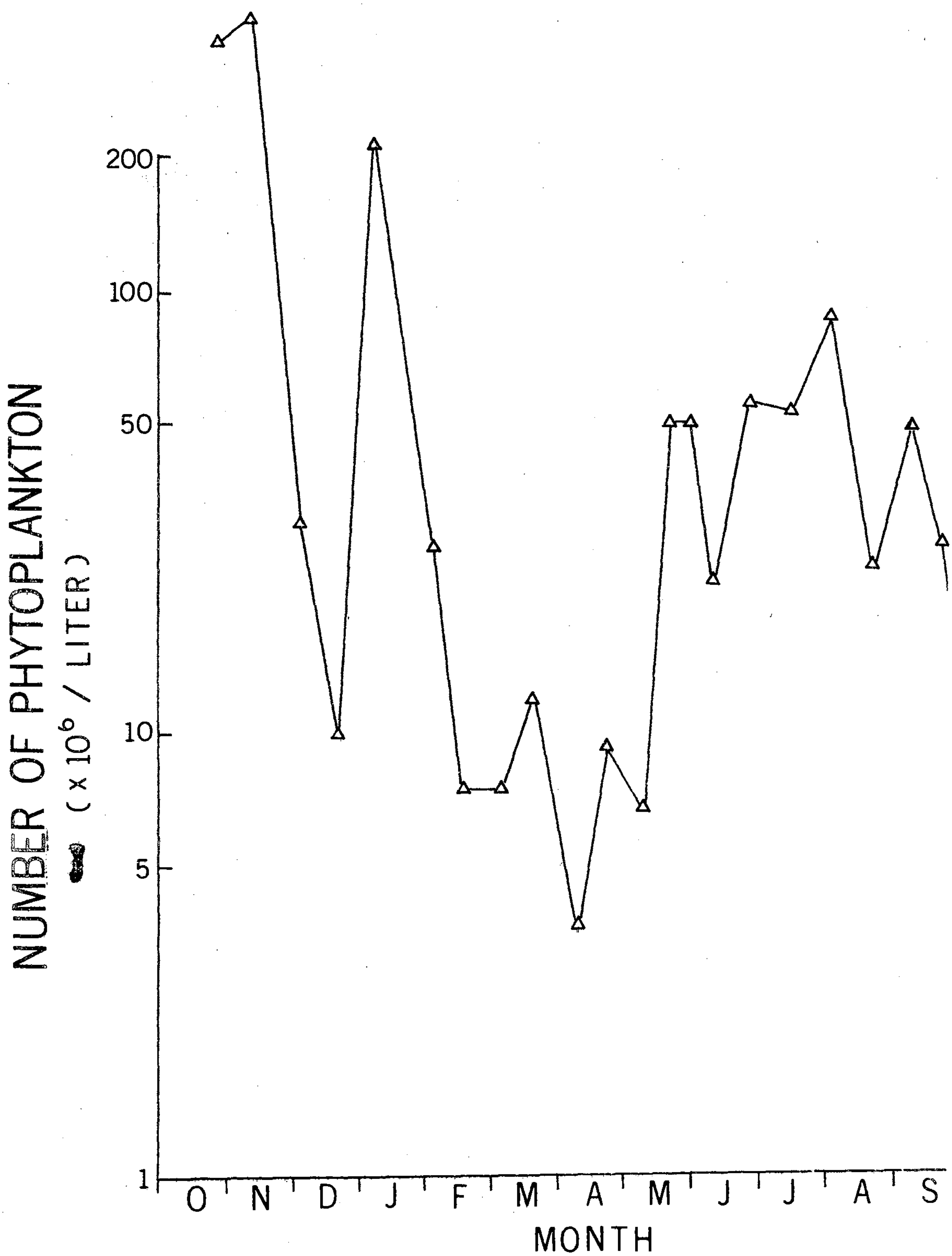


Figure 18. Annual Variation of Total Numbers of Phytoplankton in Little Clear Pond.

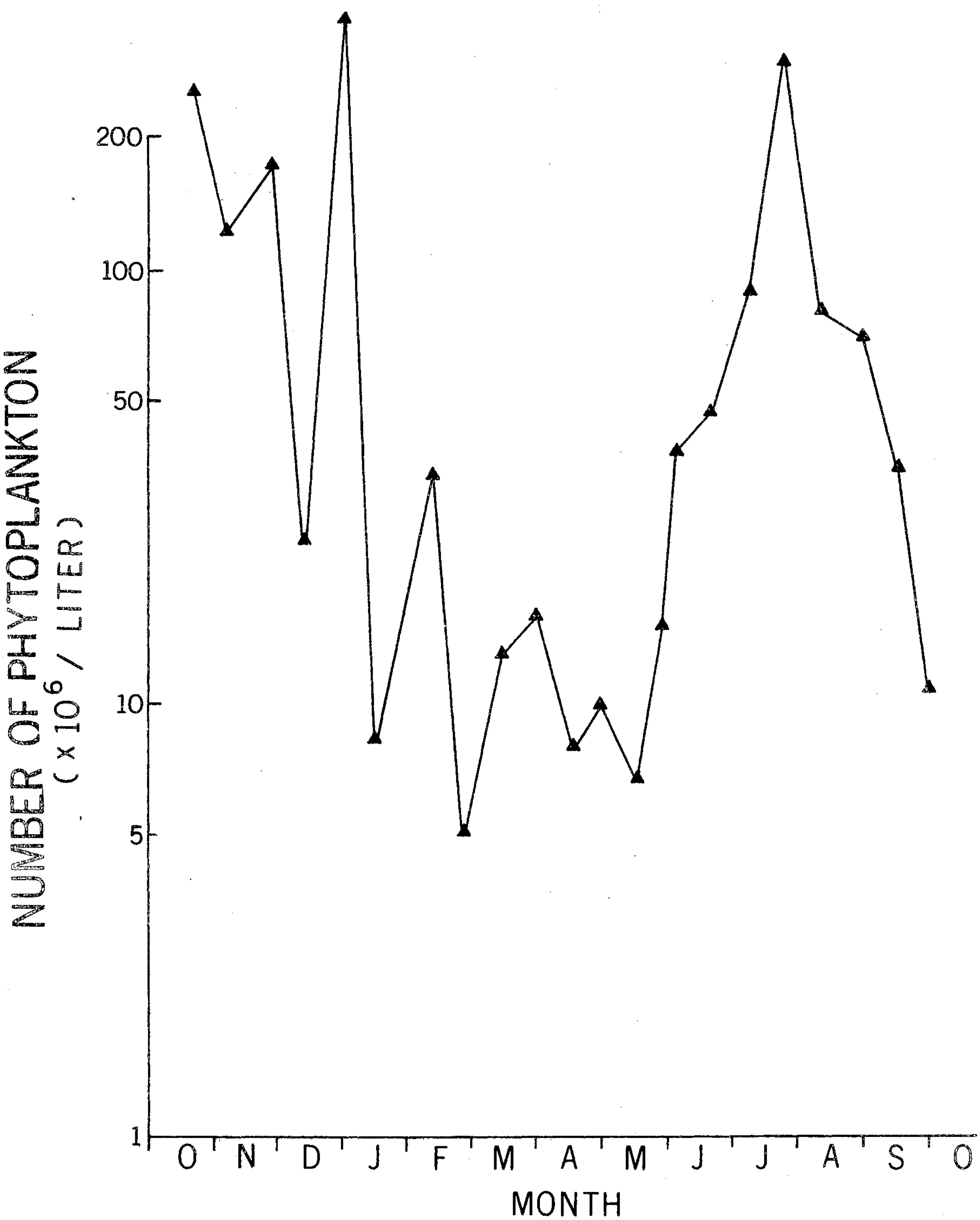


Figure 19. Annual Variation of Total Numbers of Phytoplankton in Big Clear Pond.

decreased when ice again covered the ponds in February. Diatoms and blue-green algae remained dominant until the green algae and euglenoids appeared in April. The latter increased during May and June.

On 23 July Lobomonas, Chlamydomonas, and Euglena bloomed in Little Muddy Pond. On the same date, Big Clear Pond had a peak due to an increase in Scenedesmus, Oocystis, Cosmarium, and a variety of other species. This summer increase was possibly a result of enrichment from runoff.

Total numbers of phytoplankton were related to temperature in that the numbers decreased in the fall as the temperature decreased to a minimum. As the temperature increased in the spring, the phytoplankton numbers increased generally to the point of maximum temperature after which they decreased.

Reduced numbers of phytoplankton in April may be related to lack of nutrients due to little runoff water evidenced by declining water levels. A decrease in Little Muddy Pond on 5 July may be due to disturbance and dilution by rains.

Annual means of total numbers of phytoplankton from clear ponds were higher than from turbid ponds (Table VI). Differences between means of the turbid and clear ponds were significant at the 95% level of confidence.

A total of 124 species were collected during the study (Table VII). Nearly half the species belonged to Chlorophyta. Phytoplankton species were more numerous in the clear ponds than in the turbid ponds, but Little Clear Pond and Big Muddy Pond were similar (Table VI). Correlation of phytoplankton numbers with percent transmission of light was not significant at the 95% confidence level ($r = 0.10$).

TABLE VI

MEAN ANNUAL NUMBERS AND TOTAL SPECIES OF PHYTOPLANKTON

| | (Individuals/ml) | | | | | |
|---|---|---|---|---|---|---|
| Pond | Total | Myxophyta | Chrysophyta | Euglenophyta | Pyrrophyta | Chlorophyta |
| | | Mean Annual Numbers in Each Botanical Division | | | | |
| Little Muddy | 45,359 | 27,298 | 1,052 | 8,417 | 204 | 8,388 |
| Big Muddy | 44,673 | 24,331 | 6,517 | 2,017 | 117 | 11,691 |
| Little Clear | 71,138 | 40,260 | 1,914 | 6,430 | 789 | 21,745 |
| Big Clear | 77,297 | 49,268 | 1,731 | 1,300 | 248 | 24,390 |
| | | Total Numbers of Species in Each Botanical Division | | | | |
| Little Muddy | 43 | 9 | 16 | 6 | 1 | 11 |
| Big Muddy | 63 | 16 | 19 | 4 | 1 | 23 |
| Little Clear | 65 | 17 | 15 | 4 | 3 | 26 |
| Big Clear | 72 | 17 | 13 | 4 | 1 | 37 |

## TABLE VII

## PHYTOPLANKTON SPECIES

**Cyanophyta**

*Anabaena variabilis* Kuetzing
*Anacystis marginata* Meneghini
*Anacystis penicystis* (Kuetzing) Drouet & Daily
*Aphanizomenon flos-aquae* (L.) Ralfs
*Aphanocapsa* sp.
*Chroococcus limneticus* Lemmermann
*Chroococcus rufescens* (Kuetzing) Naegeli
*Gleocystis planktonica* (W. & G. West) Lemmermann
*Gomphosphaeria aponina* Kuetzing
*Merismopedia convoluta* Brebisson
*Microcystis aeruginosa* Kuetzing
*Microcystis incerta* Lemmermann
*Nostoc* sp.
*Oscillatoria curviceps* C. A. Agardh
*Phormidium retzii* (C. A. Agardh) Gomont
*Phormidium tenue* (Meneghini) Gomont
*Plectonema nostocorum* Bornet
*Pleurocapsa varia* (Braun) Drouet & Daily
*Raphidiopsis curvata* Fritsch
*Spirulina major* Kuetzing
*Synechocystis aquatilis* Sauv.

**Chrysophyta**

*Amphora* sp.
*Cocconeis* sp.
*Cyclotella* sp.
*Cymbella cistula* (Hemprich) Grunow
*Cymbella prostrata* (Berkeley) Cleve
*Diatoma vulgare* Bory
*Epithemia argus* (Ehrenberg) Kuetzing
*Fragilaria capucina* Desmazieres
*Fragilaria crotonensis* Kitton
*Frustulia vulgaris* (Thwaites) De Toni
*Gyrosigma* sp.
*Melosira distans* (Ehrenberg) Kuetzing
*Melosira juergensii* C. A. Agardh
*Navicula exigua* (Gregory) Mueller
*Navicula gastrum* Ehrenberg
*Navicula oblonga* Kuetzing
*Navicula radiosa* Kuetzing
*Navicula rhyncocephala* Kuetzing
*Navicula viridula* Kuetzing
*Nitzschia acicularis* (Kuetzing) Wm. Smith
*Nitzschia palea* (Kuetzing) Wm. Smith
*Nitzschia vermicellaris* (Kuetzing) Hantzsch
*Pinnularia globiceps* Gregory
*Pinnularia parva* Gregory
*Pleurosigma angulatum* (Quekett) Wm. Smith

TABLE VII (continued)

Chrysophyta

*Rhizosolenia eriensis* H. L. Smith
*Rhizosolenia longiseta* Zachary
*Stauroneis anceps* Ehrenberg
*Stauroneis phoenicentron* (Nitzsch) Ehrenberg
*Stauroneis producta* Grunow
*Stephanodiscus* sp.
*Surirella didyma* Kuetzing
*Surirella linearis* Wm. Smith
*Surirella ovalis* Breb.
*Synedra acus* Kuetzing
*Synedra dorsiventralis* Mueller
*Synedra rumpens* Kuetzing
*Synedra ulna* (Nitzsch) Ehrenberg
*Tabellaria* sp.

Chlorophyta

*Ankistrodesmus* sp.
*Asterococcus limneticus* G. M. Smith
*Carteria* sp.
*Chlamydomonas* sp.
*Chlorella* sp.
*Chlorococcum humicola* (Naegeli) Rabenhorst
*Closterium lunula* (Mueller) Nitzsch
*Closterium moniliferum* (Bory) Ehrenberg
*Closterium turgidum* Ehrenberg
*Closterium venus* Kuetzing

Euglenophyta

*Euglena gracilis* Klebs
*Euglena oxyuris* Schmarda
*Euglena viridis* Ehrenberg
*Trachelomonas hispida* (Perty) Stein
*Trachelomonas schauinslandii* Lemmermann
*Trachelomonas similis* Stokes
*Trachelomonas volvocina* Ehrenberg

Pyrrophyta

*Ceratium hirundinella* (O. F. Mueller) Dujardin
*Glenodinium cinctum* Ehrenberg
*Peridinium bipes* Stein
*Peridinium pusillum* (Penard) Lemmermann
*Phacus* sp.

Chlorophyta

*Coelastrum reticulatum* (Dang.) Senn
*Coelosphaerium* sp.
*Cosmarium formosulum* Hoffman
*Cosmarium granatum* Brebisson
*Cosmarium polygonum* (Naegeli) Archer
*Cosmarium punctulatum* Brebisson
*Cosmarium sexangulare* Lundell
*Cosmarium subcostatum* Nordstedt
*Cosmarium supraspeciosum* Wolle
*Cosmarium triplicatum* Wolle

TABLE VII (continued)

Chlorophyta

*Crucigenia apiculata* (Lemmermann) Schmidle
*Euastrum pulchellum* Brebisson
*Gonium pectorale* Mueller
*Hematococcus lacustris* (Girod) Rostaf
*Hormidium* sp.
*Kirchneriella lunaris* (Kirch.) Moebius
*Kirchneriella obesa* (W. West) Schmidle
*Lobomonas* sp.
*Microspora* sp.
*Oedogonium* sp.
*Oocystis borgei* Snow
*Oocystis gigas* Archer
*Oocystis naegeli* A. Braun
*Pandorina morum* (Mueller) Bory
*Phacotus* sp.
*Protococcus viridis* C. A. Agardh

Chlorophyta

*Scenedesmus acutiformis* Schroeder
*Scenedesmus arcuatus* Lemmermann
*Scenedesmus bijuga* (Turp.) Lagerheim
*Scenedesmus quadricauda* (Turp.) Brebisson
*Schroederia setigera* (Schroeder) Lemmermann
*Selenastrum* sp.
*Sphaerocystis schroeteri* Chodat
*Spirogyra* sp.
*Staurastrum cuspidatum* Brebisson
*Staurastrum oxycanthum* Archer
*Staurastrum polymorphum* Brebisson
*Volvox* sp.
*Wislouchiella* sp.
*Zygnema* sp.

Unidentified green filament
Unidentified green unicellular algae

## Numbers of Botanical Divisions

Annual means of number of individuals in the division Chrysophyta were highest in Big Muddy Pond. Euglenophyta and Pyrrophyta were similar in clear and turbid ponds (Table VI). The small ponds contained the most individuals of Euglenophyta. The clear ponds contained more individuals of Myxophyta and Chlorophyta. Mean number of Chlorophyta were proportional to mean percent transmission of light (Fig. 20). The reduction of Chlorophyta numbers was accompanied by a reduction of species of Chlorophyta in turbid ponds. Chlorophyta appeared to be most sensitive to turbidity.

## Species Diversity

Community diversity (d) in phytoplankton was 2-3 times higher in clear ponds than in the muddy ponds (Table VIII). Means between turbid and clear ponds were significantly different at the 95% confidence level. Since community diversity is correlated to numbers (Wilhm, 1967), higher values for the clear ponds are reasonable.

TABLE VIII

PHYTOPLANKTON COMMUNITY MEASUREMENTS

| Pond | Number of Species | Mean Annual d | Mean Annual $\bar{d}$ | Mean Annual r |
|---|---|---|---|---|
| Little Muddy | 43 | 46,332 | 1.29 | 0.46 |
| Big Muddy | 63 | 34,088 | 2.05 | 0.34 |
| Little Clear | 65 | 106,073 | 2.17 | 0.27 |
| Big Clear | 72 | 102,876 | 2.19 | 0.35 |

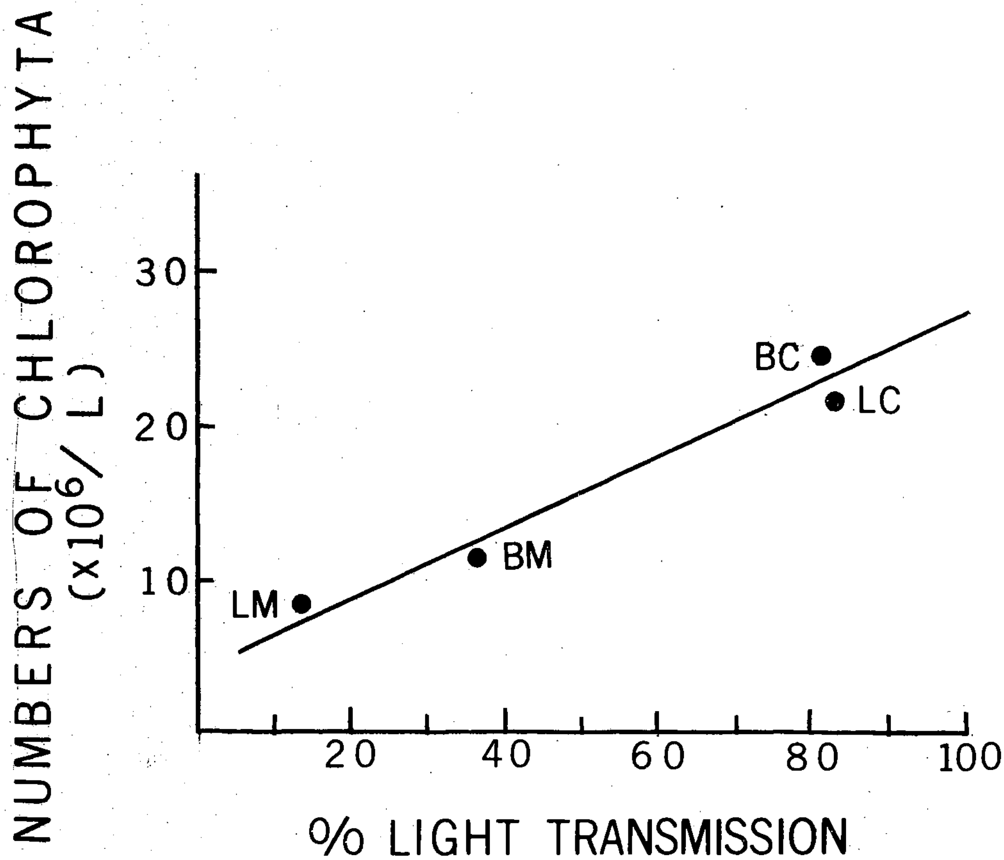


Figure 20. Comparison of Mean Annual Numbers of Chlorophyta with Mean Annual Light Transmission. LM = Little Muddy Pond, BM = Big Muddy Pond, LC = Little Clear Pond, BC = Big Clear Pond.

Phytoplankton diversity (d) in all ponds decreased in the fall, remained low during winter and early spring and increased to a high value in the summer. Diversity (d) in Big Muddy Pond was often higher when turbidity was high. The reverse was generally true in the other ponds. The relation of mean (d) to light transmission is shown in Fig. 21.

Redundancy (r) is a measure of the extent to which dominance is expressed by one or more species (Patten et al., 1963). Redundancy of phytoplankton in all ponds was lowest in spring but varied widely. A redundancy greater than 0.5 occurred in each turbid pond on five occasions and on only three occasions in each clear pond. The phytoplankton of the turbid ponds were more often comprised of large numbers of relatively few species.

Mean annual redundancy of phytoplankton is shown in Table VIII. Redundancy of the large ponds was similar, but redundancy in Little Muddy Pond exceeded that of Little Clear Pond.

Species diversity ($\bar{d}$) was generally higher during warm months in all ponds (Fig. 22). Phytoplankton $\bar{d}$ was higher in the clear ponds than in the muddy ponds (Table VIII). However, annual means of $\bar{d}$ in Big Muddy Pond and the clear ponds were not significantly different at the 95% confidence level. Annual means of Little Muddy Pond and the clear ponds were significantly different at the 95% level of confidence. Since Little Muddy Pond was more turbid than Big Muddy Pond, turbidity seemed to reduce phytoplankton $\bar{d}$ significantly only at higher levels.

However, mean diversity ($\bar{d}$) was related to turbidity and light (Table IX). The natural logarithm of the percent transmission of light was used since this more nearly describes the penetration of light

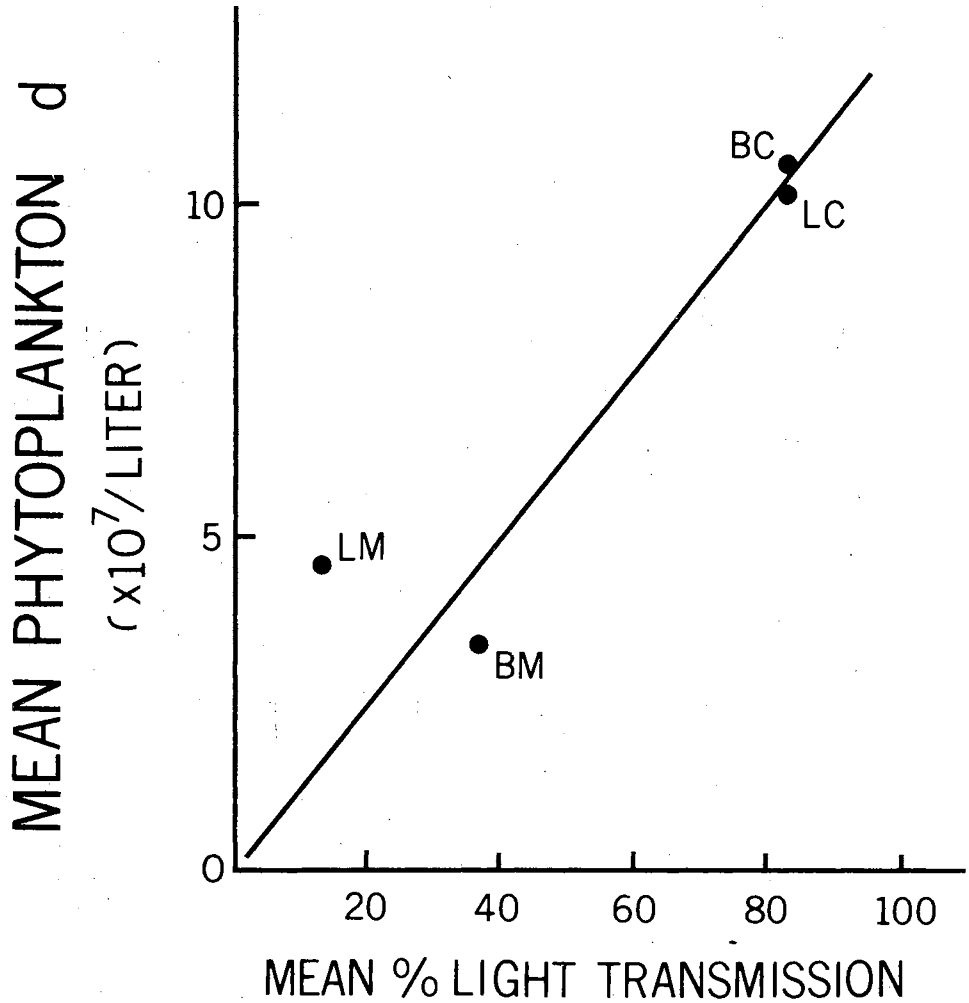


Figure 21. Comparison of Mean Annual Phytoplankton Diversity (d) with Mean Annual Light Transmission. LM = Little Muddy Pond, BM = Big Muddy Pond, LC = Little Clear Pond, BC = Big Clear Pond.

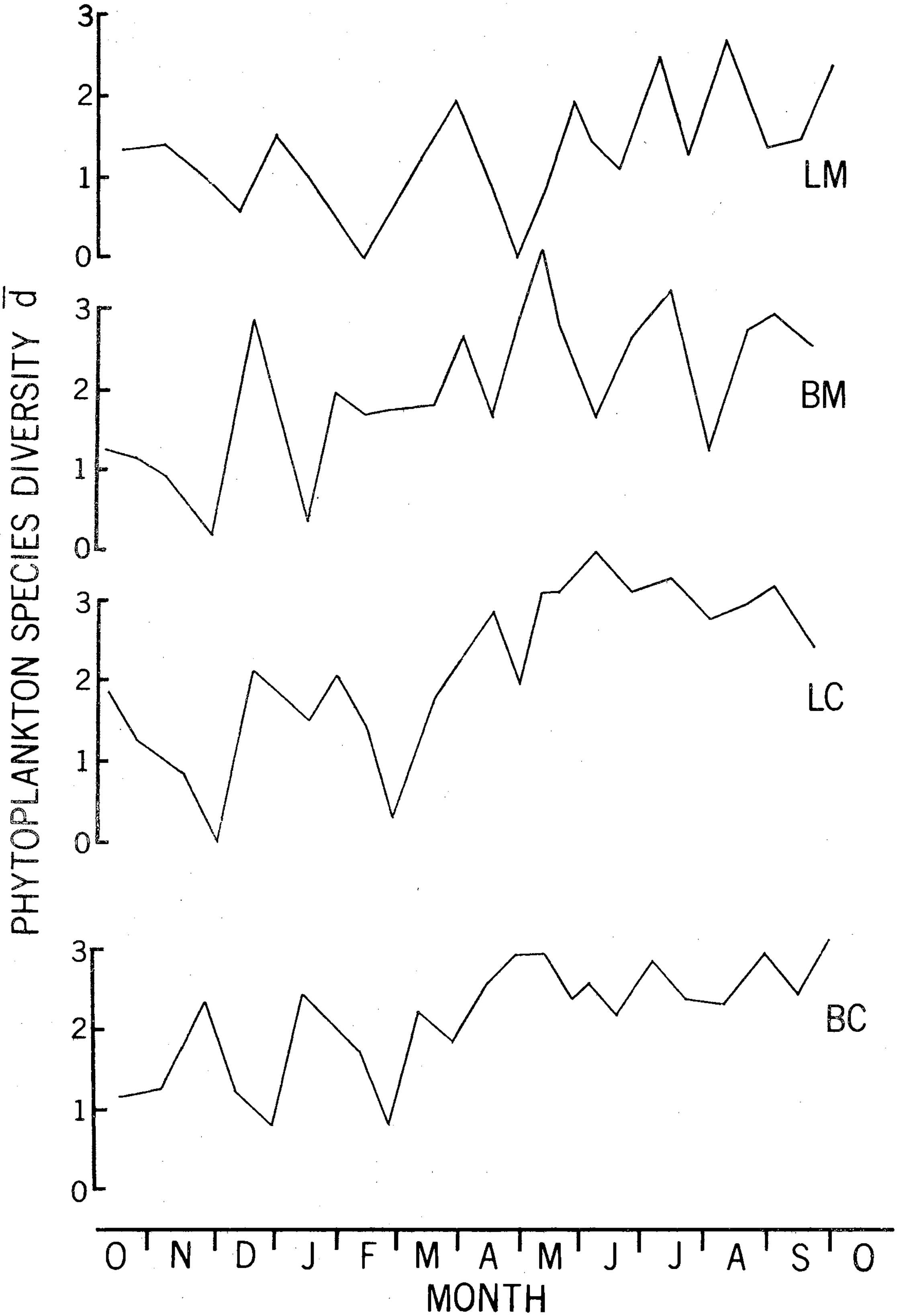


Figure 22. Annual Variation of Phytoplankton Species Diversity $\bar{d}$.
LM = Little Muddy Pond, BM = Big Muddy Pond,
LC = Little Clear Pond, BC = Big Clear Pond.

through water. Division of the second column values by two gives a quotient that is very similar to mean $\bar{d}$. This suggests that light limited community diversity.

TABLE IX

COMPARISON OF PHYTOPLANKTON SPECIES DIVERSITY AND LIGHT

| Pond | Mean Annual % Transmission of Light | $Log_e$ % Trans | Mean Annual Phytoplankton ($\bar{d}$) |
|---|---|---|---|
| Little Muddy | 13.0 | 2.56 | 1.29 |
| Big Muddy | 37.5 | 3.62 | 2.05 |
| Little Clear | 83.0 | 4.42 | 2.17 |
| Big Clear | 81.0 | 4.40 | 2.19 |

Low diversity can be explained by strong physicochemical limiting factors or intense interspecific competition reducing the diversity (Odum, 1959). Of special importance are the reductions in diversity indices following pollutional disturbances (Patrick, Hohn, and Wallace, 1954).

The factor or set of factors which increase diversity are not as apparent. MacArthur (1957) demonstrated that bird census data fit best a model in which the niches were contiguous and non-overlapping. Hairston (1959) showed that this indicated that food is the factor likely to qualify as something that cannot be shared, but is fully utilized. Engelman (1961) has shown that the best fit of this model is with energy units. The niche may thus be defined in terms of food or energy consumed. Connell and Orias (1964) proposed that the level of community diversity is determined by the amount of energy flowing through the food web.

The energy available to higher trophic levels under natural conditions is difficult to measure. It is possible to measure the energy of sunlight available to primary producers. The relation of species diversity of phytoplankton to light in this study adds support to the hypothesis that energy is a regulator of diversity.

The phytoplankton communities in the turbid ponds had fewer numbers of individuals, total species, and species of Chlorophyta. They were less diverse and had more instances of dominance by one or more species. All of these conditions indicate communities which were less stable than those found in the clear ponds.

From the ecological viewpoint, all measures showed the phytoplankton community structure to be inferior in the turbid ponds and indicated that inorganic turbidity reduced species diversity of phytoplankton communities. This implies a widespread effect by turbidity on aquatic ecosystems. Due to the ubiquity of inorganic suspended solids in ponds, lakes and streams, turbidity may be an important factor in the restriction of phytoplankton communities as well as the direct degradation of water quality.

# CHAPTER VI

## COMMUNITY STRUCTURE OF ZOOPLANKTON

### Numbers of Individuals and Species

Zooplankton numbers were generally high in the fall, but decreased rapidly in winter (Figs. 23-26). Low numbers were sampled in December and February when ice covered the ponds. Zooplankton populations were low in all ponds in March, but increased rapidly in April and then increased generally until fall.

Large pulses of Protozoa occurred in the turbid ponds, but Protozoa were rare in the clear ponds. The late summer pulse in Little Muddy Pond was due primarily to an increase in *Arcella*; the spring and fall pulses in Big Muddy Pond were due primarily to concentrations of *Difflugia*.

Rotifer populations were variable among ponds. The rotifer population in the Big Clear Pond remained low through the warm season. Little Clear Pond had the highest concentration in mid-summer with a maximum of 246 rotifers, mainly *Keratella cochlearis*. A pulse of *Filinia* and *Keratella* was exhibited in two August collections from Little Muddy Pond. Populations were minimal during the rest of the warm season. Big Muddy Pond exhibited a spring pulse, fairly high concentrations through the summer and a fall pulse at the end of the study. *Keratella* contributed heavily to all high densities of rotifers.

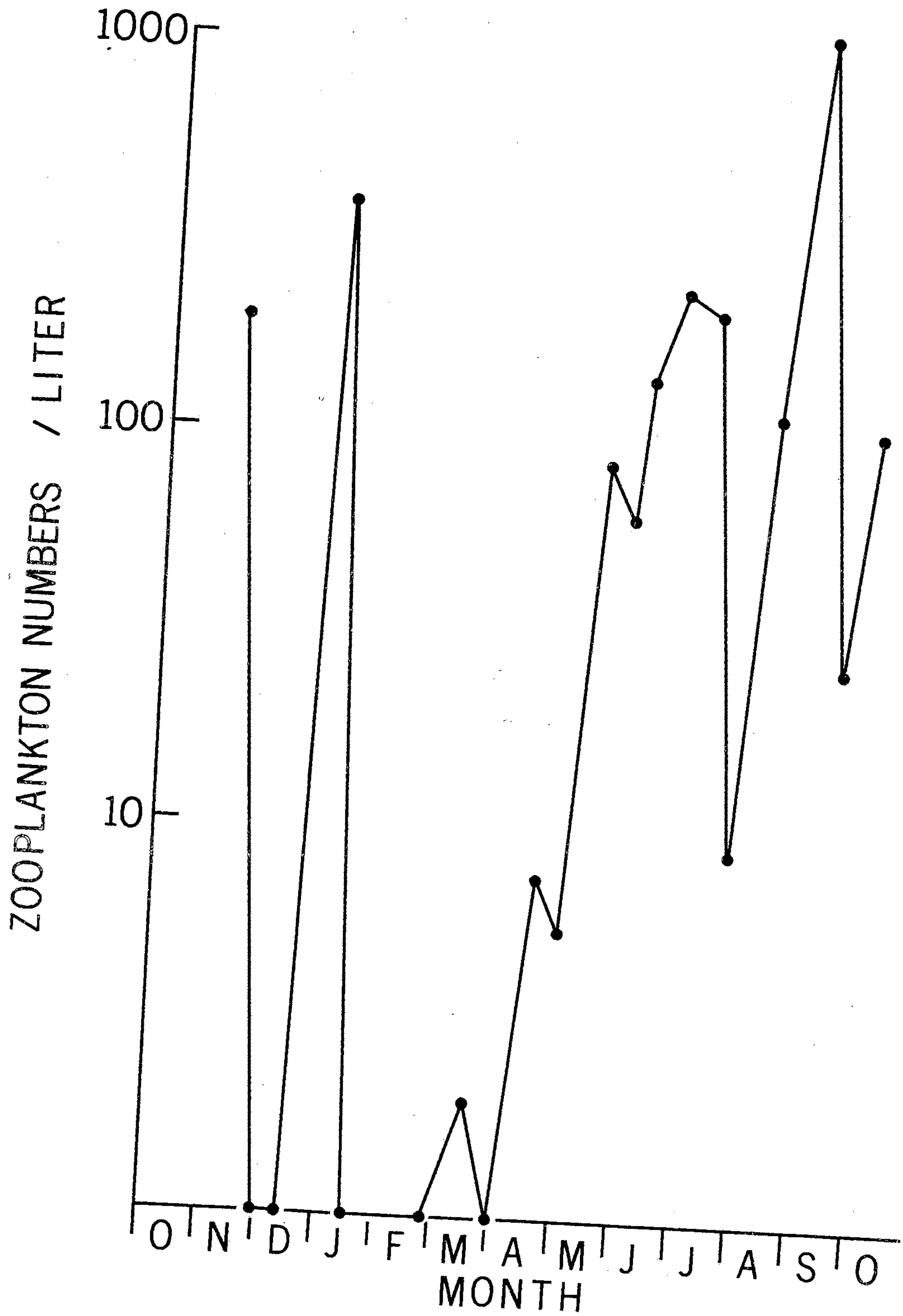


Figure 23. Annual Variation of Total Numbers of Zooplankton in Little Muddy Pond.

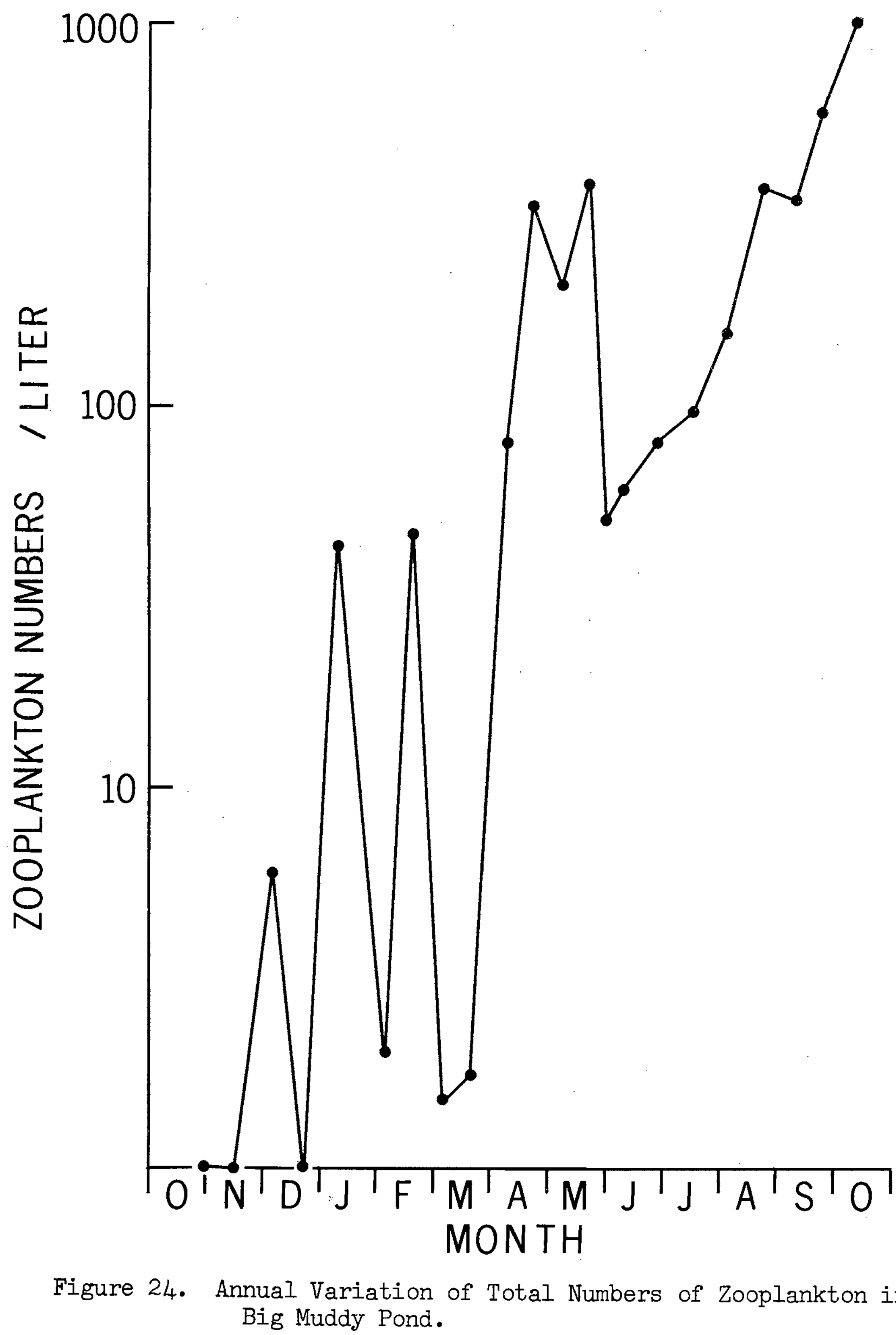


Figure 24. Annual Variation of Total Numbers of Zooplankton in Big Muddy Pond.

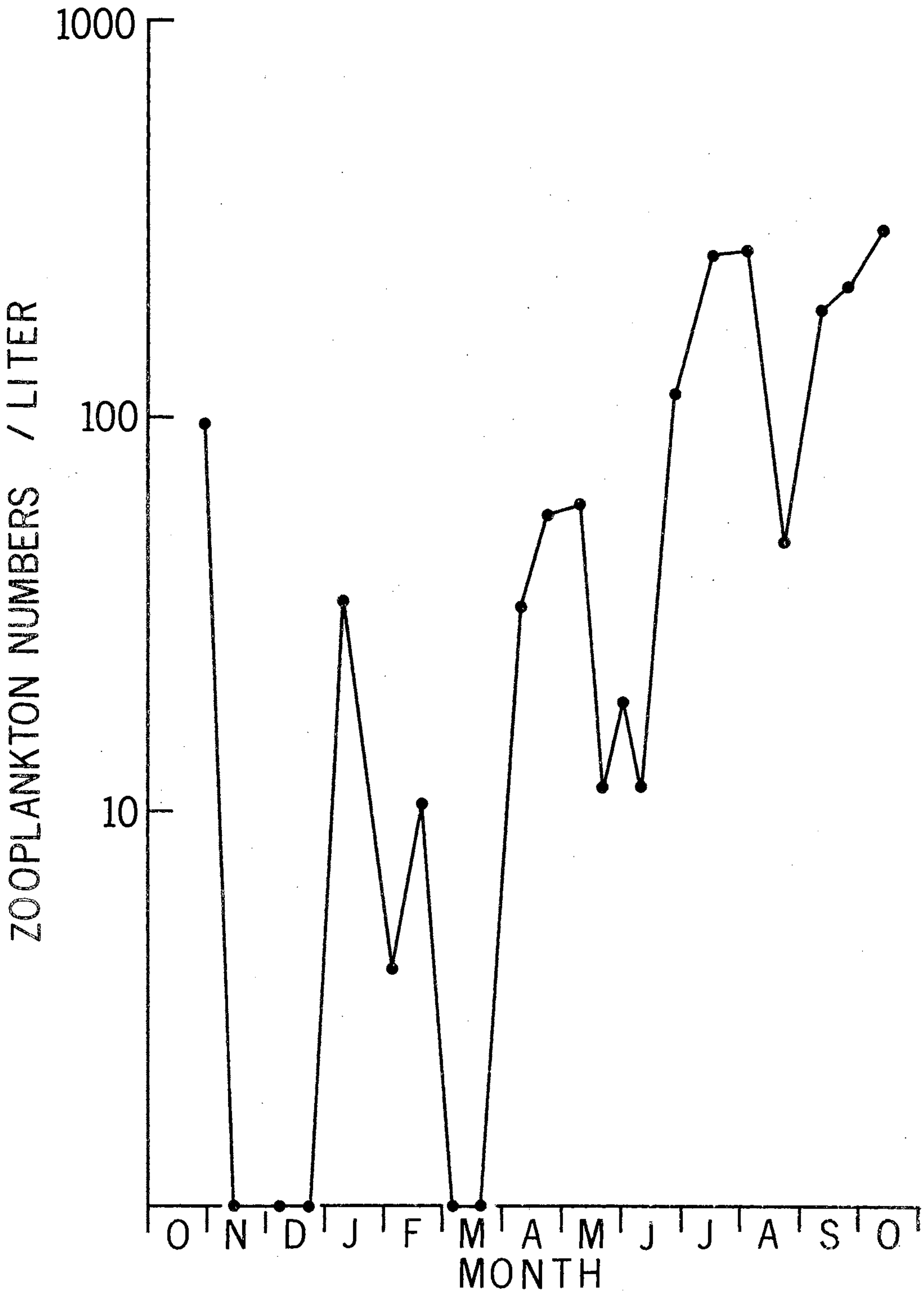


Figure 25. Annual Variation of Total Numbers of Zooplankton in Little Clear Pond.

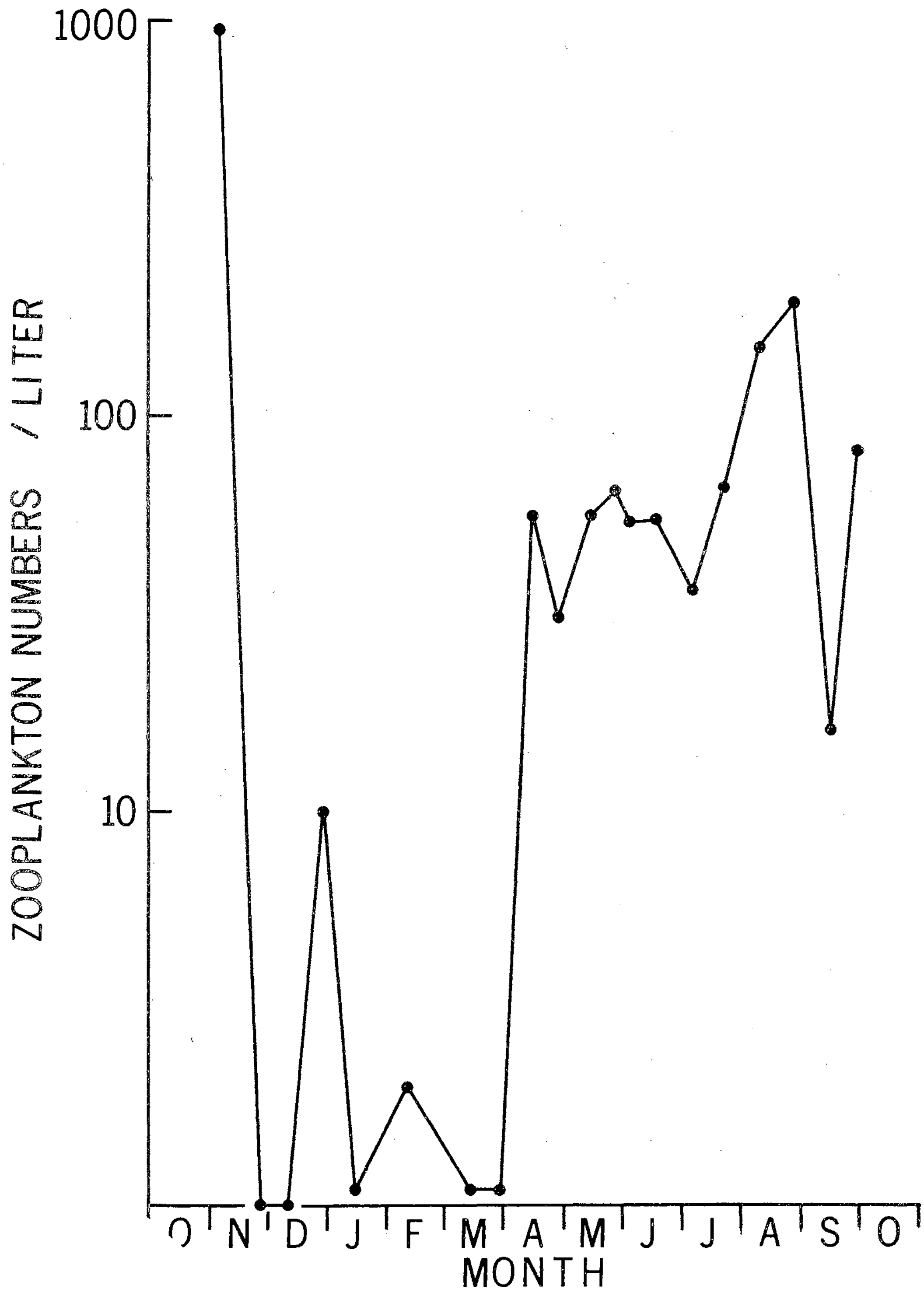


Figure 26. Annual Variation of Total Numbers of Zooplankton in Big Clear Pond.

Cladocera populations remained relatively low in Big Muddy Pond. Little Muddy Pond had high concentrations in early summer due mainly to *Ceriodaphnia*, but remained at low levels through the remainder of warm season. Cladocera in both clear ponds increased in midsummer and also in September. High densities in clear ponds were due primarily to increases in *Ceriodaphnia*.

Copepod densities increased in spring in the turbid ponds. Copepod populations in the clear ponds were more stable through the spring and summer. A fall pulse of copepods developed in all ponds except Big Clear Pond. The dominant copepod in all ponds was *Diaptomus* sp.

Populations of Protozoa and copepods appeared to fluctuate more in the turbid ponds than in clear ponds. These fluctuations may have been due to less predation, greater variation in food supply, sampling error, or turbulence.

Big Clear Pond had relatively low populations of zooplankton except for Cladocera. The numbers of other groups may have been stabilized at low levels by predation or competition. Brooks and Dodson (1965) have shown that predation by fish can affect the composition of the zooplankton community.

Mean annual numbers of zooplankton were higher in the turbid ponds (Table X). The difference was largely due to larger populations of Protozoa in the turbid ponds. Zooplankton numbers were significantly correlated with phytoplankton numbers ($r = 0.44$). Whether this correlation was due to direct trophic relationships or to environmental conditions affecting both phytoplankton and zooplankton could not be determined. Since nearly all of the zooplankters collected were herbivores, it seems probable that the zooplankton used phytoplankton as food.

TABLE X

MEAN ANNUAL NUMBERS OF INDIVIDUALS

| | Individuals/liter | | | | | |
|---|---|---|---|---|---|---|
| Pond | Protozoa | Rotifera | Cladocera | Copepoda | Other | Total |
| Little Muddy | 75.9 | 12.0 | 17.8 | 23.3 | 0.2 | 129.2 |
| Big Muddy | 106.2 | 35.8 | 5.8 | 25.1 | 4.2 | 177.1 |
| Little Clear | 4.2 | 27.8 | 18.9 | 22.4 | 5.1 | 78.4 |
| Big Clear | 51.3 | 4.9 | 22.0 | 4.8 | 1.9 | 84.9 |

Species Diversity

The diversity indices for zooplankton collections did not agree with the patterns of phytoplankton diversities even though the total numbers of species were slightly higher in the clear ponds.

Zooplankton diversity (d) was not reduced by turbidity (Fig. 27). The maximum mean d occurred in Big Muddy Pond and the minimum mean diversity was in Big Clear Pond. Predation by fish would be less effective in muddy water and may have allowed greater numbers to remain. Large numbers of individuals increase diversity d.

Species diversity ($\bar{d}$) was minimal in Little Muddy Pond and maximal in Big Clear Pond. Annual means of zooplankton $\bar{d}$ in Little Clear Pond and Big Muddy Pond were not significantly different at the 95% confidence level (Table XI). Means of Little Clear Pond and Little Muddy Pond were significantly different.

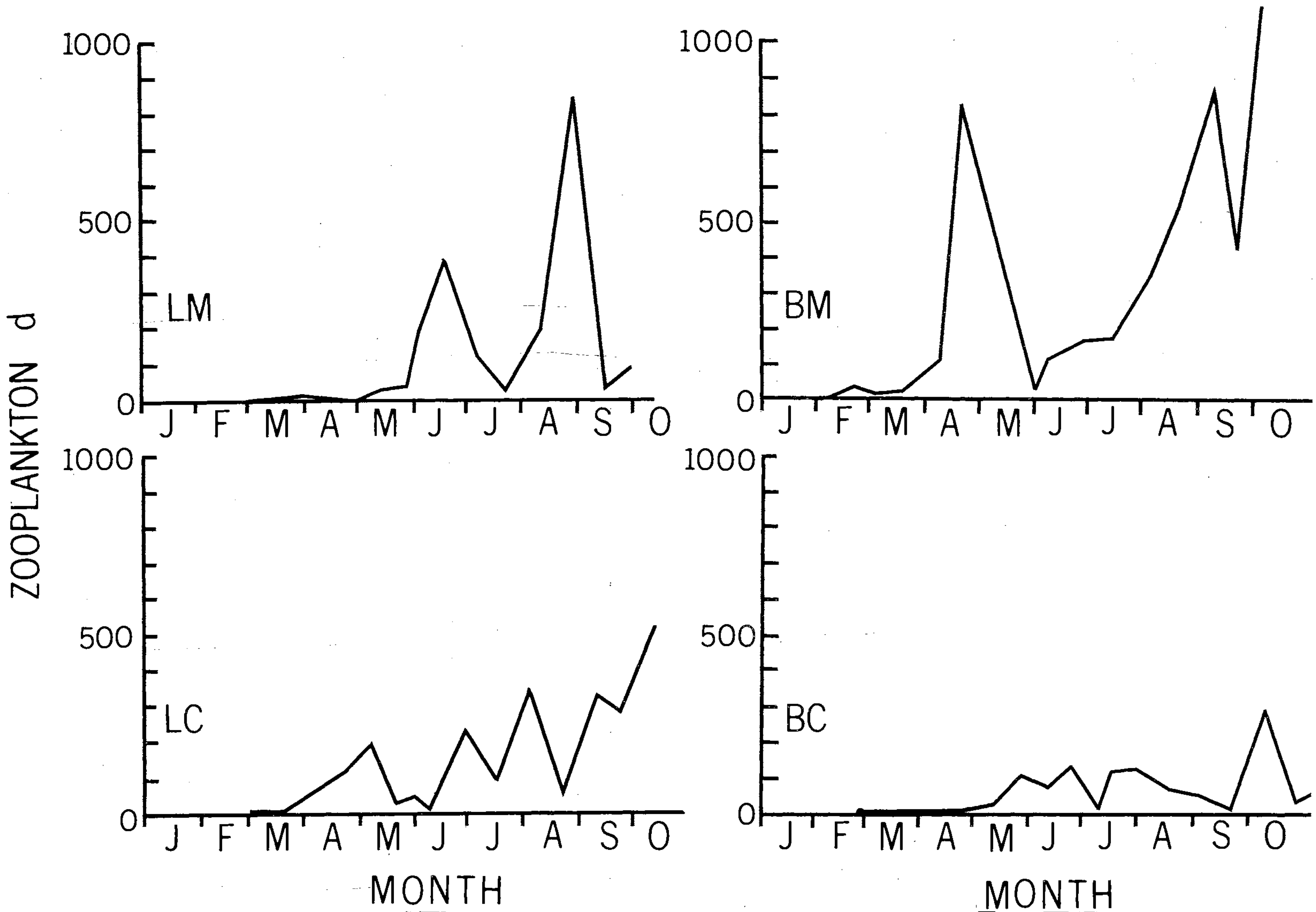


Figure 27. Variation of Zooplankton Diversity d. LM = Little Muddy Pond, BM = Big Muddy Pond, LC = Little Clear Pond, BC = Big Clear Pond.

Zooplankton $\bar{d}$ seemed to be directly related to pond size. Either zooplankton $\bar{d}$ was affected by parameters other than turbidity in each pond or was reduced by turbidity only when the level of turbidity was high (Fig. 28). The latter explanation agrees with the phytoplankton $\bar{d}$ relationship.

TABLE XI

DIVERSITY INDICES OF ZOOPLANKTON

| Pond | Number of Species | Mean Annual d | Mean Annual $\bar{d}$ | Mean Annual r |
|---|---|---|---|---|
| Little Muddy | 21 | 115.18 | 1.01 | 0.72 |
| Big Muddy | 23 | 316.42 | 1.61 | 0.40 |
| Little Clear | 25 | 133.40 | 1.62 | 0.90 |
| Big Clear | 31 | 63.38 | 1.92 | 0.40 |

Zooplankton $\bar{d}$ was inversely correlated ($r = -0.55$) with phytoplankton $\bar{d}$. More diverse zooplankton populations having a variety of food habits could have reduced the diversity of phytoplankton. This also indicated that the zooplankton used phytoplankton as at least part of their food supply.

Mean redundancy (r) appeared to be influenced more by size of pond than by turbidity because r was greater in the small ponds and the values were similar for both small ponds and for both large ponds.

Low correlation between zooplankton diversity and phytoplankton diversity may have been due in part to errors in sampling zooplankton. Zooplankton can evade sampling devices (Hardy, 1956), but would be less able to evade samplers in turbid waters. Vertical migration in response to light may have caused a bias in zooplankton sampling since light penetrated to the bottom of the clear ponds, but less than 1 m in Big Muddy Pond and 0.3 m in Little Muddy Pond.

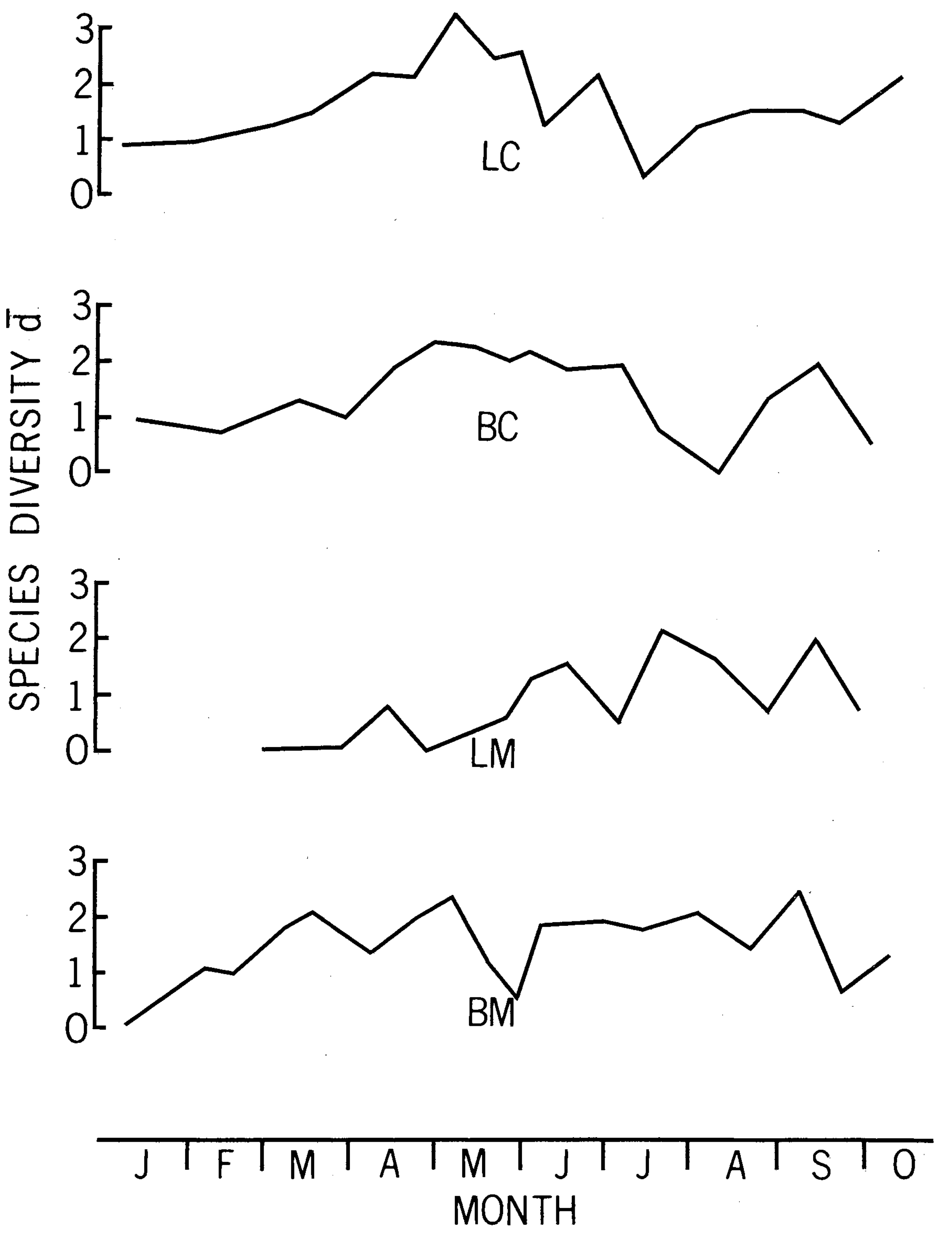


Figure 28. Variation of Zooplankton Diversity ($\bar{d}$). LM = Little Muddy Pond, BM = Big Muddy Pond, LC = Little Clear Pond, BC = Big Clear Pond.

# CHAPTER VII

## MICROCELLS

Bacteria, unicellular blue-green algae and tiny green algae which could not be identified were counted as microcells. The estimated concentrations of microcells are shown in Figures 29-32. Mean annual numbers were much smaller in the clear ponds than in the turbid ponds. The correlation coefficient between percent transmission of light and microcells was -0.37. Although Claffey (1955) reported more bacteria in clear than in turbid ponds, Henrici (1939) indicated bacteria were more numerous in turbid water.

Turbidity particles may stimulate bacterial growth by increasing surfaces and by protecting bacteria from light waves. Lyman (1944) indicated that silt in flood waters provided surfaces which favor the growth of water bacteria. The total area of 1 oz [28 g] is equal to 5.5 acres [2.2 ha] (Frink, 1963).

In water, toxicity of ultraviolet rays is inversely proportional to turbidity and light rays are practically without effect in turbid water (Salle, 1954). The antiseptic action of light may explain why microcells in the clear ponds remained fairly constant while the microcells in muddy ponds increased generally through the warm months (Figs. 29-32). The correlation coefficient between microcells and Secchi disk readings was -0.53.

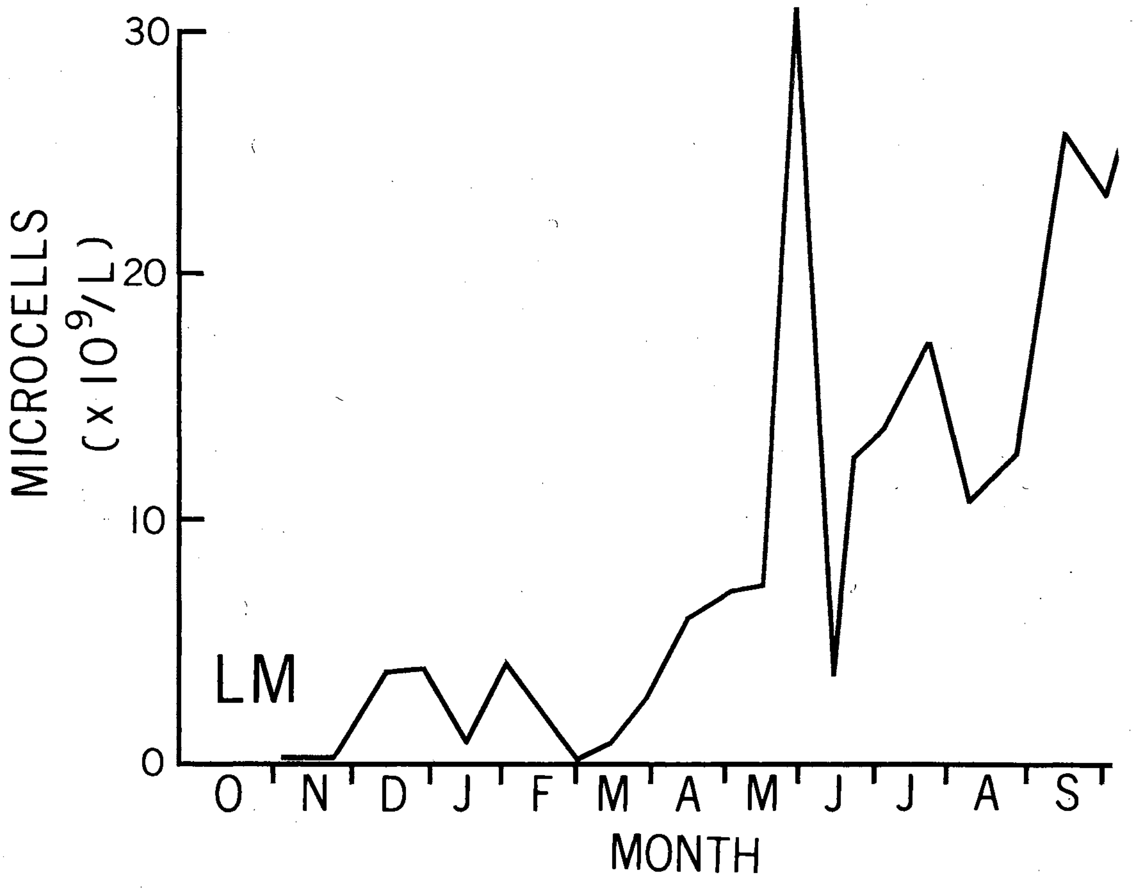


Figure 29. Annual Variation of Estimated Numbers of Microcells in Little Muddy Pond.

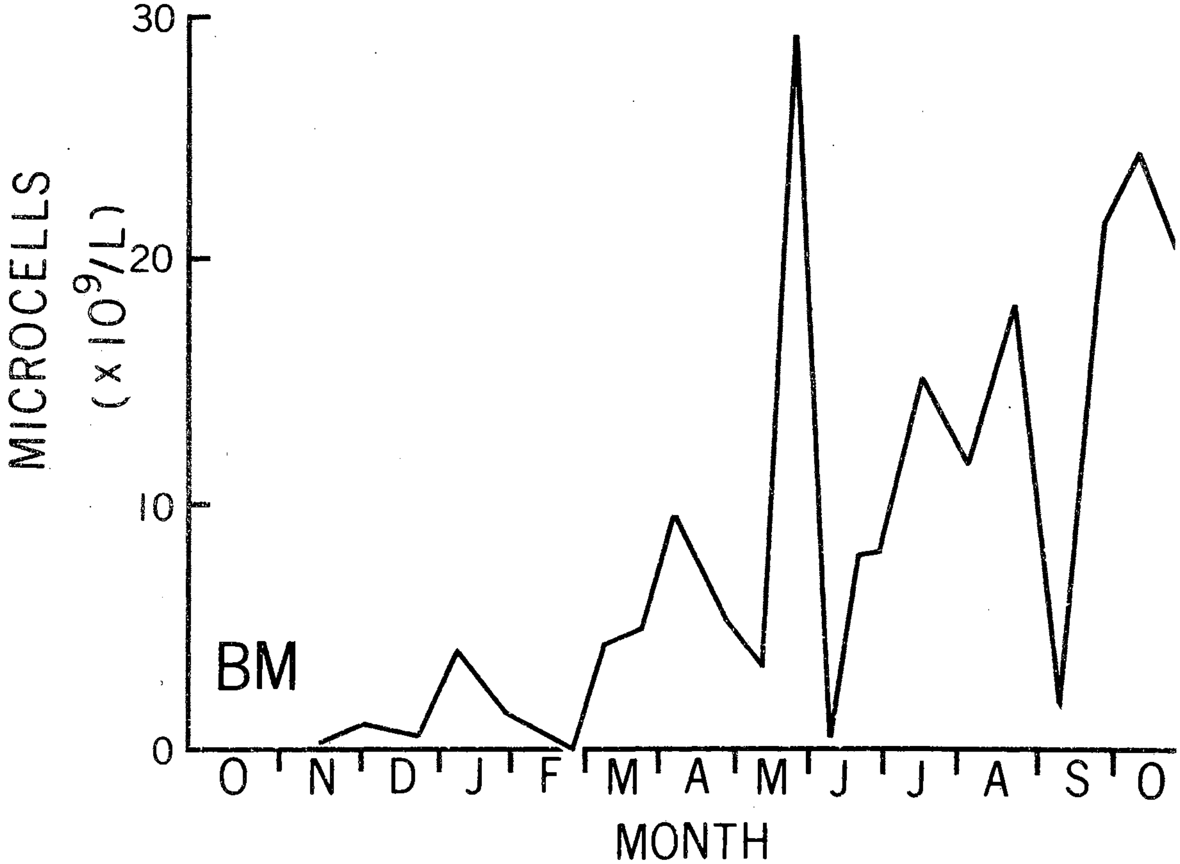


Figure 30. Annual Variation of Estimated Numbers of Microcells in Big Muddy Pond.

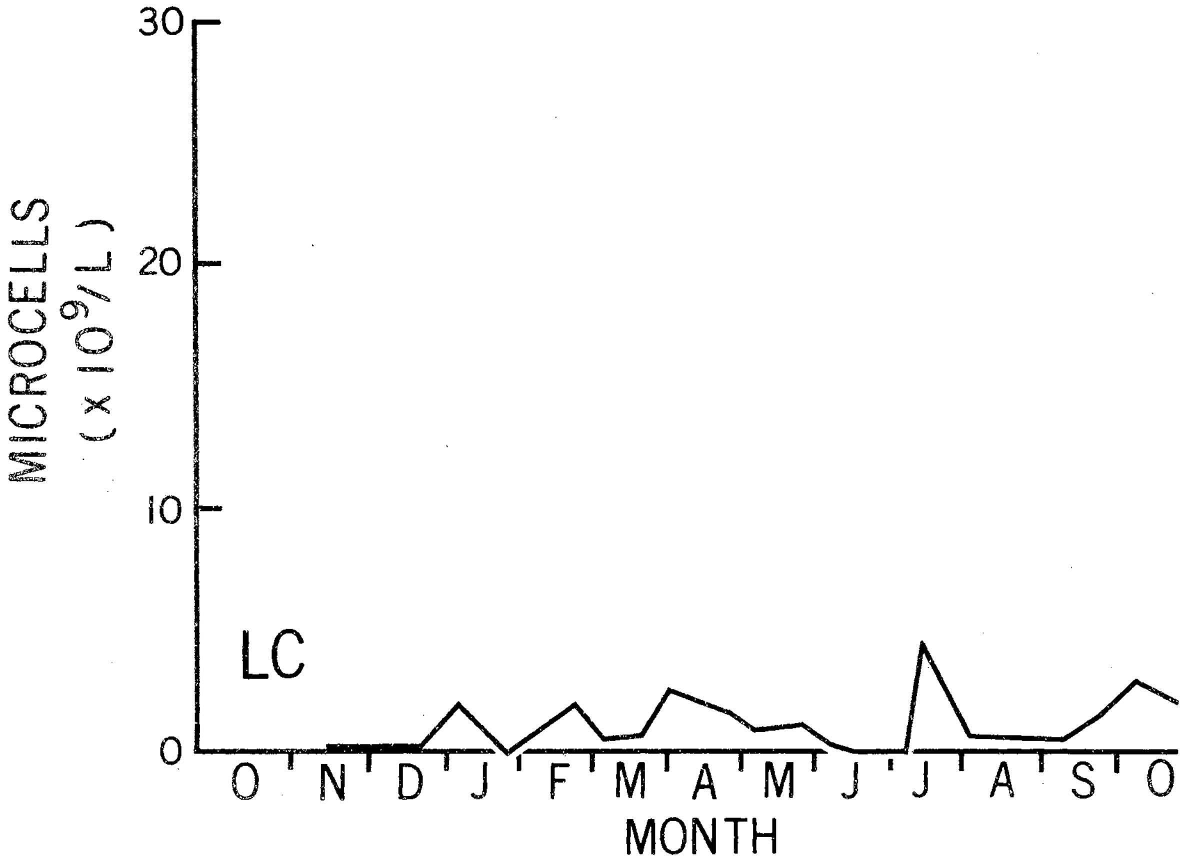


Figure 31. Annual Variation of Estimated Numbers of Microcells in Little Clear Pond.

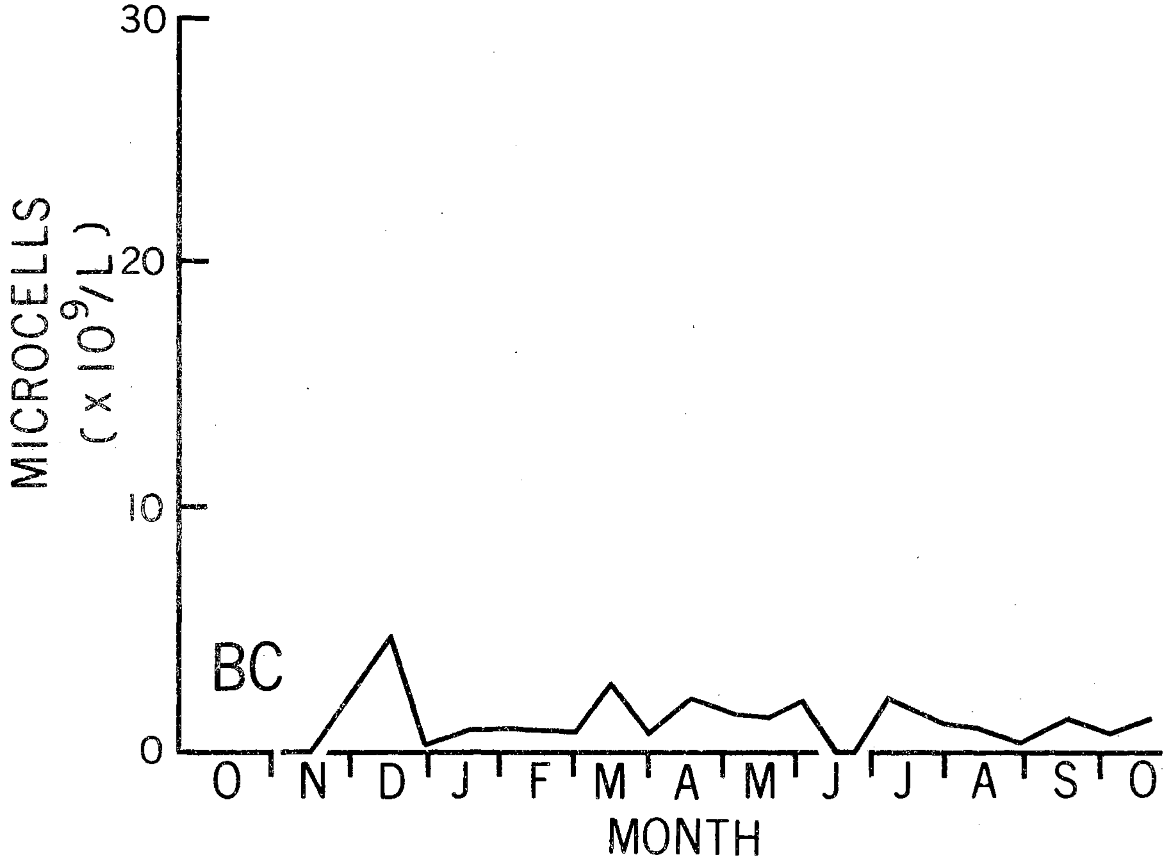


Figure 32. Annual Variation of Estimated Numbers of Microcells in Big Clear Pond.

Microcells increased following rainfall and decreased during periods of low rainfall. The correlation coefficient between water level below spillway and microcell numbers was -0.44. Surface runoff water coming into the ponds probably transported organic materials, minerals, and growth factors which initiated reproduction of the microcells.

The high numbers of microcells in turbid ponds indicate they may play an important ecological role. The decomposer organisms in this group may maintain a rapid turnover rate of minerals, so that the turbid ponds have a continuous supply of inorganic nutrients.

CHAPTER VIII

# BIOCHEMICAL APPROACH TO PLANKTON COMMUNITY STRUCTURE

## Pigment Diversity

An estimate of the biochemical diversity of the plankton community was made during the warm months using a method similar to that of Margalef (1961, 1965). Plankton samples were concentrated with a Millipore filter and immersed in 90% acetone. The pigment diversity ratio was obtained by dividing the optical density at 430 mμ by the optical density at 665 mμ. The intent was to compare pigment diversity with species diversity of phytoplankton and zooplankton in order to determine how closely they were allied and to find out if all were affected similarly by ecological factors.

Pigment diversity ratios of the turbid ponds varied generally between 1.0 and 3.5 during spring, summer, and fall (Fig. 33). Pigment diversity in Big Clear Pond increased to a peak in April and reached a maximum in Little Clear Pond in May. Since changes in pigment diversity have been ascribed to temporary ecological succession in plankton (Margalef, 1968), possibly successional changes were more pronounced in the clear ponds. High pigment diversity might also have resulted from a nitrogen deficiency caused by greater competition for this element by macrophytes.

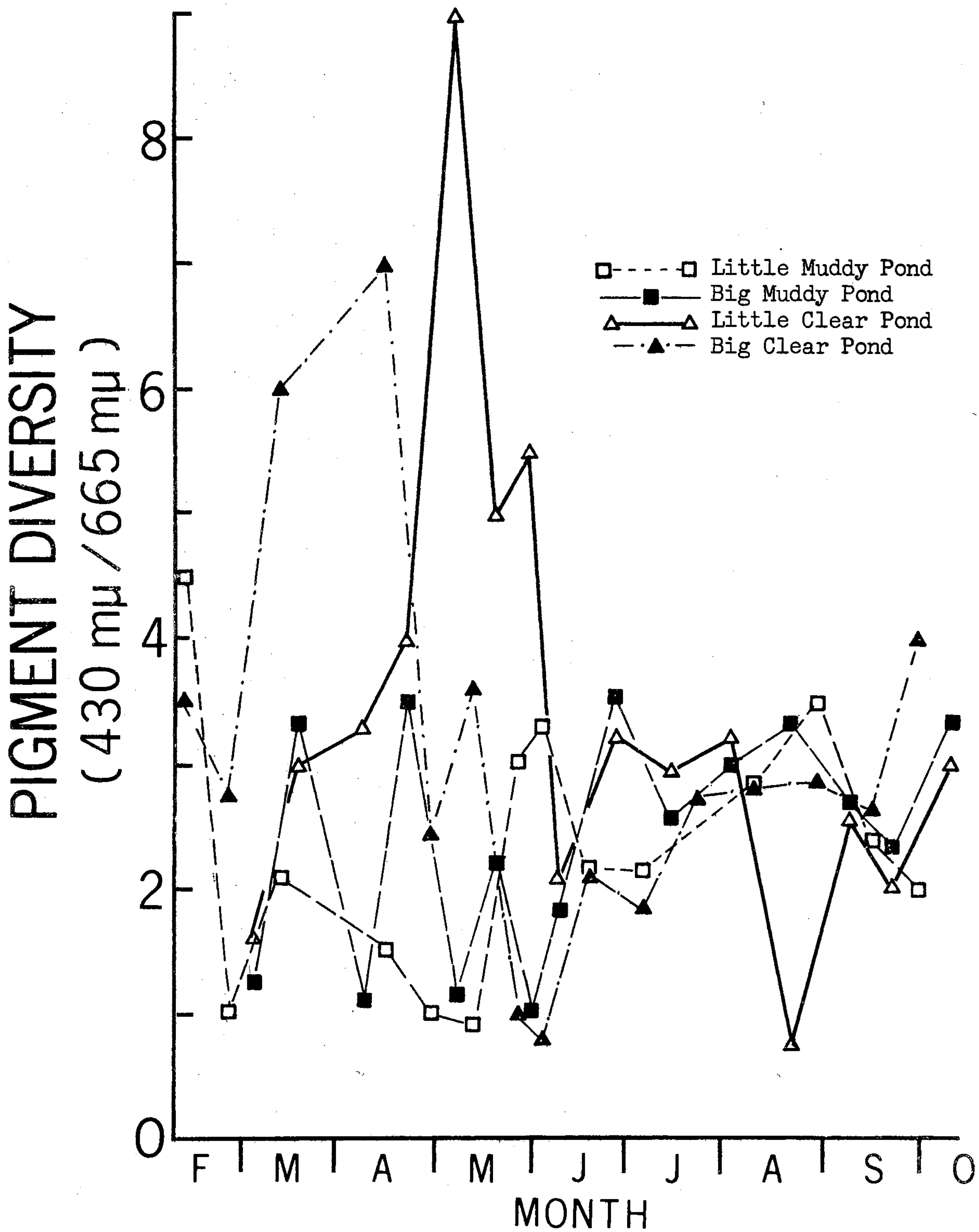


Figure 33. Fluctuation in Pigment Diversity During the Most Active Months.

Mean pigment diversity was highest in Little Clear Pond, followed by Big Clear Pond, Big Muddy Pond, and Little Muddy Pond (Table XII). Plankton communities in the clear ponds appear to be biochemically more complex than those in the turbid ponds.

Annual means of pigment diversity were related to the means of light transmission in much the same way as phytoplankton $\bar{d}$ (Fig. 34). The correlation coefficient for pigment diversity and light transmission was 0.26. However, correlations of pigment diversity with phytoplankton d, phytoplankton $\bar{d}$, zooplankton d, or zooplankton $\bar{d}$, were not significantly different from zero at the 95% confidence level.

Turbidity seems to reduce pigment diversity as well as species diversity ($\bar{d}$) of phytoplankton, although pigment diversity and species diversity may be independent of each other. Changes in pigment diversity appear to be determined by changes in the relative abundance of pigments in cells of many species rather than by changes in species composition. Cellular changes result from the rapid manufacture of chlorophyll a and the slower accumulation of carotenoids when cells are growing rapidly following exposure to adequate nutrients. Reduction of species diversity should also follow the introduction of nutrients, but the rate and amplitude of change may differ.

Low pigment diversity ratios have been associated with young, rapidly growing phytoplankton and a high index has been ascribed to mature cells (Margalef, 1968). Fogg (1966) has shown that algae in nutrient-rich cultures are characteristically bright green and that algae in nutrient-deficient cultures accumulate carotenoid pigments. Yentsch and Vaccaro (1958) reported that nitrogen deficiency caused phytoplankton cells to become chlorotic and increased the ratio of

TABLE XII

MEAN BIOCHEMICAL MEASUREMENTS OF PLANKTON COMMUNITIES

| Pond | Pigment Diversity | INT Biomass Estimate (O.D.) | Total Pigments (μg/liter) | Pigment Curve Area |
|---|---|---|---|---|
| Little Muddy | 2.34 | 0.252 | 40.83 | 1.25 |
| Big Muddy | 2.41 | 0.153 | 9.20 | 0.30 |
| Little Clear | 3.21 | 0.230 | 9.29 | 0.29 |
| Big Clear | 2.83 | 0.120 | 9.52 | 0.29 |

| | Pigment Analysis | | | | |
|---|---|---|---|---|---|
| | Chlorophylls | | | Carotenoids | |
| | a ($mg/M^3$) | b ($mg/M^3$) | c ($MSPU/M^3$) | Astacin ($MSPU/M^3$) | Non-Astacin ($MSPU/M^3$) |
| Little Muddy | 15.36 | 3.02 | 14.67 | 3.90 | 8.92 |
| Big Muddy | 3.87 | 0.34 | 3.02 | 0.34 | 1.66 |
| Little Clear | 2.80 | 0.99 | 3.74 | 0.84 | 1.54 |
| Big Clear | 3.11 | 1.03 | 3.91 | 0.51 | 0.71 |

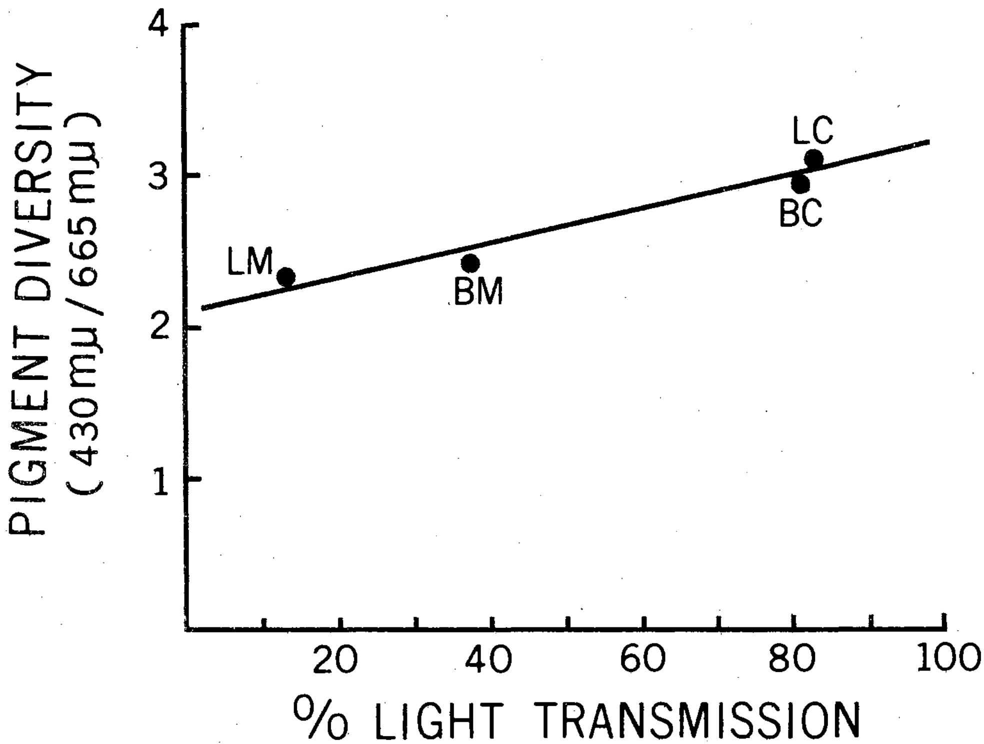


Figure 34. Comparison of Mean Annual Pigment Diversity with Mean Annual Light Transmission.

LM = Little Muddy Pond
BM = Big Muddy Pond
LC = Little Clear Pond
BC = Big Clear Pond

carotenoids per cholorophyll a. Manny (1969) showed a definite relationship between organic nitrogen in cells and the carotenoid to chlorophyll a ratio. However, his results did not agree with those of Yentsch and Vaccaro. Temperature and light may also be involved.

The pigment diversity index might have predictive value since great increases in phytoplankton populations ought to be preceded by low pigment diversity. High pigment diversity should accompany or follow phytoplankton maxima. In fact, high pigment diversity generally was associated with static populations, and low pigment diversity was followed by rapid growth of populations.

In Little Muddy Pond, a low pigment diversity ratio (Fig. 35,A) was measured during April and May and was followed by a large increase of phytoplankton (A') in June. Pigment diversity in early July decreased (B) prior to the phytoplankton maxima (B') on 23 July.

Big Muddy Pond had a low pigment diversity (Fig. 36,A) in early April which was followed by a small phytoplankton increase (A'). A low pigment diversity ratio (B) in early June preceded a phytoplankton increase (B') in late June. Declining pigment diversity (C) in late July antedated the phytoplankton peak (C') in August.

A low pigment diversity (Fig. 37,A) was present in Little Clear Pond in the spring. Subsequently, a large increase in algae numbers (A') appeared in May. A decreasing pigment diversity (B) in June preceded the high populations of phytoplankton (B') in midsummer.

In Big Clear Pond, the pigment diversity index decreased sharply in February (Fig. 38,A) followed by an increase in phytoplankton numbers (A'). The pigment diversity remained high while the populations decreased. The decline of pigment diversity (B) was followed by a

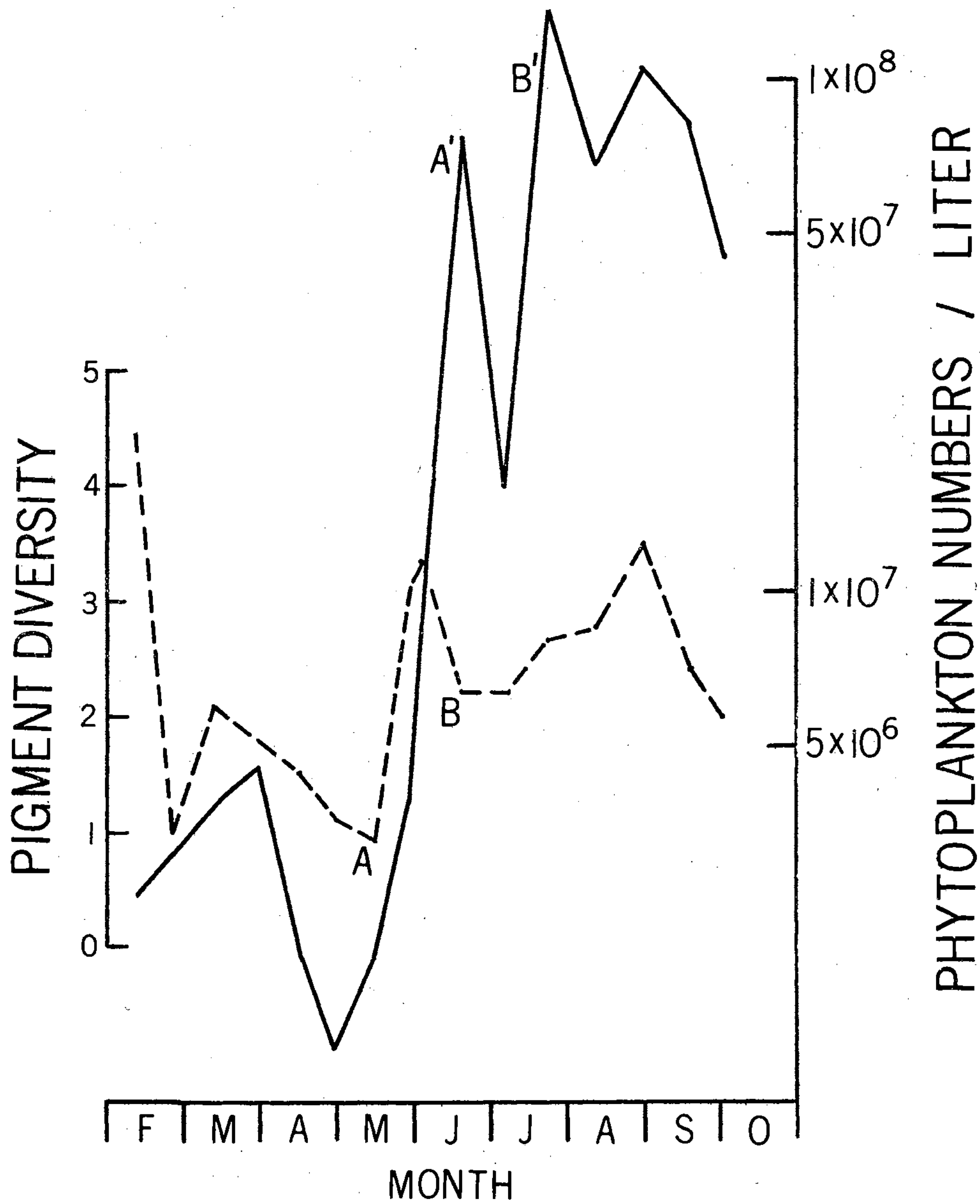


Figure 35. Comparison of Pigment Diversity (---) with Phytoplankton Numbers (——) in Little Muddy Pond. A, A',... = Comparison points.

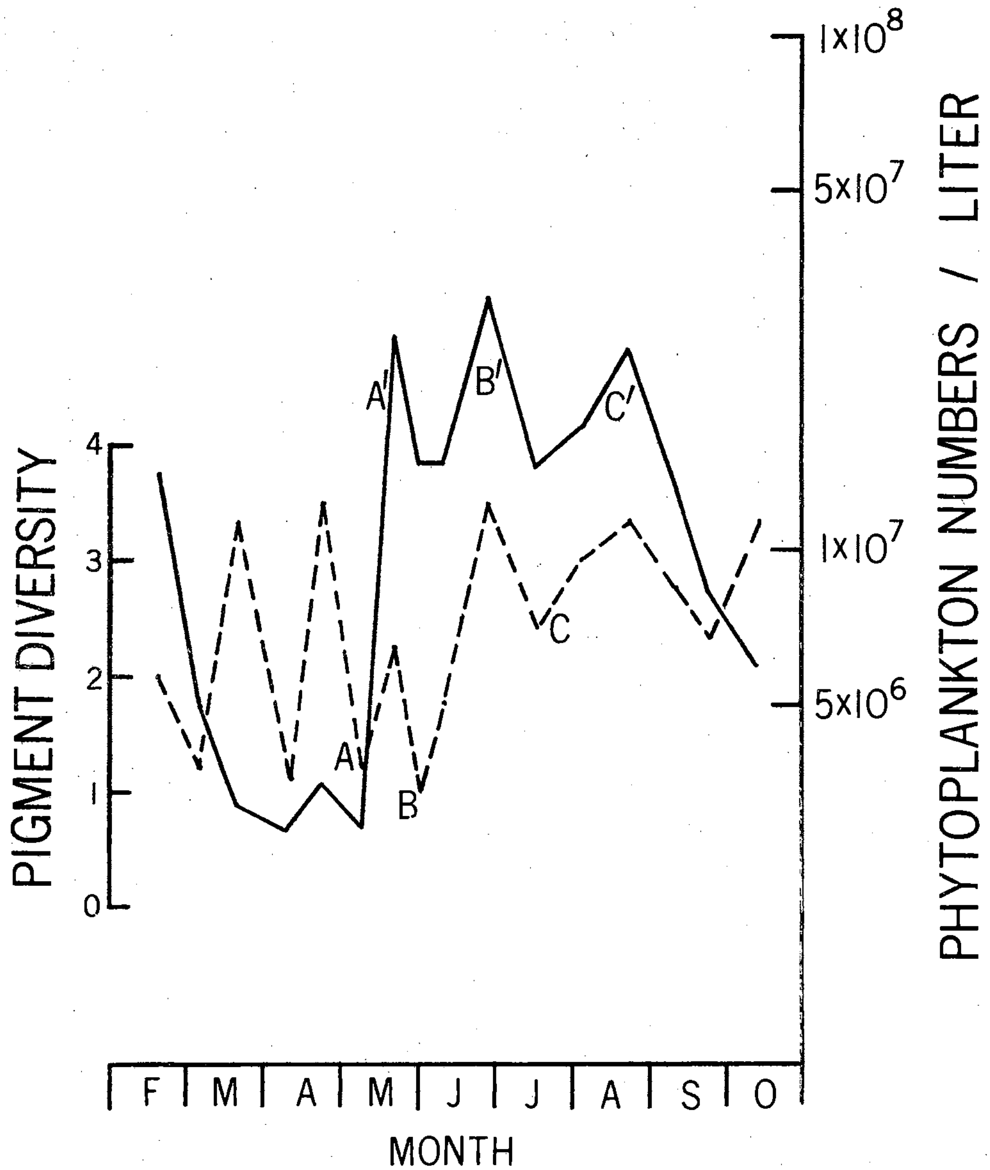


Figure 36. Comparison of Pigment Diversity (----) with Phytoplankton Numbers (——) in Big Muddy Pond. A, A',... = Comparison points.

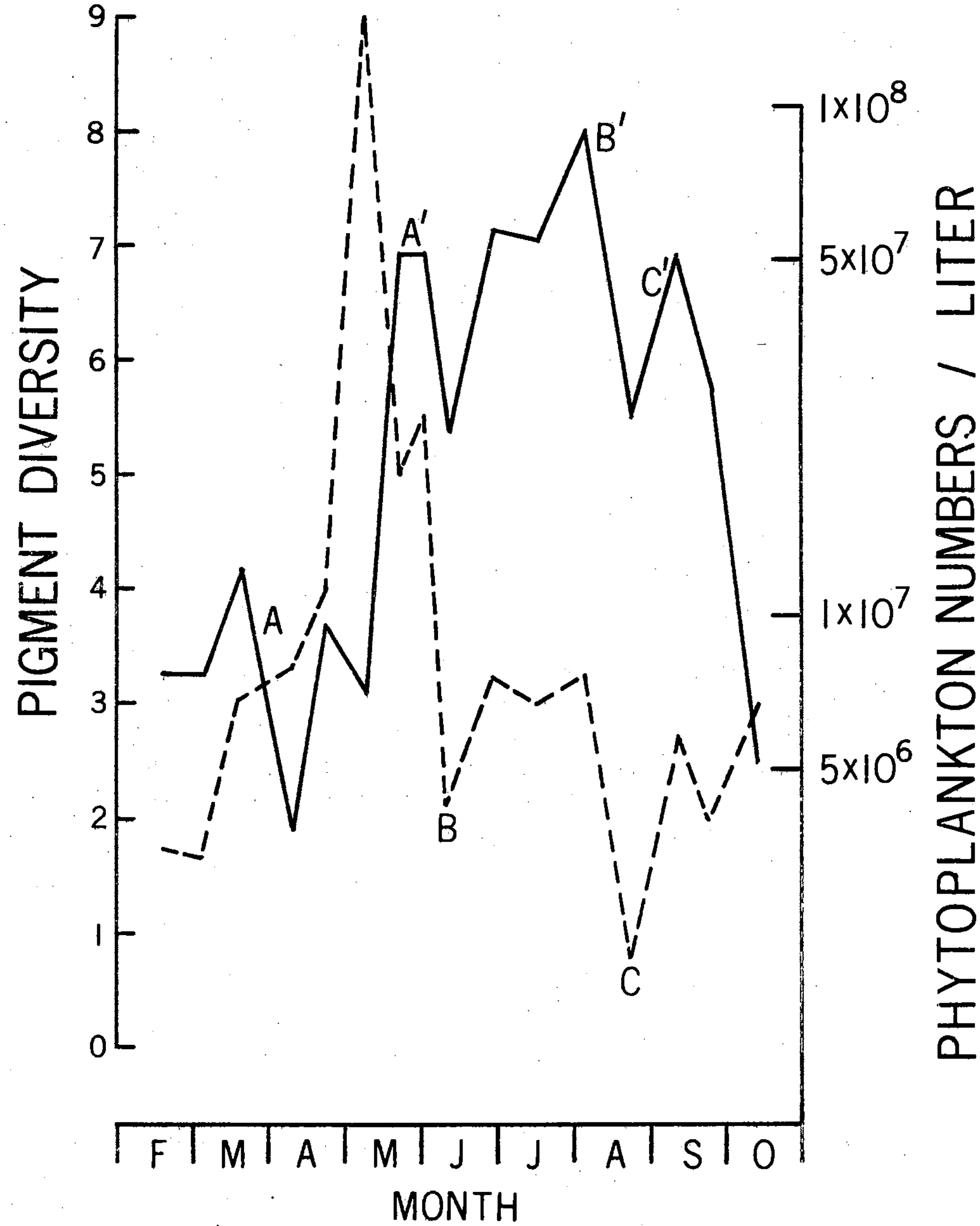


Figure 37. Comparison of Pigment Diversity (---) with Phytoplankton Numbers (——) in Little Clear Pond. A, A',... = Comparison points.

logarithmic increase in phytoplankton (B'). The minimum pigment diversity ratio (C) occurred prior to the summer phytoplankton maximum (C'). As the pigment diversity index increased, the phytoplankton populations decreased in the fall.

Biomass Estimations

An attempt was made to estimate biomass of plankton from the ash-free weight (AFW) of pond water. This method appeared to be inaccurate since it was actually a measure of the organic content of seston, including non-living components. Living biomass was estimated by the optical density of formazan formed by reduction of 2(p iodophenyl)-2-(p nitrophenyl)-5-phenyltetrazolium chloride (INT) by plankton.

Curl and Sandberg (1961) showed that a good correlation exists between the quantity of biomass of both homogenized and intact organisms and the resulting formazan production. Packard and Taylor (1968) demonstrated a good correlation of succinic dehydrogenase activity with oxygen consumption in brine shrimp. Results were affected very slightly by sizes of individuals.

Tests of plankton concentrated from 1 liter of pond water during the early spring gave low values and were considered invalid. In the summer months (Fig. 39) mean optical density for Little Muddy Pond was higher than that of Little Clear Pond, and the mean was higher for Big Muddy Pond than for Big Clear Pond. This difference may have been due to sampling bias, since the samples were taken from the upper foot of water and certain plankters tend to be concentrated in the upper layers of turbid ponds. Bacteria, being more prevalent in the turbid ponds, may have increased the values for turbid ponds.

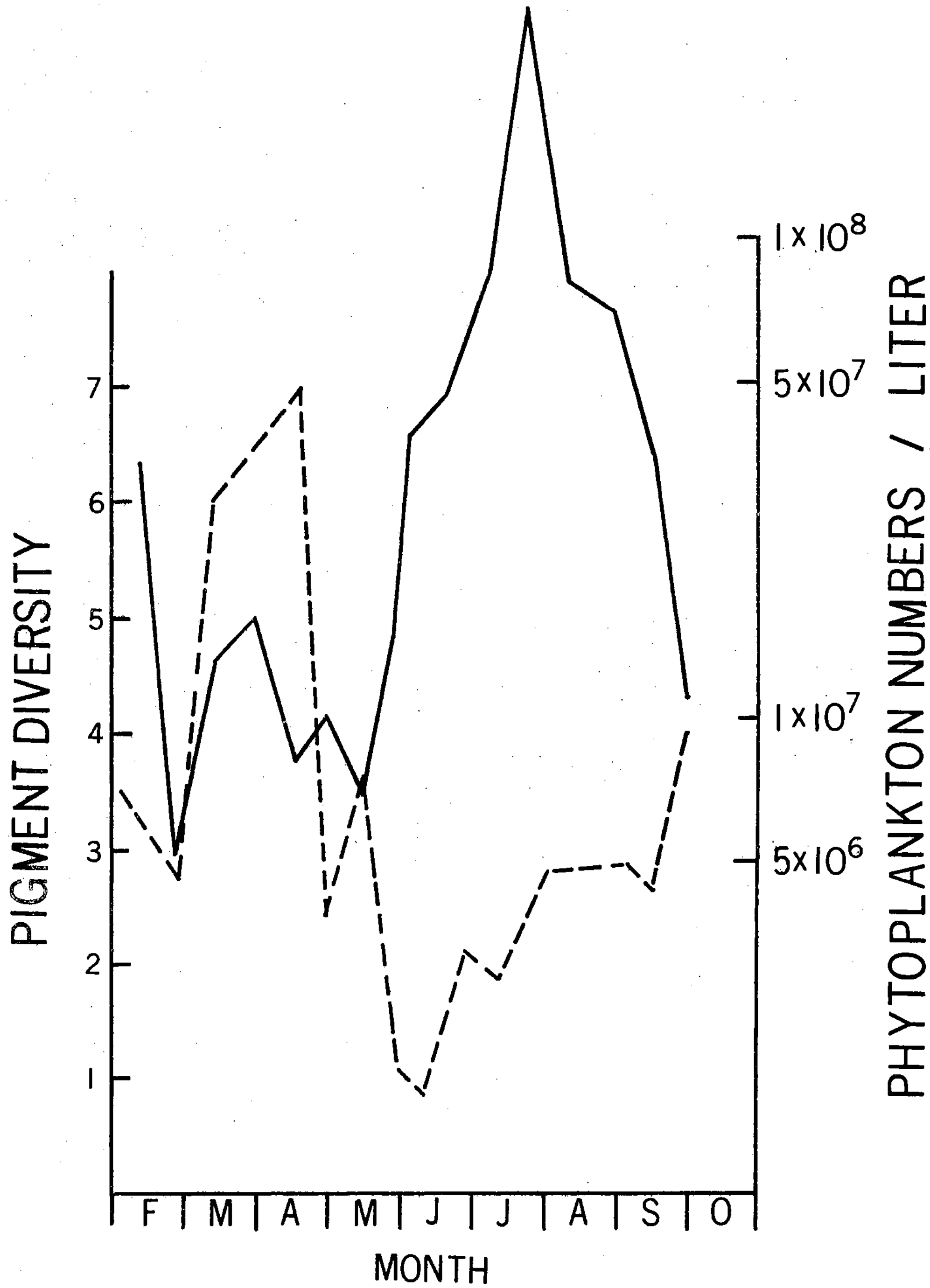


Figure 38. Comparison of Pigment Diversity (----) with Phytoplankton Numbers (——) in Big Clear Pond. A, A',... = Comparison points.

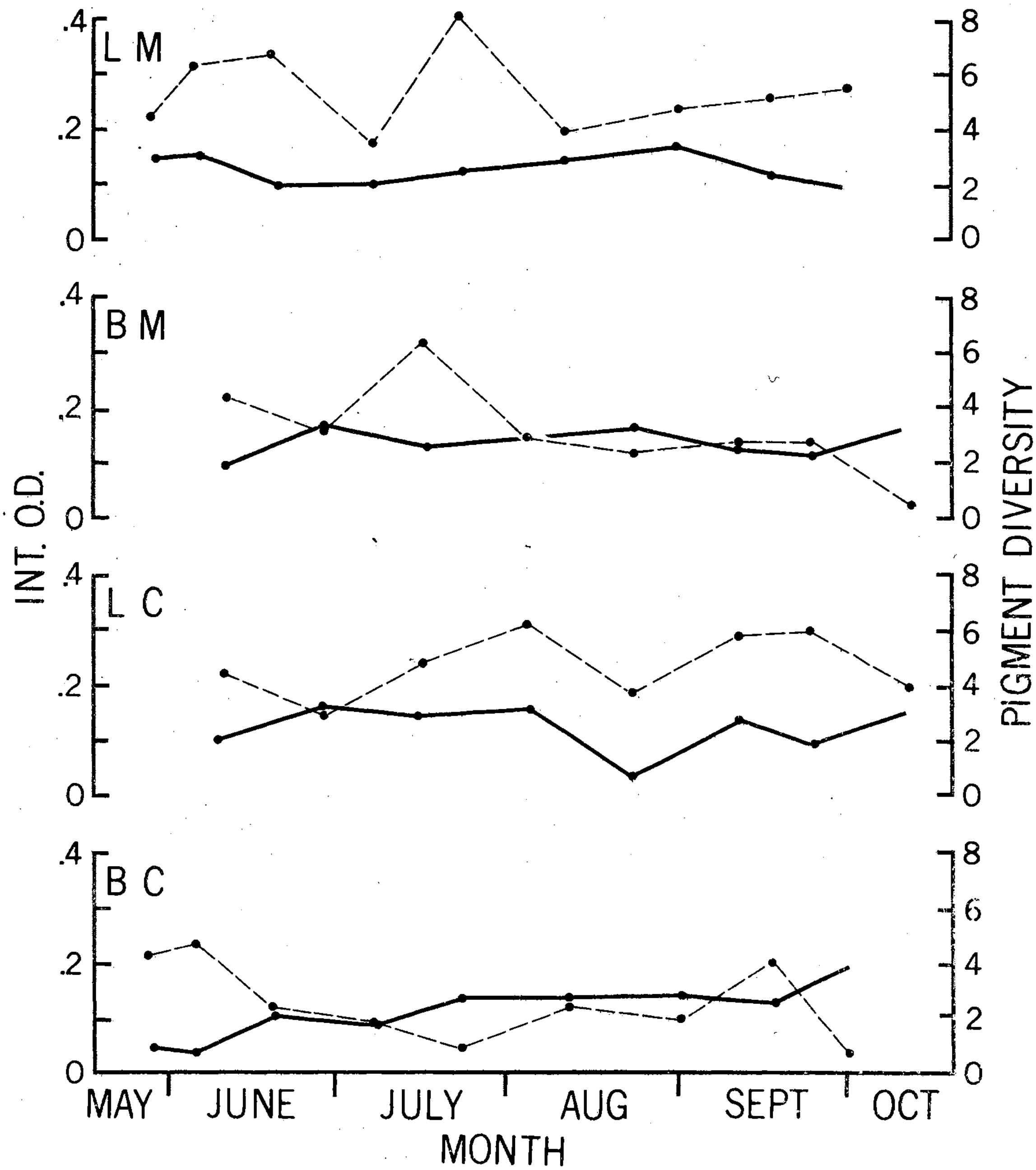


Figure 39. Variation of INT Estimate of Active Biomass and Pigment Diversity During the Warmer Months.
---- Optical Density of INT
—— Pigment Diversity Ratio
LM = Little Muddy Pond, BM = Big Muddy Pond, LC = Little Clear Pond, BC = Big Clear Pond.

Biomass estimates in small ponds were always higher than in those of the larger counterparts. The range in values was greater in the turbid ponds, indicating less stability of living biomass in turbid ecosystems.

The INT biomass estimates were not related to numbers of phytoplankton or zooplankton. Biomass and numbers need not be related since the sizes of plankters vary greatly. Ruttner (1953) stated that counts of plankton are of no value in determining standing crop.

When INT measurements are compared to pigment diversity ratios, an inverse relationship is apparent in the large ponds (Fig. 39). Generally the INT estimate of biomass increased as the pigment diversity decreased and was reduced with increased pigment diversity. One explanation might be that low pigment diversity ratio indicates more nutrients and active cells which form greater biomass. Conversely, a high pigment diversity index indicates a lack of nutrients which results in decreased biomass.

## Photosynthetic Pigments

Amounts of chlorophylls a, b, and c and astacin and non-astacin carotenoids varied considerably among ponds during the summer months (Table XII). The highest concentration of every pigment was taken from Little Muddy Pond, and Little Muddy Pond had the highest mean for all pigments. Little Clear Pond had the lowest mean concentration of chlorophyll a. The lowest mean for chlorophylls b and c was in Big Muddy Pond.

The high concentration of pigments in samples taken from Little Muddy Pond might be an adaptation of the phytoplankton community to the narrow euphotic zone. Under conditions of high light intensity and high temperature during the summer, organisms which can remain near the surface by flotation or swimming are productive and numerous.

Since only individuals of Chlorophyta and Euglenophyta contain chlorophyll b and since only members of Pyrrophyta and Chrysophyta contain chlorophyll c, the relationship of the abundance of these groups to their specific pigments was explored. Comparisons of chlorophyll b with numbers of Chlorophyta and Euglenophyta did not demonstrate any significant relationship. Comparison of chlorophyll c with numbers of Pyrrophyta and Chrysophyta were also inconclusive. Since chlorophyll content is related to biomass, this was a comparison of biomass with numbers of algal cells which are not necessarily comparable (Tucker, 1949).

Strickland (1960) has stated that pigment analysis should be extended to include the carotenoids in order to estimate standing crop. Cassie (1963) has stated that inclusion of non-astacin carotenoids with chlorophyll a was a better indicator of photosynthesis than chlorophyll a alone. Margalef (1965) argued against limiting pigment analysis to a narrow band since irretrievable information about structure of phytoplankton may be lost.

Concentrations of all pigments for each sampling date were added to explore the feasibility of using the sum as an indicator of plankton biomass. A second value was derived from the area under the absorption curve of the continuous record from 400 mμ to 700 mμ. The total pigment value in μg/liter is somewhat related to the area under the pigment curve (Fig. 40). The two values show a certain correspondence with INT biomass estimates also. The dissimilarity shown by Big Muddy Pond samples taken on 4 August may be due to the persistence of pigments in aging, inactive plankton cells. The area beneath the continuous optical density curve would appear to be a more complete indicator of biomass than measurements of chlorophyll a alone or of the total pigments since the area is the result of more measurements.

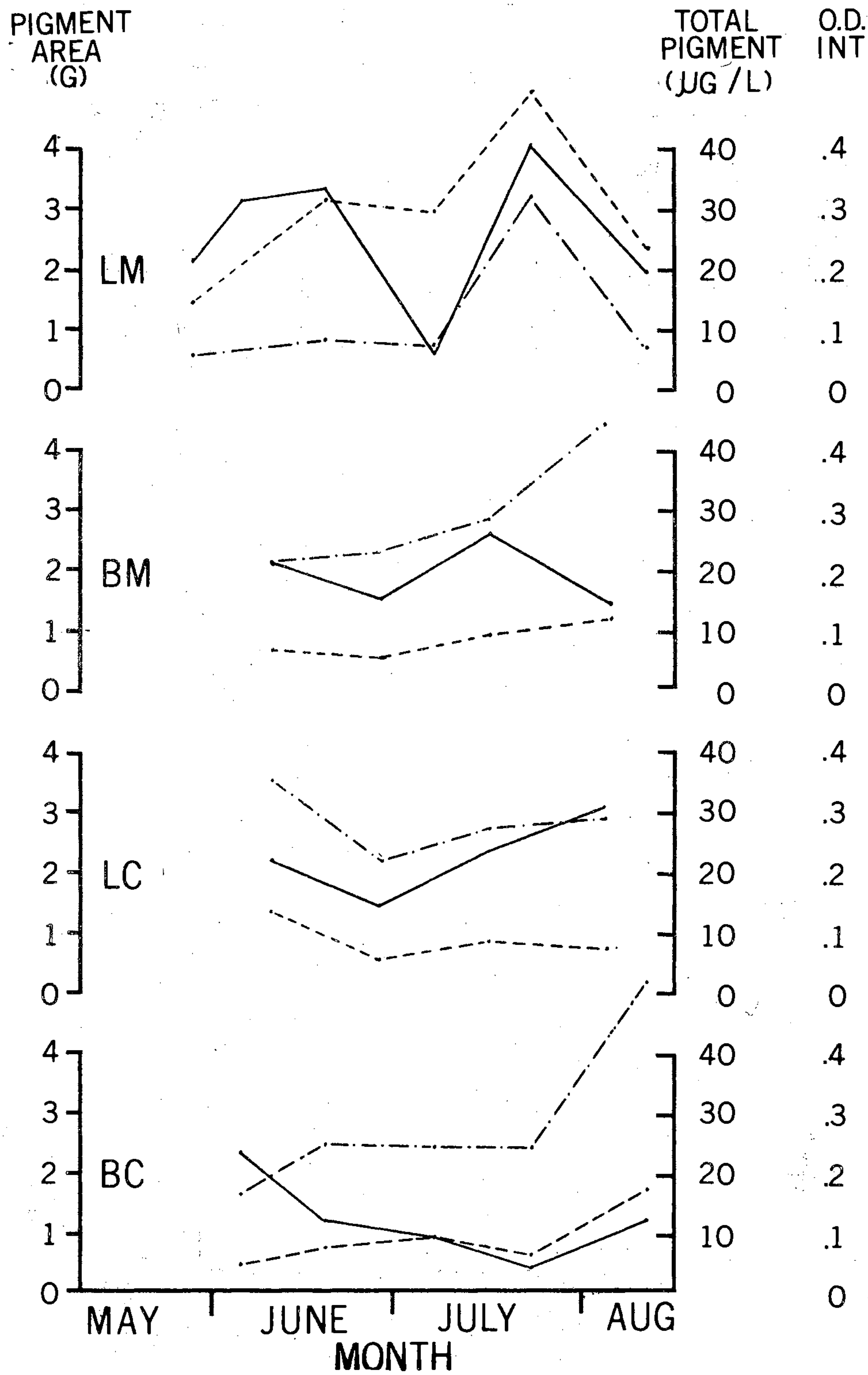


Figure 40. Comparison of Total Pigment, the Area Under the Pigment Curve, and INT Biomass Measurements.
--- Total Pigments
-·- Pigment Area
—— INT Biomass
LM = Little Muddy Pond BM = Big Muddy Pond
LC = Little Clear Pond BC = Big Clear Pond

# CHAPTER IX

## PRIMARY PRODUCTION AND COMMUNITY RESPIRATION

### Primary Production

Values of gross and net production as estimated from light and dark bottles are shown in Table XIII. This method produced low and indefinite results during the cold sampling dates so these data are not included.

Surface gross production was variable among ponds (Fig. 41). Highest gross production was measured in Little Muddy Pond on 23 July. The other ponds also show a maximum during July or early August. Mean gross production was highest in Little Muddy Pond, followed by Big Clear Pond, Big Muddy Pond, and Little Clear Pond.

Light and dark bottles were suspended at 1 m from a rod connected between two floats. Although the floats were anchored and tied to the shore, the wind often shifted them so that the bottles at 1 m touched bottom in Little Muddy Pond and were shaded by macrophytes in Little Clear Pond. Because of these interferences, only surface measurements were taken in the two small ponds.

Mean gross production at 1 m depth was nearly seven times greater in Big Clear Pond than in Big Muddy Pond. Average gross production for both surface and 1 m depths in Big Clear Pond was nearly twice that of Big Muddy Pond. Correlation of transmission of light and gross

TABLE XIII

MEAN COMMUNITY METABOLISM

| Pond | Pg (mg $O_2$/liter) | Pn (mg $O_2$/liter) | Rt (mg $O_2$/liter) | $\frac{Pn}{Pg}$ | $\frac{Pg}{Rt}$ |
|---|---|---|---|---|---|
| | | Measurements of Surface Water | | | |
| Little Muddy | 2.37 | 1.19 | 1.18 | 0.50 | 2.01 |
| Big Muddy | 0.91 | 0.42 | 0.49 | 0.47 | 1.87 |
| Little Clear | 0.80 | 0.24 | 0.56 | 0.30 | 1.43 |
| Big Clear | 1.04 | 0.47 | 0.57 | 0.45 | 1.81 |
| | | Mean Measurements of Surface and 1 m Depth | | | |
| Big Muddy | 0.53 | 0.23 | 0.42 | 0.43 | 1.25 |
| Big Clear | 0.99 | 0.46 | 0.53 | 0.47 | 1.87 |

Legend: Pg = Gross Production
Pn = Net Production
Rt = Respiration
$\frac{Pn}{Pg}$ = Net Production/Gross Production
$\frac{Pg}{Rt}$ = Gross Production/Respiration

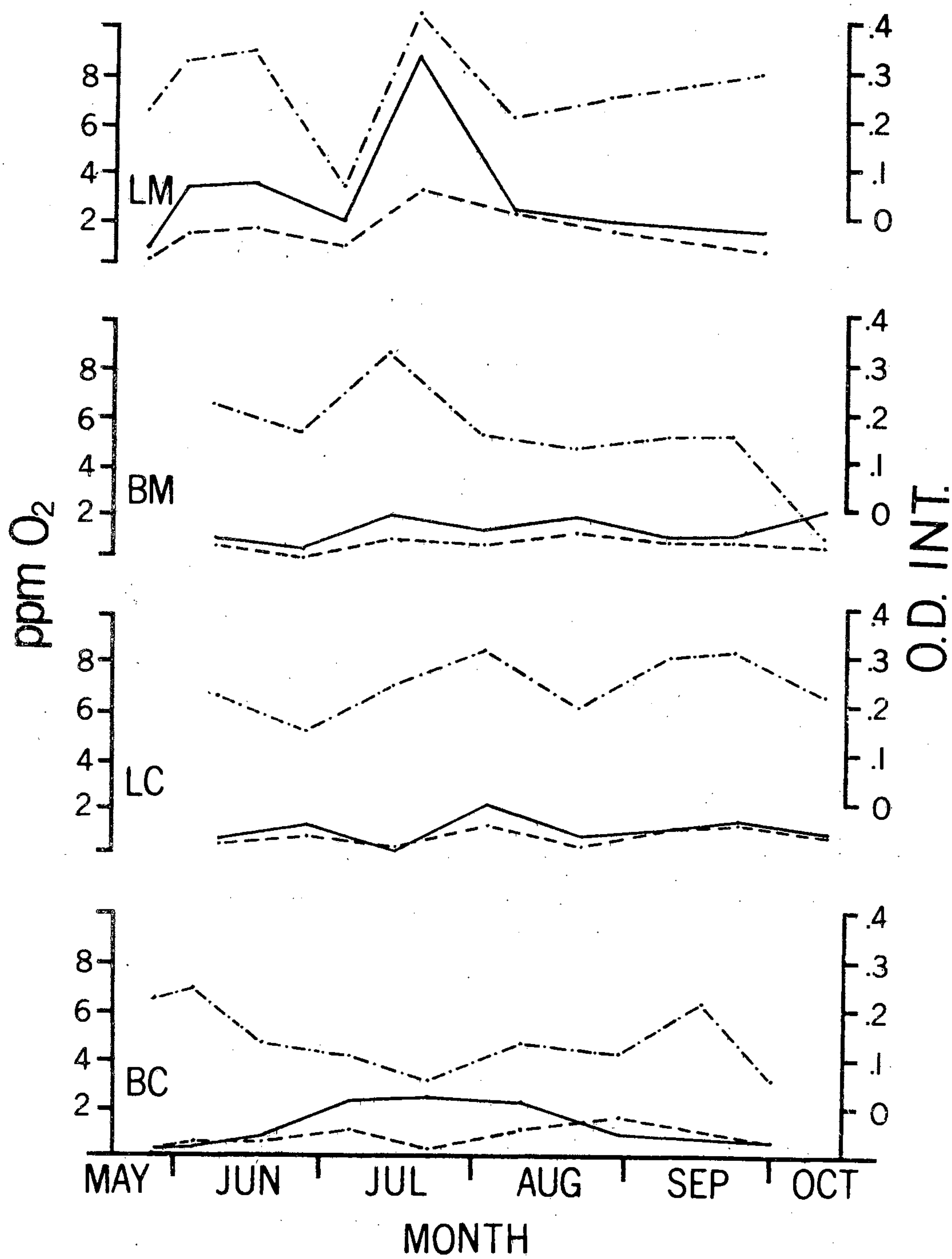


Figure 41. Comparison of Gross Primary Production, Community Respiration, and INT Biomass Measurements During the Warmer Months.
—— Gross Production
– – – Respiration
•–• INT Biomass
LM = Little Muddy Pond  BM = Big Muddy Pond
LC = Little Clear Pond  BC = Big Clear Pond

production at 1 m depth was 0.55 which was significantly different from zero at the 95% confidence level. Correlation of Secchi disk readings with gross production at 1 m was 0.65, which was significantly different from zero at the 99% level of confidence.

Since production was dissimilar for the same dates, it may be assumed that this parameter was influenced more by the organisms and limnological factors which characterize each pond than by more general factors such as sunlight and air temperature. Numbers of phytoplankton were correlated with gross production at the surface ($r = 0.31$) and at 1 m depth ($r = 0.59$). The latter correlation coefficient was significantly different from zero at the 95% confidence level.

Mean net production at the surface was highest in Little Muddy Pond. The ponds ranked in the same order as for gross production. The turbid ponds had higher net production in relation to gross production than the clear ponds. Respiration usually exceeded gross production at the 1 m depth in Big Muddy Pond. The average net production for Big Clear Pond was 16 times that of Big Muddy Pond at the 1 m depth. Mean net production at both levels was twice as high in Big Clear Pond as in Big Muddy Pond.

One purpose of the surface production study was to investigate the major source of energy in turbid ecosystems. Turbid ponds support considerable populations of zooplankton, benthic invertebrates, and fish, yet the sources of energy are limited to phytoplankton primary production and allochthonous materials.

Sunlight usually penetrated no deeper than 0.3 m in Little Muddy Pond and 1 m in Big Muddy Pond. Surface production in this limited euphotic zone was expected to be greater than in clear ponds and mean surface production was 3 times higher in Little Muddy Pond than in Little Clear Pond. Light penetrated to the bottom of Little Clear Pond, so the euphotic zone was 10 times deeper. Phytoplankton in muddy ponds were quite productive in surface waters but it is evident that the clear ponds were more productive through the water column per unit volume.

Although total primary production of the turbid ponds appeared to be lower, greater numbers of zooplankton were collected from the turbid ponds. Food for the turbid pond zooplankton must have included allochthonous materials.

## Community Respiration

Surface respiration was greater in Little Muddy Pond than in the other ponds (Table XIII). Highest respiration was reached in all ponds in July or August. During the cool months respiration in all ponds was too low to be measured satisfactorily. Respiration increased in the spring and declined in the fall.

Respiration at 1 m depth was generally lower than at surface in Big Clear Pond and Big Muddy Pond. Respiration in Big Clear Pond exceeded that in Big Muddy Pond at both depths. Surface respiration was correlated more closely with surface production ($r = 0.82$) than with respiration at 1 m depth ($r = 0.53$).

INT values varied similarly with respiration and production in many instances (Fig. 41). Correlation between gross production and INT measurements was 0.41 and between respiration and INT measurements was 0.47. The correlation of INT with gross production indicates that INT values measured photosynthetic as well as non-photosynthetic organisms. Lack of close parallels on certain sampling dates may have been due to varying field conditions which affected production and respiration. In Little Clear Pond, both respiration and photosynthesis were inhibited by some deleterious factor on 16 July, since the biomass was average but respiration and production were low. INT measurements may be valuable as estimates of potential photosynthetic and respiratory capacities of plankton.

Mean P/R ratios for surface plankton in turbid ponds were higher than those of the clear ponds. At the 1 m depth, the mean P/R ratio for Big Clear Pond was 1.985 and 0.385 for Big Muddy Pond. The mean P/R ratio for surface and 1 m combined was greater in Big Clear Pond than in Big Muddy Pond.

The surface P/R ratio was inversely related to phytoplankton diversity since the turbid ponds had the highest P/R ratio and the lowest mean annual $\bar{d}$ and mean annual d. This is in agreement with the theory of Margalef (1965) and Odum (1956). Means for the surface P/R ratio were also inversely related to pigment diversity (Fig. 42). All ponds were autotrophic according to the classification proposed by Odum (1956).

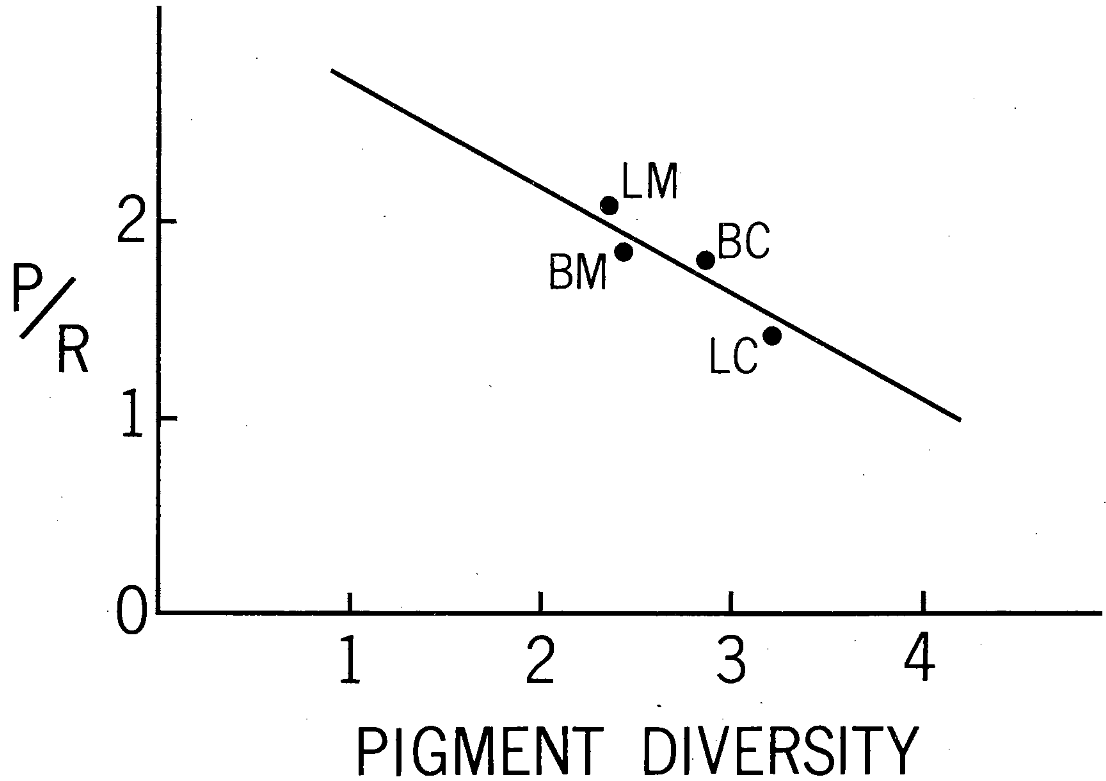


Figure 42. Comparison of Mean Annual P/R Ratio with Mean Annual Pigment Diversity.
LM = Little Muddy Pond, BM = Big Muddy Pond,
LC = Little Clear Pond, BC = Big Clear Pond.

# CHAPTER X

## SUMMARY

1. Plankton in two clear and two turbid ponds was studies from September, 1965 to October, 1966 to determine the effects of turbidity on the plankton community.
2. Conductivity was inversely correlated with water level. Fall rains recharged water levels after the summer decrease.
3. The clear ponds had a heavy growth of aquatic macrophytes during the summer. Carbonate concentration and pH increased markedly in the clear ponds at this time.
4. Turbidity appeared to be inversely related to conductivity and reduced by formation of hydroxide alkalinity by macrophyte and algal photosynthesis.
5. The clear ponds contained more dissolved solids and less suspended solids than the turbid ponds. Mean total dissolved solids were closely related to mean conductivity. Mean total organic solids were inversely related to mean turbidity.
6. Annual means of phytoplankton numbers per liter of the turbid ponds were lower and significantly different from the clear ponds.
7. A total of 124 species of phytoplankton were identified. Numbers of species ranged from 43 in Little Muddy Pond to 72 in Big Clear Pond. Species and individuals of Chlorophyta were reduced in the turbid ponds.

8. Phytoplankton community diversity (d) in the clear ponds was two to three times greater than in the turbid ponds. Annual means of the clear ponds were significantly different from the turbid pond means at the 95% confidence level. Species diversity ($\bar{d}$) was higher in the clear ponds than in turbid ponds. Annual means of the clear ponds were significantly different from Little Muddy Pond, but not from Big Muddy Pond at the 95% confidence level. The turbid ponds had more periods of high phytoplankton redundancy than did the clear ponds.

9. The turbid ponds had greater numbers of individuals and fewer species of zooplankton than the clear ponds. Zooplankton diversity (d) was not reduced by turbidity. Zooplankton diversity ($\bar{d}$) was slightly higher in the clear ponds than in the turbid ponds. Mean annual $\bar{d}$ in the clear pond zooplankton was significantly different from Little Muddy Pond, but not from Big Muddy Pond at the 95% confidence level. Numbers of zooplankton individuals were correlated with phytoplankton numbers.

10. Numbers of microcells were much higher in the turbid ponds. Microcells increased through the warm months in the turbid ponds, but remained at a low level in the clear ponds. Microcells generally increased following rainfall.

11. Pigment diversity, a ratio of pigment absorption at 430 m$\mu$ to 665 m$\mu$, was higher in the clear ponds than in the turbid ponds. Low pigment diversity appeared to precede phytoplankton population increases.

12. Estimates of active plankton biomass by dehydrogenase activity were not related to numbers of zooplankton or phytoplankton, but were related to surface gross production and respiration. Biomass was estimated by measurements of photosynthetic pigments, also. Means of these estimates corresponded to respiration means.

13. Surface gross production and respiration were highest in Little Muddy Pond. The surface P/R ratio was higher in turbid ponds. Surface production was correlated with respiration.

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APPENDIX

TABLE XIV

CORRELATION COEFFICIENTS FOR SELECTED PARAMETERS USED IN THE TEXT

| Variables | | Sample Size (N) | Correlation Coefficient (r) |
|---|---|---|---|
| Conductivity | Water Level Below Spillway | 76 | 0.65** |
| pH | % Light Transmission | 82 | 0.62** |
| % Light Transmission | Phytoplankton Numbers | 86 | 0.10 |
| % Light Transmission | Phytoplankton Diversity $\bar{d}$ | 85 | 0.39** |
| Zooplankton Numbers | Phytoplankton Numbers | 88 | 0.44** |
| Zooplankton Diversity $\bar{d}$ | Phytoplankton Diversity $\bar{d}$ | 80 | -0.56** |
| % Light Transmission | Microcell Numbers | 86 | -0.38** |
| Secchi Disk Reading | Microcell Numbers | 49 | -0.53** |
| Water Level Below Spillway | Microcell Numbers | 76 | -0.44** |
| Pigment Diversity | % Light Transmission | 57 | 0.27 |
| Pigment Diversity | Phytoplankton d | 58 | -0.10 |
| Pigment Diversity | Phytoplankton $\bar{d}$ | 57 | 0.13 |
| Pigment Diversity | Zooplankton d | 58 | -0.03 |
| Pigment Diversity | Zooplankton $\bar{d}$ | 54 | -0.06 |
| INT Biomass Estimate | Gross Production, Surface | 32 | 0.41 |
| INT Biomass Estimate | Respiration, Surface | 32 | 0.47* |
| Gross Production, 1 m | % Light Transmission | 19 | 0.55* |
| Gross Production, 1 m | Secchi Disk Reading | 18 | 0.65** |
| Gross Production, Surface | Phytoplankton Numbers | 40 | 0.30 |
| Gross Production, 1 m | Phytoplankton Numbers | 19 | 0.59* |
| Respiration, Surface | Gross Production, Surface | 40 | 0.82** |
| Respiration, Surface | Respiration, 1 m | 19 | 0.53* |
| Pigment Diversity | INT Biomass Estimate | 34 | -0.20 |

* Significant at 95% Level of Confidence
** Significant at 99% Level of Confidence

TABLE XV

PIGMENT DIVERSITY DATA

| Date | Optical Density 430 mμ | Optical Density 665 mμ | Pigment Diversity Ratio $D_{430} / D_{665}$ | Optical Density 430 mμ | Optical Density 665 mμ | Pigment Diversity Ratio $D_{430} / D_{665}$ |
|---|---|---|---|---|---|---|
| | Little Muddy Pond | | | Big Clear Pond | | |
| Feb 12 | .09 | .02 | 4.5 | .04 | .01 | 3.5 |
| Feb 26 | .30 | .30 | 1.0 | .05 | .02 | 2.8 |
| Mar 13 | .32 | .15 | 2.1 | .06 | .01 | 6.0 |
| Mar 30 | | | | | | |
| Apr 16 | .58 | .38 | 1.5 | .04 | .005 | 7.0 |
| Apr 30 | .38 | .35 | 1.1 | .06 | .025 | 2.4 |
| May 14 | .30 | .32 | 0.9 | .09 | .025 | 3.6 |
| May 28 | .66 | .21 | 3.1 | .07 | .07 | 1.0 |
| Jun 5 | .10 | .03 | 3.3 | .17 | .21 | 0.8 |
| Jun 19 | .69 | .32 | 2.2 | .26 | .12 | 2.2 |
| Jul 07 | .73 | .34 | 2.2 | .26 | .14 | 2.1 |
| Jul 23 | 1.42 | .56 | 2.6 | .40 | .15 | 2.7 |
| Aug 11 | 1.09 | .38 | 2.8 | .85 | .30 | 2.8 |
| Aug 31 | .14 | .04 | 3.5 | .12 | .04 | 2.9 |
| Sep 17 | .90 | .38 | 2.4 | .54 | .21 | 2.6 |
| Oct 1 | .04 | .02 | 2.0 | .02 | .005 | 4.0 |

TABLE XV (continued)

| Date | Optical 430 mμ | Density 665 mμ | Pigment Diversity Ratio $D_{430} / D_{665}$ | Optical 430 mμ | Density 665 mμ | Pigment Diversity Ratio $D_{430} / D_{665}$ |
|---|---|---|---|---|---|---|
| | | Big Muddy Pond | | | Little Clear Pond | |
| Feb 19 | .300 | .015 | 2.0 | .050 | .300 | 1.7 |
| Mar 5 | .310 | .250 | 1.2 | .120 | .075 | 1.6 |
| Mar 19 | .165 | .050 | 3.3 | .300 | .100 | 3.0 |
| Apr 9 | .220 | .200 | 1.1 | .050 | .015 | 3.3 |
| Apr 23 | .070 | .020 | 3.5 | .040 | .010 | 4.0 |
| May 8 | .140 | .120 | 1.2 | .045 | .005 | 9.0 |
| May 21 | .100 | .045 | 2.2 | .050 | .010 | 5.0 |
| Jun 1 | .265 | .265 | 1.0 | .055 | .010 | 5.5 |
| Jun 10 | .200 | .110 | 1.8 | .290 | .140 | 2.1 |
| Jun 28 | .390 | .110 | 3.5 | .290 | .090 | 3.2 |
| Jul 16 | .450 | .190 | 2.4 | .470 | .160 | 3.0 |
| Aug 4 | .750 | .250 | 3.0 | .420 | .130 | 3.2 |
| Aug 23 | .100 | .030 | 3.3 | .070 | .090 | 0.8 |
| Sep 11 | .540 | .200 | 2.7 | .380 | .140 | 2.7 |
| Sep 24 | .035 | .015 | 2.3 | .040 | .020 | 2.0 |
| Oct 12 | .050 | .015 | 3.3 | .030 | .010 | 3.0 |

TABLE XVI

PHOTOSYNTHETIC PIGMENT ANALYSIS

| Pond and Date | CHLOROPHYLLS a (mg/M$^3$) | CHLOROPHYLLS b (mg/M$^3$) | CHLOROPHYLLS c (MSPU/M$^3$) | CAROTENOIDS Astacin (MSPU/M$^3$) | CAROTENOIDS Non-Astacin (MSPU/M$^3$) | Total Pigments (mg/M$^3$) |
|---|---|---|---|---|---|---|
| Little Muddy Pond | | | | | | |
| May 28 | 3.7454 | 1.9719 | 7.2208 | 1.3716 | 1.0954 | 15.4051 |
| Jun 19 | 6.5802 | 5.3174 | 17.5268 | 3.8529 | -1.2570 | 32.0203 |
| Jul 7 | 7.0236 | 5.7346 | 14.8152 | 3.8176 | -1.4328 | 29.9578 |
| Jul 23 | 51.1036 | 0.5736 | 24.6296 | -9.9435 | 36.5977 | 102.9610 |
| Aug 11 | 8.3782 | 1.4972 | 9.1836 | 0.5322 | 4.2177 | 23.8089 |
| Big Muddy Pond | | | | | | |
| Jun 10 | 2.3780 | 0.9988 | 3.6232 | 0.7270 | 0.0591 | 7.7861 |
| Jun 28 | 2.6694 | 0.3050 | 1.4324 | -0.0383 | 1.8994 | 6.2679 |
| Jul 16 | 4.3762 | 0.0000 | 3.1604 | -0.0131 | 2.3889 | 0.9124 |
| Aug 4 | 6.0451 | 0.0542 | 3.8494 | 0.5900 | 2.3026 | 12.8413 |
| Little Clear Pond | | | | | | |
| Jun 10 | 2.9000 | 2.6900 | 7.9888 | 1.8285 | -1.2675 | 14.1418 |
| Jun 28 | 1.9458 | 0.9352 | 1.9348 | 0.5908 | 0.7966 | 6.2032 |
| Jul 16 | 3.4772 | 0.0000 | 2.7576 | 0.3330 | 2.3416 | 8.9094 |
| Aug 4 | 2.8855 | 0.3368 | 2.2766 | 0.6188 | 1.7670 | 7.8847 |
| Big Clear Pond | | | | | | |
| Jun 5 | 0.8717 | 0.7251 | 2.1977 | 0.3470 | 0.2050 | 4.3468 |
| Jun 19 | 2.1928 | 1.0682 | 3.6974 | 0.9574 | 0.3120 | 8.2274 |
| Jul 7 | 2.8766 | 1.9354 | 3.5132 | 0.8650 | 0.9138 | 10.1040 |
| Jul 23 | 3.0160 | 0.1306 | 1.8432 | -0.1168 | 2.1458 | 7.0188 |
| Aug 11 | 6.6120 | 1.3032 | 6.5040 | -0.2777 | -3.7362 | 17.8777 |

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