SOME LIMNOLOGICAL FEATURES
OF GLADFELTER POND
June, 1965 - May, 1966

A Thesis
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by
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CHAPTER I

INTRODUCTION

Kansas has a total of 56,484 artificial farm ponds with an average surface area of one acre and an average depth of seven feet; of this total 2,957 were built in 1965. During that same year 53 ponds were constructed in Lyon County, making a total of 1,564 new ponds since 1940. The ponds have an average surface area of one acre and an average depth of twelve feet (Felkner, personal communication). The construction of these farm ponds, along with federal reservoirs and lakes, has stimulated interest in Kansas limnology by providing areas for study and compounding the need for more knowledge of freshwater impoundments.

This investigation was conducted to gain information concerning physicochemical and biological relationships in Kansas farm ponds. From June 5, 1965, to May 26, 1966, various physicochemical and biological features were measured in Gladfelter Pond. Water temperature, water level, calcium, sodium, potassium, hydrogen-ion concentration, specific conductance, alkalinity, dissolved oxygen, solar insolation, nitrate nitrogen, and orthophosphate were the physicochemical parameters recorded. The biological features studied were organic seston, chlorophyll, and primary productivity. The annual fluctuations of these limnological characteristics were compared.

It is the hope of the investigator that a better understanding of limnology of farm ponds in Kansas will be achieved through this study.

CHAPTER II

DESCRIPTION OF GLADFELTER POND

Gladfelter Pond, completed June 8, 1958, is approximately 14 miles northeast of Emporia, Kansas, (T18S, 57, R10E) on the F.B. and Rena Ross Natural History Reservation. The 200-acre reservation is in the eastern edge of the Flint Hills Upland in Lyon County. The pond lies in a ravine which runs northeast along a scrubby and wooded course (Figure 1). The watershed for the ravine and pond consists of 80 acres of rolling bluestem prairie, located in an area of dark, friable and silty to clayey soil.

The basin of the pond, situated between two hills, has a surface area of approximately 2.5 acres. It is in a region of grayish-brown, silty or gravelly soil three to four inches deep that occurs on hills with steep, rough, and broken slopes littered with limestone outcroppings and heavy gully erosion. The basin extends up two arms on the west side. The shoreline is irregular and is exposed during periods of low water as a sloping, silt-covered area, with only sparse aquatic or terrestrial vegetational cover (Figure 1).

Griffith (1961) reported that Gladfelter Pond, after construction, had a maximum depth of 20 feet. At present the maximum depth is approximately 15 feet, indicating that the pond is filling with sediment. During periods of heavy runoff, the water level is controlled by an overflow pipe extended through the body of the earthen dam and by an emergency spillway on the northeast corner of the basin. The pond, seldom at full capacity, undergoes frequent fluctuations in water level, simultaneous with wet and dry climatic conditions. Wave action, generally slight, tends to be somewhat greater when the wind is from a southwestwardly direction thus increasing turbidity along the shorelines. Ice cover may form in December, January, and February.

Vegetation surrounding the pond consists primarily of the dominates and subdominates found in the tall grass prairie association of the Flint Hills. These include *Andropogon gerardi*, *Andropogon scoparius*, *Sorghastrum nutans*, *Sporobolus asper*, *Bouteloua curtipendula*, *Bouteloua hirsuta*, *Bouteloua gracilis*, *Buchloe dactyloides*, *Panicum virgatum*, and *Elymus canadensis*. During construction of the pond, the dam and side spillway bank were seeded with bermuda grass, *Cynodon dactylon* (Hartman, 1960).

Figure 1. Aerial view of Gladfelter Pond showing location of sample site, May, 1966.

CHAPTER III

METHODS AND MATERIALS

Sampling was started on June 5, 1965, and was terminated on May 26, 1966. A single sampling station was selected approximately thirty feet west of the dam in the area of maximum depth of the pond. Samples were obtained weekly between 0900 and 1100 hours except during periods of unfavorable weather.

All water samples were taken with a Kemmerer water sampler. Top and bottom water samples were placed in plastic bottles and returned to the laboratory. Samples from the bottom were used to determine alkalinity, pH, specific conductance, chlorophyll, calcium, sodium, potassium, nitrate, and phosphate. Those from the top were analyzed for alkalinity, pH, and specific conductance. Ten liters of water from the top meter (equivalent to the euphotic zone, as estimated by a Secchi disc) were placed in a plastic carboy. A portion of this water was siphoned into a plastic bottle to be used for laboratory analyses of calcium, sodium, potassium, nitrate, phosphate, chlorophyll, and organic seston. The composite sample was also used in the estimation of primary productivity. Dissolved oxygen concentrations in the top, middle, and bottom meters of water were also determined.

Most of the chemical analyses were determined by methods described in Standard Methods for the Examination of Water and Sewage (APHA, 1961). Dissolved oxygen determinations were conducted by the unmodified Winkler method. A Beckman Zeromatic II (Model 9604) pH meter was used. Methyl orange and phenolphthalein alkalinity were obtained by titrating a 100 ml sample with N/50 sulfuric acid to the end points of pH 4.6 and pH 8.3, respectively. The results were then used to estimate the carbonate and bicarbonate values by the formulae described in Standard Methods (1961). Water samples, from which calcium, sodium, potassium, nitrate, and phosphate contents were determined, were cleared of all organic material by centrifuging in a Foerst plankton centrifuge and stored in a refrigerator until the analyses were made. A Coleman Model 21 flame photometer, with a Coleman Model 6 D Junior spectrophotometer as the readout, was used in measuring the calcium, sodium, and potassium levels in the water. Phosphate was measured colorimetrically by the stannous chloride method, and nitrate was determined by a modification of the brucine method as suggested by the Hach Chemical Company. A Model R C 12 Industrial Instruments conductivity bridge was used to measure the electrical resistance of the water. Specific conductance was then calculated from the reciprocal of the resistance and expressed as micromhos/cm at 25°C. Water temperatures were measured at intervals of one meter from the surface to the bottom with a Whitney Underwater Thermistor thermometer. Air temperature was determined before dropping the thermistor probe into the water. Water level was estimated by measuring the difference between the surface of the water and the top of the overflow pipe.

Organic seston was obtained by centrifuging a 500 ml sample from the composite sample in a Foerst plankton centrifuge operating at 20,000 rpm. Residue was removed to a preweighed procelain crucible which was placed in an electric drying oven at 65°C. After the residue and the crucible were dried, they were removed and weighed. The crucible containing the residue was then placed over a gas flame and brought to a red heat for a period of 30 minutes, after which it was cooled in a desiccator and weighed again. Weights were determined to the nearest .0001 gram on an Aloe chainomatic balance. Weight loss after heating multiplied by two was equal to the organic seston expressed in mg/liter.

Chlorophyll was used as an estimate of the abundance of phytoplankters. Five-hundred ml of water were centrifuged in a Foerst plankton centrifuge. Residue left in the centrifuge cup was transferred to a clean glass test tube, and then centrifuged in a clinical centrifuge for 10 minutes. Excess water was then decanted and 5 ml of 90 per cent acetone were added. The acetone extracted the chlorophyll from the phytoplankton during 24 hours in a refrigerator. Absorbances at 665, 645, and 630 mμ were read on a Beckman Model B spectrophotometer and used to estimate chlorophyll (chlorophyll with a peak absorbance at 665 mμ) by methods described by Richards with Thompson (1952).

Primary productivity estimates were made by the light and dark bottle method which was first described by Gaarder and Gran in 1927 (Ryther, 1956). Eight 250 ml glass-stoppered bottles were filled from the composite water sample, taking care to overflow each bottle to rid it of bubbles. Three of the bottles were clear (the light bottles), and three were painted black and covered with aluminum foil and masking tape (the dark bottles). The remaining two were used to determine the amount of oxygen present in the composite water at the beginning of incubation.

Paired light and dark bottles were suspended from a chain, held in a vertical position by a float and anchor, at three intervals. The paired light and dark bottles were suspended just below the surface and at depths of 0.5 and 1.0 meters. The bottles were allowed to incubate for a period of three to four hours. After incubation, the bottles were returned to the laboratory and the oxygen in each was measured. Oxygen values in the two start-bottles were averaged, giving an estimate of the average oxygen content in all the bottles at the beginning of the experiment. The decrease in oxygen in the dark bottles was used as a correction for community respiration. The oxygen increase in the light bottles was attributed to photosynthetic oxygen produced in excess of respiration. Gross primary productivity was calculated by subtracting the oxygen value in the dark bottles from the oxygen value of the light bottles. The results were expressed as the average rate of photosynthesis per liter per hour of euphotic zone.

Starting on July 11, 1965, solar insolation was recorded during the period of incubation of the primary productivity runs. An Eppley pyrheliometer was used to measure the intensity of direct solar radiation at normal incidence. A Bristols Model 570, 64 A-1ph Wide Strip Dynamaster recorder was used to record the measurements on a continually moving strip of calibrated paper. Solar insolation measured in gm-cal/cm^2/min was determined from the paper strips.

CHAPTER IV

RESULTS AND DISCUSSION

Temperature. The thermal conditions in Gladfelter Pond were subject to frequent and relatively rapid changes throughout the period covered by this study. The small surface area, shallow depth, and exposed location of the pond were probably the most important features which contributed to the variation in the thermal conditions. As would be expected, changes in water temperatures closely followed the pattern of air temperatures (Figure 2).

During hot, calm weather conditions, the surface water was subjected to rapid heating which resulted in the development of a marked difference between the surface and bottom temperatures. The inflow of spring water probably contributed to the thermal differences observed. Thermal profiles recorded during the warmer months of the year are shown in Figures 3 and 4. As can be seen in Figure 3, a thermocline was present at a depth of 1-2 meters on June 15. During the following weeks, the surface waters continued to heat and the difference between the surface and bottom temperatures became more marked. By July 11, there was a difference of more than 8°C between the top and bottom. On this date there was a relatively constant decrease in water temperature with increased depth. Thermal stratification persisted until late September.

Increased wind activity and decreasing air temperatures during early fall yielded a homothermous condition in the pond which continued into December. On December 18, an inverse thermal condition was noted.

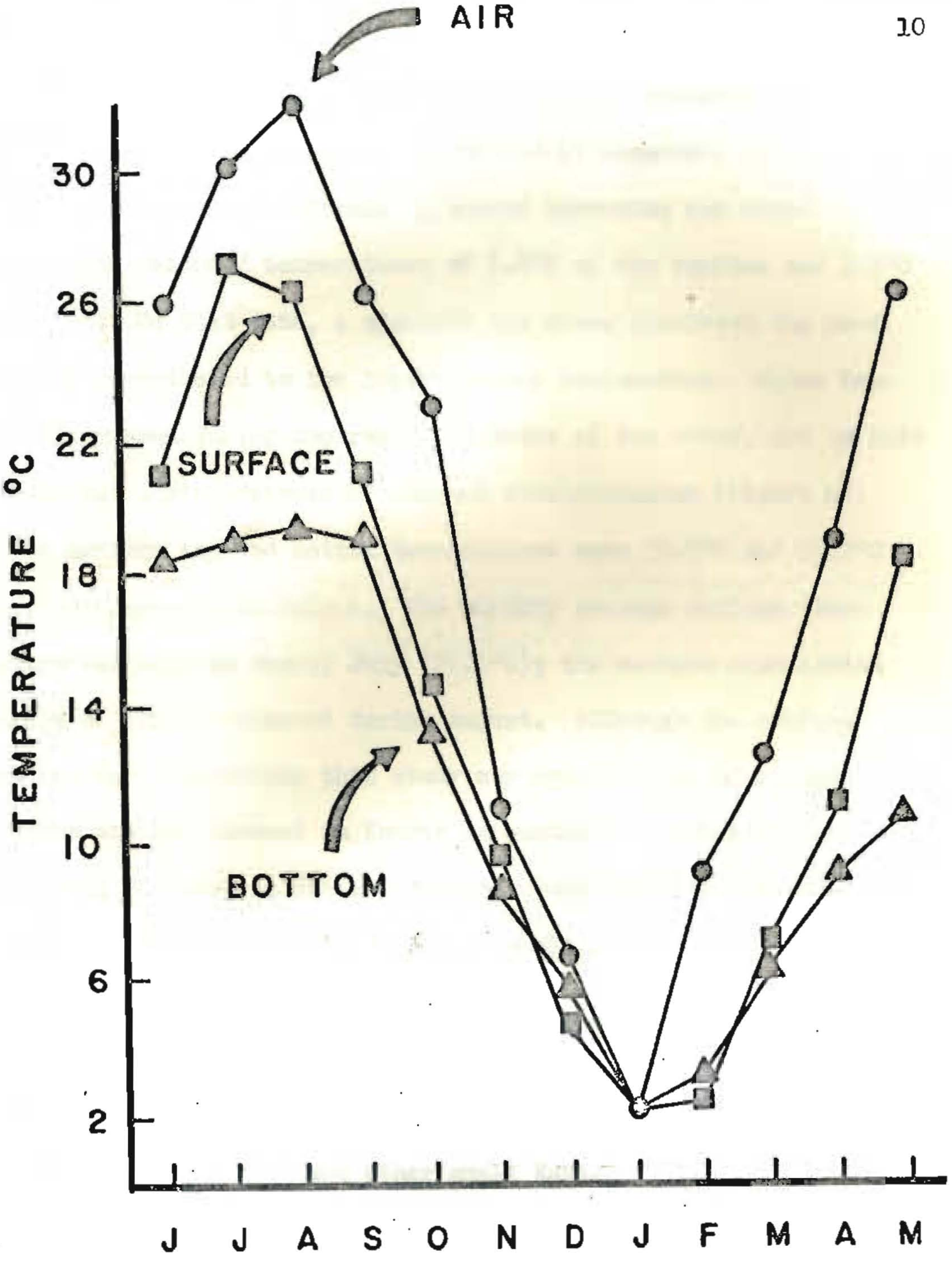
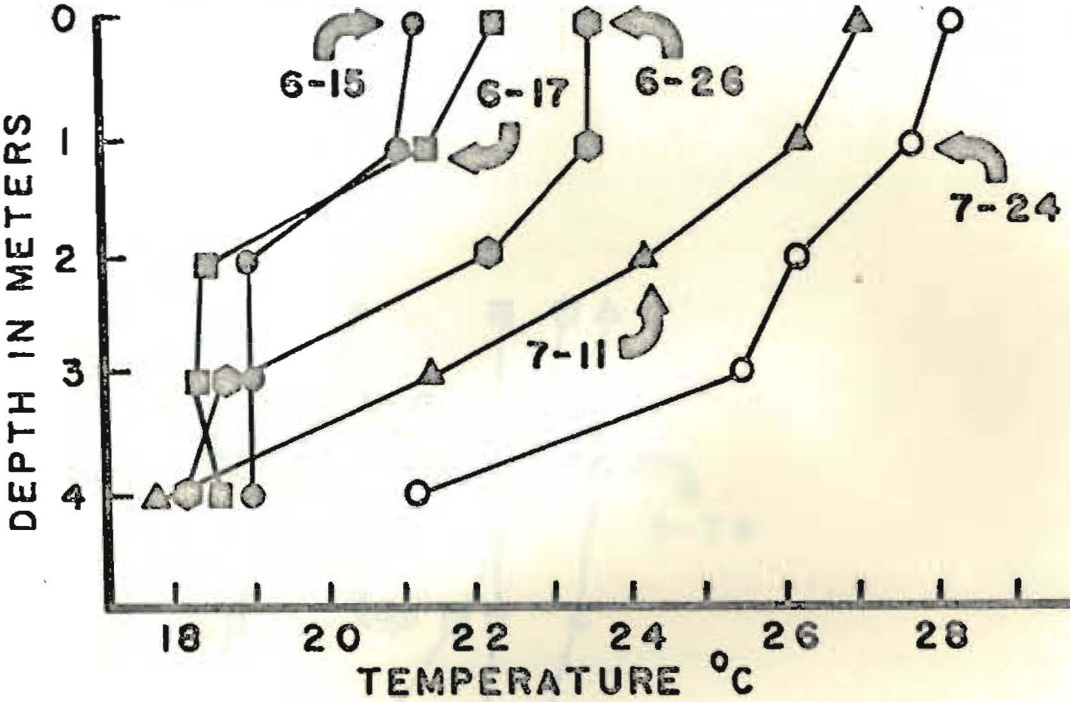


Figure 2. Monthly mean air, surface and bottom temperatures, June, 1965, to May, 1966.

This inversion was caused by a rapid decline in air temperature and the resultant cooling of the surface. By the end of December, the pond was again in a homothermous condition. A second inversion was noted on February 6 with recorded temperatures of 1.8°C on the surface and 3.2°C on the bottom. On that date, a six-inch ice cover blanketed the pond and probably contributed to the lower surface temperature. Water temperatures increased during the remaining weeks of the study, and by late April there was again evidence of thermal stratification (Figure 4).

The maximum top and bottom temperatures were 28.2°C and 21.2°C respectively, recorded on July 4. The monthly average surface water temperature was highest during July (27.4°C); the maximum mean bottom temperature of 19.1°C occurred during August. Although the surface temperatures recorded during this study may appear to be high, such temperatures are not unusual in Kansas impoundments. For example, Prophet (1964) reported an average surface temperature of 30°C during July, 1963, for Lyon County State Lake, a small lake located in north central Kansas.

The general pattern and duration of thermal stratification of Gladfelter Pond during this study was similar to that described in previous works on this pond and other small Kansas impoundments. Griffith (1961) recorded thermal stratification in Gladfelter Pond from the middle of May, 1959, through August, 1959. Kingsbury (1963) reported that Gladfelter Pond began to stratify in May and was fully stratified in June. The pattern of dissolved oxygen value observed during the current study has changed little from that reported by Kingsbury (1963).



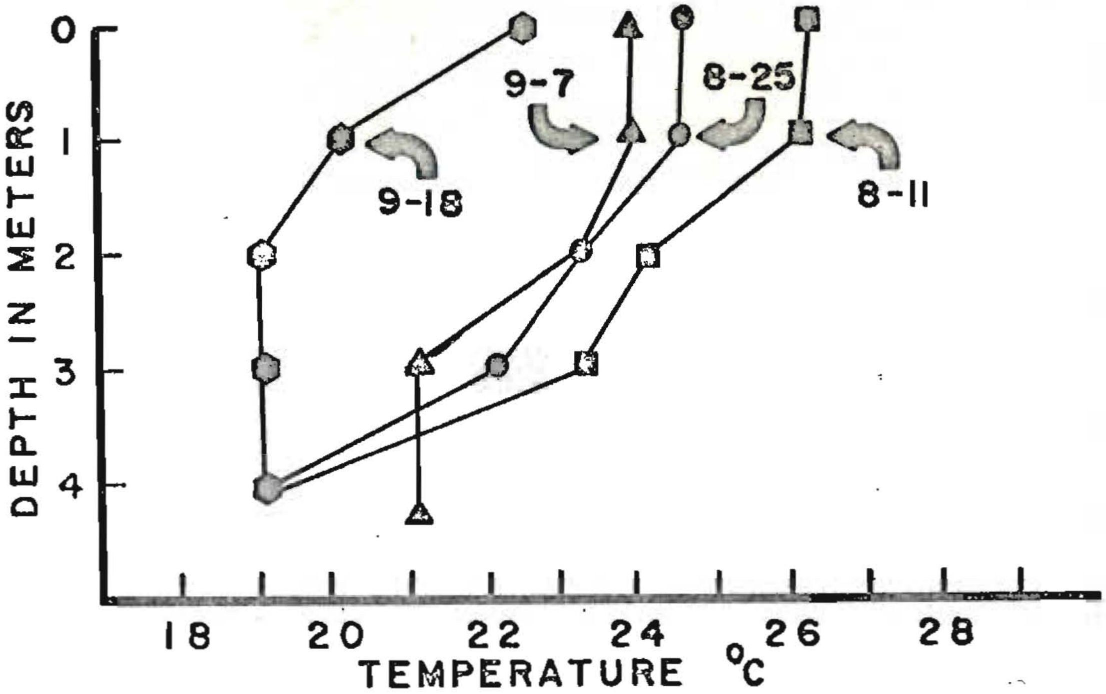


Figure 3. Thermal profiles detected during June to September, 1965. Each curve represents temperature variation with increased depths on selected dates.

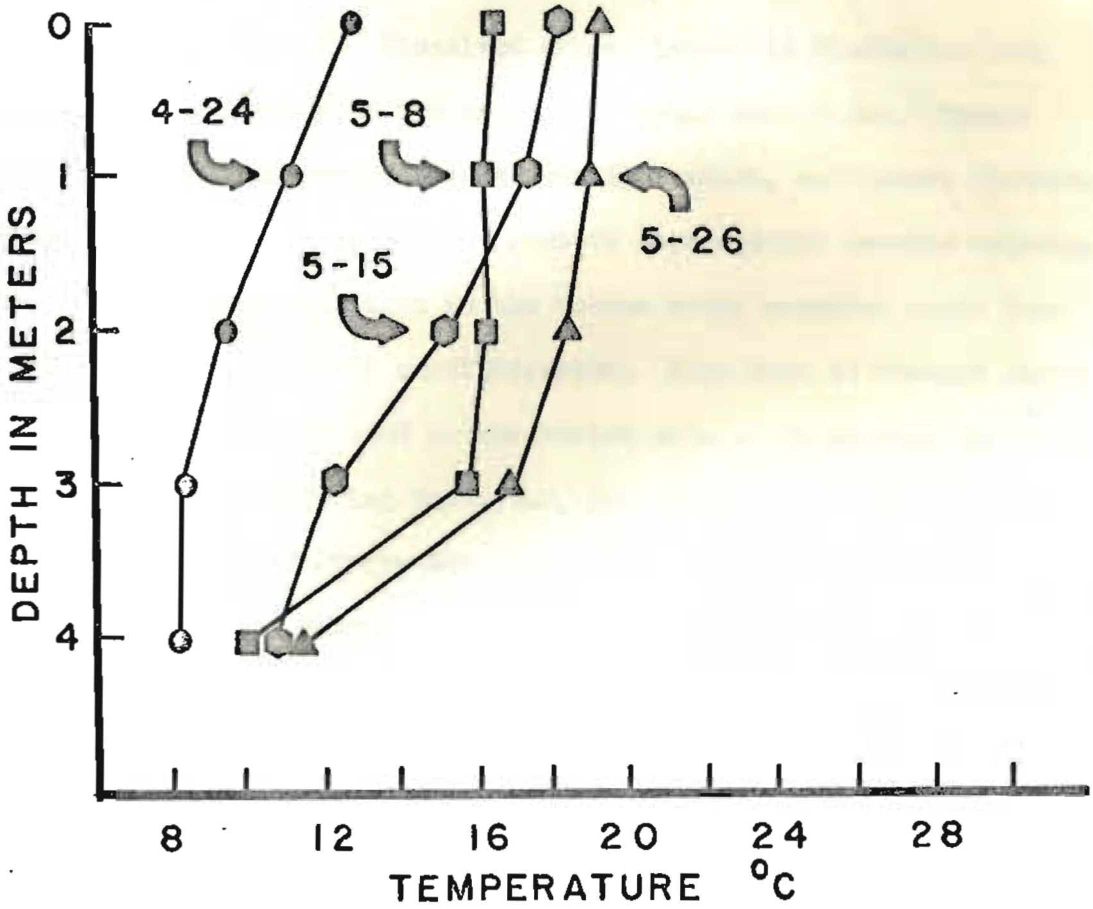


Figure 4. Thermal profiles during April and May, 1966. Each curve represents temperature variation with increased depths on selected dates.

Prophet (1964) and Schnittker (1966) reported that Lyon County State Lake tended to stratify in June and July. Tiemeier and Moorman (1957) found marked thermocline development persisting until August in eastern Kansas farm ponds.

Dissolved Oxygen. Dissolved oxygen levels in Gladfelter Pond were greatly influenced by the existing thermal conditions. Except during the period of summer thermal stratification, sufficient dissolved oxygen was present in the pond to sustain most aquatic aerobic organisms (Figure 5). Oxygen depletion in the bottom meter occurred eight days after the onset of thermal stratification. From June 13 through August 25, zero oxygen was detected in the bottom meter. As thermal stratification was destroyed during September, the amount of dissolved oxygen in the pond increased during the colder months to average 12 ppm or more at all depths during February. Kingsbury (1963) reported similar trends in oxygen throughout her study of Gladfelter Pond.

Depending upon the thermal conditions, depth, and turbidity, dissolved oxygen in many small impoundments may be decreased to critical levels throughout much of their depth. During such times, aerobic organisms would be forced to move into the oxygenated surface waters. Factors such as crowding and exposure to higher temperatures could have serious effects upon a pond's biota. According to Lagler, 1956, in reference to pollution of streams, The Aquatic Life Advisory Committee (1955) defined the dissolved oxygen criterion for habitats of warm water fishes as not less than 5 ppm for a period exceeding 16 hours of any 24 hour period and at no time being less than 3 ppm. To sustain coarse

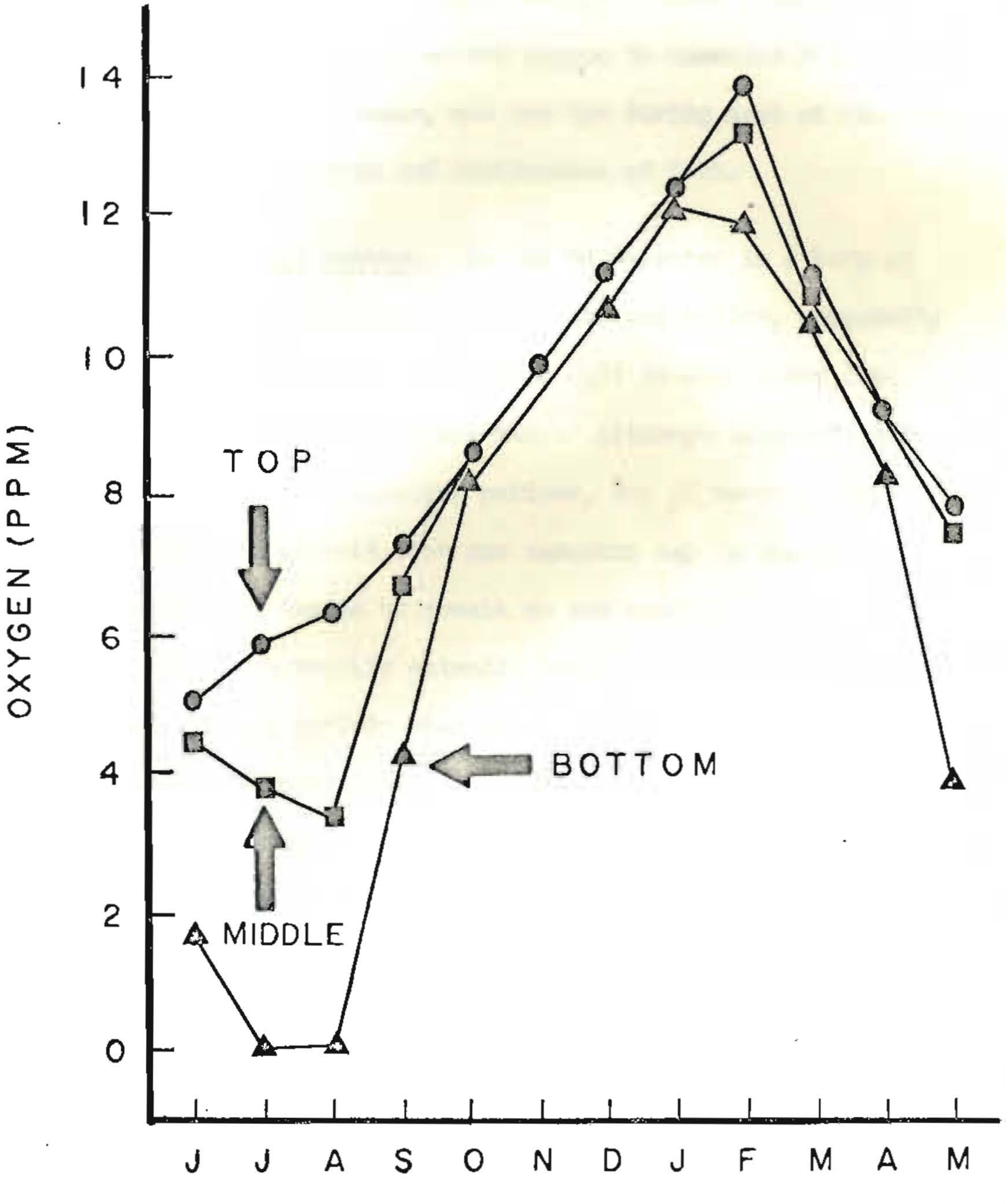


Figure 5. Dissolved oxygen in the top, middle and bottom meters of Gladfelter Pond, June, 1965, to May, 1966.

fish the value could drop below 5 ppm, but never below 2 ppm. Tiemeier and Moorman (1957) found that dissolved oxygen in numerous Flint Hills farm ponds near Manhattan, Kansas, was too low during most of the summer to be conducive to good growth and development of fish.

Hydrogen-ion Concentration. As can be expected in a body of water containing a relative abundance of dissolved solids, especially carbonates, the hydrogen-ion concentration ($_pH$) in Gladfelter Pond remained fairly stable throughout the year. Although slight fluctuations were observed between sampling periods, the $_pH$ never changed more than a few tenths of a $_pH$ unit from one sampling day to the next. Throughout the year $_pH$ tended to remain on the alkaline side.

Variations in $_pH$ usually extended throughout the entire depth of the pond, except during periods when free circulation occurred. Subsequently, the maximum values determined for the top and bottom meters were obtained on different sampling dates as were the minimum $_pH$ values. The highest $_pH$ value of 8.3 for the top meter was recorded on May 8, while the high for the bottom meter of 8.3 was observed on March 13. The minimum $_pH$ values of 7.4 for the top meter and 6.8 for the bottom meter were recorded on September 26 and July 16, respectively.

The $_pH$ values obtained in Gladfelter Pond are comparable with values obtained in other eastern Kansas artificial impoundments. Most of the values reported tend to be slightly alkaline due to the vast amount of limestone found in the area. Minter (1952) and Carter (1954) reported hydrogen-ion concentrations in Lake Wooster on the campus of Kansas State Teachers College in an inclusive range of 7.4 to 8.8.

Tiemeier and Elder (1957) noted $_pH$ values from 6.8 to 10.6 during May through September in ponds located in the Flint Hills.

In general, bottom $_pH$ values in Gladfelter Pond were low in the summer months, increasing during the winter months. Hydrogen-ion concentrations were usually higher in the bottom meter than in the top meter during the summer, with the opposite being true for the winter. Increased acidity in the bottom regions of eastern Kansas impoundments during the summer has been reported by other workers. Differences in pH, as much as .65 units, were observed between the top and bottom depths in Lyon County State Lake during thermal stratification (by Schnittker, 1966). A decrease in $_pH$ with depth during stratification was also reported in Lyon County State Lake (by Youngsteadt, 1965).

Most natural waters containing buffering agents tend to be in a pH range of 6.5 to 8.5 (Welch, 1952). When the $_pH$ extends to the extreme upper and lower portions of the pH scale, it usually limits the productivity of the water. Ordinarily, aquatic organisms, such as fish, can tolerate wide ranges and rapid changes in the acidity and alkalinity as expressed by the $_pH$ scale. Therefore, the $_pH$ of the water in Gladfelter Pond during this study was probably favorable for the growth and development of aquatic organisms (Lagler, 1956).

Alkalinity. Carbonate alkalinity was not detected in Gladfelter Pond during this study, therefore, bicarbonate alkalinity represents total alkalinity. However, carbonates have been noted in this pond by other workers. Griffith (1961) detected slight amounts during the months of January, March, and May, 1961, and Kingsbury (1963) reported

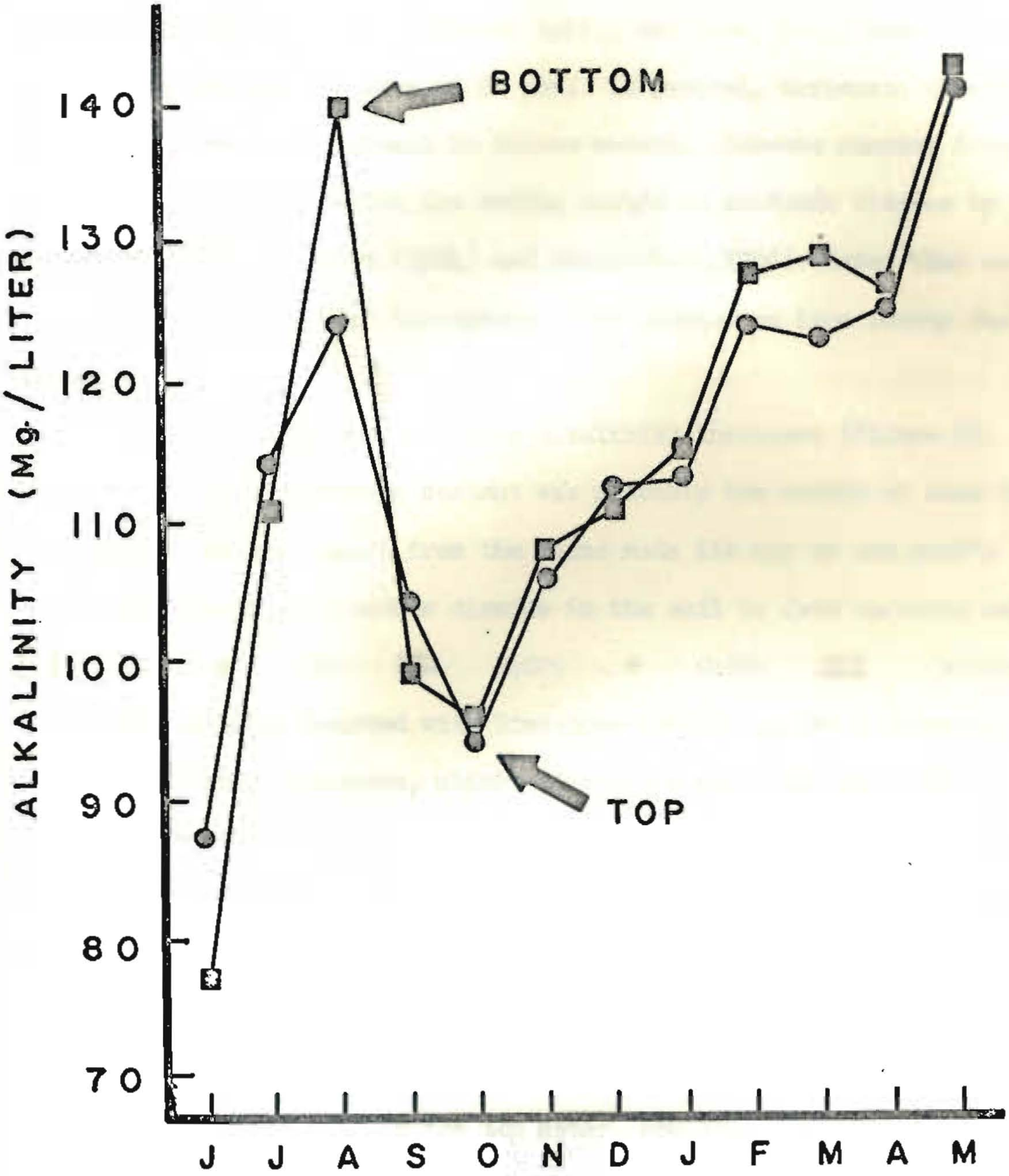


Figure 6. Monthly means of alkalinity in the top and bottom meters of Gladfelter Pond, June, 1965, to May, 1966.

carbonate alkalinities in February, April, and June, 1963, with a maximum monthly average for June of 20 ppm. In general, carbonate alkalinity tends to be low or absent in Kansas waters. Amounts ranging from 1 to 26 ppm were found during the spring months in roadside ditches by Ratzlaff (1952). Prophet (1964) and Schnittker (1966) stated that carbonates tended to be zero throughout their studies on Lyon County State Lake.

Throughout the summer months alkalinity increased (Figure 6). The rise in the bicarbonate content was probably the result of June and July rains. As the runoff from the rains made its way to the pond's basin, it reacted with carbon dioxide in the soil to form carbonic acid.

[1] $CO_2 + H_2O \rightleftharpoons H_2CO_3 + CaCO_3 \rightleftharpoons Ca(HCO_3)_2$

This acid, in turn, reacted with limestone ($CaCO_3$) in the drainage area to form calcium bicarbonate, which entered the pond and increased the alkalinity content. Free carbon dioxide from biological activity could also have contributed to the rise in alkalinity through the formation of carbonic acid which reacted with calcium carbonate to form calcium bicarbonate.

During the first two months of the study alkalinity tended to be lower in the bottom than in the top meter, however, by August the bottom alkalinity had exceeded that in the top meter (Figure 6). A difference of 16 ppm between the top and bottom monthly means was observed during that month, the greatest difference between alkalinities in the top and bottom meters for the year. The inversion of the top and bottom alkalinities in August was probably the result of calcium carbonate precipitation originating in the euphotic zone. This was probably produced by the removal of carbon dioxide by phytoplankters, shifting the equilibrium of the equation [2] to the right, and causing

$$[2] \quad Ca(HCO_3)_2 \rightleftharpoons CaCO_3 + CO_2 + H_2O$$

the formation and precipitation of calcium carbonate. Due to the more acid water in the bottom depths from the build-up of carbon dioxide from respiration and decomposition, the carbonates redissolved resulting in an increase in alkalinity.

During the fall overturn in September alkalinity became reduced in the pond, with the bottom alkalinity being lower than the surface alkalinity (Figure 6). Bicarbonate concentrations continued to decrease in October, at which time they were relatively uniform from top to bottom. This drop was probably the result of escaping equilibrium carbon dioxide from the system by aeration of the water through circulation and by its assimilation in the photosynthetic processes of algae. Calcium carbonate was then removed from the system through precipitation to the bottom sediments (Ruttner, 1953). Bicarbonate alkalinity rose sharply in November and this trend continued throughout the remainder of the study, being relatively higher in the upper stratum of water throughout the winter and spring months.

Calcium, Sodium, and Potassium. Although sodium and potassium are not considered limiting to productivity in natural waters, each of the ions are important in the biological aspect of such waters. According to Welch (1952), sodium may serve the role of a conserver of, and replacement for, potassium, and an aid in the availability of potassium for green aquatic plants. It may also be an antidotal agent for strong single-salt solutions in aquatic habitats (Reid, 1961). In some cases, potassium inhibits growth in the absence of sodium (Lewin, 1962). Potassium is required by most green aquatic plants, since it is used in food manufacture and as a catalyst (Welch, 1952). Usually, productivity is not limited by potassium in natural freshwaters. Barrett (1957) showed that production of algae increased the same when treated with phosphorus and nitrate or with phosphorus, nitrate, and potassium.

Sodium and potassium concentrations in Gladfelter Pond were lower than those reported in Lyon County State Lake by Schnittker (1966). He stated the maximum monthly mean as 9.0 ppm for potassium, while during this study it was 4.0 ppm. Sodium approximated 5.0 ppm in Gladfelter Pond during the year; the maximum mean reported by Schnittker (1966) for Lyon County State Lake was 18 ppm. Potassium contents of most natural lakes in the United States ranges from 0.2 to 3 ppm (Barrett, 1957). In normal freshwaters, sodium concentrations are usually higher than potassium concentrations (Reid, 1961).

Values for sodium were always higher in the top meter than in the bottom meter of Gladfelter Pond. Potassium fluctuated greatly between the top and bottom meters. Potassium was higher in the bottom meter during the months of February and May and between the months of July through October (Figures 7 and 8).

Trends in calcium concentrations reflect those observed for alkalinity and specific conductance. Since calcium was allied with the bicarbonate-carbonate system, factors affecting alkalinity also pertain

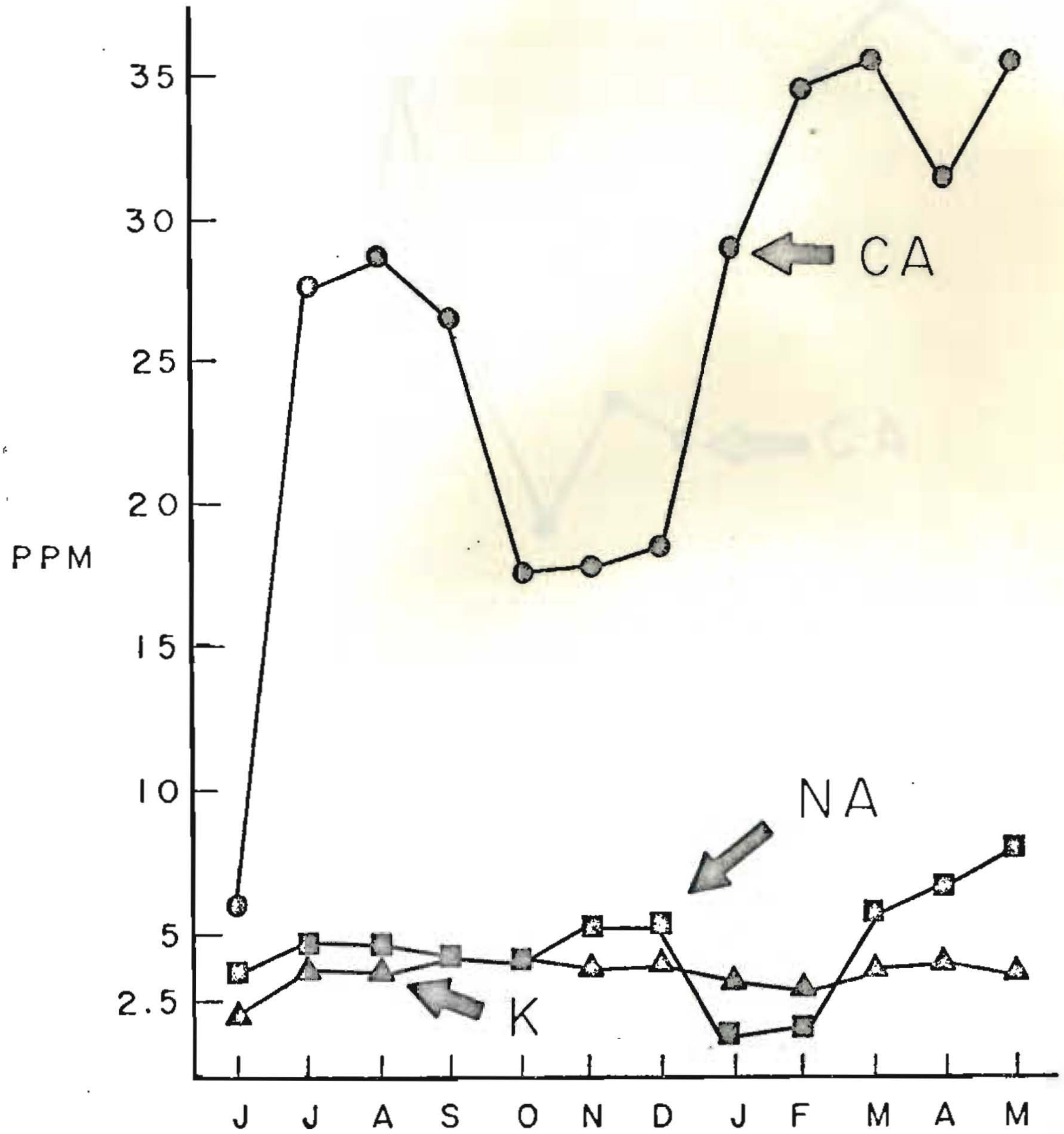


Figure 7. Calcium, sodium, and potassium monthly means in the top meter of Gladfelter Pond, June, 1965, to May, 1966.

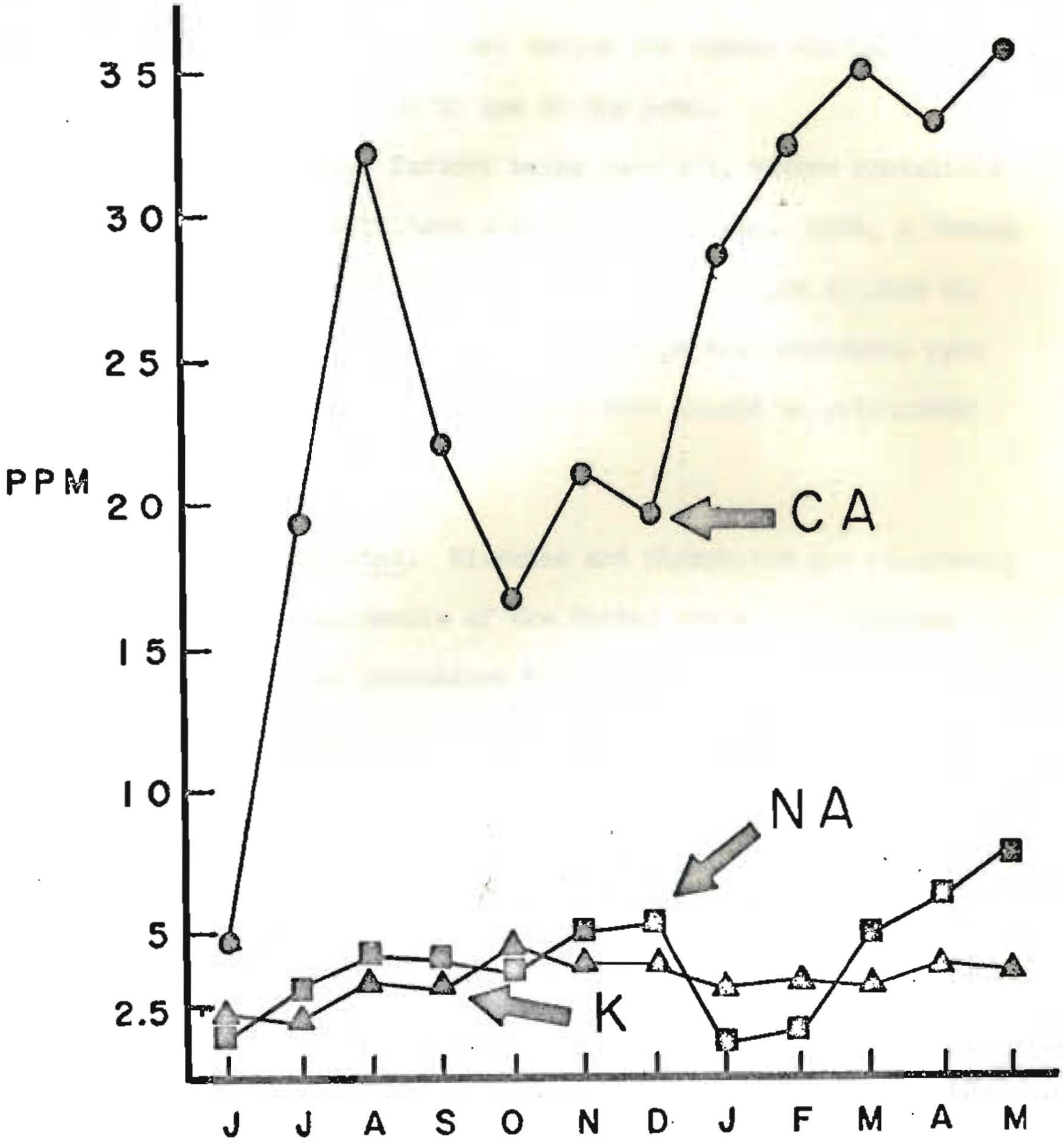


Figure 8. Calcium, sodium, and potassium monthly means in the bottom meter of Gladfelter Pond, June, 1965, to May, 1966.

to calcium. Due to the entry of calcium bicarbonate with precipitation runoff the calcium content was higher during the summer months. During that time, calcium approximated 30 ppm in the pond.

Generally, with other factors being constant, waters containing large amounts of calcium will have a high productivity. Ohle, a German limnologist, classified lakes containing more than 25 ppm as rich in production. Any lake containing less than 10 ppm was considered poor in production (Moulton, 1939). Gladfelter Pond should be relatively productive.

Nitrates and Phosphates. Nitrates and phosphates are relatively scarce in freshwater impoundments of the United States. Hutchinson (1957) stated that soluble phosphates usually range from .001 to .208 ppm in uncontaminated lake waters. The mean phosphate content for most lake waters in the United States is from .01 to .3 ppm, and nitrate concentrations are in the range of .1 to 2.0 ppm. Nitrates were more abundant in Gladfelter Pond than phosphates (Figure 9). Mean nitrate levels ranged from .199 to .894 ppm in the top meter. Phosphate means in the top meter varied from .041 to .351 ppm. The mean ranges for both nutrients were lower in the bottom meter than in the top meter (Figures 9, 12, and 13).

Although the maximum-minimum values for phosphates were higher in the top meter than in the bottom meter, the phosphates tended to be more concentrated in the bottom region. Mean phosphate values were highest in the top meter only during the months of July, October, January, and

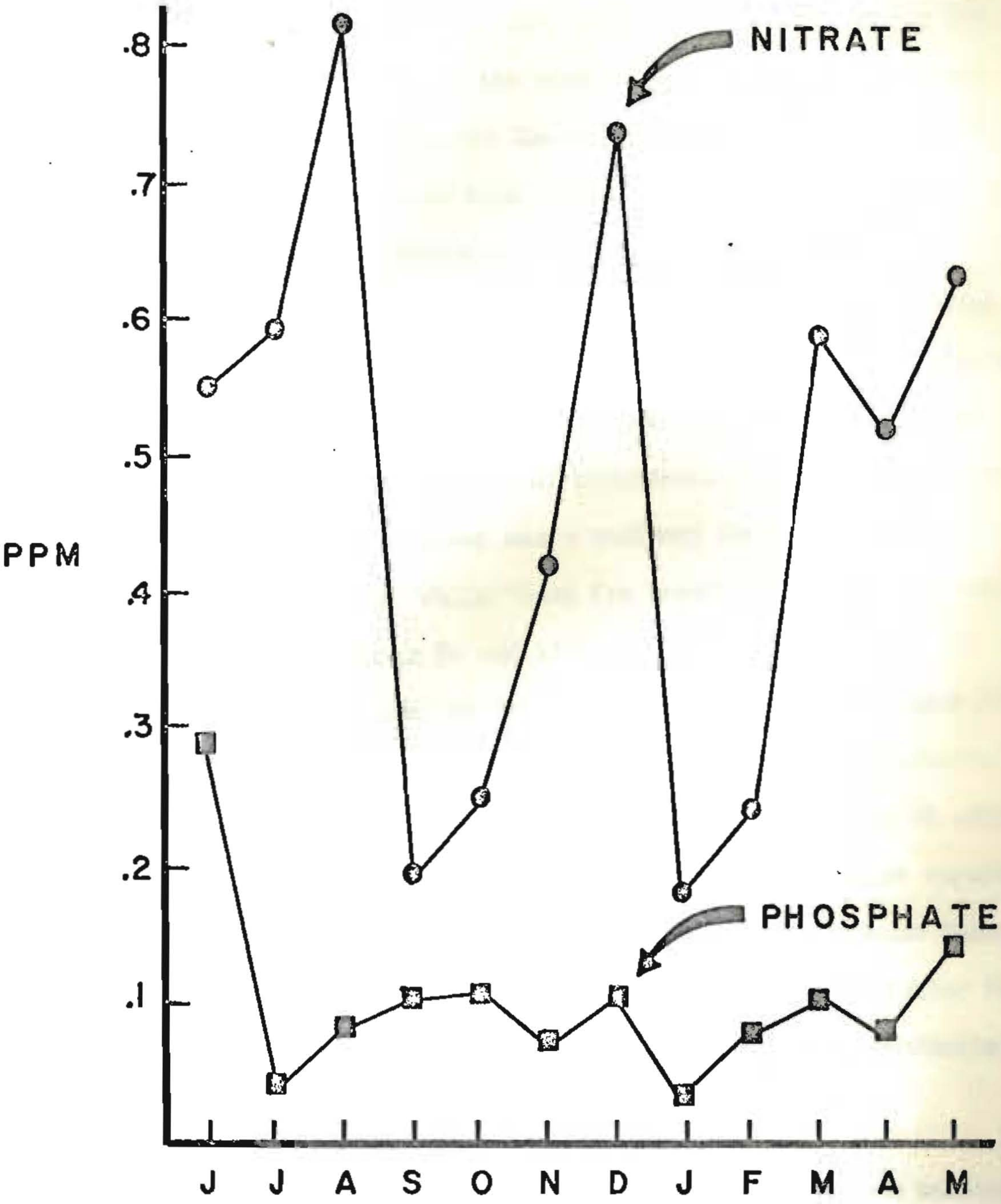


Figure 9. Nitrate and phosphate monthly means in the bottom meter of Gladfelter Pond, June, 1965, to May, 1966.

May. This was probably because of less biological demand for the nutrient in the decomposition zone of the pond, allowing for its build-up.

Nitrates and phosphates are the primary limiting nutrients for producer organisms. Amounts of both nutrients in the pond tended to be low when chlorophyll and primary productivity values were high, except during the winter (Table III). Since algae assimulate more nutrients during periods of maximum production, usually in the summer, low amounts of both nutrients can be expected during that time. Changes in nitrates were more prominent than were those of phosphate. Although cycles were not measured in this study, there was a tendency for high and low nitrate fluctuation weekly, while those for phosphates alternated every three to four weeks (Figures 12 and 13).

Phosphate has appeared to increase in Gladfelter Pond since 1963. Kingsbury (1963) reported a range of .006 to .250 ppm for her study. During the period of this study, phosphate varied from a mean of .041 to .351 ppm. These concentrations were also higher than those reported in Lyon County State Lake by Prophet (1964) and in John Redmond Reservoir by Thomas (1964). Nitrates tended to be higher in Gladfelter Pond than the average of .5 ppm recorded for most freshwater impoundments in the United States (Moulton, 1939).

Specific Conductance. Since specific conductance is a measure of the ionizable solids in the water, measurements of dissolved solids in Gladfelter Pond correspond to measurements of specific conductance. Throughout most of June and July, heavy rains filled Gladfelter Pond to overflowing, causing a sharp increase in specific conductance due to the entry of materials in the pond with runoff water (Figure 10). The increase in specific conductance corresponded with an increase in calcium, sodium, potassium, phosphate, and alkalinity. Of all the dissolved ions measured in this study, none more closely paralleled specific conductance than alkalinity (bicarbonates) and calcium (Figures 6, 7, and 10).

Specific conductance was comparable to values obtained by Kingsbury (1963) for Gladfelter Pond. Readings for her study ranged from 162 to 353 microhmos/cm from November, 1962, to June, 1963. Values for this study ranged from 172 to 316 microhmos/cm in the top meter. Specific conductance was considerably lower in Gladfelter Pond than in Lyon County State Lake during refilling. Prophet (1964) observed means in the top meter ranging from 270 to 624 microhmos/cm with little difference between the surface and bottom. A maximum of 775 microhmos/cm and a minimum value of 493 microhmos/cm were reported for Lyon County State Lake by Schnittker (1966).

Dissolved ion concentrations are of extreme importance since their limitation greatly decreases the productive capacity of any aquatic ecosystem. Waters which contain large amounts of electrolytes should be highly productive, other influences being constant.

Solar Insolation. Measurements of solar insolation began on July 11, 1965. The measurement period ran concurrently with the incubation period for primary productivity between 0900 and 1100 hours. Solar insolation readings were found to parallel the seasonal changes in the sun's position. As the angle of incidence decreased during July through

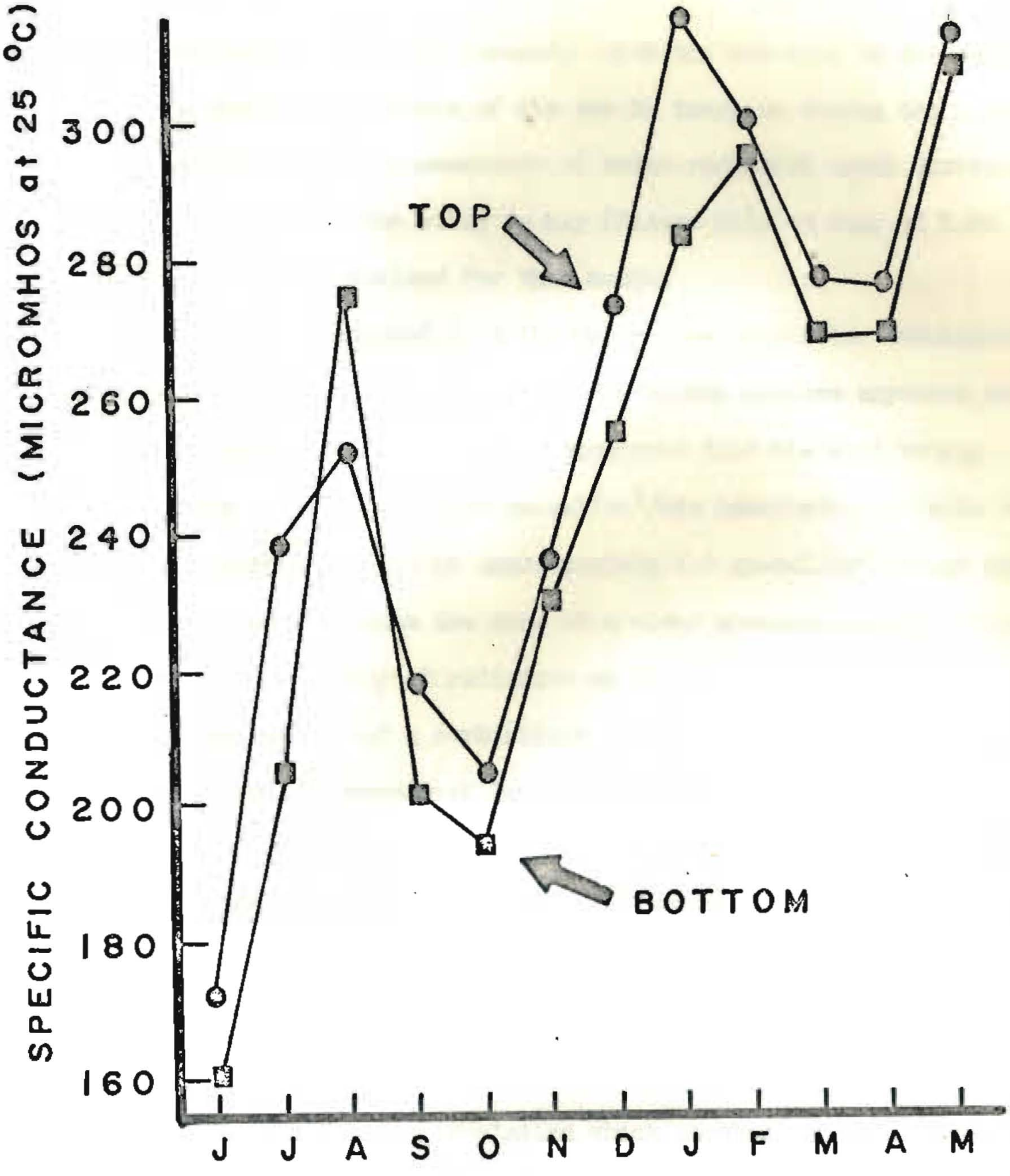


Figure 10. Monthly mean specific conductance values in the top and bottom meters of Gladfelter Pond, June, 1965, to May, 1966.

December, solar radiation was lowered. With the rotation of the earth causing the angle of incidence of the sun to increase during the late fall and spring months, measurements of solar radiation again increased, reaching the highs for the study in May (Figure 14). A mean of 1.26 gm-cal/cm^2/min was determined for that month.

Kimball (1919) stated that the general maximum solar insolation on a cloudless day was 1.71 gm-cal/cm^2/min on the surface anywhere in the United States. Edmondson (1956) suggested that the most widely accepted solar constant was 1.94 gm-cal/cm^2/min immediately outside the atmosphere, reaching a high of approximately 2.0 gm-cal/cm^2/min on the surface of the earth. When the edge of a cloud approaches near a direct solar beam, the intensity of radiation on the ground may exceed 2.0 gm-cal/cm^2/min because of a combination of direct radiation, plus scattered radiation. An average of 1.5 gm-cal/cm^2/min has been determined for the earth's surface at sea level (Reid, 1961). The highest daily average obtained during this study was 1.39 gm-cal/cm^2/min on April 24. An estimated 15 per cent cloud cover was observed on that date. The high was probably a result of a build-up of radiation caused by the 'greenhouse effect' produced by the cloud cover.

Not all of the solar insolation which strikes the earth's surface enters the surface of the water. The amount that does enter is dependent upon the altitude of the sun, surface roughness, and cloud cover. Of the total amount of solar light that strikes the surface of the water, approximately 95 per cent penetrates the surface (Ryther, 1956b). After penetrating the air-surface interface, the depth at which the light travels is determined by coloration and turbidity. In most natural waters, approximately 53 per cent of the light which enters through the surface is transformed into heat in the first meter. Over 50 per cent of the total light which strikes the surface is absorbed within a depth of two meters (Reid, 1961). Since Gladfelter Pond was highly turbid throughout most of the year, light penetration seldom reached below one meter in depth. The lack of effective light in the deeper water was probably the cause of a more effective, quicker thermocline formation since the water was not warmed at the lower depths.

Solar radiation is of extreme importance to the aquatic ecosystem as a maintainer of phytosynthetic activity of producer organisms. Low levels of radiation in natural waters can be a limiting factor in production. Such levels are produced by ice cover, coloration and turbidity of the water, overcrowding of plankton organisms, decreased solar intensities during the winter, or a combination of these factors. Ryther (1956b) found that light was a limiting factor of photosynthesis in ocean waters. Solar insolation probably directs seasonal changes in the rate of production by limiting the population density of algae during times of low light intensities.

<u>Gross Primary Productivity</u>. Primary productivity as defined by Odum (1959), is the rate energy is stored by photosynthetic and chemosynthetic activity of producer organisms (chiefly green plants) in the form of organic substances which can be used as food materials. Gross primary productivity (P_g) is the total rate of photosynthesis including the organic matter utilized in respiration by the community during the

measurement period; whereas net productivity is the rate of production in excess of respiration. In general, the productivity of an aquatic ecosystem refers to its 'richness'.

Since primary productivity in Gladfelter Pond was determined by the light-dark bottle method, it refers to photosynthetic activity by the phytoplankton, due to the exclusion of higher submerged and floating plants in the measurement procedure. Due to the scarcity of emergent and submergent vegetation types in Gladfelter Pond, primary productivity was almost totally from phytoplankton. Primary productivity was determined in the euphotic zone as a reference for the entire depth and shore region of the pond. Primary productivity is expressed herein as the average gross primary productivity/liter per hour of euphotic zone, although some net productivity did occur. Net primary productivity was usually greatest during times of high gross primary productivity. Community respiration was found to vary directly with gross primary productivity, being high in periods of high production and low in times of low production. Respiration never exceeded gross production during any measurement made throughout the study, although there were measurements taken when respiration equaled production.

Gladfelter Pond was found to be less productive than other fresh water impoundments in eastern Kansas. Throughout the length of this study, gross primary productivity ranged from 0.0 to 275 µg O_2/liter/hour. Prophet (1966) found that Pg ranged from 17 to 483 µg O_2/liter/hour during a study from May, 1964, to February, 1966, on John Redmond Reservoir. Gross primary productivity values ranging from 50.0 to

437.5 µg O_2/liter/hour were obtained by Thomas (1964) in John Redmond Reservoir during the summer of 1964. Of the total estimations taken during this study, only 23.7 per cent were found to be above 100 µg O_2/liter/hour, which was considerably lower than the approximate 75 per cent over 100 µg O_2/liter/hour reported by Prophet (1966) for John Redmond Reservoir. Lyon County State Lake was also found to be higher in production than Gladfelter Pond. Youngsteadt (1965) reported net primary productivity averaging as high as 129 µg O_2/liter/hour during July, 1965, which was approximately three times greater than gross primary productivity in Gladfelter Pond for the same month (Table III). Prophet, Youngsteadt, and Schnittker (1966) reported 52.6 per cent of their total photosynthesis estimations exceeded 200 mg O_2/M^2/hour in Lyon County State Lake from April through March, 1966. This was also considerably higher than production values recorded for Gladfelter Pond. Of the total measurements for Gladfelter Pond, 5.2 per cent exceeded 200 µg O_2/liter/hour. Gross primary productivity can be relatively high depending on environmental and biological factors. Primary productivity measurements as high as 18,883 µg O_2/liter/hour were reported by Hepher (1962) in unfertilized fish ponds in Israel.

As can be seen in Figure 14, Pg monthly means increased during the summer months to reach the peak for the study in September. This increase was simultaneous with a rise in chlorophyll estimates which indicated a build-up of the algal community. High production in September was probably enhanced by the increase of phytoplankton populations. During this same period, phosphate and nitrate levels dropped due to their uptake by algae (Figures 12 and 13). Increases in the photosynthetic activity of algae during the late summer has been noted by other workers. Prophet (1964) and Youngsteadt (1965) found Pg high during July and August in Lyon County State Lake. Thomas (1964) reported highs in John Redmond Reservoir during July.

Due to decreasing amounts of solar insolation (Figure 14) and nitrates (Figure 12) the algal populations quickly diminished during October (Figure 11) causing a decrease in Pg. With the enrichment of the water from decaying plankton cells, phosphate increased during the last of October (Figure 13) to reach the monthly high for the study. As can be seen in Figure 14, Pg continued to decrease during the winter. Although chlorophyll concentrations were relatively high during December and January, primary productivity remained low (Figure 11). It is felt that solar radiation was a possible limiting factor during those months. Wright (1960) stated that increased phytoplankton populations do not necessarily mean increased productivity. Ryther (1956) and Odum, McConnell, and Abbott (1958) believed overcrowding of algae communities reduced light by shading of the organisms themselves.

Variations in primary productivity fluctuated directly with trends in chlorophyll for the remainder of the study. The maximum fluctuation in chlorophyll and primary productivity occurred in April when both exhibited extreme lows (Figure 10). This was probably the result of low levels in nitrates and phosphates (Figures 12 and 13).

As was expected and evident during this study, primary productivity was influenced by changes in the algal populations. The algal

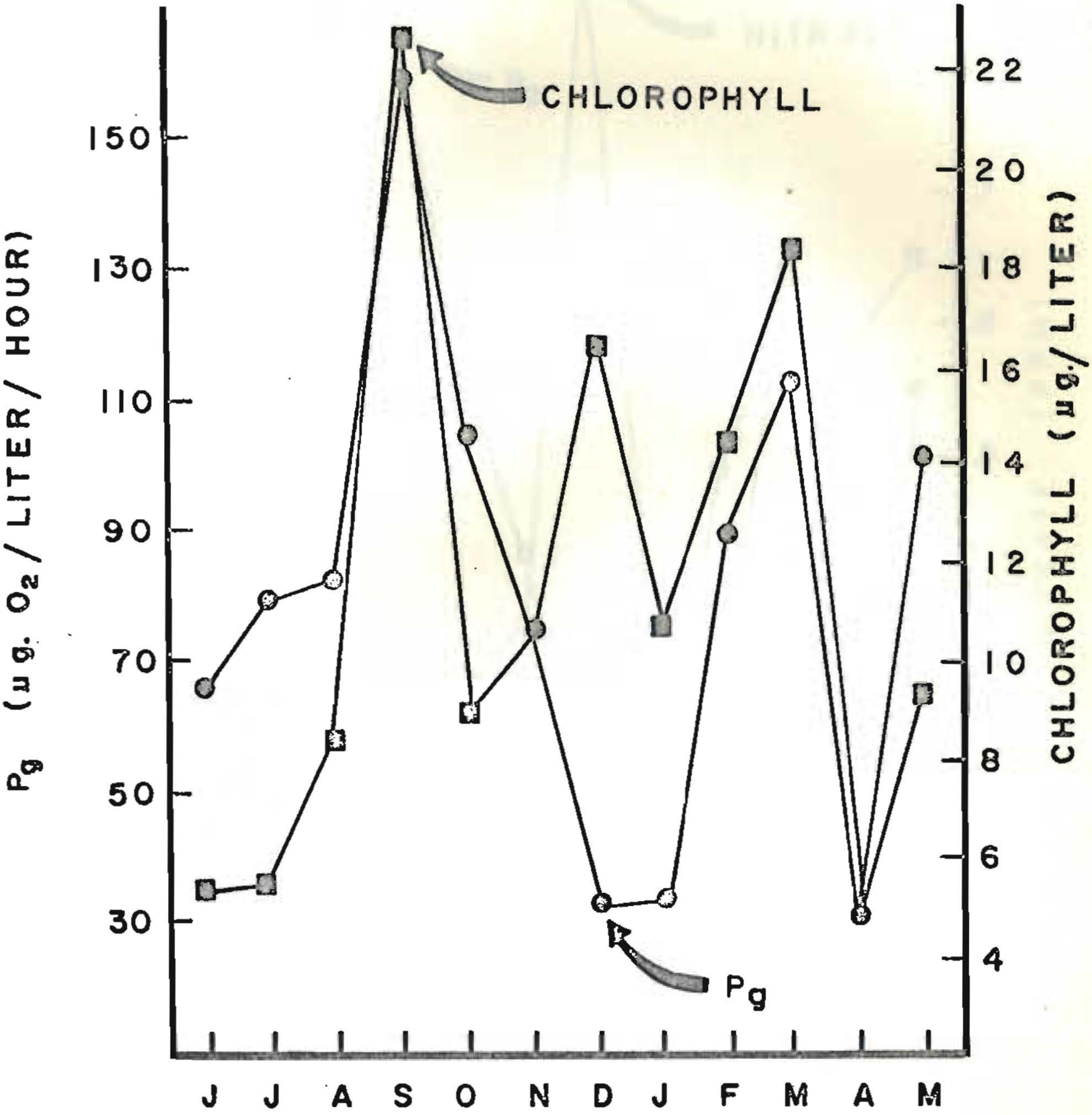


Figure 11. Monthly mean gross primary productivity and chlorophyll$_a$ estimates in the euphotic zone of Gladfelter Pond, June, 1965, to May, 1966.

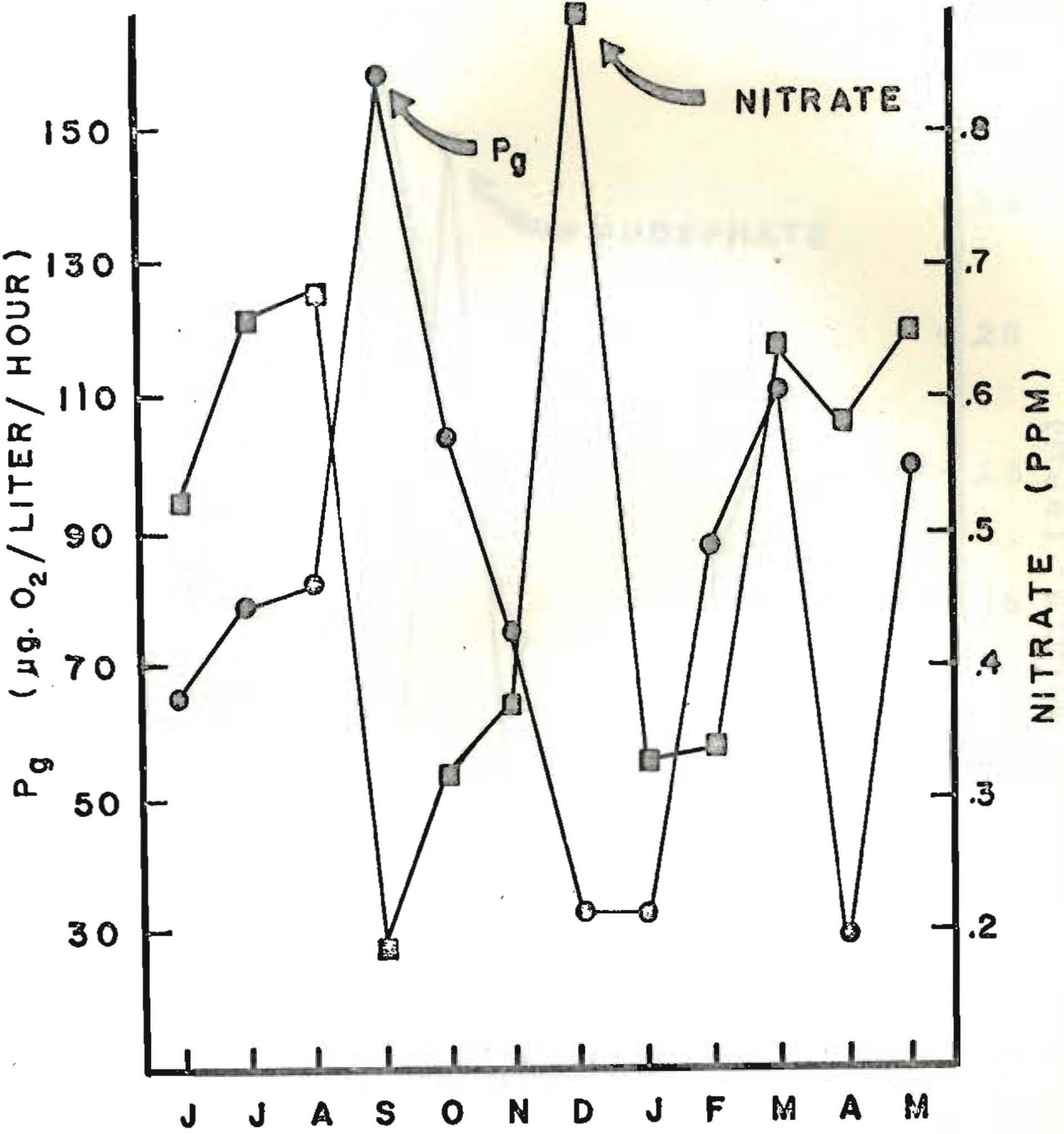


Figure 12. Monthly mean estimates of gross primary productivity and nitrates in the euphotic zone of Gladfelter Pond, June, 1965, to May, 1966.

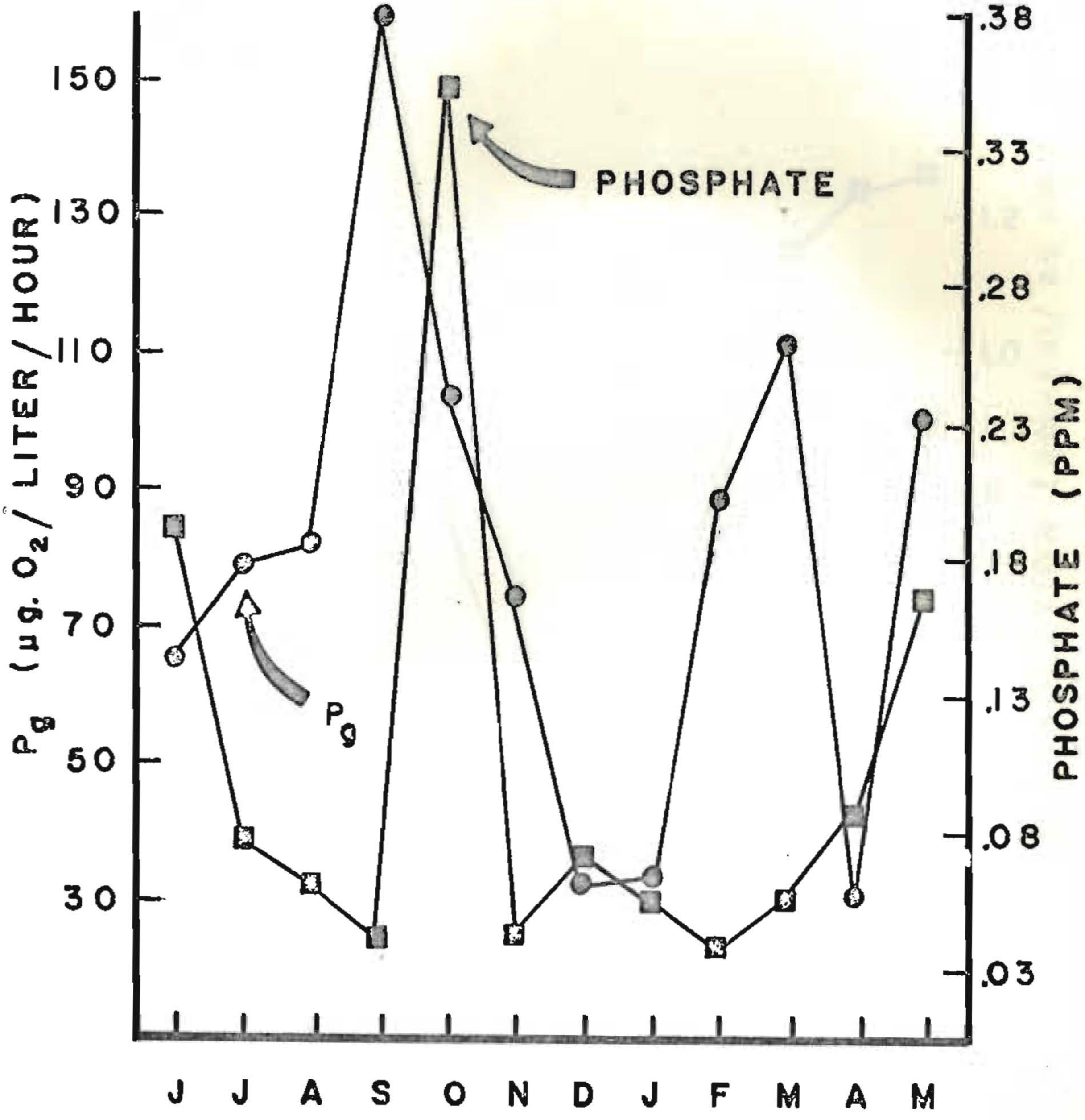


Figure 13. Phosphate and gross primary productivity monthly mean determinations in the euphotic zone of Gladfelter Pond, June, 1965, to May, 1966.

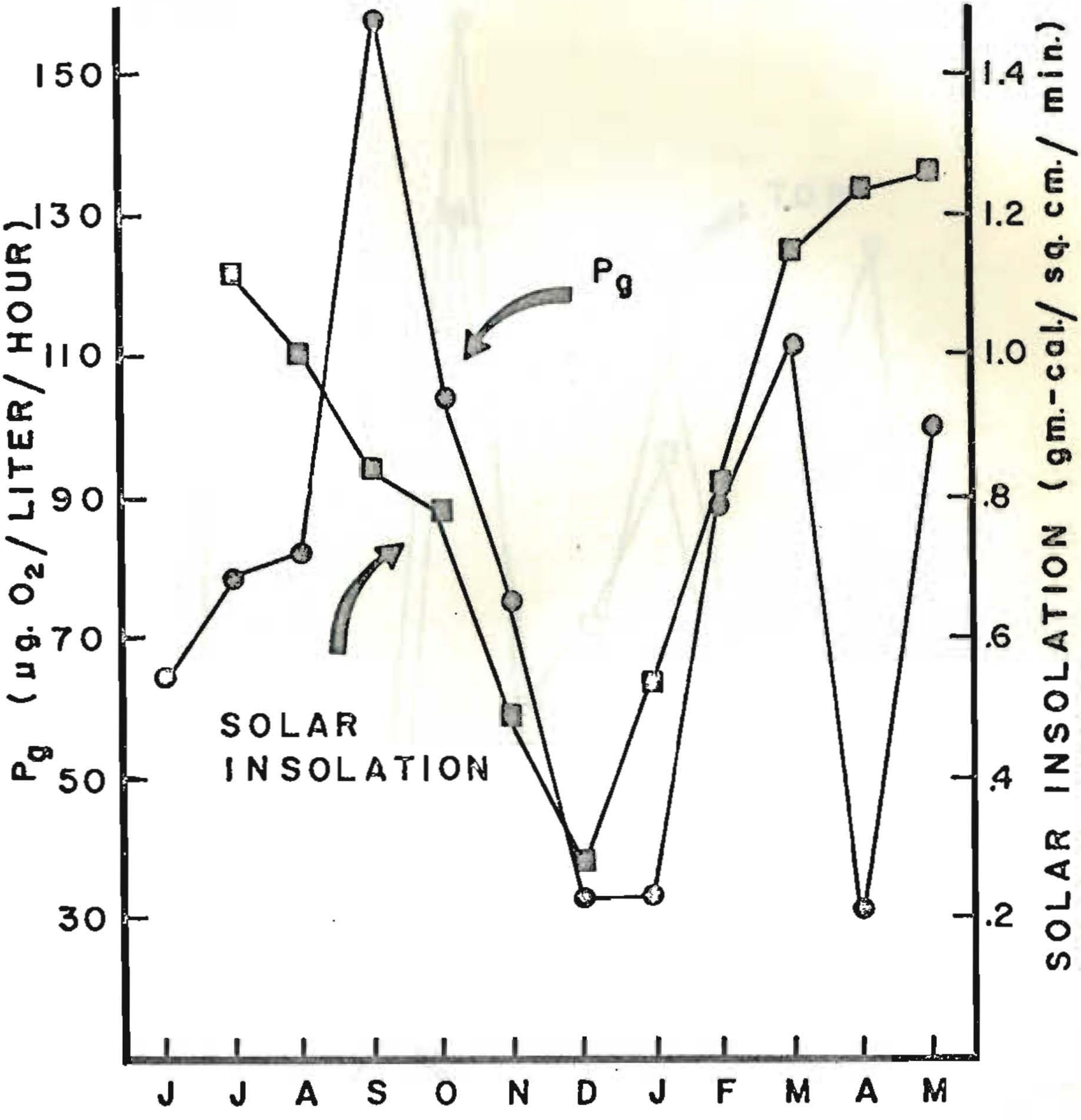


Figure 14. Monthly means for gross primary productivity and solar insolation, June, 1965, to May, 1966.

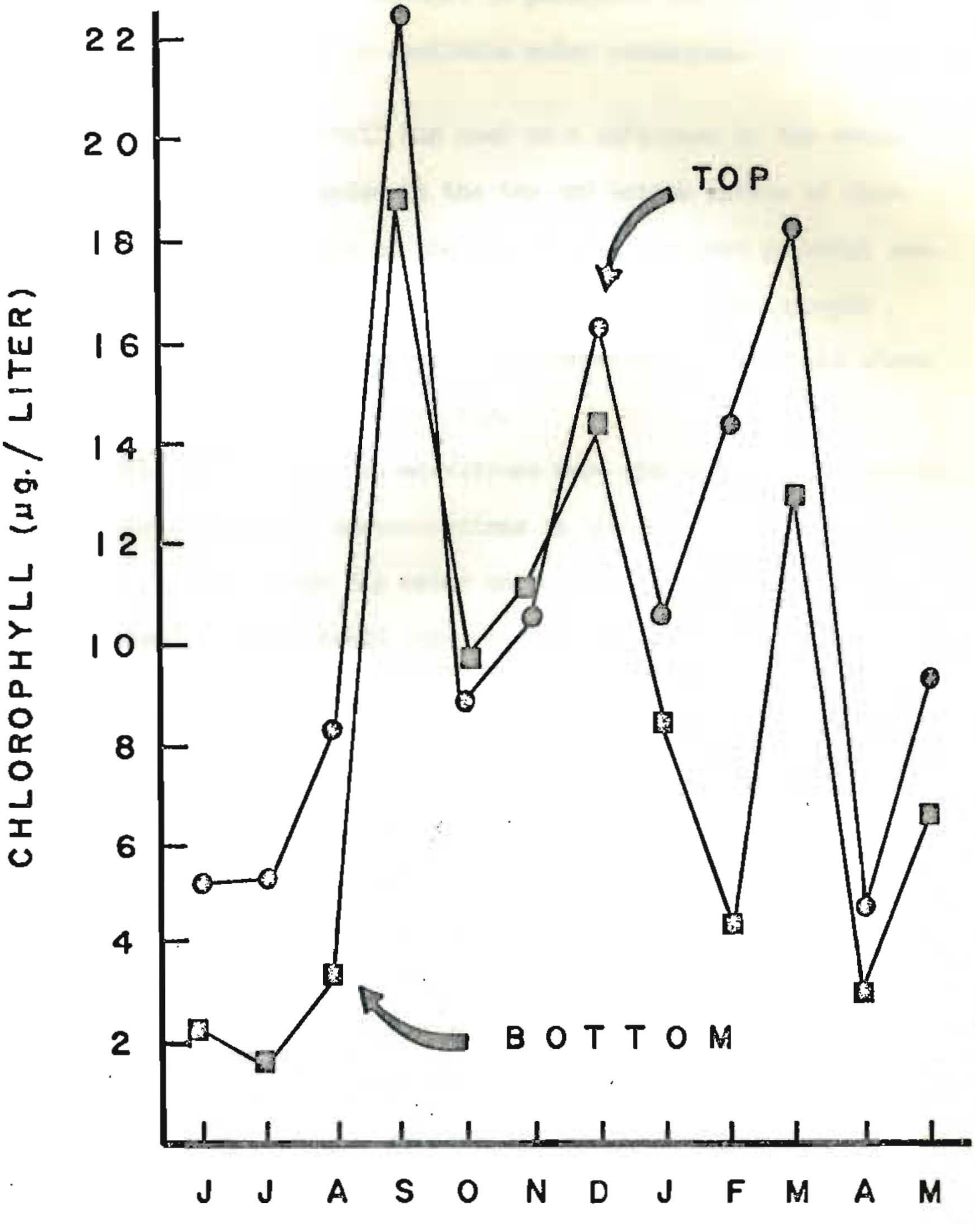


Figure 15. Monthly mean chlorophyll$_a$ estimates in the top and bottom meters of Gladfelter Pond, June, 1965, to May, 1966.

community in turn responded to changes in phosphate and nitrate levels and to seasonal fluctuations in available solar radiation.

Chlorophyll. Chlorophyll was used as a reference to the abundance of phytoplankton suspended in the top and bottom meters of Gladfelter Pond. Since extraction of the chlorophyll was from material centrifuged from the water, no distinction can be made between amounts derived from living or dead plant matter. Therefore, chlorophyll alone is an inadequate measure of productivity.

Generally chlorophyll concentrations were greatest in the euphotic zone of the pond. However, concentrations in the bottom meter did equal and even surpass that in the top meter on certain sampling days. The greatest frequency of this trend occurred during the months of November and December (Figure 15). On those days when chlorophyll was relatively uniform from the surface to the bottom, winds of approximately 15 to 20 miles/hour were observed. These winds could have caused uniformity in the chlorophyll by circulation of the water.

Throughout thermal stratification, a difference of approximately 4 µg/liter was detected between samples taken from the top and bottom meters. Lewin (1962) suggests that vertical stratification caused by temperature has important indirect effects on algal distribution and growth by limiting the vertical transfer of dissolved substances and phytoplankton. The greatest difference between top and bottom chlorophyll determinations was seen in February at the time an extensive ice cover overlaid the pond. A mean difference of 10.2 µg/liter was noted for that month.

In general, chlorophyll contents in the bottom meter were a reflection of the contents observed in the euphotic zone (Figure 15). This was probably due to the precipitation of dead algal cells (Edmondson, 1956).

Phytoplankton populations in small freshwater impoundments are known to differ greatly, even in ponds located in the same geographical region (Welch, 1952). In general, fertile ponds and small lakes contain a greater variety and density of phytoplankters than do large lakes (Reid, 1952). Throughout most of this study, chlorophyll contents ranged higher than reports from other bodies of freshwater in eastern Kansas. Monthly means for Gladfelter Pond ranged from 4.8 to 22.4 µg/liter in the top meter and 1.8 to 19.2 µg/liter in the bottom meter. Prophet (1964) reported chlorophyll contents ranging from .66 to 3.0 µg/liter in Lyon County State Lake. Lake Wooster, a small lake on the campus of Kansas State Teachers College, exhibited contents from 11.8 to 75 µg/liter during the winter of 1963. Chlorophyll levels were also higher in Gladfelter Pond than in Canyon Ferry Reservoir in Montana. Wright (1958) reported a mean of 2.9 µg/liter in that lake for April through October.

<u>Organic</u> <u>Seston</u>. Organic seston ranged from 2.0 mg/liter to 27.6 mg/liter. The highest monthly mean for the study was 18.95 mg/liter in November. The lowest mean was in March with a value of 7.2 mg/liter. In general, there was no relationship between primary productivity, chlorophyll, changes in water level, and organic seston. Organic seston tended to be lowest during June, July, March, April, and May (Figure 16).

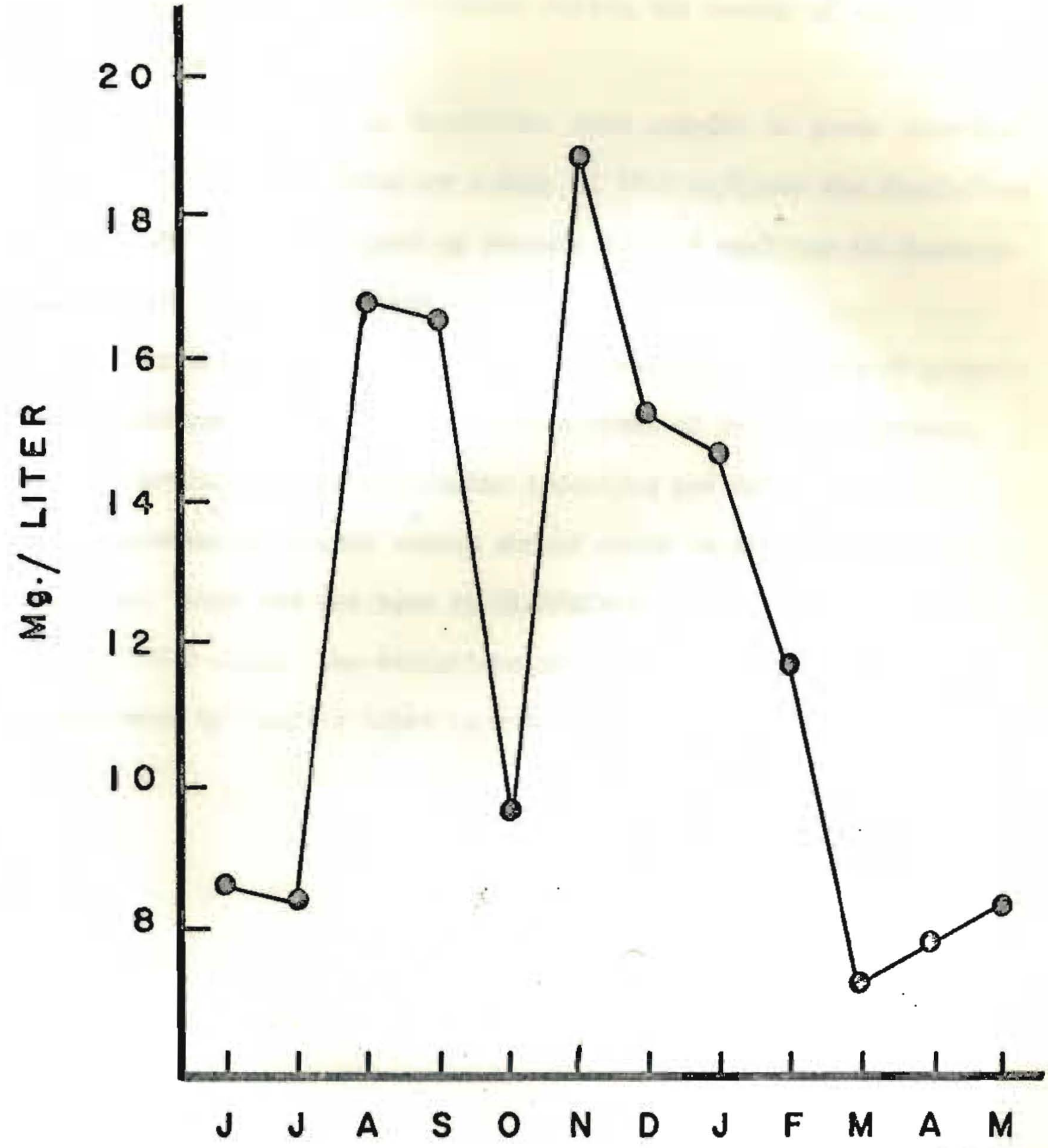


Figure 16. Monthly means for organic seston in the top meter of Gladfelter Pond, June, 1965, to May, 1966.

Highs in organic seston were exhibited during the months of August, September, and November.

The values obtained in Gladfelter Pond compare to those reported by Griffith (1961). She obtained a mean of 27.6 mg/liter for Gladfelter Pond. Ratzlaff (1952) obtained an average of 19.9 mg/liter in roadside ditches in Lyon and Chase counties.

Organic seston is probably the least reliable estimate of primary production because it is not only a measurement of primary producers, but also an estimate of heterotrophic organisms and detritus as well. However, maximums in organic seston should occur in times of greatest productivity. Such was the case in Gladfelter Pond throughout most of the study (Table III). The variations in organic seston were probably influenced most by varying rates in decomposition.

CHAPTER V

CONCLUSIONS

The long-term existence of small farm ponds, such as Gladfelter Pond, cannot be expected, due to siltation. Flora along the shoreline of Gladfelter Pond was scarce because of frequent variations in water depth. The productive capacity of the pond, in terms of flora and fauna, will probably continue to be limited due to the pond's high turbidity.

Thermocline formation can be expected with the warming of the water during the spring months. A drop in the oxygen level, below that critical for life, with a rise in the hydrogen-ion concentration in the bottom regions, can be anticipated, with the formation of epilimnetic and hypolimnetic regions.

Phosphates, nitrates, calcium, sodium, and potassium concentrations seemed to be adequate for the growth and development of flora and fauna in Gladfelter Pond. If conditions of turbidity and coloration of the water persist, the greatest amount of primary production in the pond will be in the top meter of water. Primary productivity was affected by seasonal changes in available solar radiation, with more frequent fluctuations caused by changes in mineral nutrients. If present conditions prevail, primary productivity will be highest during the period of fall overturn when algal populations increase.

CHAPTER VI

SUMMARY

1. Air temperatures were higher than water temperatures throughout the study. Water temperatures measured at meter depths ranged from 28.2°C to 1.5°C at the surface and from 21.1°C to 1.5°C at the bottom. Thermal stratification with marked thermocline formation developed during the latter part of May and persisted until late August.
2. Dissolved oxygen was determined at top, middle, and bottom depths by the Winkler titration method. Highs occurred during the winter months, decreasing in the summer months. Variations in the top and bottom meters as great as 6.6 ppm were observed during June through August. Total depletion of dissolved oxygen was noted in the bottom meter of the pond from June 13 to August 25.
3. Hydrogen-ion concentrations tended to be slightly alkaline throughout most of the study, becoming acidic in the hypolimnion region during thermal stratification. Alkalinity, specific conductance, and calcium values were lowest in the winter and highest in the summer. Maximum values determined for the top meter were 157 ppm for alkalinity, 333 micromhos/cm for specific conductance, and 33 ppm for calcium. Sodium tended to be higher than potassium throughout the study.
4. Phosphates and nitrates were measured in the top and bottom meters of the pond. Nitrates were found to be more abundant

than phosphates. Both nutrients were generally low when primary productivity and chlorophyll values were high. Mean nitrate levels ranged from .199 to .894 ppm in the top meter. Phosphates tended to be higher in the top meter than in the bottom meter, with a maximum mean for August of .351 ppm.

5. Gross primary productivity was measured with the light-dark bottle method in the euphotic zone (top meter) of Gladfelter Pond. A mean for the study of 80.0 ug O_2/liter/hour was determined. Of the total primary productivity estimates taken, 23.7 per cent were above 100 ug O_2/liter/hour. Chlorophyll was used as an estimate of phytoplankton concentrations. The range in chlorophyll from 22.4 ug/liter to 4.8 ug/liter reflected the trends in primary productivity, except during the winter. Solar insolation became limiting in December, with a mean for that month of .27 gm-cal/cm^2/min.
6. Organic seston ranged from a maximum of 27.6 mg/liter to 2.0 mg/liter. Little relationship was found between organic seston and other factors.

TABLE I

MONTHLY MEANS OF VARIOUS PHYSICAL-CHEMICAL FEATURES IN THE TOP AND BOTTOM METERS OF GLADFELTER POND, JUNE, 1965, THROUGH MAY, 1966

Month	Temperature °C.		Diss. O_2 ppm		Alkalinity ppm	
	Top	Bot	Top	Bot	Top	Bot
June	21.1	18.6	5.05	1.60	87	77
July	27.4	18.9	5.85	0.00	114	111
August	26.4	19.1	6.16	0.00	124	140
September	21.2	19.0	7.25	4.25	105	99
October	14.8	13.8	8.55	8.15	94	96
November	9.8	9.0	9.90	9.35	107	109
December	4.5	5.1	11.10	10.70	112	111
January	2.0	2.0	12.40	12.30	114	116
February	2.1	2.4	13.95	11.95	124	128
March	7.2	6.4	11.05	10.75	123	129
April	11.2	9.3	9.18	8.25	126	127
May	18.4	10.7	7.80	3.83	143	144

TABLE II

SOME MONTHLY MEAN CHEMICAL CONDITIONS IN THE TOP AND BOTTOM METERS OF GLADFELTER POND, JUNE, 1965, THROUGH MAY, 1966

Month	Specific Cond. micromhos/cm 25 °C.		Calcium ppm		Sodium ppm		Potassium ppm	
	Top	Bot	Top	Bot	Top	Bot	Top	Bot
June	172	161	5.9	4.8	3.5	1.5	2.0	1.8
July	239	206	27.8	19.3	4.6	3.0	3.6	2.3
August	252	276	29.7	32.0	4.7	4.3	3.2	4.0
September	218	202	26.9	22.0	4.4	4.0	3.3	3.8
October	205	195	17.6	16.6	4.0	3.6	3.8	3.9
November	236	231	17.8	21.0	5.2	5.1	3.8	3.7
December	274	256	18.0	19.5	5.3	5.3	3.8	3.8
January	316	285	29.0	28.5	1.4	1.4	3.1	3.0
February	301	297	34.5	32.5	1.5	1.5	3.0	3.3
March	278	270	35.5	35.0	5.4	5.0	3.8	3.2
April	277	271	31.8	33.4	6.7	6.3	4.0	3.8
May	315	309	35.5	36.3	7.9	7.6	3.5	3.7

TABLE III

MONTHLY MEANS OF SOLAR INSOLATION PLUS VARIOUS CHEMICAL AND BIOLOGICAL FEATURES IN THE EUPHOTIC ZONE OF GLADFELTER POND, JUNE, 1965, THROUGH MAY, 1966

Month	Gross Primary Productivity ug O_2/liter/hr	Chlorophyll$_a$ ug/liter	Org. Seston mg/liter	Phos. ppm	Nitrate ppm	Solar Insolation gm-cal/cm^2/min
June	65.4	5.3	8.6	.203	.521	--
July	79.5	5.4	8.4	.079	.664	1.13
August	82.0	8.1	16.8	.062	.689	1.02
September	159.0	22.4	16.6	.041	.199	.84
October	104.5	8.8	9.7	.351	.324	.78
November	75.2	10.7	18.9	.042	.372	.49
December	33.0	16.3	15.3	.076	.894	.27
January	32.5	10.3	14.6	.056	.339	.55
February	88.0	14.4	11.7	.037	.348	.80
March	111.0	18.2	7.2	.055	.641	1.15
April	30.0	4.8	7.8	.084	.586	1.25
May	100.3	9.2	8.3	.164	.657	1.26

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