AN ABSTRACT OF THE THESIS OF

Belinda A. Carrillo for the Master of Science Degree

in Environmental Biology presented on December 23, 1977

Title: Primary Productivity in Gladfelter Pond

Abstract approved: Carl W Prophet

Estimations of primary productivity and community respiration in Gladfelter Pond were made on 99 separate days from September 1, 1976, to June 30, 1977. Dissolved oxygen concentration and water temperature, monitored with a Rustrak recorder system, were used to determine productivity by the daily oxygen rate of change method. Community respiration exceeded gross primary productivity producing a heterotrophic system. Gross primary productivity averaged 5.8 g O_2 m^{-2} da^{-1}; average community respiration was 12.57 g O_2 m^{-2} da^{-1}. Daily fluctuations in gross primary productivity were often independent of solar radiation changes, but corresponded to daily variations in nitrate and phosphate levels. The fluctuations showed no pattern and were usually unpredictable; therefore, the need was established for numerous consecutive day measurements when estimating primary productivity in a fresh water system.

PRIMARY PRODUCTIVITY
IN GLADFELTER POND

A Thesis

Submitted to

the Department of Biology

Emporia State University, Emporia, Kansas

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

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INTRODUCTION

Research in limnology covers a wide area of investigation, but the ultimate goal of such research is the determination of the amount of organic material a body of water can produce. In 1931 Thienemann explained production as the "actual rate of formation of organisms under existing conditions" (Davis, 1963). Odum (1959) defined primary productivity as the rate energy is stored by photosynthetic and chemosynthetic activity of producer organisms in the form of organic substances. Gross primary productivity (P_G) is generally equated to total photosynthetic activity since it represents the total amount of organic material synthesized over an interval of time, including the amount utilized during respiration. An estimation of net primary productivity (P_N) can be obtained by subtracting community respirtaion (R) from gross primary productivity.

Three factors control photosynthesis and, in turn, primary productivity in an aquatic system (Goldman, 1966):

1) solar radiation and all physical factors originating either directly or indirectly from solar radiation, including temperature and the effects of wind action

2) nutrients present in the euphotic zone

3) the interaction of organisms present in the plankton.

Numerous techniques have evolved for estimating primary productivity in aquatic systems; Whittaker and Lieth

(1975) and Vollenweider et al. (1969) are excellent sources for their descriptions. Commonly employed techniques include the Carbon-14 method (Steeman Nielsen, 1952), the light-dark bottle oxygen change method, and the daily oxygen rate of change method (Odum, 1956). More recent investigators have modified Odum's method by calculating continuous functions based on the solution of the oxygen mass-balance equation (Hornberger and Kelly, 1972; Kelly, Hornberger, and Cosby, 1974; and Schurr and Ruchti, 1977). These modifications utilize simpler sampling techniques, but require computer solutions to the complex mathematic equations.

The majority of primary productivity studies have been conducted as a part of larger limnological surveys, and little attention has been given to frequent and extended measurement of primary productivity in a given lake or stream (Likens, 1975). It is known that photosynthetic activity within a lake will vary from season to season and even hourly during a single photoperiod (Likens, 1975; and Wetzel, 1975), but relatively little is known of day to day variations. Data based on measurements of primary productivity at intervals of one to several weeks, therefore, may not accurately characterize photosynthetic activity in a system.

Primary productivity data collected by members of the Emporia State University Aquatic Ecology Laboratory on John Redmond Reservoir during 1974 and by Jones (1977) on

Gladfelter Pond showed marked variations in productivity rates over periods of two to ten consecutive days, even though solar radiation and weather conditions were similar.

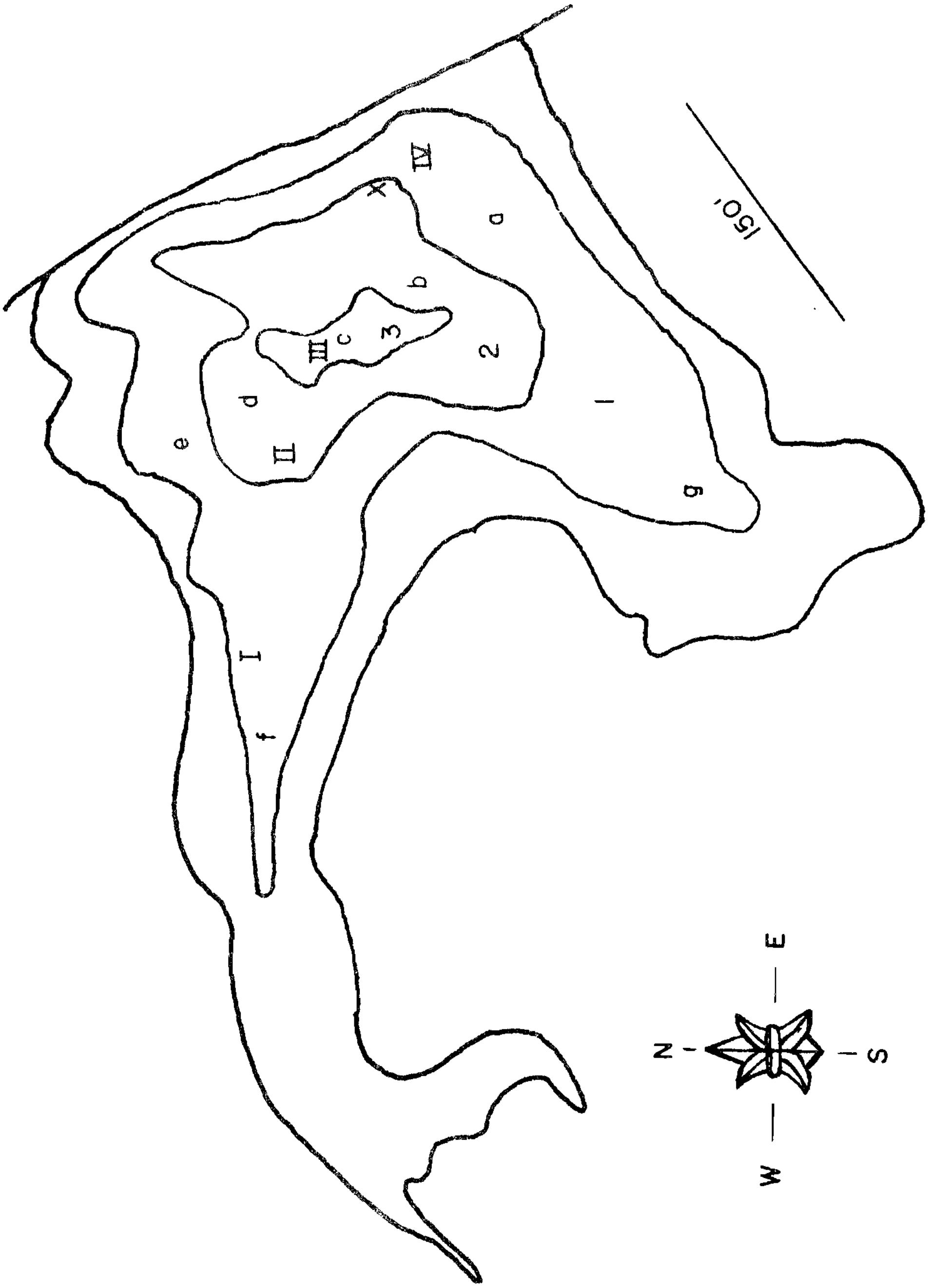
This study was designed to explore day to day fluctuations in the rate of primary productivity in Gladfelter Pond and to determine biological or physicochemical causes for these fluctuations.

METHODS AND MATERIALS

Temperature, dissolved oxygen, solar radiation, nitrate, nitrite, phosphate, pH, chlorophyll, and biomass values in Gladfelter Pond were recorded from September 1, 1976, to June 30, 1977.

Primary Productivity and Solar Insolation

A Rustrak Model 192 temp/DO recorder system was used to obtain a continuous recording of water temperatures and dissolved oxygen concentrations in the pond. The on-shore recording unit was attached to a temperature probe and an electrolytic dissolved oxygen probe. The sensor ends of the probes were attached to an anchored float located approximately 3.0 m from shore (Fig. 1) and 0.5 m below the surface, the approximate center of the euphotic zone in Gladfelter Pond (Osborne, 1968). The tip of the oxygen probe was secured near the opening of a 19 mm intake hose which was connected to an electric centrifugal pump located on shore. This provided circulation over the oxygen probe insuring accurate operation of the sensor-recorder system. Water temperature and dissolved oxygen values were recorded twelve times per minute on a continuously moving paper strip (2.3 cm hr^{-1}) from which data were later taken. The recorder was calibrated daily using a standard mercury thermometer and the Alkaline Azide


150'
IV
a
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2
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modification of the Winkler method for dissolved oxygen (APHA, 1963). During the fall of 1976 the recorder system was operated for periods of three consecutive days; continuous recordings were then made from March 24 to April 5 and from April 20 to June 30, 1977.

Dissolved oxygen and temperature values at two hour intervals were interpolated from the strip, and were used to determine percent of dissolved oxygen saturation. Dates, hours, dissolved oxygen concentration and percent saturation were entered on punch cards and analyzed by computer program USBIOR01 at the Emporia State University Computer Center. This program was modified from Eley (1970), who used a similar program to calculate primary productivity and community respiration values for Keystone Reservoir, Oklahoma. The program utilized dissolved oxygen concentrations, saturation deficits, and a calculated diffusion constant to determine gross and net primary productivity and community respiration using the daily oxygen rate of change method as described by Odum and Hoskin (1958).

Light-dark bottle experiments were conducted during three recording periods in the fall of 1976 for comparison to the daily oxygen rate of change method. Paired light and dark bottles were suspended with the oxygen probe and allowed to incubate for four hours. Gross primary production was estimated from oxygen changes in the bottles as described by Prophet (1965).

Solar radiation was determined during all productivity recordings using an Eppley pyreheliometer and Bristol Recorder on the Emporia State University campus. Measurements in g cal cm^{-2} da^{-1} were determined by the hourly averages of recordings made on a continuously moving paper strip.

Physicochemical Measurements

Water samples for chemical analysis were taken biweekly from the top and bottom meters at four stations (Fig. 1), using a Kemmerer water sampler. Samples were transported to the laboratory and filtered, using Whatman 4.15 cm GF/C glass microfibre filters. All chemical analyses were conducted according to Standard Methods (APHA, 1963). Phosphates were determined by the stannous chloride method, and all glassware was washed in dilute HCl to prevent build up of phosphate residues (Eley, 1970). A Beckman Zeromatic II pH meter was used for determination of hydrogen ion concentration.

Plankton and Chlorophyll Samples

Plankton samples were taken with a 24 cm diameter tow net of #20 bolting silk. Vertical tows were made from depths of one, two, and three meters across a transect of the pond and in each arm (Fig. 1). Organisms were preserved in 5 % formalin for later identification. Samples were then filtered using 4.25 cm GF/C filters. The filters and filtrate were placed in clean, preweighed porcelain crucibles and dried for 24 hours at 80 C. The crucibles were weighed and then ashed at 500 C for one hour. Determinations of ash weight followed an additional 24 hours in the drying oven.

Chlorophyll measurements were used to estimate the relative abundance of phytoplankton. Four one liter samples were collected across a transect of the pond (Fig. 1) and filtered as above. Filters were placed in 10 ml of 90 % acetone and refrigerated for 18 hours to extract the chlorophyll. Samples were then centrifuged, and the extract decanted. The absorbances of the extracts were read at 750 and 650 mμ on the Beckman Model B spectrophotometer. Two drops of dilute HCl were added and readings were again made to correct for pheophytins. Absorbance values were used to calculate the concentration of chlorophyll following the procedure outlined in Standard Methods (1963).

RESULTS AND DISCUSSION

General Characteristics of Gladfelter Pond

Gladfelter Pond lies on the eastern border of the Flint Hills uplands. The pond is fed by intermittant runoff from 32 ha of bluestem prairie in various stages of succession. Like most Kansas farm ponds, it suffers from fluctuating water levels and heavy siltation. Maximum depth upon completion was 6.1 m (Griffith, 1961). Maximum depth during the fall of 1976 was 2.6 m, following a summer drought. Heavy runoff during the spring of 1977 filled the pond to capacity and to a maximum depth of 3.5 m (Fig. 1). Pérez (1970) predicted complete siltation of this pond before the year 2000.

Associated Rooted Vegetation. An abundance of *Chara globularis* and *Potamogeton coccineum* was present in shallow areas during the month of September. These plants died as the water receded, and they failed to become reestablished following the spring rains. Fluctuations in water levels made other rooted aquatic plants scarce or absent in the littoral regions of the pond throughout the study. Semi-aquatic species present, usually found above the water level, included a variety of species of the following genera: *Bidens*, *Cyperus*, *Eleocharis*, *Lippia*, *Salix*, *Scirpus*, and *Typha*.

Surrounding vegetation was characteristic of the tall grass prairie and its primary and secondary invaders. These included: *Andropogon gerardii*, *Andropogon scoparium*, *Bouteloua curtipenendula*, *Bouteloua gracilis*, *Buchloe dactyloides*, *Cornus drummondii*, *Elymus canadensis*, *Juniperus virginiana*, *Panicum virgatum*, *Sorghastrum nutans*, and *Symphoricarpos orbiculatus*.

General Physicochemical Features

Water Temperature. Since Gladfelter Pond was a small, shallow body of water, its temperature closely approximated that of the atmosphere. Atmospheric temperatures and solar radiation caused daily temperature variations in the top meter as great as 4 C on several occasions in September, April, May, and June. Thermal stratification became evident the end of May and persisted until the end of the study. Previous studies of the pond (Griffith, 1961; and Osborne, 1968) reported the occurrence of thermal stratification earlier in the year, usually by the first of May. The later onset of stratification during this study was probably due to heavy spring runoff which sped warming of the water and served to maintain holomictic conditions. Reduced depth in the fall probably accounted for the more rapid cooling of the pond as compared to earlier studies (Tables I and II). Maximum and minimum temperatures recorded during productivity studies were 29 C on June 5 and 7 C on October 19 and April 5.

TABLE I. Monthly means of gross primary productivity, solar insolation, physicochemical features, and standing crop in the euphotic zone of Gladfelter Pond, September, 1976, to June, 1977.

	Sept.	Oct.	Nov.	Mar.	Apr.	May	June
P_G (g O_2/m^2/da)	12.41	4.29	1.86	3.00	5.28	6.64	6.26
Solar Ins. (g cal/cm^2/da)	401.8	267.7	268.8	297.2	364.2	453.8	484.5
Temperature (C)	20.5	11.5	8.0	10.0	15.0	21.5	24.5
Dissolved Oxygen (mg/l)	7.26	9.29	9.97	10.81	9.01	7.94	6.69
Percent Saturation	82	87	85	97	91	90	81
PO_4 (mg/l)	0.10	0.05	0.10	0.14	0.11	0.12	0.19
NO_3 (mg/l)	0.42	0.43	0.44	0.55	0.46	0.65	0.61
NO_2 (mg/l)	0.015	0.017	0.010	0.008	0.011	0.020	0.009
Biomass (mg/m^3)	46.8	36.3	36.3	13.2	29.2	28.1	47.3
Chlorophyll (µg/l)	4.3	5.5	6.6	6.4	11.3	6.1	7.7

TABLE II. Monthly means of gross primary productivity, solar insolation, physicochemical features, and chlorophyll in the euphotic zone of Gladfelter Pond, June, 1965, to May, 1966, as reported by Osborne (1968).

	Sept.	Oct.	Nov.	Mar.	Apr.	May	June
P_G (g O_2/m^2/da)	3.82	2.51	1.80	2.66	0.72	2.41	1.57
Solar Ins. (g cal/cm^2/da)	302.4	269.1	161.7	414.0	450.0	472.5	--
Temperature (C)	21.2	14.8	9.8	7.2	11.2	18.4	21.1
Dissolved Oxygen (mg/l)	7.25	8.55	9.90	11.05	9.18	7.80	5.05
Percent Saturation	82	86	90	92	85	83	57
PO_4 (mg/l)	0.04	0.35	0.04	0.06	0.08	0.16	0.20
NO_3 (mg/l)	0.20	0.32	0.37	0.64	0.59	0.66	0.52
Chlorophyll (µg/l)	22.4	8.8	10.7	18.2	4.8	9.2	5.3

Dissolved Oxygen. Mean monthly dissolved oxygen concentrations increased during the fall and decreased in the spring, following the temperature pattern (Table I). Peak concentration occurred in March, as in Osborne's (1968) study (Table II). The lowest concentration of dissolved oxygen in the top meter found during this study was 3.0 mg liter^{-1} on May 30. Tiemeier and Moorman (1957) found low levels of dissolved oxygen common throughout the summer in Flint Hills farm ponds. The highest dissolved oxygen concentration recorded was 13.0 mg liter^{-1} on April 26.

Mean monthly saturations followed the same pattern as dissolved oxygen concentrations (Table I). Maximum and minimum saturations calculated were 47 % and 136 % respectively. Supersaturation was a common occurrence during the study. High productivity during the day caused supersaturation conditions during the late afternoon and evening hours. Conditions of supersaturation increased during the spring as the water began to warm.

Alkalinity. As indicated by the abundance of *Chara globularis* at the beginning of the study, Gladfelter Pond was slightly alkaline. All pH readings were between 7.0 and 8.1. Osborne (1968) reported minimum and maximum pH values of 6.8 and 8.3. These values were well within the expected range of pH of 6.0 to 9.0 for inland waters (Wetzel, 1975).

Nutrients. Phosphates and nitrates are two of the most important limiting nutrients in aquatic systems. Most unpolluted ponds and lakes in the United States are low in both nutrients. Usual phosphate levels for unpolluted waters are between 0.01 and 0.05 mg liter^{-1} (Wetzel, 1975). Phosphate concentrations found during this study, though higher, were comparable to earlier studies on Gladfelter Pond. Maximum and minimum phosphate values were 0.39 mg liter^{-1} (June 11) and 0.04 mg liter^{-1} (Oct. 14) respectively. A slight increase in phosphate levels since Griffith's (1968) study was probably due to runoff and siltation. The increase, however, was not statistically significant.

Nitrate is the nutrient usually shortest in supply in ponds and lakes (Macon, 1973). Moulton (1939) found the average for freshwater impoundments to be 0.50 mg liter^{-1}; Hutchinson (1957) reported a range of 0.10 to 2.00 mg liter^{-1}. This increase was probably due to higher levels of pollution. Monthly means for nitrates during this study of 0.42 to 0.65 mg liter^{-1} were similar to those found by Osborne (1968) of 0.20 to 0.66 mg liter^{-1} (Tables I and II).

Mean monthly nitrite readings were low throughout the study ranging from 0.008 to 0.020 mg liter^{-1} (Table I). Apparently the nutrient is not as influential as nitrate and is usually not included in studies of this type.

Plankton Composition and Standing Crops

Chlorophyll measurements were used to estimate relative abundance of phytoplankters, and since higher aquatic plants were absent during most of the study, these measurements can be considered reasonable estimates of abundance of planktonic producer organisms. Tow net samples failed to give an accurate account of phytoplankton diversity because most species were too small to be retained by the tow net. Genera taken with the net included: Closterium, Diatoma, Frustulia, Gomphonema, and Navicula. Mean monthly chlorophyll readings showed no definite pattern, except for a slight and continuous increase during the fall months. Monthly means of 4.3 to 11.3 μg liter^{-1} were generally lower than the monthly means of 4.8 to 22.4 μg liter^{-1} reported by Osborne (1968) (Tables I and II). These lower readings can probably be attributed to corrections made for pheophytins which were not made by Osborne. Uncorrected measurements were similar to Osborne's results for the months of October, November, and May.

Since most organisms in the aquatic system consume oxygen during the process of respiration, it was necessary to determine any fluctuations in the standing crop of plankton. Although benthic organisms are often important contributors to primary productivity, Jones (1977) found that they accounted for only 3.48 % of the total production in Gladfelter Pond.

Diaptomus siciloides was the most abundant zooplankter collected. Griffith (1961) and Pérez (1970) also found this species to be the most abundant. Although there were seasonal changes, the yearly appearance of zooplankton appeared relatively stable. *Daphnia parvula* and *Bosmina longirostrus* were the most common species of Cladocera observed. *Leptodora kindtii*, an introduced species, was found in both the fall and spring. Other cladocerans collected included *Ceriodaphnia reticulata* and *Daphnia* spp. Also present were the rotifer *Keratella cochlearis* and the copopod *Cyclops bicuspidatus thomasi*.

Biomass refers to the weight of living material in a unit of area at a given moment of time (Wetzel, 1975). Since biomass measurements were made from tow net samples, the determined weights refer only to materials large enough to be retained by the net. Monthly means of biomass ranged from 13.2 mg m^{-3} in March to 47.3 mg m^{-3} in June (Table I). Biomass declined during the fall, then increased in the spring. A negative correlation of 0.78 was found between biomass and dissolved oxygen concentrations indicating that biomass levels were not dependent on availability of oxygen in the system.

Primary Productivity

A total of 99 separate estimations of gross primary productivity (hereafter referred to as gross productivity) were made during the fall of 1976 and spring of 1977. Photosynthetic activity was measured during five periods of three consecutive days from September 1 to November 4, 1976, and continuously from March 24 through June 30, 1977, except for a 15 day interval in April.

Gross productivity varied from 0.01 g O_2 m^{-2} da^{-1} on June 9 to 22.79 g O_2 m^{-2} da^{-1} on September 15. Average gross productivity for the entire study was 5.8 g O_2 m^{-2} da^{-1}. These values were similar to gross productivity values reported for most other lakes and streams in Kansas and Oklahoma. Only values reported by Eley (1970) for Keystone Reservoir, Oklahoma were appreciably higher (Table III).

Two previous studies on gross productivity were conducted on Gladfelter Pond. Osborne (1968), using the light-dark bottle method, found that gross productivity varied from 0.36 to 3.30 g O_2 m^{-2} da^{-1}. Eley (1970) made simultaneous measurements of productivity using both the light-dark bottle method and the daily oxygen rate of change method, and found measurements made using the light-dark bottle method to be significantly lower. The same experiment, conducted during three recording periods in the fall of 1976, found measurements using the light-dark bottle method to be 21 % lower. After correcting for technique, Osborne's results were still markedly lower than those found during the present study.

Jones (1977) reported variations in gross productivity from 0.48 to 40.90 g O_2 m^{-2} da^{-1} from the period 12 May through 16 June 1977. Although his maximum was nearly twice the maximum found for the present study, all but four of his 25 daily rates fell within the range of values recorded for this study. He reported an average total gross

TABLE III. Gross primary productivity values for seven lakes and streams in Kansas and Oklahoma.

System and Location	P_G g O_2/m^2/da	Method	Reference
Gladfelter Pond, Kansas	0.01-22.79	1	Present Study
Gladfelter Pond, Kansas	0.36- 3.30	2	Osborne, 1968
Gladfelter Pond, Kansas	0.48-40.90	1	Jones, 1977
Lyon County Lake, Kansas	0.02- 9.48	2	Prophet, 1970
John Redmond Res., Kansas	0.72- 3.38	2	Prophet, 1966
Cedar Creek, Kansas	1.0 -32.3	1	Prophet and Ransom, 1974
Cottonwood River, Kansas	1.5 - 7.0	1	Noyce, 1965
Keystone Reservoir, Oklahoma	11.3 -49.1*	1	Eley, 1970
Blue River, Oklahoma	1.9 -21.4	1	Duffer and Dorris, 1966

* Annual mean
1 Oxygen rate-of-change method
2 Light-dark bottle method

primary production of 114.69 kg O_2 da^{-1}, representing a photosynthetic efficiency of 2.27 %.

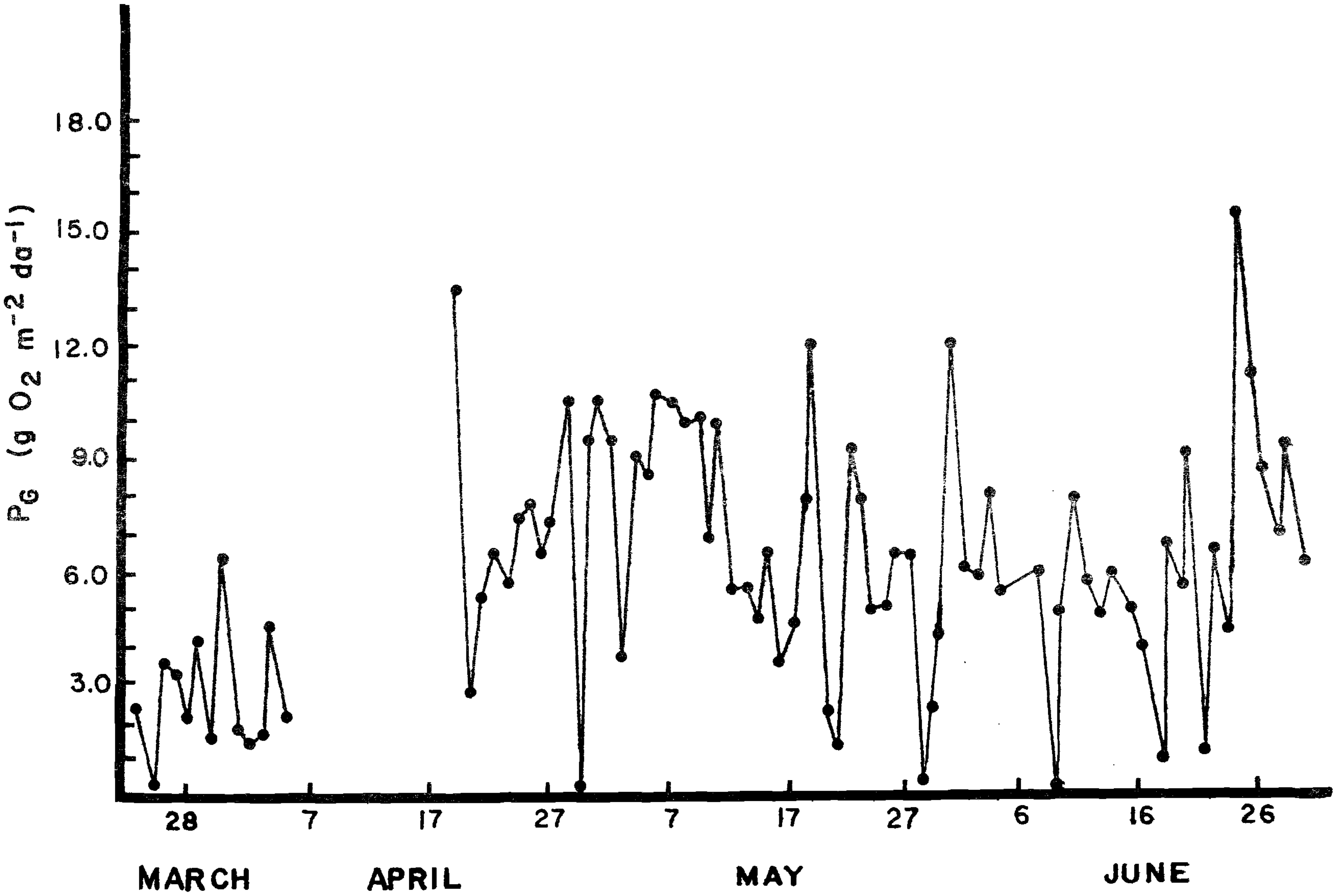
Community Respiration

Jones (1977) concluded that Gladfelter Pond operated as a heterotrophic system since community respiration usually exceeded primary productivity. Findings during the present study supported his conclusion. Only 19 % of the study days had gross productivity exceeding community respiration, resulting in net production. Even though community respiration was as high as 59.46 g O_2 m^{-2} da^{-1}, it averaged only 12,57 g O_2 m^{-2} da^{-1}. This average was nearly twice that reported by Jones (1977).

Variations in Daily Productivity Patterns

A considerable variation was found in day to day gross productivity over the course of this study (Fig. 2). Low and high extremes of gross productivity often occurred over a two day interval. Weekly or monthly measurements would have been inadequate means of estimating monthly gross productivity because measurements could have been taken on days exhibiting excessively high or low rates, and would not have represented the true average. Periods of highest gross productivity occurred at intervals of 10 to 30 days. Low gross productivity occurred at four to 22 day intervals. All days of high gross productivity were followed by a sharp drop in gross productivity the following day. Most

Figure 2. Gross primary productivity data, March 24 - June 30, 1977.



P_G (g O_2 m^{-2} da^{-1})
18.0
15.0
12.0
9.0
6.0
3.0
28
7
17
27
7
17
27
6
16
26
MARCH
APRIL
MAY
JUNE

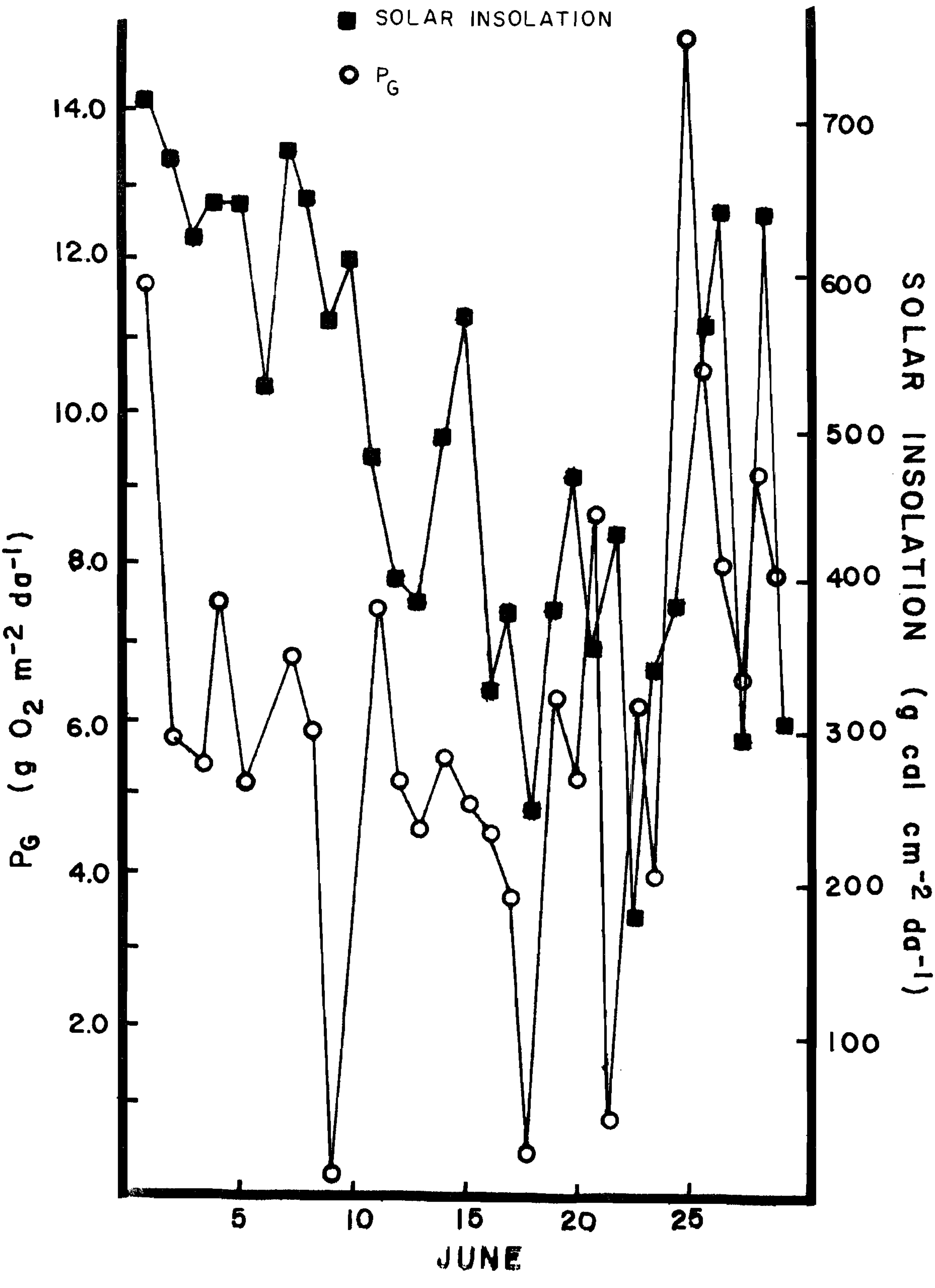
days of low gross productivity were followed by a marked rise in gross productivity. It was not possible, however, to predict a rise or fall in the photosynthetic rate until a high or low level of activity occurred.

Only a few of the lower values could be accounted for by overcast conditions. Solar radiation has been widely accepted as the controlling factor in photosynthetic activity. Although photosynthesis corresponds to solar radiation on a daily basis (Gallegos, et al, 1977), this was not found to be true on a day to day basis. Figure 3 compares gross productivity to solar radiation during the month of June. From June 15 to 24 solar radiation was moderate to low while gross productivity ranged from 0.3 to 15.3 g O_2 m^{-2} da^{-1}. The lowest level of gross productivity during the month was on the 9th when solar radiation was 572 g cal cm^{-2} da^{-1}. This figure represents high solar radiation even for that month. Highest gross productivity was on the 25th when solar radiation was a moderate 383.4 g cal cm^{-2} da^{-1}. Although the two occasionally corresponded (i.e., June 1 and 18), it was not possible to predict levels of gross productivity by changes in solar radiation. Similar variations were found throughout the study period.

Producer Standing Crop and Nutrients

Since solar radiation alone did not account for the considerable variations in gross productivity, an attempt

Figure 3. Comparison of gross primary productivity and solar radiation, June, 1977.

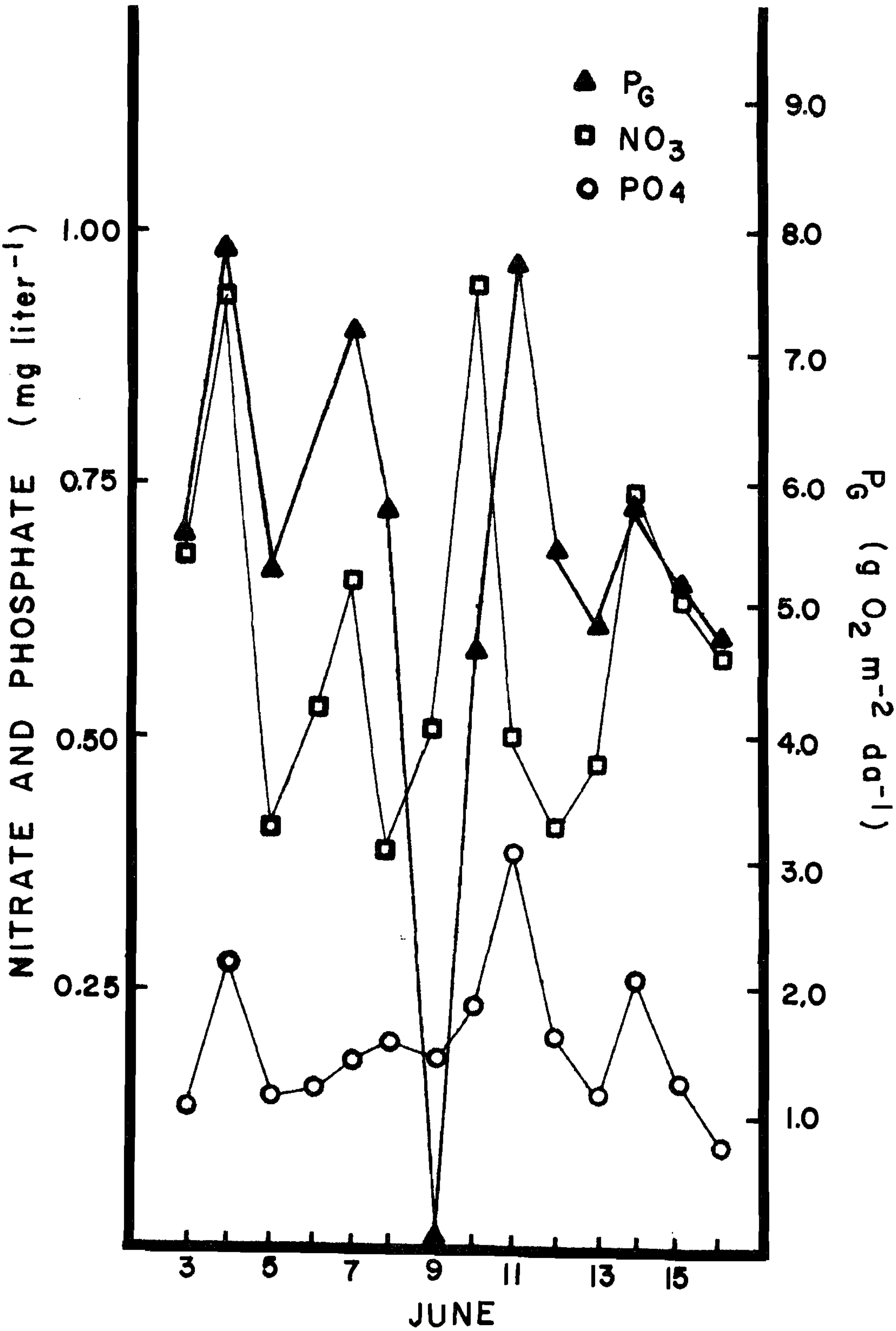


SOLAR INSOLATION
P_G
14.0
12.0
10.0
8.0
6.0
4.0
2.0
P_G (g O_2 m^{-2} da^{-1})
700
600
500
400
300
200
100
SOLAR INSOLATION (g cal cm^{-2} da^{-1})
5
10
15
20
25
JUNE

was made to explain the variations by relating them to changes in producer standing crop and nutrients. Chlorophyll and nutrient measurements were made daily for a two week interval from June 3 to 16. Phosphate, nitrate, nitrite, and pH measurements were taken daily in the top meter at approximately 9:00 a.m. Although the measurements were not made during peak hours of productivity, the nutrients found at that time would be available for the ensuing day. There was no runoff during the period to add additional nutrients to the pond.

Day to day variations did occur in both pH and nutrient levels. Nitrite and pH measurements, however, were generally stable and probably had little effect on primary productivity. In contrast, nitrate and phosphate levels showed considerable variation (Fig. 4). Phosphate levels peaked on June 4, 8, 11, and 14. Nitrates showed a similar pattern peaking on June 4, 7, 10, and 14. The concentration patterns of these two nutrients showed remarkable similarities to the gross productivity pattern over the same interval. There are three possible explanations for the corresponding patterns. Primary productivity is known to be dependent on phosphate and nitrate levels, and will slow as these nutrients are depleted. Productivity also acts to limit these nutrients. The third possibility is another factor which influences all three patterns. Although morning measurements of both nutrients found levels above limiting concentrations, little research has been done on daily

Figure 4. Comparison of nitrate and phosphate levels with gross primary productivity, June 3-16, 1977.



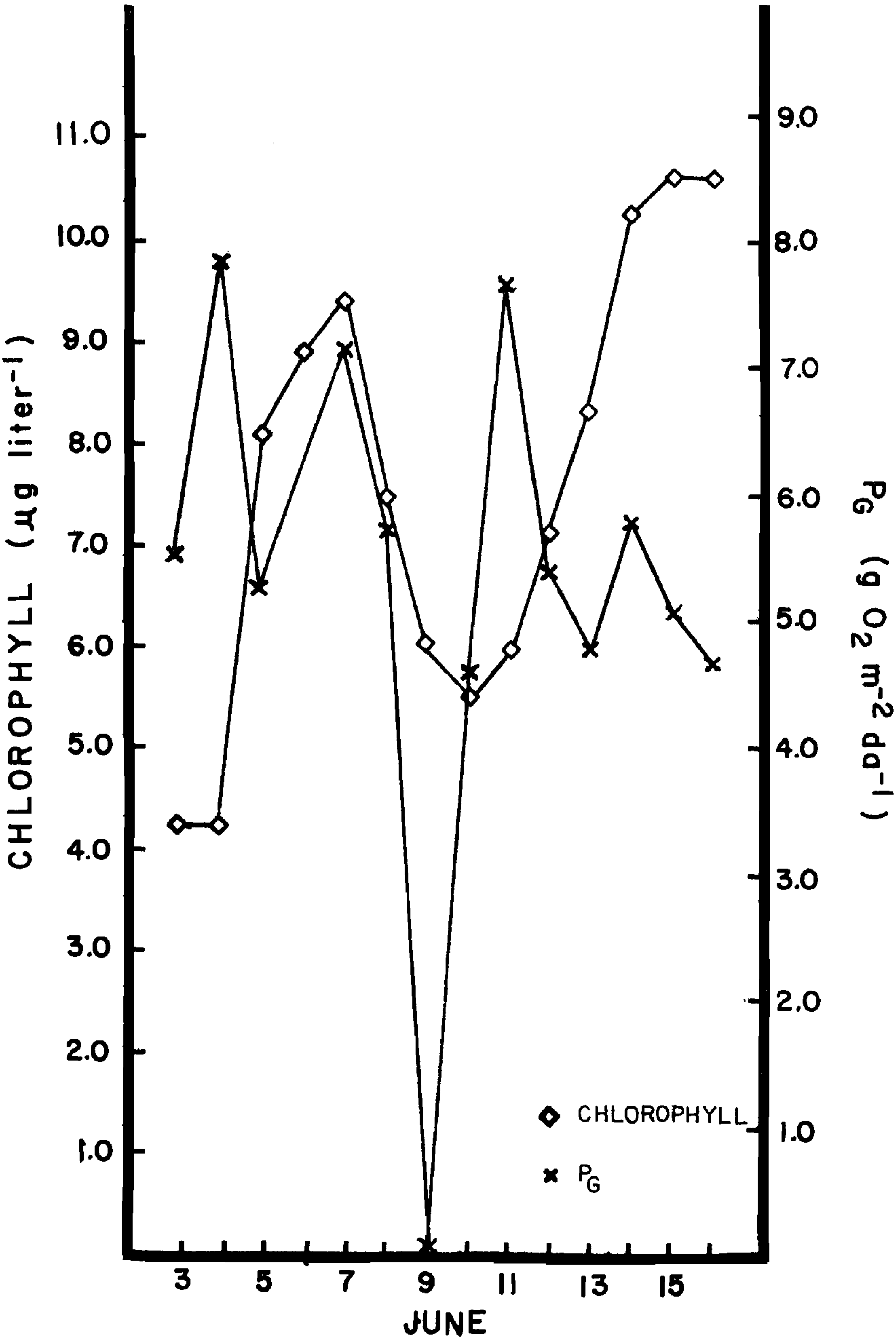
P_G
NO_3
PO4
NITRATE AND PHOSPHATE (mg liter^{-1})
1.00
0.75
0.50
0.25
P_G (g O_2 m^{-2} da^{-1})
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
3
5
7
9
11
13
15
JUNE

cycles of phosphate and nitrate. More research would be needed to document the two week correspondence of patterns and to assign causes for the patterns.

An expected correlation in chlorophyll patterns over the two week period was not found. Daily chlorophyll levels did not produce a pattern similar to that found for nutrient levels or gross productivity (Fig. 5). Chlorophyll measurements formed a curve which probably reflected the rise and fall in phytoplankton populations. Chlorophyll and gross productivity data collected by Prophet (1966 and 1970) on John Redmond Reservoir and Lyon County Lake also exhibited a lack of similarity.

Previous studies have shown a closer relationship between chlorophyll and nutrient levels or productivity. Bannister (1974) calculated primary productivity from chlorophyll content. Dillon and Rigler (1974) predicted seasonal chlorophyll levels from phosphate and nitrate concentrations from the previous season. Concentrations of chlorophyll have been found to correlate with photosynthesis over a 48 hour period (Shimada, 1958). These studies, however, dealt with seasonal and hourly intervals. The present study found a statistical correlation of only 0.03 between day to day chlorophyll concentrations and gross productivity.

Figure 5. Comparison of chlorophyll levels and gross primary productivity, June 3-16, 1977.


CHLOROPHYLL (µg liter⁻¹)
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
P_G (g O_2 m^-2 da^-1)
CHLOROPHYLL
P_G
3
5
7
9
11
13
15
JUNE

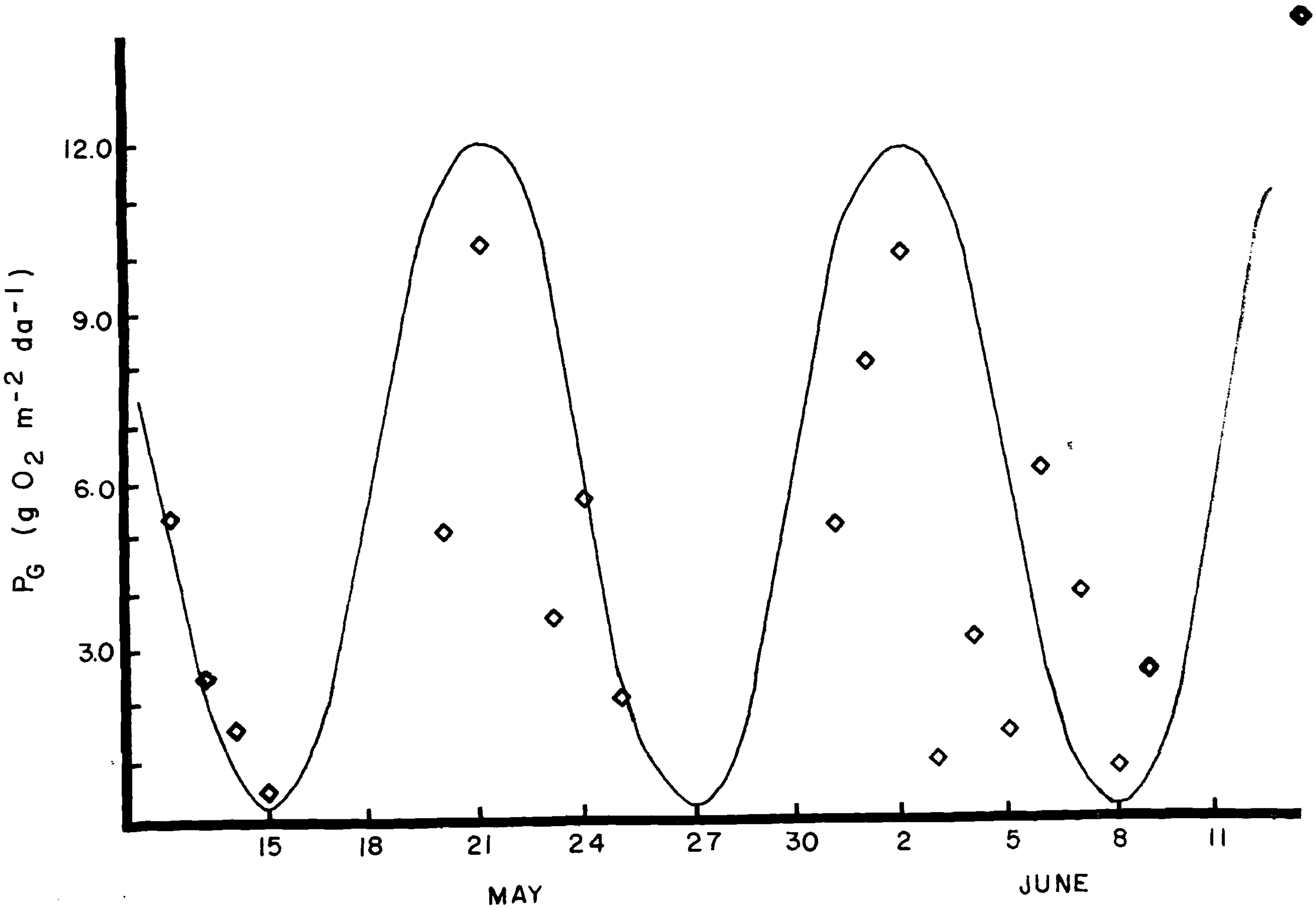
Patterns of Gross Primary Productivity

Variations in gross productivity during the fall of 1976 appeared to form a pattern with highs and lows falling at definite intervals. Jones (1977) also found intervals of high and low gross productivity in measurements made in Gladfelter Pond over four to ten consecutive day periods from May 12 to June 16, 1976. High gross productivity during Jones's study occurred about every 12 days; low gross productivity occurred at similar intervals.

It was hypothesized that if there were an approximate 12 day pattern in productivity rates, then it should be possible to predict the days on which high or low productivity would occur. From the apparent oscillation in values it was postulated that a sine function would be representative of the hypothesized pattern (Fig. 6). A cycle of 12 days was chosen to approximate Jones's data. Even though the data did not fit the curve exactly, only five values failed to follow the expected pattern.

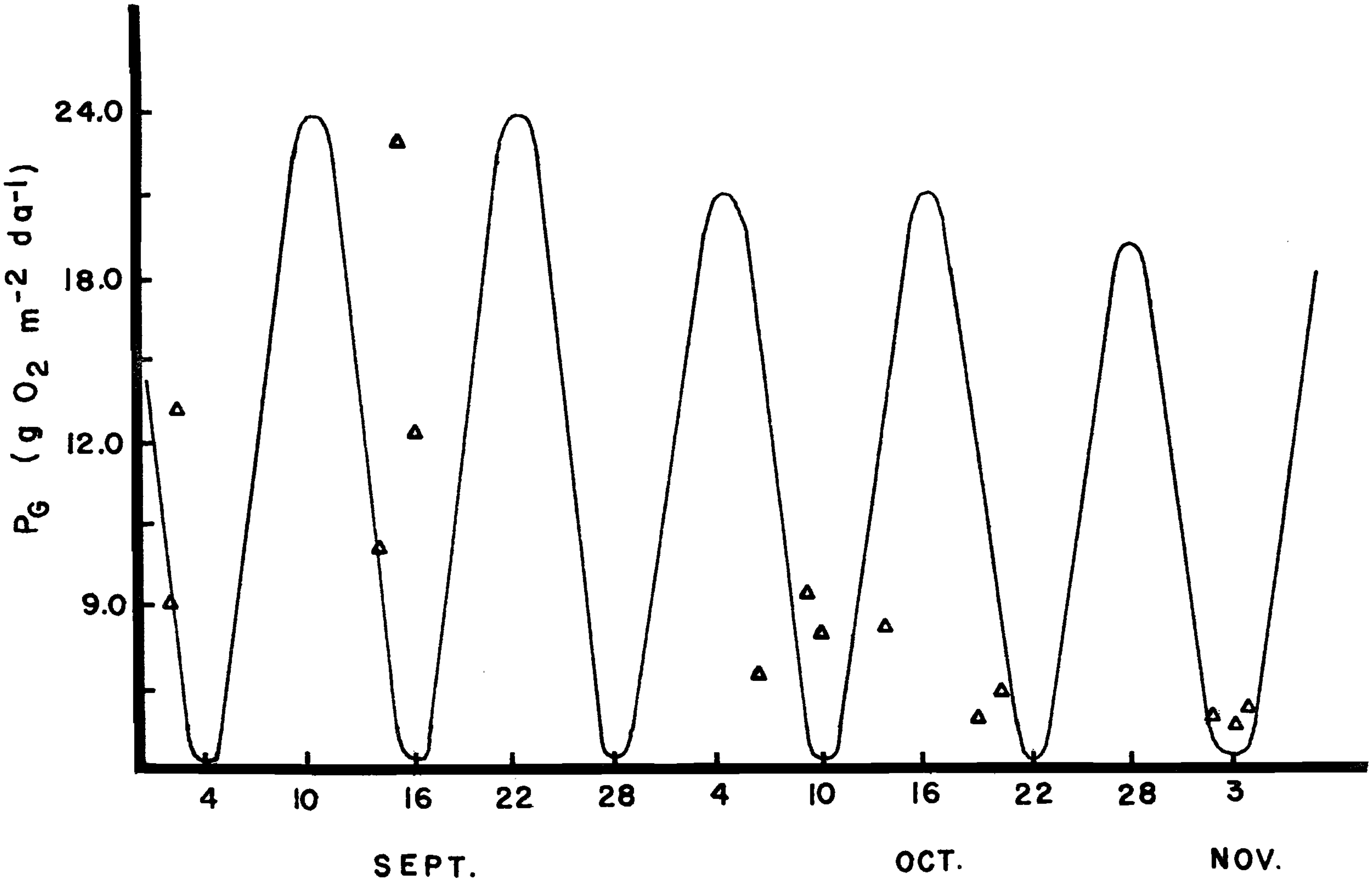
The same approach was then applied to my data collected during the fall of 1976 (Fig. 7). The sine curve was decreased in magnitude to account for a seasonal decrease in solar radiation and primary productivity. Of the 15 days plotted on the graph, six did not closely approximate the curve and cannot be explained by extremes in solar radiation. Gross productivity on September 3, 15, and 17 and October 9, 10, and 13 was higher than would be

Figure 6. Sine function calculated to illustrate pattern of gross primary productivity from May 13 to June 13, 1976. P_G data collected by Jones (1977).



12.0
9.0
6.0
3.0
P_G (g O_2 m^{-2} da^{-1})
15
18
21
24
27
30
2
5
8
11
MAY
JUNE

Figure 7. Gross primary productivity, September 1 - November 4, 1976, applied to a sine function. Sine function was calculated from gross primary productivity data collected by Jones (1977) during May and June, 1976.



24.0
18.0
12.0
9.0
P_G (g O_2 m^-2 da^-1)
4
10
16
22
28
4
10
16
22
28
3
SEPT.
OCT.
NOV.

anticipated according to the curve. Solar radiation on each of these days was high, but not above normal. The scarcity of data made conclusions difficult, but a sine function did not appear to represent the observed pattern in gross productivity during this time period. It seems that more data over an extended period of consecutive days would be necessary to test the bypothesis of a predictable pattern for gross productivity. Measurements made during the spring of 1977 (Fig. 2) also failed to conform to the sine function.

No pattern was found to conform to the day to day fluctuations in gross productivity, and no method was discovered for predicting these fluctuations. Until some method is found for predicting these fluctuations, weekly or monthly measurements cannot be considered accurate estimations of primary productivity.

Problems With Oxygen Change Method

The daily oxygen rate of change method, used to determine primary productivity in this study, had several difficulties. Previous productivity studies in Kansas and Oklahoma employed the light-dark bottle method. This method produced significantly lower results than the daily oxygen rate of change method, and made comparison of results of limited value.

The daily oxygen rate of change method computed respiration rates from oxygen changes during the nighttime hours. Respiration during the day was then equated with nighttime respiration for computation of primary productivity. Hall and Moll (1975) reported, however, that daytime respiration rates were often considerably higher than nighttime rates. This presented another area of possible error when using the daily oxygen rate of change method.

The major problem with this method was the calculation of a diffusion constant used to correct for the diffusion of oxygen between the pond and the atmosphere. Direct field measurement of diffusion was difficult, so diffusion was calculated from temperature and dissolved oxygen data. Under certain circumstances calculated constants appeared excessively high, so various methods were proposed for checking them.

Copeland and Duffer (1964) proposed the monitoring of diffusion of oxygen under a clear plastic dome. They believed their method to produce reliable results. A modification of this method was used in the laboratory to estimate diffusion rates in the field. The test system consisted of an airtight flask containing one liter of water and two oxygen probes. One probe was suspended in the water and one in the air above. Dissolved oxygen was eliminated from the water by adding Na_2SO_3. As oxygen diffused into the water, the oxygen supply in the artificial atmosphere was reduced, and diffusion slowed. This phenomenon would also occur under a plastic dome, but would not occur in the normal atmosphere above a pond. Although the concentration of dissolved oxygen in the water did not significantly affect diffusion (Himmelblau, 1964), changes in atmospheric oxygen had a direct effect on diffusion. The plastic dome method was therefore discarded as a means of checking diffusion rates.

Other laboratory experiments were then designed to simulate diffusion exchanges between the atmosphere and a water mass. Each experiment used three liters of distilled water in an open container, and the water was gently circulated with the aid of a magnetic stirrer. Since distilled water was used, it was assumed that all oxygen changes were due to diffusion. In the first experiment Na_2SO_3 was used to eliminate dissolved oxygen as in the previous experiment. Since the oxygen probe did not function properly in water containing sulfite, dissolved oxygen was measured hourly using the Winkler method. For the next experiment nitrogen gas was bubbled through the water to reduce the oxygen saturation to approximately 75 %. In a separate container, oxygen gas was bubbled into the water to increase the saturation to 120 %. Dissolved oxygen was monitored in each container using the oxygen probes and Rustrak recorders as they were used in the field. Diffusion rates were figured directly as changes in oxygen in the containers during each hour of the experiment. Maximum diffusion rates for all experiments were between 1.6 and 3.5 g O_2 m^{-2} hr^{-1}. Computer calculated diffusion constants represented the average hourly diffusion rate for a given day; 93 % of the computer calculated diffusion constants used in the analysis of my data were below the maxmum experimental value of 3.5 g O_2 m^{-2} hr^{-1}. Computer calculated diffusion constants were therefore accepted as reliable estimates of diffusion rates in the pond.

SUMMARY

Temperature, dissolved oxygen, solar radiation, nitrate, nitrite, phosphate, pH, chlorophyll, and biomass values in Gladfelter Pond were recorded from September 1, 1976, to June 30, 1977. Nutrient and chlorophyll measurements were made biweekly during the fall and spring, and daily for a two week period in June. Temperature and dissolved oxygen values were utilized by a computer program to estimate primary productivity and community respiration on 99 separate days during the fall of 1976 and the spring of 1977. Calculations were based on the daily oxygen rate of change method.

Comparisons with previous studies on the pond found that, except for heavy siltation, the pond had changed little in physicochemical or biological aspects since its completion. The pond operated as a heterotrophic system since community respiration usually exceeded gross primary productivity. Gross primary productivity averaged 5.8 g O_2 m^{-2} da^{-1}, while average community respiration was 12.57 g O_2 m^{-2} da^{-1}.

Considerable variation was found in gross productivity during this study. Fluctuations in gross productivity were not solely dependent on solar radiation, and could not be predicted by daily solar radiation changes.

Daily fluctuations in gross productivity were found to correspond to daily variation in nitrate and phosphate levels. No correlation was found between chlorophyll levels and gross productivity.

A suspected pattern of gross primary productivity did not develop. No method was found for predicting fluctuations in daily gross primary productivity. This study did, however, document wide variations in daily gross primary productivity, and establish the necessity for consecutive day measurements for the estimation of primary productivity in an aquatic system.

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