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Summer Algal Communities and Primary Productivity in Fish Ponds[1]

by

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ABSTRACT

The paper presents data on primary productivity and phytoplankton communities in new experimental ponds which received the following treatments; ammonium nitrate and triplesuperphosphate, triplesuperphosphate, cracked corn (10% crude protein) and Auburn No. 3 fish feed (36% crude protein). Comparative data on algal communities were also obtained from production ponds which received feeds or fertilizers. Basic ecological data on macro-algae are also presented.

1. All nutrient additions to experimental ponds resulted in higher levels of gross photosynthesis and greater concentrations of chlorophyll *a* than were found in the control treatments. Fertilization with both nitrogen and phosphorus gave the highest values. Chlorophyll *a* and gross photosynthesis were higher in ponds receiving high protein content feed (Auburn No. 3) than in ponds to which low protein content feed (corn) was applied.

2. Persistent blooms of blue-green algae occurred in ponds receiving nitrogen and phosphorus fertilization. Phosphorus only fertilization produced blooms of blue-greens, but these blooms did not persist as in the ponds to which nitrogen was also added. Control ponds were dominated by green algae. Blue-green algae were seldom abundant in feed treatments.

3. Production ponds had high level of gross photosynthesis and large concentrations of chlorophyll *a*.

4. Many of the production ponds which received feed applications developed heavy blooms of blue-green algae.

5. The major species of blue-green algae observed in the present study were *Oscillatoria* sp., *Raphidiopsis curvata*, *Anacystis nidulans*, *A. aeruginosa*, *Spirulina* sp., and *Anabaena circinalis*. Heterocyst bearing forms, which can presumably fix nitrogen, were seldom noted in ponds that received continuous additions of nitrogen from fish feeds.

6. Macro-algae are abundant in many fish ponds. Data illustrating the competition of macro-algae with phytoplankton are presented.

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INTRODUCTION

Additions of fertilizers or supplemental feeds to fish ponds are beneficial by increasing fish yields (SWINGLE, 1947, 1968a). However, in some ponds, the nutrients contained in feeds and fertilizers cause excessive phytoplankton production. Nitrogen and phosphorus are nutrients generally considered most limiting to phytoplankton growth, although recent work (KUENTZEL, 1969; LANGE, 1970) indicates that bacterial production of CO_2 from carbon compounds may stimulate growth of blue-green algae. Heavy blooms of phytoplankton sometimes cause environmental changes which are deleterious to fish populations. These blooms absorb and reflect heat and light, resulting in shallow thermal and chemical stratification in ponds (BEASLEY, 1965). Upwelling of oxygen deficient waters caused by cold air masses, heavy winds, or cold rains may lead to oxygen depletion and fish kills (SWINGLE, 1968b). Shallow stratification is frequently associated with blue-green algae blooms which may occur at the surface as a scum. Furthermore, blue-green algae may be directly toxic to other aquatic organisms (SHILO, 1967). Some species produce earthy-smelling substances (SAFFERMAN et al., 1967) which possibly cause off-flavors in fish flesh (ASCHNER, LAVENTER & CHORIN-KIRSCH, 1967).

Macroscopic, filamentous algae such as *Spirogyra*, *Rhizoclonium*, and *Pithophora* are also troublesome in fish ponds. Although the term filamentous algae is frequently used when referring to this type of vegetation, many phytoplankters are filaments. The term "macro-algae" will be used in this report with reference to macroscopic algae. Fertilization early in the season to produce dense phytoplankton blooms frequently shades the pond bottom and prevents the growth of macro-algae (SMITH & SWINGLE, 1942; SWINGLE, 1947; DENDY, 1963). Various herbicides are also used to control macro-algae (MULLIGAN, 1969). Control techniques are not always effective and overabundance of macro-algae occurs in many ponds.

Although problems associated with algae are widely recognized by pond fish culturists, little is known about the ecology of phytoplankton and macro-algae in ponds. Ponds situated side by side and subjected to the same management procedures may develop widely different algal floras. Thus, one cannot predict which ponds will develop blooms of blue-green algae or which ponds will have large macro-algae communities. The present report concerns phytoplankton communities that developed in experimental ponds receiving different treatments of fertilizers and feeds. Information resulting from a survey of algal communities and productivity in a number of other fish ponds are also presented. Although these findings are basically descriptive, they allow insight into the types of algal communities and the magnitude of primary production in fish ponds which receive feeds or fertilizers. Additional research on the dynamics of algal populations and ecologically sound methods of plant control are badly needed.

Materials and Methods

Experimental Studies of Phytoplankton

Fifteen newly constructed earthen ponds were used in the study. This block of ponds is located on the Auburn University Fisheries Research Unit, Auburn, Alabama. Ponds had a maximum depth of 1.7 m and an average depth of 1 m. Surface areas ranged from 0.022 to 0.066 ha, but most ponds were 0.040 ha in area. Pond bottoms were constructed from soils of the Cecil series (Hodgkins, 1965) which were excavated from a nearby hillside. The soil was a silty clay containing large amounts of highly weathered mica schist. The soils were essentially devoid of organic matter. Each pond was equipped with a stand pipe and water inflow valve. Water levels were usually maintained within 15 cm or less of the top of the stand pipes. The water supply was a nearby stream whose watershed was in the Piedmont Province. Ponds were filled between May 7 and 12, 1971. Channel catfish *(Ictalurus punctatus)* fingerlings were stocked at the rate of 4,500/ha on May 11, 1971. Fish feed and fertilizer applications were begun on May 12. A high protein and a low protein content feed was used; Auburn No. 3 fish feed – 46% crude protein (Prather & Lovell, 1971) and cracked corn – 10% crude protein (Morrison, 1961). Fertilizer materials consisted of commercial triplesuperphosphate (46% P_2O_5) and ammonium nitrate (34% N). Fertilizers were applied by broadcasting the materials by hand over the entire surface of the ponds. Feeds were always cast into the same general area of the ponds. The experimental design and rates of application of feeds and fertilizers are outlined in Table I.

After initial filling, ponds were very muddy and most ponds remained turbid for 3 to 6 weeks. Therefore, the full sampling program was not initiated until July 1, although some observations were made earlier. Primary productivity measurements were made six times during the study. Productivity bottles were filled with water collected from 0.3 m depth with a polyethylene bottle. Light and dark bottles were incubated for 24 hours at 0.3 m depth. Oxygen concentrations in light, dark, and initial bottles were

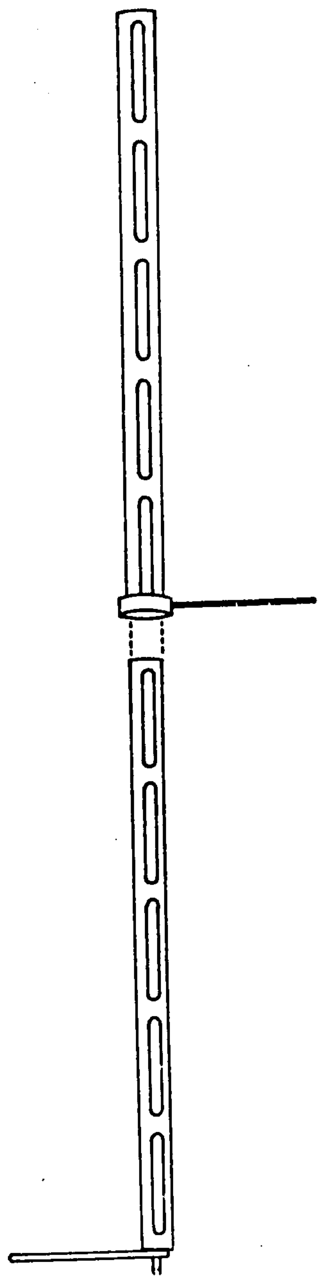


Fig. 1. Water sampler used in obtaining a 90 cm column of water. (Scale 1 : 7.5 cm).

Table 1. Rates of application of fertilizers and feeds to experimental ponds used for studies of phytoplankton communities during 1971.

Ponds	Materials applied	Frequency of application
F-68, E-76, M-24	19.45 kg/ha triplesuperphosphate (46% P_2O_5) 26.40 kg/ha ammonium nitrate (34% N)	15 day intervals
E-72, E-74, M-21	19.45 kg/ha triplesuperphosphate	15 day intervals
E-67, M-18, M-19	Auburn No.3 fish feed (46% crude protein) May 12 to May 30 - 1.46 kg/ha May 31 to July 11 - 6.74 kg/ha July 12 to August 9 - 13.47 kg/ha August 9 to September 20 - 26.95 kg/ha	6 days/week
E-73, M-16, M-17	Cracked corn (10% crude protein) Same rates as Auburn No. 3	6 days/week
E-70, E-75, M-23	Control	————

determined by the standard Winkler titration (AMERICAN PUBLIC HEALTH ASSOCIATION, 1971). Gross photosynthesis was calculated from the difference in oxygen concentrations in light and dark bottles, while respiration was calculated from decreases in oxygen in dark bottles as compared to initial bottles (AMERICAN PUBLIC HEALTH ASSOCIATION, 1971).

Water samples for phytoplankton, turbidity, and chemical analyses were taken at the deep ends of ponds with a 90 cm water column sampler (Fig. 1). The device consists of two lapped brass tubes: 1. A 5.4 cm diameter outer tube with sealed bottom that is fitted at the top with one horizontal handle. The outer tube has five 2 x 15 cm openings arranged vertically along one side. 2. An open bottomed insert tube which also has five 2 x 15 cm openings that are spaced the same as the openings in the outer tube. The top of the insert tube has a cap fitted with a short 1.5 cm diameter tube which serves as a spout. With the insert placed into the outer tube, the handles were positioned so that the vertically spaced openings in the insert and outer tube did not match, thus closing the sampler. The sampler was immersed with care to avoid disturbing the water and filled by moving the handles apart until the openings in the insert and outer tube corresponded. Closing was accomplished by returning the handles to the former position. The water was poured from the tube through the spout at the top of the insert.

Chlorophyll *a*, turbidity, and phytoplankton analyses were usually made at weekly intervals. Samples for chlorophyll *a* determinations were filtered onto 0.45 μ HA millipore filters. Filters were extracted with 90% buffered acetone in a tissue homoginizer. After centrifugation, the chlorophyll *a* content of extracts was estimated spectrophotometrically (GOLTERMAN & CLYMO, 1969). Turbidity was estimated with a Hach Chemical Co. Model 2100 turbidimeter. The simplified Lackey drop-sedimentation method (AMERICAN PUBLIC HEALTH ASSOCIATION, 1971) was used for phytoplankton evaluation. Analyses for total alkalinity, total hardness, inorganic phosphorus, nitrate, and ammonia in pond waters were made on five occasions by standard techniques outlined in AMERICAN PUBLIC HEALTH ASSOCIATION (1971). Samples for chemical analyses were always collected at least 12 days after the previous fertilizer application.

A second experiment was designed to evaluate the growth response of phytoplankton communities in plastic pools to various nutrient additions. Thirty-five, 3.05 m diameter plastic pools were filled to 0.72 m depth with well water. The following treatments were used in each of five pools: control, phosphorus, nitrogen + phosphorus, Auburn No. 3 fish feed, cane sugar, sugar + phosphorus, and sugar + nitrogen + phosphorus. Weekly additions of 7.0 g triplesuperphosphate, 9.0 g ammonium nitrate, and 75 g sugar and Auburn No. 3 were made to appropriate pools. Initially, well water contained 40.5 mg/l free CO_2, but after standing for 1 week, levels were below 1 mg/l. Nutrient applications were initiated at this time. Well water contained 0.012 mg/l PO_4-P, 0.072 mg/l NO_3-N, and 0.16 mg/l NH_3-N. Occasional additions of 2 to 3 cm of well water were necessary to replace evaporative losses from pools. Water samples were taken on three dates for estimation of phytoplankton density by chlorophyll *a* measurement.

Survey of Phytoplankton in Managed Ponds

Two series of ponds were studied. S ponds ranged in size from 0.79 to 8.90 ha. These ponds were constructed between 1944 and 1948 and were subsequently used in various fish culture experiments. During the summer of 1971, nine of these ponds contained catfish (*Ictalurus* spp.) cultures and received supplemental feeds. Three S ponds contained centrarchid populations and were fertilized. The series of R ponds was 0.04 ha in surface area. These ponds were constructed in 1966 and have since been used in various fish culture experiments. In 1971, these ponds were stocked with catfish which received feeds. Fourteen of the R ponds were aerated with submerged forced-air blowers. All feeds contained 46% crude protein (7.35% nitrogen) and 0.63% phosphorus and were applied 6 days per week at a rate of 3% of the weight of fish, adjusted monthly for weight gain. Fertilization of three S ponds consisted of monthly additions of 19.45 kg/ha of triplesuperphosphate and 24.35 kg/ha of ammonium nitrate.

Water samples were taken from S ponds at 2-week intervals between July 5 and September 5, 1971. R pond samples were collected on August 4 and 19, 1971. These samples were obtained with the sampling tube (Fig. 1) and used for nutrient, phytoplankton, and chlorophyll *a* analyses. Primary productivity measurements in eight S ponds were made on each sampling date by essentially the same procedures used in the experimental ponds. The bottles were suspended at 0.2 m depth intervals and incubated for 4 hours during the period 9:30 a.m. to 2:30 p.m. Corrections to full-day photosynthesis were made by multiplying photosynthesis values by the ratio of daily surface solar radiation: surface solar radiation during the 4-hour incubation (SCHINDLER & HOLMGREN, 1971). Surface solar radiation was measured with a Weathermeasure Corp. Model R401 mechanical pyranograph. Respiration for 24 hours was considered six times the 4-hour values.

Macro-algae Studies

Data on occurrence of various macro-algae in farm ponds of central and southcentral Alabama and Mississippi were obtained in conjunction with a study conducted in 1965 (BOYD & LAWRENCE, 1966). Ponds were located on the Piedmont, Sand, and Clay Hills, and Black Belt physiographic regions.

A block of 72 ponds, mostly 0.04 ha in size, on the Fisheries Research Unit were visited five times during the period May 21—August 25, 1971. Species occurrence and percentage coverage by each species was determined. Ponds were rectangular, so a grid system was used in tracing areas containing macro-algae onto maps of ponds. Percentage coverage of pond bottoms (some algae floated on top, some grew on or attached to the bottom, while others occurred at intermediate depths) was calculated from the maps.

Samples of *Pithophora* for standing crop estimations were harvested by carefully placing a 1.0 x 1.0 x 0.05 m hardware cloth basket beneath the mat and lifting it to the surface. Standing crop estimates of other algae were obtained by removing all plants from a 0.43 m diameter x 0.25 m high sheet metal cylinder which was positioned into the mat. Three to five samples were obtained for each population. Dry weights were determined by heating the samples at 80°C in a forced-air oven. Production data for *Pithophora* were obtained at ponds in Montgomery Co., Alabama. Other populations were on the Fisheries Research Unit or in the vicinity. Photosynthesis estimations were obtained by the oxygen light-dark bottle technique using weighed quantities of macro-algae and correcting for phytoplankton photosynthesis and respiration in the bottles. Chlorophyll *a* in macro-algae was measured by the procedure outlined by Bray (1960).

Phytoplankton Studies in Earthen Ponds

Water Chemistry

The experimental ponds had soft waters (total hardness ranged from 10.5 to 18.0 mg/l $CaCO_3$) with total alkalinity values from 16.5 to 30.0 mg/l $CaCO_3$. Potassium concentrations were usually around 1.0 mg/l. Early morning pH values were between 6.0 and 7.0, but values of 8.0 and above were encountered during afternoons in ponds having dense algal growth. Levels of above parameters in R and S ponds were similar to those in experimental ponds.

Dissolved inorganic phosphorus concentrations in control ponds were relatively low with averages of 0.010 mg/l or less (Table II).

Table II. Averages of inorganic nitrogen and phosphorus concentrations in experiment ponds used for studies of phytoplankton communities during 1971.

Treatment	June 6	June 22	July 15	August 9	August 30
		PO_4-P (mg/l)			
Control	0.005	0.006	0.010	0.006	0.010
Nitrogen*+phosphorus**	0.031	0.011	0.019	0.025	0.034
Phosphorus	0.075	0.028	0.019	0.022	0.043
Auburn No.3	0.017	0.011	0.021	0.027	0.011
Corn	0.005	0.006	0.019	0.024	0.012
		NO_3-N (mg/l)			
Control	——	0.21	0.28	0.06	0.07
Nitrogen+phosphorus	——	0.21	0.14	0.18	0.10
Phosphorus	——	0.21	0.16	0.10	0.05
Auburn No. 3	——	0.20	0.19	0.04	0.20
Corn	——	0.18	0.18	0.06	0.14
		NH_3-N (mg/l)			
Control	0.061	0.070	0.040	0.090	0.040
Nitrogen+phosphorus	0.090	0.103	0.040	0.090	0.050
Phosphorus	0.110	0.090	0.025	0.030	0.030
Auburn No. 3	0.051	0.080	0.072	0.070	0.059
Corn	0.034	0.065	0.064	0.050	0.034

*Ammonium nitrate
**Triplesuperphosphate

Concentrations in fertilized ponds were usually two or more times greater than those in controls. Both feed treatments resulted in higher phosphorus levels than were present in controls. Ammonia nitrogen levels did not form a pattern within treatments and no obvious differences were observed between treatments. Nitrate nitrogen concentrations varied greatly between individual ponds, but averages for different treatments were remarkably similar.

Concentrations of PO_4-P on individual sampling dates ranged from 0.001 to 0.060 mg/l in R ponds and from 0.001 to 0.061 mg/l in S ponds. Values below 0.010 mg/l were found in 80% of the samples. Concentrations of NO_3-N ranged from 0.034 to 0.838 mg/l and from 0.002 to 0.100 mg/l in R ponds and S ponds, respectively. Values above 0.050 mg/l were encountered in only 20% of the samples. Ammonia nitrogen determinations were not obtained for R and S ponds.

Auburn No. 3 contained 0.63% phosphorus (LAWRENCE, unpublished) and the corn had 0.27% phosphorus (MORRISON, 1961). During the experimental study, 10.85 and 4.65 kg of phosphorus per hectare were added in Auburn No. 3 feed and corn, respectively. Large quantities of phosphorus were also added to R and S ponds in feeds. Although phosphorus levels were higher in ponds receiving fertilizers and feeds than in controls, concentrations were relatively low when contrasted to amounts of phosphorus added to the ponds. Phosphate is rapidly adsorbed by bottom sediments and by organisms (HEPHER, 1958; BOYD, 1971a), so concentrations exceeding 0.050 mg/l are seldom reported in ponds. ZELLER (1952) found that average yearly concentrations of PO_4-P in surface waters of fertilized ponds in Missouri ranged from 0.016 to 0.028 mg/l, while mean level in unfertilized ponds varied 0.010 to 0.016 mg/l. HALL, COOPER & WERNER (1970) also reported higher concentrations of PO_4-P in ponds receiving high nutrient additions than in control ponds. However, EWING & DORRIS (1970) did not find higher concentrations of PO_4-P in ponds to which feeds were applied than in their control pond. Phosphate levels immediately following fertilization are high and phytoplankters apparently store phosphorus which is used later for growth (HEPHER, 1958). However, continuous additions of small amounts of phosphorus fertilizers are probably more efficient than periodic additions. LAWRENCE (1954) suggested that fertilizer materials be placed on a subsurface platform and allowed to dissolve gradually. Phosphorus is added daily in small quantities in fish feeds and solubilization and mineralization of phosphorus from excrement and unconsumed feed likely represents a continuous source of this nutrient for phytoplankton.

Nitrogen was also added in large quantities in feeds and fertilizers. However, concentrations of NO_3-N and NH_3-N were usually not substantially elevated above those of control ponds. Much nitrogen in wasted feed and excrement was probably converted to ammonia and lost in gaseous form during periods of high pH resulting from photosynthesis, although dense phytoplankton communities absorbed considerable inorganic nitrogen. ZELLER (1952) found higher concentrations of inorganic nitrogen in unfertilized than in fertilized ponds. He attributed the higher values in unfertilized ponds to nitrogen input from the watershed and low values in fertilized ponds to phytoplankton activity. However, denitrification and gaseous losses of ammonia are probably important in fertilized ponds. Conversely, HALL et al. (1970) found much higher levels of NH_3-N in ponds receiving large urea applications than in controls. Nitrate was not detectable in their ponds. EWING & DORRIS (1970) reported similar concentrations of NH_3-N in a control pond and in ponds receiving feed application, while NO_3-N values were higher in the control.

Obviously, much remains unknown about factors which regulate concentrations of inorganic nitrogen and phosphorus in ponds.

Chlorophyll a

Chlorophyll *a* concentrations allow a comparison of phytoplankton abundance in different samples (COPELAND, MINTER & DORRIS, 1964; DUST & SHINDALA, 1970). Concentrations of this pigment varied greatly within and between each experimental pond during the study (Fig. 2). Chlorophyll *a* values frequently increased rapidly, often doubling or tripling during a 1-week period. Values also decreased with equal rapidity. Only occasionally did concentrations of chlorophyll *a* remain fairly stable for more than 2 weeks. Chlorophyll *a* levels in treatments had the following ranges: control, 1.8 to 35.5 μg/l; nitrogen + phosphorus, 11.2 to 156.2 μg/l; phosphorus, 3.4 to 129.3 μg/l; Auburn No. 3, 3.6 to 162.8 μg/l; and corn - 3.4 to 75.2 μg/l. Averages were 7.45, 62.7, 33.4, 43.7, and 20.2 μg/l, respectively.

Both nitrogen + phosphorus fertilization and phosphorus fertilization caused marked increases in chlorophyll *a*. SWINGLE, GOOCH & RABANAL (1963) reported that nitrogen fertilization did not significantly increase fish production in ponds which had received nitrogen and phosphorus fertilization for several years since nitrogen for optimum phytoplankton productivity was derived from nitrogen fixation and from mineralization of nitrogen in organic matter stored in bottom muds. Data in Fig. 2 clearly reveal that nitrogen is a limiting factor in new ponds on Piedmont

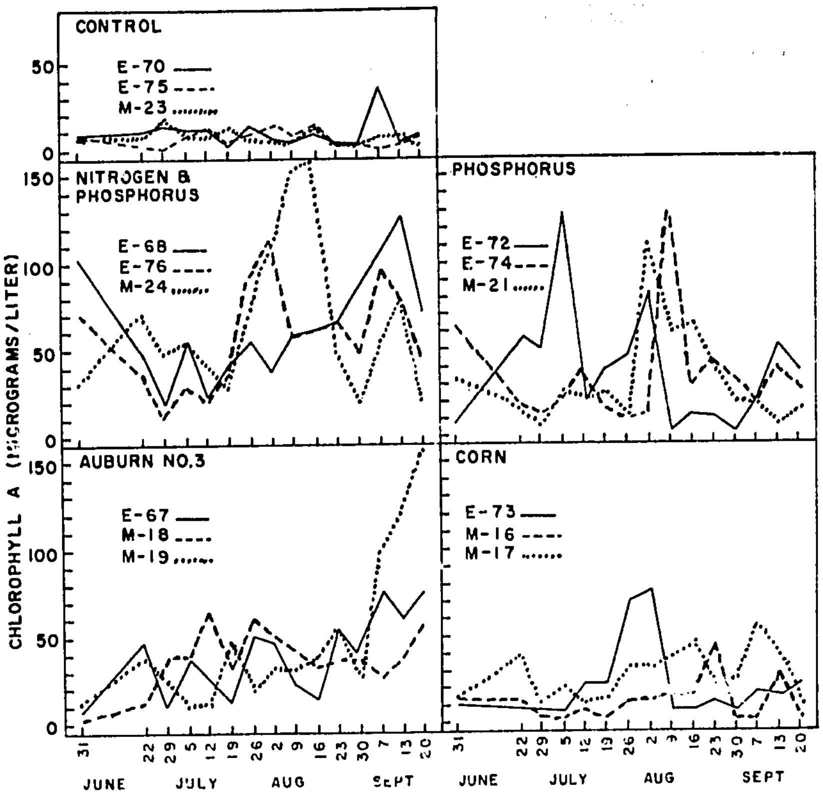


Fig. 2. Concentrations of chlorophyll *a* in control ponds and in ponds which received different fertilizer and feed treatments.

soils. The fact that Auburn No. 3 contained about twice as much phosphorus and 4.5 times as much nitrogen as corn probably accounts for the higher levels of chlorophyll *a* in the Auburn No. 3 treatment.

Chlorophyll *a* values in any particular S pond varied little between sampling dates. Averages for the 12 ponds ranged from 24.6 to 101.4 μg/l. Eight S ponds had values between 40 and 60 μg/l. Values for R ponds ranged from 12.4 to 163.0 μg/l on August 4 and from 11.2 to 230.1 μg/l on August 18 (Fig. 3). Values in many ponds doubled during this period. Cloudy weather prevailed for 3 weeks prior to August 4 so fair weather during the following 2 weeks was apparently responsible for increased growth. S ponds had chlorophyll *a* concentrations similar to those in experimental ponds. R ponds which were aerated had higher concentrations of this pigment than other R ponds. Turbulence in aerated ponds essentially produced a deeper photic zone by continually bringing

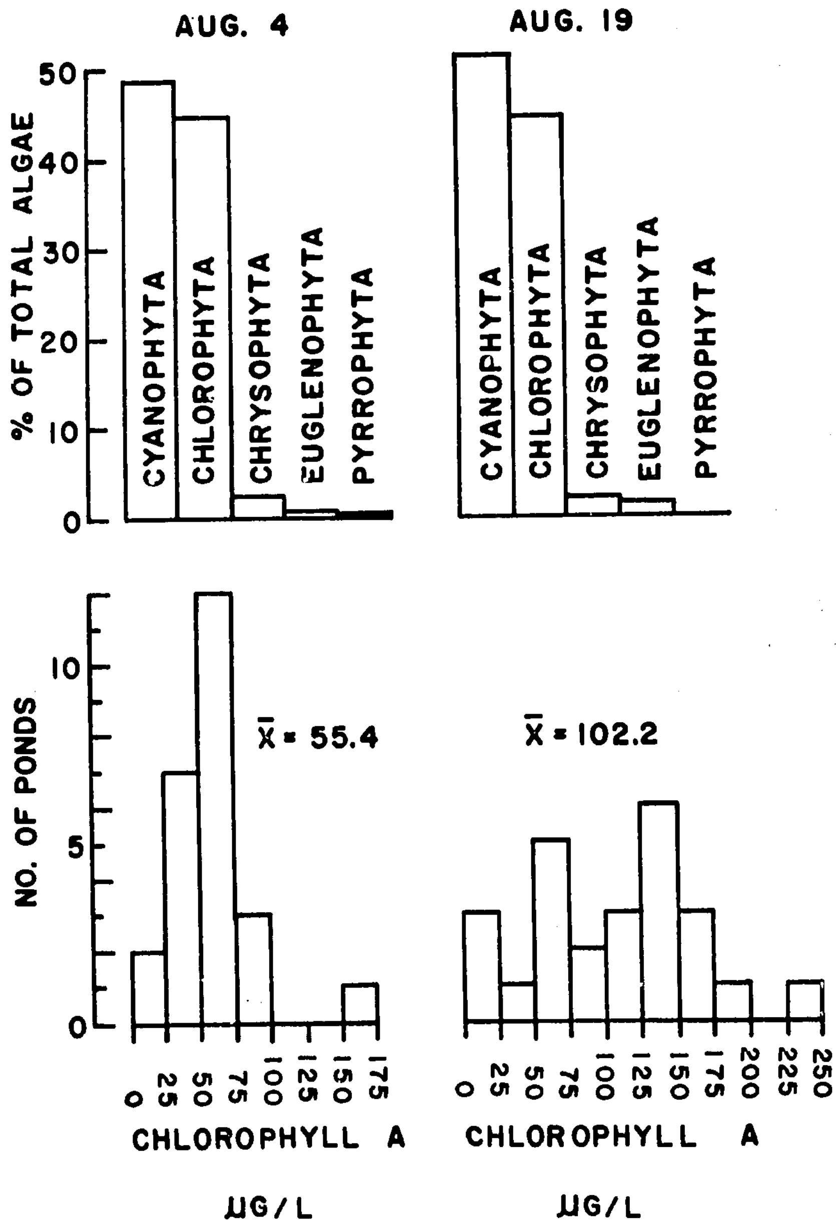


Fig. 3. Upper: Average composition according to taxonomic division of phytoplankton communities in 25, 0.04 ha ponds (R-series) which received fish feeds. Cyanophyta (blue-green algae), Chlorophyta (green algae), Chrysophyta (yellow-green algae). Lower: Frequency distribution histograms of chlorophyll *a* concentrations in R ponds. Class intervals are marked along bases of histograms.

algae from deeper waters to near surface depths where l
gimes were optimum. This probably accounts for the
production of phytoplankton.

Chlorophyll *a* concentrations in unfertilized ponds i
were between 8.8 and 115.5 μg/l, while values for fertilize
fell between 103.4 and 212.3 μg/l (HEPHER, 1962). Chlor
concentrations in unfertilized experimental ponds near
New York, averaged 2.9 μg/l, while high levels of fertiliz
sulted in an average of 55.5 μg/l of this pigment (HAL
1970). TAYLOR (1971) found chlorophyll *a* concentratio
30 μg/l in several reservoirs. Chlorophyll *a* values as high
μg/l were found in oil refinery effluent holding ponds (C
et al., 1964) and a value of 1,500 μg/l was reported in
oxidation pond (DUST & SHINDALA, 1970). However, wh
pared with most bodies of water, fish ponds have high
chlorophyll *a* and phytoplankton densities are obviously g

Primary Productivity

Gross productivity in mg carbon l^{-1} day^{-1} in different tr
(Fig. 4) had the following ranges and means: control, 0.1
($\bar{x}$ = 0.18); nitrogen + phosphorus, 1.30 to 2.07 ($\bar{x}$
phosphorus, 0.59 to 1.71 ($\bar{x}$ = 1.10); Auburn No. 3, 1.2
($\bar{x}$ = 2.30); corn, 0.73 to 1.96 ($\bar{x}$ = 1.18). Primary pro
in fertilized ponds remained at a similar level throughout t
However, in ponds receiving feed applications, primary pr
ty increased as the experiment progressed. This was
related to stepwise increases in feeding rates (Table I). T
general increase of values in feed treatments is also ob
chlorophyll *a* data (Fig. 2). The response of primary pro
to different treatments is, with one exception, similar to
tionship of chlorophyll *a* to treatment. The Auburn No.
ment usually had higher primary productivity values, b
chlorophyll *a* values, than the nitrogen and phosphorus tr
This apparent discrepancy is likely related to one or bo
following. Ponds receiving Auburn No. 3 contained
green algae, while ponds obtaining nitrogen + phospho
dominated by blue-green algae (Fig. 5). Blue-green algae
only chlorophyll *a*, while green algae contain chlorophyll *a*
(SMITH, 1950). Chlorophyll *a* is probably not as accurate a
of photosynthetic capabilities for green as for blue-gree
SWINGLE (1947), KUENTZEL (1969), and LANGE (1970) st
low carbon dioxide concentrations in natural waters of
phytoplankton photosynthesis. Decomposition of waste f

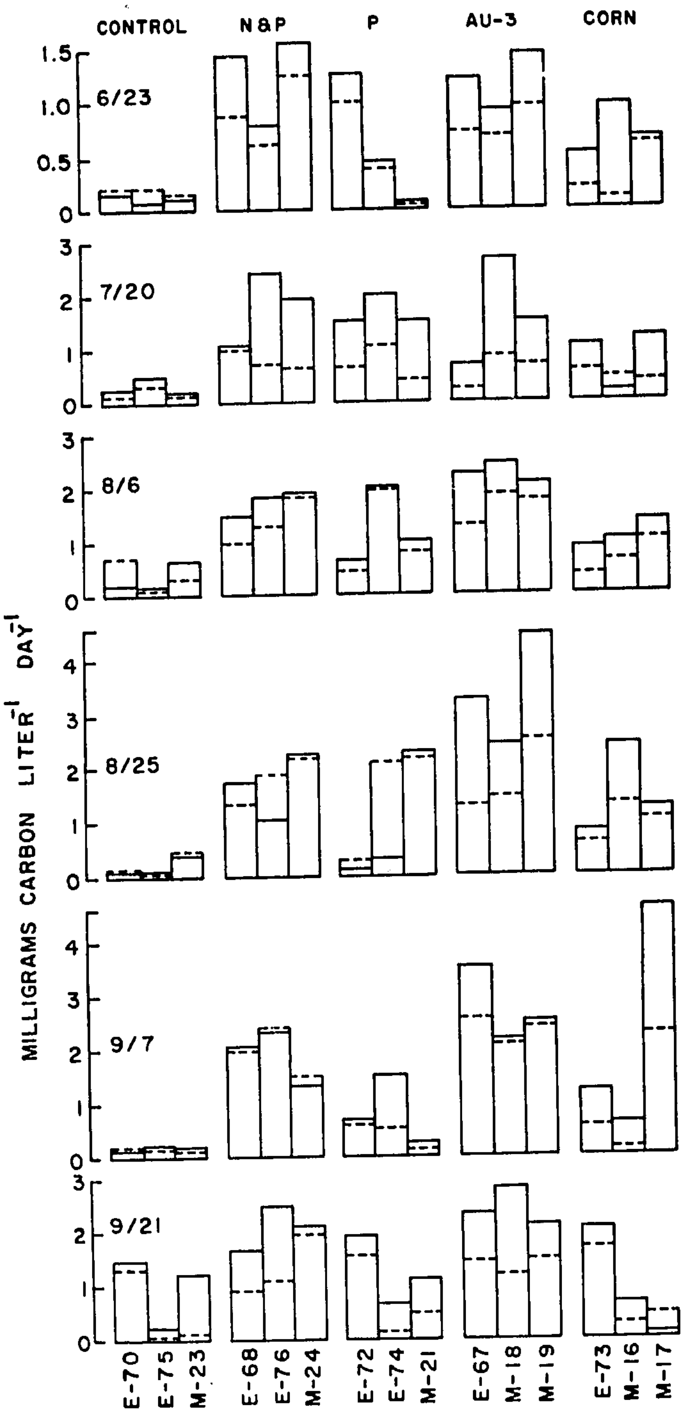


Fig. 4. Gross photosynthesis (bars terminated by solid lines) and respiration (bars terminated by dashed lines) on six sampling dates in experimental ponds. Treatments are indicated at top of figure (N and P-ammonium nitrate and triplesuperphosphate, P-triplesuperphosphate, AU-3-Auburn No. 3 fish feed, corn-cracked corn).

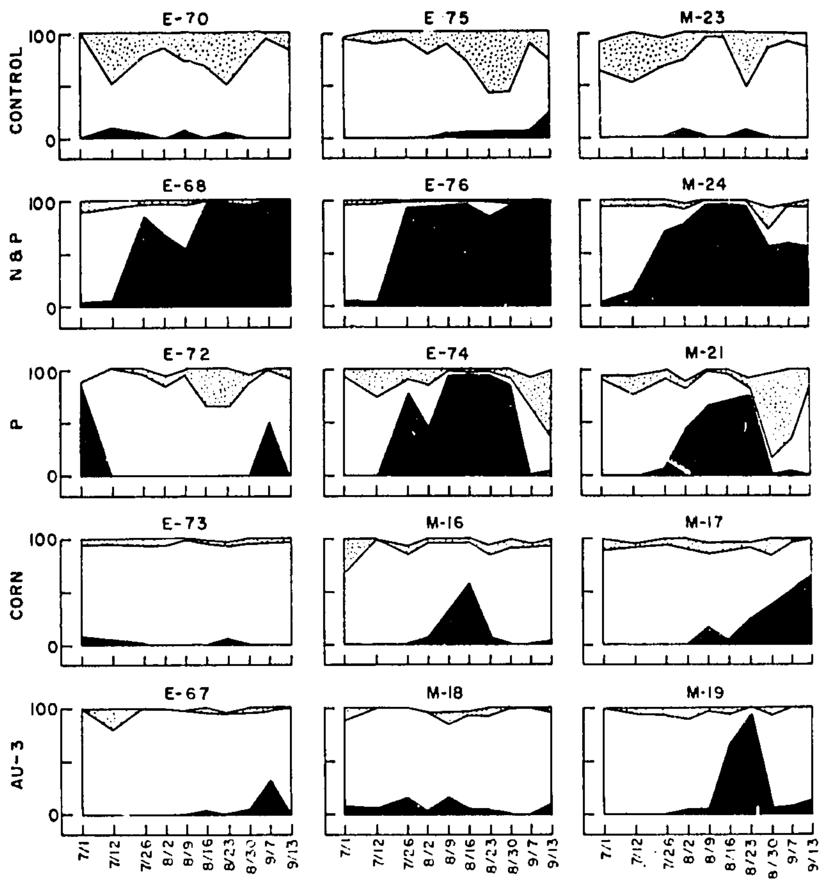


Fig. 5. Relative proportions of blue-green algae (black areas), green algae (white areas), and yellow-green algae (stippled areas) in experimental ponds. Treatments are indicated along left margin (N and P-ammonium nitrate and triplesuperphosphate, P-triplesuperphosphate, AU-3-Auburn No. 3 fish feed, corn-cracked corn).

bably augmented natural supplies of carbon dioxide in the Auburn No. 3 treatment.

Respiration rates were high in all treatments (Fig. 4). Respiration in dark bottles often exceeded gross photosynthesis in control ponds. Respiration was frequently one-half or more as large as gross photosynthesis values in other treatments.

Average gross photosynthesis data for eight S ponds are presented in Fig. 6. Gross photosynthesis was usually high in waters of 0.0 to 0.8 m depth. Peak photosynthesis usually occurred at 0.2 m where means above 3.0 mg C l^{-1} day^{-1} were usually obtained. Photosynthesis decreased rapidly with depth because of light

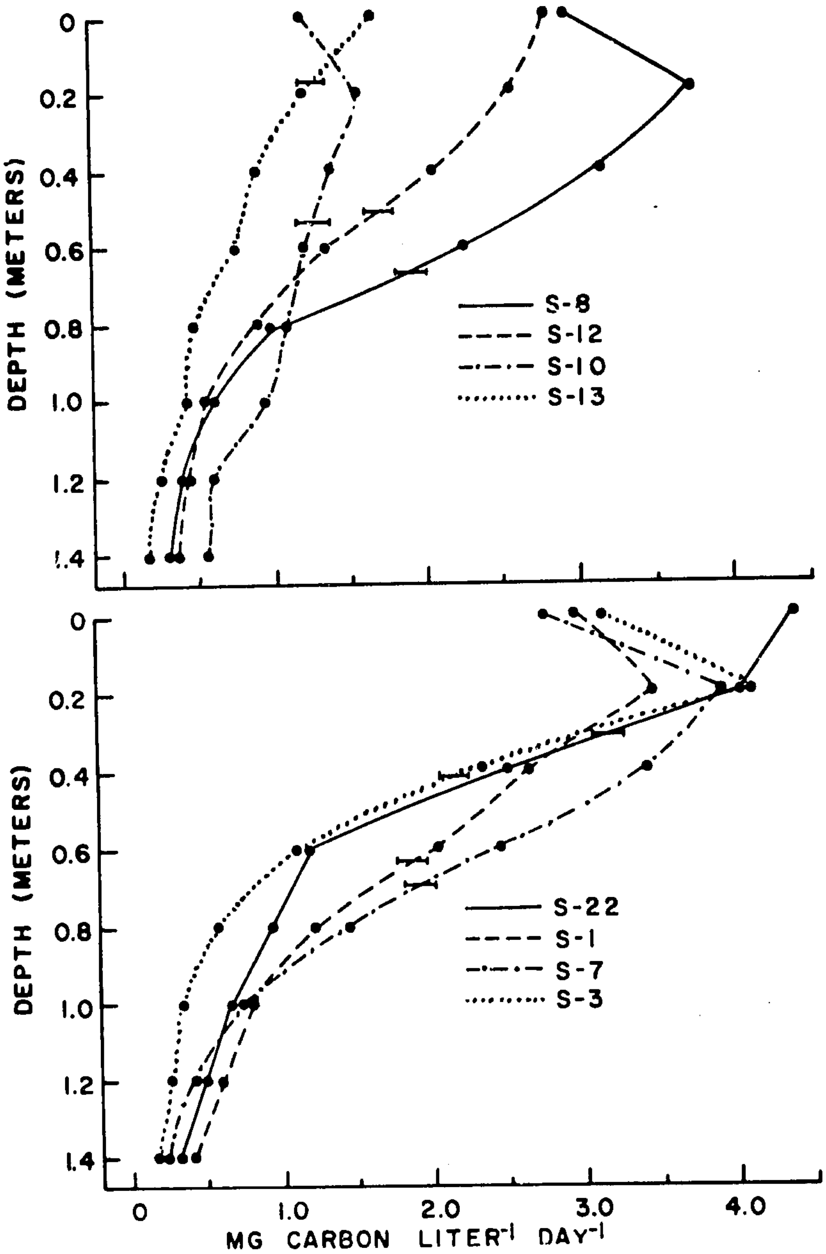


Fig. 6. Gross photosynthesis in eight S ponds on the Fisheries Research Unit, Auburn Univ. Each curve was prepared from averages of determinations made on four sampling dates. Horizontal bars represent the depth at which oxygen production equaled oxygen consumption. S-1, S-12, and S-13 were fertilized ponds. Other ponds received applications of feed.

limitations imposed by an abundance of algal cells. Integration of areas beneath curves (Fig. 6) yielded the following estimates of gross photosynthesis in mg C m^{-2} day^{-1}: S-13, 1,008; S-10, 1,456; S-12, 1,932; S-3, 2,100; S-1, 2,450; S-8, 2,492; S-22, 2,548; S-7, 2,702. Respiration was high, being equivalent to 1.0 to 3.0 mg C l^{-1} day^{-1} (Fig. 6). Compensation depths (where oxygen production was equal to oxygen consumption) were all above 0.8 m. Photosynthesis rates at 0.3 m in S ponds (estimated from Fig. 6) were similar to those found at this depth in experimental ponds which received Auburn No. 3 or nitrogen + phosphorus applications.

Several workers reported high rates of photosynthesis in fertilized ponds. Among these are HEPHER (1962) who gave average values of 3,290 to 6,430 mg C m^{-2} day^{-1} for ponds in Israel and SREENIVASAN (1964) who gave a maximum level of 11,000 mg C m^{-2} day^{-1} for a tropical pond. HALL et al. (1970) reported that primary productivity in ponds receiving high levels of fertilization was 10 times as great in 1966 and fifteen times as great in 1967 as primary productivity of control ponds. Averages of primary productivity values in nitrogen + phosphorus and Auburn No. 3 treatments (Fig. 4) were 4.8 and 6.2 times greater, respectively, than averages for controls. RODHE (1969) gave approximate ranges of phytoplankton production during the growing season as 30 to 100 mg C m^{-2} day^{-1} for oligotrophic lakes, 300 to 1,000 mg C m^{-2} day^{-1} for natural eutrophic lakes, and 1,500 to 3,000 mg C m^{-2} day^{-1} for polluted eutrophic lakes. Reservoirs studied by TAYLOR (1971) had phytoplankton productivities of 208 to 1,619 mg C m^{-2} day^{-1}. Therefore, even considering the shallow depth of most fish ponds, primary productivity rates are high. Respiration is equally elevated in deeper waters of fish ponds because of accumulation of waste feeds and/or dead algae.

Fish kills frequently result when overturns of such ponds occur (SWINGLE, 1968b). Phytoplankton kills which sometimes occur during overturns are likely associated with reduced organic or inorganic compounds from the hypolimnion which are toxic to algae. PROCTOR (1957a) showed that low levels of fatty acids are extremely toxic to species of phytoplankton.

Turbidity

Turbidity values reported in Fig. 7 were usually of the same magnitude in control and supplemental feed treatments of experimental ponds. Turbidity in ponds of both fertilizer treatments was similar, but higher than that of other treatments. Turbidity in control ponds was primarily related to suspended soil particles, while that of ponds receiving feed was caused by phytoplankton.

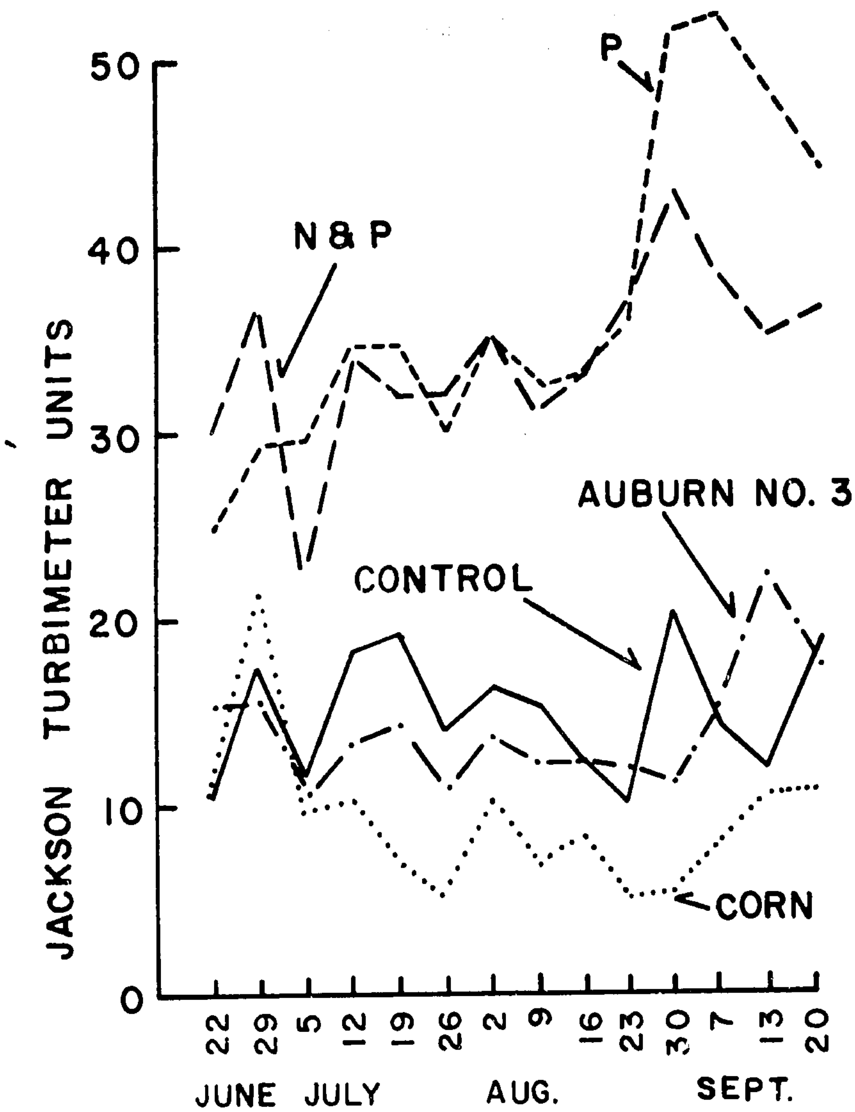


Fig. 7. Average turbidity values in experimental ponds which received additions of fertilizers or feeds. (N and P-ammonium nitrate and triplesuperphosphate, P-triplesuperphosphate).

Addition of organic matter to ponds often causes colloidal particles to precipitate (IRWIN & STEVENSON, 1951). Fertilized ponds had dense algal communities but also contained considerable quantities of colloidal clay. Therefore, turbidity measurements did not correspond well with phytoplankton density as estimated by chlorophyll *a* analysis.

Phytoplankton Communities

Relative amounts of five divisions of algae in 25 R ponds and in 12 S ponds are presented in Figs. 3 and 8, respectively. Collectively, green and blue-green algae accounted for 90% or more of the phytoplankton in almost all ponds on each sampling date. Chrysophyta were usually more abundant than Euglenophyta. Pyrrophyta were relatively rare. In six S ponds, 60% or more of the phytoplankton organisms were blue-greens and substantial amounts of blue-greens were found in four others. In only two S ponds, S-12 and S-13, were blue-greens relatively unimportant. These ponds did not receive supplemental feeding. However, S-3 was a fertilized pond and contained dense populations of blue-green algae. Blue-green algae blooms were common in past years in S ponds which were fertilized (H. S. SWINGLE, personal communications). When data for all R ponds were averaged, amounts of green and blue-green algae were approximately equal. On both sampling dates, 10 R ponds contained 75% or more blue-green organisms. Eight R ponds had communities on August 4 which consisted of 75% or more blue-greens. This number increased to nine on August 19. Thus, roughly 50% of the phytoplankton of the R and S ponds was blue-green algae and in many individual ponds, blue-green algae greatly outnumbered other groups.

Seventy-three species were observed in the phytoplankton of R and S ponds. Relatively few species were present in substantial numbers and even fewer were responsible for dense blooms which were often observed. Chlorophyta that were major species (50% of individuals) were: *Coelastrum microporum*, *Chlorella* sp., *Dictyosphaerium* sp., *Scenedesmus bijuga*, *S. quadricauda*. Species of blue-green algae that were dominant were: *Oscillatoria* sp., *Raphidiopsis curvata*, *Anacystis nidulans*, *A. aeruginosa*, and *Spirulina* sp. The most frequent bloom species were *Oscillatoria* sp. and *Spirulina* sp. Communities consisting of 80 to 90% of one or the other of these two species were noted.

Ponds dominated by green algae had a greater diversity of species than those dominated by blue-greens. For example, averages of 16.2 and 14.5 species were found in S-12 and S-13, respectively, while the average number of species in S-10 and S-22 was 6.0 and 9.0, respectively. Species composition of each S pond was remarkably stable through the 2-month period. The same species were usually dominant on each sampling date in a particular pond.

Most species noted in the R and S ponds were also in the experimental ponds. However, only 14 species were ever so abundant as to comprise 50% of the total phytoplankton (Table III). In fertilizer treatments, *Oscillatoria* sp. and *Anabaena circinalis* were

Table III.- Species of phytoplankton which were present at an abundance of 10% or more of total individuals in at least one sample from the experimental ponds. Numbers in parenthesis indicate the number of samples in which a species was present at an abundance of at least 10%. Three samples from each treatment were collected on 10 sampling dates.

Treatment	Species of phytoplankton
Control	Green algae: Chlorella sp.** (23), Chlamydomonas sp.** (10), Cosmarium tumidum* (8), Ankistrodesmus falcatus ** (6), Sphaerocystis schroeteri** (6), Quadrigula chodatii (3), Oocystis borgei (2), Gloeocystis sp. (2), Closterium sp. (1), Crucigenia sp. (1) Scenedesmus quadricauda (1), Kirchneriella sp. (1), Coelastrum microporum (1), Planktosphaeria gelatinosa (1), Nonnochlous bacillaris ** (1), Coelastrum proboscideum (1). Blue-green algae: Merismopedia tranquilla (2), Anabaena circinalis (1), Yellow-green algae: diatoms** (23).
Triplesuperphosphate + ammonium nitrate	Green algae: Chlorella sp** (9), Ankistrodesmus falcatus* (5), Chlamydomonas sp. (3), Cosmarium tumidum (2), Chlorococcum sp. (1), Scenedesmus quadricauda (1), Coelastrum microporum (1), Blue-green algae: Oscillatoria sp.** (20), Anabaena circinalis** (12), Anacystis cyanea** (7), Spirulina princeps* (3), Coelosphaerium sp. (1), Yellow-green algae: diatoms (1).
Triplesuperphosphate	Green algae: Chlorella sp.** (12), Ankistrodesmus falcatus** (11), Chlamydomonas sp.* (10), Nannochloris bacillaris* (4), Schroederia ancora** (1), Oocystis borgei* (1), Chlorococcum sp. (1), Chlorogonium sp. (1), Kirchneriella sp. (1), Coelastrum microporum (1), Blue-green algae: Anabaena circinalis ** (8), Oscillatoris sp.** (7), Spirulina princeps (1). Yellow-green algae: Bumilleria sp. (7), diatoms* (6). Euglenophyta: Euglena (1).
Auburn No. 3 fish feed	Green algae: Chlorella sp** (22), Cosmarium tumidum** (9), Coelastrum proboscideum** (7), Nephrocytium agardhianum** (4), Chlamydomonas sp* (3), Gloeocystis sp.* (3), Oocystis borgei (3), Staurastrum natator (3), Sphaerocystis schroeteri (2), Tetraedron sp. (2), Closterium sp. (1), Roya sp. (1), Scenedesmus quadricauda (1), Blue-green algae: Oscillatoria sp.** (4), Spirulina princeps (1), Gomphosphaeria sp. (1). Yellow-green algae: diatoms (2).
Cracked corn	Green algae: Cosmarium tumidum** (18), Chlorella sp** (17), Chlamydomonas sp.** (4), Oocystis borgei** (3), Sphaerocystis schroeteri** (2), Staurastrum natator (2), Chlorogonium sp. (2), Ankistrodesmus falcatus (2), Nannochloris bacillaris** (1), Scenedesmus quadricauda* (1), Gloeocystis sp. (1). Blue-green algae: Oscillatoria sp.** (6). Yellow-green algae: diatoms* (1).

* Comprised 25% or more of total individuals in one or more samples.
** Comprised 50% or more of total individuals in one or more samples.

sometimes present at levels of 80 to 99% of the total phytoplankton. The green algae *Cosmarium tumidum*, *Nephrocytium agardhianum*, *Coelastrum proboseideum* and *Chlorella* sp. were individually abundant in proportions of 80 to 95% of the total phytoplankton in a few samples. During periods of domination by green algae, there were pulses of individual species. For example, in E-67, *Chlorella* sp. and *Cosmarium tumidum* were abundant during early July, but disappeared from the community in early August. Both algae reappeared as dominants in the phytoplankton in mid-August. A strong pulse of *Nephrocytium agardhianum* (maximum of 94.2% of total individuals) appeared and practically disappeared within a 4-week period. Smaller pulses of several species (10 to 30% of total individuals) were also noted in E-67. In ponds dominated by blue-green algae, the population of a particular species tended to build up and then remain dominant. For example, *Oscillatoria* sp. increased from 2.3 to 67.2% of the phytoplankton between July 1 and July 26 in E-76. During the remainder of the study, *Oscillatoria* sp. comprised from 62.8 to 98.0% of the phytoplankton in E-76.

Composition of phytoplankton communities by division is presented in Fig. 5. Green and yellow-green algae were abundant in control ponds, although some blue-greens were occasionally found. Green algae comprised roughly two-thirds of the total phytoplankton. Early in the study, ponds receiving nitrogen and phosphorus fertilizers were dominated by green algae, however, blue-greens began to increase after July 12. From July 26 onward, 50% or more of the individuals in these ponds were blue-greens, and sometimes 90 to 99% of the phytoplankton was blue-green algae. Yellow-green forms were scarce even during the initial period when green algae were abundant. Ponds receiving phosphorus, but not nitrogen fertilization, were dominated by blue-greens at certain times; however, these populations did not persist as in ponds fertilized with both nitrogen and phosphorus. Both green and yellow-green forms were often important components of the flora of the phosphorus treatments. Green algae were usually predominant in ponds of both feed treatments. Heavy pulses of blue-green algae temporarily appeared in M-16 and M-19. There was also a late summer increase of blue-greens in M-19.

The number of species per pond varied considerably in ponds of each treatment when samples taken at different times were considered. As few as two and as many as 24 species were recorded in samples. Species diversity was calculated by the method presented by MacArthur & MacArthur (1961), where species diversity is $-\sum_{i} p_i \log_e p_i$, where p_i is the proportion of all species which belong to the i^{th} species. A community composed of 99% of one species and 1% of a second species has a diversity of 0.056 while one composed of 10% each of 10 species has a diversity of 2.300. Low species diversity was associated with dense blooms of blue-green algae. For example, between July 26 and September 13, weekly diversity indices in E-76 were in chronological order; 0.870, 0.757, 0.585, 0.975, 1.193, 0.745, 0.445, and 0.098. During the same period, diversity indices for the control pond M-23 were: 2.160, 1.952, 1.179, 2.099, 1.535, 1.777, 1.969, and 1.692. Low diversities were also obtained in ponds with blooms of green algae. On August 2, species diversity in E-67 during a bloom of *Nephrocytium* was 0.281. However, diversity indices were usually above 1.000 in ponds receiving Auburn No. 3 feed. When all dates are considered, the nitrogen + phosphorus treatment resulted in the lowest diversity (1.128) and control ponds had the highest (1.592). In fertilized ponds, a high productivity with high species diversity is desirable. Relationships between aquatic plant diversity and natural plant food was discussed by BOYD (1971b).

Several observations regarding phytoplankton communities merit further discussion. First, HALL et al. (1970) reported that blue-green algae were rare but green algae were abundant in ponds receiving high levels of urea, superphosphate and potassium chloride. SWINGLE (1947) reported that algae produced by inorganic fertilization were largely genera of Chlorophyta. However, later work (SWINGLE, personal communications) indicated that blue-green algae were abundant in older fertilized ponds where large amounts of organic matter had accumulated in bottom soils, suggesting that some organic factor was necessary for the development of intense blue-green blooms. The present findings reveal that nitrogen + phosphorus fertilization can result in persistent blooms of blue-green algae in new ponds in which bottom soils are essentially devoid of organic matter.

EWING & DORRIS (1970) reported that the phytoplankton of ponds receiving high rates of feeding was comprised largely of green algae. This situation was also noted in the new ponds (Fig. 5), but blue-green algae were frequently abundant in older R and S ponds (Figs. 3 and 8). This difference in the development of algal floras in new and old ponds to which fish feeds are applied cannot be explained from available data.

Field and laboratory experiments revealed that blue-green algae fix atmospheric nitrogen (WILLIAMS & BURRIS, 1952; DUGDALE et al, 1959; NEESS et al, 1962; STEWART, FITZGERALD & BURRIS, 1968). Nitrogen fixation is known only in those groups of blue-green algae which have heterocysts (FOGG, 1956, 1962). OGAWA & CARR (1969) presented strong evidence that heterocysts were involved in nitrogen fixation. Few heterocysts were present when algae were grown in media containing inorganic nitrogen, but large numbers were present when atmospheric nitrogen was the

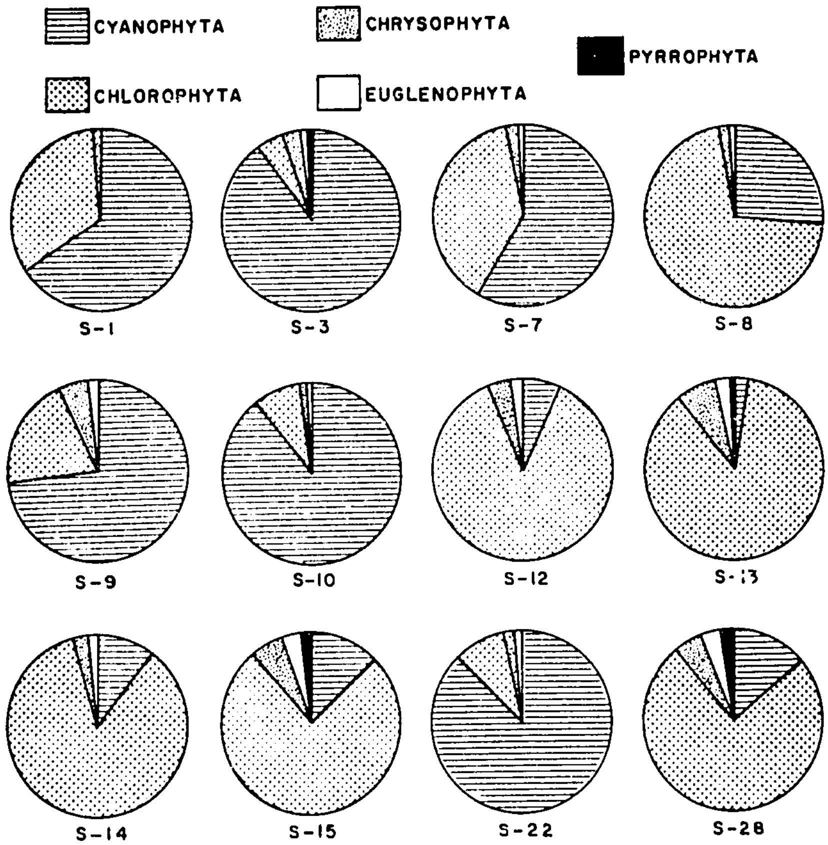


Fig. 8. Composition according to taxonomic divisions of phytoplankton communities in 0.79 to 8.90 ha ponds (S-series). Each graph is the average of data for four sampling dates. S-1, S-12, and S-13 were fertilized ponds. Other ponds received applications of feed. Cyanophyta (blue-green algae), Chlorophyta (green algae), Chrysophyta (yellow-green algae).

only source of this element. Phosphorus was essential for heterocyst production and nitrogen fixation.

In the experimental ponds, *Oscillatoria* sp., which has no heterocysts, was abundant in the nitrogen + phosphorus treatment. However, species of *Anabaena* which are capable of nitrogen fixation were also abundant and heterocysts were noted in most filaments. Inorganic nitrogen shortages possibly developed between periodic fertilizer applications, thereby encouraging development of nitrogen fixing species. Although large concentrations of inorganic nitrogen did not accumulate in ponds receiving feeds, decomposition of feed and excrement probably represented a fairly continuous supply of ammonia nitrogen. Dominant blue-green genera in R and S ponds were *Oscillatoria, Raphidiopsis, Microcystis,* and *Spirulina.* These algae lack heterocysts and presumably the ability to fix nitrogen. Furthermore, blue-green pulses in corn and Auburn No. 3 treatment consisted of *Oscillatoria* sp. During early spring, blooms of *Anabaena* spp. which are capable of fixing nitrogen were observed in some ponds on the Fisheries Research Unit. Feeding rates were low at this time and inorganic nitrogen was possibly in short supply.

Since green algae require both inorganic nitrogen and phosphorus, SHILO (1965) suggested that continuous additions of ammonium sulfate be used to enrich the growth of green over blue-green algae. HALL et al (1970) found high concentrations of NH_3-N in ponds receiving weekly applications of urea (superphosphate was also applied weekly). Green algae were abundant throughout the summer in these ponds. Nevertheless, the occurrence of blue-green algae without heterocysts in many ponds that received feed (Figs. 3 and 8) and the failure of blue-green algae to persist in the phosphorus treatment (Fig. 5) cast some doubt on the general utility of continuous nitrogen additions. PROWSE (1961) reported that the use of phosphorus only fertilization resulted in communities of diatoms, but SWINGLE et al (1963) observed that ponds which had blue-green blooms during fertilization with nitrogen + phosphorus maintained these blooms after nitrogen, but not phosphorus, additions were discontinued.

PHYTOPLANKTON IN PLASTIC POOLS

The response to nitrogen and phosphorus fertilization by phytoplankton in plastic pools (Table IV) is quite different than the

Table IV. Average chlorophyll a concentrations (mg/l) in plastic pools receiving various nutrient additions.

Treatment	June 7	June 28	July 19
Control	6.8	5.4	5.8
Phosphorus*	10.6	9.9	8.5
Nitrogen** + phosphorus	75.6	55.3	50.6
Auburn No. 3	84.4	23.4	32.0
Sugar	10.6	10.2	9.7
Sugar + phosphorus	6.5	5.9	16.5
Sugar+nitrogen+phosphorus	32.7	37.0	41.2

*Triplesuperphosphate
**Ammonium nitrate

response in earthen ponds (Fig. 3). Initial levels of phosphorus in plastic pools were only slightly higher than those in earthen control ponds. Nevertheless, there was little response to phosphorus additions in plastic pools. Inorganic nitrogen + phosphorus applications caused a marked increase in phytoplankton density in plastic pools. In earthen ponds, phosphorus is rapidly adsorbed by bottom soils, while in plastic pools, phosphorus was apparently recycled so rapidly from dead cells that this element was never limiting. Auburn No. 3 additions caused a marked increase in growth, presumably from its nitrogen content. Carbohydrate (sugar) and sugar + phosphorus did not enhance phytoplankton growth appreciably, but when ammonium nitrate was added with sugar and triplesuperphosphate good growth was obtained.

Species of phytoplankton in plastic pools were green algae of the following genera: *Scenedesmus*, *Chlamydomonas*, *Dictyosphaerium*, *Chlorella*, *Oocystis*, *Golenkinia*, and *Ankistrodesmus*. No blue-green algae were observed. Plastic pools represented a greatly simplified system as compared to ponds, so the absence of blue-green algae was probably not related to nutrient additions.

The lack of response to phosphorus in soil-free plastic pool systems (Table IV) which contained small concentrations of PO_4-P corroborates the idea that very small amounts of phosphorus are required for dense phytoplankton growth (KUENTZEL, 1969). A continuous supply of phosphate delivered at the approximate rate of utilization by phytoplankton would be the most efficient technique for applying phosphorus fertilizers to ponds.

Auburn No. 3 and sugar additions to fertilizer treatments did not increase chlorophyll *a* concentrations above those produced by nitrogen + phosphorus alone. Primary productivity estimates were 0.29, 0.42, and 0.58 mgC l^{-1} hr^{-1} for nitrogen + phosphorus, sugar + nitrogen + phosphorus, and Auburn No. 3 + nitrogen + phosphorus, respectively. These observations reinforce the conclusion that photosynthesis by phytoplankton may be increased through microbial production of carbon dioxide from organic matter.

Macro-Algae

Occurrence

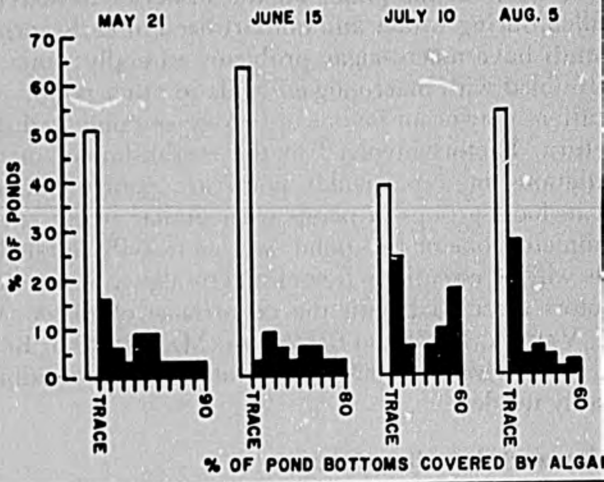
The 1965 survey revealed that *Spirogyra* spp., *Chara vulgaris*, *C. globularis*, *C. braunii*, *Nitella* sp., *Rhizoclonium hieroglyphicum*, *Pithophora kewensis*, *Hydrodictyon reticulatum*, *Cladophora* sp., *Lyngbya* sp., and *Oedogonium* sp. were the only macro-algae present at densities sufficient to interfere with ponds management. The degree of coverage required to interfere significantly with fish production and fishing will vary with type of algae, pond morphometry, and species of fish in pond. However, it seems safe to assume that above 10 to 20% coverage of fish ponds with macro-algae is almost always undesirable. Of the species listed above, *Lyngbya* sp. *Nitella* sp., *Cladophora* sp., and *Oedogonium* sp. were seldom encountered. Communities of macro-algae were never unialgal, but one species often comprised most of the biomass. Degrees of infestation ranged from a few clumps of macro-algae in some ponds to complete coverage in others. Ponds ranged in size from less than 1 ha to more than 25 ha. Macro-algae problems were more frequent in smaller ponds, but larger ponds occasionally had extensive infestations. For example, one 9 ha pond was completely filled with *H. reticulatum* for several months. It was not possible to obtain more than a visual estimate of pond size and macro-algae coverage, but a conservative assessment was that at least 5% of all ponds had 20% or more coverage. In some localities, an even greater proportion of ponds had macro-algae problems. For example, about 25% of ponds in the vicinity of Snowden, Alabama, were plagued with troublesome growths of *P. kewensis*.

A summary of water quality data for ponds of the three physiographic regions are presented in Table V. *P. kewensis* was commonly found in hard waters of the Black Belt, but this species was seldom noticed in soft water areas. *Spirogyra* spp. and *Chara* spp. were frequent in all three regions. *Chara vulgaris* usually occurred in hard waters, while *C. globularis* and *C. braunii* were more frequent in soft waters. Identification of the several species of *Spirogyra* was not attempted. *Hydrodictyon reticulatum* and *Rhizoclonium hieroglyphicum* were more commonly observed in Piedmont ponds, but these algae were often seen in other regions.

Table V. Average water quality data for ponds located on three physiographic regions of Mississippi and Alabama. Values are in mg/l as calcium carbonate for alkalinity and mg/l for individual ions.

Analysis	Black belt	Clay and sand hills	Piedmont
Total alkalinity	73.23	11.53	13.41
Calcium	25.00	2.44	2.83
Magnesium	1.32	1.52	0.83
Potassium	3.71	2.10	1.37
Sodium	3.82	0.41	1.16

Species of *Spirogyra* were about equally abundant fron fall. *R. hieroglyphicum* and *H. reticulatum* were usually enco the spring. *Chara* spp. and *P. kewensis* were often fou spring, but large populations of these species did not ge velop until July or August.



	% ALGAE INFESTED PONDS CONTAINING A PARTICUL			
SPIROGYRA	91.5	61.5	66.7	66.7
RHIZOCLONIUM	22.8	69.2	42.8	24.3
HYDRODICTYON	8.6	7.7	4.8	—
PITHOPHORA	—	7.7	6.1	6.1
CHARA	—	—	15.1	19.0

Fig. 9. Frequency distribution histograms illustrate the degree of co 0.04 ha ponds on the Auburn Univ. Fisheries Research Unit by Open bars depict the percentage of ponds in which macro-algae served. Class intervals extending from a trace to 90% coverage bases of histograms. Percentages of macro-algae infested ponds in five genera were observed are presented in the lower part of the fig

Data in Fig. 9 show the extent of macro-algae covera ponds on the Fisheries Research Unit. Various fish cult ments, including fish feeding studies, were conducted in but no consistent relationships between treatment and munities were noted. The greatest coverage was usual *gyra* spp. or *R. heiroglyphicum*. "Mats" of two of more s often observed in the same pond. The amount of c *Spirogyra* spp., *R. hieroglyphicum*, and *H. reticulatum* in m ponds generally declined after July 10. *Pithophora k* *Chara* spp. populations increased in size as the summer Species occurrence and seasonal changes in species fre abundance in small ponds (Fig. 9) agreed well with observations of Piedmont ponds during 1965, but a greater percentage of the small ponds had problems with macro-algae. This was undoubtedly related to the relatively large proportion of shallow water in small ponds on the Fisheries Research Unit as compared to farm ponds. Furthermore, many of the ponds on the Fisheries Research Unit had been filled during winter and not fertilized in early spring.

Many ponds have macro-algae problems annually; some ponds are never troubled with macro-algae, while in other ponds, macro-algae infestations may occur for one or two seasons only to disappear and not return. Factors involved in the establishment of macro-algae populations in a particular pond are poorly understood. Frequently in local groups of ponds with similar water chemistry and morphometry, one or two ponds will be heavily infested while other ponds will be essentially free of macro-algae. Some information on factors associated with the occurrence of *Chara* (Wood, 1950, 1952; Vaidya, 1967) and *Cladophora* (Mason, 1965; Bellis & McLarty, 1967; Herbst, 1969) are available, but additional research is badly needed.

Productivity and Standing Crop

Standing crop data for several macro-algae populations are reported in Table VI. Values for different populations of *P. kewensis*, *R. hieroglyphicum*, and *Spriogyra* spp. were quite variable, the maximum standing crop for each being twice or more as great as the smallest. Forsberg (1960) reported maximum dry weights of 1130 g/m² for *Chara fragilis* and 310 g/m² for *Nitella mucronata* in a

Table VI. Standing crops in macro-algae populations of ponds near Auburn and Snowden, Alabama during Summer 1971. Each entry is for a single pond and represents the average of 3 to 5 quadrats.

Species	g dry wt/m^2
Pithophora kewensis	110, 118, 137, 160, 205
Rhizoclonium hieroglyphicum	68, 181, 216
Hydrodictyon reticulatum	54
Spirogyra spp.	9, 29, 53, 67, 83
Chara fibrosa	108, 115
Chara braunii	104

Swedish lake. WETZEL (1964) found 326 g/m^2 of *Chara* sp. at 0.3 m and 764 g/m^2 at 1 m in a small pond. Literature on standing crops of other species was not located. Higher aquatic plants usually produce much larger standing crops (BOYD, 1971b) than those reported in Table VI. Yet, the smallest, *P. kewensis* population entirely covered the surface of the infested area. All other populations, except the two smallest *Spirogyra* entries (Table VI) either filled the water column or covered the surface so that light penetration was greatly restricted.

Chlorophyll *a* levels ranged from an average of 1.49 mg/g dry wt in *Chara braunii* to 6.30 mg/g dry wt in *Spirogyra* spp. These values are within the range of chlorophyll *a* concentrations in vascular aquatic macrophytes (BOYD, 1970).

Gross photosynthesis rates calculated as mg C g dry wt^{-1} hr^{-1} for mid-day light regimes were: *Spirogyra* sp. 16.7, *R. hieroglyphium* 10.0, *C. braunii* 5.4, and *H. reticulatum* 5.0. These estimations are based on single populations. Gross photosynthesis in four *P. kewensis* populations were 3.6, 5.9, 6.3, and 7.4 mg C g dry wt^{-1} hr^{-1}. The *P. kewensis* population with a standing crop of 160 g/m^2 (Table VI) had a gross photosynthesis rate of 7.4 mg C g dry wt^{-1} hr^{-1} or 1.18 g C m^{-2} hr^{-1}. Respiration was equivalent to 0.32 g C m^{-2} hr^{-1}. When converted to a daily rate by the method used by SCHINDLER & HOLMGREN, (1971) a gross photosynthesis rate of 9.44 g C m^{-2} day^{-1} was obtained. Twenty-four hour respiration was estimated at 7.68 g C m^{-2} day^{-1}. Thus, net photosynthesis was 1.76 g C m^{-2} day^{-1}. Many vascular aquatic plants have higher daily rates of net carbon accumulation (WESTLAKE, 1963).

Competition with Phytoplankton

Growth habits of *Chara* spp. are similar to those of higher plants. Charophytes are attached to the substrate by rhizoids from the base of vertical axis (WOOD, 1967). The axis of short nodes and long internodes extends upward into the water. Axes of species observed during the present study were from a few centimeters to 1 m in length. Populations of the other species of macro-algae begin growth on the pond bottom and then rise upward to completely or partially fill the water column or sometimes to float on the surface as a "mat". *Pithophora* is generally found floating on the surface. There are three obvious ways by which macro-algae compete with phytoplankton: restriction of light penetration, competition for nutrients, and competition for space.

Primary productivity of phytoplankton beneath a "mat" of *P. Kewensis* and within a stand of *Chara braunii* was much less than in open water (Fig. 10). Productivity beneath *Pithophora* was reduced

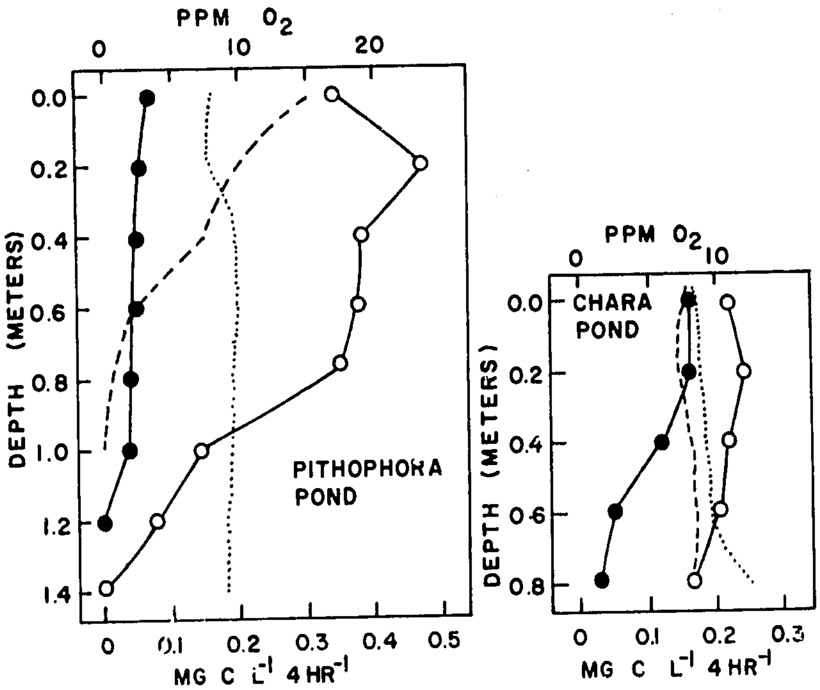


Fig. 10. Gross photosynthesis from 10 : 30 AM to 2 : 30 PM by phytoplankton beneath *Pithophora kewensis* and within *Chara braunii* populations (solid circles) is compared with gross photosynthesis in open water (open circles). Oxygen concentrations in open water are represented by dotted lines while oxygen levels beneath or within macro-algae growths are given by dashed lines.

by a factor of 10. Dissolved oxygen levels also reflected the decrease in phytoplankton, concentrations dropping to almost 0 mg/l at 0.6 m. Adequate light for phytoplankton photosynthesis penetrated to greater depths in the *Chara* stand and productivity by phytoplankton was reduced by only 50% as compared to open water. Oxygen levels were not appreciably lowered within the *Chara* stand since oxygen was released throughout the water column by *Chara*. When present in sufficient abundance, phytoplankton cells can restrict light penetration and prevent initial growth of macro-algae on pond bottoms. Thus, early spring fertilization is often used to control macro-algae (SMITH & SWINGLE, 1942). Heavy rains have been observed to cause *P. kewensis* "mats" to sink. The "mats" usually rise back to the surface in a few days. In some cases, rapid phytoplankton growth occurs after the macro-algae sinks since more light is available for photosynthesis. Resulting turbidity sometimes destroys the macro-algae before it rises back to the surface. Turbidity following periods of heavy rainfall will also occasionally muddy water enough to destroy submersed macro-algae.

LAWRENCE (1958) reasoned that competition between macro-algae and phytoplankton for nutrients might decrease phyto-plankton production and reduce fish yields. Ponds containing extensive growths of macro-algae usually have relatively transparent water and presumably low phytoplankton productivity. Concentrations of nitrogen, phosphorus and other nutrients in macro-algae were given by BOYD & LAWRENCE (1966). *Pithophora kewensis* contained an average of 2.57% nitrogen and 0.30% phosphorus. The average standing crop of *P. kewensis* (calculated from Table VI) is 146 g/m². Assuming 25% coverage in a 1 ha pond, a hypothetical *P. kewensis* "mat" would contain 10.0 kg nitrogen and 1.1 kg phosphorus. These quantities of nutrients are large when compared to amounts of dissolved nitrogen and phosphorus compounds that are normally found in pond water.

Chlorophyll *a* concentrations were used as an estimate of phyto-plankton density in catfish ponds (0.04 ha surface area) that were receiving additions of supplemental feeds. Six of these ponds were infested with macro-algae and contained from 1.0 to 7.7 μg/l of chlorophyll *a*. Chlorophyll *a* values ranged from 37.1 to 109.0 μg/l in six ponds that were free of macro-algae. Macro-algae communities covered only 25 to 50% of pond surfaces and these communities had been present at about this degree of coverage for 4 to 6 weeks. Since all ponds were receiving continuous additions of nutrients through solubilization and mineralization of unconsumed feed and fish excrement, it is difficult to conclude that phytoplankton growth was limited so severely by light and nutrient depletion. It is puzzling why phytoplankton did not grow in the open water. Possibly, macro-algae excrete antibiotic substances which inhibit phytoplankton growth. Antibiotic effects of one species of algae upon another were described by PROCTOR (1957a, b).

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