Fall 1971

SOME ECOLOGICAL EFFECTS OF ARTIFICIAL CIRCULATION ON A SMALL EUTROPHIC NEW HAMPSHIRE LAKE

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72-9827

HAYNES, Robert Chester, 1938-
SOME ECOLOGICAL EFFECTS OF ARTIFICIAL CIRCULATION ON A SMALL EUTROPHIC NEW HAMPSHIRE LAKE.

University of New Hampshire, Ph.D., 1971
Ecology

University Microfilms, A XEROX Company, Ann Arbor, Michigan

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by

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B.S.Ed., State College at Bridgewater, 1966

M.S., University of New Hampshire, 1968

A THESIS

Submitted to the University of New Hampshire

In Partial Fulfillment of

The Requirements for the Degree of

Doctor of Philosophy

Graduate School

Department of Zoology

September, 1971

This thesis has been examined and approved.

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September 1, 1971
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ACKNOWLEDGEMENTS

I am especially indepted to Dr. P. J. Sawyer for his guidance, encouragement, and invaluable suggestions in preparing this manuscript.

Appreciation is also expressed to the other members of my doctoral committee, Dr. R. A. Croker, Dr. A. C. Mathieson, Dr. J. J. Sasner, Jr., and Dr. A. E. Teeri for their suggestions and aid in preparing this manuscript.

I want to thank the New Hampshire Water Supply and Pollution Control Commission for their cooperation during my research. I want to thank especially Mr. T. P. Frost and Mr. R. E. Towne for their assistance, encouragement and for the use of a research trailer and boat. My appreciation is extended also to Mr. R. S. Kinniburgh of the New Hampshire Water Supply and Pollution Control Commission for completing nutrient analyses used in this study.

I wish to express my sincere gratitude to Mr. G. L. Byers, Chairman, New Hampshire Water Resources Research Center for his advice and for financial assistance proffered through that agency.

I should also like to thank Miss S. Koerner and Miss A. T. Packard for their assistance with the enumeration of phytoplankton.

I am indepted to my wife, Judith, for her patience in typing and reviewing this manuscript.

This investigation was supported in part by funds provided by the United States Department of Interior, Office of Water Resources Research, as authorized under the Water Resources Act of 1964, Public Act 88-379, through the New Hampshire WRRC situated at the University of New Hampshire and by the United States Department of the Interior, Federal Water Pollution Control Administration predoctoral fellowship (Nos. F1-WP-26, 461-01 and -02).

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ABSTRACT

SOME ECOLOGICAL EFFECTS OF ARTIFICIAL CIRCULATION ON A SMALL EUTROPHIC NEW HAMPSHIRE LAKE

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Several years previous to the start of this investigation, Kezar Lake had developed annual noxious blue-green algal blooms. In an attempt to improve lake conditions, the New Hampshire Water Supply and Pollution Control Commission decided to try artificial circulation of Kezar Lake. The study reported here was made to help understand some of the ecological effects of mixing the lake.

Samples were collected from meter intervals in the water column on at least a weekly basis during May through October for the years 1968 and 1969. Water chemistry was determined by standard methods. The distribution of Fe, Mn, Na, Ca, Mg, K, Zn, Cu, Cl, SiO_2 in the water column were measured before and after mixing. Nitrogen in the forms of NH_3-N, NO_2-N, NO_3-N and organic-N were studied. Ortho-P, and total-P were determined. Chlorophyll-a was measured as an index of phytoplankton potential to assimilate carbon. Primary productivity studies were made to the level of 1% surface light. Phytoplankton were identified and counted

from live and fixed material respectively under an inverted microscope. Physical measurements included temperature and transparency.

Artificial circulation destratified Kezar Lake completely and isothermal conditions were maintained throughout the test periods. Mixing caused an increase in the heat budget of the lake, and the stability of stratification was reduced to zero when the lake became homothermous. Water transparency increased after remedial aeration in 1968 but decreased following mixing in 1969.

Artificial circulation increased the oxygen content of bottom waters and concurrently removed large concentrations of carbon dioxide, which were lost to the atmosphere at the air-water interface. Most nutrients were distributed uniformly after the lake was mixed. The supply of nutrients before and after artificial circulation was sufficient to support phytoplankton populations.

A uniform, vertical distribution of the bloom-forming alga _Aphanizomenon flos-aquae_ occurred after lake mixing. In 1968 concentration of _A. flos-aquae_ eventually declined, but following preventative aeration in 1969 _A. flos-aquae_ bloomed. After decline of the blooms of _A. flos-aquae_ each year the phytoplankton became dominated by chlorophycean taxa.

Levels of chlorophyll-a became uniformly dispersed in the water column after artificial circulation. Mean values for 1968 and 1969 were 0.14 and 0.20 g/m^2 respectively.

Chlorophyll degradation to pheo-pigments appeared to be greater during a bloom of heterogeneous green algae than during the bloom of A. flos-aquae.

The average rate of carbon fixation by phytoplankton during the two summers were 190mg (particulate) C/m^2/hour in 1968 and 230 mg(total) C/m^2/hour in 1969. Extracellular release of organic carbon-14 increased with depth and accounted for 19.4% of the total carbon fixed in the euphotic zone for the summer of 1969.

A discussion of the results is included, and a comparison is made with the findings of other authors.

INTRODUCTION

Artificial circulation (destratification) of lacustrine environments was reported first by Grim (1952) and Hooper, Ball and Tanner (1952). Grim attempted to pump epilimnetic water into the hypolimnion whereas Hooper et al. used the reverse procedure. Neither attempt achieved complete destratification. Subsequent to these early studies more effective techniques to destratify lakes and reservoirs were developed. Fast (1968) presented an excellent account of the principles and techniques of artificial destratification. The subject of lake stratification, which is germane to all artificial destratification studies, is discussed comprehensively by Hutchinson (1957).

Artificial circulation has been used primarily in fresh-water impoundments. The circulation of reservoir water can prevent hypolimnetic anoxia and its attendant taste and odor problems. The subject of impoundment destratification for water quality control is covered adequately by Symons (1969). Symons' compilation of published research papers includes an extensive list of references on artificial destratification in lakes and reservoirs.

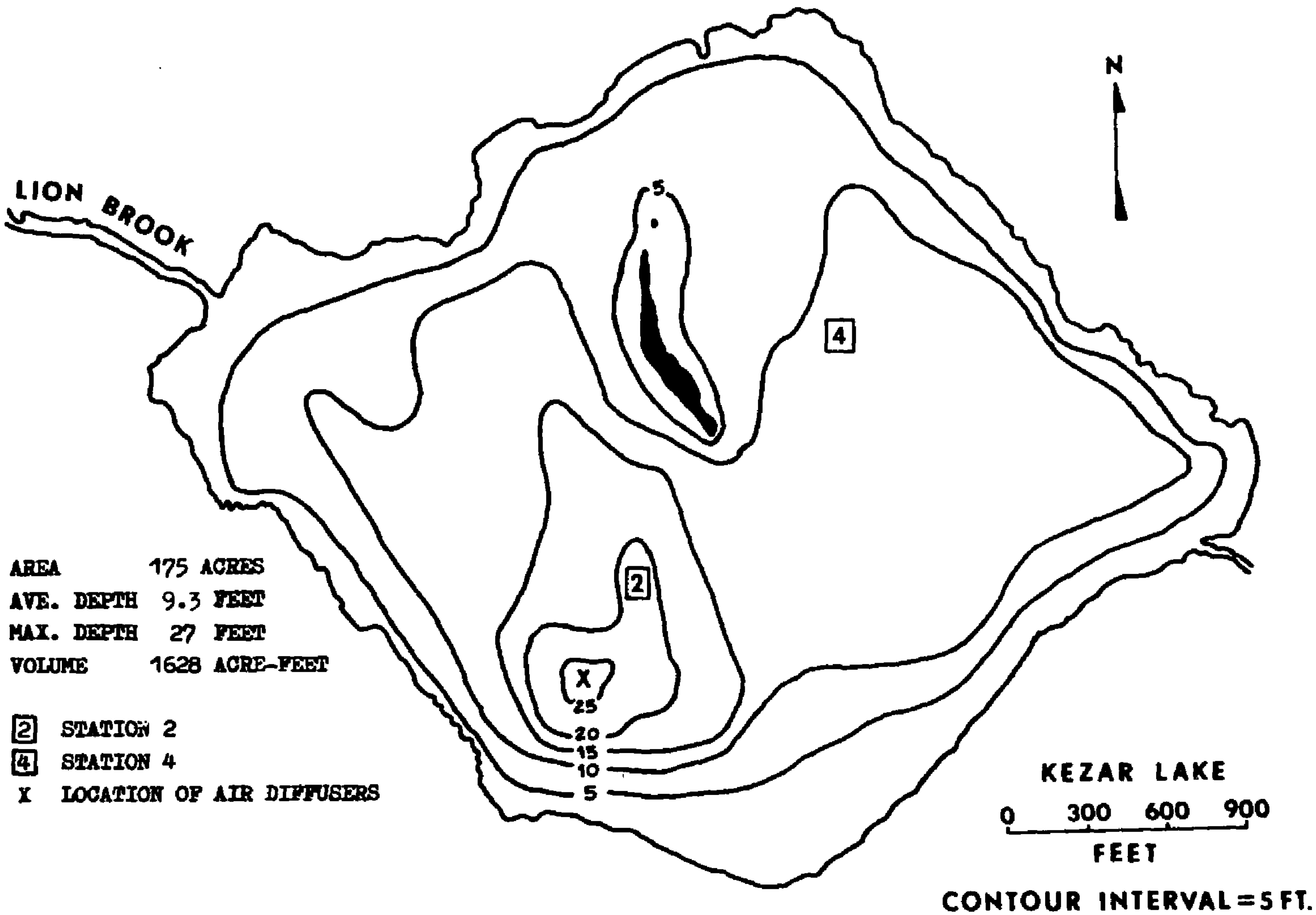
Reasons for implementing artificial circulation in lakes are few. The technique has been used successfully to prevent winterkill of fish by Burdick (1959), Halsey (1968), Hamalainen (1969), Hemphill (1954), Schmitz (1958), Rasmussen (1960), Tubb (1966) and Woods (1961). Patriarche's (1961) attempt to avert winterkill of fish was unsuccessful. In these experiments warmer, more dense bottom water was transferred to the surface to melt ice and to increase its dissolved oxygen content. The application of artificial circulation to increase the productivity of brown-stained bog lakes by intrafertilization has been reported by Hasler (1958), Schmitz (1958) and Schmitz and Hasler (1958). The objective of these investigations was to transfer nutrients, particularly phosphorus, into the euphotic zone from the mud and bottom water. Hooper et al. (1952) attempted to artificially circulate a small Michigan trout lake to stimulate phytoplankton production and thereby increase the carrying capacity of the lake for fish. Johnson (1966) caused circulation of a small lake, and reported increased productivity and rearing capacity for coho salmon. Conversely, Yount (1966) tried unsuccessfully to reduce the level of nutrients in some "hypereutrophic" Florida lakes by artificial aeration. His aim was to avert reducing conditions at the mud-water interface and thereby prevent nutrients from going into solution in the water column.

Artificial circulation has been used also to prevent summer stagnation in meso- and eutrophic lakes. Karlgren and Lindgren (1963) aerated a shallow mesotrophic lake to alleviate pronounced oxygen deficiency but reported entirely negative results. Ambuhl (1962) and Thomas (1966) described the initial and conclusive results respectively of a four year study on the aeration of eutrophic Lake Pfaffikon near Zurich, Switzerland. Improvement in the condition of "polluted" lakes following aeration has been reported (Anon., 1960; Anon., 1966; and Heath, 1961).

There is little published literature on the biological effects of artificial circulation although the need for such studies has previously been recognized by Falk (1965), Fruh (1967) and Whalls (1966). Robinson, Irwin and Symons (1969) investigated the influence of artificial circulation on phytoplankton populations in reservoirs, but they identified and enumerated to genera only. A recent report by the Inland Fisheries Branch (1970) of the California Department of Fish and Game discussed the effect of artificial circulation on the distribution of bottom organisms. This paper reports the results of my research at Kezar Lake, a small eutrophic lake located in North Sutton, New Hampshire, which was circulated artificially during the summers of 1968 and 1969 by the New Hampshire Water Supply and Pollution Control Commission (NHWSPCC) to impede noxious blooms of a blue-green alga.

Kezar Lake is a young geological feature. According to Hoover (1938) it is a shallow, kettle hole lake which rests in a depression left by melting ice blocks of the last glacial period (Fig. 1). Since 1963 annual summer blooms of filamentous blue-green algae have occurred at Kezar Lake. In 1966 a dense population of _Aphanizomenon flos-aquae_ (L.) Ralfs survived application of 0.26 ppm

Fig. 1. Hydrographic map of Kezar Lake, Merrimack County, New Hampshire indicating location of the air diffuser apparatus and sampling stations.


LION BROOK
N
4
2
X
5
25
20
15
10
5
AREA 175 ACRES
AVE. DEPTH 9.3 FEET
MAX. DEPTH 27 FEET
VOLUME 1628 ACRE-FEET
2 STATION 2
4 STATION 4
X LOCATION OF AIR DIFFUSERS
KEZAR LAKE
0 300 600 900
FEET
CONTOUR INTERVAL=5 FT.

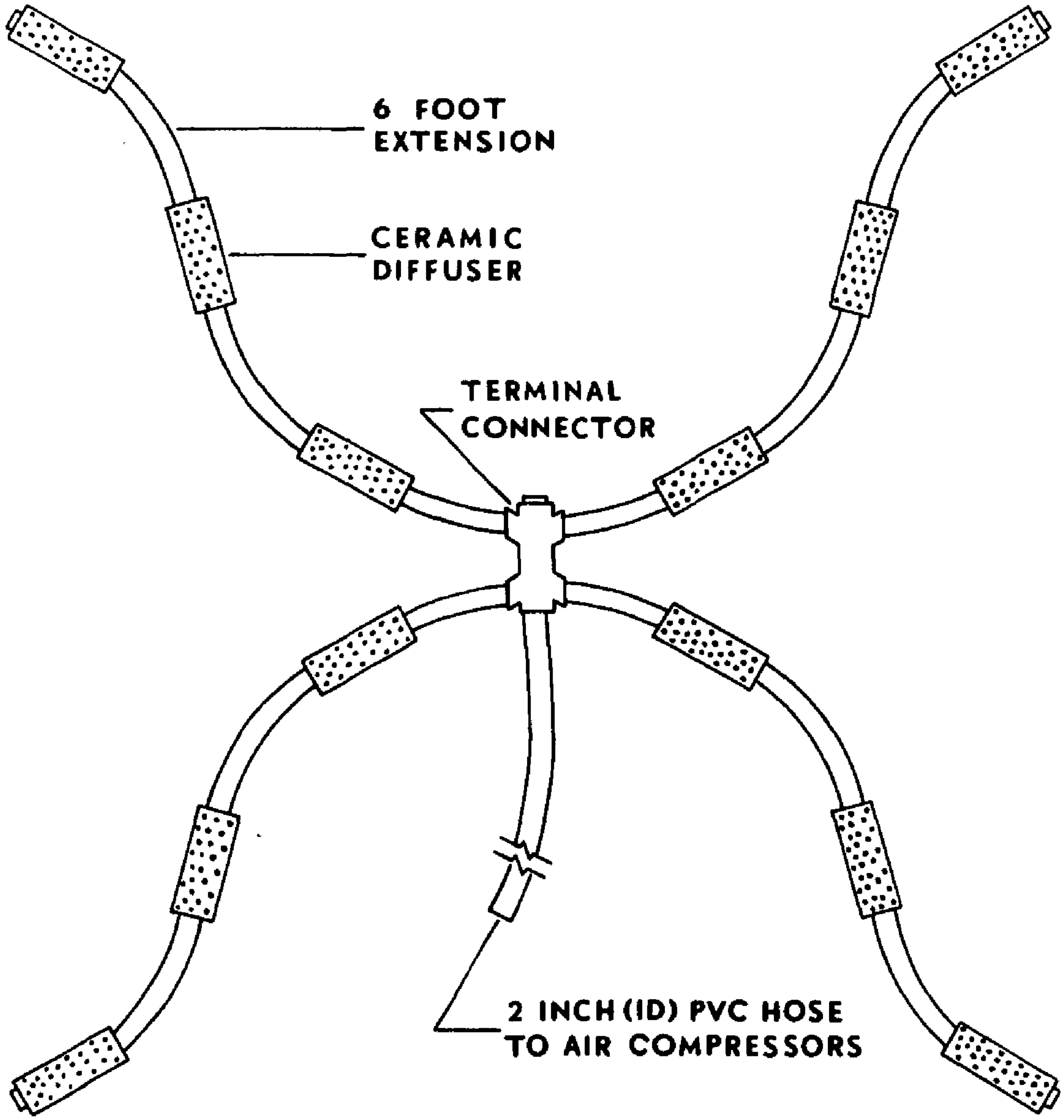
copper sulfate ($CuSO_4 \cdot 5H_2O$) by the NHWSPCC on June 15. The copper sulfate treatment was repeated at 0.54 ppm on June 30 and by July 4 a fish kill approximating 6 tons was reported by the NHWSPCC. Even after the second control attempt Aphanizomenon persisted in dense concentration.

Acting on the suspicion of the NHWSPCC Sawyer, Gentile and Sasner (1968) demonstrated that a toxic strain of A. flos-aquae was present at the time of the fish kill. This was the first unequivocally documented report of toxicity of this algal species. During the summer of 1967, mean cell counts of 1.5 and 1.4×10^6 cells per milliliter on August 3 and 9 respectively exemplified the intensity of these annual unialgal blooms. The dilemma of noxious blooms or fish kills forced the NHWSPCC to seek other methods to control this alga. The most important consideration was to reduce the level of nutrients entering the lake.

According to the NHWSPCC, the primary source of nutrients that promoted summer blooms at Kezar Lake was the sewage treatment plant at New London, New Hampshire. This activated sludge facility began operating in 1931. In recent years the plant discharged daily 200,000 gallons of treated effluent into Lion Brook, the main tributary to Kezar Lake. In 1970 the NHWSPCC modified the existing plant for tertiary sewage treatment to alleviate the excessive fertilization of the lake, but as an immediate step the NHWSPCC decided to destratify Kezar Lake to increase water clarity.

The aeration system installed at Kezar Lake in 1968 consists of four 3 h.p. Curtis CW-808 compressors that collectively discharged air at 100 cubic feet per minute at 1 atm. pressure. The compressed air is delivered through 800 feet of 2 inch polyvinyl-chloride hose that terminates at a junction of four arms, each bearing three large ceramic diffusers (Fig. 2). The diffuser arms were placed on vertically upright cement blocks in the deepest part of the lake (Fig. 1). This system was in operation continuously from July 16 to September 12, 1968, and May 28 to September 15, 1969, except for brief maintenance shutdowns.

Fig. 2. Schematic diagram of air-diffuser apparatus installed in Kezar Lake.


6 FOOT
EXTENSION
CERAMIC
DIFFUSER
TERMINAL
CONNECTOR
2 INCH (ID) PVC HOSE
TO AIR COMPRESSORS

MATERIALS AND METHODS

Two sampling stations were selected at Kezar Lake (Fig. 1). Station 2 was located at the deeper, west side of the lake adjacent to the diffusers. Station 4 was located at the shallow, east side of the lake. Sampling was conducted May through October during the years 1968 and 1969. The mean sampling frequency was every fifth day, and every tenth day for Stations 2 and 4 respectively.

Water samples were taken at meter intervals with a 3-liter polyvinyl-chloride sampler. Portions of each sample were used for chemical analyses, quantitative algal enumeration, chlorophyll-a determination, and primary productivity studies. Water transparency was measured with a 20 centimeter black and white quadrant Secchi disc. The level of 1% incident solar radiation was determined with a Whitney Underwater Daylight Meter. Water temperature was measured at one-half meter intervals with a Model FT-2 hydrographic thermistor thermometer (Applied Research/Austin, Texas).

Dissolved oxygen concentrations were determined by the Alsterberg modification of the Winkler Method using Hach reagents (Hach Chemical Co., Ames, Iowa). Total Inorganic carbon, including free carbon dioxide, bicarbonate and carbonate alkalinities, was determined stoichiometrically by titration as described in American Public Health Association et al. (1965). Hydrogen ion concentration was recorded from a Beckman Model N pH meter.

All nutrient analyses were done by the NHWSPCC. Water samples collected at Station 2 were placed in polyethylene bottles and removed immediately to the NHWSPCC Chemistry Laboratory for analyses. Laboratory analytical methods were as follows: orthophosphate and total phosphorus - Jankovic, Mitchell and Buzzell (1967); nitrate nitrogen - Montgomery and Dymock (1962); ammonia nitrogen (Method A), nitrite nitrogen and organic nitrogen - A.P.H.A. (1965); chloride - Argentometric Method (A) of A.P.H.A. (1965); silicon dioxide - Colorimetric Heteropoly Blue Method (C) of A.P.H.A. (1965). The following nutrients were assayed by a Perkin-Elmer Atomic Absorption Spectrophotometer: Calcium, copper, iron, manganese, magnesium, potassium, sodium and zinc.

Measurements of temperature, dissolved oxygen, and carbon dioxide were performed during 1968 at a control lake, Otter Pond, of similar size and morphometry to establish patterns that would be expected at Kezar Lake if the lake was not being circulated or receiving sewage effluent.

Samples for phytoplankton cell counts were preserved in acid Lugol's solution and stored at 16-18C. Phytoplankton were counted by the method of Utermohl as described in lund, Kipling and LeCren (1961) using a Unitron Model BR-BMIC inverted microscope. A 1 ml sample was pipetted into a 1 x 1.5 cm glass sedimentation tube and allowed to stand for 15 hours prior to counting. Filaments of A. flos-aquae were counted over the entire field at 100X or 200X magnifications, depending on abundance. All other phytoplankton were counted at 430X magnification over one-half the field. Dilution of phytoplankton samples was necessary at times depending on abundance. Live algae used for identification were collected from vertical tows using a #25 plankton net. The generic designations of Smith (1950) and the species designations of Prescott (1962) were used for algae whenever possible. Other sources referred to for specific identification include Huber-Pestalozzi (1938-61), Patrick and Reimer (1966), Smith (1920, 24), Skuja (1948), Teiling (1967) and Uherkovich (1966).

Chlorophyll-a concentrations were determined spectrophotometrically by the general procedures of Strickland and Parsons (1965), using a Beckman DU (Model 2400) spectrophotometer. Quartz cuvettes having a light path length of 5 centimeters were used. The extinctions of chlorophyll-a, -b, and -c were recorded at wavelengths of 663-665, 645, and 630 millimicrons respectively. The trichromatic equations of Strickland and Parsons (1965) and SCOR-UNESCO (1966) were both used in computing concentrations of chlorophyll-a in mg/m^3. The method of Lorenzen (1967) was followed for ascertaining chlorophyll degradation as pheo-pigments.

The carbon-14 method of Steeman-Nielsen (1952) as modified by Goldman (1961) was used to determine phytoplankton productivity. Water samples for productivity studies were collected at meter intervals in the water column to a depth just below 1% incident solar radiation. Two microcuries of $Na_2{}^{14}CO_3$ were introduced into 100 milliliters of sample water contained in each dark and light bottle. The bottles were submerged to their respective sample depth and incubated from 1000 to 1400 hours EST on bright, sunny days. Each sample was fixed promptly with neutral formalin (4%) when the incubation period had elapsed. All samples were filtered through Millipore^R HA (0.45u pore size) filters and rinsed with 0.001 M HCL and distilled water. The filters were dried and counted for beta emissions with a thin window gas-flow counter. Watt (1966) was followed to determine the amount of extracellular organic carbon released by phytoplankton.

RESULTS - 1968

Transparency

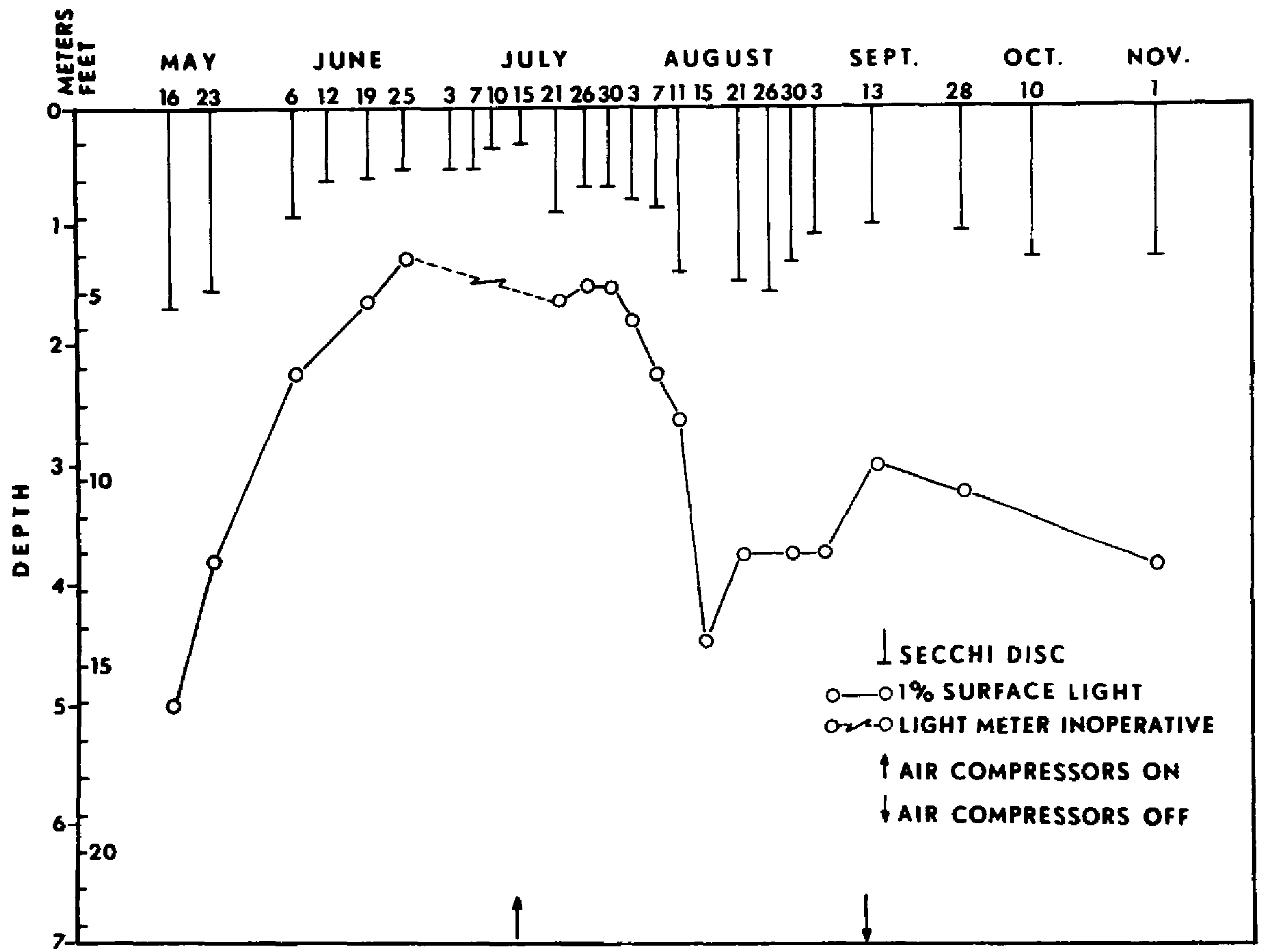
The effect of artificial circulation on water transparency is shown in Fig. 3. A maximum Secchi disc transparency of 5.5 feet on May 16 was reduced to only 1 foot by July 15 by summer growth of A. flos-aquae. Artificial circulation commenced on July 16 and by July 21 the Secchi disc transparency had increased to 3 feet. During the rest of the summer the Secchi disc transparency ranged from 2 to 5 feet, averaging between 3 and 4 feet. The Secchi disc readings at Station 4 were identical to those of Station 2 during the summer of 1968. At the control lake, Otter Pond, a Secchi disc transparency of 6 feet was recorded for June. Water transparency increased steadily during July to a maximum Secchi disc reading of 10 feet on August 6. Thereafter, transparency remained between 9 and 10 feet during August and early September.

Figure 3 shows that the trends of Secchi transparency and 1% light level are identical but the per unit changes in transparency are much greater for the latter.

Temperature

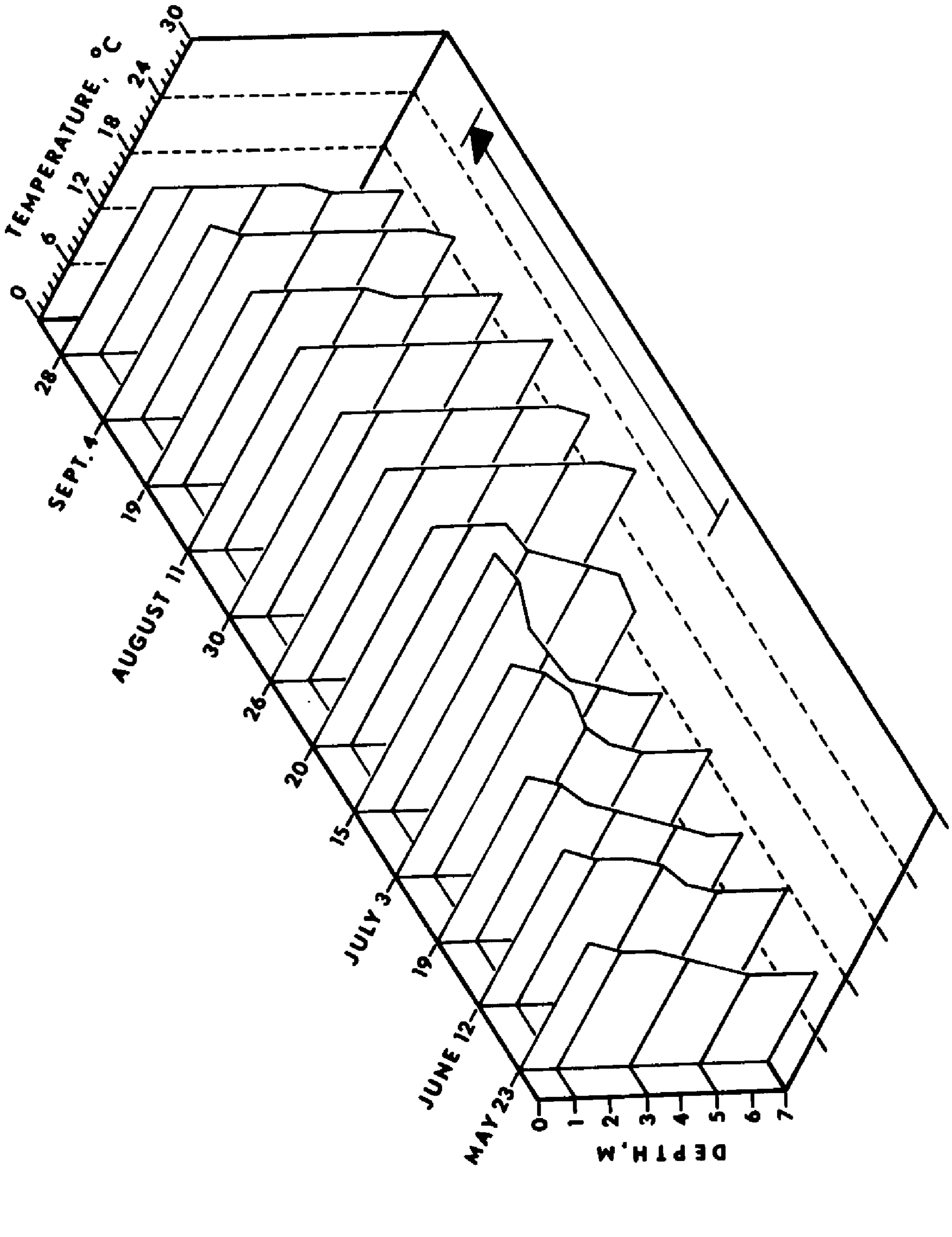
Figure 4 shows the development of thermal stratification in Kezar Lake during the summer of 1968. On July 15, the day before the air compressors were started, surface and

Fig. 3. Light transmission in Kezar Lake. Secchi disc transparency and level of 1% surface illumination at Station 2, 1968.



METERS
FEET
MAY
JUNE
JULY
AUGUST
SEPT.
OCT.
NOV.
16 23 6 12 19 25 3 7 10 15 21 26 30 3 7 11 15 21 26 30 3 13 28 10 1
0
1
-5
2
3
-10
4
-15
5
6
-20
7
DEPTH
SECCHI DISC
1% SURFACE LIGHT
LIGHT METER INOPERATIVE
AIR COMPRESSORS ON
AIR COMPRESSORS OFF

Fig. 4. Temperature profiles at Station 2 in Kezar Lake, 1968. Arrow indicates period of artificial circulation.


TEMPERATURE, °C
0
6
12
18
24
30
28
SEPT. 4
19
AUGUST 11
30
26
20
15
JULY 3
19
JUNE 12
MAY 23
0
1
2
3
4
5
6
7
DEPTH, M

bottom temperatures were 27.9C and 12.0C respectively. No change in water temperature occurred during the first day of aeration. By July 20, four days after the air compressors were started, the surface temperature was reduced to 24.0C. Conversely, the water at depths from 1.5m to 7.0m warmed from 2 to 7C (Fig. 4). By July 26 the lake was isothermal at 23C. Isothermal conditions were maintained by aeration throughout the remainder of the summer as top to bottom temperature differences never exceeded 1.8C. Thermal stratification was not reestablished after the air compressors were shut down on September 12. The temperature differential between Stations 2 and 4 was generally less than 1C.

The pronounced effect of artificial circulation on the depth distribution of temperature at Kezar Lake was contrasted by the natural events in the non-aerated control, Otter Pond. The vertical temperature profiles for both lakes were nearly identical prior to mixing of Kezar Lake (Fig. 4). Surface temperature varied during the summer, but stratification remained distinct at the control lake. For example, the surface to bottom water temperature readings at Otter Pond on August 6 were 23.0 and 13.1C respectively. On the same date at Kezar Lake water temperature ranged from 23.0 to 22.4C. Natural turnover eliminated thermal stratification at Otter Pond by September 13.

Dissolved Oxygen

The depth distribution of dissolved oxygen during the summer of 1968 is presented in Table 1. Before artificial destratification, supersaturation of dissolved oxygen developed in surface waters concomitantly with a dense growth of _A. flos-aquae_. At lower depths, steady depletion of oxygen occurred. By July 15, the day before the air compressors were started, nearly half the water column contained less than 1 ppm dissolved oxygen. This clinograde distribution was altered rapidly following artificial circulation so that by July 29 the entire water column was essentially 100% saturated with dissolved oxygen. During August and until the aerators were shut down on September 12 the dissolved oxygen concentrations remained relatively constant, except for some depletion at the bottom was evident.

Sixteen days after the air compressors were shut down on September 12 oxygen depletion at the mud-water interface was complete. However, fall turnover restored dissolved oxygen in the entire water column by October 10. The dissolved oxygen concentration at Stations 2 and 4 were usually similar for corresponding depths. The maximum difference of 2.8 ppm occurred on July 20 when the distribution of dissolved oxygen was higher at all depths at Station 2.

The vertical distribution of dissolved oxygen at Otter Pond exhibited the same trend as occurred in Kezar Lake prior to aeration (Table 1). As summer progressed the surface concentration of dissolved oxygen remained high while there was a steady depletion of dissolved oxygen at

Table 1. Depth distribution of dissolved oxygen at Station 2 in Kezar Lake, 1968.

DATE (1968)	DEPTH (M)	PPM	PERCENT SATURATION	DATE (1968)	DEPTH (M)	PPM	PERCENT SATURATION
5/23	0.5	10.5	100	7/29	0.5	9.0	103
	1.5	10.4	97		1.5	8.9	101
	2.5	8.8	81		2.5	9.0	103
	3.5	6.2	55		3.5	8.8	100
	4.5	6.6	58		4.5	9.0	103
	5.5	6.4	55		5.5	8.7	99
	6.5	6.9	59		6.5	8.6	98
6/6	0.5	11.7	125	8/6	0.5	7.9	90
	1.5	10.5	108		1.5	8.0	92
	2.5	6.4	63		2.5	6.4	73
	3.5	5.4	51		3.5	6.2	71
	4.5	3.6	33		4.5	6.0	69
	5.5	3.5	32		5.5	6.0	69
	6.5	2.9	26		6.5	5.3	60
6/25	0.5	12.2	133	8/26	0.5	8.6	96
	1.5	12.0	128		1.5	8.7	97
	2.5	8.7	89		2.5	8.0	90
	3.5	7.6	77		3.5	6.8	75
	4.5	4.0	40		4.5	6.0	67
	5.5	1.9	18		5.5	3.9	42
	6.5	0.1	1		6.5	3.6	39
7/15	0.5	10.8	135	9/10	0.5	9.6	103
	1.5	6.5	72		1.5	9.2	98
	2.5	2.7	28		2.5	8.4	90
	3.5	1.3	13		3.5	7.2	76
	4.5	0.6	5		4.5	7.0	75
	5.5	0.5	4		5.5	6.4	68
	6.5	0.3	3		6.5	4.7	50
7/20	0.5	6.8	80	9/28	0.5	8.5	90
	1.5	7.0	82		1.5	8.3	87
	2.5	6.6	77		2.5	8.4	88
	3.5	2.4	26		3.5	8.1	85
	4.5	2.0	21		4.5	5.8	60
	5.5	1.4	14		5.5	0.3	3
	6.5	0.3	3		6.5	0.0	0
7/23	0.5	10.7	128	10/10	0.5	9.4	87
	1.5	9.9	118		1.5	9.3	86
	2.5	5.4	62		2.5	9.5	88
	3.5	3.9	44		3.5	9.5	88
	4.5	3.9	44		4.5	9.4	87
	5.5	2.7	30		5.5	9.3	86
	6.5	1.6	18		6.5	8.4	77

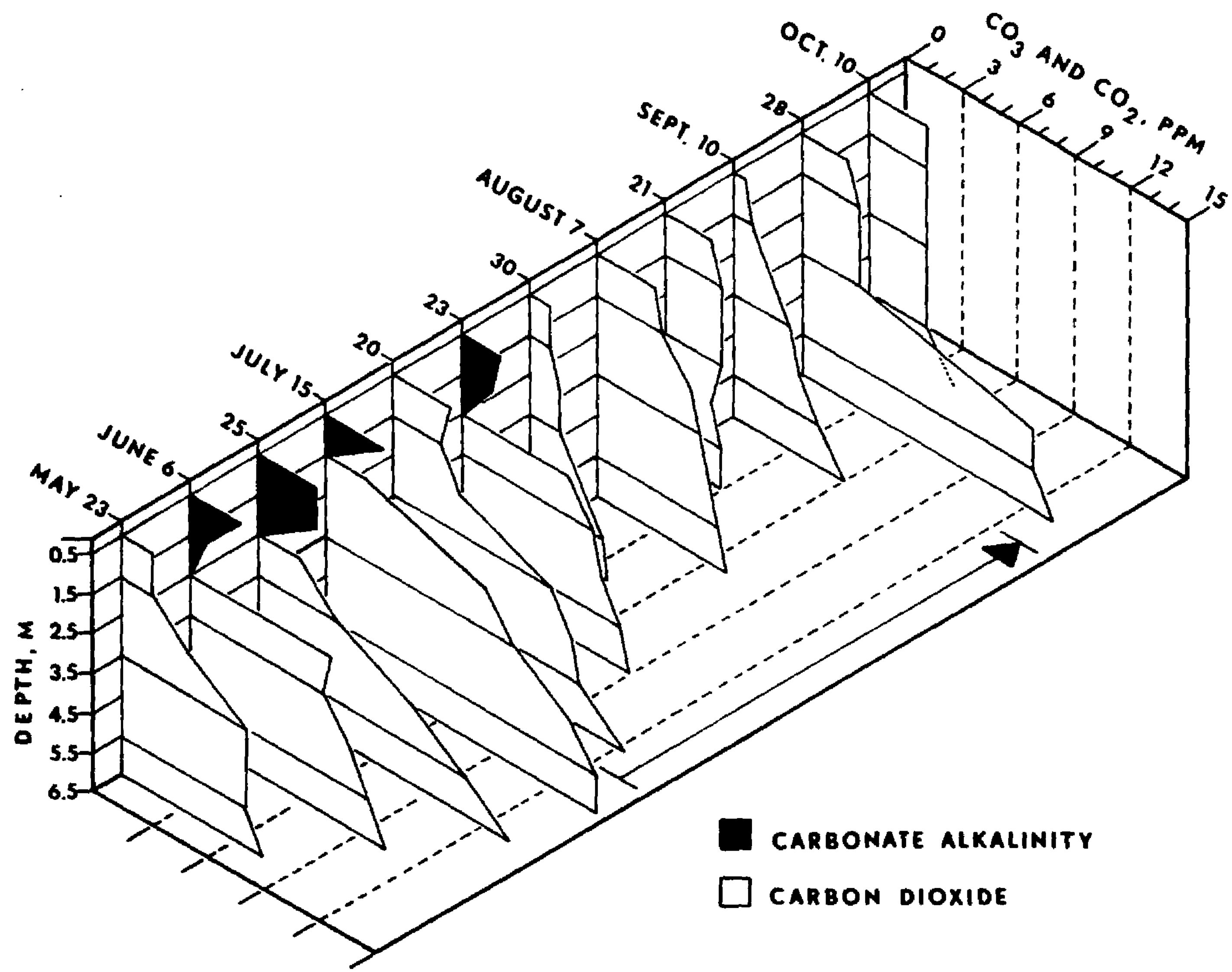
lower depths. Not until September 13 when natural turnover occurred at Otter Pond, was the vertical distribution of dissolved oxygen uniform at 8 ppm.

Carbon Dioxide, Carbonate Alkalinity, and pH

The bloom of A. flos-aquae had a profound effect on the distribution of free carbon dioxide in Kezar Lake. Figure 5 shows that free carbon dioxide was not detectable in the euphotic zone (Fig. 3) during June and until the air compressors were started on July 16. Concurrently, carbon dioxide had steadily increased in the aphotic zone, and by July 15 the carbon dioxide content had increased to 14.5ppm at the 5.5m and 6.5m depths.

The immediate effect of artificial circulation on the carbon dioxide distribution was most pronounced at 0.5 meters. At this depth CO_2 increased to 3.0 ppm after 4 days aeration. Carbon dioxide was again not measurable in the top 2 meters of the water column on July 23 but the gradual loss of carbon dioxide from lower depths continued. There occurred only small variation in the vertical distribution of carbon dioxide during August and until the air compressors were shut off on September 12 (Fig. 5). Carbon dioxide stratification was reestablished by September 28, 16 days after termination of artificial circulation. However, fall turnover had completely mixed Kezar Lake again by October 10 and the vertical distribution of carbon dioxide was nearly uniform.

Fig. 5. Carbon dioxide and carbonate alkalinity profiles at Station 2 in Kezar Lake, 1968. Arrow indicates period of artificial circulation.


MAY 23
JUNE 6
25
JULY 15
20
23
30
AUGUST 7
21
SEPT. 10
28
OCT. 10
0
3
6
9
12
15
CO_3 AND CO_2, PPM
DEPTH, M
0.5
1.5
2.5
3.5
4.5
5.5
6.5
CARBONATE ALKALINITY
CARBON DIOXIDE

The carbon dioxide concentrations at Stations 2 and 4 were similar for corresponding depths except immediately after artificial destratification. At the 2.5 and 3.5 meter depths on July 20 and 21 the carbon dioxide concentrations at Station 4 were 3.5 to 4.5 ppm higher than at corresponding depths of Station 2. Also, as previously mentioned, the dissolved oxygen content at Station 2 was higher at corresponding depths. It is probable that the proximity of Station 2 to the aerators facilitated a more rapid exchange of these gases with the atmosphere during the initial destratification period, since the large differences of carbon dioxide and dissolved oxygen concentrations at both stations were reduced by July 26. The concentration differences between stations remained small for the duration of the summer.

At the control lake, Otter Pond, free carbon dioxide varied imperceptibly in surface waters but accumulated at lower depths during the summer. By August 7 the distribution of carbon dioxide ranged from 1.5-17.0 ppm at 0.5 and 6.5m respectively. Thermal stratification in shallow Otter Pond was ephemeral and by September 13 natural circulation had occurred causing a reduced content of carbon dioxide in bottom waters. Carbonate alkalinity was not detected in any sample at Otter Pond.

At Kezar Lake the utilization of carbon dioxide in the euphotic zone by the bloom of *A. flos-aquae* resulted in the presence of measurable amounts of carbonate alkalinity (Fig. 5). After the lake was mixed, carbonate alkalinity was detected on few occasions. Carbonate alkalinity concentrations at Station 4 were generally identical to those of Station 2. Any differences could be accounted for by the brief time lag between analyses, especially during phytoplankton blooms.

As expected, the hydrogen ion concentration varied directly with the concentration of carbon dioxide. Table 2 shows the high pH at 0.5 meters prior to the start of artificial circulation. These high pH values correlate directly with the absence of carbon dioxide and the presence of carbonate alkalinity (Fig. 5). A striking effect of artificial circulation was the reduction of pH at 0.5 meters from 9.4 on July 15 to 6.7 on July 20. The gradual increase of pH at lower depths immediately following artificial circulation is related to the loss of carbon dioxide at this time (Fig. 5). Other fluctuations that occurred during the summer are recorded in Table 3.

Nutrients

Iron and Manganese

Iron and manganese concentrations were affected considerably by artificial circulation. Table 3 shows that both iron and manganese exhibited inverse clinograde distributions before aeration. The diminution of iron at 6.5m on July 10 is related (Hutchinson, 1957) to a slight increase in dissolved oxygen at this depth (Table 1). By

Table 2. Vertical pH profiles at Station 2 in Kezar Lake, 1968.

DEPTH (M)	MAY		JUNE		JULY						
	16	23	6	25	3	10	15	20	23	26	30
0.5	7.4	7.7	9.7	9.7	9.3	9.4	9.4	6.7	9.0	7.0	7.8
1.5	7.2	7.6	9.2	9.6	7.4	7.7	6.9	6.8	8.8	6.9	7.8
2.5	6.8	6.8	6.4	7.3	6.7	6.4	6.2	6.6	6.5	6.8	7.4
3.5	6.5	6.3	6.1	6.7	6.4	6.2	6.1	6.4	6.5	6.7	7.2
4.5	6.3	6.2	6.1	6.2	6.2	6.2	6.1	6.3	6.5	6.7	6.9
5.5	6.2	6.1	6.1	6.0	6.2	6.1	6.1	6.3	6.4	6.6	6.7
6.5	-	6.1	6.2	-	6.2	6.2	6.2	-	6.3	-	6.7

DEPTH (M)	AUGUST						SEPTEMBER			OCT.	NOV.
	3	7	11	21	27	30	3	10	28	10	1
0.5	8.3	6.8	6.5	6.3	6.3	7.1	8.6	7.0	6.4	6.2	6.1
1.5	7.0	6.7	6.5	6.2	6.3	6.6	8.4	6.9	6.3	6.4	6.1
2.5	6.5	6.5	6.4	6.2	6.2	6.3	6.4	6.5	6.3	6.4	6.1
3.5	6.6	6.5	6.5	6.2	6.2	6.3	6.1	6.0	6.2	6.4	6.1
4.5	6.6	6.5	6.7	6.2	6.1	6.3	6.0	5.9	5.7	6.4	6.1
5.5	6.6	6.5	6.6	6.3	6.1	6.2	6.0	5.9	5.7	6.4	6.2
6.5	6.5	6.5	6.5	6.2	6.0	6.1	-	5.7	5.7	6.2	6.2

Table 3. Depth distribution of iron and manganese at Station 2 in Kezar Lake, 1968 and 1969. Concentrations are in mg/l.

DEPTH (M)	BEFORE AERATION				AFTER AERATION					
	JUNE 26, 1968		JULY 10, 1968 (MAY 26, 1969)		JULY 24, 1968 (JUNE 4, 1969)		AUGUST 7, 1968 (JUNE 24, 1969)		AUGUST 21, 1968 (JULY 14, 1969)	
	Fe	Mn	Fe	Mn	Fe	Mn	Fe	Mn	Fe	Mn
0.5	0.25	0.061	0.190 (0.043)	0.038 (0.015)	0.247 (0.031)	0.084 (0.019)	0.285 (0.113)	0.081 (0.037)	0.062 (0.066)	0.015 (0.012)
1.5	0.24	0.055	0.194 (0.053)	0.037 (0.021)	0.197 (0.038)	0.088 (0.021)	0.230 (0.106)	0.058 (0.037)	0.044 (0.058)	0.016 (0.012)
2.5	0.24	0.062	0.281 (0.058)	0.093 (0.015)	0.249 (0.049)	0.133 (0.009)	0.232 (0.124)	0.059 (0.043)	0.075 (0.052)	0.021 (0.009)
3.5	0.27	0.071	0.366 (0.060)	0.143 (0.015)	0.327 (0.025)	0.152 (0.019)	0.184 (0.118)	0.051 (0.040)	0.057 (0.061)	0.017 (0.011)
4.5	0.50	0.201	0.722 (0.028)	0.412 (0.005)	0.303 (0.078)	0.161 (0.026)	0.256 (0.148)	0.061 (0.043)	0.058 (0.056)	0.017 (0.010)
5.5	0.88	0.355	0.733 (0.064)	0.330 (0.041)	0.380 (0.043)	0.216 (0.017)	0.265 (0.180)	0.064 (0.049)	0.057 (0.056)	0.018 (0.008)
6.5	2.14	0.328	1.06 (0.105)	0.510 (0.072)	0.458 LOST	0.283 (0.031)	0.186 (0.239)	0.054 (0.054)	0.097 (0.048)	0.029 (0.009)

July 24, after 8 days of aeration, the stratification of iron was ameliorated. Iron concentrations remained evenly distributed in the water column thereafter but were significantly reduced by August 21.

The effect of artificial circulation on the depth distribution of manganese was identical to its effect on iron. Some stratification was still evident on July 24 but manganese became evenly dispersed in the water column and its concentration was reduced also by August 21.

Sodium

The apparent effect of artificial circulation on sodium was to increase the amount of this nutrient in Kezar Lake (Table 4). Prior to aeration sodium was uniformly dispersed in the water column though its concentrations decreased slightly from June 26 to July 10. After 8 days of artificial circulation sodium had increased 60% at the 0.5m and 1.5m depths. Sodium increased an additional 60% to 29.1 mg/l on August 7. Thus, after 3 weeks of artificial circulation increases of sodium in the surface waters were most pronounced. However, by August 21 an orthograde distribution of sodium was evident and decreases had occurred at all depths.

Calcium, Magnesium and Potassium

Calcium was not affected by artificial circulation of Kezar Lake. Calcium varied only from 5.0 to 5.6 mg/l over the entire study period (Table 4).

Table 4. Depth distribution of sodium, calcium, potassium and magnesium at Station 2 in Kezar Lake, 1968. Concentrations are in mg/l.

	BEFORE AERATION								AFTER AERATION											
	JUNE 26				JULY 10				JULY 24				AUGUST 7				AUGUST 21			
DEPTH	Na	Ca	K	Mg	Na	Ca	K	Mg	Na	Ca	K	Mg	Na	Ca	K	Mg	Na	Ca	K	Mg
0.5 M	10.4	5.0	1.3	0.85	10.0	5.3	0.6	0.7	17.8	5.0	0.8	0.92	29.1	5.2	-	0.83	9.5	5.1	-	0.87
1.5 M	10.9	5.0	1.3	0.85	8.5	5.3	0.5	0.7	14.2	5.0	0.8	0.91	15.0	5.2	-	0.82	8.7	5.0	-	0.80
2.5 M	12.2	5.1	1.3	0.86	8.3	5.5	0.5	0.7	10.8	5.0	0.3	0.91	10.6	5.2	-	0.82	8.9	5.1	-	0.81
3.5 M	10.9	5.1	1.3	0.86	8.5	5.5	0.5	0.7	11.1	5.0	0.8	0.91	11.0	5.3	-	0.83	8.9	5.0	-	0.79
4.5 M	3.0	5.1	1.3	0.86	8.0	5.5	0.6	0.7	10.5	5.0	0.8	0.91	12.4	5.2	-	0.78	8.9	5.0	-	0.81
5.5 M	10.8	5.1	1.5	0.86	9.8	5.5	0.6	0.7	11.4	5.1	0.8	0.93	11.9	5.3	-	0.79	9.9	5.1	-	0.79
6.6 M	10.6	5.6	1.5	0.87	8.3	5.5	0.6	0.7	10.9	5.0	0.9	0.91	12.8	5.4	-	0.79	8.7	5.0	-	0.78

The depth distribution of magnesium was uniform throughout the summer of 1968 (Table 4). The amount of magnesium increased slightly following artificial circulation but declined subsequently to a uniform range during August.

From the data that are available in Table 4 the trend for potassium was identical to that described for magnesium. Potassium was evenly distributed in the water column also and its concentrations increased following aeration.

Copper, Chloride and Silicon Dioxide

The depth distribution of copper was irregular prior to artificial circulation (Table 5). Unlike the behavior of nutrients previously discussed, copper became stratified following artificial circulation. By August 21 copper was uniformly distributed again though reduced in concentration. Chloride and silicon dioxide appeared little affected by artificial circulation (Table 5).

Zinc

Zinc too was uniquely affected by artificial circulation. Before destratification its concentration was highest at 0.5 meters (Table 5); below 0.5m it was irregular. The data indicate a trend toward increased concentrations of zinc before and after artificial circulation. As occurred with copper, the distinct stratification of zinc on August 7

Table 5. Depth distribution of copper, silicon dioxide, chloride and zinc at Station 2 in Kezar Lake, 1968. Concentrations are in mg/l.

	BEFORE AERATION							
	JUNE 26				JULY 10			
DEPTH	Cu	SiO_2	Cl	Zn	Cu	SiO_2	Cl	Zn
0.5 M	0.011	3	15	0.043	0.012	5	15	0.059
1.5 M	0.006	3	16	0.016	0.007	4	15	0.022
2.5 M	0.005	3	15	0.013	0.009	5	14	0.029
3.5 M	0.006	3	15	0.022	0.013	5	14	0.024
4.5 M	0.006	4	16	0.014	0.005	5	13	0.018
5.5 M	0.017	4	14	0.022	0.004	5	13	0.017
6.5 M	0.008	4	15	0.028	0.009	6	13	0.022

	AFTER AERATION											
	JULY 24				AUGUST 7				AUGUST 21			
DEPTH	Cu	SiO_2	Cl	Zn	Cu	SiO_2	Cl	Zn	Cu	SiO_2	Cl	Zn
0.5 M	0.007	6	15	0.085	0.017	5	15	0.629	0.008	5	17	0.048
1.5 M	0.009	5	14	0.055	0.012	5	14	0.220	0.006	5	15	0.033
2.5 M	0.007	5	15	0.031	0.012	5	14	0.267	0.006	5	14	0.017
3.5 M	0.007	5	14	0.034	0.008	6	14	0.103	0.008	6	15	0.027
4.5 M	0.007	5	15	0.035	0.008	6	15	0.066	0.005	6	14	0.011
5.5 M	0.008	6	14	0.021	0.008	5	15	0.079	0.006	5	14	0.008
6.5 M	0.008	5	15	0.025	0.007	5	15	0.031	0.005	5	14	0.030

was due primarily to large surface increases. By August 21 the stratification of zinc had disappeared, its concentration significantly reduced, and its distribution was again irregular.

Phosphorus

The depth distribution of orthophosphate and total phosphorus in Kezar Lake is presented in Table 6. Orthophosphate ranged in concentration from zero to 0.086 mg/l during 1968. Levels of orthophosphate increased gradually after the lake was mixed. The mean orthophosphate concentrations before and after artificial circulation were 0.016 and 0.022 mg/l respectively. In contrast to orthophosphate, the decreasing trend in total phosphorus concentrations before July 16 was immediately reversed after artificial circulation (Table 6).

Nitrogen

The occurrence of nitrogenous forms in Kezar Lake is presented in Table 7. Because the methods for determining ammonia and organic nitrogen are extensive, analyses for these nutrients were performed on samples from 1.5m, 3.5m and 6.5 meters only. The data for nitrite nitrogen is not presented in tabular form.

Table 7 shows that nitrate nitrogen gradually decreased until at least July 24. After three weeks of aeration, the amount of nitrate nitrogen increased at all depths. Other

Table 6. Depth distribution of orthophosphate and total phosphorus at Station 2 in Kezar Lake, 1968 and 1969. Concentrations are in mg-PO_4/l.

DEPTH (M)	BEFORE AERATION				AFTER AERATION					
	JUNE 26, 1968		JULY 10, 1968 (MAY 26, 1969)		JULY 24, 1968 (JUNE 4, 1969)		AUGUST 7, 1968 (JUNE 24, 1969)		AUGUST 21, 1968 (JULY 14, 1969)	
	ORTHO	TOTAL	ORTHO	TOTAL	ORTHO	TOTAL	ORTHO	TOTAL	ORTHO	TOTAL
0.5	0.017	0.220	0.034 (0.112)	0.046 (0.190)	0.000 (0.046)	0.210 (0.284)	0.015 (0.304)	0.177 (0.271)	0.086 (0.175)	0.324 (0.210)
1.5	0.028	0.158	0.004 (0.069)	0.076 (0.170)	0.007 (0.047)	0.205 (0.219)	0.062 (0.029)	0.172 (0.324)	0.018 (0.097)	0.377 (0.226)
2.5	0.014	0.150	0.001 (0.078)	0.032 (0.197)	0.000 (0.051)	0.196 (0.230)	0.021 (0.047)	0.132 (0.295)	0.029 (0.288)	0.185 (0.270)
3.5	0.020	0.165	0.008 (0.083)	0.023 (0.193)	0.018 (0.050)	0.185 (0.221)	0.011 (0.067)	0.131 (0.292)	0.040 (0.134)	0.164 (0.175)
4.5	0.024	0.044	0.000 (0.101)	0.015 (0.215)	0.003 (0.069)	0.235 (0.258)	0.034 (0.036)	0.158 (0.276)	0.020 (0.073)	0.208 (0.161)
5.5	0.017	0.042	0.019 (0.091)	0.030 (0.226)	0.014 (0.066)	0.214 (0.343)	0.032 (0.027)	0.137 (0.352)	0.013 (0.045)	0.202 (0.168)
6.5	-	0.111	0.030 (0.114)	0.040 (0.286)	0.000 (0.070)	0.000 (0.224)	0.021 (0.050)	0.108 (0.437)	0.026 (0.056)	0.172 (0.139)

Table 7. Depth distribution of organic, ammonia and nitrate nitrogen at Station 2 in Kezar Lake, 1968 and 1969. Concentrations are in mg/l.

DEPTH (M)	BEFORE AERATION						AFTER AERATION								
	JUNE 26, 1968			JULY 10, 1968 (MAY 26, 1969)			JULY 24, 1968 (JUNE 4, 1969)			AUGUST 7, 1968 (JUNE 24, 1969)			AUGUST 21, 1968 (JULY 14, 1969)		
	Org-N	NH_3-N	NO_3-N	Org-N	NH_3-N	NO_3-N	Org-N	NH_3-N	NO_3-N	Org-N	NH_3-N	NO_3-N	Org-N	NH_3-N	NO_3-N
0.5	0.930	0.139	0.30	1.876 (0.492)	0.070 (0.107)	0.24 (0.12)	1.390 (0.334)	0.009 (0.000)	0.18 (0.12)	0.811 (0.844)	0.536 (0.000)	0.21 (0.16)	0.579 (0.124)	0.170 (0.090)	0.22 (0.42)
1.5	-	-	0.30	-	-	0.19 (0.08)	-	-	0.05 (0.11)	-	-	0.18 (0.17)	-	-	0.14 (0.28)
2.5	-	-	0.41	-	-	0.24 (0.07)	-	-	0.09 (0.11)	-	-	0.19 (0.27)	-	-	0.25 (0.37)
3.5	0.830	0.069	0.28	0.894 (0.455)	0.260 (0.112)	0.06 (0.10)	1.079 (0.368)	0.280 (0.000)	0.04 (0.11)	0.875 (0.816)	0.148 (0.012)	0.15 (0.21)	0.534 (0.771)	0.129 (0.063)	0.32 (0.27)
4.5	-	-	0.27	-	-	0.19 (0.10)	-	-	0.04 (0.11)	-	-	0.23 (0.16)	-	-	0.29 (0.28)
5.5	-	-	0.30	-	-	0.19 (0.10)	-	-	0.08 (0.13)	-	-	0.21 (0.18)	-	-	0.27 (0.25)
6.5	0.280	0.826	0.47	0.883 (0.733)	0.530 (0.118)	0.20 (0.12)	1.039 (0.518)	0.588 (0.000)	0.08 (0.13)	0.774 (0.913)	0.144 (0.034)	0.26 (0.24)	0.600 (0.480)	0.112 (0.053)	0.34 (0.31)

variations are shown in Table 7. Before destratification, nitrite nitrogen was not detectable by analytical methods used. After artificial circulation, the concentrations of nitrite nitrogen varied from 1.8 to 9.2 µg/l with a mean concentration of 4.1 µg/l.

Before artificial circulation ammonia nitrogen exhibited a strong inverse clinograde distribution (Table 7). The only significant change in the distribution of ammonia nitrogen after 8 days of artificial circulation occurred at 0.5 meters. At this depth a concentration of 0.070 mg/l on July 10 was reduced to 0.009 mg/l on July 24. By August 7, however, the vertical distribution of ammonia nitrogen was completely reversed although about the same amounts were measured in the water column on the two dates (Table 7). By August 21 ammonia nitrogen levels were diminished and more uniformly dispersed.

Table 7 shows that organic nitrogen was stratified in the water column on June 26. The concentration of organic nitrogen at 0.5m had increased twofold by July 10 from 0.930 to 1.876 mg/l and a threefold increase was evident at 6.5 meters. After Kezar Lake was destratified, organic nitrogen remained uniformly distributed in the water column but the high concentrations were gradually depleted.

Phytoplankton

A total of 118 species of phytoplankton in 62 genera were enumerated during the summers of 1968 and 1969 at Kezar

Lake. A complete tabulation of the phytoplankton is shown in Table 8. Through most of the research periods the phytoplankton flora was dominated by one or two species. The species that occurred in greatest numbers and that influenced the entire ecology of Kezar Lake was Aphanizomenon flos-aquae. This blue-green alga was always found as individual filaments (Fig. 6) and not in raft-like colonies. Gruendling and Mathieson (1969b) found A. flos-aquae as single filaments also in nearby lakes Newfound and Winnisquam, but they reported the "rafted" or colonial form under winter ice cover and in the spring. In this paper A. flos-aquae was enumerated as cells/ml based on the mean number of cells per trichome in each sample. Invariably, the mean was 25 cells/trichome throughout the summer except at lower depths.

The distribution and abundance of A. flos-aquae at Station 2 during 1968 is presented in Table 9. Logarithmic growth prevailed in the surface waters until July 15, the day before artificial circulation. The count of this species at 0.5m increased about 100 fold between May 16 and July 15. At lower depths maximum cell counts were recorded on June 27, but beyond this date there followed a precipitous decline in cell counts. The decline in abundance of A. flos-aquae at these depths correlates with their being below the 1% level of surface light (Fig. 3) considered essential for positive carbon assimilation (Ryther, 1956; Talling, 1962).

Thus by July 15 a surface bloom of A. flos-aquae was well established and, in terms of total cells/ml, it

Table 8. Species of phytoplankton collected from Station 2 in Kezar Lake.

CYANOPHYCEAE

Anabaena flos-aquae (Lyngb.) De Brebisson
Aphanizomenon flos-aquae (L.) Ralfs
Aphanocapsa delicatissima West & West
*Aphanocapsa elachista West & West **
*Lyngbya limnetica Lemmermann
Merismopedia tenuissima Lemmermann
Oscillatoria sp.
Oscillatoria limnetica Lemmermann

EUGLENOPHYCEAE

*Colacium vesiculosum Ehrenberg **
Entosiphon sulcatum (Duj.) Stein
Euglena sp.
*Euglena acus Ehrenberg
Peranema trichophorum (Ehren.) Stein
*Trachelomonas sp.
Trachelomonas varians (Lemm.) Deflandre **

XANTHOPHYCEAE

*Ophiocytium capitatum var. longispinum (Moeb.) Lemm.

CHRYSOPHYCEAE

Dinobryon sp. **
Dinobryon barvaricum Imhof
*Dinobryon cylindricum Imhof
*Dinobryon sertularia Ehrenberg **
Dinobryon suecicum Lemmermann **
Mallomonas sp. **
Mallomonas Fresenii Kent
Mallomonas tonsurata Teiling **

BACILLARIOPHYCEAE

*Amphora ovalis (Kuetz.) Kuetzing
Asterionella formosa Hassall
Cyclotella comta (Ehren.) Kuetzing
Cyclotella glomerata Bachmann
*Cymbella ventricosa Kuetzing
*Fragillaria sp. **
*Fragillaria crotonensis Kitton **
*Gomphonema olivaceum (Lyngb.) Kuetzing
Melosira ambigua (Grun.) Mueller
*Melosira islandica O. Mueller **
*Meridion circulare var. constrictum (Ralfs.) V.H.**
Navicula spp. **
*Nitzschia sp. **
Nitzschia acicularis W. Smith
Nitzschia filiformis W. Smith **
*Nitzschia palea (Kuetz.) W. Smith **
*Pinnularia sp. **
Stauroneis phoenicenteron (Nits.) Ehrenberg **
Surirella sp. **
Synedra radians Kuetzing
Synedra rumpens Kuetzing
*Tabellaria flocculosa (Roth) Kuetzing

DINOPHYCEAE

Glenodinium sp.
Peridinium cinctum (O. F. Mueller) Ehrenberg **
Peridinium wisconsinense Eddy **

CRYPTOPHYCEAE

Cryptomonas erosa Ehrenberg
Cryptomonas ovata Ehrenberg
Cryptomonas Marssonii Skuja
Cyathomonas truncata Fromentel
Rhodomonas minuta var. nannoplanctica Skuja

CHLOROPHYCEAE

Ankistrodesmus falcatus (Corda) Ralfs
Ankistrodesmus falcatus var. acicularis (A. Braun) G.S. West
Ankistrodesmus falcatus var. mirabilis (West & West) G.S. West
Ankistrodesmus falcatus var. tumidis (West & West) G.S. West
Chlamydomonas spp.
Chlorella vulgaris Beyerinck
*Closterium gracile De Brebisson
*Closterium moniliferum (Bory) Ehrenberg
Coelastrum microporum Naegeli
Cosmarium bioculatum De Brebisson
Crucigenia apiculata (Lemm.) Schmidle **
Dictyosphaerium Ehrenbergianum Naegeli
Dictyosphaerium pulchellum Wood
*Elakatothrix viridis (Snow) Printz
Golenkinia radiata (Chod.) Wille
*Gonium sociale (Duj.) Warming
Hormidium sp.
Kirchneriella contorta (Schmidle) Bohlin
Kirchneriella obesa (W. West) Schmidle
Kirchneriella obesa var. aperta (Teil.) Brunnthaler
*Kirchneriella obesa var. major (Bernard) G. M. Smith
Micratinium pusillum Fresenius
Nephrocytium Agardhianum Naegeli
Oocystis Borgei Snow
*Oocystis parva West & West
*Pediastrum Boryanum (Turp.) Meneghini **
*Pediastrum duplex Meyen **
Pediastrum tetras (Ehren.) Ralfs**
*Pediastrum tetras var. tetraodon (Corda) Rabenhorst **
Scenedesmus sp.
Scenedesmus abundans (Kirch.) Chodat **
Scenedesmus abundans var. asymmetrica (Schroed.) G. M. Smith
Scenedesmus acuminatus var. tetradesmoides G. M. Smith
*Scenedesmus arcuatus Lemmermann
Scenedesmus arcuatus var. platydisca G.M. Smith
Scenedesmus Bernardii G. M. Smith
Scenedesmus bicaudatus (Hansg.) Chodat
Scenedesmus denticulatus Lagerheim
Scenedesmus dimorphus (Turp.) Kuetzing
Scenedesmus longus Meyen **
Scenedesmus quadricauda var. longispina (Chod.) G. M. Smith
Scenedesmus quadricauda var. quadrispina (Chod.) G. M. Smith
Scenedesmus serratus forma minor Chodat
*Schroederia setigera (Schroed.) Lemmermann **
Selenastrum Bibraianum Reinsch
Selenastrum Westii G. M. Smith
Sphaerocystis Schroeteri Chodat
Spondylosium planum (Wolle) West & West **
*Staurastrum americanum (West & West) G. M. Smith
*Staurastrum chaetoceras (Schroder) G.M. Smith **
*Staurastrum lunatum var. planctonicum West & West
Staurastrum paradoxum var. parvum W. West **
*Staurastrum tetracerum var. validum West & West
Staurodesmus connatus (Lund) Thom.
*Staurodesmus extensus var. joshuae (Gutwinski) Teiling
Tetraedron caudatum (Corda) Hansgirg **
Tetraedron gracile (Reinsch) Hansgirg **
*Tetraedron hastatum (Reinsch) Hansgirg
Tetraedron limneticum Borge **
Tetraedron muticum (A. Braun) Hansgirg **
*Tetraedron planctonicum G. M. Smith **
Tetrallantos Lagerheimii Teiling
*Treubaria setigerum (Archer) G. M. Smith
Ulothrix subconstricta G. S. West

Fig. 6. Some phytoplankton common to Kezar Lake. a. *Aphanizomenon flos-aquae* with arrows showing an akinete (A) and a heterocyst (H). Photomicrograph courtesy of John H. Gentile. b and c. Twisted and broken filaments of *Anabaena flos-aquae* with arrows showing an akinete (A) and a heterocyst (H) adjacent to one another. d, e and f. *Rhodomonas minuta* var. *nannoplanctica* with arrows showing flagella (F) and a pyrenoid (P).

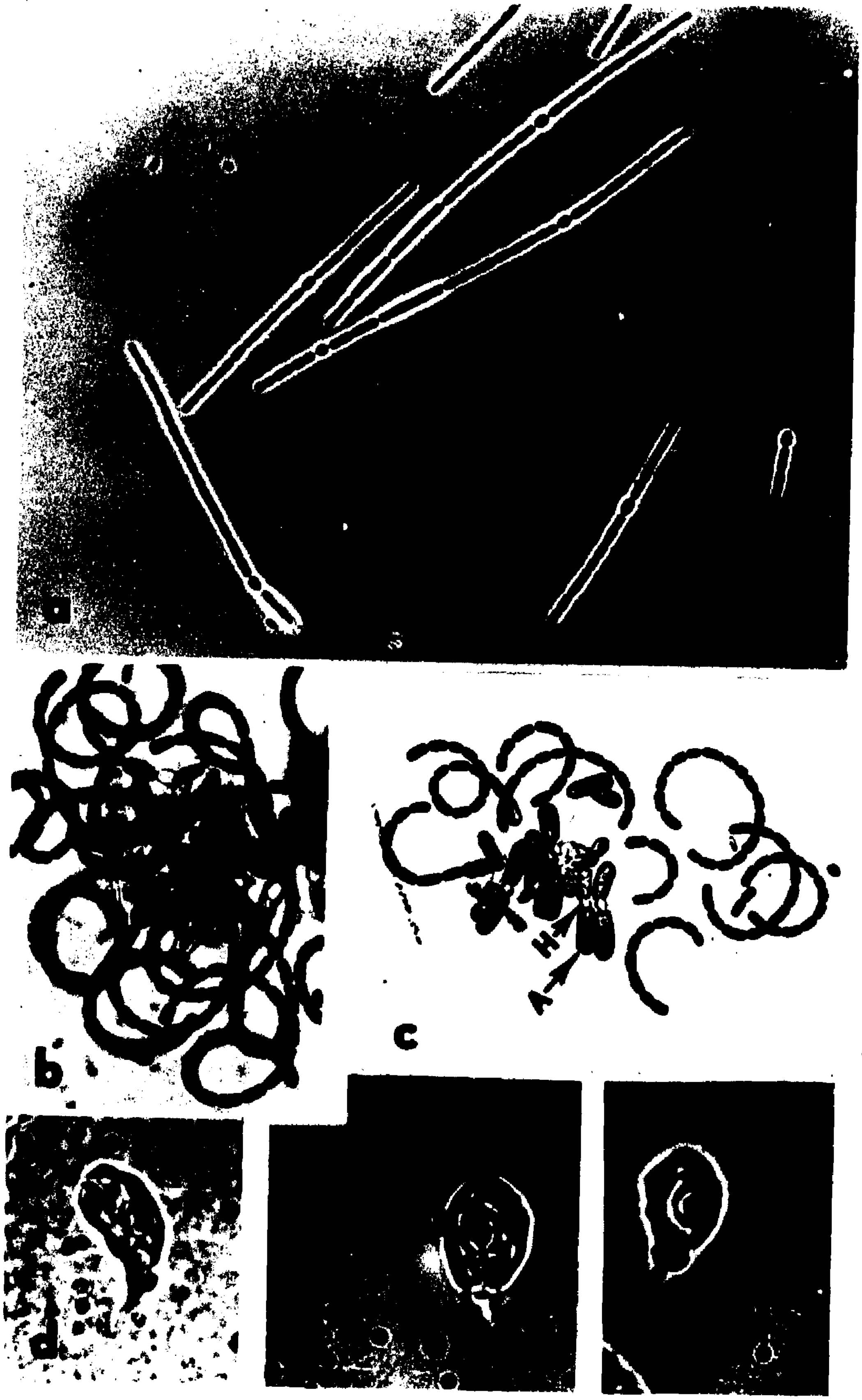
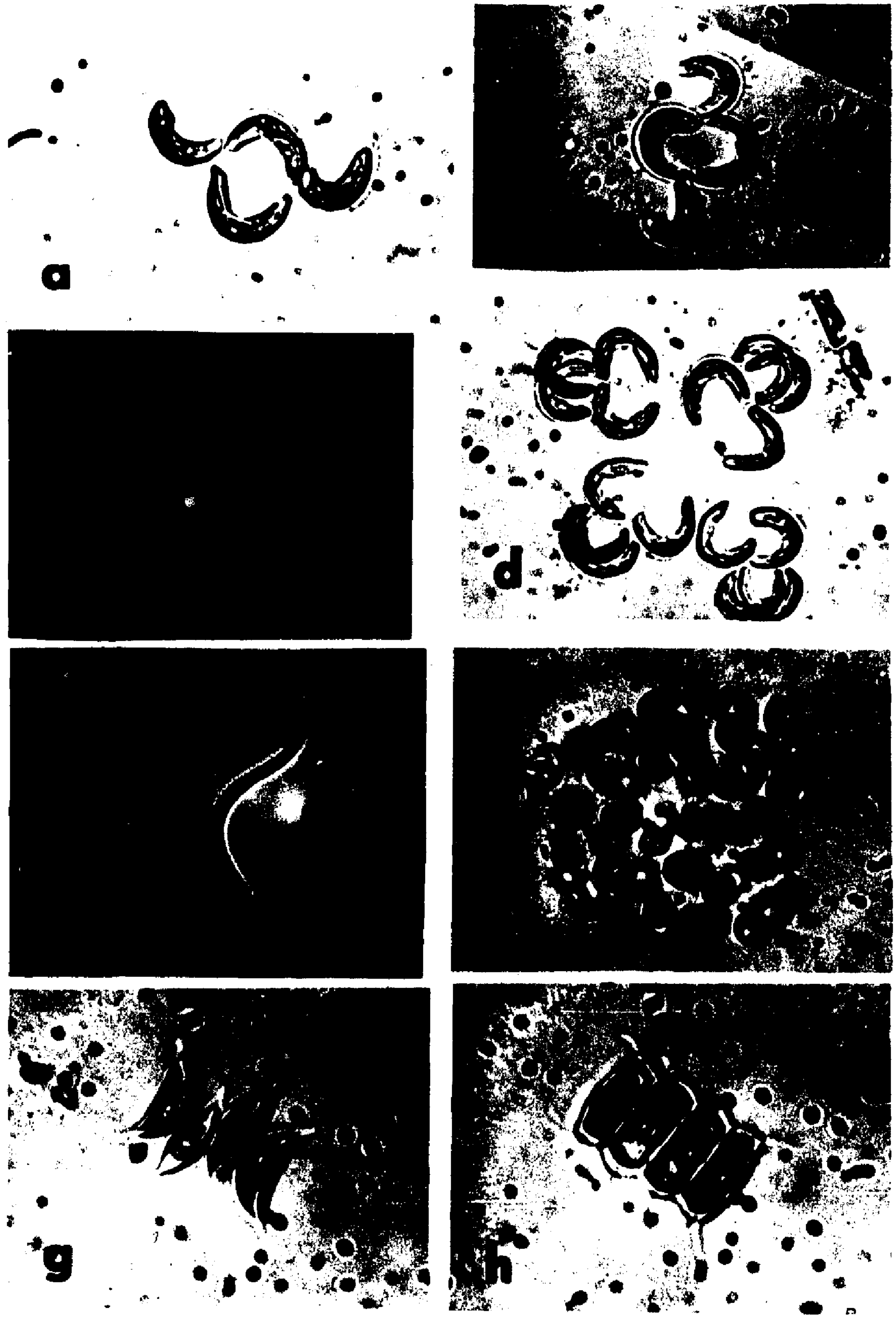

a
b
c
H
A
d

Fig. 7. Some phytoplankton common to Kezar Lake.

a, b and d. *Tetrallantos Lagerheimii*.

c. *Ulothrix subconstricta*. e. *Ankistrodesmus falcatus* var. *mirabilis*. f. *Dictyosphaerium pulchellum*. g. *Scenedesmus dimorphus*.

h. *Scenedesmus quadricauda* var. *quadrispina*.


a
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g
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Table 9. Vertical distribution and abundance ($1 x 10^3$ cells/ml) of <u>Aphanizomenon</u> <u>flos-aquae</u> at Station 2 in Kezar Lake, 1968.

DEPTH (M)	MAY 16	MAY 23	JUNE 6	JUNE 12	JUNE 19	JUNE 27	JULY 3	JULY 10	JULY 13	JULY 15	JULY 20	JULY 23
0.5	11.7	27.2	183.8	400.7	498.7	545.9	602.4	675.4	899.3	1041.1	365.5	416.8
1.5	10.2	31.8	173.4	445.8	373.3	613.1	497.1	578.0	545.0	441.1	317.8	400.0
2.5	9.8	22.0	44.4	133.8	115.2	553.9	405.6	241.1	254.7	58.0	293.6	359.1
3.5	7.2	4.9	28.6	6.5	41.0	294.7	169.5	30.1	25.5	25.1	292.0	272.5
4.5	4.8	4.2	12.5	1.6	2.8	147.8	84.0	18.3	10.9	9.8	289.8	207.4
5.5	1.6	5.0	7.0	1.1	1.4	87.2	87.5	18.9	6.8	6.0	188.4	215.5

DEPTH (M)	JULY 26	JULY 30	AUGUST 3	AUGUST 7	AUGUST 11	AUGUST 15	AUGUST 21	AUGUST 27	SEPTEMBER 4	SEPTEMBER 10	SEPTEMBER 13	SEPTEMBER 28	OCT. 10	NOV. 1
0.5	331.8	394.3	287.9	200.0	96.4	30.4	10.0	8.0	6.4	7.5	4.8	10.6	8.5	1.7
1.5	348.2	313.6	323.4	169.4	84.6	35.1	6.4	6.1	8.5	10.4	3.7	10.9	7.8	1.7
2.5	351.7	442.6	268.6	184.3	81.3	29.3	10.5	9.1	8.6	4.4	5.4	11.3	6.2	1.6
3.5	314.0	409.0	273.5	151.4	86.8	24.5	7.3	6.5	8.0	6.1	5.4	11.2	6.5	1.2
4.5	326.3	383.5	242.3	172.8	100.3	35.0	6.4	6.6	8.6	5.9	5.4	2.8	7.6	1.2
5.5	320.6	360.8	206.0	101.2	101.5	28.0	8.2	7.4	3.9	3.9	4.5	1.4	7.2	1.4

accounted for over 97% of the standing crop of phytoplankton at that time. This essentially unialgal bloom exerted tremendous control over many chemical and physical aspects in the lake. For example, the great abundance of filaments in the surface water: (a) reduced the Secchi transparency to 1 foot (Fig. 3); (b) increased oxygen production at 0.5m to 135% saturation (Table 1); (c) precluded oxygen production at depths below 1.5m (Table 1) by reducing light penetration, that event in turn induced iron and manganese to become soluble (Table 3) and concentrations of ammonia nitrogen to increase (Table 7); and (d) exhausted free carbon dioxide in the surface waters that concurrently accounted for measurable quantities of carbonate alkalinity (Fig. 5) and high pH (Table 2).

Table 9 data show that artificial circulation distributed _A. flos-aquae_ throughout the entire water column. However, on the basis of cells per meter square there was just as much _A. flos-aquae_ in Kezar Lake on July 20 as on July 15. The chemical and physical conditions caused by the bloom of _A. flos-aquae_ were reversed on July 20 following redistribution of this species. These changes included: (a) increased Secchi transparency (Fig. 3); (b) decreased oxygen production at 0.5m and increased oxygen distribution at lower depths (Table 1); (c) decreased concentrations of iron and manganese at lower depths (Table 3); (d) presence of free carbon dioxide and absence of carbonate alkalinity in surface waters (Fig. 5); and (e) lower pH in surface waters (Table 2).

The distribution of A. flos-aquae in the water column was uniform by July 26 (Table 9). This correlates with the occurrence of isothermal conditions (Fig. 4) and demonstrates that the lake was thoroughly mixed at this time. Aphanizomenon flos-aquae increased again by July 30, but there followed a gradual decline in the abundance and dominance of A. flos-aquae throughout August, with a subsequent improvement in water transparency (Fig. 3). Beyond August 21 the population of A. flos-aquae never exceeded 12.0×10^3 cells/ml. Aeration was discontinued on September 12 and by September 28 the homogeneous distribution of A. flos-aquae was interrupted temporarily (Table 9). The greater abundance of cells in surface waters at this time was reduced again by fall turnover on October 10.

Throughout most of the summer the cell counts of A. flos-aquae at Station 4 closely resembled those at Station 2 (Table 9). Until July 10 the bloom was just as intense at both stations. From July 10 through July 15 however, the growth of A. flos-aquae at 0.5m proceeded more logarithmically at Station 2. Thus on July 15 the comparative counts at 0.5m were 1041.1×10^3 and 737.6×10^3 cells/ml for Stations 2 and 4 respectively. After artificial circulation station to station differences became less pronounced and the trend toward decreasing abundance of A. flos-aquae during August was identical.

The phytoplankton flora other than A. flos-aquae can be separated arbitrarily into four general categories:

(a) those species whose occurrence was primarily in the spring and before artificial circulation; (b) those species that were common throughout the summer; (c) those species whose occurrence were generally favored by artificial circulation; and (d) those algae whose occurrence was infrequent or irregular.

Phytoplankton common before artificial circulation

This group consists largely of diatoms that characteristically prevail in spring waters (Hutchinson, 1967). The dominant species was Asterionella formosa. Table 10 shows that the cell count for this species declined gradually during early summer and only 10 cells/ml were found at 5.5m on July 15. Asterionella formosa was observed again by August 3 but its occurrence thereafter was sparse, never exceeding 200 cells/ml. Other common spring diatoms were Synedra radians, Cyclotella comta, and Nitzschia acicularis. Nitzschia acicularis was not observed after June 6, while Cyclotella comta and S. radians were found in a few samples during August through October. The colonial chrysomonad Dinobryon barvaricum was only observed from samples of May 16 and 23.

The filamentous blue-green Anabaena flos-aquae[1] appeared in surface samples above 3 meters during the brief

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[1]To avoid confusion Anabaena flos-aquae will not be abbreviated to A. flos-aquae in this paper. The latter will designate Aphanizomenon flos-aquae only.

Table 10. Vertical distribution and abundance ($1x10^3$ cells/ml) of five common species of phytoplankton at Station 2 in Kezar Lake, 1968.

	DEPTH (M)	5/16	5/23	6/6	6/12	6/19	6/27	7/3	7/10	DATE 7/15	(1968) 7/20	7/26	8/3	8/7	8/15	8/21	8/30	9/13	9/28	10/10	11/1
	0.5	4.58	4.82	1.65	0.21	0.10	0.04	0.02	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.15	0.00	0.06	0.00	0.03
Asterionella	1.5	6.45	6.11	1.57	0.34	0.04	0.03	0.02	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.04
formosa	2.5	6.10	4.21	2.18	0.32	0.16	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.11	0.01	0.00	0.00	0.13
	3.5	5.57	1.54	0.99	0.15	0.02	0.06	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.11
	4.5	4.55	1.50	1.16	0.09	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.04	0.00	0.00	0.06
	5.5	2.29	1.05	0.84	0.20	0.02	0.05	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.06	0.00	0.00	0.13
	0.5	2.81	5.74	0.25	0.25	0.08	0.20	0.04	0.12	0.06	0.12	0.60	0.65	1.11	13.04	26.27	112.36	149.38	92.82	84.08	36.80
	1.5	4.33	7.21	0.45	0.08	0.20	0.04	0.08	0.04	0.08	0.04	0.30	0.30	1.56	9.78	30.19	85.16	136.16	91.92	104.42	94.64
Dictyosphaerium	2.5	4.20	4.97	0.63	0.20	0.08	0.12	0.38	0.12	0.18	0.00	0.32	0.51	1.11	3.86	27.49	101.09	214.24	90.80	122.40	101.09
pulchellum	3.5	3.48	1.42	0.37	0.12	0.00	0.08	0.04	0.08	0.14	0.04	0.40	1.44	0.98	8.19	23.24	133.67	84.34	97.13	115.07	90.44
	4.5	2.86	1.76	0.21	0.04	0.00	0.10	0.08	0.06	0.00	0.16	0.12	1.14	1.92	8.42	15.67	36.32	158.66	149.01	112.64	56.33
	5.5	0.67	1.68	0.17	0.04	0.00	0.05	0.04	0.32	0.04	0.00	0.52	0.23	0.66	11.99	30.29	44.83	70.48	134.54	101.25	82.16
	0.5	0.85	0.56	3.86	6.63	11.10	19.08	34.86	23.66	30.36	11.73	10.94	19.58	29.76	23.04	8.06	25.62	33.77	101.60	0.00	0.00
	1.5	0.00	1.68	6.29	7.99	9.46	15.75	8.84	19.88	19.19	12.24	16.59	28.22	19.48	10.80	11.62	25.25	53.96	74.40	0.00	0.70
Oscillatoria sp.	2.5	0.49	0.00	0.92	0.86	3.15	10.92	21.17	18.00	8.37	5.89	11.59	20.32	26.17	9.83	11.73	26.75	44.80	81.95	0.22	1.46
	3.5	0.00	0.00	0.56	0.00	0.00	11.20	10.54	4.55	0.95	6.30	14.56	21.10	24.73	10.43	9.66	24.36	34.70	95.74	0.00	0.99
	4.5	0.18	0.00	0.00	0.00	0.00	7.20	6.10	0.81	0.81	4.21	12.25	22.96	26.03	17.64	5.05	11.37	51.07	58.65	0.72	1.13
	5.5	0.00	0.00	0.38	0.00	0.00	2.64	6.80	1.43	0.14	5.25	15.68	17.23	15.46	11.31	9.24	20.72	35.77	17.63	0.00	0.00
	0.5	0.36	0.88	0.10	0.40	0.44	0.92	1.12	0.30	0.08	0.04	0.28	0.20	0.92	0.44	0.00	0.34	0.87	0.68	0.32	0.00
	1.5	0.86	1.01	0.28	0.32	0.56	0.36	0.60	0.16	0.10	0.08	0.16	0.32	0.44	0.16	0.17	0.92	0.28	0.32	0.08	0.17
Scenedesmus	2.5	1.08	0.61	0.33	0.28	0.13	0.52	0.60	0.22	0.28	0.06	0.16	0.44	0.56	0.22	0.28	0.73	0.59	0.40	0.24	0.06
dimorphus	3.5	0.96	0.87	0.40	0.24	0.20	1.00	0.46	0.86	0.32	0.32	0.16	0.52	0.40	0.52	0.11	1.39	0.34	0.72	0.20	0.06
	4.5	1.88	1.19	0.21	0.00	0.04	0.48	0.64	0.60	0.74	0.28	0.28	0.38	0.48	0.50	0.22	0.28	1.01	0.06	0.24	0.17
	5.5	1.10	0.67	0.34	0.00	0.04	0.12	0.28	0.20	0.16	0.12	0.28	0.32	0.40	0.34	0.11	0.48	0.11	0.36	0.36	0.00
	0.5	1.13	1.59	0.60	0.31	0.09	0.08	0.13	0.10	0.04	0.02	0.09	0.01	0.37	2.80	0.29	0.17	0.28	0.28	0.70	0.07
Ankistrodesmus	1.5	1.07	1.33	0.69	0.23	0.21	0.06	0.15	0.03	0.04	0.03	0.10	0.24	0.23	1.46	0.25	0.14	0.17	0.32	0.54	0.46
falcatus var.	2.5	1.04	0.92	0.25	0.17	0.10	0.11	0.17	0.10	0.06	0.03	0.08	0.05	0.29	1.60	0.49	0.29	0.35	0.22	0.96	0.24
mirabilis	3.5	0.72	0.60	0.28	0.03	0.02	0.19	0.09	0.10	0.11	0.03	0.05	0.14	0.21	1.83	0.28	0.15	0.07	0.22	0.70	0.15
	4.5	0.70	0.49	0.16	0.02	0.01	0.09	0.08	0.07	0.08	0.04	0.09	0.25	0.21	1.81	0.15	0.01	0.28	0.18	0.70	0.25
	5.5	0.52	0.62	0.13	0.04	0.00	0.10	0.03	0.16	0.03	0.06	0.13	0.11	0.24	2.39	0.36	0.14	0.04	0.13	0.72	0.29

period May 23 through June 12. The highest count of 2.24 x 10^3 cells/ml was from the 1.5m sample on May 23. Akinete formation was in an advanced state (Fig. 6) in the June 12 samples and Anabaena flos-aquae was not observed after this date.

Of the Chlorophyceae, 3 species occurred primarily in the spring. Ankistrodesmus falcatus var. acicularis and Micratinium pusillum were most abundant on May 23. Schroederia setigera was present in the surface water only from June 6 through June 19. Ankistrodesmus falcatus var. acicularis and M. pusillum were found only sparingly after June 19. These species were generally observed at 10-50 cells/ml, although higher peaks were recorded for each alga.

Phytoplankton common throughout the summer

Of those algae whose occurrence continued generally without interruption, Dictyosphaerium pulchellum (Fig. 7) was the predominant form. The abundance and distribution of this colonial green alga is presented in Table 10. Dictyosphaerium pulchellum experienced a spring pulse in May followed by a sharp decline in abundance in early June. During the period June 12 through July 20, D. pulchellum was present at less than 400 cells/ml. By late August D. pulchellum was the dominant species of a heterogeneous phytoplankton bloom. During the period August 30 through November 1 counts of D. pulchellum were frequently in excess of 100 x 10^3 cells/ml. Dictyosphaerium pulchellum was always distributed in the entire water column, even after the shut down of air compressors on September 12.

A third filamentous blue-green, *Oscillatoria* sp., was a subdominant species before and after artificial circulation of Kezar Lake. Table 10 shows that as summer progressed *Oscillatoria* sp. flourished in the surface waters and that it behaved somewhat comparably to *A. flos-aquae*, although it was less numerous. By July 15, the day preceding aeration, the stratification of this species in the water column was strongly established. The combined cell counts of *A. flos-aquae* and *Oscillatoria* sp. at this time accounted for 99% of the phytoplankton standing crop in Kezar Lake.

Similar to its effect on *A. flos-aquae*, artificial circulation redistributed *Oscillatoria* sp. (Table 10). The filaments of *Oscillatoria* sp. were dispersed evenly in the water column by July 26 and an increased abundance of this species again was evident. There followed a gradual decline in cell numbers through mid-August, but by the end of this month the abundance of *Oscillatoria* sp. returned to August 7 levels. This trend continued until September 28 when a peak count of 101.60×10^3 cells/ml was observed. On the latter date *Oscillatoria* sp. had restratified in the water column after discontinuation of artificial circulation. *Oscillatoria* sp. had almost disappeared on October 10, and it was a relatively low numbers on November 1.

Eleven species of *Scenedesmus* were found in Kezar

Lake. Of these, five were common throughout the summer of 1968. Scenedesmus dimorphus (Fig. 7) was the most abundant, and it was most numerous during May (Table 10). The distribution and abundance of S. bicaudatus and S. quadricauda var. longispina was similar to that of S. dimorphus, with the exception that the latter species was not found during July 15 to July 26. Scenedesmus abundans var. asymmetrica was common also throughout the summer of 1968 but its numbers were sparse before artificial circulation. Throughout August and September S. abundans var. asymmetrica was very common, and it was observed frequently in excess of 100 cells/ml.

Several other species of the Chlorophyceae occurred commonly throughout the summer of 1968. Ankistrodesmus falcatus var. mirabilis (Fig. 7) was invariably present from phytoplankton samples collected at Kezar Lake. Table 10 shows that A. falcatus var. mirabilis experienced a spring maximum in the surface waters during May. There followed a gradual diminution in abundance of this species and by late June and early July less than 200 cells/ml were generally observed at each depth. After artificial circulation A. falcatus var. mirabilis became more numerous at each depth, and it attained maximum abundance on August 15 (Table 10). Only small fluctuations were observed through the remainder of the summer.

Other chlorophycean species that reached peak abundance in May included Chlorella vulgaris, Coelastrum microporum and Golenkenia radiata. Hormidium sp. flourished in late June, and it attained counts as high as 1.16 - 1.93 x 10^3 cells/ml. The desmids Cosmarium bioculatum , Staurastrum paradoxum var. parvum, Staurodesmus connatus, and the colonial green alga Selenastrum Westii, were all common before artificial circulation but were not abundant. All of these species were sparse at the height of the A. flos-aquae bloom, except for C. vulgaris. At this time, C. vulgaris was stratified in the water column, and it was counted usually at 100-500 cells/ml in surface waters.

All of the aforementioned species became more numerous following artificial circulation and they reached peak counts (up to 800 cells/ml) during mid or late August. Hormidium sp. was relatively abundant at this time and it varied from 4.44 to 8.89 x 10^3 cells/ml in the water column on August 21. Only C. microporum, S. connatus, and S. Westii were commonly encountered in phytoplankton samples collected during September and October.

The pigmented flagellates enumerated at Kezar Lake during 1968 were common throughout the summer. The most prominent flagellates were three species of Cryptomonas: C. erosa, C. Marssonii and C. ovata. The abundance and distribution of C. erosa was typical of the other cryptomonads and cell counts for this species are presented in Table 11. These data show that the population of C. erosa had shifted from bottom waters on May 16 to surface waters on June 12. Cryptomonas erosa continued to be most prominent in surface

Table 11. Vertical distribution and abundance ($1x10^3$ cells/ml) of five common species of phytoplankton at Station 2 in Kezar Lake, 1968.

Species	DEPTH (M)	5/16	5/23	6/6	6/12	6/19	6/27	7/3	7/10	DATE 7/15	(1968) 7/20	7/26	8/3	8/7	8/15	8/21	8/30	9/13	9/28	10/10	11/1
	0.5	0.02	0.14	0.04	0.31	0.21	0.36	0.86	1.08	0.10	0.00	0.06	0.21	0.73	1.89	0.81	0.22	0.04	0.02	0.08	0.03
	1.5	0.03	0.05	0.07	0.09	0.11	0.21	0.42	0.16	0.06	0.06	0.05	0.12	0.47	1.36	0.76	0.21	0.04	0.18	0.08	0.08
Cryptomonas	2.5	0.27	0.19	0.00	0.02	0.02	0.16	0.15	0.03	0.01	0.02	0.06	0.08	0.30	1.50	1.08	0.24	0.04	0.10	0.12	0.04
erosa	3.5	0.20	0.07	0.01	0.00	0.02	0.07	0.03	0.00	0.00	0.00	0.05	0.10	0.25	1.35	0.76	0.24	0.06	0.14	0.04	0.04
	4.5	0.35	0.08	0.01	0.00	0.00	0.01	0.01	0.02	0.00	0.00	0.04	0.12	0.37	1.36	0.70	0.13	0.10	0.00	0.06	0.04
	5.5	0.21	0.03	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.10	0.18	1.49	0.97	0.07	0.03	0.01	0.12	0.03
	0.5	0.22	0.77	2.06	0.23	0.07	0.16	0.00	0.00	0.00	0.00	0.00	0.04	0.56	0.70	1.71	0.31	0.15	0.14	0.62	1.02
Rhodomonas	1.5	0.42	0.59	1.97	0.15	0.04	0.03	0.00	0.00	0.06	0.00	0.01	0.04	0.27	0.88	1.34	0.21	0.08	0.20	0.64	1.08
***minuta* var.**	2.5	0.20	0.58	0.07	0.04	0.03	0.03	0.00	0.00	0.05	0.00	0.00	0.00	0.09	0.94	1.53	0.46	0.08	0.10	0.72	1.46
nannoplanctica	3.5	0.19	0.26	0.04	0.00	0.01	0.01	0.00	0.00	0.07	0.00	0.00	0.01	0.05	0.77	1.86	0.34	0.03	0.06	0.64	1.34
	4.5	0.10	0.04	0.01	0.01	0.01	0.01	0.00	0.00	0.04	0.00	0.00	0.00	0.05	0.76	1.13	0.04	0.04	0.02	0.54	1.29
	5.5	0.04	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.05	0.96	1.82	0.15	0.04	0.01	0.36	1.23
	0.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.80	1.90	0.80	0.80	0.07
Scenedesmus	1.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	2.20	0.90	0.48	0.64	0.34
***arcuatus* var.**	2.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.69	2.46	0.48	0.80	0.22
platydisca	3.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22	2.82	0.56	0.32	0.64	0.25
	4.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.56	1.57	1.92	0.32	0.17
	5.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.45	0.67	1.79	0.56	0.15
	0.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.04	0.02	0.22	0.44	0.82	0.34	5.46	4.06	0.80	0.12	0.03
Scenedesmus	1.5	0.00	0.00	0.04	0.04	0.00	0.00	0.00	0.04	0.00	0.02	0.06	0.16	0.43	0.94	1.29	4.98	1.60	0.88	0.12	0.04
***serratus* forma**	2.5	0.00	0.00	0.12	0.04	0.16	0.00	0.10	0.04	0.00	0.04	0.08	0.33	0.26	1.13	1.75	6.18	3.45	0.64	0.20	0.08
minor	3.5	0.00	0.08	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.47	0.48	1.30	1.55	4.84	1.24	1.27	0.32	0.06
	4.5	0.00	0.00	0.08	0.00	0.00	0.04	0.12	0.08	0.00	0.08	0.04	0.24	0.34	0.77	0.62	1.40	4.46	2.76	0.16	0.00
	5.5	0.02	0.00	0.02	0.00	0.00	0.00	0.04	0.00	0.04	0.02	0.12	0.14	0.12	1.27	1.28	1.04	1.09	2.57	0.30	0.00
	0.5	0.01	0.07	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.20	2.56	1.34	3.53	3.42	0.72	0.28	0.00
	1.5	0.04	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.29	0.96	1.18	4.37	3.02	0.76	0.18	0.00
Tetrallantos	2.5	0.00	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.28	1.85	3.64	4.82	3.86	0.64	0.18	0.17
Lagerheimii	3.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.28	2.28	2.52	5.38	2.46	0.48	0.26	0.01
	4.5	0.01	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.56	1.79	1.29	2.74	2.30	1.68	0.00	0.00
	5.5	0.00	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.20	1.92	1.46	2.30	2.69	2.41	0.12	0.00

waters throughout June and early July. Similarly, _C. ovata_ and _C. Marssonii_ were observed primarily in surface waters at this time. The trends of all three species of _Cryptomonas_ are nearly identical after artificial circulation. Fluctuations of these species can be followed in Table 11. Table 11 shows also the population trends of the small flagellate _Rhodomonas minuta_ var. _nannoplanctica_ (Fig. 6) before and after mixing of Kezar Lake.

The chlorophycean flagellate _Chlamydomonas_ spp. and the dinoflagellate _Glenodinium_ sp. were common through most of the summer, but they were most numerous following artificial circulation. Both flagellates were most abundant (10-60 cells/ml) in the surface waters during June. Subsequent artificial circulation, both _Chlamydomonas_ spp. and _Glenodinium_ sp. were distributed evenly in the water column and they were generally counted between 70 and 200 cells/ml. The remaining flagellate and last species that was common throughout the summer is _Trachelomonas varians_. This test-bearing euglenoid was observed on every sampling date, but it was distributed sparingly before July 16. After artificial circulation _T. varians_ became more numerous and it was evenly dispersed in the water column. The highest count of 100 cells/ml was recorded at 0.5m on August 7. _Trachelomonas varians_ and _Chlamydomonas_ spp. were encountered only sparingly after August 30 whereas Glenodinium sp. was still a common phytoplankter.

Phytoplankton common after artificial circulation

The third general category of phytoplankton is composed almost exclusively of chlorophycean taxa. The abundance and distribution of Scenedesmus arcuatus var. platydisca exemplifies this category best and cell counts of this species are presented in Table 11. The Table shows that S. arcuatus var. platydisca was absent from the phytoplankton flora until August 15. By August 30, however, a maximum count was recorded and most of the population was located in surface waters irrespective of artificial circulation. A gradual diminution in the abundance of S. arcuatus var. platydisca followed, and subsequent to the discontinuation of artificial circulation most of the population of this phytoplankter was located in bottom waters on September 28 (Table 11).

Table 11 shows also the population increments of two other green algae, Scenedesmus serratus forma minor and Tetrallantos Lagerheimii, following artificial circulation of Kezar Lake. Tetrallantos Lagerheimii (Fig. 7) was observed in large numbers during late August and early September. According to Smith (1950) and Prescott (1962) this species is rare in the United States. Crucigenia apiculata (2.52-5.82 x 10^3 cells/ml) and Selenastrum Bibraianum (1.36 - 2.02 x 10^3 cells/ml) also reached peak populations during late August and early September respectively. Other green algae that were numerous (generally, 50-500 cells/ml) following artificial circulation of Kezar

Lake are (in order of abundance): Kirchneriella contorta, K. obesa, Sphaerocystis Schroeteri, Scenedesmus sp., S. quadricauda var. quadrispina (Fig. 7), S. acuminatus var. tetradesmoides, Nephrocytium Agardhianum, Tetraedron limneticum, T. gracile, and T. muticum.

The abundance and distribution of Ulothrix subconstricta (Fig. 7) stands in contrast to chlorophycean taxa previously mentioned. Only after artificial circulation was discontinued on September 12 was U. subconstricta relatively abundant. Counts of U. subconstricta often exceeded 1.00×10^3 cells/ml; a peak abundance was reached by October 10. On September 28 U. subconstricta was most numerous at 1.5m, which is contrary to the vertical distributions of S. arcuatus var. platydisca, S. serratus forma minor, Scenedesmus sp., T. Lagerheimii, K. contorta, K. obesa, and S. Bibraianum mentioned previously. It should be noted that the abundance of all the latter species diminished after September 28, while U. subconstricta remained numerous.

In addition to the many green algae previously discussed, two species of diatoms appeared in phytoplankton samples after artificial circulation of Kezar Lake. Melosira ambigua was common at 20-266 frustules/ml throughout August and September, but it was distributed intermittently in the water column. Synedra rumpens occurred in phytoplankton samples during this same interval, but it was not as numerous.

Phytoplankton distributed irregularly

In the remaining category, we find great diversity and the largest number of species. Among the blue-green algae, Aphanocapsa delicatissima was observed in phytoplankton samples collected during mid-June and again in the fall. Merismopedia tenuissima was encountered sparingly during late June and early July, whereas in samples collected after artificial circulation, trichomes of Oscillatoria limnetica were occasionally present. Several diatoms were found in phytoplankton samples collected in the spring and fall months, but they were uncommon. Of these, Navicula spp. and Cyclotella glomerata were present (10-50 cells/ml) during the spring but only the latter species was common in September and October. Both Mallomonas Fresenii and Mallomonas tonsurata reappeared in phytoplankton samples at 10-110 cells/ml during late August, after small peaks in May and early June.

Six species of Chlorophyceae are categorized as generally not abundant or irregularly distributed. Ankistrodesmus falcatus was common on May 16 only, and it was observed infrequently thereafter. Spondylosium planum appeared in some spring samples, but it was not observed again until late August. Scenedesmus denticulatus was counted at 40-120 cells/ml during late June, early August, and in samples collected during September and October. Scenedesmus Bernardii was not abundant and it prevailed in surface phytoplankton samples on only 7 of 20 collection dates. *Pediastrum tetras* was most numerous (40-224 cells/ml) from September 13 until October 10, but it was distributed sparingly in the water column. *Oocystis Borgei* did not appear in phytoplankton samples until September but was uncommon until November 1.

Euglena sp. was observed usually on each sampling date, but only in one or two samples and at 10 cells/ml. In addition, two nonpigmented flagellates were enumerated from phytoplankton samples collected at Kezar Lake. *Entosiphon sulcatum* was observed in only one sample, while *Cyathomonas truncata* was encountered sporadically throughout the summer.

Finally, thirty-eight species of algae were encountered in 5% or less of the 120 phytoplankton samples collected at Kezar Lake during the summer of 1968. Since these species contributed insignificantly to the standing crop of phytoplankton they will not be discussed. Instead, they are indicated in Table 8 by a single asterisk.

Total phytoplankton

In summary, the phytoplankton standing crop before and shortly after artificial circulation was exclusively blue-green, being dominated by *A. flos-aquae*. Throughout August the bloom of *A. flos-aquae* dissipated, and it was succeeded by a heterogeneous assemblage of green algae. By late August 80 percent of the phytoplankton standing crop was composed of chlorophycean species. Figure 8 shows this trend. After mixing was terminated on September 12 the percent standing crop attributed to blue-green algae increased to 53% during the peak growth of *Oscillatoria* sp. However, by October 10 the chlorophycean genera were again dominant. It is clear also from Fig. 8 that phytoplankton other than *Cyanophyceae* and *Chlorophyceae* contributed insignificantly to the standing crop of phytoplankton following artificial circulation of Kezar Lake.

Chlorophyll-a

Chlorophyll-a concentrations were determined at Kezar Lake as indices of phytoplankton standing crop and of algal potential to assimilate carbon. For comparative reasons calculation of chlorophyll-a in mg/m^3 was accomplished by two different equations and at two different spectrophotometric wavelengths (665mu, 663mu) as suggested respectively by Strickland and Parsons (1965) and SCOR-UNESCO (1966). The results of these comparisons will be submitted for publication separately, but I will state now that no significant differences were found regardless of the equation or wavelength employed. Since earlier studies (Gentile, 1966; Gallup, 1969) on New Hampshire lakes have reported chlorophyll-a results based on the trichromatic equation and recommended wavelength suggested by Strickland and Parsons (1965) the results in this paper will be reported similarly.

Fig. 8. Major successional changes in the phytoplankton standing crop at Station 2 following artificial circulation of Kezar Lake. Pumps on July 16 - off September 12, 1968.

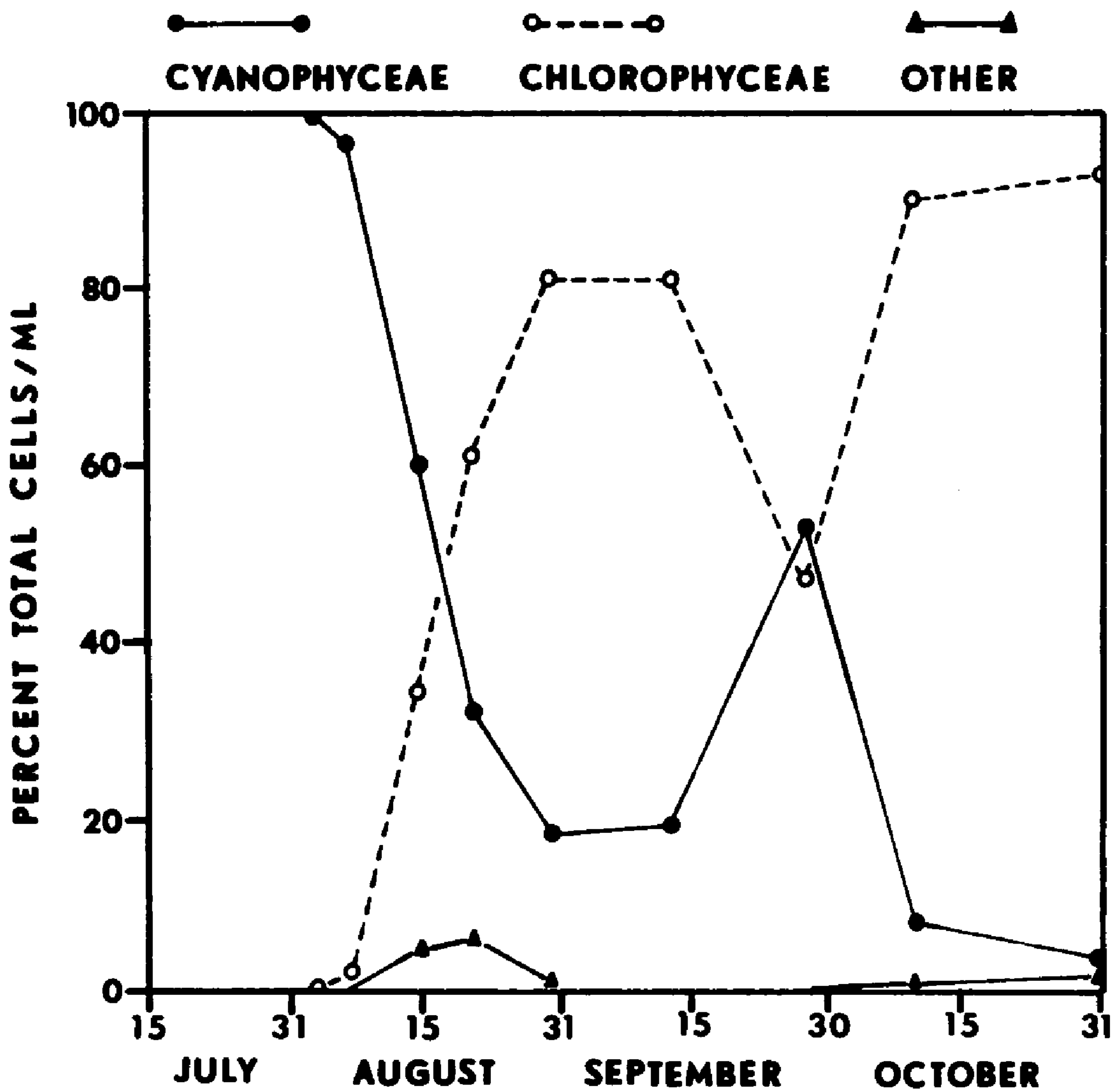

CYANOPHYCEAE
CHLOROPHYCEAE
OTHER
PERCENT TOTAL CELLS/ML
100
80
60
40
20
0
15
31
15
31
15
30
15
31
JULY
AUGUST
SEPTEMBER
OCTOBER

Table 12 shows the distribution of chlorophyll-a in Kezar Lake during the summer of 1968. Through June and July chlorophyll-a samples were collected frequently to the depth of 1% surface illumination only. Otherwise, chlorophyll-a samples were collected to a depth of 5.5m. Concentrations of chlorophyll-a were stratified in the water column at Station 2 on sampling dates prior to artificial circulation. The largest concentration of chlorophyll-a on May 23 was found at 2.5m, but on succeeding dates it was invariably at 0.5 meters. At the latter depth the amount of chlorophyll-a increased gradually to 76.09 mg/m^3 on June 30, then leveled off to 72.21 mg/m^3 on July 15. A similar event occurred at 1.5 meters. At lower depths maximum concentrations of chlorophyll-a were recorded on July 3 whereupon rapid depletion ensued. The stratification of chlorophyll-a on July 15 correlates closely with the vertical distribution of _A_. _flos-aquae_ (compare Tables 9 and 12).

After artificial circulation, chlorophyll-a was uniformly dispersed in the water column. A gradual reduction in chlorophyll-a was evident during early August, which is in agreement with the decline in abundance of _A_. _flos-aquae_. By August 15, however, the concentration of chlorophyll-a leveled off, and it remained stable with a mean concentration of 22.20 mg/m^3 during the next 6 weeks. Thereafter, chlorophyll-a decreased steadily, and it was evenly dispersed at 10.69 - 12.18 mg/m^3 on November 1.

The distribution of chlorophyll-a at Station 4 is

Table 12. Depth distribution of chlorophyll-a at Station 2 in Kezar Lake, 1968. Concentrations are in mg/m^3.

DEPTH (M)	MAY 23	JUNE 12	JUNE 19	JUNE 30	JULY 3	JULY 15	JULY 21	JULY 23	JULY 26	JULY 30	AUGUST 3
0.5	12.9	41.7	59.3	76.1	71.2	72.2	42.8	41.9	46.2	50.8	57.3
1.5	14.2	40.0	53.5	72.5	66.0	63.9	44.2	42.9	51.6	56.0	47.7
2.5	18.7	31.8	17.1	-	60.2	14.4	38.4	39.5	53.2	44.9	53.3
3.5	8.4	4.9	7.0	-	42.9	5.1	-	42.2	58.3	50.4	42.8
4.5	5.9	3.5	-	-	29.1	7.5	-	35.0	-	53.1	45.2
5.5	4.9	-	-	-	-	-	-	36.2	-	55.9	46.3

DEPTH (M)	AUGUST 7	AUGUST 11	AUGUST 15	AUGUST 21	AUGUST 27	AUGUST 30	SEPTEMBER 3	SEPTEMBER 13	SEPTEMBER 28	OCTOBER 10	NOV. 1
0.5	36.0	22.3	17.3	22.4	20.0	21.2	16.7	24.8	22.4	16.2	10.8
1.5	37.4	27.1	16.6	21.8	19.3	20.2	19.6	27.5	21.0	17.4	12.2
2.5	30.3	23.1	21.5	22.8	22.2	20.3	19.3	25.9	21.7	15.6	10.7
3.5	39.5	24.9	14.9	22.4	19.0	24.7	25.2	26.9	19.6	18.3	10.8
4.5	36.3	23.2	19.3	18.9	16.8	24.2	25.9	-	28.0	14.2	11.3
5.5	30.3	24.5	15.7	20.7	19.5	18.5	20.8	-	32.3	13.1	10.8

very similar to that shown for Station 2. The important exception is at 0.5m on July 15, when 35.40 mg/m^3 chlorophyll-a measured at Station 4 was one-half the amount measured at Station 2 (Table 12). Similarly, at 1.5m the amount of chlorophyll-a was less at Station 4. I cannot explain the slower growth rate of A. flos-aquae and reduced levels of chlorophyll-a bound in surface waters at Station 4 during mid-July.

Primary Productivity

In situ primary productivity studies were conducted at Kezar Lake as an index of the vitality of phytoplankton populations. At Station 2 the rate of photosynthesis more than doubled at 0.5m between June 30 and July 15 (Table 13). On the latter date a summer maximum of 2109.2 mg(particulate) $C/m^3/4$ hrs. was fixed at the 0.5m depth. Primary productivity at 1.5m was severely curtailed and no photosynthetic activity was evident at 2.5 meters attesting to the dense shade caused by very high cell numbers near the surface. The extremely high assimilation rates of carbon in surface waters at this time was responsible for the absence of free carbon dioxide and subsequent increase in carbonate alkalinity (Fig. 5) and pH (Table 2).

The initial effect of artificial circulation on primary productivity was a sharp decrease at 0.5 meters by July 21. At the 1.5 and 2.5m depths primary productivity increased (Table 13) in response to deeper light penetration (Fig. 3).

Table 13. Primary productivity in mg (particulate) $C/m^3/4$ hrs. at Station 2 in Kezar Lake, 1968.

DEPTH (M)	JUNE	JULY					AUGUST	
	30	3	15	21	26	30	3	7
0.5	867.5	1218.6	2109.2	331.7	838.4	1040.7	738.2	385.6
1.5	18.4	17.2	10.1	62.4	100.7	170.2	199.3	65.5
2.5	-	-	0.0	1.9	-	6.7	13.5	7.8
3.5	-	-	-	-	-	-	-	1.1

DEPTH (M)	AUGUST					SEPTEMBER		
	11	15	21	27	30	3	13	28
0.5	258.0	178.6	201.2	141.8	79.7	56.2	23.2	1.3
1.5	208.9	127.6	100.7	79.4	45.9	29.0	9.3	0.9
2.5	65.2	68.0	29.9	28.0	15.2	7.8	1.3	0.1
3.5	12.8	21.3	6.5	7.8	5.4	1.6	0.2	-
4.5	-	5.7	2.3	4.9	2.7	-	-	-

After 10 days of aeration, primary productivity had increased measurably and this trend continued until July 30 when a post-aeration maximum of 1040.7 mg(particulate) $C/m^3/4$ hrs. At 0.5m was recorded. Beyond July 30 decreasing rates of photosynthesis were found at 0.5 meters. At 1.5, 2.5 and 3.5m the maximum rates of photosynthesis were recorded on August 11 and 15, thereafter a gradual diminution occurred also at these depths. No primary production was detected at any depth on November 1.

With few exceptions the primary productivity at Station 4 parallels closely that presented previously for Station 2 (Table 13). At Station 4 primary productivity decreased from 1546.3 to 1028.3 mg(particulate) $C/m^3/4$ hrs. on July 7 and 15 respectively in contrast to the significant increases recorded at Station 2. The decrease in primary productivity at Station 4 during this interval contradicts increases in the population of _A_. _flos_-_aquae_ but correlates with a lower level of chlorophyll-a (see page 75). Primary productivity was severely curtailed also at 0.5m after the lake was mixed and the increases at lower depths were nearly identical to the rates shown for Station 2 (Table 13). At 0.5m, primary productivity remained lower at Station 4 until August 11 whereupon the results became similar for both stations.

RESULTS 1969

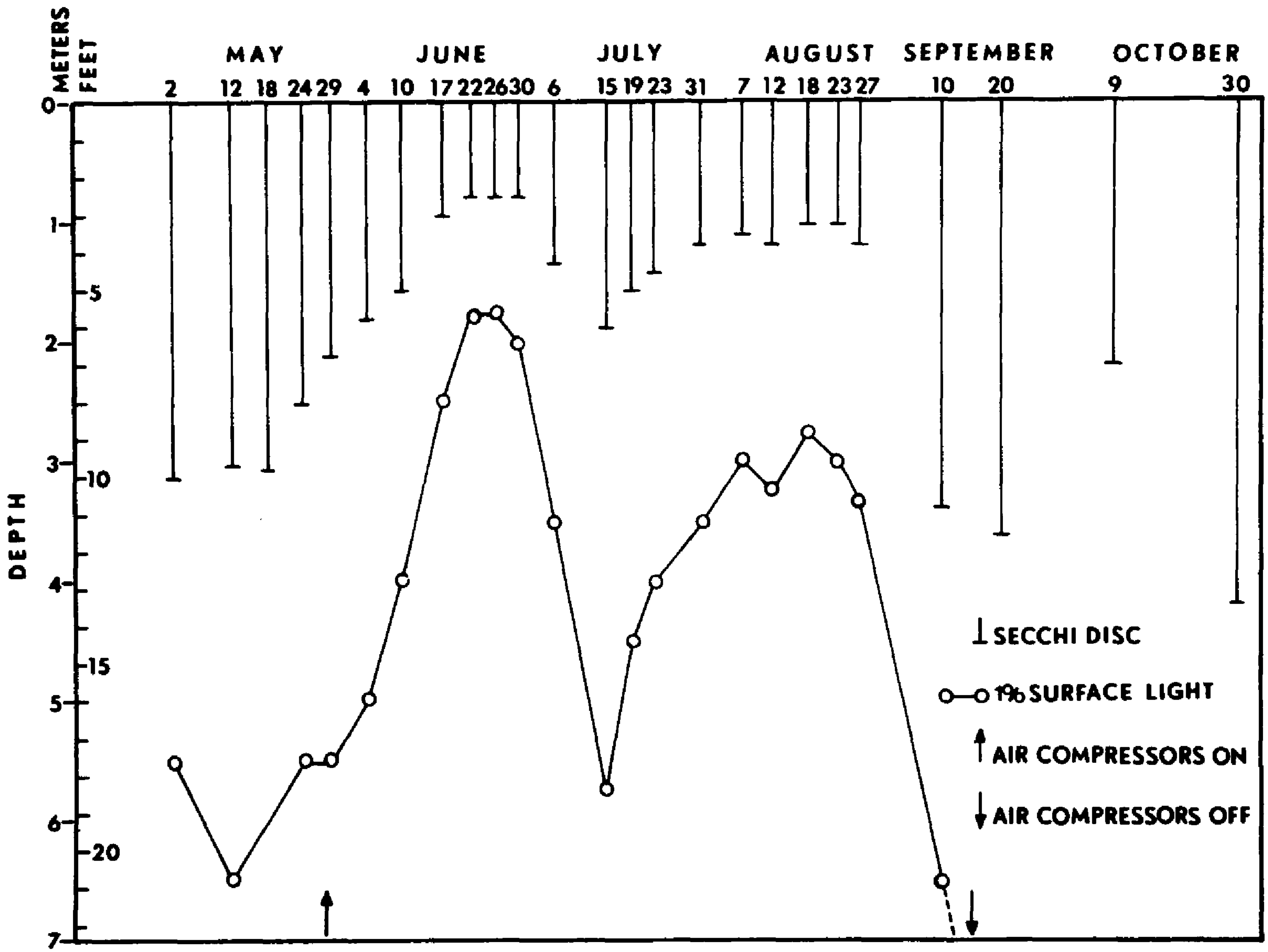
Transparency

The changes in water transparency during the summer of 1969 were not unlike those of 1968. Even though the air compressors were started on May 28 the water transparency continued to decline (Fig. 9). The Secchi disc transparency of 10 feet on May 2 was reduced to 2.5 feet during the last week of June. As the bloom of A. flos-aquae dissipated, the water transparency increased, and by July 15 the Secchi disc transparency was 6 feet.

The improved water clarity was only transitory for a subsequent increase of predominantly green algae occurred during the latter half of July and throughout August. During this period the Secchi disc transparency varied between 3 and 4 feet. By September 10 the water had cleared favorably, but on October 9 the Secchi disc transparency was diminished again because of the accumulation of algae in surface waters. However, on October 30 a Secchi disc transparency of 13.5 feet was observed, the deepest Secchi disc reading recorded during the 2 year research period. The Secchi readings at Station 4 were identical to those at Station 2 during the summer of 1969.

The level of 1% surface light proved again to be a more sensitive indicator of water transparency. Figure 9 shows that in shallow lakes more than 1% of surface light

Fig. 9. Light transmission in Kezar Lake. Secchi disc transparency and level of 1% surface illumination at Station 2, 1969.


METERS
FEET
DEPTH
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
2 12 18 24 29 4 10 17 22 26 30 6 15 19 23 31 7 12 18 23 27 10 20 9 30
0
1
2
3
4
5
6
7
5
10
15
20
SECCHI DISC
1% SURFACE LIGHT
AIR COMPRESSORS ON
AIR COMPRESSORS OFF

may reach the bottom when the water transparency is good.

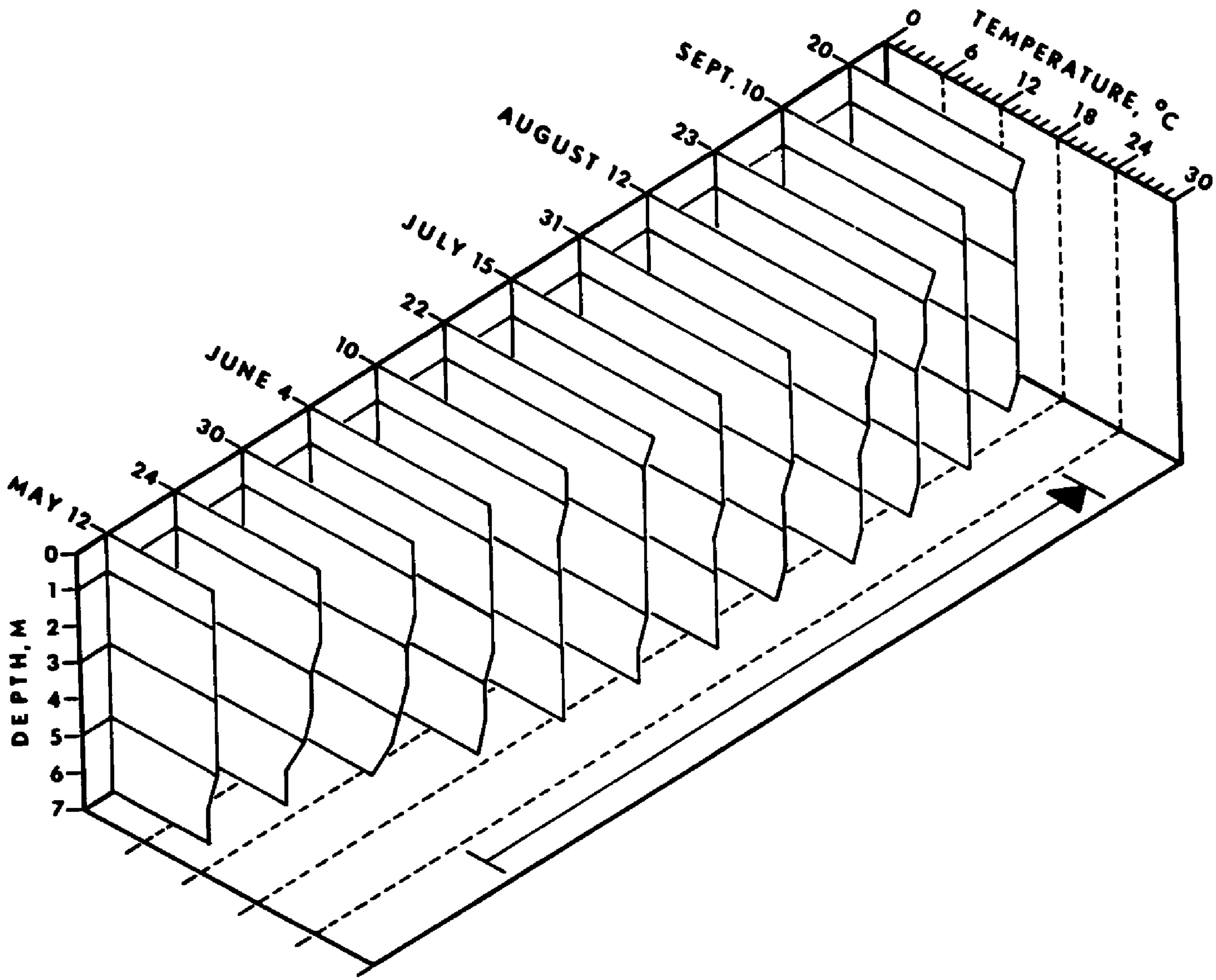
Temperature

The effect of artificial circulation on the temperature regime at Kezar Lake during 1969 is illustrated in Fig. 10. Since the surface to bottom temperature differential was less on May 28, 1969 (Fig. 12) than on July 15, 1968 (Fig. 4) less work was required to completely circulate the lake. With only 2 of 4 air compressors in operation the lake was completely mixed after 7 days aeration. Still, the lake waters gradually warmed to between 20C and 25C and remained isothermal throughout the summer. The lake remained thermally destratified after the air compressors were shut down on September 15. Since only 3 compressors were operative during most of the summer slight surface-to-bottom temperature differences are evident (Fig. 10). These temperature differences generally were less than 2C. Temperature differences between Stations 2 and 4 were always less than 1C during the entire summer.

Dissolved Oxygen

Stratification of dissolved oxygen was obvious as early as May 28, the same day the air compressors were started (Table 14). After circulation the dissolved oxygen content of the surface waters was high in June due to the bloom of _A. flos-aquae_. By July 6 the bloom had dissipated

Fig. 10. Temperature profiles at Station 2 in Kezar Lake, 1969. Arrow indicates period of artificial circulation.


TEMPERATURE, °C
0
6
12
18
24
30
MAY 12
24
30
JUNE 4
10
22
JULY 15
31
AUGUST 12
23
SEPT. 10
20
DEPTH, M
0
1
2
3
4
5
6
7

and the vertical distribution of dissolved oxygen was extremely uniform.

The high levels of oxygen during the latter half of July and throughout August were caused by high density of predominantly green algae. By September 10 the bloom of green algae had subsided and the dissolved oxygen content was extremely uniform again in the water column (Table 14). The reason(s) for the uniformly low dissolved oxygen concentrations on July 6 and September 10 is (are) unknown. Both dates occur, however, at the termination of successive algal blooms, and a high BOD must have existed (Prescott, 1962). Stratification of oxygen did not reoccur after the air compressors were shut off on September 15. By October 9 the dissolved oxygen content was near saturation in the entire water column. The difference between oxygen concentrations at Stations 2 and 4 was generally less than 1 ppm.

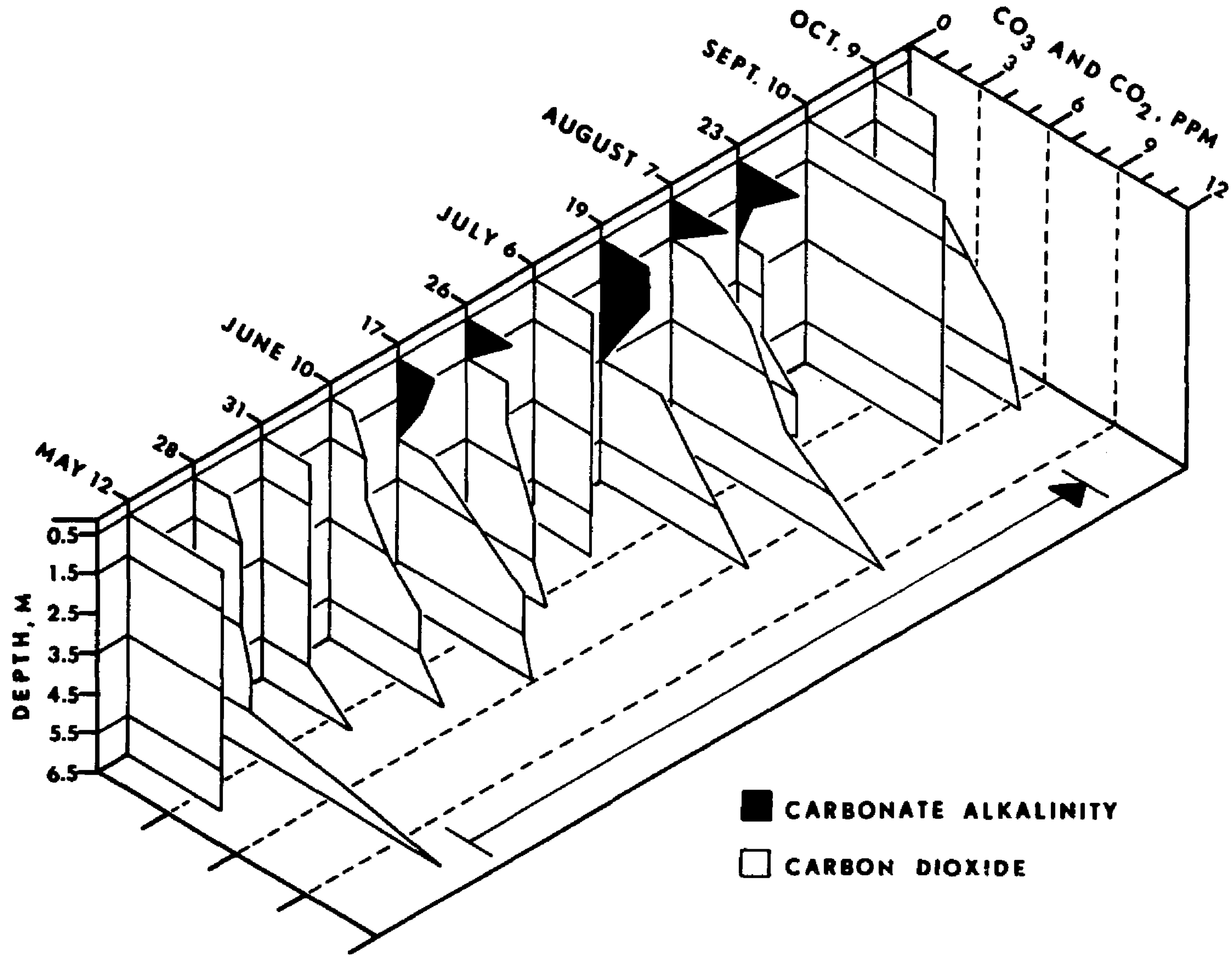
Carbon dioxide, Carbonate alkalinity

The vertical distribution of free carbon dioxide in Kezar Lake during the summer of 1969 is presented in Fig. 11. Carbon dioxide stratification was well established by May 28, the day artificial circulation was started. As in 1968, a reduction of carbon dioxide occurred at lower depths after the lake was mixed. The concentration of carbon dioxide was reduced by 7.0 ppm at 6.5m on May 31, after only 3 days of aeration. During the remainder of the summer and until the air compressors were shut off on September 15 the carbon

Table 14. Depth distribution of dissolved oxygen at Station 2 in Kezar Lake, 1969.

DATE (1969)	DEPTH (M)	PPM	PERCENT SATURATION	DATE (1969)	DEPTH (M)	PPM	PERCENT SATURATION
5/12	0.5	10.3	93	7/15	0.5	8.5	96
	1.5	10.3	93		1.5	8.5	96
	2.5	10.4	93		2.5	8.4	94
	3.5	10.3	93		3.5	7.9	89
	4.5	9.9	88		4.5	7.9	89
	5.5	10.0	89		5.5	7.7	85
	6.5	9.7	86		6.5	6.7	74
5/28	0.5	10.0	100	7/19	0.5	10.4	125
	1.5	10.1	100		1.5	10.3	124
	2.5	10.0	99		2.5	9.5	113
	3.5	9.9	98		3.5	8.0	94
	4.5	9.3	90		4.5	6.7	78
	5.5	8.9	86		5.5	5.9	67
	6.5	2.1	19		6.5	4.1	46
5/31	0.5	9.6	97	8/7	0.5	11.1	130
	1.5	9.4	95		1.5	7.9	91
	2.5	9.6	97		2.5	7.9	90
	3.5	9.4	95		3.5	7.0	80
	4.5	9.6	97		4.5	6.4	73
	5.5	9.5	96		5.5	5.7	64
	6.5	6.4	63		6.5	3.7	41
6/10	0.5	10.0	108	8/23	0.5	10.4	118
	1.5	9.9	106		1.5	8.8	100
	2.5	9.3	99		2.5	8.1	91
	3.5	8.6	92		3.5	8.1	90
	4.5	7.8	83		4.5	8.1	90
	5.5	7.6	80		5.5	7.3	80
	6.5	7.1	75		6.5	7.3	80
6/22	0.5	11.5	127	9/10	0.5	5.0	54
	1.5	9.6	105		1.5	5.0	54
	2.5	8.5	94		2.5	4.9	53
	3.5	8.5	94		3.5	4.8	51
	4.5	8.4	92		4.5	4.8	51
	5.5	8.7	95		5.5	4.9	53
	6.5	8.6	94		6.5	5.0	54
7/6	0.5	7.5	84	10/9	0.5	10.2	98
	1.5	7.5	84		1.5	10.4	99
	2.5	7.5	84		2.5	10.5	99
	3.5	7.5	84		3.5	10.4	98
	4.5	7.4	83		4.5	10.2	96
	5.5	7.5	84		5.5	10.0	94
	6.5	7.4	83		6.5	-	-

Fig. 11. Carbon dioxide and carbonate alkalinity profiles at Station 2 in Kezar Lake, 1969. Arrow indicates period of artificial circulation.



MAY 12
28
31
JUNE 10
17
26
JULY 6
19
AUGUST 7
23
SEPT. 10
OCT. 9
0
3
6
9
12
CO_3 AND CO_2, PPM
DEPTH, M
0.5
1.5
2.5
3.5
4.5
5.5
6.5
CARBONATE ALKALINITY
CARBON DIOXIDE

dioxide concentration in the bottom waters was comparatively low except around August 7, when the carbon dioxide level reached a high of 9.5 ppm. Recall from Table 14 that stratification of dissolved oxygen during the period of aeration was most pronounced also on August 7.

In the euphotic zone complete utilization of carbon dioxide was evident again during phytoplankton blooms even though the air compressors were in operation (Fig. 11). The black areas of Fig. 11 depict times and depths when no carbon dioxide was found. After the bloom of _A. flos-aquae_ had subsided, the distribution of carbon dioxide in the water column was uniform (July 6, Fig. 11). By September 10 the second phytoplankton pulse had dissipated at Kezar Lake and carbon dioxide was present again in surface waters for the first time since July 19.

When the air compressors were shut down on September 15 the carbon dioxide distribution gradually restratified (Fig. 11). Fall turnover eliminated this transitory stratification, and the carbon dioxide distribution was uniform again at 1.5 ppm on October 30. The differences in carbon dioxide concentration between Stations 2 and 4 were usually less than 1.0 ppm.

The detection of carbonate alkalinity in measurable quantities coincided with the absence of carbon dioxide on the dates specified previously (Fig. 11). The differences in carbonate alkalinity between stations 2 and 4 never exceeded 1.0 ppm.

Nutrients

Iron

The vertical distribution of iron is given in Table 3. Comparison of data in this Table shows that lower concentration of iron prevailed during the summer of 1969. The iron content decreased slightly at most depths from May 26 to June 4. It increased markedly after 4 weeks of aeration, and on June 24 varied from a 0.5 meter value of 0.13 to 0.239 milligrams per liter at 6.5 meters. Iron concentrations were lower by July 14 after 7 weeks of artificial circulation, and the similarity in the distribution of iron on this date and on August 21, 1968 (after 5 weeks aeration) is striking. The mean concentrations of iron were 0.057 mg/l and 0.064 mg/l on these dates respectively.

Manganese

Stratification of manganese was absent during 1969 and manganese concentrations varied less perceptibly and were much lower than those of 1968 (Table 3). The mean concentration of manganese changed insignificantly from May 26 to June 4, but the variation at differenct depths was less on the latter date. The depth to depth variation was smaller once more on June 24 but the amount of manganese had approximately doubled. By July 14, however, manganese concentrations of 0.008 to 0.012 mg/l in the water column were the lowest recorded.

Sodium

Early circulation of Kezar Lake in 1969 caused initially a different sodium distribution than in 1968 (compare Tables 4 and 5). Eventually, the sodium content was greater at all depths in 1969, and a 60% increase was observed at 0.5 meters on July 14. Levels of 10.5 - 13.7 mg/l on July 14 are contrasted with the lower concentrations on June 24.

Calcium, potassium and magnesium

Unlike sodium, the concentrations of calcium, potassium and magnesium varied imperceptibly during the analysis period (Table 15). The calcium content was slightly lower in 1969 than in 1968 (Tables 4 and 15). Except for 1.1 mg/l potassium measured at 0.5m on June 4, the concentrations of 0.6 to 0.9 mg/l at other depths and on other dates for both years are comparable. Magnesium concentrations were constant also and evenly dispersed in the water column. The range of magnesium during the analysis period was from 0.7 to 0.83 mg/l with a mean concentration of 0.73 milligrams per liter.

Chloride

In contrast to 1968, the level of chloride slowly increased following artificial circulation of Kezar Lake in 1969 (Table 16). Increases of 2-5 mg/l chloride were evident by June 24, except at 1.5 meters, and by July 14 chloride was evenly dispersed in the water column at 19 or

Table 15. Depth distribution of sodium, calcium, potassium and magnesium at Station 2 in Kezar Lake, 1969. Concentrations are in mg/l.

	BEFORE AERATION				AFTER AERATION											
	MAY 26				JUNE 4				JUNE 24				JULY 14			
DEPTH	Na	Ca	K	Mg	Na	Ca	K	Mg	Na	Ca	K	Mg	Na	Ca	K	Mg
0.5 M	9.2	3.2	-	0.72	8.3	3.1	1.1	0.7	8.7	3.3	0.8	0.73	13.7	3.6	0.8	0.77
1.5 M	10.6	3.5	-	0.72	8.8	3.1	0.7	0.7	8.6	3.2	0.8	0.72	10.8	3.8	0.8	0.77
2.5 M	11.4	3.3	-	0.73	8.8	3.1	0.7	0.7	7.8	3.2	0.8	0.72	12.1	3.8	0.8	0.77
3.5 M	8.8	3.2	-	0.72	8.8	3.1	0.9	0.7	8.0	3.2	0.8	0.72	10.7	3.8	0.8	0.77
4.5 M	10.5	3.5	-	0.73	8.8	3.1	0.6	0.7	9.5	3.3	0.8	0.74	12.7	3.8	0.9	0.79
5.5 M	9.3	3.2	-	0.73	8.2	3.1	0.6	0.7	9.4	3.3	0.8	0.83	12.5	3.8	0.8	0.77
6.5 M	9.5	3.0	-	0.73	8.7	3.0	0.6	0.7	9.5	3.3	0.9	0.77	10.5	3.8	0.8	0.77

Table 16. Depth distributions of copper, silicon dioxide, chloride and zinc at Station 2 in Kezar Lake, 1969. Concentrations are in mg/l.

	BEFORE AERATION				AFTER AERATION											
	MAY 26				JUNE 4				JUNE 24				JULY 14			
DEPTH	Cu	SiO_2	Cl	Zn	Cu	SiO_2	Cl	Zn	Cu	SiO_2	Cl	Zn	Cu	SiO_2	Cl	Zn
0.5 M	0.002	4	15	0.109	0.003	3	16	0.018	0.006	7	19	0.045	0.006	7	20	0.065
1.5 M	0.002	4	17	0.013	0.005	3	16	0.018	0.006	7	14	0.028	0.008	7	19	0.050
2.5 M	0.002	4	16	0.013	0.003	3	17	0.009	0.008	8	19	0.047	0.006	8	19	0.049
3.5 M	0.006	5	16	0.014	0.004	3	16	0.016	0.007	8	19	0.047	0.006	7	20	0.067
4.5 M	0.002	5	15	0.003	0.004	3	16	0.011	0.006	8	19	0.051	0.005	7	20	0.044
5.5 M	0.003	6	16	0.013	0.004	3	17	0.008	0.006	8	20	0.079	0.007	8	19	0.043
6.5 M	0.003	7	15	0.014	0.004	3	15	0.019	0.005	10	20	0.066	0.006	8	20	0.056

20 milligrams per liter.

Silicon

After an initial decrease in concentration, silicon dioxide also increased in Kezar Lake following continued aeration. Table 16 shows that an inverse clinograde distribution of silicon dioxide on May 26 was completely altered after one week of aeration. At this time the silicon dioxide content was diminished but uniform at 3 mg/l. There followed substantial increases and slight restratification of this nutrient by June 24. Silicon dioxide was evenly dispersed once more at 7 or 8 mg/l on July 14.

Copper

Table 16 shows that copper was only marginally influenced by artificial circulation and that it remained uniformly dispersed in the water column during the summer of 1969. Generally, lower concentrations of copper were detected in 1969. After at least four weeks of artificial circulation, however, the range of copper (0.005-0.008 mg/l) and mean concentration (0.006 mg/l) are identical for both 1968 and 1969 (Tables 5 and 16).

Zinc

Similar to 1968, the high concentration of 0.109 mg/l zinc before artificial circulation was detected at 0.5 meters. Unlike 1968, however, the immediate effect of artificial circulation was a decrease of zinc at this depth (Table 16). No significant changes in zinc content occurred at depths below 0.5m from May 26 to June 4. During the next 20 days the mean zinc content rose from 0.014 to 0.052 milligrams per liter. Although depth to depth variations were evident the mean zinc content remained unchanged between June 24 and July 14. Zinc never exhibited stratification following aeration in 1969.

Phosphorus

The depth distributions of orthophosphate and total phosphorus during 1969 are shown in Table 6. The mean concentration of 0.093 mg/l orthophosphate on May 26 was reduced after artificial circulation to 0.057 mg/l by June 4. The downward trend in orthophosphate content continued until June 24 except at 0.5 and 3.5 meters. At 0.5m orthophosphate had increased more than sixfold to 0.304 mg/l; a summer high. This high concentration had diminished considerably by July 14 (Table 6). conversely, at all depths below 0.5m increases in orthophosphate ensued between June 24 and July 14 and the mean content increased from 0.080 to 0.124 mg/l on these dates respectively. The vertical distribution of orthophosphate on the latter date was irregular and 75% of this nutrient was contained in the top half of the water column. As compared to 1968, orthophosphate concentrations were significantly higher during the 1969 analyses period (Table 6).

Total phosphorus concentrations in 1969 were also generally higher (Table 6). The depth distribution of total phosphorus was homogeneous in the water column before and after artificial circulation. Nevertheless, the data indicate a trend toward greater concentrations of total phosphorus from May 26 to June 24. However, reduction of total phosphorus occurred by July 14 at all depths (Table 6).

Nitrogen

Data presented in Table 7 show increasing levels of nitrate nitrogen following aeration of Kezar Lake in 1969. On June 4, after one week aeration, concentration increments were small but the distribution of nitrate nitrogen was less irregular. Between June 4 and July 14 significant increases in nitrate nitrogen content were evident and the mean concentrations on these dates rose from 0.12 to 0.31 mg/l respectively. The content of nitrate nitrogen in Kezar Lake after at least 3 weeks aeration are comparable for both 1968 and 1969 (Table 7).

Contrary to 1968, the levels of nitrite nitrogen diminished immediately following artificial circulation in 1969. Two days before aeration nitrite nitrogen was stratified in the water column at a range of 9 ug/l at 0.5m to 6 ug/l at 6.5 meters. These levels dropped after 7 days aeration to 1 - 2 ug/l evenly distributed at each depth. The mean nitrite nitrogen concentration remained unchanged until July 14. On the latter date nitrite nitrogen levels varied from 3 to 7 ug/l, which are comparable to 1968 levels after 3 to 5 weeks of artificial circulation.

Depletion of ammonia nitrogen was evident immediately following aeration in 1969 (Table 7). However, after continued aeration, ammonia nitrogen increased to between 0.053 and 0.090 mg/l on July 14. In contrast to 1968, stratification of ammonia nitrogen was absent, and concentrations were subsequently much lower throughout the summer of 1969 (Table 7).

Table 7 shows also the depth distribution of organic nitrogen. Initially there occurred a reduction of organic nitrogen at all depths subsequent to artificial circulation. The lower concentrations recorded for June 4 were still distributed unevenly, and the tendency of higher concentrations at 6.5m remained unaltered as of June 24 even though the organic nitrogen content had redoubled. On the latter date concentrations of 0.816 to 0.913 mg/l were recorded; they were comparable to those recorded on August 7, 1968 (Table 7). Both dates follow 27 and 23 days respectively after initiation of artificial circulation. By July 14, 1969 the distribution of organic nitrogen was erratic, the result of large concentration losses at 0.5 and 6.5 meters.

Phytoplankton

The succession of phytoplankton during the summer of 1969 was similar to that described for 1968. The dominant alga as summer progressed was again A. flos-aquae even though

Table 17. Vertical distribution and abundance ($1x10^3$ cells/ml) of Aphanizomenon flos-aquae at Station 2 in Kezar Lake, 1969.

DEPTH (M)	MAY					JUNE						JULY
	2	12	18	26	29	4	10	17	22	26	30	6
0.5	0.00	0.06	0.04	0.56	0.55	4.50	15.50	121.10	241.40	266.90	309.70	70.20
1.5	0.00	0.01	0.19	0.52	0.14	5.90	15.70	142.00	280.60	248.50	230.00	71.90
2.5	0.03	0.02	0.13	0.45	0.33	5.40	19.30	144.20	322.60	235.90	248.20	77.70
3.5	0.00	0.03	0.13	0.20	0.34	4.30	17.90	110.80	247.10	223.20	289.50	83.10
4.5	0.06	0.02	0.03	0.29	0.29	3.60	12.90	94.40	276.00	204.00	166.70	65.60
5.5	0.04	0.01	0.06	0.18	0.36	3.10	10.10	96.80	272.10	200.00	74.50	71.10

DEPTH (M)	JULY				AUGUST					SEPT.		OCT.
	15	19	23	31	7	12	18	23	27	10	20	9
0.5	9.60	18.60	29.10	15.90	31.00	25.60	44.30	23.50	24.60	1.60	0.17	0.00
1.5	8.60	23.50	24.00	14.10	26.00	26.30	33.80	19.00	17.60	1.60	0.33	0.00
2.5	10.00	18.90	21.00	11.10	20.40	27.20	40.60	20.30	21.20	1.10	0.36	0.02
3.5	8.20	19.50	18.60	11.10	12.70	23.80	23.40	21.30	28.10	1.20	0.44	0.00
4.5	8.70	19.00	16.00	5.60	10.30	16.90	22.20	22.70	26.60	2.00	0.13	0.00
5.5	9.50	16.40	20.40	6.20	5.70	20.20	27.50	21.30	24.50	1.40	0.06	0.00

artificial circulation was started on May 28, 1969. Table 17 shows that less than 600 cells/ml A. flos-aquae were present at any depth when aeration was started. However, logarithmic growth of this species was evident as early as June 4 and prevailed during that month. Because the lake was being mixed by artificial circulation growth of A. flos-aquae proceeded uniformly at all depths.

By late June A. flos-aquae was the dominant alga and was responsible for 98% of the phytoplankton standing crop (as percent of total cells per milliliter). During this period A. flos-aquae attained a maximum of 322.60×10^3 cells per milliliter. The abundance and distribution of this species during late June, 1969 (Table 17) is similar to that shown for July, 1968 (Table 9) following circulation of Kezar Lake. It is noted also in Table 21 that a trend toward stratification of A. flos-aquae appeared between June 26 and June 30. However, 3 of 4 air compressors were operating on June 26 and by June 30 only 2 air compressors were in operation.

The bloom of A. flos-aquae dissipated abruptly and by July 15 counts diminished to 10.00×10^3 cells/ml or less. Four days later the counts of this species had redoubled and through late July and August A. flos-aquae was sustained at 10.30 to 44.30×10^3 cells/ml. On July 31 and August 7 stratification of A.flos-aquae was evident again and quantitative counts were lower in bottom waters. However, on both these sample dates only 2 of 4 air compressors were in operation. Aphanizomenon flos-aquae gradually disappeared from phytoplankton samples during September (Table 17) and no cells were detected on October 30. The abundance and distribution of A. flos-aquae at Station 4 was identical to that described for Station 2.

The bloom of A. flos-aquae during June, 1969 influenced the chemical and physical conditions of Kezar Lake as in 1968. The enormous number of filaments in the water column was responsible for: (a) decreased transparency (Fig. 9); (b) high dissolved oxygen concentrations in surface waters (Table 14); and (c) loss of free carbon dioxide and detection of carbonate alkalinity in surface waters (Fig. 11). All of these conditions were ameliorated by July 6 during the terminal phase of the bloom.

Early aeration of Kezar Lake in 1969 precluded using general algal categories that facilitated a discussion of phytoplankton other than A. flos-aquae collected in 1968. Nevertheless, a few species appeared briefly in the spring, many species were common throughout the summer, and still other phytoplankters appeared in samples later in the summer.

Phytoplankton common in spring samples

Of the algal species that appeared primarily in samples collected in the spring Dinobryon bavaricum was the most numerous. This alga occurred in samples during the period May 18 through June 10 and it reached a peak of 1.16 x 10^3 cells per milliliter. Dinobryon cylindricum occurred in phytoplankton samples during the same time interval, but it numbered only 190 cells/ml at its population peak.

Among the diatoms, Asterionella formosa was most prominent but this species was far less numerous than described for the spring of 1968. Asterionella formosa was only common (10-250 cells/ml) during May and June; it reappeared in autumn samples and by October 30 this diatom was counted at 30-230 cells/ml. Melosira ambigua was present from May 18 through July 15, and similar to A. formosa, it was encountered again later in the season. Synedra rumpens was common at 10-100 cells/ml from May 2 until June 10, but it was observed thereafter only sparingly. Another diatom, Cyclotella comta was rarely encountered in Kezar Lake samples except during the brief interval of May 12 through June 4.

Other algae that were common in spring waters included Anabaena flos-aquae, Mallamonas Fresenii, Ankistrodesmus falcatus var. acicularis, Chlamydomonas spp., Gonium sociale and Ophiocytium capitatum var. longispinum. The filamentous blue-green Anabaena flos-aquae was observed first on May 29, and it reached maximum numbers of $1.29\text{-}6.43 \times 10^3$ cells/ml in the top 4 meters of water on June 10. Thereafter, Anabaena flos-aquae became less abundant and this alga was not found in any samples after June 26. Mallomonas Fresenii was most numerous (130-350 cells/ml) on May 12, but subsequently it was counted at 50 cells/ml or less until June 10. Mallomonas Fresenii was rare throughout the summer but it reappeared in October samples. Ankistrodesmus falcatus var. acicularis peaked at 160-220 cells/ml in the surface waters on May 2 and then disappeared after June 4.

Another green alga, Chlamydomonas spp., attained maximum counts (80-250 cells/ml) on May 12, but it rarely exceeded the minimum value thereafter. Chlamydomonas spp. was scant after July 15. Gonium sociale was present in samples collected from May 12 to July 6 but it was absent on all other sampling dates. The last alga that occurred primarily in the spring at Kezar Lake is Ophiocytium capitatum var. longispinum. This phytoplankter was present from May 26 until June 17, but at 10-60 cells/ml it was not abundant.

Phytoplankton common throughout the summer

Tables 18 and 19 show the abundance and distribution of representative phytoplankton exclusive of A. flos-aquae. Of these, Dictyosphaerium pulchellum was the most numerous species. Dictyosphaerium pulchellum flourished in the spring and it was the dominant alga during May (Table 18), with a peak population of 100.71 x 10^3 cells/ml on May 29. The decreased abundance of D. pulchellum during June was coincident with the growth of A. flos-aquae (Tables 17 and 18). Thus, a renewed abundance of D. pulchellum occurred during July after the bloom of A. flos-aquae. The second and smaller peak abundance of D. pulchellum was observed between July 15 and July 31. Thereafter D. pulchellum was

Table 18. Vertical distribution and abundance ($1x10^3$ cells/ml) of five common species of phytoplankton at Station 2 in Kezar Lake, 1969.

	DEPTH											DATE (1969)											
	(M)	5/2	5/12	5/18	5/26	5/29	6/4	6/10	6/17	6/26	7/6	7/15	7/23	7/31	8/7	8/12	8/18	8/27	9/10	9/20	10/9	10/30
	0.5	0.36	0.75	7.05	41.23	61.04	8.09	14.70	5.25	0.95	0.99	6.51	13.13	5.39	2.21	1.50	1.89	4.30	1.65	2.11	5.91	0.72
	1.5	0.53	3.26	7.15	63.28	-	70.82	37.27	0.54	0.74	0.63	7.75	13.04	15.54	1.68	3.54	2.32	1.62	1.84	1.38	1.86	0.54
Dictyosphaerium	2.5	0.29	2.61	12.68	45.08	74.47	65.00	34.19	4.08	1.00	1.05	7.59	16.60	14.87	0.66	2.46	1.12	2.94	1.52	2.15	3.58	1.16
pulchellum	3.5	0.33	0.76	7.49	48.20	100.71	73.84	28.77	1.17	1.14	1.33	6.59	11.48	11.43	1.72	3.37	3.44	1.48	1.47	1.47	3.04	0.60
	4.5	0.31	2.67	6.27	39.69	69.69	68.55	31.33	4.52	0.87	1.24	7.08	14.02	24.92	1.64	1.62	2.44	3.37	1.24	1.81	1.24	0.58
	5.5	0.21	2.97	6.36	28.29	71.95	67.36	29.52	3.50	0.60	1.18	6.37	13.10	21.29	1.74	1.44	2.58	1.65	1.56	1.00	3.76	1.57
	0.5	0.01	0.05	0.11	0.28	0.51	0.26	0.25	0.18	0.22	0.29	0.53	0.60	0.14	0.66	0.50	0.15	0.45	0.16	0.07	0.98	4.66
Ankistrodesmus	1.5	0.01	0.03	0.12	0.37	0.36	0.51	0.27	0.02	0.15	0.33	0.59	0.50	0.24	0.49	0.50	0.15	0.34	0.15	0.05	0.47	4.78
falcatus var.	2.5	0.00	0.03	0.06	0.54	0.44	0.41	0.28	0.15	0.14	0.31	0.63	0.59	0.41	0.35	0.56	0.24	0.43	0.19	0.05	0.74	4.75
mirabilis	3.5	0.00	0.02	0.08	0.34	0.47	0.43	0.11	0.05	0.18	0.41	0.67	0.36	0.24	0.36	0.50	0.25	0.36	0.17	0.06	0.62	4.52
	4.5	0.00	0.05	0.05	0.34	0.57	0.36	0.25	0.13	0.20	0.32	0.62	0.50	0.18	0.35	0.42	0.20	0.34	0.17	0.06	0.61	4.45
	5.5	0.01	0.03	0.05	0.21	0.37	0.60	0.29	0.12	0.19	0.31	0.67	0.74	0.14	0.38	0.39	0.20	0.46	0.16	0.06	0.66	4.68
	0.5	0.00	0.00	0.12	0.36	0.17	0.12	0.00	0.00	0.10	0.18	0.32	0.63	0.28	0.56	0.28	0.69	0.52	0.02	0.00	0.02	0.01
	1.5	0.00	0.00	0.20	0.18	0.12	0.04	0.04	0.04	0.04	0.04	0.17	1.11	0.57	0.77	0.22	0.21	0.48	0.02	0.03	0.00	0.00
Scenedesmus	2.5	0.00	0.00	0.08	0.16	0.08	0.08	0.00	0.00	0.04	0.20	0.28	0.70	0.50	0.64	0.83	0.53	0.14	0.05	0.00	0.06	0.00
dimorphus	3.5	0.00	0.00	0.12	0.24	0.24	0.22	0.04	0.04	0.08	0.16	0.56	0.74	0.78	0.74	0.87	0.38	0.10	0.03	0.02	0.11	0.00
	4.5	0.00	0.04	0.00	0.12	0.12	0.06	0.05	0.00	0.12	0.06	0.45	0.73	0.55	0.62	0.70	0.63	0.27	0.09	0.02	0.03	0.02
	5.5	0.00	0.00	0.00	0.20	0.16	0.11	0.00	0.04	0.00	0.04	0.39	0.62	0.43	0.56	0.56	0.74	0.53	0.05	0.01	0.07	0.02
	0.5	0.01	1.65	1.91	0.26	0.14	0.02	0.03	0.08	0.74	0.69	7.91	2.25	0.66	0.20	0.53	0.28	0.34	0.31	0.58	1.13	1.76
Rhodomonas	1.5	0.03	1.65	2.69	0.20	0.03	0.04	0.06	0.11	0.07	0.68	7.97	0.80	1.33	0.53	0.56	0.32	0.28	0.28	0.60	0.32	2.22
minuta var.	2.5	0.00	1.67	2.36	0.32	0.03	0.07	0.11	0.20	0.07	0.74	6.96	0.14	1.01	0.06	0.24	0.20	0.29	0.35	0.52	0.49	1.92
nannoplanctica	3.5	0.01	1.33	2.23	0.18	0.10	0.13	0.11	0.01	0.02	0.83	7.48	0.15	0.66	0.00	0.35	0.22	0.32	0.36	0.27	0.29	1.74
	4.5	0.00	1.91	0.58	0.42	0.11	0.07	0.01	0.01	0.05	0.65	4.19	0.15	0.01	0.00	0.03	0.07	0.21	0.35	0.12	0.03	2.26
	5.5	0.00	0.90	0.69	0.40	0.08	0.08	0.02	0.00	0.02	0.50	1.55	0.48	0.01	0.03	0.03	0.01	0.11	0.28	0.08	0.35	2.36
	0.5	0.01	1.38	1.11	0.46	0.07	0.01	0.06	0.00	0.07	0.06	0.21	0.45	0.27	0.18	0.32	0.50	0.07	0.77	0.85	0.20	0.12
	1.5	0.15	1.72	1.39	0.35	0.09	0.03	0.05	0.05	0.03	0.03	0.20	1.64	0.85	3.11	0.74	0.31	0.08	0.82	3.96	0.15	0.10
Cryptomonas	2.5	0.09	1.43	1.37	0.28	0.11	0.02	0.10	0.05	0.03	0.08	0.22	0.83	0.62	0.32	0.49	0.42	0.03	0.85	3.88	0.15	0.12
Marssonii	3.5	0.03	1.72	1.60	0.18	0.09	0.07	0.06	0.03	0.02	0.06	0.18	0.70	0.59	0.08	0.21	0.34	0.08	0.80	2.52	0.12	0.05
	4.5	0.00	1.32	0.69	0.52	0.26	0.13	0.01	0.01	0.03	0.10	0.31	0.57	0.01	0.04	0.07	0.24	0.08	0.81	1.55	0.00	0.10
	5.5	0.00	1.73	0.72	1.12	0.72	0.13	0.06	0.02	0.08	0.09	0.13	0.81	0.08	0.10	0.35	0.21	0.04	0.91	0.97	0.15	0.13

Table 19. Vertical distribution and abundance (1×10^3 cells/ml) of five common species of phytoplankton at Station 2 in Kezar Lake, 1969.

	DEPTH (M)	5/2	5/12	5/18	5/26	5/29	6/4	6/10	6/17	6/26	7/6	DATE (1969) 7/15	7/23	7/31	8/7	8/12	8/18	8/27	9/10	9/20	10/9	10/30
	0.5	0.00	0.00	0.01	0.16	0.25	0.08	0.01	0.00	0.12	0.90	4.98	18.52	11.52	29.13	18.17	14.59	18.44	0.16	0.06	0.02	0.01
	1.5	0.00	0.00	0.06	0.25	0.10	0.00	0.06	0.04	0.17	0.52	6.31	18.77	45.64	29.25	17.60	17.39	18.72	0.16	0.16	0.03	0.00
Tetrallantos lagerheimii	2.5	0.00	0.01	0.09	0.36	0.22	0.06	0.05	0.00	0.40	0.43	3.94	23.63	43.27	16.93	19.96	15.61	20.10	0.17	0.09	0.02	0.00
	3.5	0.00	0.00	0.06	0.11	0.20	0.01	0.34	0.00	0.29	0.36	3.53	17.04	42.06	30.70	19.12	16.35	21.52	0.14	0.09	0.02	0.00
	4.5	0.00	0.00	0.00	0.16	0.29	0.14	0.08	0.12	0.23	0.78	4.33	19.22	34.47	29.13	18.27	15.22	21.28	0.19	0.06	0.01	0.00
	5.5	0.00	0.01	0.03	0.01	0.22	0.22	0.46	0.00	0.20	0.49	4.52	21.17	38.67	18.73	18.87	16.20	19.88	0.20	0.06	0.01	0.00
	0.5	0.01	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.05	1.39	2.34	10.36	27.12	41.22	35.81	0.99	0.46	0.47	0.00
	1.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.64	3.32	14.60	34.03	39.13	39.21	1.83	0.06	0.07	0.00
Ulothrix subconstricta	2.5	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	1.72	2.58	12.82	36.83	63.10	27.23	1.42	0.32	0.16	0.00
	3.5	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.40	3.35	12.14	36.82	63.25	32.31	0.88	0.52	0.08	0.00
	4.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.64	5.15	8.15	27.73	67.86	33.00	1.64	0.14	0.05	0.00
	5.5	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.04	5.74	11.54	34.99	62.36	35.97	1.39	0.10	0.24	0.00
	0.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.45	1.05	0.20	0.67	1.71	2.84	0.80	0.02	0.01	0.02	0.02
	1.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.17	1.92	1.48	1.08	1.69	1.95	0.88	0.04	0.03	0.02	0.00
Scenedesmus arcuatus	2.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.04	0.20	1.99	1.01	0.21	1.30	2.13	0.64	0.06	0.04	0.06	0.00
	3.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.31	1.40	1.26	0.97	2.18	3.70	0.76	0.03	0.01	0.10	0.00
	4.5	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.08	0.11	0.78	0.71	1.34	1.93	2.30	0.48	0.05	0.05	0.07	0.01
	5.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.06	0.24	1.78	1.20	0.92	1.43	2.10	0.77	0.02	0.02	0.08	0.02
	0.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	1.18	0.00	0.80	0.29	0.01	0.36	0.02	0.05	0.80	0.03
	1.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.95	0.67	0.45	0.83	0.46	0.36	0.00	0.06	0.44	0.09
Scenedesmus arcuatus var. platydisca	2.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	1.26	1.02	0.11	0.22	0.34	0.34	0.03	0.10	0.48	0.12
	3.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	1.06	0.70	1.05	0.38	0.22	0.11	0.05	0.08	0.51	0.01
	4.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.88	0.71	0.97	0.69	0.43	0.00	0.02	0.02	0.28	0.02
	5.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	1.12	0.64	0.46	0.64	0.56	0.18	0.06	0.03	0.47	0.07
	0.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.17	4.35	0.33	0.00	0.00	0.00
	1.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.73	1.79	4.56	0.08	0.05	0.00	0.00
Oscillatoria sp.	2.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.44	1.06	5.60	0.25	0.00	0.00	0.00
	3.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.73	1.40	4.45	0.01	0.00	0.00	0.00
	4.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.07	0.81	4.76	0.54	0.14	0.00	0.00
	5.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.31	0.99	4.45	0.08	0.00	0.23	0.00

sustained primarily at 1.00 to 3.60 x 10^3 cells/ml.

Table 19 presents the distribution of Tetrallantos Lagerheimii during the summer of 1969. During late June and July T. Lagerheimii grew vigorously to a peak of 45.64 x 10^3 cells/ml on July 31. Tetrallantos Lagerheimii was abundant during August, but it disappeared gradually during September and October. Another green alga, Ulothrix subconstricta, was abundant also during August. Unlike D. pulchellum and T. Lagerheimii, however, U. subconstricta was scant prior to July 23. Table 19 shows the growth of U. subconstricta, with a maximum population on August 18. Cell counts of U. subconstricta were lower at most depths by August 27, but it remained the most numerous species during the last half of that month. The abundance of U. subconstricta was substantially reduced by September 10, and this species gradually disappeared from phytoplankton samples.

Ankistrodesmus falcatus var. mirabilis was a very common species at Kezar Lake and it was observed in every sample collected after May 12. Table 18 shows that A. falcatus var. mirabilis was present in varying numbers throughout the summer, and that by October 30 it was the dominant alga in Kezar Lake.

Chlorella vulgaris was a common phytoplankter also throughout the summer. After a peak abundance (336-574 cells/ml) on July 15, C. vulgaris remained at 100-300 cells/ml until September 20. Numbers of Nephrocytium Agardhianum fluctuated up and down during the summer, but this alga was common until September 20, varying usually between 100-800 cells/ml. Both C. vulgaris and N. Agardhianum gradually disappeared beyond the latter date. The frequency and distribution of the colonial green alga, Sphaerocystis Schroeteri, resem - bled that of N. Agardhianum. However, during June S. Schroeteri was rare.

Three species of Scenedesmus were observed frequently throughout the summer of 1969. The distribution and abundance of S. dimorphus is presented in Table 18. The frequency and distribution of Scenedesmus bicaudatus and Scenedesmus quadricaudata var. longispina duplicate very closely the data shown for S. dimorphus. Unlike S. dimorphus, the abundance of the other two species of Scenedesmus remained high at 100-225 cells/ml on September 10. S. bicaudatus was numerous also on October 9.

Another common species, Scenedesmus serratus forma minor, reached a peak of 100-400 cells/ml during July, but it was less abundant at other times. Scenedesmus abundans var. asymmetrica was scant until June 26, but it was numerous (100-300 cells/ml) during most of July. Scenedesmus abundans var. asymmetrica was less abundant during August and it was encountered sparingly after September 10.

Several pigmented flagellates were widespread and often important contributers to the phytoplankton standing crop. Table 18 presents the distribution of the smallest but most numerous species, Rhodomonas minuta var. nannoplanctica. Peak populations of R. minuta var. nannoplanctica occurred during mid-May, mid-July and late in October. Table 18 shows also the abundance and distribution of *Cryptomonas Marssonii*. *Cryptomonas Marssonii* also reached a peak in mid-May too and it exhibited stratification of cell numbers at that time. Similar to *R. minuta* var. *nannoplanctica*, *C. Marssonii* was more abundant by mid-July and it tended to accumulate in surface waters. In the fall *C. Marssonii* flourished earlier than *R. minuta* var. *nanno-planctica*, and it reached a maximum population on September 20 (Table 18).

Three other pigmented flagellates were of common occurrence throughout the summer of 1969. Though less abundant the distributions of *Cryptomonas erosa*, *Cryptomonas ovata* and *Glenodinium* sp. were all similar. Between May 2 and June 26 all three species were usually counted at 10-50 cells/ml. Counts increased during July (10-250 cells/ml) for all three flagellates, but *C. erosa* and *C. ovata* were the most numerous. Similar to *C. Marssonii* discussed previously, *C. erosa* and *C. ovata* were most frequently observed during September, but these two phytoplankters were uncommon during October. *Glenodinium* sp. was scant in samples collected after August 27.

There are four species whose occurrence in phytoplankton samples was documented throughout the summer months but whose abundance was comparatively low. Two diatoms, *Nitzschia acicularis* and *Synedra radians*, were counted at 10-50 cells/ml from May to October although occasional increments to 90 cells/ml were observed. The desmid *Cosmarium bioculatum* was common from May 12 to August 12 varying between 10-50 cells/ml. *C. bioculatum* was not observed after the latter date. *Treubaria setigerum* was found sparingly from late May through mid-June, but it was missing thereafter until July 23. During the interval July 23 to August 27 *T. setigerum* was common at 15-60 cells per milliliter. *T. setigerum* was rare in algal samples collected during September and was absent entirely from October samples.

Phytoplankton common in late summer

In addition to *U. subconstricta* discussed previously, several other chlorophycean species were important contributers tothe standing crop of phytoplankton subsequent to the bloom of *A. flos-aquae*. Table 19 shows the abundance and distribution of two of these phytoplankters, *Scenedesmus arcuatus* and *Scenedesmus arcuatus* var. *platydisca*. Prior to July *S. arcuatus* was observed only in three samples. Subsequently, *S. arcuatus* became more numerous and attained counts of 0.78 - 1.99 x 10^3 cells/ml on July 23. Depth to depth fluctuations were evident until August 12 when the distribution of *S. arcuatus* in the water column was more homogeneous. *Scenedesmus arcuatus* reached a population peak on August 18 (Table 19) and then gradually disappeared.

Table 19 shows also the frequency and distribution of *S. arcuatus* var. *platydisca*. This phytoplankter was not encountered until July 15, but its abundance during the remainder of that month and early August approximates closely that of the nominal species, *S. arcuatus*. However, throughout the remainder of August *S. arcuatus* var. *platydisca* was less numerous, and it varied mostly between 100–800 cells per milliliter.

Other green algae not shown in my tables but which were present in phytoplankton samples in varying numbers during mid- and late summer include the following: *Selenastrum Westii*, *Coelastrum microporum*, *Dictyosphaerium Ehrenberghianum*, *Hormidium* sp., *Staurodesmus connatus*, *Kirchneriella contorta*, *Kirchneriella obesa*, *Ankistrodesmus falcatus*, *Ankistrodesmus falcatus* var. *tumidis*, *Elakatothrix viridis*, *Scenedesmus* sp., *Scenedesmus Bernardii*, *Scenedesmus denticulatus*, *Golenkenia radiata*, *Oocystis Borgei*, *Oocystis parva*, and *Closterium gracile*.

Two species of Cyanophyceae were not present in algal samples until late summer. Unlike its abundance and distribution during 1968 *Oscillatoria* sp. was common only during the interval from August 12 through September 10 (Table 19). Counts of *Oscillatoria* sp. increased gradually during this period and they reached a peak on August 27. *Oscillatoria* sp. diminished by September 10 and thereafter disappeared. The colonial blue-green *Aphanocapsa delicatissima* was absent before July 31, and it was common only from mid- to late August. During this brief span *A. delicatissima* was counted frequently at 20-200 small colonies/ml (20–40 u diameter).

Aphanocapsa delicatissima was sparse during September and October.

The non-pigmented flagellates *Cyathomonas truncata* and *Peranema trichophorum* were encountered in varying numbers throughout the summer of 1969. There remains 37 additional species of phytoplankton that were enumerated during 1969. These species were rare and many were observed from only one sample. All of these uncommon species contributed little to the standing crop of phytoplankton, and they will not be discussed. These phytoplankters are indicated in Table 8 by a double asterisk.

Total phytoplankton

Figure 12 summarizes the major successional changes in phytoplankton standing crop during the summer of 1969. In late May the green algae (Chlorophyceae) predominated due to the large population of *Dictyosphaerium pulchellum*. After the start of artificial circulation on May 28 there occurred a precipitous decline in the green algae from 97% of the standing crop of phytoplankton to a summer minimum of only 1% on June 26. Coincident with the decline of the chlorophycean species was an increase in the blue-green algae (Cyanophyceae), composed almost entirely of *Aphanizomenon flos-aquae*. Thus, between late May and late June the algal populations shifted from a green to a predominantly blue-green composition.

When *A. flos-aquae* decreased during early July many chlorophycean species replaced it. However, throughout late July and August an equilibrium was formed between blue-green and green algal populations (Fig. 12). In September and early October the blue-green algal populations declined and consequently the green algae prevailed in Kezar Lake during this time. Fig. 12 shows also that algae other than Cyanophyceae or Chlorophyceae attained brief population peaks only when the dominance of the blue-green and green algal populations were in transition. However, late in the sampling season these other algae accounted for 15 to 27% of the total standing crop of phytoplankton.

Chlorophyll - a

The depth distribution of chlorophyll-a in Kezar Lake during the summer of 1969 is presented in Table 20. At Station 2 little change occurred in chlorophyll-a concentration between May 12 and June 4. The amount of chlorophyll-a redoubled by June 10, and concurrent with the bloom of *A. flos-aquae* increased nearly tenfold by late June. The concentration of chlorophyll-a was 70.32 - 77.29 mg/m^3 on June 22; the values correlated with the spatial distribution of *A. flos-aquae* on that date (Table 17).

Chlorophyll-a values dropped during the first 3 weeks of July but they rose again by July 31 (Table 20). A bloom of predominantly green algae mentioned previously caused the rise. The maximum concentration of chlorophyll-a recorded during this bloom was 64.54 mg/m^3 on July 31, but during the

Fig. 12. Major successional changes in the phytoplankton standing crop at Station 2 following artificial circulation of Kezar Lake on May 28, 1969.

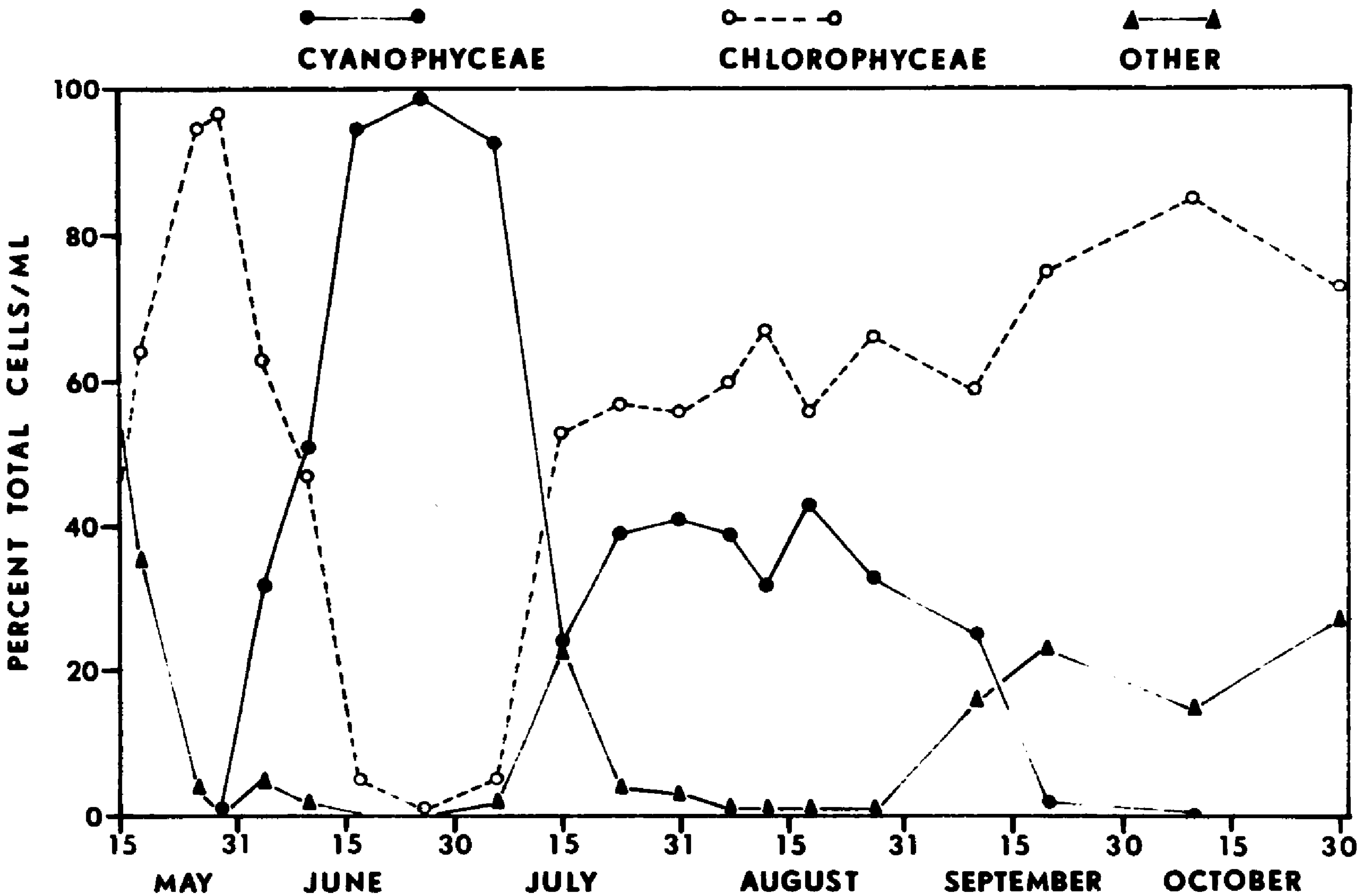

CYANOPHYCEAE
CHLOROPHYCEAE
OTHER
PERCENT TOTAL CELLS/ML
100
80
60
40
20
0
15
31
15
30
15
31
15
31
15
30
15
30
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER

Table 20. Depth distribution of chlorophyll-a, pheopigments, and the ratio of absorbance of chlorophyll-a before and after acidification at Station 2 in Kezar Lake, 1969.

DATE (1969)	DEPTH (M)	CHLOROPHYLL-A MG/M^3	PHEO-PIGMENTS MG/M^3	RATIO $665_o:665_a$
5/12	0.5	8.46	3.95	1.4
	1.5	6.75	3.84	1.4
	2.5	7.35	3.55	1.4
	3.5	8.10	2.91	1.5
	4.5	7.96	3.40	1.4
	5.5	6.72	3.55	1.4
5/26	0.5	6.48	8.56	1.1
	1.5	6.25	8.49	1.1
	2.5	6.34	8.32	1.1
	3.5	6.70	8.92	1.1
	4.5	7.41	9.24	1.1
	5.5	8.20	7.95	1.2
5/29	0.5	6.04	7.26	1.1
	1.5	5.84	7.78	1.1
	2.5	5.97	7.14	1.1
	3.5	6.12	6.80	1.2
	4.5	7.27	8.13	1.2
	5.5	8.64	7.79	1.2
6/4	0.5	7.06	6.15	1.3
	1.5	7.57	6.32	1.3
	2.5	7.57	7.78	1.2
	3.5	7.92	6.19	1.3
	4.5	8.31	6.79	1.3
	5.5	7.92	8.37	1.2
6/10	0.5	17.44	16.23	1.2
	1.5	17.46	14.80	1.3
	2.5	17.63	15.82	1.2
	3.5	17.97	17.88	1.2
	4.5	16.14	21.43	1.1
	5.5	16.17	16.34	1.2
6/17	0.5	49.30	3.93	1.6
	1.5	50.72	5.10	1.6
	2.5	53.88	14.18	1.5
	3.5	45.16	11.15	1.5
	4.5	37.20	5.25	1.6
	5.5	36.85	6.11	1.6
6/22	0.5	76.07	11.02	1.6
	1.5	77.29	10.64	1.6
	2.5	76.10	8.54	1.6
	3.5	72.60	7.22	1.6
	4.5	70.32	13.07	1.6
	5.5	73.75	13.67	1.6
6/26	0.5	72.17	9.53	1.6
	1.5	66.05	6.62	1.6
	2.5	68.38	6.89	1.6
	3.5	67.70	5.25	1.6
	4.5	70.63	10.77	1.6
	5.5	63.68	7.82	1.6
6/30	0.5	62.85	15.77	1.5
	1.5	57.54	13.58	1.5
	2.5	52.83	14.23	1.5
	3.5	47.95	9.95	1.6
	4.5	42.87	18.42	1.4
	5.5	31.20	16.59	1.4
7/6	0.5	24.93	5.49	1.6
	1.5	27.09	5.01	1.6
	2.5	28.99	6.09	1.6
	3.5	27.64	6.55	1.5
	4.5	28.10	7.56	1.5
	5.5	29.11	6.91	1.5
7/15	0.5	31.48	17.62	1.4
	1.5	34.28	16.77	1.4
	2.5	35.23	18.56	1.4
	3.5	33.96	18.43	1.4
	4.5	32.05	16.37	1.4
	5.5	30.32	16.00	1.4
7/19	0.5	25.84	12.34	1.4
	1.5	27.68	14.08	1.4
	2.5	26.91	13.96	1.4
	3.5	34.39	16.23	1.4
	4.5	31.55	15.35	1.4
	5.5	27.94	14.92	1.4
7/31	0.5	56.30	-	-
	1.5	64.54	32.91	1.4
	2.5	61.60	46.49	1.3
	3.5	46.86	32.50	1.3
	4.5	42.68	37.21	1.3
	5.5	47.47	35.93	1.3
8/7	0.5	46.78	31.35	1.3
	1.5	60.96	41.49	1.3
	2.5	54.81	34.22	1.4
	3.5	50.65	33.57	1.3
	4.5	49.35	38.02	1.3
	5.5	37.21	27.54	1.3
8/12	0.5	50.06	23.65	1.4
	1.5	48.30	27.63	1.4
	2.5	56.35	36.31	1.3
	3.5	46.41	29.00	1.4
	4.5	43.77	33.23	1.3
	5.5	41.91	28.48	1.3
8/18	0.5	47.13	18.99	1.5
	1.5	48.01	21.94	1.4
	2.5	45.40	23.27	1.4
	3.5	41.99	23.39	1.4
	4.5	47.85	23.82	1.4
	5.5	43.74	21.30	1.4
8/23	0.5	43.51	17.36	1.5
	1.5	43.92	23.05	1.4
	2.5	46.84	24.51	1.4
	3.5	47.95	24.85	1.4
	4.5	44.39	22.50	1.4
	5.5	41.03	24.81	1.4
8/27	0.5	45.86	35.37	1.3
	1.5	45.72	24.16	1.4
	2.5	44.35	31.95	1.3
	3.5	47.84	34.30	1.3
	4.5	45.04	33.15	1.3
	5.5	41.46	30.79	1.3
9/10	0.5	8.23	5.83	1.3
	1.5	8.41	7.30	1.2
	2.5	8.56	6.81	1.3
	3.5	8.62	6.93	1.3
	4.5	8.37	6.51	1.3
	5.5	8.01	6.06	1.3
9/20	0.5	6.33	5.36	1.3
	1.5	17.93	12.14	1.3
	2.5	17.39	8.19	1.4
	3.5	12.21	8.73	1.3
	4.5	8.27	5.40	1.3
	5.5	5.86	4.58	1.3
10/9	0.5	17.54	11.16	1.3
	1.5	18.37	8.47	1.4
	2.5	18.64	11.86	1.3
	3.5	13.83	7.76	1.4
	4.5	12.36	7.34	1.4
	5.5	9.38	8.48	1.2
10/30	0.5	4.92	2.82	1.4
	1.5	4.84	2.85	1.4
	2.5	4.88	3.20	1.3
	3.5	4.87	2.76	1.4
	4.5	4.92	2.97	1.4
	5.5	4.79	2.79	1.4

entire month of August most concentrations ranged from 40-50 mg/m^3 chlorophyll-a. The relatively uniform distribution and concentration of chlorophyll-a during August correlates with the stability in the phytoplankton composition (Fig. 12).

By September 10 the previously large phytoplankton populations were reduced substantially and this is reflected in a five-fold decrease in chlorophyll-a (Table 20). After the discontinuation of artifical circulation on September 15, chlorophyll-a increments were evident at 1.5 to 3.5 meters on September 20 and at all depths by October 9. The distribution of chlorophyll-a was uniform again at 4.79-4.92 mg/m^3 on October 30, which were the lowest values recorded during the summer of 1969.

Table 20 includes also the amount of chlorophyll-a degraded to pheo-pigments. Since pheo-pigments absorb light in the red portion of the spectrum also and may account for overestimates of chlorophyll-a (Lorenzen, 1967) the decision was made to monitor chlorophyll degradation in samples collected during the summer of 1969. Table 20 shows that pheo-pigments increased from May 12 to May 26, and then doubled again by June 10. Throughout June the amount of pheo-pigments was variable and the distribution was irregular. By July 6, however, the pheo-pigments were again dispersed evenly in the water column and were less concentrated.

Pheo-pigments increased during late July and remained high during August in concurrence with increased amounts of chlorophyll-a. The distribution of pheo-pigments was uniform throughout the water column during this interval and stands in contrast to the distribution during late June (Table 20). The amount of pheo-pigments diminished again on September 10, and they were at lowest levels by October 30. During the intervening period small increases in pheo-pigments were most obvious in surface waters (Table 20).

The ratio of fresh chlorophyll extracts to that after acidification (corrected for turbidity at 750 mu), $665_o:665_a$, can be used to estimate the percent of chlorophyll or pheo-pigments present in a sample Lorenzen (1967). As shown in Golterman (1969) this relationship is not entirely linear. Thus, ratios of 1.0, 1.3, 1.5 and 1.7 indicates that 0%, 55%, 80% and 100% of the sample contains non-detrital or healthy chlorophyll. Table 20 shows chlorophyll-a readings expressed as the ratio of absorbance before divided by absorbance after the addition of acid.

These ratios indicate that on May 12 about 20% to 30% of the chlorophyll-a measured was actually detrital. The ratios of 1.1 to 1.3 during the sampling period of May 26 through June 10 imply that the algal community was senescent at this time and contained mostly (45-75%) degraded chlorophyll-a. However, due to equipment failure these particular samples were stored (in the dark over silica-gel at OC) and very likely (SCOR-UNESCO, 1966) suffered some conversion to pheo-pigments. Coincident with the bloom of <u>A. flos-aquae</u> the most common ratio recorded was 1.6 (90% healthy chlorophyll-a), and this confirms the vitality of this alga. Some degradation of chlorophyll-a is evident on June 30, particularly at 4.5m and 5.5m, but only two compressors were in operation on this date.

The moderate ratios calculated during the succeeding bloom of predominantly green algae during late July and August are perplexing. Except for a ratio of 1.5 recorded at 0.5m on both August 18 and 23, all remaining samples yielded ratios of 1.3 or 1.4 during this interval. This indicate that only 55% to 70% of the measured chlorophyll-a was functional and is contrary to the growth and division of phytoplankton mentioned previously. Little change was evident in the percent of healthy chlorophyll-a during September and October (Table 20).

No important differences were observed in the amount of chlorophyll-a or pheo-pigments at Station 4 during the summer of 1969. The chlorophyll-a concentrations were high at Station 4 during both phytoplankton blooms and they were very close to the specific values presented for Station 2 (Table 20). Also, at Station 4 the absorbance ratio of chlorophyll-a before and after the addition of acid was 1.5 or 1.6 during the peak growth of _A. flos-aquae_, and it diminished to only 1.3 or 1.4 during the heterogeneous bloom of green algae.

Primary Productivity

In addition to determining the amount of particulate carbon fixation during 1969, analyses were routinely performed to ascertain the amount of carbon bound organically and released to the extracellular environment during the brief period of incubation. The combination of these two parameters permits the calculation of total carbon fixation and the percent of this total released out of the cells. All of this information is presented in Table 21.

At Station 2, the primary productivity[2] was relatively constant from May 12 through June 4. As the bloom of A. flos-aquae progressed the primary productivity increased significantly at 0.5m and reached 310.6mg(particulate) $C/m^3/4$ hrs. on June 30, the maximum rate of photosynthesis recorded at this time. After the bloom of A. flos-aquae dissipated and coincident with the diminution of chlorophyll-a (Table 20), the primary productivity was much lower during early July.

The vitality of the second bloom of heterogeneous algae is indicated by the high rates of primary productivity during late July and early August (Table 21). The results contradict data that indicated much of the chlorophyll-a (30-45%) was detrital during this period (Table 20). The primary productivity subsided at 0.5m by August 12 but increased gradually thereafter until August 23. The rates of primary productivity on August 7 and 23 are quite comparable. At lower depths and on all sampling dates the primary productivity decreased on a gradient in agreement

[2]For comparative reasons and to be consistent with the data presented for 1968 (Table 13) primary productivity will be discussed initially as particulate carbon fixation.

Table 21. Primary productivity, including particulate carbon fixation, extracellular organic carbon and total carbon fixation in $mgC/m^3/4$ hrs. at Station 2 in Kezar Lake, 1969.

DATE (1969)	DEPTH (M)	PARTICULATE CARBON FIXATION	EXTRACELLULAR ORGANIC CARBON	TOTAL CARBON FIXATION	P.E.R.*
5/12	0.5	57.4	-	-	-
	1.5	69.1	-	-	-
	2.5	59.3	-	-	-
	3.5	18.6	-	-	-
	4.5	15.2	-	-	-
	5.5	4.7	-	-	-
5/26	0.5	51.4	11.5	62.9	18
	1.5	48.0	9.9	57.9	17
	2.5	31.8	11.7	43.5	26
	3.5	14.7	6.3	21.0	30
	4.5	8.4	0.0	8.4	0
5/29	0.5	73.2	17.0	90.2	18
	1.5	54.5	19.3	73.8	26
	2.5	36.9	13.5	50.4	26
	3.5	17.6	7.0	24.6	28
	4.5	10.2	LOST	-	-
	5.5	7.4	6.7	14.1	47
6/4	0.5	56.2	12.7	68.9	18
	1.5	49.0	12.3	61.3	20
	2.5	32.1	9.1	41.2	22
	3.5	13.7	1.2	14.9	8
	4.5	4.4	2.7	7.1	38
	5.5	2.0	2.5	4.5	55
6/10	0.5	119.2	19.9	139.1	14
	1.5	102.0	16.2	118.2	13
	2.5	43.2	13.0	56.2	23
	3.5	13.1	4.3	17.4	24
	4.5	5.3	7.7	13.0	59
	5.5	5.7	LOST	-	-
6/17	0.5	204.3	36.2	240.5	15
	1.5	83.7	15.1	98.8	15
	2.5	11.2	9.1	20.3	44
	3.5	2.5	4.9	7.4	66
	4.5	0.6	3.2	3.8	84
6/22	0.5	269.6	60.2	329.8	18
	1.5	58.2	19.4	77.6	25
	2.5	7.8	5.4	13.2	40
	3.5	3.8	8.0	11.8	67
6/26	0.5	305.4	27.5	332.9	8
	1.5	78.6	19.6	98.2	19
	2.5	4.6	4.5	9.1	49
	3.5	2.4	8.0	10.4	76
6/30	0.5	310.6	52.4	363.0	14
	1.5	85.2	20.4	105.6	19
	2.5	11.1	9.2	20.3	45
	3.5	3.3	0.0	3.3	0
7/6	0.5	37.6	15.7	53.3	29
	1.5	31.0	13.1	44.1	29
	2.5	13.1	2.9	16.0	18
	3.5	2.9	4.0	6.9	57
	4.5	0.0	6.0	6.0	100
7/15	0.5	35.0	3.9	38.9	15
	1.5	31.9	3.7	35.6	10
	2.5	19.8	12.2	32.0	38
	3.5	7.9	0.0	7.9	0
	4.5	3.2	0.4	3.6	11
	5.5	1.1	1.1	2.2	50
7/19	0.5	56.2	7.2	63.4	11
	1.5	40.4	5.6	46.0	12
	2.5	12.0	6.2	18.2	34
	3.5	6.6	2.9	9.5	30
	4.5	2.6	8.7	11.3	76
7/31	0.5	993.7	515.4	1509.1	34
	1.5	544.2	262.0	806.2	32
	2.5	94.7	44.8	139.5	32
	3.5	21.5	11.8	33.3	35
8/7	0.5	1273.6	276.8	1550.4	17
	1.5	398.0	95.7	493.7	19
	2.5	87.1	39.8	126.9	31
	3.5	16.6	19.7	36.3	54
8/12	0.5	798.1	128.8	926.9	13
	1.5	388.4	85.6	474.0	18
	2.5	84.6	18.0	102.6	17
	3.5	18.5	4.6	23.1	19
	4.5	3.5	2.2	5.7	38
8/18	0.5	985.5	105.8	1091.3	9
	1.5	373.5	47.0	420.5	11
	2.5	69.6	16.8	86.4	19
	3.5	11.9	4.5	16.4	27
	4.5	6.7	2.0	8.7	22
8/23	0.5	1271.8	193.9	1465.7	13
	1.5	533.9	89.4	623.3	14
	2.5	97.9	20.7	118.6	17
	3.5	14.9	0.0	14.9	0
8/27	0.5	575.2	56.2	631.4	8
	1.5	336.1	59.3	395.4	14
	2.5	94.9	21.1	116.0	18
	3.5	23.4	9.2	32.6	28
	4.5	7.0	0.5	7.5	6
9/10	0.5	109.6	15.9	125.5	12
	1.5	73.4	7.6	81.0	9
	2.5	51.2	6.7	57.9	11
	3.5	18.4	2.8	21.2	13
	4.5	9.6	0.0	9.6	0
	5.5	5.4	0.0	5.4	0
9/20	0.5	75.3	3.2	78.5	4
	1.5	63.8	8.3	72.1	11
	2.5	58.3	7.9	66.2	11
	3.5	30.5	1.4	31.9	4
	4.5	14.1	6.4	20.5	31
	5.5	5.2	4.0	9.2	43
10/9	0.5	40.8	16.8	57.6	29
	1.5	38.4	26.3	64.7	40
	2.5	27.4	14.3	41.7	34
	3.5	11.8	6.3	18.1	34
	4.5	6.4	0.0	6.4	0
	5.5	2.5	2.6	5.1	51
10/30	0.5	0.3	0.9	1.2	75
	1.5	0.2	0.0	0.2	0
	2.5	0.2	0.6	0.8	75
	3.5	0.2	0.6	0.8	75
	4.5	0.1	0.0	0.1	0
	5.5	0.1	0.0	0.1	0

* PERCENT EXTRACELLULAR RELEASE

with the penetration of light. Table 21 shows the gradual decrease in planktonic primary production beyond August 23. This trend is related not entirely to the amount of chlorophyll-a (Table 20) but more likely to the inclination of solar illumination. By October 30 the primary productivity was less than 1.0 mg (particulate) $C/m^3/4$ hrs. at all depths.

It is evident also from Table 21 that extracellular release of organically bound carbon during in situ primary productivity studies was routinely observed at Kezar Lake. The Percent Extracellular Release (P.E.R.) of organic carbon indicates the extent that particulate carbon fixation underestimates total primary productivity. On most sampling dates the P.E.R. increased with depth and frequently exceeded 50% at the lowest incubation depth during June and July. P.E.R. values in excess of 50 imply large errors in using particulate carbon fixation only as an indices of phytoplankton vitality. However, it is obvious from Table 21 that P.E.R. values of 50 or greater were responsible for 8.7 mg(organic) $C/m^3/4$ hrs. or less except at 3.5m on August 7.

In general, the P.E.R. at lower depths was greater during the bloom of A. flos-aquae than during the subsequent bloom of heterogeneous algae. In the surface waters there was little difference in P.E.R. even though primary productivity was considerably higher during the August bloom. At the 0.5m depth a P.E.R. between 8 and 20 was observed on most (75%) sampling dates and more than half of the determinations were included in the range of 13-18.

The release of extracellular carbon on July 31 is a striking exception. On this date the P.E.R. was uniform at 32 to 35 in the euphotic zone and accounted for 515.4 mg (organic) $C/m^3/4$ hrs. at the 0.5 meter depth. Thus the total carbon fixation at 0.5m on July 31 is comparable to the rates given at the same depth on August 7 and 23.

The primary productivity at Station 4 was nearly identical to the rates of carbon fixation given previously for Station 2. The only notable exceptions were at 0.5m on July 6 and July 19 when the particulate carbon fixation for Station 4 was 66.2 and 73.9 mg(particulate) $C/m^3/4$ hrs. respectively as compared to 37.6 and 56.2 mg $C/m^3/4$ hrs. at Station 2.

The P.E.R. was similar also for both stations. At the 0.5m depth most (78%) P.E.R. values were included in the range of 8-20 at Station 4. The release of extracellular organic carbon was most pronounced also on July 31. On this date the P.E.R. was very uniform at 30 or 32 and at 0.5m was responsible for 505.3 mg(organic) $C/m^3/4$ hours.

DISCUSSION

Physical Effects of Artificial Circulation

Lakes as small as 98 acre-feet and as large as 1260 acre-feet have been completely mixed by mechanical pumping (Irwin, Symons and Robeck, 1966). Riddick (1958) proposed that larger bodies of water (3000 acre-feet or more) might be completely mixed with the aeration system provided sufficient power was used. Based on their initial investigation, Irwin *et al*. (1966) concluded that artificial mixing of lakes causes a uniform distribution of water quality parameters. Vanray (1969) demonstrated with Rhodamine dye that the water mass of a lake behaves as a unit during the destratification process. I have shown in Figs. 4 and 10 and Tables 3-7, 15 and 16 that the temperature regime and chemistry of Kezar Lake responded to mixing similarly to those lakes investigated by Irwin *et al*. and Vanray mentioned above.

Heat Budget

As a result of artificial circulation the heat budget of Kezar Lake was altered greatly. The summer heat income (wind-distributed heat) prior to destratification in 1968 was 4004 gram-calories/cm^2. After 10 days the lake was isothermal at 23C (Fig. 4) and the annual heat income had increased 33% to 5320 gram calories/cm^2. This large addition of heat to the lake was due principally to warming and redistribution of cold bottom water. For example, at 6.5m the temperature increased from 12.1C to 22.8C during this brief period (Fig. 4). Others (Fast, 1968; Robinson, Irwin and Symons, 1969) have observed the heat content of lakes to increase subsequent to artificial circulation because of the distribution of heat to lower depths. The calculation of summer heat income is from Welch (1948).

Stability

Concomitant with the heat increment at lower depths was a decrease in the stability of stratification at Kezar Lake (Ruttner, 1966). Based on Symons and Robeck (1969) the stability before circulation was 7.9 kg hrs. After 10 days the lake was isothermal and the stability was zero. When the air compressors were restarted on May 28, 1969 the surface-to-bottom temperature differential was slight (Fig. 10) and at this time the stability was only 0.4 kg hrs. With only 2 of 4 air compressors in continuous operation the lake was completely mixed after 7 days. Fast (1968) and Symons *et al.* (1967) also reported a decrease in stability following aeration.

Chemical Effects of Artificial Circulation

Oxygen

After Kezar Lake was mixed the dissolved oxygen content increased in bottom waters, but decreased initially in surface waters (Tables 1 and 14). Among others who have measured higher concentrations of dissolved oxygen in bottom waters following artificial circulation are Fast (1968), Hooper et al. (1952), Thomas (1966), and Wirth and Dunst (1967). Some (Halsey, 1968; Schmitz, 1958; and Riddick, 1958) have witnessed initial losses of dissolved oxygen after lake mixing whereas more extensive losses have been reported by Johnson (1966). Most authors ascribe lower levels of oxygen to the increased biological oxygen demand of organic matter agitated from bottom muds during artificial circulation. At Kezar Lake, I feel the decreased levels of dissolved oxygen in surface waters is associated also with reduced photosynthesis (Table 13). Wirth and Dunst (1967) measured higher concentrations of dissolved oxygen initially at a sampling station which was nearer to the site of aeration. Similar results were observed at Station 2 in Kezar Lake.

Carbon dioxide and pH

At a lake's surface there is a tendency for establishment of an equilibrium between the carbon dioxide content of the air and water (Ruttner, 1966). I believe that artificial mixing of lakes enhances this tendency when bottom water rich in carbon dioxide is transferred to the air-water interface. The loss of large concentrations of carbon dioxide tothe air was evident after Kezar Lake was mixed (Figs. 5 and 11). Riddick (1958) measured an increase in pH from 6.0 in the zone of stagnation to a uniform value of 6.9 in the water column coincident with reduced levels of carbon dioxide. I observed similar results at Kezar Lake (Table 2).

Symons et al. (1969) detected lower pH values in surface waters after brief periods of aeration, which they ascribed to increases in carbon dioxide transferred from bottom waters. The latter workers observed little change in the carbon dioxide content of bottom waters. At Kezar Lake, the increased levels of carbon dioxide measured in surface waters after destratification was due to reduced uptake by photosynthesizing algae. I believe this to be true because the dense surface algal population present before aeration was re-distributed throughout the water column by aeration. Also, primary productivity was severely curtailed at this time (Table 13). The variability of pH (Table 2) in Kezar Lake was not sufficient to significantly affect algal populations (Lund, 1965; Talling, 1962).

Iron and Manganese

The inverse clinograde distribution of iron and manganese (Table 3) in Kezar Lake, prior to aeration, is typical of shallow, eutrophic lakes (Ruttner, 1966). Ruttner states that the iron content in bottom waters of these lakes is generally "a few" milligrams per liter. As soon as oxygen is distributed to lower depths by mixing (natural or artificial), soluble iron and manganese compounds are precipitated and their concentrations are subsequently diminished.

After Kezar Lake was mixed the distributions of iron and manganese became uniform and these elements decreased in concentration (Table 3). Fast (1968), Irwin et al.(1966), Wirth and Dunst (1967), and Bernhardt (1967) report similar findings.

Neither iron nor manganese were considered (Gerloff and Skoog, 1957a) as factors limiting algal growth under natural conditions. Rodhe (1948) removed iron from highly productive cultures of Scenedesmus quadricauda and he observed continued growth and chlorophyll formation for 6 months if the iron-free media was renewed. Little is known about the natural availability of manganese (Talling, 1962) and the quantitative requirements of phytoplankton appear to vary from species to species (Hutchinson, 1957). Hutchinson noted that manganese may play a role in regulating phytoplankton succession, and both he and Lund (1965) cite Guseva (1937a, 1939) who proposed that quantities of manganese found in nature (0.2 mg/l and above) inhibited A. flos-aquae. Quantities of manganese this high were found only in bottom waters at Kezar Lake (Table 3), and I feel that manganese did not reach toxic levels near the surface.

Calcium, Magnesium and Potassium

The results reported in this paper concerning calcium, magnesium and potassium (Tables 4 and 15) are in general agreement with the literature and these substances were little influenced by artificial mixing (Fast, 1968;

and Symons, Irwin and Robeck, 1969. There is little evidence that amounts of calcium, magnesium, or potassium found in natural waters limits the production of planktonic algae (Lund, 1965; Talling, 1962; and Wiessner, 1962).

Sodium and Chloride

Tables 4 and 15 show that significant increases in the surface water content of sodium occurred after the lake was mixed in July of 1968 and 1969 respectively. Hutchinson (1957) stated that cyclical salts carried in maritime air may be precipitated in lake basins close to the ocean so that sodium (and chloride) can become the dominant inorganic ion. However, I believe the magnitude of the increments shown in these Tables and the coincidence of its occurrence (July 1968 and 1969) preclude any possibility that greater intrusion of maritime air may have been responsible for the increased levels of sodium detected at Kezar Lake.

Instead, I have learned from the NHWSPCC that pre-winter storage of road salt (sodium chloride) by the town of New London, N.H., is deposited during July on a lot adjacent to Lion Brook, the main tributary draining into Kezar Lake. The time and place of deposition of this allochthonous source of sodium is the more probable explanation for the high content of this element measured from Kezar Lake water. In contrast to my data Fast (1968) indicates decreased levels of sodium subsequent to destratification.

There is little evidence (Lund, 1965; Talling,1962;

Wiessner, 1962) that sodium limits algal production, but Wiessner points out that certain blue-green algae require appreciable amounts of this element. In Kezar Lake, sodium concentrations were highest when the bloom of A. flos-aquae subsided (Table 4). Thus, sodium seems not to be limiting algal growth at Kezar Lake.

The levels of chloride tended to increase after aeration of Kezar Lake and similar results are given by Fast (1968). Wirth and Dunst (1967) provide data showing levels of chloride to increase when they compared a lake during aeration to a previous non-aerated year. Chloride does not seem to have a direct effect on plankton production (Lund, 1965).

Silicon

Silicon can become limiting to diatom populations when concentrations diminish to 0.03 to 0.04 mg/l (Lund, 1965). The presence of diatom populations in the spring at Kezar Lake was accompanied by lower concentrations (3-4 mg/l) of dissolved silicon, which were 2 orders of magnitude above critical levels. Extensive diatom populations have been recorded (Gruendling and Mathieson, 1969a) at nearby Lake Winnisquam when silicon levels were below 0.10 mg/l. I found that silicon dioxide was little influenced by aeration of Kezar Lake. Fast's (1968) data is in agreement with my results.

Copper and Zinc

Little attention has been given to the availability and occurrence of copper and zinc in inland waters Hutchinson (1957) and Talling (1962). Nevertheless, the levels of these elements determined at Kezar Lake do fall within the range of concentrations that have been measured to date as shown in Hutchinson (1957). Hutchinson mentions that levels of copper generally increase in the autumnal circulation period. In agreement with this statement my data (Tables 5 and 16) show some increase in copper following artificial lake mixing.

To the best of my knowledge there is no literature available regarding the influence of artificial circulation on levels of copper or zinc. Also, there is little information about the influence of zinc on phytoplankton populations (Lund, 1965 and Wiessner, 1962). In sufficient quantities (0.030-0.050 mg/l) ionic copper is toxic to phytoplankton and copper sulfate has long been used to destroy algal blooms in lakes and reservoirs Hutchinson (1957). Levels of total copper measured from Kezar Lake samples (Tables 5 and 16) were invariably below the concentrations considered to be toxic to phytoplankton.

Nitrogen

The rapid uptake of nitrate nitrogen in Kezar Lake as summer progressed is typical of eutrophic lakes supporting extensive phytoplankton growth (Ruttner, 1966). The effect of artificial circulation was to increase levels of nitrate nitrogen in Kezar Lake (Table 7) and similar results have been reported by Brezonick, Delfino and Lee (1969), Johnson (1966), and Symons et al. (1969).

At Kezar Lake levels of nitrite nitrogen increased subsequent to lake mixing in 1968 because this constituent was an intermediate in the oxidation of ammonia nitrogen to nitrate nitrogen (Hutchinson, 1957). Brezonick et al.(1969) noted increased concentrations of nitrite nitrogen following the appearance of oxygen throughout the water column. The authors interpreted these results as indicating the onset of nitrification shortly after artificial circulation distributed oxygen to lower depths. The diminished concentrations of nitrite nitrogen after artificial circulation in 1969 was probably related to the complete loss of ammonia nitrogen (Table 7).

During natural turnover ammonia may disappear entirely from the water column without compensating increases in other forms of nitrogen (Hutchinson, 1957). The un-ionized species of ammonia (NH_3) is a gas and may be lost from natural waters at pH as low as 8.5 (Stratton, 1968). Vigorous aeration promotes the transfer of NH_3 from liquid to air.

The accumulation of ammonia nitrogen in the hypolimnion of Kezar Lake is characteristic of eutrophic lakes and results primarily from the breakdown of protein (Ruttner, 1966). The large concentration of ammonia nitrogen at 0.5m shortly after artificial circulation in 1968 (Table 7) is perplexing. Perhaps this is associated with the immediate breakdown of protein upon dissipation of the _A. flos-aquae_ bloom and, in part, with the transfer of ammonia nitrogen from bottom waters during mixing. Wirth and Dunst (1967) observed a transfer of ammonia nitrogen to surface waters following lake aeration. Depletion of large concentrations of ammonia nitrogen in the hypolimnion following artificial circulation has been reported by Irwin _et al_. (1966), and Wirth and Dunst (1967; see also Brezonick _et al_., 1969).

There is general agreement (Hutchinson, 1957; Lund, 1965; Syrett, 1962; and Talling, 1962) that fresh-water algae can use either nitrate or ammonia as a source of nitrogen. Nitrite nitrogen can serve as a nitrogen source for some algae, but high concentrations are inhibitory (Syrett, 1962). Many Cyanophyta can utilize simple organic compounds (Lund, 1965). Most important, there is evidence now that _Aphanizomenon flos-aquae_ is a nitrogen-fixing alga (Gentile and Maloney, 1969; Stewart, Fitzgerald and Burris, 1967; and Stewart, 1968). This information helps explain the prominence of _A. flos-aquae_ in Kezar Lake and other eutrophic lakes. It also explains in part the high nitrogen content of _A. flos-aquae_ as compared to algae not able to fix nitrogen (Stewart, 1968). Crude analysis (dry weight) shows that _A. flos-aquae_ is 62.8 percent protein (Prescott, 1960).

There is evidence that large concentrations of soluble organic nitrogen (mostly peptide) are released from healthy cultures of nitrogen-fixing blue-green algae (Fogg 1962a) and that most organic nitrogen found in lakes is protein or protein degradation products (Hutchinson, 1957). Organic nitrogen appears to be the predominant form of combined nitrogen in lakes due to the uptake of inorganic nitrogen during photosynthesis (American Water Works Association, 1970). The large concentrations of organic nitrogen (Table 7) measured from Kezar Lake waters during the bloom of _A. flos-aquae_ seem explicable in view of the information cited above.

Phosphorus

Generally, levels of orthophosphate increase after artificial mixing of Kezar Lake and its distribution was isometric. Lower amounts of orthophosphate recorded after the 1969 mixing (Table 6) may be associated with onset of the _A. flos-aquae_ bloom. Hammer (1964) observed orthophosphate levels to decline prior to maximum development of blue-green blooms, and it is known that some algae can incorporate phosphate in excess of amounts required for immediate growth (Ruttner, 1966).

An isometric distribution of soluble phosphorus following aeration was noted also by Hasler (1958). Hasler observed a trend toward higher levels near the surface, which was also evident at Kezar Lake. Bernhardt (1967) detected no increase of soluble phosphorus in the "free-water zone" following complete destratification. Wirth and Dunst (1967) found dissolved phosphate to approach uniform distributions after aeration but with subsequent reductions.

The large increase in total phosphorus following aeration of Kezar Lake in 1968 (Table 6) is ascribed to suspended organic detritus transferred into the water column from the profundal mud. This material was visibly evident in phytoplankton samples. Similar to my observations, other authors (Hasler, 1958; Hooper et al., 1952; and Wirth and Dunst, 1967) have reported a uniform distribution of total phosphorus after lake mixing.

Sawyer (1947) proposed that algal blooms could be expected if inorganic nitrogen and phosphorus exceeded the critical levels of 0.3 mg/l and 0.015 mg/l respectively. Gentile and Maloney (1969) provide corroborating evidence from culture studies of A. flos-aquae by suggesting 0.010 mg/l phosphorus as the critical level for development of nuisance blooms. Gerloff and Skoog (1957b) concluded that 0.001 mg/l phosphorus would be adequate for development of another blue-green, Microcystis aeruginosa. The mean value of inorganic phosphorus measured at Kezar Lake during both summers was in excess of the critical levels cited above (Table 6).

In 1969 only, the mean value of 0.24 mg/l inorganic nitrogen was slightly below the critical level suggested by Sawyer (1947). However, as mentioned previously there is now evidence that blooms of A. flos-aquae can fix nitrogen. This information, coupled with the knowledge that blooms of A. flos-aquae commonly occur when inorganic nitrogen levels are low and inorganic phosphorus is undetectable (Hutchinson, 1967), suggests strongly that nitrogen and phosphorus were not limiting the growth of planktonic algae in Kezar Lake.

Some Biological Effects of Artificial Circulation

Phytoplankton

The annual massive blooms of A. flos-aquae characteristic of Kezar Lake typify many eutrophic lakes (Prescott, 1962). The numbers of A. flos-aquae filaments decreased under the influence of remedial circulation in 1968, while the numbers of filaments increased under the preventative treatment attempted in 1969. The major difference between the two years was the time at which these two events took place. In 1968 the air compressors were started in July, while in 1969 aeration began in May.

There is some evidence (Symons, 1969) that blue-green algae are more adversely affected by lake mixing than are green algae. Bernhardt (1967) noted that filaments of a blue-green alga (Oscillatoria rubescens) were distributed throughout the water column and were reduced in abundance by artificial destratification. Bernhardt proposed that exposure to UV light and lower epilimnetic temperatures were responsible for the decline of O. rubescens. Wirth and Dunst (1967) conjectured that mixing might limit blooms by lowering the temperature of the epilimnion and by preventing algae from stratifying in the euphotic zone.

It is probable also that mixing caused dilution of inhibitory substances released by _A_. _flos_-_aquae_ (Lefevre, 1964), thus permitting growth of other phytoplankton. But Lund (1965) astutely proclaimed that "in explaining the rise and fall of [phytoplankton] populations in nature, chemical inhibition is as easy to suggest as it is difficult to prove." A paucity of any essential element can limit the growth of algae but it is unlikely (Sawyer, 1968) that micronutrients (those not measured) were limiting phytoplankton growth in eutrophic Kezar Lake. Many nutrients required by phytoplankton, especially nitrogen and phosphorus, have been shown to be not limiting at Kezar Lake.

I believe that temperature alone was not responsible for the decline of _A_. _flos_-_aquae_ subsequent to artificial circulation. Although Gentile and Maloney (1969) found 26C to be optimum for a toxic strain of _A_. _flos_-_aquae_ in culture, peak growth of this alga has been observed in another New Hampshire lake (Gruendling and Mathieson, 1969a) in a temperature range of 21-22C. Natural blooms of _A_. _flos_-_aquae_ have been reported also at temperatures of 22.5 - 26.5C by Hammer (1964) and over a temperature range of 5-28C by O'Flaherty and Phinney (1970). The water temperature at Kezar Lake varied between 22C and 23C when the decline of _A_. _flos_-_aquae_ occurred in 1968.

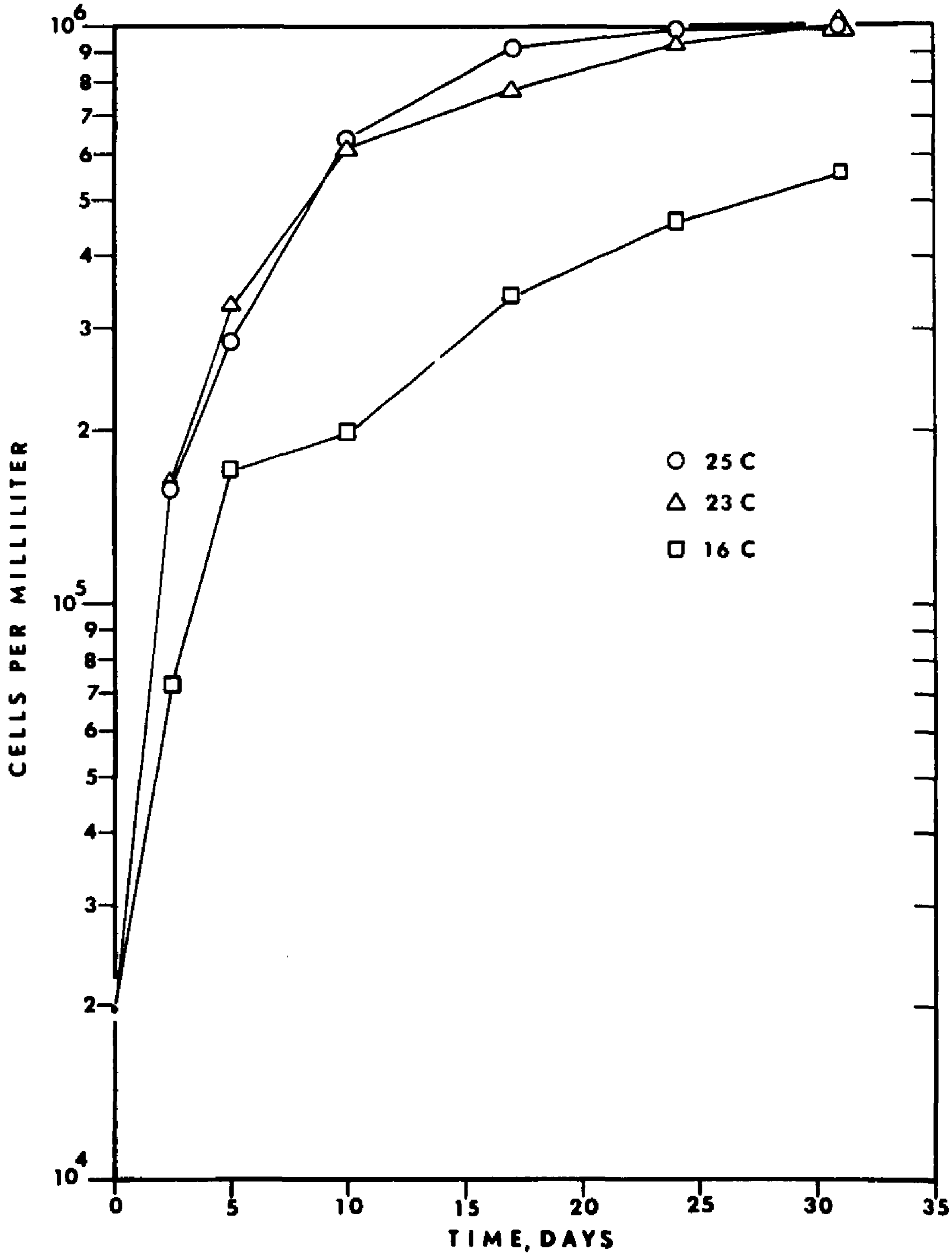
In addition, A. flos-aquae bloomed early in 1969 irrespective of artificial circulation and I observed log growth in a temperature range of 12-22C. Hammer (1969) reported log growth of this alga in a temperature range of 17-19C. Thus, strains of this species seem to tolerate a wide range of temperatures.

Experimentally, Kezar Lake cultures of this alga attained log growth equally well at 23C and 25C, and the species reached nuisance levels even at 16C (Fig. 13). Because these samples remained quiescent during incubation it is suggested that artificial circulation per se is responsible (at least indirectly) for averting continuous blooms of A. flos-aquae. It is important to reiterate that while in vitro log growth of A. flos-aquae was observed no change in abundance occurred in situ (Table 17, August).

I have shown earlier in this paper (Tables 9 and 13) that summer blooms of A. flos-aquae exclude most other phytoplankton. Gruendling and Mathieson (1969a) reported the same results from their investigation of Lake Winnisquam in Laconia, New Hampshire. These authors believed the paucity of other phytoplankton was probably due to antagonistic substances released by A. flos-aquae, and to the shading effect from the surface growth of this alga. I suspect these same controls were operating to inhibit algal growth at Kezar Lake.

The advent of chlorophycean species after the blooms of A. flos-aquae is not surprising. Usually, planktonic

Fig. 13. In vitro growth of *Aphanizomenon flos-aquae* at different temperatures. Data represent duplicate 50 ml samples of unadulterated lake water incubated in 250 ml Erlenmeyer flasks at each temperature on a 14 hr.-10 hr. light-dark cycle under about 225-250 ft-candles illumination.



CELLS PER MILLILITER
TIME, DAYS
25 C
23 C
16 C

green algae are most numerous during late spring and early autumn, but they are found at all times and the numbers of fresh-water species is very large (Smith, 1950). Among the Chlorophyceae, the genera likely to be present in the phytoplankton of shallow fertile lakes are: *Chlamydomonas*, *Elakatothrix*, *Sphaerocystis*, *Tetraedon*, *Oocystis*, *Ankistrodesmus*, *Kirchneriella*, *Selenastrum*, *Dictyosphaerium*, *Pediastrum*, *Coelastrum*, *Crucigenia* and *Scenedesmus* (Hutchinson, 1967). All of the aforementioned taxa contributed in varying degree to the phytoplankton flora of Kezar Lake, primarily after termination of the *A. flos-aquae* blooms.

Palmer (1962) listed the following algae found at Kezar Lake, as tolerant of organically enriched waters: *Chlorella vulgaris*, *Scenedesmus quadricauda*, *Tetraedron muticum*, *Nitzschia acicularis* and *Nitzschia palea*. Not previously mentioned but characteristic of eutrophic phytoplankton and found in Kezar Lake are the diatoms *Asterionella*, *Fragillaria crotonensis*, *Synedra* and *Melosira*; the desmids *Staurastrum chaetocerus* and *Cosmarium bioculatum*; and the dinoflagellate *Glenodinium* (Hutchinson, 1967). Some of these genera and their included species are common to oligotrophic waters as well (Hutchinson, 1967).

The "ideal" environmental conditions of nutrient availability, deeper light penetration, and lower surface temperatures after mixing of Kezar Lake stimulated large populations of green algae, but they did not reach the concentrations attained by the blooms that typify *A. flos-aquae* and other noxious blue-greens. This is explicable in terms of the slower rate of reproduction of green algae (Prescott, 1962). The most numerous green algae at Kezar Lake were Dictyosphaerium pulchellum, Tetrallantos Lagerheimii and Ulothrix subconstricta (Tables 10, 18 and 19).

Robinson, Irwin and Symons (1969) found green algae to be favored over blue-green algae during brief mixing periods of two test lakes. This was true of most experiments by this research group (see Symons, 1969). In two studies where complete destratification was not achieved blue-green algal populations increased (Hooper et al., 1952; and Thomas, 1966).

Chlorophyll-a

The chlorophyll-a values recorded at Kezar Lake (Tables 12 and 20) agree with the amounts reported by other authors (Aruga and Monsi, 1963; and Odum, McConnell and Abbot, 1958) for eutrophic lakes. Thus, Aruga and Monsi (1963) classified lakes as oligo-, meso-, or eutrophic based on the amount of functional chlorophyll present in the euphotic zone (with a lower limit at the level of 1 percent surface light). Under this classification eutrophic lakes were those with 0.03-0.12 g chlorophyll/m^2 of lake surface. Aruga and Monsi pointed out that the amount of chlorophyll may vary from 0.1 to 1 g/m^2 during phytoplankton blooms. The mean concentrations of chlorophyll-a (only) at Kezar Lake for June, July and August of 1968 and 1969 were 0.14 and 0.20 g/m^2 respectively. The maximum concentration during phytoplankton blooms of A. flos-aquae was 0.30g chlorophyll -a/m^2.

A value of 0.3g chlorophyll/m^2 was suggested by Steeman-Nielsen (cited in Talling, 1962) as maximum for the euphotic zone. This value agrees closely with my data and with data of Aruga and Monsi (1963). Odum et al. (1958) found a range of 0.1 to 3.0g chlorophyll/m^2 in euphotic zones (to level of 1% light) in many varied environments. However, chlorophyll concentrations as high as 3.0g/m^2 are rare.

As far as I am aware only Johnson (1966) has considered the influence of artificial circulation on the distribution of chlorophyll-a. He reported increased levels in surface waters of a small test lake before and after mixing. However, complete destratification was not evident in his experiment.

Primary Productivity

The high rates of carbon fixation at Kezar Lake (Tables 13 and 21) are indicative of its eutrophic status. For June, July and August the average rates were 190mg (particulate) C/m^2/hour and 230mg (total) C/m^2/hour for 1968 and 1969 respectively. The amount of carbon fixed by phytoplankton during blooms at Kezar Lake was high, reaching 530 mg (particulate) C/m^2/hour in 1968 and 620 mg(total) C/m^2/hour in 1969. Goldman's (1968) average of 300 mg C/m^2/hour for Clear Lake during the "growing season" compares favorably with my data. Clear Lake is shallow, "very eutrophic" and it supports periodic blooms of *Aphanizomenon flos-aquae*.

On each sampling date the amount of carbon fixation invariably decreased with depth (Tables 13 and 21) due to light inhibition. To demonstrate that light was the only factor limiting primary productivity at lower depths water samples collected at 2.5m, 3.5m and 4.5m on August 23, 1968, were innoculated with $Na_2{}^{14}CO_3$ but incubated at 0.5m, 1.5m and 2.5m respectively. Table 22 shows the primary productivities of these samples in comparison to standard samples which were incubated at the same depth from which the water was drawn.

Table 22. Primary productivity in mg $C/m^3/4$ hrs. of samples drawn from different depths but incubated at the same depth.

Depth of Sample (M)	Depth of Incubation (M)	Particulate Carbon Fixation	Extracellular Organic Carbon	Total Carbon Fixation
0.5 (2.5)	0.5	42.1 (37.5)	3.6 (5.3)	45.7 (42.8)
1.5 (3.5)	1.5	17.5 (15.7)	2.7 (6.2)	20.2 (21.9)
2.5 (4.5)	2.5	4.9 (4.4)	4.2 (5.6)	9.1 (10.0)

Since chlorophyll-a was uniformly dispersed in the water column at 37.09–44.33 mg/m^3 on this date and because the primary productivities resulting were nearly identical, it is apparent that diminution of carbon fixation with depth is a function of decreased light penetration.

In the only literature found pertaining to the effects of artificial circulation on primary productivity, Johnson (1966) measured carbon fixation in a surface sample once before (1.76mg C/m^3/hour) and once after (4.10mg C/m^3/hour) mixing of a small test lake. In this experiment the lake was not completely destratified. On the basis of these two measurements Johnson believed that the primary productivity had increased by a factor of 2.3. It was my experience that many carbon-14 trials were required to define primary productivity trends.

In this paper the release of extracellular organic matter is primarily of quantitative importance. As I mentioned previously (see page 128) the percent extracellular release (P.E.R.) of organic carbon-14 varied from 0 to 100, but 75% of the values ranged from 8-20. Similarly, Fogg (1962b) found liberation of extracellular products amounted to 3 to 90% of the total carbon fixed when diatoms were predominant. Fogg, Nalewajko and Watt (1965) noted that in a 10m water column extracellular organic carbon-14 amounted to 17.1% of the total carbon fixed over a four-hour incubation period. I found a similar mean value (19.4%) in the euphotic zone for the summer of 1969. This data provides an indication of what extent particulate carbon fixation underestimates total primary productivity.

Watt (1966) found the amount of extracellular carbon-14 to be highest at depths where carbon fixation was highest but the P.E.R. was at its lowest value. The P.E.R. in light bottles always increased with depth and with decreasing population densities. The liberation of organic-14 usually increased with depth at Kezar Lake (Table 21) and so my data complies with that of Watt (1966). In addition, I have checked duplicate samples to determine whether or not addition of formalin to one sample caused lysed cells, which could liberate intracellular organic carbon-14 molecules. In these experiments no important differences were observed. Breakage of cells during filtration is considered an unlikely source of labelled organic substances in sample water (Fogg et al., 1965). Watt(1966) ascribed the escape of organic molecules partly to high concentration gradients although he recognized that such products as growth inhibitors may be actively secreted into the environment.

SUMMARY

On the basis of data from 2 summers, several conclusions can be stated concerning the ecological effects of artificially circulating Kezar Lake:

1) The entire lake became isothermal due to the distribution of warmer water to lower depths causing an increase in the heat budget of the lake. The stability of stratification was reduced to zero.

2) Bottom waters poor in oxygen were reaerated at the surface during the mixing, and the vertical oxygen distribution became more isometric. A true orthograde distribution of oxygen was seldom observed because of the heavy algal growth, which produced excess oxygen in the euphotic zone but respired oxygen as it was cycled through the aphotic zone.

3) High concentrations of carbon dioxide in bottom waters were lost to the atmosphere during mixing. An isometric distribution of carbon dioxide was seldom observed as a result of rapid utilization by dense algal growth near the surface. Carbonate alkalinity and pH varied directly with the presence or absence of CO_2 and both were little affected in surface waters by artificial circulation. The pH increased in bottom waters when the large concentrations of carbon dioxide were reduced.

4) Isochemical distributions were evident for Fe,

Mn, and NH_3-N only after artificial circulation distributed dissolved oxygen to bottom waters. There was a definite tendency for levels of Zn and perhaps Cu to exhibit temporary stratification after the lake was destratified. Artificial circulation had little effect on the depth distributions of Ca, Mg and K.

5) Levels of Na, Zn, NO_2-N, ortho-P and total-P increased following artificial circulation in 1968 whereas Fe, Mn, NH_3-N and Organic-N were reduced in concentration. After 5 to 7 weeks of continuous aeration the concentrations of Fe, Cu, Mg, K, NO_2-N and NO_3-N were similar for both summers. Reasons are given for the view that the supplies of each nutrient, particularly nitrogen and phosphorus, were sufficient to support phytoplankton populations.

6) A uniform, vertical distribution of the bloom-forming alga *Aphanizomenon flos-aquae* occurred after lake mixing. After remedial aeration (1968) *A. flos-aquae* eventually declined but following preventative aeration (1969) *A. flos-aquae* bloomed.

7) Water transparency increased after artificial destratification (1968) but decreased following preventative mixing (1969).

8) After the blooms of *A. flos-aquae* dissipated the phytoplankton became dominated by chlorophycean taxa. The species composition seemed to be related to the small size and eutrophic status of Kezar Lake.

9) Levels of chlorophyll-a became uniformly dispersed in the water column after artificial circulation.

Chlorophyll degradation to pheo-pigments appeared to be greater during a bloom of heterogeneous green algae than during the bloom of *A. flos-aquae*.

10) Primary productivity was high in surface waters and varied in accordance with the phytoplankton standing crop and the amount of chlorophyll-a. At lower depths the primary productivity decreased rapidly because of the poor penetration of light.

11) A discussion of the effects of artificial circulation on the physical, chemical and biological aspects of Kezar Lake is presented, and the results are compared with the findings of other authors.

REFERENCES CITED

Ambuhl, H. 1962. Die kunstliche Beluftung des Pfaffikersees. Orientierung uber die ersten Ergebnisse. Verbands-Bericht VSA Nr. 77/3, 9s.

American Public Health Association et al. 1965. Standard methods for the examination of water and waste water including bottom sediments and sludges. 12th ed. A.P.H.A., Inc., New York. 769 p.

American Water Works Association, Committee on Nutrients in Water. 1970. Chemistry of nitrogen and phosphorus in water. J. Amer. Water Wks. Assoc. 62(2):127-140.

Anon. 1960. New Life for polluted Swedish lakes. J. Wat. and Waste Treat. 8:65.

Anon. 1966. Le systeme a bulles d'air, Une nouvelle vie pour l'eau polluee. Tech. de l'Eau et de l'Assain. No. 237:43-47.

Aruga, Y., and M. Monsi. 1963. Chlorophyll amount as an indicator of matter productivity in bio-communities. Plant & Cell Physiol. 4(1):29-39.

Bernhardt, H. 1967. Aeration of Wahnbach Reservoir without changing the temperature profile. J. Amer. Water Wks. Assoc. 59:943-964.

Brezonik, P. L., J. J. Delfino, and G. F. Lee. 1969. Chemistry of N and Mn in Cox Hollow Lake, Wis., following destratification. J. Sanit. Eng. Div., Amer. Soc. Civil Eng. 95 (SA 5):929-940.

Burdick, M. E. 1959. Open water in winter. Wisconsin Conserv. Bull. 24:21-23.

Falk, L. L. 1965. Discussion, p. 335 and 336. In J. G. Bryan Improvement in the quality of reservoir discharges through reservoir mixing and aeration, Symp. Streamflow Regul. for Quality Control. U.S. Public Health Service Pub. No. 999-WP-30.

Fast, Arlo W. 1968. Artificial destratification of El Capitan Reservoir by aeration. Part I. Effects on chemical and physical parameters. Calif. Dept. Fish and Game, Fish. Bull. 141. 97 p.

Fogg, G. E. 1962a. Nitrogen fixation, p. 161 to 170. In R. A. Lewin (ed.) Physiology and biochemistry of algae. Academic Press, New York.

Fogg, G. E. 1962b. Extracellular products, p. 475 to 489. In R. A. Lewin (ed.) Physiology and biochemistry of algae. Academic Press, New York.

Fogg, G. E., C. Nalewajko, and W. D. Watt. 1965. Extracellular products of phytoplankton photosynthesis. Roy. Soc. (London) Proc., B. 162:517-534.

Fruh, G. E. 1967. The overall picture of eutrophication. J. Wat. Pollut. Control Fed. 39(9):1449-1463.

Gallup, Donald N. 1969. Zooplankton distribution and zooplankton-phytoplankton relationships in a mesotrophic lake. Ph.D. Thesis, University of New Hampshire. 217 p.

Gentile, John H. 1966. A limnological study of planktonic primary producers in a shallow eutrophic reservoir. Ph.D. Thesis, University of New Hampshire. 159 p.

Gentile, J. H., and T. E. Maloney. 1969. Toxicity and environmental requirements of a strain of Aphanizomenon flos-aquae (L.) Ralfs. Can. J. Microbiol. 15:165-173.

Gerloff, G. C., and F. Skoog. 1957a. Availability of iron and manganese in southern Wisconsin lakes for the growth of Microcystis aeruginosa. Ecology 38(4):551-555.

Gerloff, G. C., and F. Skoog. 1957b. Nitrogen as a limiting factor for the growth of Microcystis aeruginosa in southern Wisconsin lakes. Ecology 38(4):556-561.

Goldman, C. R. 1961. The measurement of primary productivity and limiting factors in freshwater with carbon-14, p. 103 to 113. In M. S. Doty (ed.) Proc. Conf. Primary Productivity Measurement, Marine and Freshwater, U. S. Atomic Energy Comm., TID-7633.

Goldman, C. R. 1968. Aquatic primary production. Am. Zool. 8(1):31-42.

Golterman, H. L. (ed.). 1969. Methods for chemical analysis of fresh waters. IBP Handbook No. 8, Blackwell Scientific Publications, Oxford, England. p. 118.

Grim, J. 1952. Ein See wird umgepflugt. Allg. Fisch. Zeit. 77(14,S):281-283.

Gruendling, G. K., and A. C. Mathieson. 1969a. Phytoplankton populations in relation to trophic levels of lakes in New Hampshire, U.S.A. Water Resources Res. Cntr., Univ. New Hampshire, Durham. 81 p.

Gruendling, G. K., and A. C. Mathieson. 1969b. Phytoplankton flora of Newfound and Winnisquam Lakes, New Hampshire. Rhodora 71:444-477.

Halsey, T. G. 1968. Autumnal and over-winter limnology of three small eutrophic lakes with particular reference to experimental circulation and trout mortality. J. Fish. Res. Bd. Can. 25(1):81-99.

Hamalainen, M. 1969. Preventing the depletion of oxygen by changing the hypolimnion. Vesitalous 10(3):25-27, 34.

Hammer, U. T. 1964. The succession of "bloom" species of blue-green algae and some causal factors. Verh. Internat. Verein. Limnol. 15:829-836.

Hammer, U. T. 1969. Blue-green algal blooms in Saskatchewan lakes. Verh. Internat. Verein. Limnol. 17:116-125.

Hasler, A. D. 1958. Natural and artificially (air ploughing) induced movement of radioactive phosphorus from the muds of lakes. In R. C. Extermann (ed.) Radioisotopes in sci. res., Proc. First (UNESCO) Internat. Conf. IV:658-673.

Heath, W. A. 1961. Compressed air revives polluted Swedish lakes. Wat. and Sewage Wks. 108:200.

Hemphill, J. 1954. A method of winterkill prevention. Arizona Game and Fish Dept., Phoenix, Arizona. 8 p.

Hooper, F. F., R. C. Ball, and H. A. Tanner. 1952. An experiment in the artificial circulation of a small Michigan lake. Trans. Amer. Fish. Soc. 82:222-241.

Hoover, Earl E. 1938. Biological survey of the Merrimack watershed. Surv. Rep. No. 3, New Hampshire Fish and Game Dept. pp. 136-148.

Huber-Pestalozzi, G. 1938-1961. Das Phytoplankton des Susswassers. Vol. 16, Pts. 1-5. In A. Thienemann (ed.) Die Binnengewasser. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart.

Hutchinson, G. E. 1957. A treatise on limnology. Vol. 1. John Wiley & Sons, Inc., New York. 1015 p.

Hutchinson, G. E. 1967. A treatise on limnology. Vol. II. John Wiley & Sons, Inc., New York. 1115 p.

Inland Fisheries Branch. 1970. Effects of artificial destratification on distribution of bottom organisms in El Capitan Reservoir. Calif. Dept. Fish and Game, Fish Bull. 148. 30 p.

Irwin, W. H., J. M. Symons, and G. G. Robeck. 1966. Impoundment destratification by mechanical pumping. J. Sanit. Eng. Div., Amer. Soc. Civil Eng. 92(SA 6):21-40.

Jankovic, S. G., D. T. Mitchell, and J. C. Buzzell, Jr. 1967. Measurement of phosphorus in wastewater. Water & Sew. Wks. 114(12):471-474.

Johnson, R. C. 1966. The effect of artificial circulation on production of a thermally stratified lake. Washington Dept. Fish., Fish. Res. Papers2(4):5-15.

Karlgren, L., and O. Lindgren. 1963. Aeration studies in Lake Trask. Vattenhygien 19:67-78.

Lefevre, M. 1964. Extracellular products of algae. p. 337 to 367. In D. F. Jackson (ed.) Algae and man. Plenum Press, New York.

Lorenzen, C. J. 1967. Determination of chlorophyll and pheo-pigments: spectrophotometric equations. Limnol. Oceanogr. 12(2):343-346.

Lund, J. W. G. 1965. The ecology of the freshwater phyto-plankton. Biol. Rev. 40(2):231-293.

Lund, J. W. G., C. Kipling, and E. D. LeCren. 1961. The inverted microscope method of estimating algal numbers and the statistical basis of estimations by counting. Hydrobiologia 11:143-170.

Montgomery, H. A. C., and J. F. Dymock. 1962. The rapid determination of nitrate in fresh and saline waters. The Analyst 87 (1034):374-378.

Odum, H. T., W. McConnell, and W. Abbott. 1958. The chlorophyll "A" of communities. Pub. Inst. Marine Sci., Univ. Texas, Austin. pp. 65-96.

O'Flaherty, L.M., and H.K. Phinney. 1970. Requirements for the maintenance and growth of Aphanizomenon flos-aquae in culture. J. Phycol. 6(1):95-97.

Palmer, C. M. 1962. Algae in water supplies. U. S. Dept. Health, Educ. and Welfare, Publ. Health Serv. Pub. No. 657. p. 38.

Patriarche, M. H. 1961. Air-induced winter circulation of two shallow Michigan lakes. J. Wildlife Manage. 25(3): 282-289.

Patrick, R., and C. W. Reimer. 1966. The diatoms of the United States exclusive of Alaska and Hawaii. Vol. 1. Monograph No. 13, Acad. Nat. Sci., Philadelphia. 688 p.

Prescott, G. W. 1960. Biological disturbances resulting from algal populations in standing waters. p. 22 to 37. In C. A. Tryon, Jr. and R. T. Hartman (ed.) The ecology of algae, Spec. Pub. No. 2, Pymatuning Lab. Field Biol., Univ. Pittsburgh.

Prescott, G. W. 1962. Algae of the Western Great Lakes area. Wm. C. Brown Co. Publishers, Dubuque, Iowa. 977 p.

Rasmussen D. H. 1960. Preventing a winterkill by use of a compressed-air system. Progve. Fish Cult. 22(4): 185-187.

Riddick, T. M. 1958. Forced circulation of large bodies of water. J. Sanit. Eng. Div., Amer. Soc. Civil Eng. 84(SA 4):1703(1)-1703(21).

Robinson, E. L., W. H. Irwin, and J. M. Symons. 1969. Influence of artificial destratification on plankton populations in impoundments. Trans. Kentucky Acad. Sci. 30(1,2):1-18.

Rodhe, W. 1948. Environmental requirements of fresh-water plankton algae. Symbol. Bot. Upsal. 10(1):1-149.

Ruttner, F. 1966. Fundamentals of limnology. 3rd ed. Univ. Toronto Press, Canada. 295 p.

Ryther, J. H. 1956. Photosynthesis in the ocean as a function of light intensity. Limnol. Oceanog. 1(1):61-70.

Sawyer, C. N. 1947. Fertilization of lakes by agricultural and urban drainage. J. New England Water Wks. Assoc. 61:109-127.

Sawyer, C. N. 1968. The need for nutrient control. J. Water Pollut. Control Fed. 40(3):363-370.

Sawyer, P. J., J. H. Gentile, and J. J. Sasner, Jr. 1968. Demonstration of a toxin from Aphanizomenon flos-aquae (L.) Ralfs. Can. J. Microbiol. 14(11):1199-1204.

Schmitz, W. R. 1958. Artificially induced circulation in thermally stratified lakes. Ph.D. Thesis, Univ. Wisconsin, Madison. 96 p.

Schmitz, W. R., and A. D. Hasler. 1958. Artificially induced circulation of lakes by means of compressed air. Science 128(3331):1088, 1089.

SCOR-UNESCO. 1966. Monographs on oceanographic methodology. I. Determination of photosynthetic pigments in sea-water. UNESCO, Paris. 69 p.

Skuja, H. 1948. Taxonomie des Phytoplanktons einiger Seen in Uppland, Schweden. Symbol. Bot. Upsal. 9(3):1-399; Pls. 1-39.

Smith, G. M. 1920. Phytoplankton of the inland lakes of Wisconsin. Part I. Wisconsin Geol. Nat. Hist. Surv. Bull. 57. 243 p.

Smith, G. M. 1924. Phytoplankton of the inland lakes of Wisconsin. Part II. Desmidiaceae. Wisconsin Geol. Nat. Hist. Surv. Bull. 57. 227p.

Smith, G. M. 1950. The fresh-water algae of the United States. 2nd ed. McGraw-Hill Book Co., Inc., New York. 719 p.

Steeman-Nielsen, E. 1952. The use of radioactive carbon for measuring organic production in the sea. J. Cons. Int. Explor. Mer. 43:117-140.

Stewart, W. D. P. 1968. Nitrogen input into aquatic ecosystems, p. 53 to 72. In D. F. Jackson (ed.) Algae, man and the environment. Syracuse Univ. Press, Syracuse, N.Y.

Stewart, W. D. P., G. P. Fitzgerald, and R. H. Burris. 1967. In situ studies on N_2 fixation using the acetylene reduction technique. Proc. Nat. Acad. Sci. U.S.A. 58:2071-1078.

Stratton, F. E. 1968. Ammonia nitrogen losses from streams. J. San. Eng. Div., Amer. Soc. Civil Eng. 94:1085.

Strickland, J. D. H., and T. R. Parsons. 1965. A manual of sea water analysis. 2nd ed. Bull. No. 125, Fish. Res. Bd. Canada. pp. 117-124.

Symons, J. M. 1969. Water quality behavior in reservoirs, a compilation of some published research papers. U.S. Dept. Health, Educ. and Welfare, Public Health Serv. Pub. No. 1930. 616 p.

Symons, J. M., W. H. Irwin, E. L. Robinson, and G. G. Robeck. 1967. Impoundment destratification for raw water quality control using either mechanical or diffused-air pumping.

Symons, J. M., W. H. Irwin, and G. G. Robeck. 1969. Control of reservoir water quality by engineering methods, p. 449 to 480. In J. M. Symons Water quality behavior in reservoirs, a compilation of some published research papers. U. S. Dept. Health, Educ. and Welfare, Public Health Serv. Publ. No. 1930.

Syrett, P. J. 1962. Nitrogen assimilation, p. 171 to 178. In R. A. Lewin (ed.) Physiology and biochemistry of algae. Academic Press, New York.

Talling, J. F. 1962. Freshwater algae, p. 743 to 757. In R. A. Lewin (ed.) Physiology and biochemistry of algae. Academic Press, New York.

Teiling, E. 1967. The desmid genus Staurodesmus: A taxonomic study. Archiv fur Botanik 6(11):467-629.

Thomas, E. A. 1966. Der Pfaffikersee vor, wahrend und nach kunstlicher Durchmischung. Verh. Internat. Verein. Limnol. 16:144-152.

Tubb, R. 1966. Limnological conditions in aerated lakes of the Turtle Mountains. Prelim. Rept. No. 1093-a, North Dakota Game and Fish Dept., Bismark. 25 p.

Uherkovich, G. 1966. Die Scenedesmus-Arten ungarns. Akademiai Kiado, Budapest. 173 p.

Vanray, L. C. 1969. Aeration of Stockade Lake, South Dakota. Masters Thesis, South Dakota State Univ., Brookings, S. D. 50 p.

Watt, W. D. 1966. Release of dissolved organic material from the cells of phytoplankton populations. Roy. Soc. (London), Proc., B. 164:521-551.

Welch, Paul S. 1948. Limnological methods. McGraw-Hill Book Company, Inc., New York. p. 122.

Whalls, M. J. 1966. Lake destratification. Inland Fish. Manage., Dept. Fish and Game, State of Calif., Sacramento. p. 167, 168.

Wiessner, W. 1962. Inorganic micronutrients, p. 267 to 286. In R. A. Lewin (ed.) Physiology and biochemistry of algae. Academic Press, New York.

Wirth, T. L., and R. C. Dunst. 1967. Limnological changes resulting from artificial destratification and aeration of an impoundment. Wisconsin Conserv. Dept., Prog. Rep. No. 22. 15 p.

Woods, D. E. 1961. The effects of compressed air on winter oxygen levels in a fertile southern Minnesota lake. Minnesota Fish and Game Invest., Fish Series No. 3. pp. 51-62.

Yount, J. L. 1966. Causes and relief of hyper-eutrophication of lakes. Entomol. Res. Cen ter, Vero Beach, Florida. 23 p.