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Selective Feeding By Zooplankton: Implications For Lake Productivity

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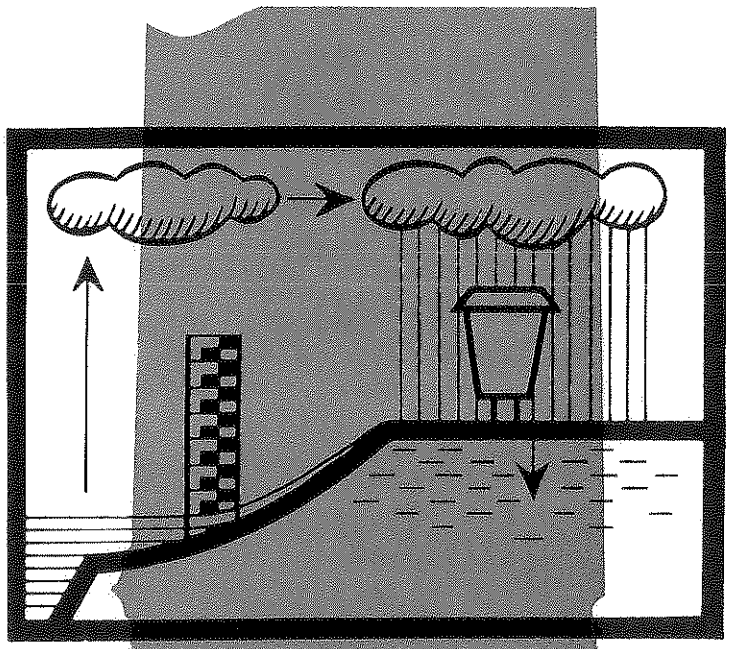

by

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PURDUE UNIVERSITY
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SELECTIVE FEEDING BY ZOOPLANKTON: IMPLICATIONS FOR LAKE PRODUCTIVITY

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and Charles R. Lovell

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ABSTRACT

The relationship between phytoplankton, bacteria, and zooplankton activities and distributions was studied in two Indiana lakes: Crooked and Little Crooked. Primary production in the metalimnion was an important source of fixed carbon in these lakes. In Crooked Lake, metalimnetic production accounted for 30-45% of the total production during the summers of 1979-1981. Changes in the vertical distribution of biomass in the water column had a greater effect upon metalimnetic production than differences in water transparency or incident solar radiation. From 1979 to 1981, the depth at which the metalimnetic layer of cyanobacteria stratified decreased from 9 m to 5 m.

Excretion of organic carbon by phytoplankton populations is a potentially important source of carbon for heterotrophic bacteria. The effects of light intensity, oxygen concentration, and pH on the rates of excretion and photosynthesis of metalimnetic phytoplankton populations of Little Crooked Lake, IN, were studied. The photosynthetic rates of water samples were proportional to light intensity and increased from 1.42 to 3.14 mg $C \cdot mg^{-1}$ chlorophyll $a \cdot hr^{-1}$ within a range of light intensities from 65 to 150 $\mu E \cdot m^{-2} \cdot sec^{-1}$. Rates of excretion in this range of light intensities remained constant at 0.05 mg $C \cdot mg^{-1}$ chlorophyll $a \cdot hr^{-1}$. Elevated oxygen concentrations in samples incubated at 150 $\mu E \cdot m^{-2} \cdot sec^{-1}$ decreased rates of both photosynthesis and excretion. The photosynthetic rate increased from 3.0 to 5.0 mg $C \cdot mg^{-1}$ chlorophyll $a \cdot hr^{-1}$ as the pH was raised from 7.5 to 8.8. Excretion rates within this pH range decreased slightly. Calculation of total primary production using a numerical model showed that whereas 225.8 g $C \cdot m^{-2}$ was photosynthetically fixed during the period between May 12 to August 24, 1982, only 3.1 g $C \cdot m^{-2}$ was excreted by phytoplankton. Thus, excreted carbon constitutes a small percentage of the

Little Crooked Lake metalimnetic carbon pool and is not significantly increased by variations in pH, oxygen concentration, or light intensity typically found in the metalimnion of this lake.

Heterotrophic bacterial activity in the two lakes generally correlated very well with the distribution of phytoplankton. Although there were relatively small changes in bacterial cell numbers with depth (range: x 10^6 cells/ml), bacterial activity, assayed by the incorporation of ^{3}H-methyl-thymidine into cell material, was highest in the region of the metalimnetic chlorophyll maximum. Bacterial activity was primarily associated with planktonic bacteria rather than cells attached to particles. Several zooplankton species found in the lake were capable of ingesting bacteria and unicellular cyanobacteria but could not feed on filamentous cyanobacteria, the most important phytoplankton in the lakes.

Vertical distributions of zooplankton were correlated to the vertical distribution of phytoplankton. Thus, peak abundance was often found in the metalimnion. In 1981, *Diacyclops thomasii* was the most important zooplankton in the two lakes. In subsequent years, its importance decreased, *Diaptomus* species remained important in the lakes, and in 1983 *Daphnia magna* became the predominant member of the zooplankton community in Little Crooked Lake.

The relationship between primary producers (algae) and primary consumers (zooplankton) is extremely important to the structure and productivity of lakes. Selective grazing by zooplankton can influence the algal species that predominate in lakes, and zooplankton populations may in turn be determined by selective foraging by fish populations. The structure of the phytoplankton community is often altered as a result of eutrophication (nutrient enrichment), a major problem in the United States and throughout the world. Blue-green algae densely populate eutrophic lakes, possibly due to the inability of zooplankton to efficiently graze populations of these organisms.

Crooked and Little Crooked Lakes (Noble-Whitley Counties, Indiana) are excellent systems for studying the interaction of zooplankton grazing and algal productivity for several reasons. First, Crooked Lake has been one of the cleanest lakes in Indiana, and an understanding of the effects of zooplankton grazing here may therefore allow us to understand how algal blooms in more productive lakes may be controlled. Second, species of large blue-greens (*Oscillatoria rubescens*), small blue-greens, and bacteria are all present in the lake, along with several species of zooplankton (calanoid and cyclopoid copepods as well as *Daphnia*), allowing results to be generalized to most Indiana lakes. Third, populations of commercially important planktivorous fish such as cisco, brown and rainbow trout, and sunfish are also abundant in the lake and are already under study by fisheries biologists from the Department of Natural Resources.

Thus, this problem requires monitoring the biological activity of several trophic levels simultaneously and then analyzing how these trophic levels interact with one another. In this report, we have analyzed the distribution and activity of phytoplankton, bacterial, and zooplankton populations in these lakes.

I. PRIMARY PRODUCTION

Northern Indiana contains a number of marl lakes, which are characterized by high concentrations of bicarbonate and calcium ions, alkaline pH, and deposition of carbonate minerals (Wetzel 1966). These and other factors interact to limit productivity in such lakes (Wetzel 1972). Many of the lakes contain metalimnetic populations of phototrophs, which usually consist of diatoms, dinoflagellates, or cyanobacteria (Eberly 1964). The lake examined in this study, Crooked Lake, is a marl lake that contained dense cyanobacterial layers in 1979, 1980, and 1981.

Metalimnetic phytoplankton populations have been shown to exist in a number of different types of lakes (Eberly 1964, Fee 1976, DeAmezaga et al. 1973). However, the relative importance of metalimnetic populations to total lake productivity, and the factors which influence metalimnetic production have not been well characterized. One might expect a significant fraction of the photosynthesis in the water column to occur in the metalimnion, because phototrophic population densities are often much greater than in the epilimnion. In this report, I use a numerical model to estimate primary productivity in Crooked Lake during the summers of 1979-1981 in order to examine the factors that influenced metalimnetic production. Calculation of primary production in the metalimnion, a region that has a temperature discontinuity and a physiologically distinct phytoplankton population from that in the epilimnion, presents computation problems not found in models which calculate production in a homogeneous epilimnion. These aspects are discussed for a model which is of general use in calculating metalimnetic production. Furthermore, the results are compared to primary production values determined in 1963-1964 (Wetzel 1965), and related to other changes found in Crooked Lake.

Materials and Methods

Crooked Lake is located in Noble and Whitley counties, Indiana, U.S.A. Data were collected from the lake at weekly or biweekly intervals from April to September during 1979, 1980, and 1981. The water column was 30 m deep at the sampling site. Temperature and oxygen measurements at various depths of the lake were made with a YSI model 54 temperature/oxygen probe (Yellow Springs Instruments, Kettering, Ohio). Light penetration was determined with a Li-Cor quantum sensor (Lambda Instruments, Lincoln, Nebraska). Water samples were collected with a Van Dorn bottle (Wildco Supply Co., Saginaw, Mich.). Chlorophyll *a* concentrations in samples were determined from the absorbance at 663 nm of dimethyl sulfoxide:acetone extracts (40:60) of organisms filtered onto glass fiber filters (Burnison 1980).

The photosynthetic rate of natural samples was determined at six light intensities at 10 to 14 d intervals during 1980 and 1981. Photosynthetic rate was measured in a sample from 2 m (epilimnion population) at irradiances up to 1500 $\mu E \cdot m^{-2} \cdot s^{-1}$. In a sample from the metalimnetic chlorophyll maximum, photosynthetic rate was determined at intensities of 0-300 $\mu E \cdot m^{-2} \cdot s^{-1}$. Experiments were initiated in the Crooked Lake Biological Station laboratory within 30 min after sample collection. Photosynthesis was determined by the uptake of $NaH^{14}CO_3$ into particulate material. Seventy-four kBq of ^{14}C was added to 25 mL of lake water in a screw cap test tube. In the laboratory, tubes were incubated in duplicate at 25°C for 3 h at the appropriate light intensities using photoflood lamps for the epilimnion samples and cool white fluorescent lamps for the metalimnion samples. At the end of the incubation period, samples were filtered through either 0.45 µm pore size membrane filters (Gelman GN-6) for epilimnion samples or glass fiber filters (Reeve Angel 984H)

for metalimnion samples, rinsed with distilled water, exposed to HCl fumes for 20 minutes, dried, and counted in a Tracor Delta 300 scintillation counter by employing a toluene-based scintillation cocktail with 4 g of 2,5 diphenyloxazole and 0.1 g of p-bis-[2-(4-methyl-5-phenyloxazolyl)]-benzene per liter. The concentration of dissolved inorganic carbon was determined from measurements of pH and alkalinity (Stumm and Morgan 1970).

In situ measurements of primary production were made by collecting samples from discrete depths before 08:00 hours adding 74 kBq $NaH^{14}CO_3$ to 25 mL of lake water in a screw cap tube. For each sample, three tubes (2 light and 1 dark) were suspended at the depth from which the sample was collected. After incubation for 3-4 h, the tubes were recovered and processed as described above.

Solar radiation measurements were made during 1981 at the Crooked Lake Biological Station with a LiCor quantum sensor attached to an integrator (LiCor Solar Monitor, Lambda Instruments, Lincoln, Nebraska). Solar radiation data for 1979, 1980, and 1981 were obtained from the U.S. National Weather Service station located in Ft. Wayne, Indiana, located 50 km from the study site.

A numerical model was used to calculate primary production. A program was written in Pascal 6000 and run on a Control Data Corporation 6500 computer at the Purdue University Computing Center. The program takes as input the vertical distribution of light penetration, temperature, and chlorophyll _a_ in the lake, as well as the photosynthetic response of phytoplankton to light intensity measured in the laboratory. Solar radiation values may be input or calculated by the program.

Results and Discussion

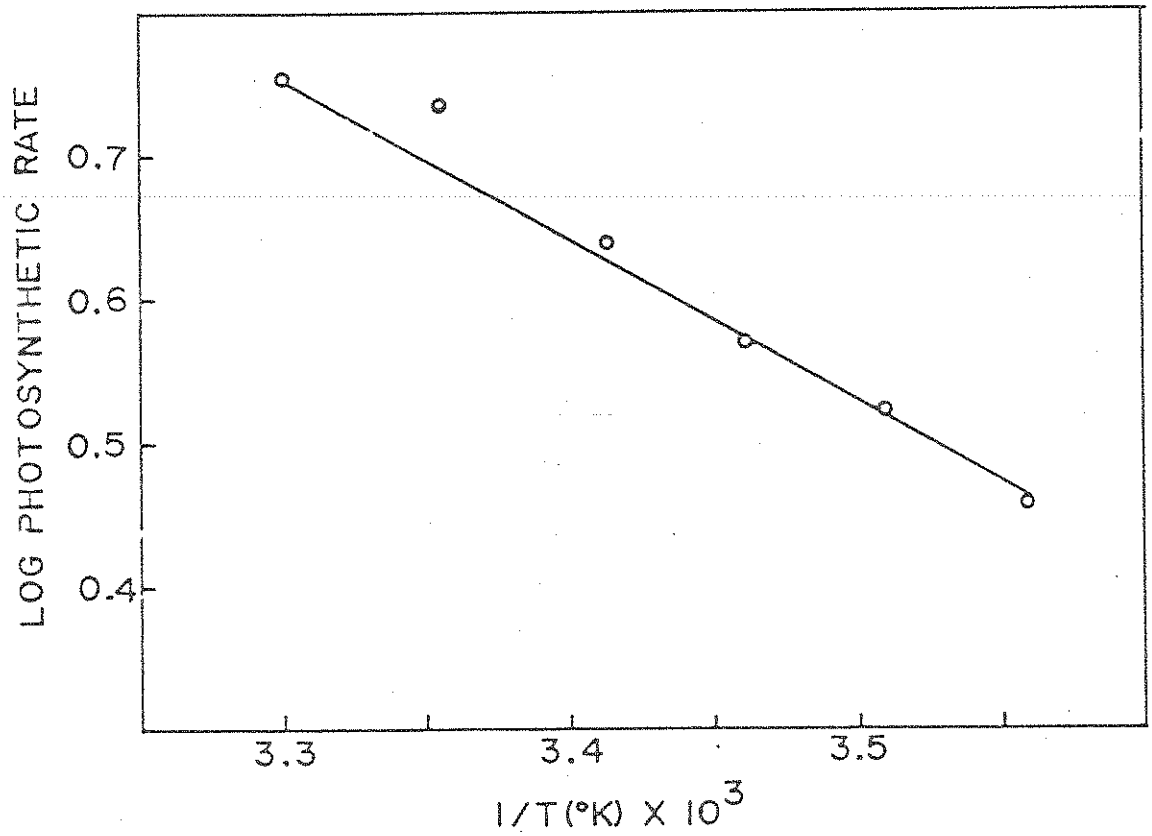
Photosynthetic production at 1 m depth intervals and hourly time intervals was calculated according to the equation of Jassby and Platt (1976):

$$P(\text{mg C} \cdot \text{m}^{-3}) = P_m^B \tanh (\alpha \cdot I/P_m^B) \cdot C \cdot T$$

where P_m^B and α are kinetic parameters corresponding to the maximum rate (mg C • mg Chl $\underline{a}^{-1}$ • h^{-1}) and initial slope of photosynthetic rate as a function of light irradiance for natural populations. These parameters were determined from measurments of photosynthetic rate that were made in laboratory incubators. I, the light irradiance at the depth and time considered was calculated using vertical profiles of light attenuation in the lake coupled with values for solar radiation determined (a) mathematically for cloudless weather (Brock 1981), (b) by direct measurement at Crooked Lake, or (c) from U.S. Weather Service data collected 50 km away in Ft. Wayne, Indiana. C is the density of algal biomass (mg Chl a • m^{-3}), and T is the time increment (hours). In lakes such as Crooked Lake, where the depth of the photic zone exceeds the depth of the epilimnion, there are two additional factors to consider in calculating production. First, the lake contains distinct phototrophic populations in the epilimnion and metalimnion. Photosynthetic responses to light irradiance were measured in samples from both strata. The second problem is that temperature within the metalimnion varied from 6 to 17°C and temperature changes could affect short term photosynthetic rates and cause physiological changes in the metalimnetic phytoplankton species found at different strata. Experimentally, it was most convenient to measure the functional response of photosynthetic rate to changes in light intensity at one

temperature (25°C) and then make corrections in the model for in situ temperatures. The effect of temperature upon short-term photosynthetic rates are primarily upon P_m^B rather than α (Aruga 1965; Li 1980; Konopka 1981). Experimental measurements of P_m^B at a series of temperatures were made in samples from the metalimnion of Crooked Lake (Fig. I-1), and a Q_{10} of 1.5 was found. This was similar to the values previously reported for organisms from this lake (Konopka 1981). In the numerical model, P_m^B was corrected for differences between the temperatures of the environment and the experimental incubators by using the Q_{10} value. Physiological changes that resulted from differences in the temperature at which metalimnetic organisms existed might also affect primary productivity. However, possible effects of temperature "adaptation" were ignored in this study for 2 reasons. First, most studies have found that although the photosynthetic rate per cell is different for organisms adapted to different temperatures, photosynthetic rate per unit chlorophyll (as used in this study) did not change (Rhee 1982). Second, the gas vacuolate cyanobacteria found in Crooked lake vertically migrated through the metalimnion (Konopka 1982). Although their rate of movement was not fast (approximately 1 $m \cdot day^{-1}$), this vertical movement would prevent physiological heterogeneities in photosynthetic rates if it were faster than the time required for temperature "adaptation". This time course is poorly understood, and values from 0 to 100 hours have been reported (Li 1980). Because of these considerations, and previous data which showed that organisms sampled from different temperatures within the metalimnion had the same photosynthetic rates (Konopka, 1980), no corrections for physiological adaptations to temperature at different depths were made.

Figure I-1. Arrhenius plot of the maximum photosynthetic rate of Crooked Lake phytoplankton at different temperatures. The photosynthetic rate of a sample from the metalimnion was measured at 300 uE/m^2/s at temperatures from 8-30 C.



The two parameter model was used to describe photosynthesis at different irradiances instead of a four parameter model which included terms for high irradiances and dark respiration (Platt and Gallegos 1981). This latter model was not used because photoinhibition was not found in epilimnion samples incubated at irradiances up to 1500 $\mu E \cdot m^{-2} \cdot s^{-1}$, and light intensities in the metalimnion never exceeded 200 $\mu E \cdot m^{-2} \cdot s^{-1}$, well below the threshold where photoinhibition was observed in metalimnetic populations.

Fee (1978) corrected the metalimnetic production values that were calculated using a numerical model to "force" them to agree with production values obtained from in situ incubations. Although he originally suggested that such corrections were necessary because of differences in light quality between the lake metalimnion and the laboratory incubators, it is now known that the problem was a systematic error in measuring irradiances in the incubators (E. Fee, Freshwater Institute, Winnipeg, Manitoba, personal communication). This procedure was not used in this study, because the model becomes less general. These correction factors must be determined for each lake, and values for a particular lake will probably change during the season, because the light extinction coefficients and photosynthetic characteristics of the phytoplankton vary (Konopka 1982b). Whereas Fee (1978) reported that his model overestimated in situ production 2 to 5-fold in the metalimnion and hypolimnion, the differences in this study were much less (Table I-1). Although I cannot explain the smaller differences between the model and in situ measurements in this study, metalimnetic samples were incubated under lamps that emit strongly in the 500-600 nm range, which has been found to be the most penetrating component of sunlight into the lake (R. Wetzel, Kellogg Biological Station, Michigan State University, Hickory Corners, Michigan, personal

Table I-1. Comparison of in situ measurements and model estimates of primary production in Crooked Lake for three types of weather conditions.[a]

Date	July 12, 1979		September 7, 1979		October 6, 1979	
Weather	Sunny		Partly Cloudy		Cloudy	
Depth	In situ	Model	In situ	Model	In situ	Model
0	50	70	112	152	25	40
1	61	88	113	135	23	39
2	92	47	114	122	20	28
3	63	58	85	92	20	24
4	68	74	56	69	16	20
5	84	71	56	43	10	13
6	123	70	37	69	10	11
7	68	110	65	47	6	7
8	817	1140	40	34	9	9
9	934	639	41	31	3	8
10	26	25	99	65	10	13
Total (mg C $m^{-2} \cdot d^{-1}$)	2566	2392	818	859	152	212

[a] values an expressed as mg C $\cdot$ m^{-3} $\cdot$ d^{-1}

communication). For this study, it was preferable to have a small discrepancy between the model and measured in situ production, rather than introduce factors for which there is no clear biological rationale.

Estimates of primary production were restricted to the periods May 1-August 31 of 1979, 1980, and 1981. Crooked Lake was thermally stratified at these times, and contained a metalimnetic layer of cyanobacteria. Kinetic parameters for photosynthesis were determined for epilimnetic and metalimnetic samples during these periods in 1980 and 1981 (Table I-2). These data were not collected in 1979, but to estimate production during this year the means of the parameters determined during 1980 and 1981 were used in the numerical model.

The most direct comparison of productivity among the 3 years occurs if identical inputs of solar radiation are used. The intensity of cloudless solar radiation was calculated (Brock 1981) at hourly intervals for each day and used to estimate primary productivity (Fig. I-2 and Table I-3). Total production was similar in 1979 and 1980, but 50% higher in 1981. Production in the top 4 m of the water column was twofold greater in 1981, primarily because a relatively dense population (16 mg chlorophyll *a* $\cdot$ m^{-3}) persisted in the epilimnion during May and contributed 40 g of C production, and chlorophyll *a* levels in the epilimnion during the remainder of the summer were approximately twice as large as in previous years. Total metalimnetic production (at depths below 5 m in 1979 and 1980, and depths below 4 m in 1981) was similar in 1980 and 1981, although metalimnetic production was a smaller proportion of the total in 1981 because of increased production in the epilimnion.

The production estimates listed in Table I-3 represent an upper limit for actual production in the lake because they were calculated using maximum possible solar radiation. Actual daily radiation was estimated from data

Table I-2. Mean and standard deviation of photosynthetic parameters measured in samples from Crooked Lake.[a]

	1980	1981
Epilimnion sample		
α[b]	0.042±0.030	0.040±0.026
P_m^B [c]	6.2±2.4	5.2±1.7
Metalimnion sample		
α	0.112±0.12	0.050±0.022
P_m^B	3.4±1.2	4.3±1.5
n =[d]	10	7

[a] In the numerical model, the kinetic parameters that were used to calculate production for a specific day were those experimentally determined on the date closest to the day for which production was calculated.

[b] g C • mg chlorophyll^{-1} • h^{-1} • (μE • m^{-2} • s^{-1})$^{-1}$ ± S.D.

[c] g C • mg chlorophyll^{-1} • h^{-1} ± S.D.

[d] number of determinations made from May 1-August 31 of each year.

Table 3. Primary productivity and some environmental parameters of Crooked Lake.

YEAR	PRODUCTION[a] g C · m^{-2}	METALIMNETIC PRODUCTION[a] g C · m^{-2}	LIGHT EXTINCTION COEFF.(m^{-1})[b]	mg CHL a · m^{-2}[b]	DEPTH OF METALIMNETIC LAYER(m)[c]	% SURFACE LIGHT	n=[d]	PREDOMINANT SPECIES
1979	183	53.4	0.50 ± 0.15	169 ± 53	9	1.1	12	Oscillatoria rubescens
			(0.34 - 0.67)	(97 - 267)	(7 - 11)			
1980	194.6	86.4	0.54 ± 0.05	99 ± 29	7	2.3	15	Oscillatoria rubescens
			(0.43 - 0.59)	(63 - 159)	(6 - 8)			Oscillatoria redekei
1981	295	99.4	0.60 ± 0.19	120 ± 30	5	8.2	14	Aphanizomenon flos-aquae
			(0.42 - 0.89)	(73 - 169)	(4 - 6)			Oscillatoria rubescens

[a] calculated for May 1 - August 31, presuming cloudless solar radiation

[b] values are reported as annual mean ± standard deviation, with anual range listed in parentheses

[c] values are reported as median, with annual range listed in parentheses

[d] number of vertical profiles measured from May 1 - August 31

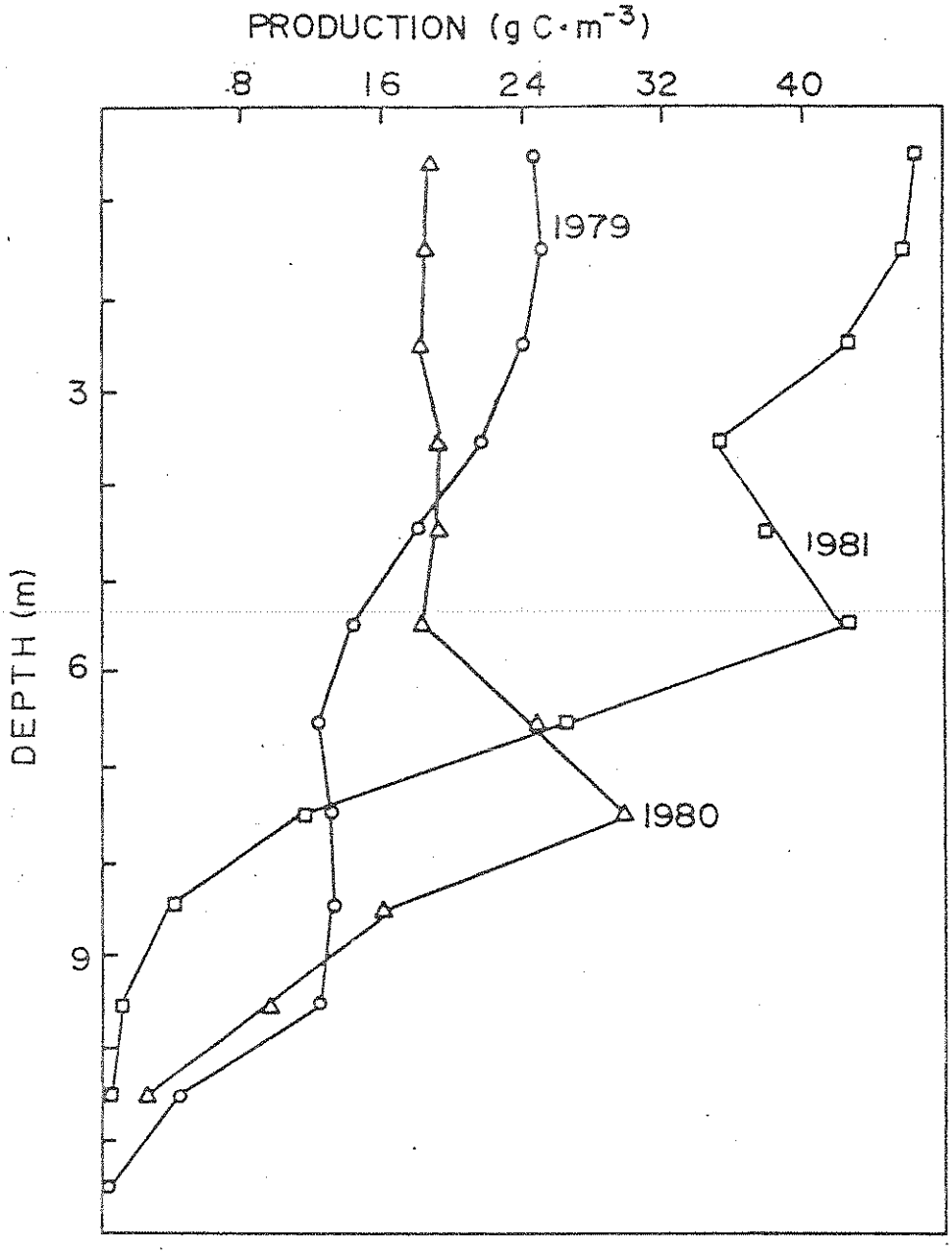


Figure I-2. Photosynthetic production at 1 m depth intervals in Crooked Lake for the period May 1 to August 31 of (o) 1979, (Δ) 1980, and (□) 1981. Production was calculated using cloudless solar radiation as the input to the numerical model.

collected by the U.S. National Weather Service at Fort Wayne, Indiana. A linear regression of the daily percent possible sunshine reported by the Weather Service against the quotient of daily quantum radiation measured at Crooked Lake divided by the calculated cloudless radiation for the day was determined for the period May 1 - August 31, 1981 ($r = 0.74$). The regression coefficients were used to estimate daily quantum radiation for each year from National Weather Service data. Production values calculated using these estimates of solar inputs were 170.2, 177.4, and 246.2 g C $\cdot$ m^{-2} for May 1 - August 31 of 1979, 1980, and 1981 respectively. These values are very similar to those calculated using cloudless insolation, except for 1981, in which the estimate was 10% lower. Radiation measured by the Weather Service was proportionally lower in 1981; the mean value of possible sunshine decreased from 81% during the summers of 1979 and 1980 to 73% in 1981. Solar radiation at Crooked Lake was directly measured during 1981, and using these data, a value of 228 g C $\cdot$ m^{-2} was calculated for the period May 1-August 31, 1981. Therefore, the use of National Weather Service radiation data in this study may have overestimated production by about 10%.

In 1963 and 1964, the primary productivity of Crooked Lake was determined using in situ incubation of samples to which $NaH^{14}CO_3$ was added (Wetzel 1965). For the period May 1 - August 31, production was 112 g C $\cdot$ m^{-2} in 1963 and 70 g C $\cdot$ m^{-2} in 1964. These values are 2-4 fold lower than those calculated for 1979-1981. Thus, primary production in the lake appears to have increased during this time interval, although it is difficult to know how much the different methods used to estimate production, rather than real increases in algal production, contributed to the observed increases.

The concentration and photosynthetic activity of phytoplankton are

important determinants of primary productivity. However, the relative importance of productivity in the metalimnion is determined by the intensity of solar radiation, transparency of the water column, and depth distribution of the metalimnetic population, all of which affect the light intensity which reaches the phototrophs in the metalimnion. Computer simulations were used to study each factor independently; typical values found in 1980 were specified for other parameters used in the calculations. Changing the light extinction coefficient had the most severe effect upon metalimnetic production (Fig. I-3). However, the light extinction coefficients measured in the lake were fairly consistent from June through August; most of the dispersion in these data was due to high coefficients measured in May. Furthermore, although the mean light extinction coefficient increased from year to year, the metalimnetic production estimate also increased. Thus, variation in light transparency was not the most important factor affecting production in the metalimnion.

Metalimnetic production decreased more sharply than photosynthetic production in the epilimnion when the amount of solar radiation entering the lake was decreased (Fig. I-4). Thus, cloudy climatic conditions would diminish the relative importance of metalimnetic production, but if such conditions persisted for several days, the gas vacuolate cyanobacteria could compensate by floating up to a shallower depth. No clearcut correlations between the depth of cyanobacterial stratification and changes in radiation input were found in Crooked Lake. However, the conditions under which this response was anticipated (very low solar radiation inputs) only persist for 2-3 days, and the cyanobacterial filaments can only migrate 1 m in this time (Konopka, 1982a).

Variations in the depth at which the metalimnetic phytoplakton stratified

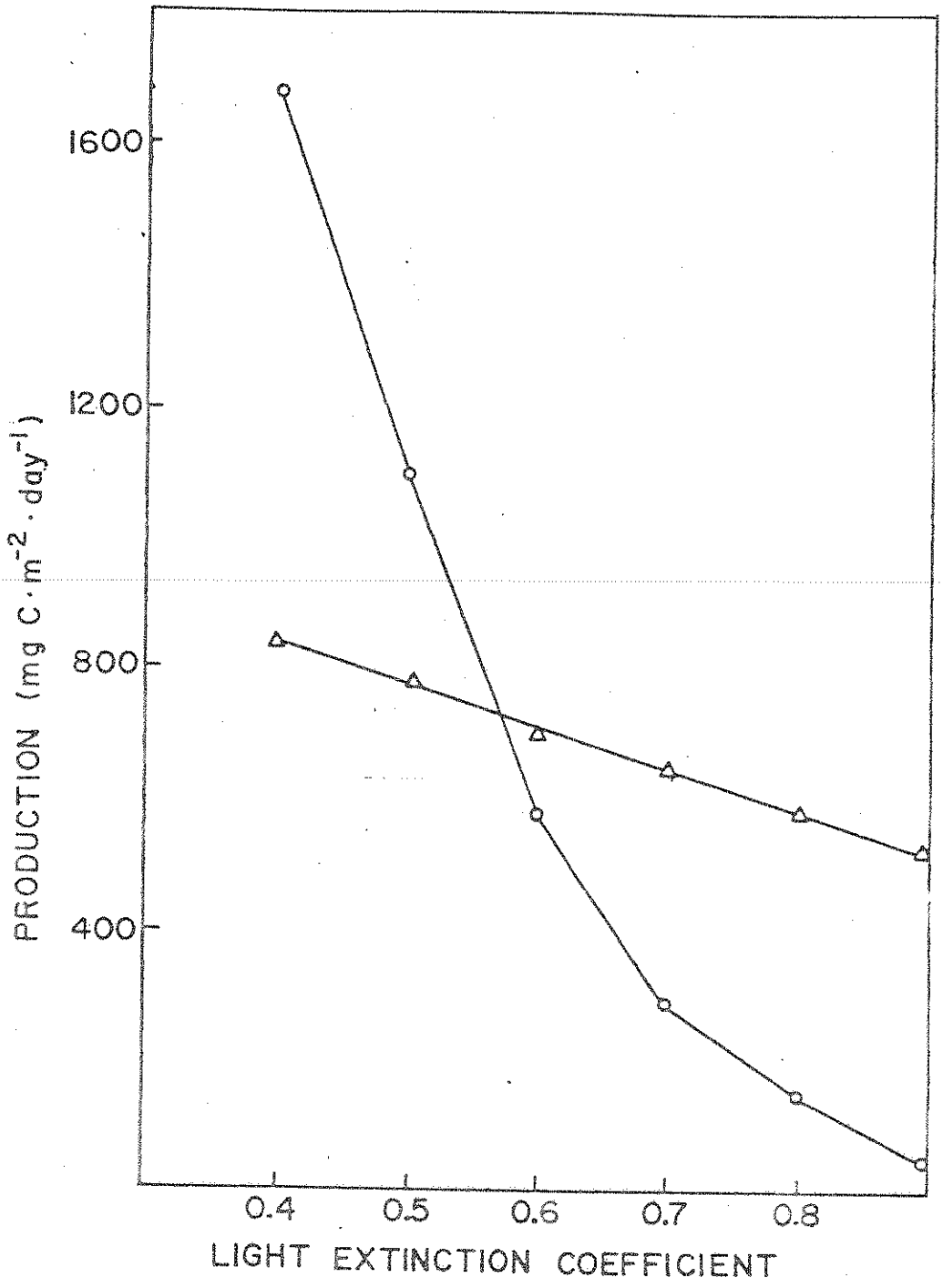


Figure I-3. Simulation of primary productivity in the (△) epilimnion and (□) metalimnion at different values of the light extinction coefficient into the water column. Other factors for the simulation were average values measured in 1980, and solar input of 50 E/m^2/day was specified.

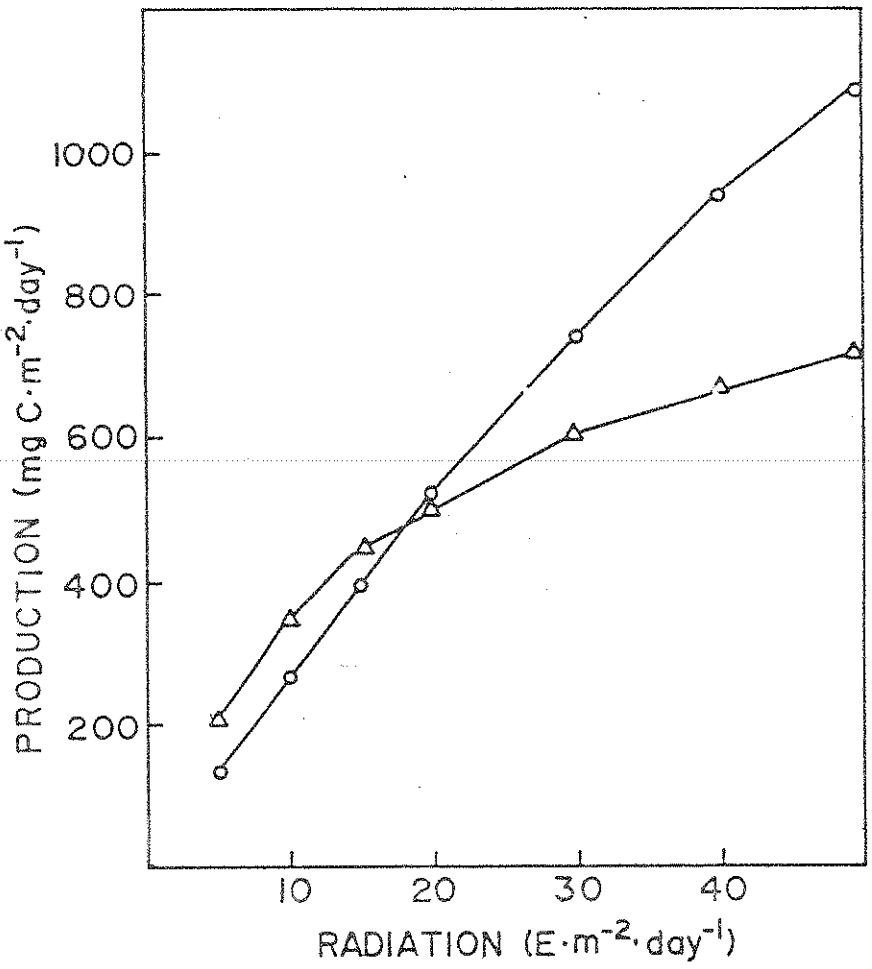


Figure I-4. Simulation of primary productivity in the (Δ) epilimnion and (o) metalimnion at different daily solar radiation inputs. Other parameters for the simulation were average values measured in 1980.

had the greatest actual effect upon metalimnetic production in the lake. Computer simulations demonstrated that shifting the metalimnetic layer of cyanobacteria 1 m toward the surface doubled the calculated production in the metalimnion. Total phototrophic biomass (chlorophyll *a* • m^{-2}) in the water column was larger in 1979 than in subsequent years, but metalimnetic production was much less that year because most of the biomass consisted of *Oscillatoria rubescens*, which stratified at a depth of 9 m (Fig. I-5), where incident light intensity was only 1% of that at the surface. Therefore, photosynthetic production by this larger population was severely limited by available light. In subsequent years the metalimnetic populations stratified at shallower depths and as a result the irradiance that reached the metalimnetic peak of biomass was 8.2% of the surface irradiance in 1981 and production in the 4-6 m layer was much higher.

The metalimnetic populations were comprised of gas vacuolate cyanobacteria; buoyancy in these organisms is regulated such that the photosynthetic rate determined by light intensity does not exceed the rate at which inorganic nutrients can be assimilated for growth (Dinsdale and Walsby 1972). Stratification at shallower depths in 1981 can be interpreted in two ways. (A) Nutrient availability may have been greater, and this allowed the organisms to maintain neutral buoyancy at a higher light intensity. (B) Different species inhabited the metalimnion in 1981 (Table I-2), including heterocystous species which have a high energy requirement when fixing nitrogen gas (Zevenboom 1980). Perhaps stratification at shallower depths (and higher irradiance) was necessary for these species to meet higher energy demands. The appropriate physiological experiments have not been done to resolve these two hypotheses, although the 3-fold higher rainfall recorded in May, 1981 and increased biomass

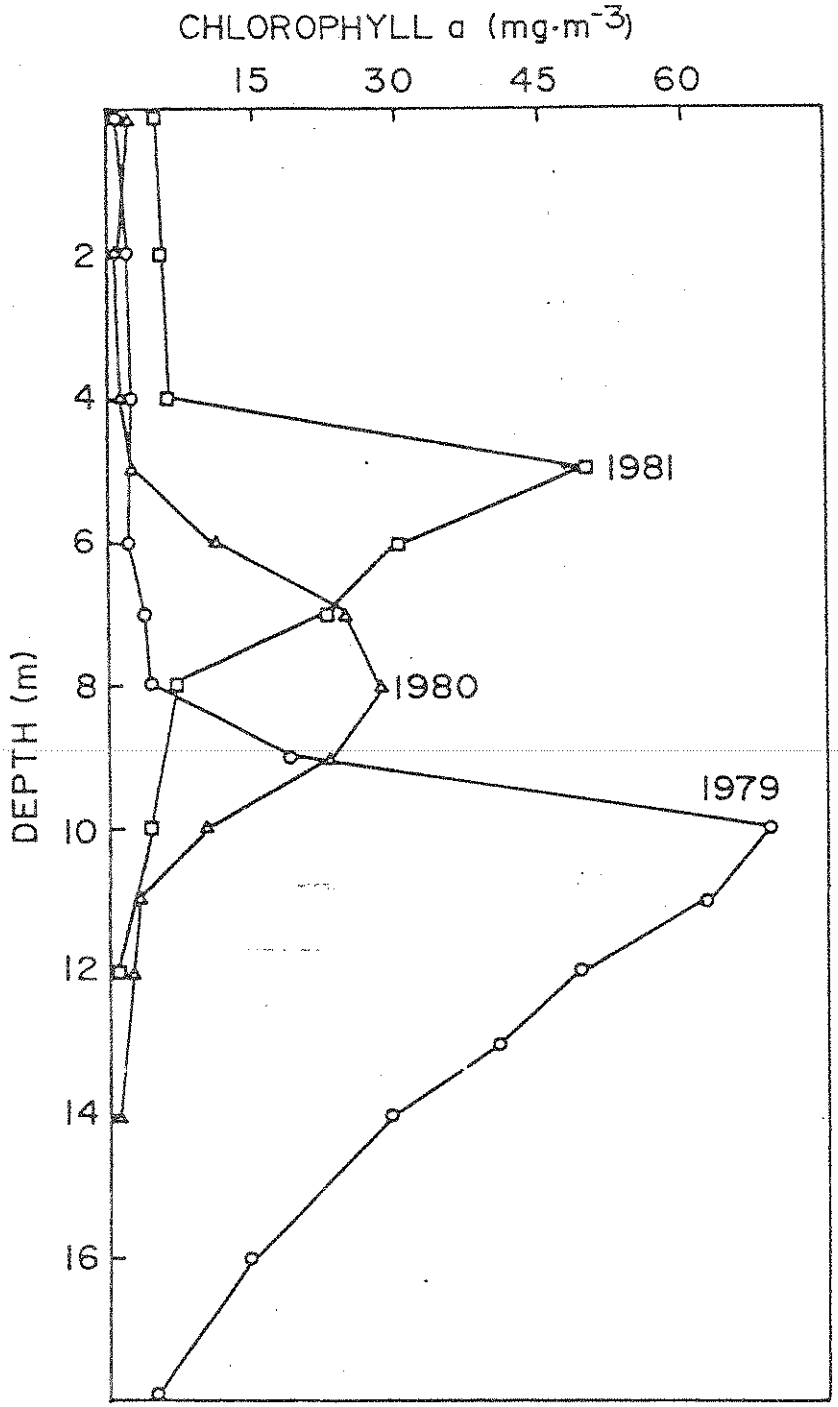


Figure I-5. Vertical distribution of chlorophyll in Crooked Lake during the first week of July for (o) 1979, (Δ) 1980, and (□) 1981.

found in the epilimnion during this year suggest that nutrient inputs may have been larger than in the previous years. If nutrient inputs are indeed increasing the lake will contain dense phytoplakton populations in the epilimnion within a few years. New sources of nutrient loading are not obvious: the watershed of this lake includes some agricultural fields but is relatively small, and construction of homes along the shoreline has not increased during the past 3 years.

Stratification of the cyanobacteria at 5 m and increased primary production during 1981 affected other aspects of the lake. The vertical distribution of dissolved oxygen was different in 1981 (Fig. I-5). Crooked Lake has been one of the few Indiana lakes to support a fish population of the planktivore Coregonus artredii (cisco). These fish inhabited the cold, oxygenated metalimnetic layers of the lake. However, because cyanobacteria stratified at a shallower depth in 1981, the oxygen accumulated in warmer water, and in the zone just below the cyanobacterial layer (a region in which respiration is relatively high) oxygen was depleted in early July. After this time, dead cisco were seen in the lake. The zooplankton density in the lake was 3-fold higher in 1981 than in previous years; perhaps this was due in part to decreased predation by cisco. The lake bottom became anaerobic in early July, 1981, about 6 weeks earlier than in previous years. As a result, the sediments served as a source of phosphate in the hypolimnion for a longer period of time in 1981 (the dissolved inorganic phosphate concentration 1 m above the bottom sediment rose from 30 $\mu g\ P \cdot L^{-1}$ on June 29 to 300 $\mu g\ P \cdot L^{-1}$ on August 17) and might contribute to increased primary production in 1982. Crooked Lake will provide an interesting study of the interaction between factors which limit

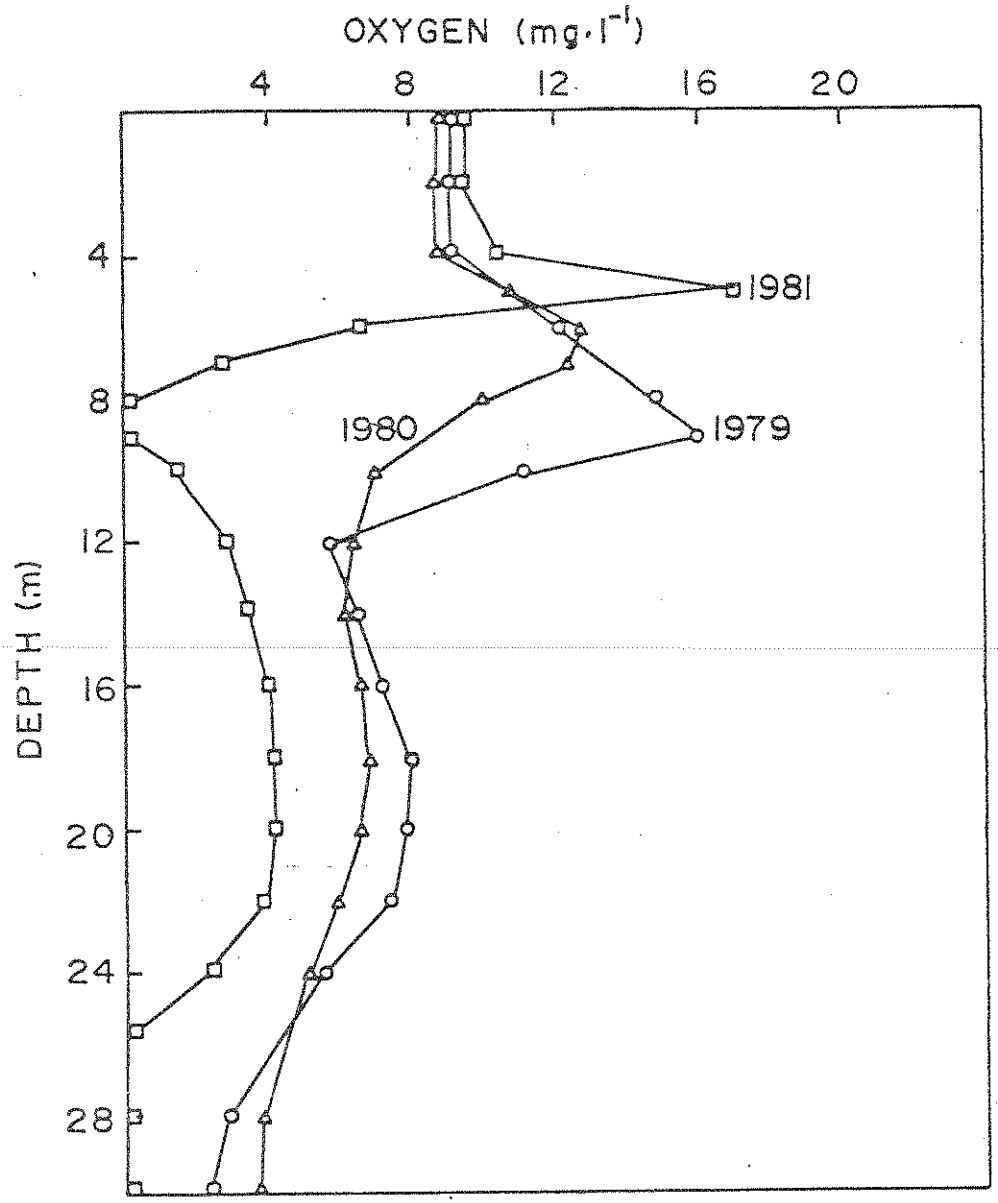


Figure I-6. Vertical distribution of dissolved oxygen in Crooked Lake during the first week of July for (o) 1979, (△) 1980, and (□) 1981.

productivity in hardwater lakes such as calcium carbonate precipitation (Wetzel 1972), and factors involved in eutrophication, such as the formation of anaerobic layers and subsequent release of phosphate from sediments.

In Crooked Lake, metalimnetic production was responsible for 30-45% of total production, a much larger proportion than was reported for Canadian lakes in the Experimental Lakes Area (Fee 1978). Simulations using the model demonstrated that, in general, metalimnetic production decreased as the light extinction coefficient increased, solar radiation decreased, or the depth at which the phytoplankton stratified increased. In most system, the depth of stratification should be most important, because the species which form these deep layers (usually cyanobacteria or flagellates) can actively regulate their vertical position. Cyanobacteria have been shown to regulate their buoyancy in response to light intensity and nutrient concentration (Konopka, 1982a). Thus, the quantitative importance of metalimnetic production in these lakes will be determined by the light intensity at which the phytoplakton can maintain their vertical position, as dictated by the interaction between nutrient and light availability at that stratum.

II. ALGAL EXCRETION

Photosynthetically fixed organic carbon excreted by phytoplankton populations has been shown to be an important carbon source for planktonic bacteria in several aquatic ecosystems. Derenbach and Williams (1974) and Larsson and Hagström (1982) found that excreted carbon could support up to about 50% of the total bacterial production in two different marine habitats. However, relatively few studies of the environmental factors which influence rates of excretion have appeared. We have been studying populations of heterotrophic and blue-green bacteria in the metalimnia of hardwater Indiana lakes. These organisms are exposed to gradients of light intensity, oxygen concentration, and pH in these habitats. In comparison to the epilimnion, light intensities which penetrate to the metalimnion are low (1-2% of the intensity at the lake surface) and the concentration of oxygen is high and often exceeds the saturation value (Konopka, 1981). To assess the importance of phytoplankton excretion as a source of carbon to heterotrophic bacteria, the effects of pH, oxygen concentration and light intensity on rates of photosynthesis and excretion by metalimnetic phytoplankton from Little Crooked Lake (Noble County, IN) were determined. The results showed that rates of excretion by metalimnetic phytoplankton were not influenced to any great degree by changes in pH, oxygen concentration and light intensities of magnitudes likely to be seen in Little Crooked Lake. Furthermore, estimates of primary production and excretion in Little Crooked Lake that were made using the data collected in this study and calculated by a numerical model indicated that excreted carbon represented less than 2% of total photosynthetic carbon fixation.

Materials and Methods

This study was conducted on Little Crooked Lake (Noble County, IN). Temperature and oxygen measurements were made with a YSI model 54 temperature oxygen probe (Yellow Springs Instruments, Kettering, OH). Light penetration was determined with a Li-Cor quantum sensor (Lambda Instruments, Lincoln, NB). Water samples were collected with a Van Dorn bottle (Wildco Supply Co., Saginaw, MI). The location of the metalimnetic cyanobacterial layer was determined from chlorophyll a measurements of discrete samples from the water column. Chlorophyll a concentrations were determined from the absorbance at 663 nm of dimethyl sulfoxide-acetone extracts (40:60) of organisms filtered onto glass fiber filters (Shaaf and Lium, 1976). The pH of lake water samples were determined with a Digisense pH meter (Cole-Parmer, Chicago, IL). Samples for experiments were taken from the depth of maximum chlorophyll concentration. Experiments were initiated 10 minutes after sample collection in the laboratory of the Crooked Lake Biological Station.

Rates of photosynthesis and excretion were determined from incorporation of $NaH^{14}CO_3$ into particulate and dissolved organic matter. Triplicate 25 ml samples of lake water were dispensed into screw-capped test tubes fitted with hole caps and teflon-lined septa (Supelco, Bellefonte, PA). The tubes were preincubated in the laboratory at 25°C and appropriate light intensities (provided by cool white fluorescent bulbs) for 30 minuts. After preincubation one µCi of purified (see below) $NaH^{14}CO_3$ (Amersham, 58 mCi/mmole) was injected through the septum of each tube and the samples were incubated for 2-3 hours. Samples incubated in the dark were included as controls in each experiment. For experiments involving varied pH or oxygen concentration water samples were adjusted to the desired value of pH or of oxygen concentration before

dispensing, and samples were incubated at a light intensity of 150 $\mu E \cdot m^{-2} \cdot sec^{-1}$. At the end of the incubation period, samples were filtered through glass fiber filters at low vacuum (<90 mm Hg). Filtrates were recovered in glass test tubes, acidified to pH 2-3 by addition of 1 N HCl, and bubbled for 15 minutes to remove all inorganic ^{14}C. The filtrates were transferred to scintillation vials and evaporated to dryness. The remaining residues were redissolved in 1 ml distilled water. Ten ml of ACS scintillation fluid (Amersham, Arlington Heights, IL) was added to each vial. Filters were fumed with HCl for one hour to remove precipitated inorganic carbon and transferred to scintillation vials containing 10 ml OCS scintillant (Amersham, Arlington Heights, IL). For pH experiments the fuming process was insufficient to remove the $Ca^{14}CO_3$ that precipitated at high pH. Filters from these experiments were placed in vials and a few drops of HCl added direcly to the filters. After one hour ACS fluid was added. All vials were counted in a Tracor Delta 300 (Tracor Analytic, Austin, TX) liquid scintillation counter. Counting efficiencies were determined using the channel ratios method and a quench curve constructed from a series of quenched standards. A purified solution of $NaH^{14}CO_3$ was prepared by reducing the pH of the stock solution to about 2 and trapping the resulting $^{14}CO_2$ in 3 mM bicarbonate buffer, pH 9. The purified solution was diluted to the desired concentration, dispensed into glass ampoules, and autoclaved at $121^{o}C$ for 30 minutes. The dissolved inorganic carbon concentrations were calculated from pH and alkalinity data for each water sample (APHA, 1975). Species abundances of phytoplankton were determined from direct microscopic counts of samples preserved in formalin (Brock, 1978).

Estimates of primary production by the phytoplankton in Little Crooked Lake were made from experimental measurements of the photosynthetic rate of

epilmnetic and metalimnetic samples at a series of light intensities. Samples were incubated with $NaH^{14}CO_3$ in the laboratory at known irradiances, and processed as described above. Measurements were made at 10 day intervals, and the data were used to calculate photosynthetic carbon fixation by using a numerical model. The model was modified to also calculate the amount of excreted organic carbon, using the data obtained in this study.

Results and Discussion

Little Crooked Lake is a dimictic, hardwater lake. Throughout the summer of 1982 the maximum concentration of chlorophyll was found in the metalimnion at depths which fluctuated from 2 to 6 m. The metalimnetic phytoplankton layer contained several species. Usually filamentous cyanobacterial species were the dominant forms, but in early June flagellated eucaryotic species predominated (Table II-1).

The light intensities that penetrated to the top of the metalimnetic phytoplankton layer ranged from 0.2 to 5.0% of the surface light intensity during the summer (mean = 2.4%). There were gradients of oxygen, temperature and pH in the water column. Changes in pH and oxygen concentration occurred primarily in the metalimnion as is illustrated in the typical profile shown in Figure II-1. Oxygen concentrations were highest in the metalimnion, with the peak concentration always in excess of saturation at atmospheric pressure. The highest concentration observed was 19 $mg \cdot l^{-1}$ (219% saturation) on 2 August 1982. The pH of the lake water decreased from 8.5 in the epilimnion to 7.4 in the metalimnion on 2 August 1982. This pH range was typical of the profiles taken during the summer of 1982. The seasonal pH range of the chlorophyll maximum was 7.5-8.8.

Because the phytoplankton in the metalimnetic layer were subjected to a

Table II-1. Species composition of metalimnetic phytoplankton in Little Crooked Lake during the summer of 1982[a]

Date	Depth (m)	Total biovolume ($mm^3 \cdot l^{-1}$)	Dominant organisms	% of total biovolume
6/5/82	6	1.17	*Cryptomonas*	30.8
			Unidentified flagellate	29.5
			Fragilaria	23.8
6/28/82	3	16.97	*Aphanizomenon flos-aquae*	44.7
			Anabaena	30.2
			Oscillatoria princeps	21.9
7/11/82	4	1.13	*Oscillatoria princeps*	60.4
			Aphanizomenon flos-aquae	33.7
			Anabaena	4.8
8/2/82	4	36.00	*Aphanizomenon flos-aquae*	55.5
			Anabaena	29.5
			Ceratium hirundinella	10.9

[a]Calculated from direct microscopic counts.

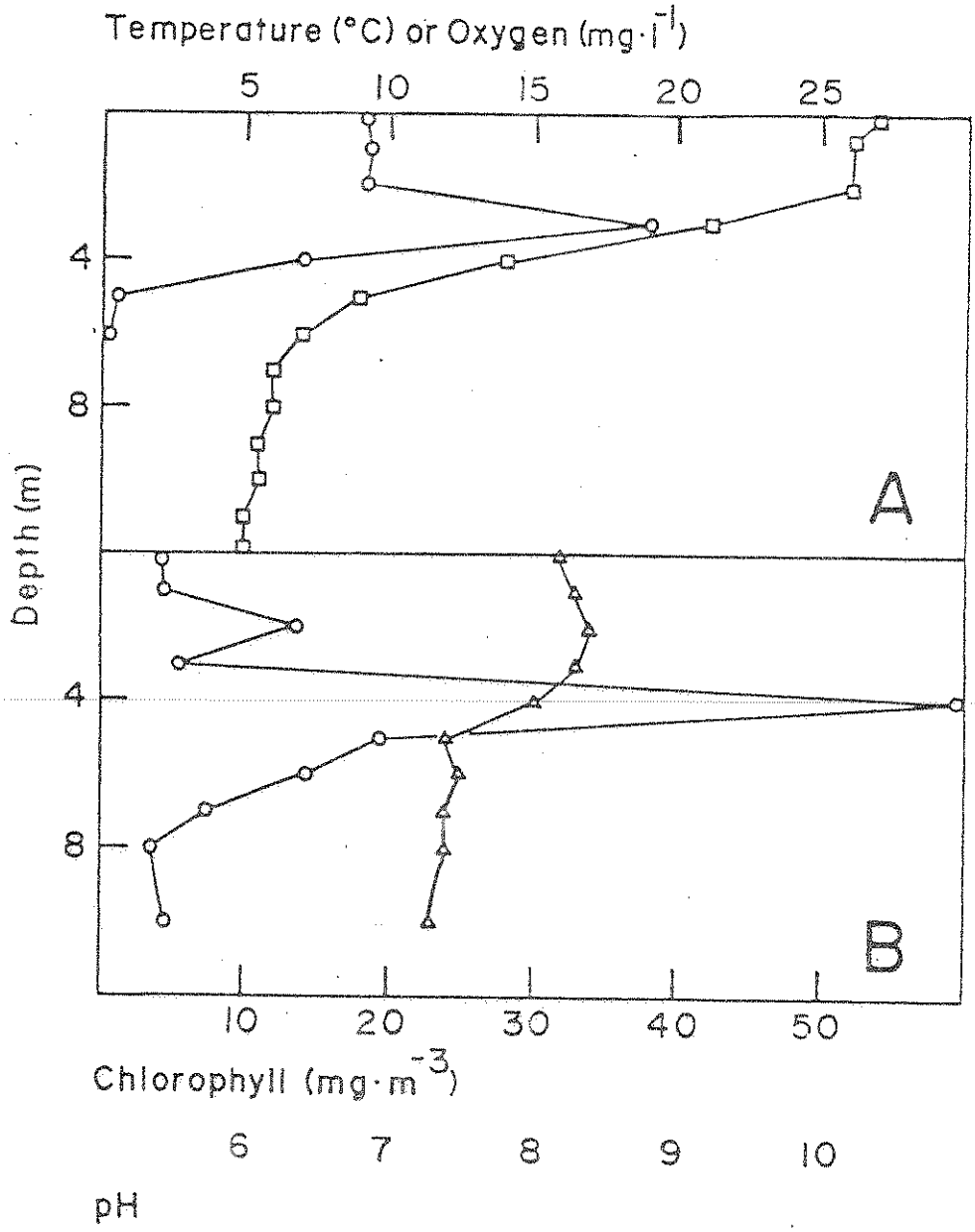


Figure II-1. Vertical profiles of (A) temperature (□) or oxygen concentration (o) and (B) chlorophyll concentration (o) or pH (△) from Little Crooked Lake on 2 August 1982.

variety of light intensities, oxygen concentrations, and pH values, the effect of these factors upon the excretion of photosynthetically-fixed organic carbon was determined. Care must be taken in measuring excretion by photoautotrophs, because artificially high values can result for a variety of reasons. Major problems include impure isotope stocks, incomplete removal of $NaH^{14}CO_3$ from the samples, rupture of cells during filtration and shock to the cells caused by exposure to transient high light intensities. To eliminate these problems we repurified the $NaH^{14}CO_3$ we obtained, and acidified and bubbled the samples to completely remove inorganic ^{14}C after experimental incubation. Cell breakage was avoided by filtration of small volumes (25 ml) at low (<90 mmHg) vacuum. Transient high excretion values due to light shock (14) were avoided by transporting samples in dark bottles in an ice-chest and by preincubating all tubes at the desired light level for at least 30 minutes. Short incubation times were used to minimize the amount of ^{14}C organic compounds respired by bacteria.

The photosynthetic rate of samples taken from the chlorophyll maximum was proportional to light intensity up to values of 150 $\mu E \cdot m^{-2} sec^{-1}$. This relatively low saturating light intensity was in agreement with the findings of Morris and Glover (1981) for Synechococcus and of Konopka and Schnur (1980) for Oscillatoria rubescens populations. Rate of excretion were fairly constant through the entire range of light intensities used (Table II-2). Although these data are pooled from experiments done on three different dates, individual experiments had similar changes in rates of photosynthesis and excretion as a function of light intensity, despite differences in phytoplankton species composition during the season. These data indicated that excretion rates of metalimnetic phytoplankton populations in Little Crooked

Table II-2. Rates of photosynthesis and excretion at different light intensities in samples from Little Crooked Lake[a]

Light ($\mu E \cdot m^{-2} \cdot sec^{-1}$)	Photosynthesis (mg $C \cdot mg^{-1}$ chl $\cdot hr^{-1}$)	Excretion (mg $C \cdot mg^{-1}$ chl $\cdot hr^{-1}$)
65	1.42 ± 0.34	0.05 ± 0.01
100	2.62 ± 0.58	0.05 ± 0.01
150	3.14 ± 0.70	0.06 ± 0.02
250	3.03 ± 1.07	0.05 ± 0.05
500	2.81 ± 0.87	0.05 ± 0.03

[a]Means of three experiments ± standard error.

Lake were independent of light intensity over the range likely to occur at those depths.

The dissolved oxygen concentration in the metalimnion of Little Crooked Lake usually exceeded that found above or below this layer and was generally in excess of the saturation concentration. Since oxygen is a competitive inhibitor of ribulose bisphosphate carboxylase and in the light can enhance photorespiration with subsequent production of glycollate, the metalimnetic phytoplankton population was examined for possible increases in excretion rate at high oxygen concentrations. The observed decrease of photosynthetic rate by 33% at elevated oxygen concentrations was in agreement with studies of Synechococcus (Morris and Glover, 1981) and Oscillatoria thiebautii (Li et al., 1980), although in the latter study high oxygen concentrations decreased the photosynthetic rate by 84%. Rates of excretion decreased as oxygen concentration was increased, following the same trend as the photosynthetic rates. Therefore, we found no evidence for increased excretion (for example, from photorespiration) at high oxygen concentrations. The low excretion rates were not due to the loss of volatile glycollate when filtrates were concentrated by drying, because similar rates were obtained by counting unconcentrated filtrates. Perhaps the light intensity used (150 $\mu E \cdot m^{-2} \cdot sec^{-1}$) was not high enough to enhance photorespiration. Higher irradiances were not used because light intensities in excess of 150 $\mu E \cdot m^{-2} \cdot sec^{-1}$ did not penetrate to the metalimnion. Thus, the higher oxygen concentrations in the metalimnion of Little Crooked Lake did not enhance excretion rates.

The effect of the pH range found in Little Crooked Lake upon the rate of excretion was also examined (Figure II-2). Both photosynthetic and excretion rates were lower at unusually high or low pH values and the rate of excretion

Table II-3. Effects of oxygen concentration on photosynthesis and excretion by metalimnetic samples from Little Crooked Lake[a,b]

Oxygen concentration ($mg \cdot l^{-1}$)	Photosynthesis ($mg\ C \cdot mg^{-1}\ chl \cdot hr^{-1}$)	Excretion ($mg\ C \cdot mg^{-1}\ chl \cdot hr^{-1}$)
4	2.02 ± 0.04	0.14 ± 0.02
11.85	1.97 ± 0.04	0.11 ± 0.02
12.4[c]	1.91 ± 0.04	0.07 ± 0.01
20.7	1.40 ± 0.14	0.06 ± 0.01
30.7	1.33 ± 0.05	0.05 ± 0.01
35.3	1.33 ± 0.03	0.08 ± 0.01

[a] Means of 3 replicates ± standard error.

[b] Oxygen concentrations obtained by bubbling with O_2 or N_2.

[c] In situ oxygen concentration.

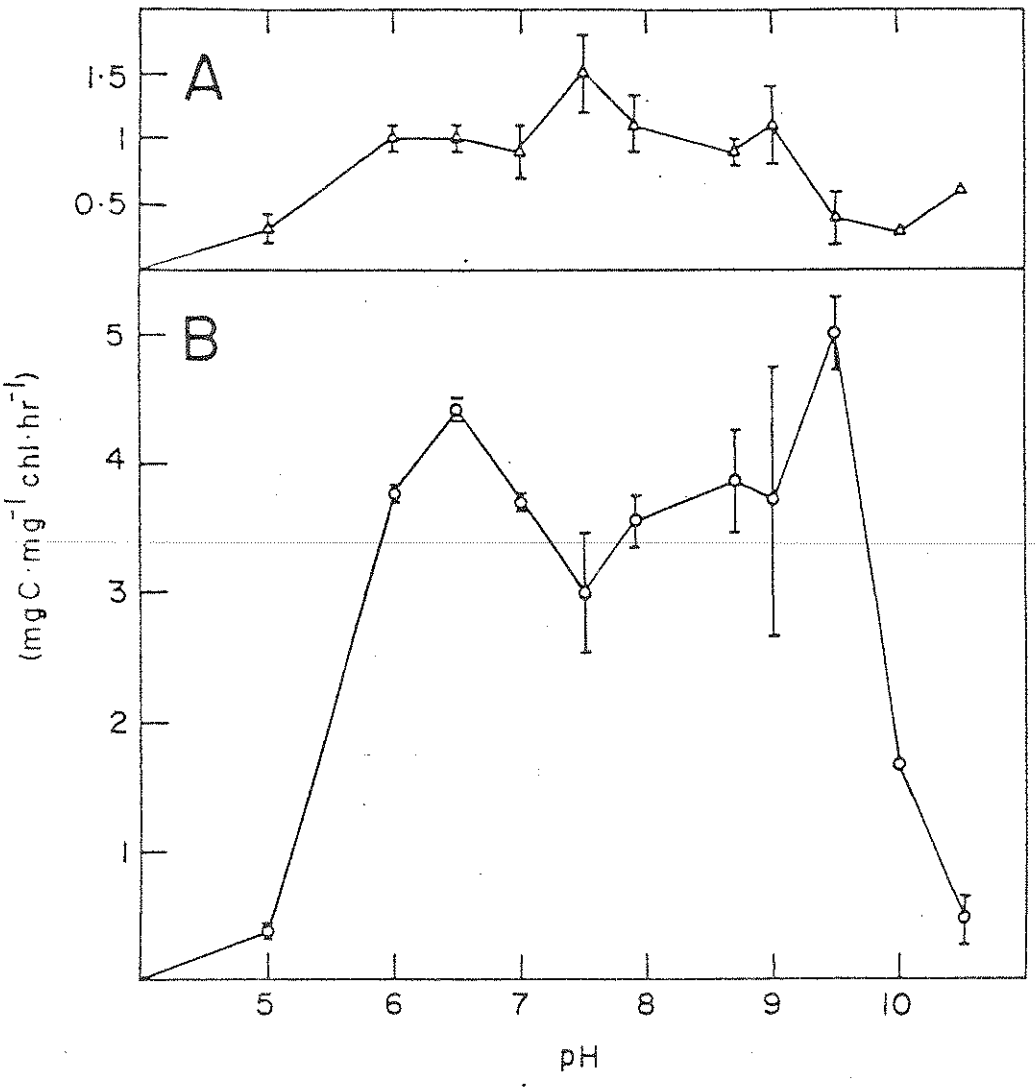
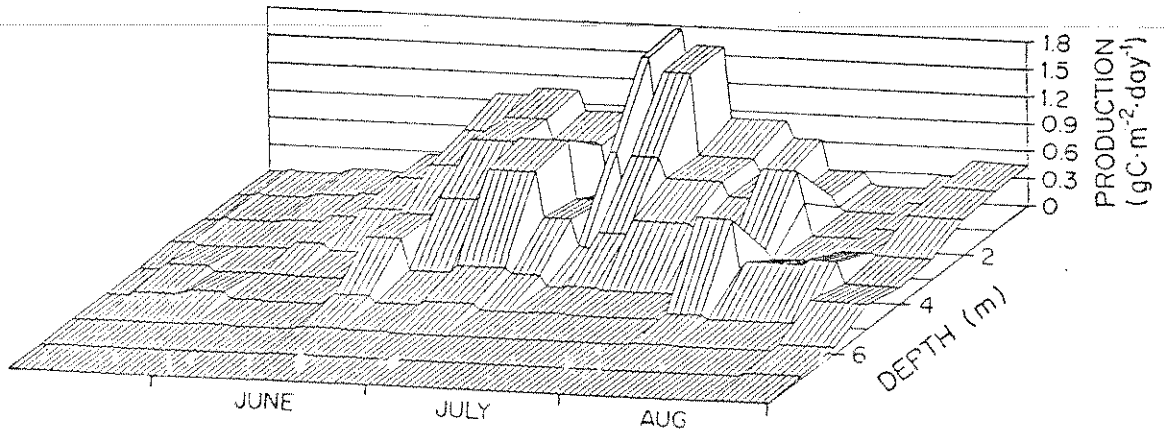


Figure II-2. Rates of excretion (A) and photosynthesis (B) at different pH values in samples from Little Crooked Lake. Error bars represent means of three replicates ± standard error.

decreased slightly within the environmental pH range of 7.5-8.8 found during this study. The photosynthetic rate appeared to increase from 3.0 to 5.0 mg C• mg chlorophyll a^{-1}•hr^{-1} within the 7.5-8.8 pH range. Variations in pH within the metalimnion did not significantly affect excretion rates.

The conclusion by Sharp (1977) that excretion of photosynthetically fixed organic carbon by healthy algal populations amounts to 0±5% of the total fixed carbon is supported by the data presented here. Calculation of the total amount of carbon photosynthetically fixed in Little Crooked Lake during the summer of 1982 with a numerical model showed that whereas 225.8 g C•m^{-2} was produced from 13 May to 31 August, 1982 (Figure II-3) only 3.1 g were excreted. This represents about 1.4% of the total. The suggestion that variations in environmental conditions might produce higher rates of excretion than those found normally was not borne out by the results obtained from Little Crooked Lake in summer 1982. Variations in pH and light intensity within the ranges measured in the lake had little effect on rates of excretion while high oxygen concentrations actually decreased excretion rates. These results indicate that excreted organic carbon consitutes only a small fraction of the carbon pool available to heterotrophic bacteria in the Little Crooked Lake metalimnion.

Figure II-3. Primary production in Little Crooked Lake from 13 May 1982 to 31 August 1982 from 0 to 8 meters depth.



III. Bacterial activity

The distribution of heterotrophic bacteria in a lake water column is an important consideration in any study of the importance of these organisms as a food source for zooplankton. In a thermally stratified lake both the numbers and growth rates of heterotrophic bacteria vary with depth. Since zooplankton dependent upon bacteria as a food source would benefit from existing at depths of maximal bacterial productivity, due to the resulting richer food supply, it becomes necessary to locate these productive water layers and to examine factors affecting their locations.

Heterotrophic bacteria are responsible for most of the decomposition of organic matter in freshwater lakes. This decomposition process not only sustains the bacterial population as a food source for zooplankton but also releases essential inorganic nutrients which may be utilized by primary producers (Rheinheimer, 1980). Since the concentration of dissolved organic carbon (DOC) in freshwater lakes in frequently an order of magnitude higher than that of particulate organic carbon (POC) (Saunders, 1976), the production of POC (bacterial cells) can constitute a large fraction of total lake productivity.

Organic carbon in a freshwater lake may arise from any of several sources. These may be loosely defined as allochthonous input (from external sources) and autochthonous (within the lake) primary production. Since the pelagic or open water zone of a deep lake constitutes a much larger volume of light-exposed water than the literal or near shore waters, primary production in a lake of this type will be chiefly due to photosynthesis by planktonic microalgae and cyanobacteria. The photic zone, the segment of the water column extending from the surface to the depth to which 1% of the

incident light penetrates (Cole, 1979), is too shallow in most deep lakes to allow growth of rooted macrophytes in pelagic waters. Within the large pelagic water volume the most important sources of carbon for heterotrophic bacteria will be the products of algal excretion and autolysis.

Central to the problem of determining bacterial productivity is the determination of bacterial standing crop or biomass. The many methods of microbial biomass determination can be divided into two groups: the indirect determination of biomass from the concentration of some cellular component, and direct determination from enumeration of microorganisms.

Indirect methods of biomass determination include analysis of ATP (Bottomley and Stewart, 1976; Hamilton and Holm-Hansen, 1967; Holm-Hansen, 1970; Holm Hansen and Booth, 1966; Karl, 1980), lipopolysaccharide (LPS) (Daley, 1979; Watson et al., 1977), muramic acid (King and White, 1977; Moriarty, 1977), and DNA (Holm-Hansen, 1969; Holm-Hansen et al, 1968). The fact that none of these compounds is limited exclusively to bacteria makes these techniques most useful for deep ocean waters and sediments where microbial populations can be assumed to be essentially free of algae and cyanobacteria. The mixed populations of bacteria, cyanobacteria and algae found in most freshwater lakes render these techniques useless for determination of bacterial biomass alone, and as yet no technique for the complete separation of bacteria from algae exists (Berman, 1975; Jassby, 1975; Rudd and Hamilton, 1973). Other problems with these methods include fluctuations in ATP: carbon ratios (Bottomley and Stewart, 1976; Holm-Hansen, 1970), time required for assay to muramic acid (King and White, 1977), expense of the LPS assay, and unreasonably high biomass values due to the slow breakdown of DNA in nature (Holm-Hansen, 1969; Holm-Hansen et al., 1968).

Other methods of bacterial biomass determination are based on conversion of observed bacterial biovolume using cell density and carbon content values from the literature (Doetsch and Cook, 1973; Luria, 1960; Rheinheimer, 1980). Enumeration via culture methods (plate counts, most probable number data) gives no information on volume of bacteria in nature and has long been known to result in low estimates of bacterial numbers in natural samples (APHA, 1971; Buck, 1979; Colwell, 1979; Daley, 1979; Fliermans and Schmidt, 1975; Jannasch and Jones, 1969).

The most extensively tested and commonly used method of enumerating bacterial in natural samples is the acidine orange direct count (AODC) method originally described by Francisco et al. (1973) and further developed by Daley (1979), Hobbie (1977) and Jones (1975). In this procedure the natural sample, either fresh from the sample site or preserved with formalin, is stained with a low concentration of the fluorochrome, filtered onto a darkly stained Nuclepore filter (0.2 µm pore size) and examined via epifluorescence microscopy. The bright contrast of the fluorescing cells against the dark filter allows accuracy in counting comparable to that obtained from electron microscopy (Bowden, 1977; Daley, 1979; Krambeck et al., 1981; Zimmerman, 1973). Control counts of dilution water and filters provide a check on bacterial contamination. As a reasonable compromise for volume estimation between measuring each cell counted and taking an average cell volume from the entire population, total counts are broken down into several size classes and an average volume for each class determined. Several alternative epifluorescence-counting methods have been suggested by various authors (Caron, 1983; Coleman, 1980; Daley, 1979; Fliermans and

Schmidt, 1975; Porter and Fieg, 1980), but none has been used successfully in as many different environments as acidine orange.

It is clear that although valuable in finding the locations of productive water layers, bacterial counts alone are insufficient for the determination of bacterial productivity. The numbers of bacteria at a given depth and time give no information on productivity due to the interplay between increases in cell numbers from growth and decreases due to grazing by zooplankton, sinking, and autolysis. It is possible to visualize a situation wherein at a given depth bacterial productivity is high, due to a rapid growth rate, and call numbers are low due to heavy grazing stress. It is therefore necessary to obtain estimates of bacterial productivity which will allow different water layers to be compared.

A recently devised method for the estimation of bacterial productivity based on the incorporation of (^{3}H-methyl)-thymidine into DNA has successfully been used in several ecosystems (Fuhrman and Azam, 1980; Moriarty and Pollard, 1981; Fuhrman and Azam, 1982; Moriarty and Pollard, 1982; Riemann, et al., 1982; Hanson and Lowery, 1983). In this method samples from the desired depth are incubated briefly (20-30 minutes) at in situ temperature with (^{3}H-methyl)-thymidine. Incorporation is stopped by fixing the samples with formalin and the cells filtered onto 0.2 µm Nuclepore Filters. The filters are treated with 5% trichloroacetic acid to remove unincorporated nucelotide pools and radioactivity determined via liquid scantillation counting. Since no means for determining the specific activity of thymidine triphosphate exists (i.e. algal TTP cannot be separated from bacterial TTP) this method cannot be used to determine a precise rate of production. It does however provide a comparative measure of bacterial growth which can be used to locate productive

water layers.

Since the algae, cyanobacteria, and heterotrophic bacteria of Crooked and Little Crooked lakes were often found in large numbers at a particular depth it was necessary to prove that thymidine was incorporated into DNA solely or predominantly by the heterotrophic bacteria. To establish the specificity of thymidine incorporation samples were labeled and separated into size classes using Nucleopore filters. Since the majority of the phototrophs occurred as large filaments or colonies a clean separation was usualy obtained. The same method was used to estimate the fraction of bacterial productivity due to particle-bound bacteria.

Throughout the 1981, 1982, and 1983 sampling seasons the maximum rates of thymidine incorporation in both Crooked and Little Crooked Lakes were found in the metalimnion (Tables III-1 to 5, Fig. III-1). The thymidine maxima were typically within a zone from one meter above to one meter below the depth of maximum chlorphyll concentration and often corresponded with the chlorophyll maximum (Tables III-6 to 9; Fig. III-2). If rates of thymidine incorporation are normalized to bacterial biomass (Tables III-10 to 13) the maximum rate of incorporation per unit bacterial biomass may be seen to lie one meter above or below the rate of maximum incorporation per unit volume. The results of this shift in location still leave the maximal incorporation rates within one meter of the chlorophyll maximum. This close linkage of bacterial growth to algal biomass implies a dependence of the bacteria on the algae for growth substrates. Clearly zooplankton associated with dense algal layers may be feeding on bacteria instead of the algae.

Since the bacteria found in freshwater lakes occur in all shapes and sizes bacterial biomass is a better indicator of population size than

bacterial numbers. Some example data on bacterial numbers in Crooked and Little Crooked Lakes are included (Tables III-14 and 15) for the sake of comparison to other lakes.

Since the bacterial populations sustaining the greatest rates of growth (as estimated via thymidine incorporation) are in close association with large algal populations, it is necessary to demonstrate that thymidine incorporation is not carried out by the algae. The data in Tables III-16 and III-17 show that throughout most of a typical sampling season the largest fraction of thymidine incorporation, usually in excess of 85% will pass through a filter capable of retaining the algal cells and cyanobacterial filaments. As the summer ends and the algal population senesces many bacteria will attach themselves to moribund algal filaments. This results in the observed increases in the percentage of thymidine incorporated into large particles. It is interesting to note that even in August and September depths other than the chlorophyll maximum show size distribution patterns similar to those from earlier in the season.

In order to determine which zooplankton genera in a given population are capable of grazing on bacteria these zooplankton must be fed bacteria labeled in some way. The zooplankton must then be sorted for the active genera to be determined (Hollibaugh et al., 1980). Alternaa natural assemblage of zooplankton may be fed labeled bacteria and counted as a whole. Unfortunately, this can only show whether or not grazing is occurring, not which genera are responsible (Roman and Rublee, 1981).

Another method for determining actively grazing genera involves feeding the zooplankton fluorescently stained bacteria and observing gut tube fluorescence via epifluorescence microscopy (Lane et al., 1976). This

method gives a rapid assessment of active grazing without the necessity of hand sorting. Since chlorphyll a fluoresces red, grazing on algae may be determined without the addition of any stain.

Zooplankton were suspended in 0.45 µm filtered lake water at the numbers found in situ (i.e. the organisms taken from a one liter sample were suspended in one litter). These organisms were then preincubated for 2 hours at in situ temperature to eliminate gut tube fluorescence from previous feeding on algae. After the starvation period either algae or acridine orange stained bacteria were added to the zooplankton suspensions and incubation resumed for one hour. At the end of incubation zooplankton were filtered out and placed in club soda to prevent the loss of gut contents. The organisms were then examined via epifluorescence and counted. Table III-18 gives typical results.

Clearly starving the zooplankton for a lengthy period is a very unnatural condition, but information on potential food sources should be accurate since if the organisms are capable of feeding on a particular food source they should feed after the 2 hour starvation. The results in Table III-18 show that even the large Daphmia magna were incapable of feeding on the large filamentous cyanobacteria which occurred at the depth they were taken from. Both Diaptomus and Daphnia species were found to feed on acridine orange stained bacteria and unstained unicellular cyanobacteria.

Table III-1. Vertical distribution of thymidine incorporation ($pmoles \cdot l^{-1} \cdot hr^{-1}$) in Crooked Lake during 1981.

Depth(m)	9 June	14 July	20 July	5 Aug	12 Aug	6 Sept	20 Sept	3 Oct	15 Nov
0	42.5	1.6	17.2	27.7	15.1	104.1	21.6	7.7	10.6
1	4.0	3.8	14.2	19.8	25.8	135.2	23.7	7.9	15.1
2	4.0	6.1	11.1	11.9	36.4	166.3	25.8	7.9	19.6
3	14.2	8.0	24.8	47.9	34.9	135.8	24.8	7.4	25.2
4	24.5	9.8	48.8	62.1	31.0	175.0	24.4	6.8	30.7
5	33.5	9.8	49.8	64.1	39.8	190.1	28.7	8.7	24.6
6	15.9	22.7	43.2	73.6	68.8	199.6	51.2	22.6	18.6
7	9.7	7.1	44.9	84.1	124.5	178.8	39.2	21.0	20.4
8	7.2	14.4	62.1	60.5	79.9	160.6	43.2	34.8	22.1
9	6.4	10.0	36.4	74.9	71.5	144.4	67.7	11.6	27.2
10	5.5	4.7	10.6	40.2	41.8	186.7	46.4	23.8	21.3
11	3.9	5.0	8.3	25.9	28.6	135.8	29.7	20.8	20.0
12	2.3	5.4	6.0	11.6	15.3	85.0	13.0	11.7	15.0
13	1.6	3.7	-	9.0	10.6	62.2	11.0	10.4	14.0
14	0.9	2.0	-	6.5	5.9	39.5	7.0	9.1	13.1
15	0.7	1.4	-	5.2	-	-	-	-	11.0
16	0.5	0.7	-	3.9	-	-	-	-	8.9

Table III-2. Vertical distribution of thymidine incorporation ($pmoles \cdot l^{-1} \cdot h^{-1}$) in Crooked Lake during 1982.

Depth(m)	15 Apr	12 May	1 June	1 July	18 July	5 Aug	25 Aug	25 Sept	25 Oct	29 Nov
0	10.8	19.5	40.2	23.9	19.2	8.6	4.4	0.5	17.4	3.1
1	-	30.0	44.7	39.6	19.5	8.6	3.8	2.1	12.7	3.4
2	-	40.5	49.2	55.3	19.8	8.7	3.2	3.7	8.0	3.8
3	-	29.3	52.2	50.0	19.2	11.6	4.5	5.0	8.6	3.8
4	-	27.9	55.1	44.8	18.7	14.5	5.8	6.2	9.3	3.8
5	11.7	43.8	37.8	30.0	14.8	39.5	10.5	7.7	10.4	3.8
6	-	34.0	11.9	28.0	18.0	64.5	12.0	9.2	11.6	3.8
7	-	25.5	4.4	32.8	18.4	18.5	8.6	9.6	13.9	3.8
8	-	36.0	5.9	28.5	8.1	26.3	7.0	5.2	16.2	3.7
9	-	21.9	6.7	17.0	3.4	4.7	11.8	11.4	19.7	5.4
10	12.8	7.8	6.9	5.6	5.5	2.9	9.4	11.1	29.6	7.1
11	-	-	-	3.8	4.2	1.6	5.5	8.4	-	-
12	-	-	-	2.0	3.0	1.2	2.2	5.7	-	-
13	-	-	-	-	-	-	1.6	-	-	-
14	-	-	-	-	-	-	1.5	-	-	-
15	16.5	-	-	-	-	-	-	-	-	-

Table III-3. Vertical profiles of thymidine incorporation ($pmoles \cdot l^{-1} \cdot hr^{-1}$) in Crooked Lake during 1983.

Dept(m)	5 Apr	9 May	23 May	6 June	5 July
0	4.5	2.4	46.3	7.6	5.6
1	6.0	2.3	36.2	14.0	5.8
2	6.0	2.2	26.4	20.4	6.0
3	6.0	5.2	32.1	21.2	13.7
4	7.4	8.3	37.8	21.9	21.4
5	6.0	13.2	29.2	22.4	30.9
6	6.0	18.0	20.7	23.0	40.4
7	6.0	11.0	18.4	18.9	-
8	5.9	4.1	16.2	14.8	-
9	6.0	3.2	15.6	13.1	-
10	6.0	2.4	14.9	11.4	-
11	6.0	2.8	12.7	-	-
12	6.5	3.2	10.5	-	-
13	-	3.7	7.2	-	-
14	-	4.2	3.9	-	-

Table III-3. Vertical distribution of thymidine incorporation ($pmoles \cdot l^{-1} \cdot hr^{-1}$) in Little Crooked Lake during 1981.

Depth(m)	25 June	15 July	21 July	4 Aug	11 Aug	5 Sept	19 Sept	14 Nov
0	136.4	270.7	57.0	257.4	200.5	209.8	18.8	11.6
1	149.5	166.5	157.8	338.2	268.6	201.5	36.5	12.8
2	178.2	270.0	237.6	247.6	264.7	205.7	29.5	14.0
3	39.3	162.6	132.5	190.2	151.9	206.6	53.8	11.2
4	24.0	71.1	39.1	150.4	118.9	202.6	25.4	8.3
5	16.9	20.7	22.7	50.2	16.0	161.3	102.8	10.2
6	34.6	20.7	5.9	24.7	8.3	53.6	18.4	11.8
7	26.4	12.6	4.2	17.0	5.1	36.7	4.3	15.7
8	18.1	4.6	2.6	4.4	1.9	19.8	3.0	10.2
9	11.1	3.3	-	3.4	1.9	16.0	2.6	5.6
10	4.1	2.0	-	2.4	1.9	12.2	2.3	0.9
11	3.1	-	-	2.0	1.6	10.9	2.3	1.0
12	2.1	-	-	1.5	1.3	9.6	2.3	1.1

Table III-4. Vertical distribution of thymidine incorporation ($pmoles \cdot l^{-1} \cdot hr^{-1}$) in Little Crooked Lake during 1982.

Depth(m)	15 Apr	12 May	1 June	1 July	18 July	5 Aug	25 Aug	25 Sept	25 Oct	29 Nov
0	11.6	63.1	124.6	80.7	47.1	12.4	21.8	30.1	30.5	9.5
1	10.4	82.0	123.4	69.5	74.1	78.5	31.1	23.9	28.2	19.2
2	9.3	101.0	108.2	60.4	38.3	123.9	22.6	17.0	25.8	28.8
3	9.7	60.9	49.0	66.2	12.5	94.6	54.0	21.2	31.1	16.0
4	8.4	37.1	41.8	53.1	31.5	37.9	51.3	27.6	35.7	32.2
5	7.0	36.2	46.6	30.8	97.6	117.0	24.0	45.7	31.9	27.3
6	8.1	27.6	8.6	18.9	92.1	103.8	79.5	150.8	49.3	24.3
7	9.2	12.6	7.8	12.1	74.9	80.1	90.8	41.7	87.1	32.3
8	10.3	9.5	14.6	5.3	57.7	69.0	84.5	23.9	78.5	31.1
9	11.8	11.8	-	7.1	-	71.8	56.8	21.0	82.8	18.1
10	13.2	19.0	-	8.9	-	74.6	17.9	18.1	87.0	10.4

Table III-5. Vertical distribution of chlorophyll ($\mu g \cdot l^{-1}$) in Crooked Lake during 1981.

Depth(m)	9 June	14 July	20 July	5 Aug	12 Aug	6 Sept	20 Sept	3 Oct	15 Nov
0	4.2	6.9	4.8	3.0	2.4	5.0	4.3	5.5	6.9
1	4.5	7.0	5.8	3.6	3.6	5.8	4.8	5.5	7.5
2	4.8	7.1	6.8	4.2	4.8	6.7	5.2	5.5	8.1
3	6.5	9.2	8.7	5.4	3.6	5.5	5.4	5.5	8.1
4	14.3	21.4	12.8	7.1	3.6	5.5	5.0	5.5	8.1
5	22.6	47.6	39.3	8.9	8.3	4.3	5.5	5.5	8.7
6	47.2	27.4	23.8	19.0	19.0	5.2	6.2	5.2	9.3
7	17.8	22.6	19.6	20.2	19.0	24.3	7.1	5.7	8.7
8	9.5	10.7	12.7	11.9	14.3	26.7	13.1	5.7	8.1
9	7.1	5.7	4.8	10.7	11.9	10.5	13.4	6.4	8.1
10	3.0	4.3	4.2	4.8	9.5	9.0	13.1	6.4	7.8
11	3.3	3.4	2.6	4.2	7.2	8.8	10.8	9.0	7.1
12	3.6	2.5	2.1	3.6	4.8	8.6	8.6	10.2	7.1
13	3.0	2.0	-	3.5	3.6	6.8	6.8	8.4	6.9
14	3.0	2.0	-	3.2	2.4	5.0	5.0	6.7	6.7
15	3.0	2.0	-	3.0	-	-	-	-	6.4
16	3.0	2.0	-	3.0	-	-	-	-	6.0

Table III-6. Vertical distribution of chlorophyll ($\mu g \cdot l^{-1}$) in Crooked Lake during 1982.

Depth(m)	15 Apr	12 May	1 June	1 July	18 July	5 Aug	25 Aug	25 Sept	25 Oct	29 Nov
0	36.3	1.2	1.6	2.5	1.3	1.3	2.6	2.5	3.6	3.9
1	-	1.2	1.8	2.8	1.4	1.3	2.7	2.8	3.6	3.8
2	-	1.2	1.9	3.0	1.6	1.3	2.7	3.1	3.6	3.8
3	-	1.3	2.8	4.8	1.8	1.3	2.7	3.0	3.7	3.8
4	-	1.3	3.6	5.2	2.3	1.6	3.0	2.8	3.8	3.8
5	35.7	6.8	4.6	6.2	3.6	2.6	3.0	2.6	3.8	3.8
6	-	8.2	3.0	7.7	3.6	3.1	4.2	2.5	3.9	3.7
7	-	6.0	1.4	8.3	4.2	3.3	4.4	2.8	3.8	3.6
8	-	6.4	1.0	10.6	6.0	4.8	3.9	3.1	3.4	3.7
9	-	4.5	0.8	7.7	6.0	5.8	3.8	3.4	3.8	4.1
10	35.9	2.6	0.6	4.8	5.1	4.2	4.2	2.8	3.8	3.8
11	-	-	-	6.2	4.4	4.4	3.6	2.2	-	-
12	-	-	-	7.7	3.6	4.6	3.0	1.9	-	-
13	-	-	-	-	-	-	3.0	-	-	-
14	-	-	-	-	-	-	3.0	-	-	-
15	35.7	-	-	-	-	-	-	-	-	-

Table III-7. Vertical profiles of chlorophyll a ($\mu g \cdot l^{-1}$) in Crooked Lake during 1983.

Depth(m)	5 Apr	9 May	23 May	6 June	5 July
0	7.7	4.5	3.2	4.2	3.0
1	7.7	4.8	3.0	6.2	3.3
2	7.7	5.2	2.9	8.2	3.6
3	8.0	5.9	2.8	7.4	3.4
4	8.3	6.6	2.7	6.6	3.2
5	8.3	6.3	3.5	5.8	5.4
6	8.3	6.0	6.8	5.0	7.6
7	8.0	5.6	5.5	6.8	-
8	7.7	5.2	4.2	7.1	-
9	7.7	5.2	3.6	8.2	-
10	7.7	5.2	2.9	5.5	-
11	7.7	5.2	2.2	-	-
12	7.7	5.2	2.2	-	-
13	-	4.6	1.8	-	-
14	-	4.0	1.4	-	-

Table III-8. Vertical distribution of chlorophyll ($\mu g \cdot l^{-1}$) in Little Crooked Lake during 1981.

Depth(m)	25 June	15 July	21 July	4 Aug	11 Aug	5 Sept	19 Sept	14 Nov
0	39.7	25.1	25.0	37.0	14.5	40.9	17.8	33.8
1	82.5	29.2	22.2	39.7	18.5	41.2	18.1	35.6
2	93.6	46.3	29.8	42.3	19.8	43.3	18.8	37.4
3	74.6	89.3	140.4	76.7	58.2	42.6	17.6	35.6
4	19.8	39.8	45.2	82.0	103.1	48.3	17.8	33.8
5	14.3	22.8	23.8	34.0	38.3	36.22	50.8	33.3
6	11.9	14.6	4.2	21.2	18.5	16.2	23.3	32.8
7	9.5	1.3	9.8	10.6	10.6	12.0	9.3	31.7
8	7.9	11.9	15.5	9.2	9.3	7.9	7.8	26.7
9	6.3	9.0	-	9.9	8.6	6.7	6.4	15.8
10	7.1	7.0	-	10.6	7.9	5.5	5.0	4.8
11	5.0	-	-	10.6	7.0	5.2	4.0	3.6
12	5.0	-	-	10.6	7.0	5.0	3.1	2.4

Table III-9. Vertical distribution of chlorophyll ($\mu g \cdot l^{-1}$) in Little Crooked Lake during 1982.

Depth(m)	15 Apr	12 May	1 June	1 July	18 July	5 Aug	25 Aug	25 Sept	25 Oct	29 Nov
0	11.9	2.0	1.8	11.4	8.7	4.2	6.9	5.1	5.8	6.5
1	11.2	2.8	3.2	11.3	7.4	4.5	7.1	6.0	7.6	6.2
2	10.6	3.6	4.5	19.0	11.3	13.9	7.1	5.1	9.3	6.0
3	10.8	10.1	7.5	48.8	34.5	5.4	5.4	5.2	9.7	5.8
4	10.4	11.1	2.5	32.1	14.3	59.5	7.1	7.1	10.1	5.7
5	10.1	12.0	3.8	27.4	11.5	19.6	20.2	9.2	8.2	4.2
6	10.0	7.7	12.8	22.6	8.3	14.2	13.1	16.7	8.3	4.8
7	9.5	5.4	5.5	9.5	7.1	7.6	11.2	25.9	13.7	4.2
8	9.5	4.4	3.9	9.6	5.7	3.7	5.7	13.1	7.4	4.4
9	9.5	5.4	-	8.0	-	4.2	4.6	6.0	6.0	4.2
10	9.5	6.3	-	6.5	-	4.6	3.6	5.0	5.0	4.0

Table III-10. Vertical distribution of bacterial biomass ($\mu gC \cdot l^{-1}$) in Crooked Lake during 1983.

Depth(m)	5 Apr	9 May	23 May	6 June	5 July
0	109	189	170	207	497
1	110	212	163	233	489
2	112	197	159	259	481
3	113	182	143	254	479
4	115	185	127	249	478
5	117	193	125	230	480
6	120	202	124	210	482
7	122	183	120	200	-
8	126	165	116	243	-
9	128	173	115	165	-
10	131	181	115	116	-
11	119	-	100	-	-
12	119	-	100	-	-
13	-	-	116	-	-
14	-	-	131	-	-

Table III-11. Vertical distribution of specific rate of thymidine incorporation (pmoles thymidine•µg bacterial C^{-1}•hr^{-1}) in Crooked Lake During 1983.

Depth(m)	5 April	9 May	23 May	6 June	5 July
0	0.04	0.01	0.27	0.04	0.01
1	0.05	0.01	0.22	0.06	0.01
2	0.05	0.01	0.17	0.08	0.01
3	0.05	0.03	0.22	0.08	0.03
4	0.06	0.04	0.30	0.09	0.04
5	0.05	0.07	0.23	0.10	0.06
6	0.05	0.09	0.17	0.11	0.08
7	0.05	0.06	0.15	0.09	-
8	0.05	0.02	0.14	0.06	-
9	0.05	0.02	0.14	0.08	-
10	0.04	0.01	0.13	0.10	-
11	0.05	-	0.12	-	-
12	0.05	-	0.10	-	-
13	-	-	0.06	-	-
14	-	-	0.03	-	-

Table III-12. Vertical distribution of bacterial biomass (µg C·l^{-1}) in Little Crooked Lake during 1983.

Depth(m)	5 Apr	9 May	23 May	6 June	20 June	5 July	11 July
0	271	189	424	245	343	381	327
1	532	212	456	212	482	283	339
2	528	197	487	254	422	328	339
3	524	181	383	243	530	264	327
4	488	185	356	218	432	412	401
5	453	193	296	234	427	617	678
6	471	202	174	167	372	302	507
7	489	183	166	162	326	305	255
8	506	165	158	-	260	313	311
9	473	173	-	-	-	-	-
10	441	181	-	-	-	-	-

Table III-13. Vertical distribution of specific rate of thymidine incorporation (pmoles thymidine•µg bacterial C^{-1}•hr^{-1}) in Little Crooked Lake during 1983.

Depth(m)	5 Apr	9 May	23 May	6 June	20 June	5 July	11 July
0	0.03	0.11	0.06	0.16	0.08	0.15	0.08
1	0.03	0.13	0.08	0.26	0.09	0.17	0.18
2	0.04	0.15	0.09	0.22	0.11	0.26	0.15
3	0.04	0.15	0.11	0.31	0.13	0.36	0.08
4	0.03	0.12	0.03	0.13	0.15	0.25	0.21
5	0.04	0.09	0.04	0.05	0.05	0.08	0.25
6	0.04	0.06	0.10	0.05	0.02	0.06	0.10
7	0.04	0.11	0.06	0.04	0.02	0.06	0.11
8	0.04	0.17	0.05	-	0.02	0.04	0.12
9	0.04	0.18	-	-	-	-	-
10	0.05	0.19	-	-	-	-	-

Table III-14. Distribution of bacterial cell numbers (10^6 cells$\cdot ml^{-1}$) in Crooked Lake during 1983.

Depth(m)	4 Apr	9 May	23 May	6 June	20 June	5 July
0	1.15	1.48	1.86	2.00	3.02	2.91
2		1.19	1.73	2.27	2.15	3.61
4		1.76	1.38	1.83	2.55	3.72
5	1.27					
6		1.38	1.31	1.77	2.44	3.26
7				1.57	2.41	
8		1.57	1.19	1.83	3.24	
9				1.57	2.84	
10	1.53	1.27	1.19	1.18	2.95	
12		1.49	1.20		1.64	
14		1.46	1.50			
15	1.51					
20	1.62					

Table III-15. Vertical distribution of bacterial cell numbers (10^6 cells$\cdot ml^{-1}$) in Little Crooked Lake during 1983.

Depth(m)	4 Apr	9 May	23 May	6 June	20 June	5 July	11 July
0	2.38	1.70	3.92	2.83	3.70	2.98	3.09
1	5.78	2.06		2.36	4.72	2.79	3.32
2		2.04	4.98	3.09	4.55	2.78	3.17
3	5.55	2.02	4.65	2.93	5.41	2.55	3.10
4		2.05	3.98	2.69	4.91	4.24	3.72
5	5.04		3.33	2.73	5.40	5.91	6.25
6		2.19	1.91	1.88	4.15	3.31	6.03
7			1.87	1.96	3.79	3.00	2.84
8	5.69	1.98	1.85	2.76	2.53	2.88	3.14
9							
10	4.68	2.18			1.97	2.72	

Table III-16. Size fractionation of thymidine incorporation in Little Crooked Lake.

Date	Depth(m)	% total incorporation on filter of pore size (μm): 5.0	3.0	1.0	0.2
18 May, 1982	2	1.7	0.9	4.0	93.4
22 July, 1982	3	-	7.5	4.7	87.8
22 July, 1982	6	-	1.9	9.0	89.1
3 Aug, 1982	6	8.1	-	7.6	84.3
25 Sept, 1982	6	8.8	-	35.4	53.8
26 Oct, 1982	0	-	2.1	2.6	95.3
26 Oct, 1982	7	-	39.7	18.1	42.2
6 Apr, 1983	0	-	3.8	15.3	80.9
11 May, 1983	2	-	2.4	9.4	88.2
11 May, 1983	8	-	6.5	8.0	85.4
24 May, 1983	2	-	4.7	15.4	79.9
24 May, 1983	4	-	0.0	2.8	97.2
7 June, 1983	1	-	3.0	4.3	92.7
7 June, 1983	3	-	2.7	1.0	96.3
7 July, 1983	0	-	0.5	5.1	94.9
7 July, 1983	4	-	1.1	3.4	95.5
7 July, 1983	6	-	2.0	3.3	94.7
16 Aug, 1983	2	-	0.3	1.7	98.0
16 Aug, 1983	5	-	2.4	2.7	94.9
16 Aug, 1983	8	-	11.7	21.1	67.2

Table III-17. Size fractionation of thymidine incorporation in Crooked Lake.

Date	Depth(m)	% total incorporation on filter of pore size (µm): 5.0	3.0	0.2
3 June, 1981	6	2.6	-	97.4
22 June, 1981	6	3.1	-	96.9
8 Aug, 1981	1	-	10.4	89.6
8 Aug, 1981	4	-	7.9	92.1
8 Aug, 1981	7	-	46.6	53.4

Table III-18. Zooplankton grazing on algae and bacteria.

Food Source	Organism	Organisms Counted[d]	% Positive
None	Daphnia	29	3.4
Bacteria[a]	Daphnia	16	90
Bacteria	Diaptomus	20	100
Synechococcus[b]	Daphnia	40	90
Ntatural Algae[c]	Daphnia	24	42

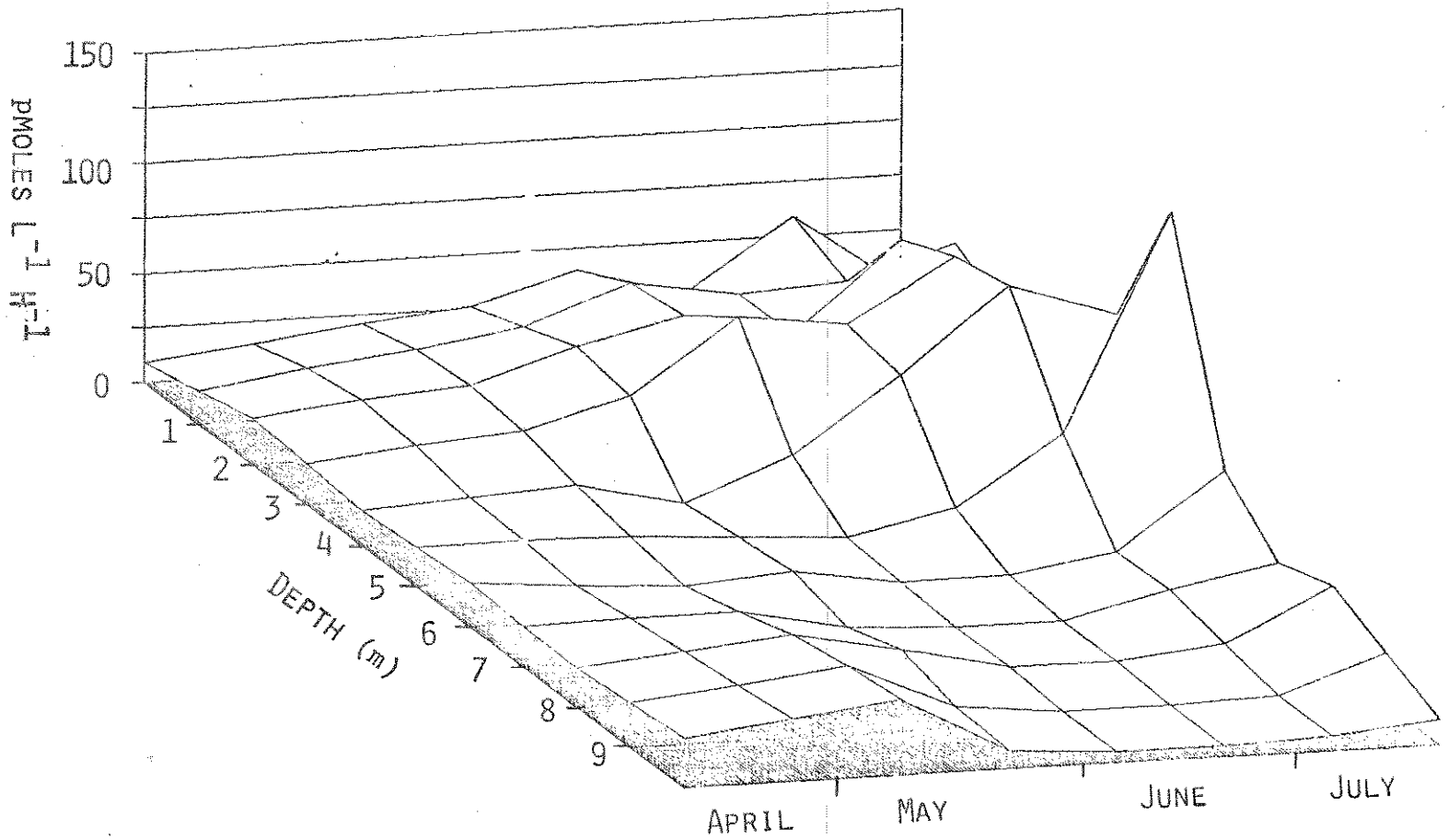
a. A mixed culture of bacteria isolated from Little Crooked lake, and grows in liquid culture. Added to concentration of 10^6 cells ml^{-1}.

b. Axenic laboratory culture added to concentration of 10^5 cells ml^{-1}.

c. Natural algal population retained on zooplankton netting (predominantly Aphanizomenon). Added to give a final concentration equal to in situ.

d. Species represented by less than 10 individuals were not counted.

Figure III-1. Vertical distribution of thymidine incorporation in Little Crooked Lake during 1983.



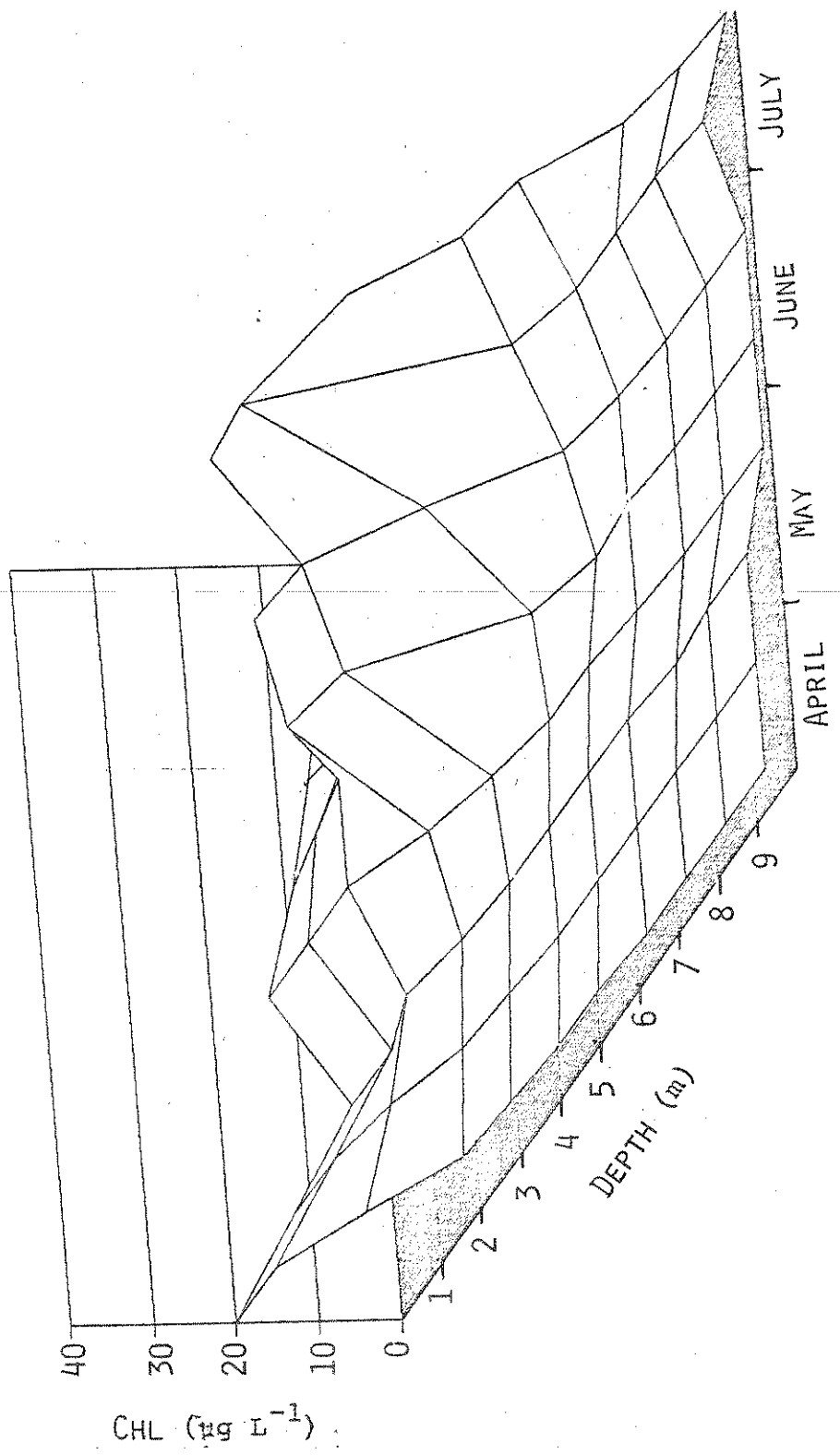


Figure III-2. Vertical distribution of chlorophyll in Little Crooked Lake during 1983.

IV. ZOOPLANKTON

One specific aspect of the research was to correlate changes in zooplankton abundance in Crooked and Little Crooked Lakes, Noble Co., Indiana, to (1) changes in algal productivity, (2) competition between zooplankton species, and (3) predation by Cisco, a zooplanktivorous fish common in Crooked Lake.

1. Crooked lake

The study occurred during a unique time interval in Crooked Lake, when water quality was significantly degraded. Due to high rainfall in the spring of 1981, nutrient loadings were high in the lake, and the phytoplankton changed dramatically. Prior to this time Crooked was classified as a mesotrophic lake, with the one of the best overall water quality ratings in the state of Indiana. Oxygen was present throughout the water column, and that there was a metalimnetic oxygen maximum produced by the blue green alga Oscillatoria rubescens. This species is adapted to photosynthesize well at low nutrient and light levels, and is only found in clean lakes.

In 1981, however, physical patterns were quite different by mid-summer. Due to high nutrient levels, other genera of blue greens increased in the lake, and grew at shallower depths. These species included Aphanizomenon flos-aquae, Anabaena sphaeroides, and Oscillatoria redekii. These populations crashed in late June, 1981, and significantly reduced oxygen levels at the metalimnion for the rest of the summer. This drop in oxygen concentration caused fish kills for many of the cold water fish in the lake, including natural populations of Cisco (Coregonus artredii) and introduced trout. For example,

netting studies by the D.N.R. showed a steady decline in Cisco catches per unit effort, with few fish at all caught in 1981 (Jed Pearson, personal communication).

In 1982 and 1983, water quality improved in Crooked Lake, and the hypolimnion was oxygenated to the bottom in both years, probably due to low nutrient imputs because of lower spring precipitation levels.

The one bad year for the lake, and subsequent recovery, allow us to ask several significant questions. First, what zooplankton species respond to a large increase in food resource levels (algal productivity)? What responses occur in the zooplankton community when a major planktivore is removed from the community? And finally, how do resource levels, competition, and predation determine zooplankton species relative abundance?

To answer these questions we sampled zooplankton populations in Crooked and Little Crooked Lakes in 1981, 1982, and 1983. Biweekly samples were taken in both lakes.

Each sample consisted of a verticle profile where replicate subsamples were taken at every other meter depth (0,2,4m, etc.) down to 20 m in Crooked Lake (max. depth ~ 30 m) and 10 m in Little Crooked (max. depth 14 m). Three replicate subsamples were taken at each depth. Each subsample consisted of a haul from a 4.3 ℓ Van Dohrn Sampler. Samples were preserved in a 10% formalin solution and were counted within 2 days under a dissecting scope. Counts were kept for each major zooplankton type (Diaptomus, Diacyclops, Daphnia, Diaphanosoma, Bosmina, and the zooplankton predators Leptodora and Chaoborus). All values were

converted to numbers per liter, and average values (n=3) are shown in the tables.

The first sample was taken in Crooked Lake on May 12, 1981 (Table IV-1). Peak densities of Diaptomus were about 5 per liter at 4 m, and nearly 30 per liter for Diacyclops at 2 m, while Daphnia was fairly rare. By late May (Table IV-2), Diaptomus reached a peak at 15 organisms per liter at 2 m, but Diacyclops numbers topped 200 per liter at 6 m, where peak phytoplankton abundance also occurred. Daphnia were still rare. By early June (Table IV-3), Diacyclops densities were still high (over 90 per liter around 6 m), and Diaptomus and Daphnia densities had dropped to 50 per liter, and Daphnia densities were only slightly less. By early July (Table IV-5) Diaptomus was near 28 per liter at 8 m, but was still less than peak Diacyclops abundance (67 per liter at 8 m), and Daphnia populations were declining. By late July (Table IV-6), Diacyclops populations reached a second peak, at over 140 per liter at 8 m), while the other copepod (Diaptomus) and (Daphnia) were fairly rare. By early August (Table IV-7), Diacyclops densities were again declining, while the other 2 plankters remained fairly constant. The same relative abundances held into mid August (Table IV-8), but by late August (Table IV-9) Daphnia peaked in abundance again at over 60 per liter at 4 m depth. By early September, the last sample taken in 1981, Daphnia was declining, as was Diaptomus, but Diacyclops populations increased (Table IV-10).

In summary, Diaptomus populations did not really respond to increased food levels in 1981, but Diacyclops and Daphnia did increase dramatically in numbers, each showing 2 peaks, with the Daphnia peaks

about a month after the Diacyclops peaks. Bosmina was found only occasionally early in the season, and Leptodora was found sporadically throughout the season.

Crooked Lake in 1982 did not receive appreciably large rainfall during the spring. Nutrient and algal abundances were lower in 1982 than in 1981 for this reason. Zooplankton abundances were also lower than in the previous year. In early May (Table IV-11), Diaptomus and Daphnia were fairly rare, with Diacyclops at levels similar to fall of 1981 (Table IV-10). By mid May (Table IV-12), Diaptomus and Diacyclops peak densities were near 40 per liter, and Daphnia were still rare. By late May (Table IV-13) all three populations had approached 10-15 animals per liter. In early June (Table IV-14), abundances were essentially the same for all 3 groups. Densities continued to drop, and by late June, only at a few depths (Table IV-15) were abundances more than 10 organisms per liter. In early July (Table IV-16), Diacyclops started to increase in abundance, but other plankters were still scarce. In late July, (Table IV-17) Diacyclops abundance continued near 20 per liter at 10 meters depth, and Diaptomus and Daphnia were still fairly rare. The same pattern continued into early August (Table IV-18).

To summarize dynamics in 1982, Diaptomus had roughly similar abundances to 1981, although peak abundances averaged 2 meters deeper in 1982 than in 1981 (8 vs. 6 m depth). Both Diacyclops and Daphnia densities decreased dramatically from 1981 levels, although Diacyclops was still the most abundant zooplankter. Its depth distribution also shifted, from maximum densities at 8 m in 1981, to 10 m in 1982. Again, Bosmina was occasionally found early in the season, and Leptodora was

found sporadically throughout the season.

Similarly, 1983 was a fairly dry year, with little precipitation and nutrient imput into Crooked Lake. By mid May (Table IV-19) peak copepod abundances were around 12 per liter, and peak Daphnia abundance was somewhat higher, at 18 per liter. By early June (Table IV-20), Diaptomus and Daphnia populations had increased in number, but not Diacyclops. Peak Diaptomus abundances were 20 per liter at 8 meters by mid June (Table IV-21) with a slight increase in numbers for Diacyclops and a decline for Daphnia. Abundances were fairly similar for all 3 species in late June (Table IV-22) and mid to early July (Table IV-23). All 3 populations declined in numbers by late July (Table IV-24), but increased somewhat again by early August (Table IV-25).

In summary, populations of all 3 species showed fairly stable, but low abundances across the field season of 1983 in Crooked Lake. In particular, peak abundances of Diacyclops dropped somewhat from 1982 to 1983, and abundances of Daphnia increased.

2. Little Crooked Lake

Approximately similar changes in water quality occurred in Little Crooked Lake during the interval studied. However, Little Crooked Lake, due to its shallower basin, usually develops a hypolimnetic oxygen deficit by early June in all years. Hence it can be considered to be naturally more eutrophic than the larger, deeper basin of the lake.

For example, by early June 1981 (Table IV-26), the hypolimnion was already anoxic, and populations of Diaptomus had already built up to near 100 per liter. By late June (Table IV-27), Diaptomus populations had crashed, and zooplankton were limited primarily to the top few

meters; Chaoborus were apparently feeding in the deeper regions of the lake. But by early August (Table IV-28) Diacyclops densities were near 100 per liter at 3 meters. By mid August (Table IV-29), Diacyclops populations had dropped in half, and other zooplankters were still rare. By late August (Table IV-30), Diacyclops reached a peak density of 60 per liter, but other zooplankton were rare, although Bosmina were present in respectable numbers. Diacyclops numbers crashed by early September (Table IV-31).

In summary, only Diacyclops was abundant in Little Crooked Lake in 1981, although Diaptomus did have one early bloom. Bosmina was found in somewhat higher numbers than in Crooked Lake, and Leptodora was replaced by Chaoborus as a zooplankton predator.

In early May of 1982 (Table IV-32), Diaptomus peaked at 20 per liter at 2 m, whereas Diacyclops densities were much higher, near 80 per liter at 4 meters. Daphnia reached a density over 15 per liter at 2 m. By mid May (Table IV-33), oxygen levels were dropping rapidly in the hypolimnion, and Diacyclops density had dropped in half. By late May (Table IV-34) Diacyclops levels were less than Diaptomus, while Daphnia abundances changed little. By early June (Table IV-35), Diaptomus populations had increased to about 50 per liter near the top of the thermocline (5 m), and other zooplankters were fairly rare. By late June (Table IV-36), abundances had again declined to less than 15 per liter for all 3 species. The same relative abundances continued into early July (Table IV-37), and late July (Table IV-38). By early August, however, Daphnia had increased to over 30 per liter at 3 m (Table IV-39).

In summary, Diacyclops abundance declined steadily from peak abundances in 1981, and reached low levels by late May 1982. Diaptomus showed one peak in early June (as it had the year before), and low abundances for the rest of the year. Daphnia was rare for most of the season, but did increase by August. Bosmina was present at low densities, as was Diaphanosoma. Chaoborus was found near the thermocline in low numbers in late summer.

In mid May 1983 (Table IV-40), Diaptomus and Daphnia were common in the epilimnion, but both decreased in numbers by early June (Table IV-41). This same pattern of low abundances remained in mid June (Table IV-42), late June (Table IV-43), and all the way through the rest of the season (Tables IV-44 to 46). However, Daphnia abundances did increase in Little Crooked Lake by mid June, and Daphnia was the dominant zooplankton for the rest of the season.

In summary, Diacyclops was fairly rare in Little Crooked Lake in 1983, and Diaptomus was common only early in the season. Daphnia increased so that it was the dominant species by mid June.

3. Overall Summary of Zooplankton Population Dynamics

In Crooked Lake, Diacyclops thomasii dominated zooplankton abundance during the poor water quality period in 1981, twice reaching near 200 animals per liter. Daphnia abundances were somewhat elevated, with 2 peaks of around 50 per liter. Each peak was displaced about a month after the Diacyclops peak. In 1982, Diacyclops abundances crashed early in the season, and were very similar to the abundances of the other 2 plankters for the rest of the season. In 1983, all 3

zooplankters had uniform low abundances throughout the season, although Daphnia did increase somewhat early in the season.

In Little Crooked Lake, the patterns through time were roughly the same. Diacyclops abundances were higher, often near 100 per liter, during the peak in algal productivity in 1981. Again, the abundance of the cyclopoid copepod crashed early in 1982, and was extremely rare in 1983. In both 1981 and 1982, Diaptomus populations peaked in early summer in Little Crooked, but abundances of the diaptomid were fairly low in 1983. Over the 3 years, Daphnia increased markedly in abundance in Little Crooked Lake. It rarely reached 5 organisms per liter in 1981, but peaked at over 40 organisms per liter in 1983.

Table IV-1. Zooplankton depth distributions, Crooked Lake, May 12, 1981

Depth	Dissolved oxygen	Temperature	Light	Diaptomus	Diacyclops	Daphnia
0	12.0(ppm)	14(°C)	3400(F.C.)	.35	1.63	0
2	12.1	13.5	460	3.95	27.8	0.93
4	11.8	13.0	79	4.76	25.3	1.16
6	10.2	12.5	12	3.02	25.6	0.23
8	8.0	10.0	3.2	1.51	19.7	0
10	8.4	9.0	1.3	3.72	17.9	0.12
12	8.3	8.5	.66	6.05	18.6	0.69
14	8.5	7.5	.35	3.02	16.7	0.47
16	8.6	7.0	0	1.51	11.9	1.05
18	8.3	6.0	0	1.86	9.77	0.23
20	8.1	6.0	0	1.16	5.9	0.81
22	8.1	5.5	0	0.81	6.16	1.40
24	7.7	5.5	0	0.35	5.11	1.51

ppm = parts per million

F.C. = foot candles

Zooplankton abundance in individuals per liter

Table IV-2. Zooplankton depth distributions, Crooked Lake, May 26 1981

Depth	Temp.	D.O.	Light	Diaptomus	Diacyclops	Daphnia	Bosmina	Leptodora
0	21.0	10.0	1600	.23	.70	0	2.9	0.0
2	18.0	12.0	510	15.0	19.4	.47	1.86	0.0
4	14.5	12.8	160	6.51	120.0	0.0	1.0	0.0
6	13.0	9.5	28	2.01	206.9	.08	0.62	0.16
8	11.0	5.9	5.1	1.24	43.3	.16	.16	0.0
10	9.0	5.0	1.8	7.67	34.7	.23	0.0	0.0
12	9.0	5.5	.79	4.11	28.4	2.17	.08	0.0
14	8.0	6.3	.39	1.94	9.33	1.31	.23	0.0
16	7.0	6.3	.21	.93	11.8	1.86	.23	0.0
18	6.0	6.3	.11	.23	5.9	1.05	0.0	0.0
20	6.0	6.2	.06	.58	15.46	1.16	.34	0.0
22	6.0	6.1	0.0	.35	6.63	0.70	0.12	0.0
24	6.0	5.8	0.0	.69	8.14	0.70	.23	0.0

Table IV-3. Zooplankton depth distributions, Crooked Lake, June 10, 1981

Depth	Temp.	D.O.	Lifht	Diaptomus	Diacyclops	Daphnia	Leptodora	Bosmina
0	23	10.2	7000	.11	0.0	.11	0.0	0.0
2	22	10.0	2700	1.86	1.63	1.63	0.0	0.0
4	18	13.3	1100	5.97	6.57	8.5	.08	0.0
6	13	7.4	260	5.73	93.0	4.7	.08	0.0
8	11	4.8	39	2.3	90.5	1.2	.08	0.0
10	10	4.3	10	2.6	46.2	0.16	.08	0.0
12	9	5.1	3.4	4.8	40.9	0.62	0.0	0.0
14	8	5.9	1.6	2.9	29.8	0.78	0.0	0.0
16	7	6.1	.56	5.0	30.3	0.81	0.11	0.0
18	6.5	6.1	.31	4.2	31.5	0.69	0.16	0.0
20	6.0	6.2	.16	1.16	16.4	1.3	0.0	0.0
22	6.0	5.5	.10	1.4	28.7	1.7	0.0	0.0
24	6.0	4.8	.06	0.81	14.2	0.35	0.0	0.0

Table IV-4. Zooplankton depth distirbutions, Crooked Lake, June 22, 1981

Depth	Temp.	D.O.	Light*	Diaptomus	Diacyclops	Daphnia	Bosmina	Leptodora
0	23.0	9.9	910	.12	.47	.35	0.0	0.0
2	23.0	9.9	300	7.3	2.21	32.1	0.0	0.0
4	21.0	11.0	85	9.7	8.6	40.3	0.0	0.0
6	14.0	6.3	15	13.1	30.2	46.2	0.0	0.0
8	11.0	2.7	1.9	8.7	50.7	13.9	0.08	0.0
10	10.0	2.6	0.9	5.2	47.9	2.1	0.0	0.0
12	9.0	3.7	0.4	2.4	40.8	1.5	0.0	0.0
14	8.0	4.4	0.4	1.8	39.6	0.4	0.08	0.0
16	7.0	5.0	.3	1.4	28.3	0.6	0.0	0.0
18	6.5	5.1	0.0	1.7	45.2	0.4	0.0	0.0
20	6.0	5.0	0.0	1.0	36.1	1.2	0.0	0.0
22	6.0	4.8	0.0	1.2	24.3	0.8	0.0	0.0
24	5.5	4.0	0.0	1.0	24.5	0.7	0.0	0.0

*microeinsteins/cm

Table IV-5. Zooplankton depth distributions, Crooked Lake, July 6, 1981

Depth	Temp.	D.O.	Light*	Diaptomus	Diacyclops	Daphnia	Bosmina	Leptodora
0	29.0	9.6	580	.81	7.6	10.0	0.0	0.0
2	26.0	9.1	180	2.9	3.3	3.3	0.0	0.0
4	24.0	10.4	74	4.7	3.9	11.7	0.0	0.0
6	15.0	6.6	6.5	21.2	54.6	17.4	0.0	0.0
8	11.5	.07	1.2	25.1	66.7	7.6	0.0	0.0
10	10.0	1.5	.04	10.2	50.0	2.4	0.0	0.0
12	9.0	2.7	.02	3.3	27.8	0.6	0.0	0.0
14	8.0	3.4	0	2.1	24.2	0.4	0.0	0.0
16	7.0	4.0	0	1.0	19.2	0.3	0.0	0.0
18	6.5	4.1	0	1.1	21.6	0.6	0.0	0.0
20	6.0	4.2	0	0.0	27.7	0.1	0.0	0.0
22	6.0	3.8	0	0.7	35.6	0.5	0.0	0.0
24	5.5	2.5	0	0.7	45.3	0.6	0.0	0.0

*microeinsteins

Table IV-6. Zooplankton depth distributions, Crooked Lake, July 20, 1981 (12 noon sample)

Depth	Temp.	D.O.	Light	Diaptomus	Diacyclops	Daphnia	Bosmina	Leptodora
0	25.5	8.7	2100	0.0	.12	.12	0.0	0.0
2	24.8	9.4	500	.94	1.8	1.9	0.0	0.0
4	22.2	15.2	280	5.1	6.3	6.8	0.0	0.0
6	13.6	6.4	100	14.7	47.9	9.6	0.0	1.0
8	10.1	0.4	50	13.3	142.9	5.6	0.0	0.0
10	8.8	1.1	1.8	6.3	56.3	2.8	0.0	0.0
12	7.9	2.5	1.0	2.8	12.2	0.6	0.0	0.0
14	7.2	3.1	0.3	3.2	5.4	0.4	0.0	0.0
16	6.8	3.5	0.1	2.0	9.8	0.5	0.0	0.0
18	6.2	3.5	.05	1.3	11.9	0.5	0.0	0.0
20	5.9	3.6	.03	0.6	10.3	0.5	0.0	0.0
22	5.8	2.8	.03	1.2	21.4	1.1	0.0	0.0
24	5.6	2.2	.02	0.5	15.2	3.3	0.0	0.0

Table IV-7. Zooplankton depth distributions, Crooked Lake, August 7, 1981

Depth	Temp.	D.O.	Light	Diaptomus	Diacyclops	Daphnia	Bosmina	Leptodora
0	27.0	8.7	3300	.35	.35	0	0	0
2	25.5	8.7	1000	2.2	0.70	.84	0	0
4	24.0	10.2	520	2.4	0.71	10.8	0	0
6	17.0	4.6	110	13.6	17.5	8.7	0	0
8	12.0	.06	18	11.9	41.2	9.7	0	0
10	10.0	.03	5.5	1.5	14.6	.93	0	0
12	8.5	1.5	3.0	2.7	1.7	.23	0	0
14	7.0	2.1	1.6	1.3	6.4	1.8	0	0
16	7.0	2.2	.48	.72	2.6	.94	0	0
18	6.0	2.4	.27	1.4	3.5	.47	0	0
20	6.0	2.3	.14	.47	6.9	.82	0	0
22	6.0	1.8	.08	1.0	8.6	1.3	0	0
24	6.0	1.2	0	0.5	3.0	1.7	0	0

Table IV-8. Zooplankton depth distributions, Crooked Lake, August 18, 1981

Depth	Temp.	D.O.	Light	Diaptomus	Diacyclops	Daphnia	Bosmina	Leptodora
0	24.0	9.1	1050*	1.3	.82	2.3	0	0
2	24.0	8.9	380	4.9	1.7	7.1	0	0
4	23.0	8.7	185	6.7	1.2	10.3	0	0
6	17.0	4.9	39	6.5	15.6	11.6	0	.16
8	12.0	.04	6.5	4.1	62.7	12.3	0	0
10	10.0	.03	3.4	.86	19.4	2.0	0	.07
12	8.5	.09	2.5	.46	2.6	.39	0	.07
14	7.5	1.6	2.5	2.6	1.2	1.0	0	0
16	7.0	2.0	0	0.60	1.1	0.6	0	0
18	6.5	2.3	0	.47	.70	.94	0	0
20	6.0	2.3	0	.35	1.2	.60	0	0
22	6.0	1.7	0	.35	.95	1.3	0	0
24	6.0	1.0	0	.47	.24	.53	0	0

*microeinsteins

Table IV-9. Zooplankton depth distributions, Crooked Lake, August 26, 1981

Depth	Temp.	D.O.	Light	Diaptomus	Diacyclops	Daphnia	Bosmina	Leptodora
0	25.0	8.9	550*	.82	.47	5.5	0	0
2	24.0	9.0	210	10.1	1.7	42.5	0	0
4	23.0	8.7	95	4.4	.62	62.3	0	0
6	18.0	5.2	40	4.8	3.1	16.3	0	.15
8	12.0	.06	7.5	3.7	26.4	10.7	0	.16
10	10.0	.04	2.0	.62	13.6	1.4	0	0
12	8.5	.08	.09	.08	1.7	.23	0	0
14	8.0	1.5	.06	1.0	.70	.78	0	0
16	7.0	1.7	.05	.58	.60	.47	0	0
18	6.5	2.0	0	.35	.23	.23	0	0
20	6.0	1.8	0	.23	.14	.60	0	0
22	6.0	1.5	0	.39	.72	.70	0	0
24	6.0	.06	0	.35	.60	1.4	0	0

*microeinsteins

Table IV-10. Zooplankton depth distributions, Crooked Lake, September 2, 1981

Depth	Temp.	D.O.	Light	Diaptomus	Diacyclops	Daphnia	Leptodora	Chaoborus
0	25	8.7	140*	2.3	.35	3.7	0	0
2	24.5	8.6	49	7.4	.84	12.0	0	0
4	24.0	8.3	24	1.9	2.5	13.6	0	0
6	17.0	5.4	9.3	4.6	15.6	33.9	.08	0
8	13.0	0.4	2.4	2.2	48.0	11.8	0.15	0
10	10.0	.25	.07	.08	.78	.39	0	0
12	9.0	.40	.06	.47	1.7	.96	0	0
14	8.0	1.1	0	.63	.71	1.8	0	.08
16	7.0	1.6	0	.24	.23	1.8	0	0
18	6.5	1.9	.12	.60	.93	0	0	.12
20	6.0	1.7	0.00	.60	.35	1.4	0	0
22	6.0	1.7	0	.23	.47	1.9	0	0
24	6.0	.7	0	.23	.70	.23	0	0

*microeinsteins

Table IV-11. Zooplankton depth distributions, Crooked Lake, May 10, 1982 (n = 4)

Depth	Temp	D.O.	Light	Diaptomus	Diacyclops	Daphnia	Bosmina	Leptodora
0	17.3	12.8	3850	2.8	3.5	3.5	0.0	0.0
2	17.0	13.0	1600	4.3	7.5	4.4	.53	0.0
4	14.8	13.8	690	7.1	5.8	7.3	1.1	0.0
6	10.9	15.3	210	3.9	40.0	2.8	.27	0.0
8	8.3	13.0	63	4.5	17.3	2.5	.67	0.0
10	7.0	12.8	28	2.2	7.9	1.4	.27	0
12	6.3	13.0	0	2.6	10.4	2.2	0.0	0.0
14	6.0	12.9	0	1.6	5.8	0.8	.27	0.0
16				.93	4.9	.93	0.0	0.0
18				.54	4.5	.53	0.0	0.0
20				1.1	5.6	1.1	.27	0.0
22				.81	5.0	1.1	.27	0.0
24				.94	2.4	.27	0.0	0.0

Table IV-12. Zooplankton depth distributions, Crooked Lake, May 17, 1982

Depth	Temp	D.O.	Light	Diaptomus	Diacyclops	Daphnia	Bosmina
0	23.3	9.0	4550	.72	5.0	.60	0.0
2	22.5	8.3	1910	2.3	2.8	3.1	0.0
4	16.7	13.6	975	12.5	20.3	3.7	0.0
6	11.7	13.5	415	37.1	28.8	9.9	.16
8	9.0	10.4	161	7.4	35.2	3.0	0.0
10	7.6	10.0	61.0	5.2	40.0	2.0	0.0
12	6.7	10.0	30.0	2.5	10.8	.47	0.0
14	6.1	10.2	15.5	.83	5.6	.60	0.0
16	5.9	10.2	0	1.9	7.8	.47	0.0
18	5.9	10.5	0	1.1	2.8	.24	0
20	5.7	10.5	0	1.6	6.3	.36	0
22	5.5	10.4	0	.72	2.6	.24	0
24	5.4	10.4	0	.36	2.0	0	0

Table IV-13. Zooplankton depth distributions, Crooked Lake, May 28, 1982

Depth	Temp	D.O.	Light	Diaptomus	Diacyclops	Daphnia	Bosmina
0	20.6	10.0	3410	0.8	1.0	0.1	0.0
2	20.0	9.5	1430	16.9	1.8	7.5	0.2
4	18.2	13.4	558	15.0	8.7	16.1	0.2
6	12.1	12.2	281	11.2	14.1	7.6	0.1
8	9.0	9.6	153	7.4	14.5	8.1	0.4
10	7.8	9.4	85.4	5.6	17.2	12.5	0.8
12	6.9	9.4	49	4.3	13.1	12.7	0.3
14	6.3	9.7	29.9	3.1	8.6	5.2	1.3
16	5.9	9.9		4.9	13.7	2.7	0.2
18	5.7	10.0		4.4	15.9	3.4	1.2
20	5.6	9.9		3.3	10.6	4.7	1.0
22	5.5	9.8		2.4	6.5	2.9	1.1
24	5.5	9.8		2.0	6.4	2.3	2.0
26	5.4	9.7					
28	5.4	9.7					
30	5.3	9.7					

Table IV-14. Zooplankton depth distributions, Crooked Lake, June 7, 1982

Depth	Temp	D.O.	Light	Diaptomus	Diacyclops	Daphnia	Bosmina	Leptodora
0	21.0	10.0	1950	3.5	.60	1.2	0.0	0.0
2	20.8	9.9	821	25.5	1.43	8.6	0.0	0.0
4	20.5	10.0	490	12.9	1.7	7.1	0.2	0.0
6	12.7	12.1	172	12.7	13.5	6.5	0.2	0.3
8	9.8	9.0	73	5.4	12.3	3.7	0.2	0.0
10	8.2	8.7	38	4.4	12.9	3.7	0.2	0.1
12	7.0	9.1	15	2.5	8.6	2.3	0.0	0.1
14	6.4	9.2	9.0	3.9	20.7	1.3	0.4	0.1
16	6.0	9.3	5.0	4.9	13.6	2.2	0.1	0.4
18	5.8	9.2	0.0	1.4	10.9	1.2	0.2	0.0
20	5.7	9.2	0.0	0.5	12.5	3.3	1.0	0.1
22	5.5	9.2	0	0.60	10.4	2.5	0.6	0.0
24	5.4	9.2	0.0	.72	3.4	1.5	0.1	0.0

Table IV-15. Zooplankton depth distribution, Crooked Lake, June 24, 1982

Depth	Temp	D.O.	Light	Diaptomus	Diacyclops	Daphnia	Leptadora
0	23.1	9.6	2260	0.0	0.8	0.0	0.0
2	22.4	9.6	1075	1.1	0.5	1.2	0.0
4	20.7	9.5	334	2.4	0.6	3.9	0.1
6	14.2	11.8	120	4.3	12.1	6.2	0.0
8	10.6	9.0	35	20.8	7.3	1.9	0.2
10	8.6	7.9	16	6.1	6.1	3.6	0.2
12	7.2	8.3	9.6	0.5	3.8	1.1	0.0
14	6.4	8.5		0.5	6.8	0.5	0.0
16	6.0	8.5		0.5	12.9	0.3	0.0
18	5.8	8.4		0.0	8.1	0.0	0.0
20	5.7	8.4		0.0	3.3	0.2	0.0
22	5.6	8.0		0.3	3.5	0.0	0.0
24	5.5	7.7		0.0	5.3	0.5	0.2

Table IV-16. Zooplankton depth distributions, Crooked Lake, July 9, 1982

Depth	Temp	D.O.	Light	Diapto-mus	Dia-cyclops	Daphnia	Diapha-nosoma	Bosmina	Leptadora
0	27.2	8.8	3800	0.0	0.4	0.12	0.0	0.0	0.0
2	26.3	8.5	1840	4.6	0.2	3.5	0.7	0.0	0.0
4	23.5	10.8	665	1.5	0.7	4.1	0.1	0.0	0.0
6	16.3	12.8	218	2.6	13.1	1.8	9.3	0.0	0.2
8	11.0	8.2	46.1	17.0	22.6	1.1	2.8	0.1	0.0
10	8.5	7.0	14	5.9	17.3	1.4	0.6	0.0	0.0
12	7.2	7.4		2.1	10.0	1.0	0.1	0.0	0.0
14	6.3	8.1		1.1	6.4	0.9	0.0	0.0	0.0
16	6.0	8.6		3.3	4.4	0.5	0.0	0.0	0.0
18	5.8	8.7							
20	5.6	8.5		0.1	3.0	0.4	0.0	0.0	0.0
22	5.5	7.8		2.1	1.7	1.2	0.0	0.0	0.0

Table IV-17. Zooplankton depth distributions, Crooked Lake, July 26, 1982

Depth	Temp	D.O.	Light	Diapto-mus	Dia-cyclops	Daphnia	Diapha-nosoma	Bosmina	Leptadora
0	27.2	8.1	2760	0.0	0.0	0.1	0.1	0.0	0.0
2	27.2	8.2	1340	0.8	1.1	1.6	0.0	0.0	0.0
4	24.8	11.5	508	3.2	0.4	16.1	0.1	0.0	0.0
6	15.5	12.2	209	4.1	1.8	3.2	4.8	0.0	0.0
8	10.8	6.7	55.5	18.3	15.7	2.8	0.0	0.0	0.0
10	8.5	6.1	14.3	4.8	20.5	1.1	0.1	0.0	0.0
12	7.2	6.9	5.9	0.8	14.7	1.0	0.0	0.0	0.0
14	6.4	7.3	2.6	3.1	11.7	0.9	0.0	0.0	0.0
16	6.0	7.6		0.9	5.4	0.1	0.0	0.0	0.0
18	5.7	8.0		1.6	5.1	0.1	0.1	0.0	0.0
20	5.5	7.6		0.0	1.8	0.1	0.0	0.0	0.0
22	5.4	7.3		1.0	1.9	0.0	0.0	0.0	0.0

Table IV-18. Zooplankton depth distribution, Crooked Lake, August 11, 1982

Depth	Temp	D.O.	Light	Diaptoms	Dia-cyclops	Daphnia	Bosmina	Lepta-dora	Diaphan-soma
0	25.4	8.2	1290	0.1	0.0	0.5	0.0	0.0	0.0
2	25.1	8.0	610	0.1	0.0	0.1	0.0	0.0	0.0
4	24.8	8.2	323	6.1	0.3	4.8	0.0	0.0	0.0
6	16.8	11.0	120	6.9	3.1	6.0	0.0	0.2	4.3
8	11.1	7.2	46.4	14.8	25.6	2.8	0.0	0.0	1.5
10	7.1	5.1	12.5	4.2	20.6	0.6	0.0	0.0	1.1
12	6.8	5.7	3.2	1.4	9.7	1.2	0.0	0.0	0.3
14	6.3	6.8		1.4	7.4	0.4	0.0	0.0	0.0
16	6.1	7.2		0.0	6.2	0.5	0.0	0.0	0.0
18	6.0	7.0		1.2	5.3	1.9	0.0	0.0	0.0
20	5.9	6.9		0.0	4.3	0.5	0.0	0.0	0.0

Table IV-19. Zooplankton depth distribution, Crooked Lake, May 17, 1983

Depth	Temp	D.O.	Light	Diapto-mus	Dia-cyclops	Daphnia	Bosmina	Lepta-dora	Diapha-nosoma	Nauplii
0	16.0	10.4	2800	1.9	4.7	0.9	0.0	0.0	0.0	0.2
2	15.0	10.8	1400	9.3	11.3	8.8	0.0	0.0	0.0	2.0
4	15.0	10.8	450	9.9	5.9	18.4	0.0	0.0	0.0	2.6
6	12.0	11.6	320	12.5	6.4	9.5	0.0	0.0	0.0	2.5
8	10.0	10.2	160	4.1	6.2	10.1	0.0	0.0	0.0	4.8
10	8.0	10.2	66	1.5	5.9	6.0	0.0	0.0	0.0	0.4
12	7.0	10.4	34	0.8	2.8	2.9	0.0	0.0	0.0	0.7
14	6.0	10.6	20	0.5	2.0	2.0	0.0	0.0	0.0	0.0
16	6.0	10.6	10	0.1	1.6	1.2	0.0	0.0	0.0	0.6
18	6.0	10.5	5.8	0.1	0.8	1.3	0.0	0.0	0.0	0.5
20	6.0	10.6	3.2	0.4	1.1	2.4	0.0	0.0	0.0	0.1

Table IV-20. Zooplankton depth distributions, Crooked Lake, June 2, 1983

Depth	Temp	D.O.	Light	Diapto-mus	Dia-cyclops	Daphnia	Bosmina	Lepta-dora	Diaphano-soma	Nauplii
0	16.5	10.0	1500	3.1	1.5	0.6	0.1	0.0	0.0	4.5
2	16.5	9.9	730	7.8	3.2	1.3	0.0	0.0	0.0	3.7
4	16.0	9.8	420	19.5	5.2	5.2	0.0	0.0	0.0	4.2
6	14.5	10.0	210	15.3	11.4	7.7	0.0	0.0	0.0	3.4
8	11.0	9.3	100	21.4	13.8	33.2	0.0	0.0	0.0	0.9
10	8.0	8.6	46	5.9	7.6	10.8	0.0	0.0	0.0	0.6
12	6.5	9.2	26	5.4	9.2	12.5	0.0	0.0	0.0	0.9
14	6.0	9.3	16	2.8	5.3	3.4	0.0	0.0	0.0	2.0
16	6.0	9.3	11	1.9	3.9	3.1	0.0	0.0	0.0	0.1
18	5.5	9.3	4.4	1.3	5.1	1.4	0.0	0.0	0.0	0.1
20	5.5	9.1	2.3	5.1	4.8	4.1	0.0	0.0	0.0	2.4

Table IV-21. Zooplankton depth distribution, Crooked Lake, June 16, 1983

Depth	Temp	D.O.	Light	Diaptomus	Diacyclops	Daphnia	Nauplii	Chaoborus
0	25.8	9.6	2500	1.8	1.3	2.9	0	0.4
2	24.0	9.1	1200	3.1	2.0	5.5	0	0.3
4	20.0	10.2	500	8.4	2.2	12.0	0.4	0.1
6	16.5	10.0	200	15.1	10.8	8.0	0.2	0
8	11.5	9.9	83	21.5	19.8	2.5	0.4	0
10	8.3	8.2	35	12.7	10.9	4.3	0.9	0
12	7.0	8.4	16	3.9	3.6	1.7	0.8	0
14	6.0	8.6	8.3	3.2	3.6	1.7	0.6	0
16	6.0	8.3	4.0	2.0	2.8	0.8	0.3	0
18	5.5	8.3	2.1	1.7	2.2	1.2	0.5	0
20	5.5	7.6	1.1	1.6	2.8	1.7	0.2	0

Table IV-22. Zooplankton depth distributions, Crooked Lake, June 27, 1983

Depth	Temp	D.O.	Light	Diaptomus	Diacyclops	Daphnia	Nauplii
0	27.5	8.8	3700	0.8	0.5	2.3	0.1
2	27.5	8.8	1600	2.2	0.0	10.5	0
4	22.5	11.8	910	1.6	1.7	16.6	0
6	17.0	11.8	320	6.9	7.8	13.2	0.2
8	12.5	10.0	190	8.7	7.1	22.7	0.8
10	9.0	8.8	60	17.3	12.8	6.4	2.8
12	7.0	8.1	26	10.2	12.2	4.9	6.1
14	6.0	7.9	14	9.4	13.5	10.3	4.1
16	6.0	7.8	5.9	4.3	6.2	8.1	1.9
18	6.0	7.9	3.7	8.2	6.1	3.6	1.2
20	5.5	7.4	2.0	3.2	5.9	2.6	1.2

Table IV-23. Zooplankton depth distribution, Crooked Lake, July 12, 1983

Depth	Temp	D.O.	Light	Diaptomus	Diacyclops	Daphnia	Nauplius	Leptodora
0	27.0	9.5	3600	0.3	0.3	0.9	0.1	0
2	27.0	9.6	1800	1.4	0.0	17.5	.2	0
4	25.0	9.9	680	4.7	1.3	17.8	0	0.1
6	18.0	13.4	320	7.0	6.5	11.9	.2	0.1
8	13.0	10.6	83	10.2	8.5	12.3	3.8	0
10	8.5	8.3	27	10.9	14.8	6.9	4.0	0.3
12	7.0	7.3	11	5.4	12.7	1.7	1.5	0
14	6.0	7.3	5.1	4.1	6.9	1.5	.5	0.1
16	6.0	7.5	2.7	2.2	7.5	2.7	.6	0
18	5.5	7.6	1.5	2.4	6.5	4.1	1.2	0
20	5.5	7.2	.7	4.3	3.2	0.6	2.0	0

Table IV-24. Zooplankton depth distributions, Crooked Lake, July 26, 1983

Depth	Temp	D.O.	Light	Diaptomus	Diacyclops	Daphnia	Nauplii	Diaphanosoma	Leptodor
0	29.0	8.5	2000	5.2	9.9	1.1	0.0	0.5	0.0
2	29.0	8.0	840	1.5	3.1	0.1	0.0	0.6	0.0
4	28.0	8.2	360	1.0	1.3	1.8	0.0	0.0	0.1
6	20.5	14.6	140	3.3	2.9	2.5	0.3	7.4	0.0
8	13.8	9.2	32	7.4	8.3	1.5	0.0	3.0	0.1
10	10.0	6.5	6.7	2.9	8.1	0.7	0.6	0.1	0.0
12	8.0	5.7	2.7	4.4	7.2	0.4	0.2	0.3	0.1
14	7.0	6.4	1.3	4.7	6.4	0.0	0.3	0.0	0.0
16	6.5	6.2	0.7	3.2	5.1	0.0	0.1	0.0	0.0
18	6.5	6.1	0.4	2.6	3.5	0.0	0.1	0.0	0.0
20	6.0	5.4	0.2	0.8	1.7	0.0	0.0	0.0	0.0

Table IV-25. Zooplankton depth distributions, Crooked Lake, August 8, 1983

Depth	Temp	D.O.	Light	Diapto-mus	Dia-cyclops	Daphnia	Nauplii	Diaphan-soma	Chao-borus	Lepto-dora
0	28.0	8.5	2900	0.0	0.1	0.1	0.0	0.0	0.0	0.0
2	28.0	8.4	1700	0.1	0.4	0.1	0.0	0.0	0.0	0.0
4	27.2	7.6	730	0.1	0.1	0.9	0.2	0.0		0.0
6	21.2	13.8	310	15.1	1.3	21.9	0.1	0.3		0.1
8	14.2	9.7	62	12.8	26.0	3.9	0.0	35.1		0.0
10	10.3	5.6	8.5	7.9	22.2	2.6	0.0	1.4		0.1
12	8.3	5.2	3.3	6.7	12.2	1.8	0.0	0.7		0.0
14	7.1	5.6	1.4	4.8	3.8	0.5	0.0	0.0		0.0
16	6.7	6.0	0.7	2.4	1.8	0.1	0.0	0.2		0.0
18	6.5	5.7	0.4	1.7	3.7	0.5	0.1	0.3		0.0
20	6.2	5.0	0.2	2.7	2.1	0.0	0.0	0.1		0.0

Table IV-26. Zooplankton depth distributions, Little Crooked Lake, June 10, 1981

Depth	Temp.	D.O.	Light	Diaptomus	Diacyclops	Daphnia	Chaoborus
0	23	11.2	-	.46	6.7	.23	0
1	23	11.1	-	1.2	2.4	.70	0
2	20	14.0	-	57.2	5.6	.47	0
3	14.5	9.6	-	83.3	3.3	6.7	0
4	11.5	.08	-	26.0	2.3	7.2	0
5	10.0	.05	-	13.3	3.5	7.0	0
6	8.0	.03	-	2.6	0.9	2.6	0
7	7.0	.03	-	0.7	.47	.93	0
8	6.0	.03	-	.7	0	.93	0
9	5.0	.05	-	.47	.23	1.6	0
10	5.0	.04	-	0	0	0.7	0

Table IV-27. Zooplankton depth distributions, Little Crooked Lake, June 30, 1981

Depth	Temp.	D.O.	Light	Diaptomus	Diacyclops	Daphnia	Chaoborus
0	28	13	500*	.35	15.6	0	0
1	26.0	17.0	150	.70	41.0	0	0
2	22.0	9.0	65	2.9	2.8	.12	0
3	17.0	1.5	5.0	8.4	4.8	0	0
4	14.0	1.0	1.5	.93	.23	0	0
5	10.0	.6	.5	.35	.23	0	0
6	8.0	.4	.4	0	.12	0	.58
7	7.0	.30	.3	0	0	0	0
8	6.0	.2	.3	0	0	0	0
9	5.0	.2	0	0	.60	0	.23
10	5.0	.2	0	0	0	0	.35
11	-	-	-	0	0	0	0
12	-	-	-	0	0	0	.58
13	-	-	-	0	0	0	.81
14	-	-	-	0	0	0	.12

*microeinsteins

Table IV-28. Zooplankton depth distributions, Little Crooked Lake, August 3, 1981

Depth	Temp.	D.O.	Light	Diaptomus	Diacyclops	Daphnia	Chaoborus
0				.24	44.3	0	0
1				.24	70.1	0	0
2				2.4	51.7	0	0
3				9.6	95.5	.12	0
4				8.3	76.8	0	0
5				.48	11.6	0	0
6				.23	3.8	0	.12
7				0	3.7	0	.23
8				.12	3.5	0	2.5
9				0	1.5	0	2.5
10				.12	1.9	.12	3.0

Table IV-29. Zooplankton depth distributions, Little Crooked Lake, August 12, 1981

Depth	Temp.	D.O.	Light	Diaptomus	Diacyclops	Daphnia	Chaoborus
0	26	10.5	650*	.39	30.6	.15	0
1	25.5	10.6	300	.23	30.5	.08	0
2	25.0	10.0	110	1.2	37.1	.08	.16
3	20.0	7.9	40	5.2	45.6	.23	.62
4	15.0	1.1	8	2.7	43.7	.08	.62
5	11.0	.08	5.5	.94	13.4	0	.35
6	9.0	.07	5.0	2.9	8.4	0	0
7	7.0	.06	4.0	.12	4.2	0	0
8	6.0	.05	0	.12	1.1	.12	0
9	6.0	.05	0	0	.82	.23	0
10	5.5	.04	0	0	1.2	0	0

Table IV-30. Zooplankton depth distributions, Little Crooked Lake, August 20, 1981

Depth	Temp.	D.O.	Light	Diaptomus	Diacyclops	Daphnia	Bosmina	Chaoborus
0	23.0	9.4	1100	.46	35.4	.62	6.3	0
1	23.0	9.3	450	.31	60.7	1.0	8.8	0
2	22.5	8.9	110	1.31	37.9	1.2	2.5	.08
3	21.0	10.0	37	1.2	51.9	2.3	2.8	.16
4	15.0	.08	7.0	4.7	37.1	.90	.16	.15
5	11.0	.06	1.8	2.3	47.1	.6	0	.23
6	9.0	.05	.07	1.5	7.8	.35	0	.35
7	7.0	.04	.04	.60	1.2	.12	0	.58
8	6.5	.04	.02	.24	1.8	0	0	.23
9	6.0	.04	.01	0	1.7	0	0	.47
10	6.0	.03	0	0	2.1	.35	.12	.70

Table IV-31. Zooplankton depth distributions, Little Crooked Lake, Steptember 3, 1981

Depth	Temp.	D.O.	Light	Diaptomus	Diacyclops	Daphnia	Bosmina	Chaoborus
0	24.5	8.9	260*	.84	10.5	2.9	.11	0
1	24.5	9.0	90	.42	10.5	1.7	.23	0
2	24.0	8.2	43	.52	13.3	2.8	.11	0
3	21.0	9.2	16	.42	10.2	3.9	0	.23
4	16.0	0.4	2.5	.95	12.3	2.0	0	.16
5	11.0	0.3	1.2	.63	5.7	2.2	0	0
6	9.0	.2	.06	0	.47	.47	0	.47
7	7.5	.2	.05	0	1.9	2.5	0	.93
8	6.5	.2	.04	0	2.4	1.6	0	.93
9	6.0	.15	.04	0	0.6	.31	0	0
10	5.5	.15	0	.17	.33	.33	0	.12

Table IV-32. Zooplankton depth distributions, Little Crooked Lake, May 12, 1982

Depth	Temp	D.O.	Light	Diaptomus	Diacyclops	Daphnia	Bosmina
0	24.2	11.0	2330	1.0	14.5	2.7	0.1
1	22.2	11.2	1220	4.5	9.1	8.4	0.0
2	19.3	18.1	620	21.2	12.2	16.9	0.0
3	12.7	10.4	220	8.6	21.4	3.9	0.2
4	9.3	7.6	51	6.3	78.8	1.2	0.0
5	6.7	4.1	20	1.5	29.2	0.9	0.0
6	6.2	3.1	8.5	0.9	6.5	0.2	0.0
7	6.0	3.0	3.9	0.3	2.4	0.0	0.0
8	5.8	2.0	2.0	0.6	2.6	0.0	0.0
9	5.8	1.3	0	1.4	1.5	0.0	0.0
10	5.8	0.4	0	0.4	0.3	0.0	0.0

Table IV-33. Zooplankton depth distributions, Little Crooked Lake, May 18, 1982

Depth	Temp	D.O.	Light	Diaptomus	Diacyclops	Daphnia	Bosmina
0	23.0	9.2	2030	0.5	2.3	0.8	0.8
1	23.0	8.6	1250	3.5	4.7	2.4	0.3
2	21.8	13.4	643	2.1	3.6	5.3	0.8
3	15.6	20.0	377	11.7	16.2	11.0	0.0
4	9.8	14.0	84.1	7.6	34.4	4.3	0.0
6	6.4	2.1	13.0	9.0	23.7	1.3	0.2
7	6.3	1.8	6.0	1.4	3.6	0.2	0.2
8	6.2	1.5	0.0	1.2	1.1	0.3	0.0
9	6.0	0.8	0.0	1.0	1.1	0.0	0.0
10	6.0	0.6	0.0	0.7	0.6	0.0	0.0

Table IV-34. Zooplankton depth distributions, Little Crooked Lake, May 26, 1982

Depth	Temp	D.O.	Light	Diaptomus	Diacyclops	Daphnia	Bosmina
0	19.5	10.1	521	0.8	2.1	0.3	0.0
1	19.5	10.0	262	1.6	2.6	2.5	0.0
2	19.3	10.4	167	1.6	2.0	1.6	0.0
3	15.9	17.9	66.1	5.0	7.2	5.1	0.0
4	10.5	13.6	28.9	16.4	6.9	13.1	0.0
5	7.8	1.6	9.3	11.2	9.5	4.3	0.1
6	6.6	0.9	4.0	2.6	4.0	0.7	0.1
7	6.3	0.7	1.9	1.6	0.8	0.8	0.1
8	6.2	0.6	1.1	0.9	0.5	1.1	0.0
9	6.1	0.0	0.7	0.2	1.0	0.5	0.0
10	6.0	0.0	0.4	0.0	0.2	0.0	0.0

Table IV-35. Zooplankton depth distributions, Little Crooked Lake, June 2, 1982

Depth	Temp	D.O.	Light	Diaptomus	Diacyclops	Daphnia
0	21.9	10.4	3450	0.08	0.64	0.2
1	21.7	10.2	820	0.2	2.3	0.6
2	20.2	9.8	157	3.1	3.7	6.4
3	17.7	11.8	12.3	3.8	3.3	5.2
4	11.5	11.0	7.7	14.5	7.9	9.9
5	8.4	3.4	3.5	45.4	7.7	23.7
6	7.0	0.9	1.7	18.3	4.2	9.9
7	6.5	0.7	1.1	2.0	1.2	3.1
8	6.3	0.6	0.7	.7	0.6	0.4
9	6.1	0.6	0.0	.1	0	0.6
10	6.0	0.0	0.0	0.0	0.0	0.5

Table IV-36. Zooplankton depth distributions, Little Crooked Lake, June 23, 1982.

Depth	Temp	D.O.	Light	Diaptomus	Diacyclops	Daphnia	Bosmina
0	21.9	10.8	1750	0.1	2.2	0.1	0.1
1	21.1	12.6	565	0.5	3.5	0.7	0.0
2	20.4	11.7	262	4.8	6.6	12.4	0.0
3	16.9	8.5	92	7.5	6.6	12.4	0.0
4	12.5	7.3	43	13.2	4.7	2.6	0.0
5	8.4	2.4	21.9	10.8	2.3	0.3	0.2
6	7.1	0.8	9.8	3.4	3.0	0.8	0.2
7	6.8	0.6	3.5	0.0	0.2	0.3	0.0
8	6.5	0.0	0.0	0.0	4.2	0.0	0.0
9	6.2	0.0	0.0	0.2	0.4	0.2	0.0
10	6.1	0.0	0.0	0.0	0.2	0.0	0.0

Table IV-37. Zooplankton depth distributions, Little Crooked Lake, July 7, 1982

Depth	Temp	D.O.	Light	Diaptomus	Diacyclops	Daphnia
0	27.0	8.6	3120	0.3	0.2	0.3
1	26.4	9.0	1640	0.41	0.8	0.3
2	24.2	12.6	415	2.0	0.8	1.8
3	19.0	10.0	65.6	2.7	6.4	7.3
4	12.0	1.6	23.3	15.1	4.1	2.9
5	9.9	0.8	9.82	8.8	1.5	2.0
6	8.2	0.0	4.5	3.6	0.3	0.0
7	7.6	0.0	2.2	0.3	0.0	0.2
8	7.2	0.0	1.1	0.3	0.0	0.4
9	6.9	0.0	0.0	0.0	0.0	0.0
10	6.7	0.0	0.0	0.0	0.0	0.0

Table IV-38. Zooplankton depth distributions, Little Crooked Lake, July 21, 1982

Depth	Temp	D.O.	Light	Diaptomus	Dia-cyclops	Daphnia	Diaphano-soma	Chaoborus
0	28.0	7.9	3630	0.3	0.5	1.0	0.0	0.0
1	27.8	9.7	1870	0.8	0.6	2.0	0.1	0.0
2	26.9	15.7	736	7.0	4.7	10.2	1.0	0.0
3	20.9	10.0	27.2	14.9	6.0	5.2	0.4	0.2
4	13.6	1.4	8.1	15.1	2.1	6.3	0.2	0.0
5	9.9	0.7	4.1	12.9	1.4	1.5	0.1	0.2
6	8.2	0.0	2.0	0.4	0.1	0.0	0.0	0.1
7	7.4	0.0	1.2	0.0	0.0	0.0	0.0	0.0
8	7.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
9	6.8	0.0	0.0	0.0	0.1	0.0	0.0	0.0
10	6.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1

Table IV-39. Zooplankton depth distributions, Little Crooked Lake, August 10, 1982

Depth	Temp	D.O.	Light	Diaptomus	Dia-cyclops	Daphnia	Diaphano-soma	Chaoborus
0	24.3	8.3	922	6.9	20.5	6.2	3.4	0.0
1	24.9	8.1	472	2.8	1.7	1.4	0.9	0.0
2	23.2	15.2	270	2.9	1.3	10.1	0.6	0.0
3	15.0	3.2	152	8.9	3.7	34.2	0.5	0.0
4	9.8	2.6	12.5	9.7	3.4	22.7	0.1	0.6
5	8.3	2.2	3.9	3.1	2.4	6.0	0.0	0.4
6	7.7	1.4	2.0	0.7	1.0	2.4	0.0	0.3
7	7.2	0.0	1.1	0.7	0.5	2.0	0.0	0.1
8	6.9	0.0	0.0	1.3	1.0	1.1	0.0	0.0
9	6.7	0.0	0.0	0.2	0.2	0.0	0.0	0.0
10	6.5	0.0	0.0	0.1	0.1	0.0	0.0	0.0

Table IV-40. Zooplankton depth distributions, Little Crooked Lake, May 17, 1983

Depth	Temp	D.O.	Light	Diaptomus	Dia-cyclops	Daphnia	Nauplii	Chao-borus	Bosmina
0	17.5	10.6	1500	10.2	0.0	8.4	.1	0.0	
2	15.0	10.3	130	19.4	1.4	13.4	.2	0.0	
4	9.0	8.2	19	1.65	0.0	2.1	0.0	0.0	
6	7.0	7.3	4.1	.2	.4	1.4	0.0	.2	
8	6.0	3.8	1.3	.1	1.0	1.6	0.0	0.0	
10	6.0	1.3	.35	.1	1.8	11.0	0.0	0.0	
12	5.0	.4	.11	.1	.7	2.2	0.0	0.0	

Table IV-41. Zooplankton depth distributions, Little Crooked Lake, June 2, 1983

Depth	Temp	D.O.	Light	Diaptomus	Dia-cyclops	Daphnia	Nauplii	Chao-borus	Bosmina
0	17.5	10.0	240	8.6	.8	1.4	.8	0.0	0.0
2	17	10.0	48	7.2	.2	6.6	1.2	.1	0.0
4	10	4.7	7.9	1.0	.1	2.2	.6	0.0	0.0
6	6.5	4.2	2.5	.2	.7	4.7	0.0	0.0	.2
8	6	2.3	.92	0.0	.8	6.4	0.0	0.0	0.0
10	5.5	.03	.35	0.0	.1	.8	0.0	0.0	.2
12			.14	0.0	0.0	.1	0.0	0.0	.1

Table IV-42. Zooplankton depth distributions, Little Crooked Lake, June 17, 1983

Depth	Temp	D.O.	Light	Diaptomus	Diacyclops	Daphnia	Nauplii	Chaoboru
0	25.5	8.4	3300	2.1	.5	.4	.2	0.0
2	23.5	11.4	950	4.8	.7	5.8	.1	1.4
4	12	4.9	130	2.9	1.0	15.3	.2	.2
6	7	3.6	27	.8	.1	1.6	0.0	0.0
8	6	.5	9.7	.4	1.0	1.9	0.0	.1
10	5.5	.2	3.9	0.0	0.0	.6	0.0	0.0
12	-	-	1.2	0.0	0.0	1.2	0.0	0.0

Table IV-43. Zooplankton depth distributions, Little Crooked Lake, June 28, 1983

Depth	Temp	D.O.	Light	Diaptomus	Diacyclops	Daphnia	Chaoboru
0	27.5	8.5	300	.6	.1	.4	0.0
2	27	9.6	61	3.2	2.5	3.2	.1
4	12.5	6.1	5.5	2.1	1.3	28.5	2.8
6	7	2.1	1.3	5.2	.6	9.4	.7
8	6	.4	.39	4.4	.6	7.6	.1
10	5.5	.25	.17	1.0	.2	3.0	.4
12	5	.2	.07	2.0	.1	1.9	.4

Table IV-44. Zooplankton depth distributions, Little Crooked Lake, July 13, 1983

Depth	Temp	D.O.	Light	Diaptomus	Diacyclops	Daphnia	Nauplii	Chaoborus
0	28	8.4	3900	.1	.9	1.8	.4	0.0
2	26.5	7.7	1300	.5	1.6	1.2	.4	0.0
4	15	9.3	280	6.4	3.3	11.6	6.8	2.2
6	8	.7	39	3.4	2.2	8.7	1.4	.6
8	6	.6	13	0.0	.1	1.0	0.0	.1
10	6	.6	4.7	0.0	0.0	0.0	0.0	.2
12	5.5	.6	1.7	0.0	.1	0.0	0.0	.1

Table IV-45. Zooplankton depth distributions, Little Crooked Lake, July 27, 1983

Depth	Temp	D.O.	Light	Diaptomus	Diacyclops	Daphnia	Nauplii	Chaoborus
0	29.8	8.0	2800	.2	0.0	.1	0.0	0.0
2	28.3	7.8	650	.1	.7	4.4	.1	0.0
4	18	10.5	140	7.4	3.6	11.3	1.5	1.8
6	8.5	.8	25	4.4	1.8	16.8	.4	.4
8	7	.6	6.3	.6	.7	3.0	0.0	.4
10	6.2	.5	2.4	.4	.1	1.9	.2	.2
12	6	.45	1.3	.1	0.0	1.8	.1	.6

Table IV-46. Zooplankton depth distributions, Little Crooked Lake, August 8, 1983

Depth	Temp	D.O.	Light	Diap-tomus	Dia-cyclops	Daphnia	Nauplii	Chao-borus	Diapha-nosoma
0	28	7.7	2000	.1	.8	2.0	.2	0.0	.2
2	28	7.3	570	3.0	5.4	35.6	.2	0.0	.9
4	20.6	9.2	180	10.4	5.7	43.0	2.1	2.6	17.2
6	9.8	1.1	26	1.0	5.0	14.6	.5	1.2	.7
8	7.1	.8	5.9	0.0	.2	.4	0.0	1.2	0.0
10	6.5	.7	1.6	0.0	.2	.4	0.0	.4	0.0
12	6	.65	.43	.1	.1	.4	0.0	.7	0.0

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