Effects of Artificial Destratification on a Lake Ecosystem

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THESIS

EFFECTS OF ARTIFICIAL DESTRATIFICATION ON A LAKE ECOSYSTEM

Submitted by

Robert T. Lackey

In partial fulfillment of the requirements
for the Degree of Doctor of Philosophy
Colorado State University
Fort Collins, Colorado
August, 1971

COLORADO STATE UNIVERSITY

AUGUST 1971

WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION

BY ROBERT T. LACKEY

ENTITLED EFFECTS OF ARTIFICIAL DESTRATIFICATION ON A LAKE ECOSYSTEM

BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

Committee on Graduate Work

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Head of Department

ABSTRACT OF THESIS

EFFECTS OF ARTIFICIAL DESTRATIFICATION ON A LAKE ECOSYSTEM

Effects of maintaining a 19 ha Colorado montane lake in a thermally destratified condition year around were evaluated. Water temperatures were kept vertically and horizontally isothermal throughout the year. Water temperatures for the entire lake were 1-2 C colder than normal in winter and 1-2 C warmer in summer. Deep water in summer was 5-6 C warmer than normal hypolimnion temperatures. No reduction in summer surface temperature was observed.

Dissolved oxygen depletion normally develops in summer and winter, but oxygen was kept at near saturation throughout the year. Hydrogen ion concentration, alkalinity, conductivity, and total residue were not significantly affected. Seston decreased and this was probably mainly due to declines in planktonic diatom populations.

Deep water increases in iron and manganese did not develop during destratification. Calcium increased slightly. Magnesium and most anions (chloride, nitrate-N, and silica) were not greatly altered, but sulfate was reduced in concentration.

Total phytoplankton numbers for the year were reduced, but phyla varied in their responses. Green phytoplanktonic algae decreased in abundance during treatment. Diatoms were nearly eliminated by destratification. Blue-green algae, however, increased in abundance. Vertical distribution of phytoplankton was not affected.

The zooplankton community was generally reduced. Cladocerans, copepods, and rotifers generally exhibited slight declines. Vertical distribution was not pronounced in the zooplankton and this did not change with destratification.

Benthic populations remained at about the same level or increased slightly. The amphipod (Hyalella) and chironomids were the most affected.

Summer depth distribution of rainbow trout was unaffected by destratification.

The potential of destratification for aquatic resource management is most promising for chemical problems (especially low oxygen or high iron and manganese). Although reduction in total phytoplankton populations was shown, there was an increase in the troublesome blue-greens.

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I. INTRODUCTION

Water resource managers and aquatic scientists are well aware of lake management problems caused by thermal stratification. Massive fish mortality, habitat deterioration, limited commercial and domestic water use, lessened recreational water use, and high evaporation rates have been identified with thermal stratification. As one solution to these problems, efforts have been made to control or eliminate thermal stratification.

Fishery biologists have often attempted artificial destratification in lakes to eliminate mortality caused by winter oxygen loss. Results have not been uniformly successful, but Hemphill (1954), Rasmussen (1960), and Halsey (1968), to cite a few papers, were reasonably successful in preventing winterkill. On the other hand, Patriarche (1961), Woods (1961), and Seaburg (1966) found their attempts unsuccessful with small scale aeration.

Habitat improvement specifically for fish populations has been attempted by eliminating thermal stratification (Hooper, Ball, and Tanner, 1953; Johnson, 1966). Both efforts dealt with increasing production of fish by improving environmental conditions.

Use of water for industrial or domestic consumption is sometimes limited by thermal stratification. Derby (1956), Riddick (1957), Nickerson (1961), Koberg and Ford (1965), Bernhardt (1967), and Symons, Carswell, and Robeck (1970) have reported successful results of lake destratification on industrial or domestic water use. In most cases noxious gases would normally build up in the hypolimnion or plankton blooms develop in the epilimnion.

Recreational use of lakes has been lessened due to eutrophication. Specifically, plankton blooms and warm epilimnion water seriously lessen aesthetic appeal of the lake. Wirth, Dunst, Uttormark, and Hilsenhoff (1970) demonstrated marked reduction in plankton blooms by eliminating thermal stratification in a popular Wisconsin recreational lake.

Evaporation control in lakes is a significant management problem in many arid areas of the world (Streiff, 1955). Koberg and Ford (1965) showed significant reduction in evaporation rates from a California reservoir by eliminating thermal stratification.

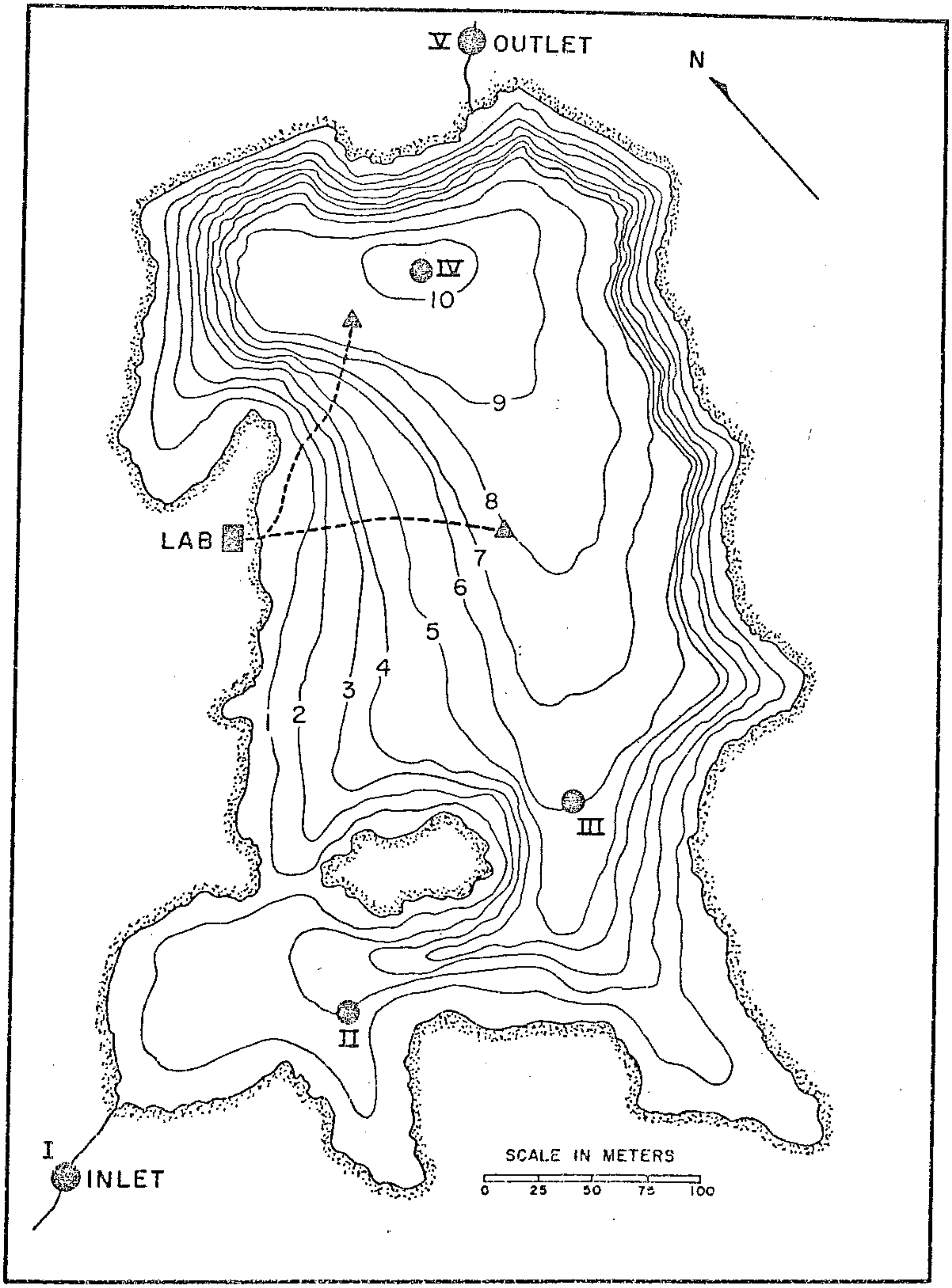
The purpose of my study was to evaluate the effect of eliminating thermal stratification on various ecosystem components in a montane lake throughout the year. Ecosystem parameters were selected that would likely provide a basis for determining areas of potential use in lake management.

II. STUDY AREA

Parvin Lake, Colorado, was selected for study to evaluate effects of destratification (Figure 1). This 19 ha mesotrophic reservoir, constructed in 1927, has a maximum depth of 10 m and a mean depth of 4.4 m. This lake has the advantages of considerable limnological background data, controlled public access, and laboratory facilities. It is dimictic and, compared to other Colorado montane lakes, highly fertile. The lake is located at an elevation of 2500 m in the Rocky Mountains of northern Colorado and has served as an experimental lake for fishery and limnological research since 1949.

Summer surface temperature usually does not exceed 21 C. Dissolved oxygen loss develops in deep water during summer and winter. Ice cover lasts from November to April and reaches 20-50 cm thickness.

Figure 1. Map of Parvin Lake, Colorado (depth contours in meters; sampling stations, circles; aerators, triangles; dashed line, plastic pipe).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III. METHODS

Destratification System

Aerators used during this study were manufactured by the Polcon Corporation, Montreal, Canada (Figure 2). Each aerator consists of a one-piece polyethylene tube 46 cm in diameter containing a continuous polyethylene coil, which longitudinally divides the tube into two separate longitudinal sections. Air is released at the bottom of the aerator through several small holes. Upwelling is created by bottom water drawn up the tube (Figure 2). Two aerators were used in Parvin Lake.

Anchored polyethylene pipe (3.8 cm diameter) connected aerators and compressor. Compressed air was provided by a single stage air cooled compressor mounted in a lakeside laboratory (Figure 1). Maximum displacement of this compressor was rated at 2.1 m^3/min and maximum operating pressure at 4.2 kg/cm^2. Normal operating equilibrium pressure was reached at 1.0-1.4 kg/cm^2.

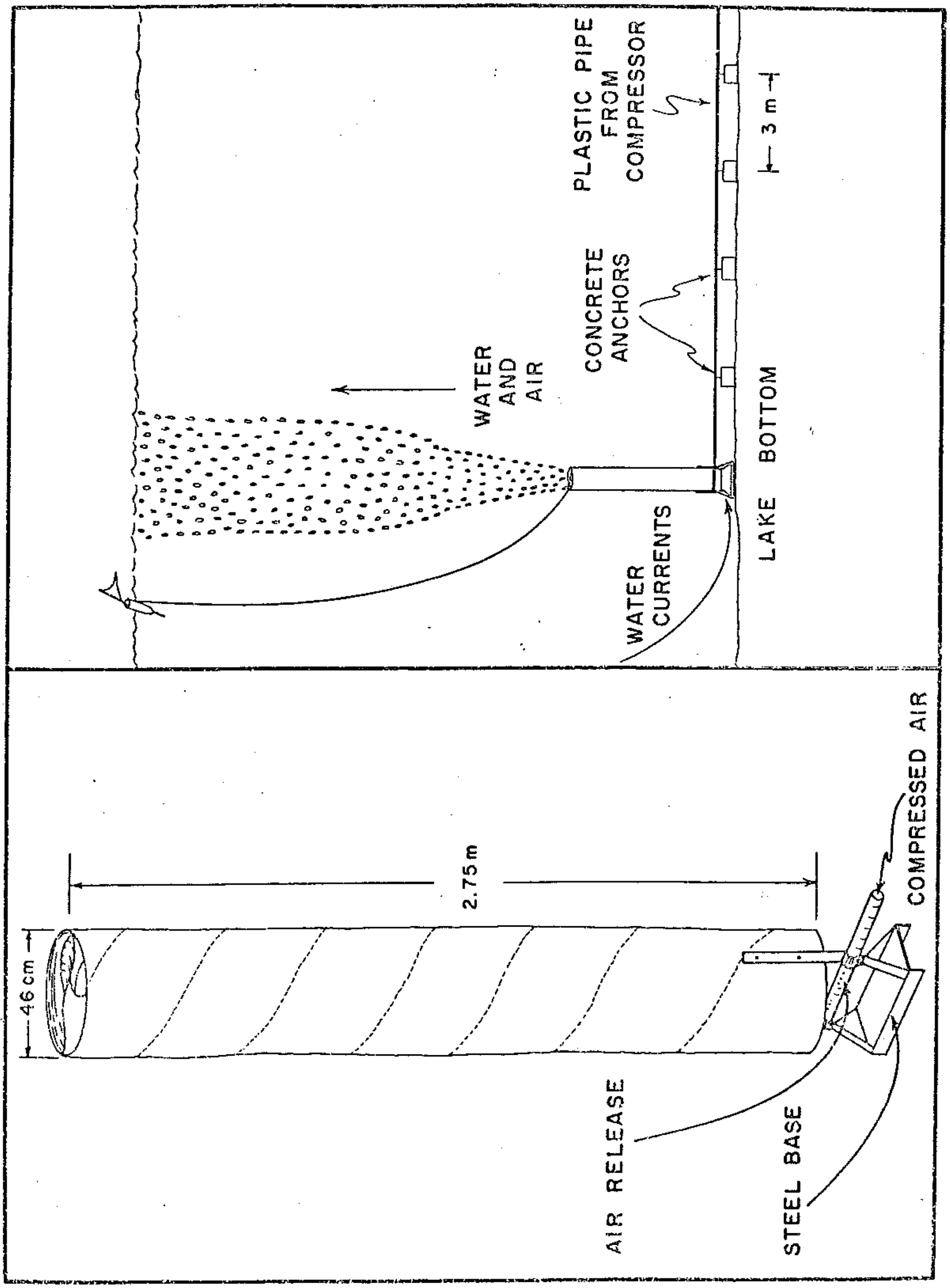
Design, installation, and operation of this destratification system is described more fully in Lackey (1971).

Sampling

A standard sampling program was carried out at Parvin Lake during a control year (November, 1968-October, 1969) and a treatment year (November, 1969-October, 1970). During the treatment year the destratification system was in continuous operation.

Five sampling stations were selected and permanently marked (Figure 1). Station I was located in the inlet creek approximately 50 m above the confluence with the lake. Station II was in water 2 m

Figure 2. Aerators used at Parvin Lake showing general design and placement in lake.


WATER AND AIR
CONCRETE ANCHORS
PLASTIC PIPE FROM COMPRESSOR
3 m
WATER CURRENTS
LAKE BOTTOM
46 cm
2.75 m
COMPRESSED AIR
AIR RELEASE
STEEL BASE

deep and outside the main body of the lake. Station III was in water 6 m deep. Station IV was in the deepest part of the lake (10 m). The outlet stream station (V) was about 50 m downstream.

Samples and measurements at each lake station were taken on a single day near the middle of each month.

Analytical Methods

Physical-Chemical Parameters

Physical and chemical parameters were estimated by Standard Methods (Amer. Pub. Health Assoc., 1965) unless otherwise noted. Temperature profiles were taken with an Applied Research Associates Model FT-2 electronic thermometer at 1 m intervals at all lake stations. Dissolved oxygen was determined with the Alsterberg modification of the Winkler method at 2 m intervals at lake stations. Hydrogen ion concentration was determined with a Beckman Electromate 1009 pH meter at 2 m intervals at lake stations and the inlet and outlet. Alkalinity was determined by the titrimetric indicator method with endpoint pH 4.4 at 2 m intervals at lake stations and inlet and outlet. Conductivity was determined at 25 C with a Beckman Model RC-16B2 conductivity bridge at 2 m intervals for lake stations and inlet and outlet. Total residue was estimated by evaporation to constant weight at 100-106 C at 2 m intervals at lake stations and inlet and outlet.

An estimate of the amount of seston at each 2 m interval in the lake and the inlet and outlet was made by filtration through a Whatman GF/C glass fiber filter (Reed and Reed, 1970).

Four cations and four anions were selected for monthly determination. Profiles at 2 m intervals were taken at lake stations and inlet and outlet.

Cations (calcium, magnesium, iron, and manganese) were determined on a Perkin-Elmer Model 303 atomic absorption spectrophotometer. All cation samples were preserved in 1% HCl or HNO_3 solution (Fed. Wat. Pol. Contr. Admin., 1969). Maximum storage time was 6 months.

Anions (chloride, nitrate nitrogen, silica, and sulfate) were determined by wet chemical techniques. Chloride was estimated with the mercuric nitrate method with pH adjustment to 3.1 (Golterman, 1969). Nitrate nitrogen was determined by the phenoldisulfonic acid method. Silica was determined with the colorimetric molybdosilicate method. Sulfate was determined with the turbidimetric method (Fed. Wat. Pol. Contr. Admin., 1969).

Biological Parameters

Plankton sampling consisted of straining 12 liters (four separate 3 liter hauls at each 0.5 m depth within each 2 m stratum) through a 75 nm mesh net. Contents were then preserved in 4% formaldehyde and enumerated in Palmer (phytoplankton) cells or Sedgewick-Rafter (zooplankton) cells.

Benthic samples (four Ekman dredge grabs combined to cover 0.093 m^2) were sieved through a wash bucket (0.515 mm mesh screen) and sugar flotation and rose bengal dye used to separate organisms from debris (Lackey and May, 1971).

Vertical distribution of rainbow trout during summer was determined with nets and procedures similar to those described by Lackey

(1968, 1970) at Stations III and IV. Nets with 3.2 cm mesh were operated 1-2 days/week from June to August.

IV. RESULTS

Physical and Chemical Parameters

Weighted means for the entire lake of physical and chemical parameters are given in Table 1. These data were obtained by weighting the parameter value obtained for each stratum in proportion to that stratum's volume of the total lake volume.

Water Temperature

Temperature profiles from lake stations for control (1968-69) and treatment (1969-70) years are shown in Figure 3. Data from the control year are similar to previous years and this year can be taken as a normal annual temperature cycle.

Vertical stratification during summer months was nearly eliminated during treatment (Figure 3). Winter temperatures range from 1 to 3 C difference between lake top and bottom. This was completely eliminated during treatment (Figure 3).

Changes in absolute temperatures at certain times of the year were very marked. During ice covered months of November through April, the weighted mean temperature of the lake was 3.7 C during control and 2.0 C during treatment. The opposite relationship developed during months of open water (May-October). This is reflected in the run test ($P < 0.07$). The mean control temperature was 12.0 C and treatment 12.9 C. These deviations from the typical cycle essentially balanced to yield a treatment annual average temperature of 7.4 C compared to 7.8 C for control year.

Table 1. Weighted lake means of physical and chemical parameters (temperature, C; dissolved oxygen, mg/liter; hydrogen ion, pH; alkalinity mg/liter; conductivity, micromhos/cm; total residue and seston, mg/liter; cations and anions, mg/liter) in Parvin Lake during control year (C) and treatment year (T).

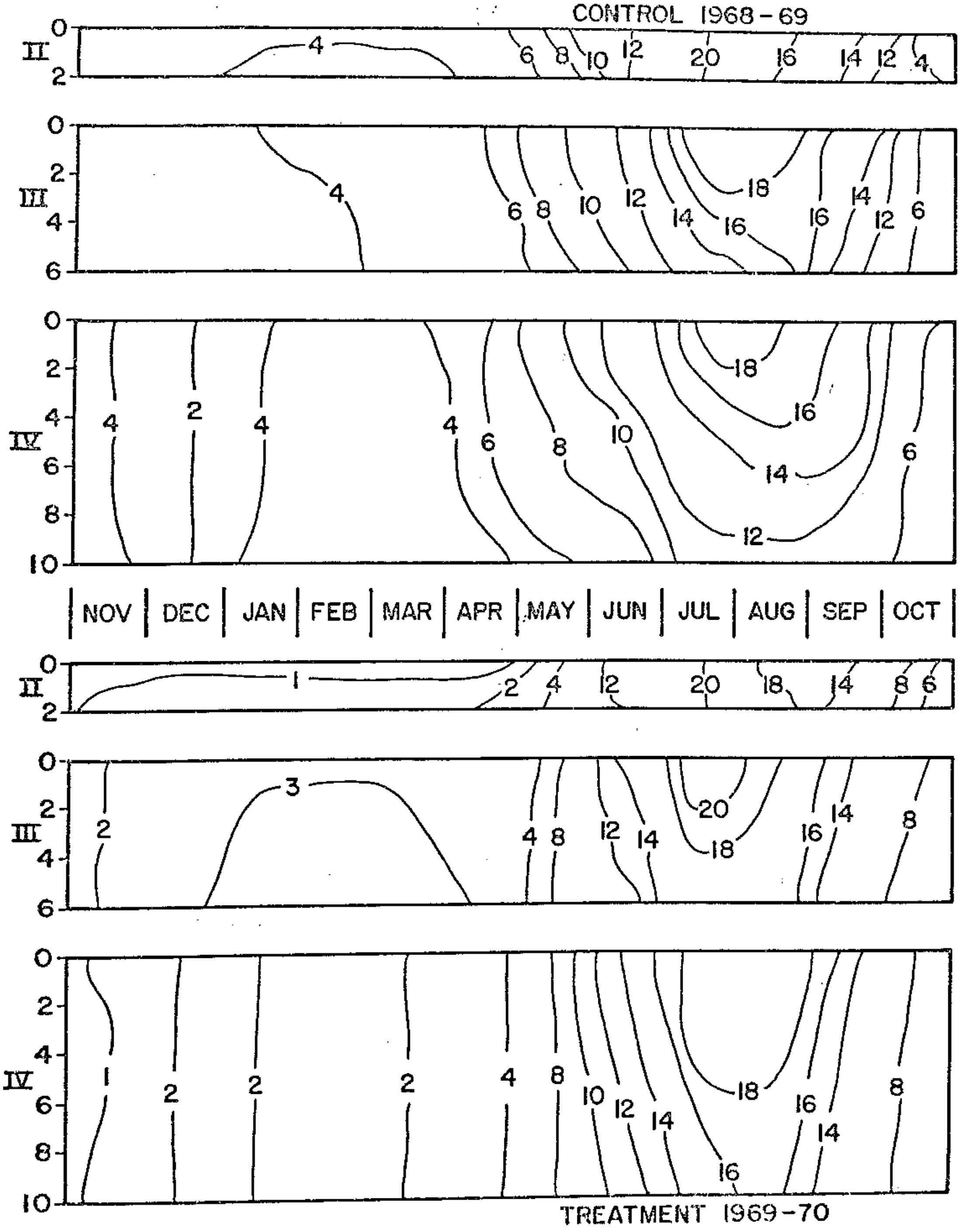
Parameter	Year	Weighted Mean Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Mean	P of Run Test	Paired t Test
Temperature	C	4.0	1.6	4.2	3.6	3.3	5.7	8.8	11.3	16.4	16.6	13.6	5.0	7.8	0.07	0.70
	T	1.5	2.0	2.2	1.9	2.2	1.9	7.5	13.0	18.7	17.8	13.5	7.1	7.4		
Dissolved Oxygen	C	7.1	8.1	5.6	7.3	7.4	9.7	8.2	6.6	6.0	6.4	6.8	8.2	7.3	0.07	2.95*
	T	10.0	9.4	8.7	9.4	9.1	9.5	11.5	7.4	6.3	7.5	6.3	7.1	8.5		
Hydrogen Ion	C	---	---	6.9	6.9	6.8	7.0	7.2	6.9	6.6	6.9	7.0	6.9	6.9	0.20	0.86
	T	6.8	6.8	7.0	6.9	6.8	7.1	6.8	7.1	6.7	7.2	7.0	7.0	6.9		
Alkalinity	C	---	29.7	30.0	24.8	28.0	24.0	28.4	22.8	23.8	26.0	26.3	25.6	26.3	0.26	0.08
	T	27.2	27.9	29.1	29.2	31.1	30.6	29.0	21.6	20.9	24.1	23.2	23.4	26.4		
Conductivity	C	---	56.4	---	58.5	63.2	63.8	61.1	55.0	80.5	88.4	64.1	61.3	65.2	0.36	0.45
	T	63.4	65.9	70.3	70.7	66.7	68.4	73.0	62.6	52.3	61.5	53.8	56.0	63.7		
Total Residue	C	54.4	56.4	---	58.8	61.2	58.8	84.1	60.4	57.2	61.8	31.3	44.0	57.1	0.91	0.76
	T	48.7	61.2	78.0	66.2	60.4	65.3	68.2	68.8	58.5	52.6	54.8	50.1	61.1		
Seston	C	---	1.9	2.6	---	5.7	5.5	4.4	2.8	1.4	3.8	2.8	1.9	3.3	0.52	3.12*
	T	1.2	1.2	1.5	1.4	0.8	2.5	3.5	2.5	0.7	1.8	2.9	0.7	1.7		
Cations Calcium	C	6.5	6.9	7.0	7.0	6.6	6.6	6.5	6.3	5.8	6.7	6.5	6.4	6.6	0.91	3.85**
	T	7.0	7.1	7.7	7.2	7.3	7.5	7.5	6.5	6.0	7.7	6.3	6.4	7.0		

Table 1. Weighted lake means of physical and chemical parameters (temperature, C; dissolved oxygen, mg/liter; hydrogen ion, pH; alkalinity mg/liter; conductivity, micromhos/cm; total residue and seston, mg/liter; cations and anions, mg/liter) in Parvin Lake during control year (C) and treatment year (T) (continued).

Parameter	Year	Weighted Mean												Mean	P of Run Test	Paired t Test
		Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.			
Magnesium	C	1.7	1.8	1.8	1.8	1.6	1.8	1.9	1.6	1.6	1.8	1.8	1.8	1.8	0.02	1.49
	T	1.9	2.0	2.1	2.0	2.1	2.2	1.8	1.6	1.6	1.7	1.6	1.6	1.8		
Iron	C	.83	.87	.96	.99	1.05	.77	.57	.48	.54	.72	.86	.60	.77	0.07	5.39**
	T	.60	.62	.62	.50	.42	.47	.50	.35	.47	.61	.32	.29	.48		
Manganese	C	0.1	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	----	2.85*
	T	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Anions Chloride	C	0.7	1.2	1.2	---	0.7	0.7	1.1	1.1	0.3	0.7	0.7	0.9	0.8	0.52	0.74
	T	0.8	1.0	1.0	1.1	0.8	1.2	1.5	0.8	0.7	0.9	0.5	0.8	0.9		
Nitrate-N	C	0.4	0.5	0.4	---	1.0	0.4	0.4	0.6	0.3	0.2	0.2	0.2	0.4	0.88	1.57
	T	0.2	0.2	0.0	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.6	0.6	0.2		
Silica	C	11.3	10.5	10.4	8.3	9.9	6.8	7.9	11.2	13.6	13.0	10.8	11.5	10.4	0.18	1.84
	T	12.5	12.0	12.8	11.2	15.8	13.3	11.0	10.5	9.6	11.0	13.5	11.3	12.0		
Sulfate	C	4	4	4	9	5	6	6	6	3	3	3	3	5	0.28	4.86**
	T	3	3	3	3	3	4	4	0	0	2	1	0	2		

* Significant at α = 0.05.
** Significant at α = 0.01.

Figure 3. Water temperature (C) in Parvin Lake during control and treatment years. Stations (Roman numerals) and station depth (m) are given on left side of each graph.


CONTROL 1968-69
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TREATMENT 1969-70

Dissolved Oxygen

Weighted lake means (Table 1) and oxygen profiles (Figure 4) for control year are similar to past years at Parvin Lake. Mean monthly dissolved oxygen in Parvin Lake during treatment increased significantly (paired t test, $P < 0.02$) from control.

Dissolved oxygen loss did not develop during treatment year (Figure 4). The slight decrease in deep water oxygen content during summer resulted from minor thermal gradients hindering circulation. Greatest increases in oxygen were during winter months (run test, $P < 0.07$).

Hydrogen Ion

Hydrogen ion concentration varied (pH: 6.5-7.5) little in either control or treatment year (Table 1). Vertical gradients did not develop nor was a seasonal cycle apparent. Control and treatment years were nearly identical.

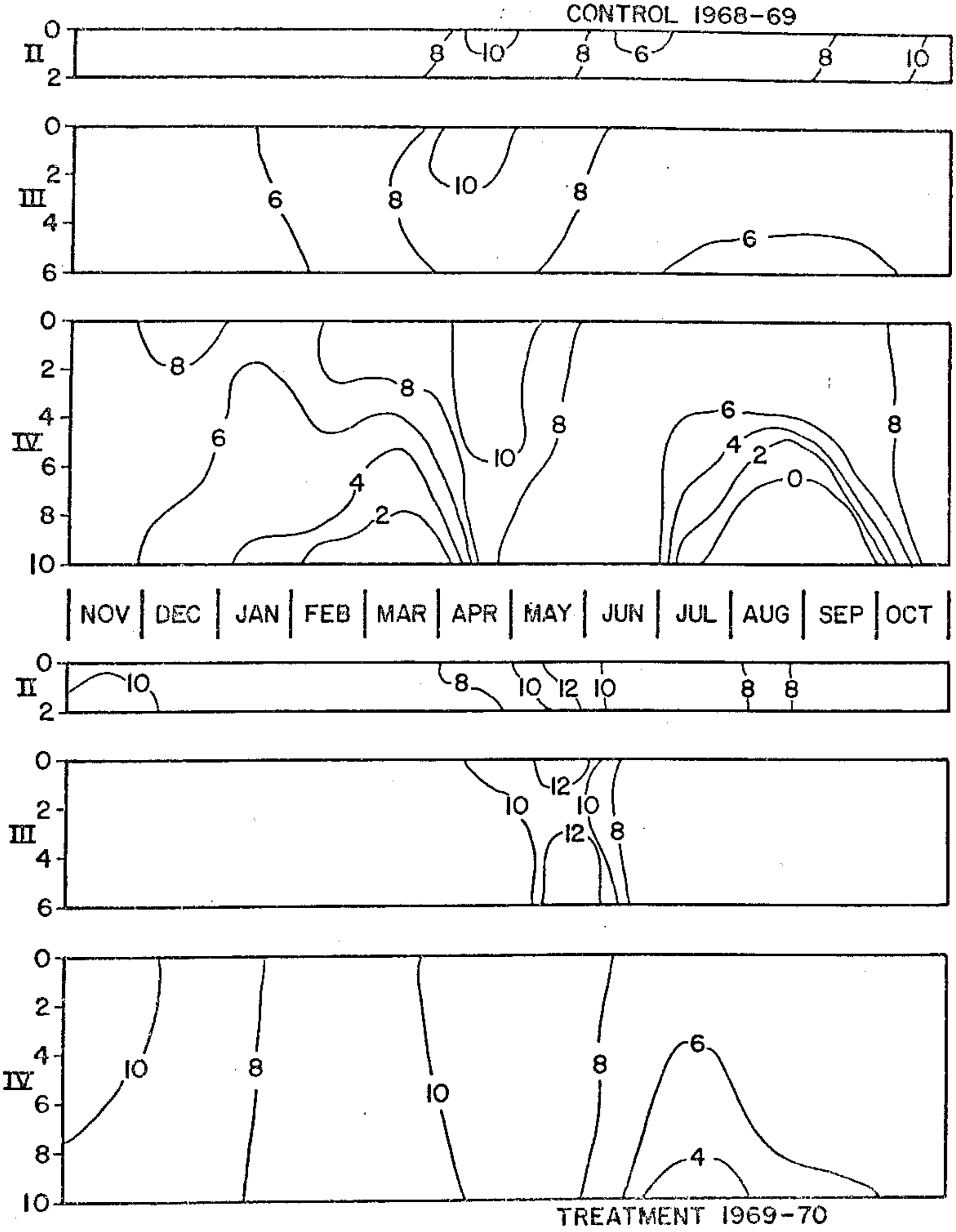
Alkalinity

The annual alkalinity cycle (Table 1) generally had higher values in winter than summer. Both years followed a nearly identical pattern.

Conductivity

Weighted lake means of conductivity showed little difference between control and treatment years except for slightly higher treatment winter values and lower summer values (Table 1). The range of conductivity during control year was 53-102 micromhos/cm and during treatment, 51-84 micromhos/cm.

Figure 4. Dissolved oxygen (mg/liter) in Parvin Lake during control and treatment years. Stations (Roman numerals) and station depth (m) are given on left side of each graph.



CONTROL 1968-69

TREATMENT 1969-70

Vertical stratification of conductivity was apparent only during July and August of the control year. Horizontal gradients sometimes occurred and were associated with higher concentrations near the inlet (Stations I and II).

Total Residue

Variations in total residue were great in both years (control: 21-117 mg/liter; treatment: 37-102 mg/liter). However, weighted lake means were similar (Table 1). Vertical stratification and horizontal gradients could not be seen in either year.

Seston

Weighted lake means of seston differed (paired t test, $P < 0.02$) between years (Table 1). Within month variation was great, but most concentrations were between 0 and 4 mg/liter. Vertical stratification or horizontal gradients did not develop.

Cations

Calcium

Weighted lake means for calcium are shown in Table 1. Calcium did not follow an annual cycle in either control or treatment year, but the treatment year was consistently (paired t test, $P < 0.01$) higher. The mean increase was, however, only 0.4 mg/liter.

No indication of vertical stratification or horizontal gradients was found for calcium. This ion was always fairly homogeneously distributed in Parvin Lake.

Magnesium

Weighted lake means of magnesium are given in Table 1. There is little annual variation in control or treatment years except that winter changes were generally positive and summer changes negative (run test, $P < 0.02$). Vertical stratification or horizontal gradients were not observed.

Iron

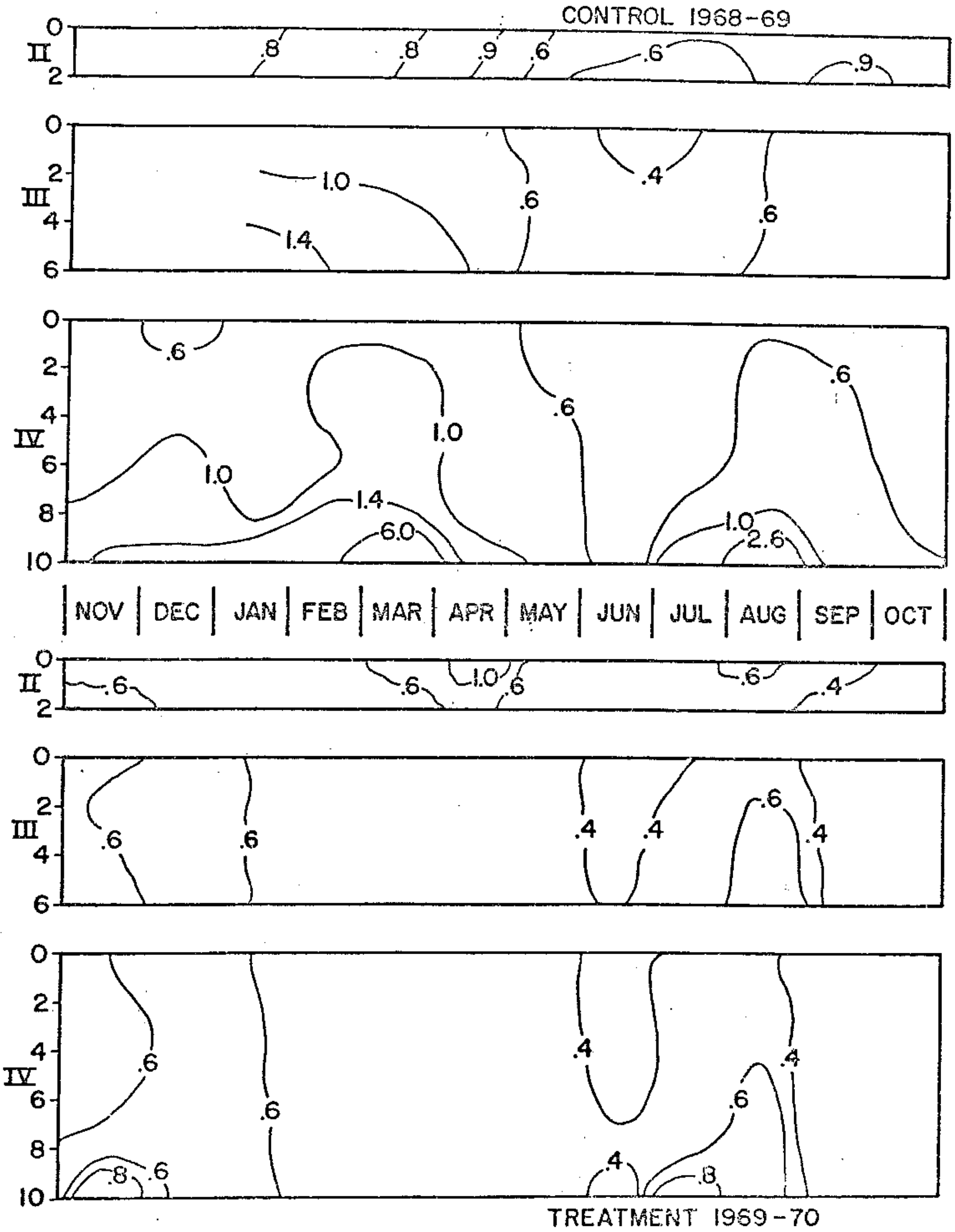
Weighted lake means for iron are shown in Table 1. Iron normally follows a definite seasonal cycle in Parvin Lake and this cycle is due to deep water increases in winter and summer. Winter weighted means are highest and reach a maximum in March. Iron remains fairly low during spring and early summer, but rises somewhat in late summer. Weighted means in the treatment year did not follow such a pronounced cycle, although concentrations were highest in winter. There was significantly (paired t test, $P < 0.01$) less iron in the treatment year.

Vertical stratification of iron was pronounced (Figure 5). During the control year, iron increased in deep water during both winter and summer. Only a slight increase in iron was detected in deep water during winter and summer of the treatment year.

Manganese

Weighted lake means of manganese are given in Table 1. Manganese in Parvin Lake was detectable only during summer and winter during the control year and rarely during the treatment year and was significantly lower (paired t test, $\alpha = 0.05$) during treatment. The most pronounced increases occurred in deep water in winter and summer of the control

Figure 5. Iron (mg/liter) in Parvin Lake during control and treatment years. Stations (Roman numerals) and station depth (m) are given on left side of each graph.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TREATMENT 1969-70

year. Concentrations reached 0.9 mg/liter at 10 m in March and 0.8 mg/liter at 10 m in August. Concentrations were lower ($\alpha = 0.05$) during the treatment year.

Horizontal gradients were not observed.

Anions

Chloride

Weighted lake means of chloride are given in Table 1. Chloride followed no clear annual pattern in either year. Vertical stratification or horizontal gradients were not observed.

Nitrate Nitrogen

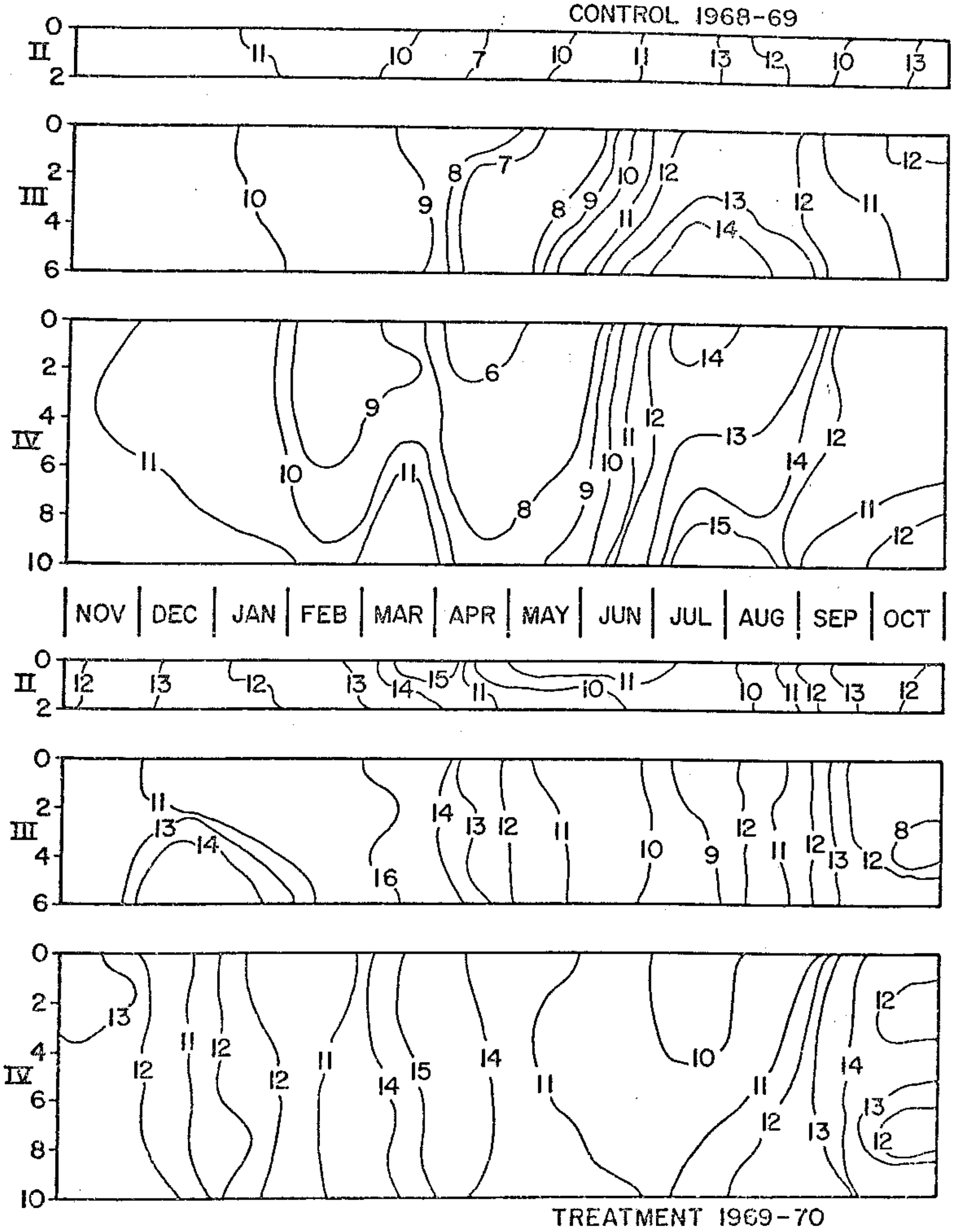
Weighted lake means of nitrate nitrogen are given in Table 1. Concentrations during treatment were slightly lower than those from control. In both years there was much variability within a given month, but no indication of vertical or horizontal gradients.

Silica

Weighted lake means of silica in Parvin Lake are given in Table 1. During the control year silica concentration was low during late winter and spring and fairly uniform during other seasons. During the treatment year, silica was at fairly high levels all year.

Silica was much more stratified during the control year than during the treatment year (Figure 6). Lower concentrations tended to be uppermost in a water column. Little horizontal differences were present.

Figure 6. Silica (mg/liter) in Parvin Lake during control and treatment years. Stations (Roman numerals) and station depth (m) are given on left side of each graph.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TREATMENT 1969-70

During November to May of the treatment year, silica was higher than during corresponding control months. This is probably due to decreased diatom densities (discussed later).

Sulfate

Weighted lake means of sulfate are given in Table 1. Within month data are highly variable and followed no clear vertical or horizontal distribution pattern. Concentrations during the treatment year were lower (paired t test, $P < 0.01$) than during control year. This was probably due to decreased SO_4 levels of inflowing water during the treatment year. Seasonal differences were not appreciably different in either year except for lower concentrations in summer and early fall during treatment.

Phytoplanktonic Community

Chlorophyta

Green algal species commonly found in the phytoplanktonic community were: Eudorina elegans, Sphaerozosma auburtianum, Staurastrum gracile, and Volvox sp.. The abundance of Chlorophyta (total abundance of these four common species) significantly decreased (sign test, $P < 0.04$) during treatment (Table 2). Summer and early fall increases were not present in the treatment year.

Eudorina elegans declined (sign test, $P < 0.01$) in abundance during the treatment year (Table 2). No pattern of vertical stratification (Table 3) was present in either control or treatment year.

Sphaerozosma aubertianum increased during winter months and was eliminated during summer months of the treatment year (Table 2). No

Table 2. Weighted lake means (number organisms or colonies/liter) of phytoplankters collected in Parvin Lake during control (C) and treatment (T) years.

Group	Year	Weighted Mean												Mean	P of Sign Test	P of Run Test
		Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.			
Chlorophyta	C	51	22	63	40	4	57	64	30	62	630	176	309	126	0.04	0.07
	T	26	32	28	26	11	2	16	3	25	16	11	2	16		
Eudorina	C	27	18	55	34	4	32	23	290	36	2	70	57	53	0.00	0.53
	T	3	2	1	3	1	0	1	0	4	0	0	0	1		
Sphaerozosma	C	3	0	0	1	0	18	39	0	10	11	11	76	14	0.61	0.18
	T	5	17	16	9	2	1	15	3	0	0	0	0	6		
Staurastrum	C	21	4	3	2	0	2	1	9	16	590	93	170	75	0.39	0.01
	T	13	10	10	12	7	1	0	0	0	16	11	2	7		
Volvox	C	0	0	5	3	0	5	1	1	0	27	2	6	4	0.39	0.39
	T	5	3	1	2	1	0	0	0	21	0	0	0	3		
Pyrrhophyta	C	11	2	0	0	0	0	1	15	260	3100	87	46	290	0.75	0.36
Ceratium	T	3	5	2	2	0	0	0	1	1200	400	5	2	140		
Chrysophyta	C	0	0	0	260K	82K	0	0	0	0	0	0	0	28K	0.50	----
Mallomonas	T	0	0	0	0	0	0	0	0	0	0	0	0	0		
Bacilliariophyta	C	81K	49K	190K	210K	140K	270K	100K	70	330	20	100	0	100K	0.06	0.11
	T	6	19	61	110	11K	6000	2400	2200	1100	0	0	0	1900		
Asterionella	C	330	26K	160K	210K	140K	270K	100K	44	0	0	0	0	75K	0.11	0.07
	T	2	14	26	110	11K	6000	2400	2200	850	0	0	0	1900		

Table 2. Weighted lake means (number organisms or colonies/liter) of phytoplankters collected in Parvin Lake during control (C) and treatment (T) years (continued).

Group	Year	Weighted Mean												Mean	P of Sign Test	P of Run Test
		Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.			
Fragilaria [a]	C	200	2300	3200	300	360	200	2	0	2	2	10	0	550	0.01	0.00
	T	0	0	0	0	1	2	1	1	0	0	0	0	0		
Melosira	C	79K	87	1500	19	42	6	7	26	330	0	1	0	6700	0.00	0.52
	T	4	5	35	0	1	0	0	0	260	0	0	0	25		
Cyanophyta	C	46	0	8	4	26	34	580	300	320	80	153K	180	1200	0.39	0.39
	T	2	6	0	0	0	1	0	7	2200	310K	140K	2900	38K		
Anabaena	C	0	0	0	2	25	32	580	300	320	80	13K	160	1200	0.55	0.11
	T	2	6	0	0	0	1	0	7	1100	19K	1800	12	1800		
Aphanizomenon	C	0	0	0	0	0	0	0	0	0	0	150	1	13	0.12	----
	T	0	0	0	0	0	0	0	0	1100	290K	140K	2400	36K		
Gomphosphaeria	C	46	0	8	2	1	2	0	1	0	0	38	16	10	0.26	0.14
	T	0	0	0	0	0	0	0	0	0	2	2500	460	250		

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[a] Reported as number of Fragilaria chains (approximately 10 individuals/chain).

Table 3. Median depth (m) of phytoplankters collected at Station IV in Parvin Lake during control (C) and treatment (T) years.

Group	Year	Median Depth												P of Sign Test
		Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	
Chlorophyta	C	6	2	2	5	3	5	5	4	4	1	5	6	0.69
Eudorina	T	8	5	4	6	n	n	1	n	1	n	n	n	
Sphaerozosma	C	7	n	n	n	n	4	6	n	2	1	5	6	0.25
	T	7	5	9	2	4	n	5	7	n	n	n	n	
Staurastrum	C	8	5	5	5	9	1	5	1	2	4	5	6	0.75
	T	6	6	7	1	2	n	3	9	n	6	5	5	
Volvox	C	n	n	2	2	n	3	n	n	n	1	4	1	0.25
	T	8	5	9	4	4	n	n	n	1	n	n	n	
Pyrrhophyta	C	5	4	n	n	n	n	n	2	4	4	5	6	0.63
Ceratium	T	6	4	3	n	n	n	n	6	1	5	1	5	
Chrysophyta	C	n	n	n	2	5	n	n	n	n	n	n	n	----
Mallomonas	T	n	n	n	n	n	n	n	n	n	n	n	n	
Bacilliariophyta	C	4	4	4	5	4	5	3	6	n	n	n	n	0.30
Asterionella	T	3	2	3	4	5	2	4	4	7	n	n	n	
Fragilaria	C	2	5	5	5	4	7	9	n	3	5	4	9	0.50
	T	6	n	n	n	3	6	7	9	n	n	n	n	

n = no organisms taken.

Table 3. Median depth (m) of phytoplankters collected at Station IV in Parvin Lake during control (C) and treatment (T) years (continued).

Group	Year	Median Depth												P of Sign Test
		Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	
Melosira	C	9	8	9	8	6	1	9	8	5	n	n	n	0.50
	T	4	n	9	9	7	n	n	n	5	n	n	n	
Cyanophyta	C	n	n	n	n	2	3	3	2	1	2	3	4	0.75
Anabaena	T	6	3	n	n	n	1	n	2	1	4	6	4	
Aphanizomenon	C	n	n	n	n	n	n	n	n	n	n	2	n	0.50
	T	n	n	n	n	n	n	n	n	1	4	4	4	
Gomphosphaeria	C	6	9	6	7	7	n	n	5	n	n	2	7	0.75
	T	5	n	n	n	n	n	n	n	n	3	5	5	

n = no organisms taken.

pattern of vertical stratification (Table 3) in either control or treatment year was found.

Staurastrum gracile (Table 2) generally increased during winter and decreased during summer of the treatment year as is shown by a run test ($P < 0.01$). The August pulse accounted for the overall higher mean density. Vertical stratification (Table 3) was not present in control or treatment years.

Volvox sp. abundance was similar in both years. During the control year, this species was typically found in the upper 4 m of the lake, but during treatment, it was often found below 4 m (Table 3).

Pyrrhophyta

Ceratium hirundinella followed a similar pattern during both years (Table 2 and 3). The peak of the summer pulse was somewhat higher during the control year, hence the higher mean.

During both summers, this species was most dense in the upper 2 m of water but was found throughout the water column.

The general seasonal cycle shown for 1969-70 is very similar to that found in Parvin Lake in 1952 (Boyd, 1953) and 1955 (Marshall, 1956).

Bacilliariophyta

Asterionella formosa did not significantly (sign test, $P < 0.11$) decrease during treatment (Table 2). Control winter numbers were high for November-May, while treatment abundance was low from November to February and only moderate from March to May.

The annual depth distribution of Asterionella formosa for all three lake stations is given in Figure 7. Maximum densities developed in mid-water in April during control and in March during treatment.

Fragilaria crotonensis failed to develop during the treatment year (Table 2). Abundance was significantly (sign test, $P < 0.01$) less during treatment and, as might be expected, the run test $P < 0.01$) shows greatest changes in winter. No pattern of vertical distribution was present in either control or treatment.

Melosira granulata decreased (sign test, $P < 0.01$) during the treatment year (Table 2). The fall and winter pulse of the control year was totally absent during treatment.

During control winter months, this species was most dense in deep water. However, during treatment winter months, no indication of this stratification was present.

Chrysophyta

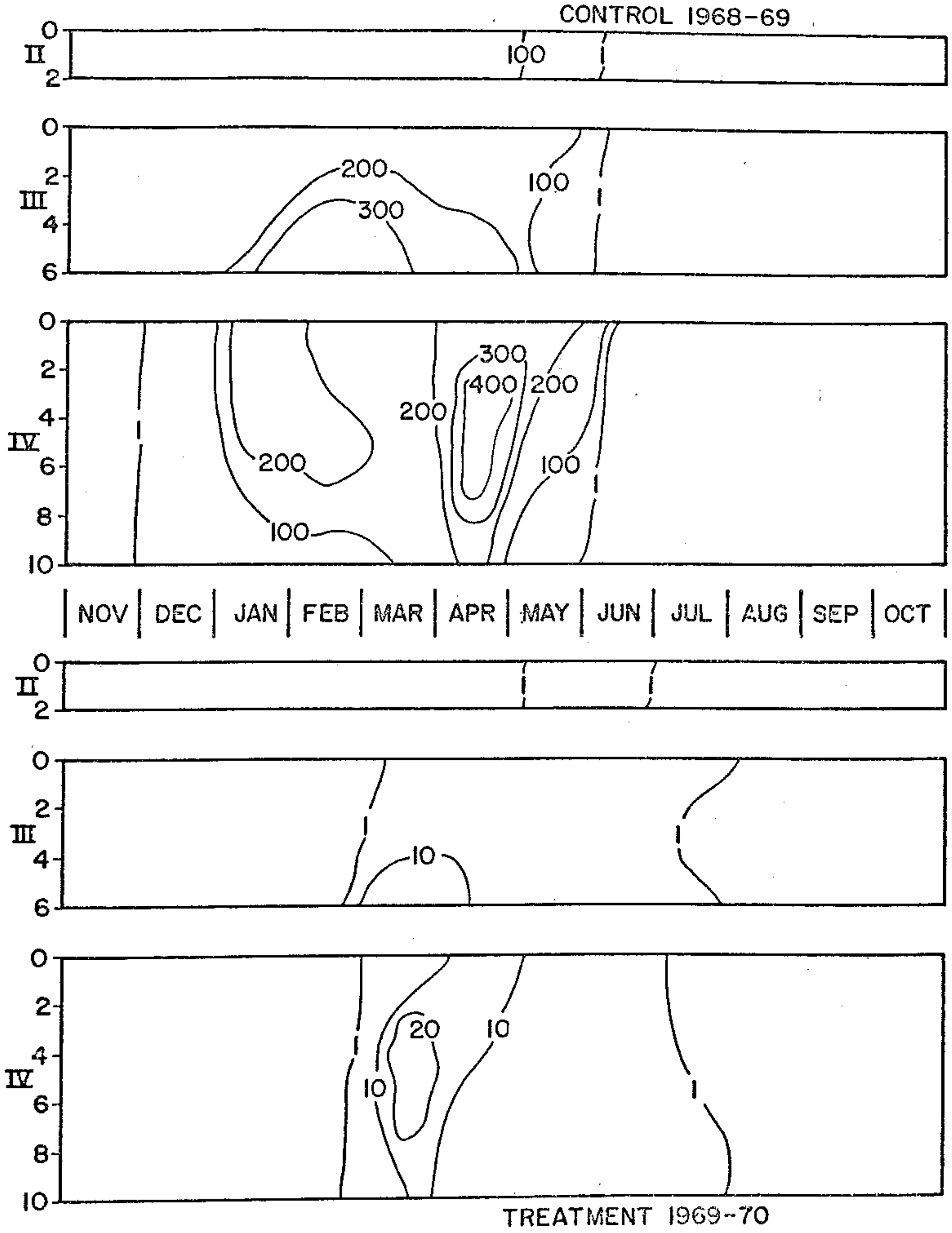
Mallomonas sp. reached very high densities during February and March of the control year, but was never observed during the treatment year (Table 2).

Cyanophyta

Representatives of this phylum bloomed in late summer (Table 2). Although monthly differences were not significantly (sign test) different, abundance was higher during the treatment year.

Anabaena flos-aquae followed a similar pattern during both years (Table 2). Mean density was comparable in both years. Greatest densities were found in surface water during control, but were distributed about evenly during treatment.

Figure 7. *Asterionella formosa* (thousands/liter) in Parvin Lake during control and treatment years. Stations (Roman numerals) and station depth (m) are given on left side of each graph.


CONTROL 1968-69
II
III
IV
0
2
4
6
8
10
100
1
200
300
400
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
10
20
TREATMENT 1969-70

Aphanizomenon flos-aquae was nearly absent during the control year, but bloomed during the treatment (Table 2). Aphanizomenon blooms are typical (unpublished data) in Parvin Lake in late summer and the absence of a control year bloom is unusual.

This species was generally found in the upper water in both control and treatment.

Gomphosphaeria lacustris increased in September and October during control year, but increased greatly during treatment (Table 2). No pattern of vertical stratification was present during the study.

Zooplankton Community

Cladocera

The weighted lake mean number of Cladocera/liter was significantly (sign test, $P < 0.01$) less during treatment than control (Table 4). Greatest densities of Cladocera were reached in summer and fall.

Daphnia galeata mendotae weighted lake means are given in Table 4. The absence of D. galeata mendotae during the control year winter contrasts with low, but consistent, presence during treatment.

Vertical distribution was similar during both years (Table 5). D. galeata mendotae were fairly evenly distributed through the water column and between station differences were not great.

Daphnia schødleri was significantly (sign test, $P < 0.01$) more abundant during the control year (Table 4). During the control year, this species was found nearly every month.

Table 4. Weighted lake means (number/liter) of zooplankton collected in Parvin Lake during control (C) and treatment (T) years.

Group	Year	Weighted Mean												Mean	P of Sign Test	P of Run Test
		Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.			
Cladocera[a]	C	18	1	6	14	3	4	2	10	12	25	16	14	10	0.01	0.26
	T	3	6	3	2	0	1	0	1	12	8	7	4	4		
<u>Daphnia galeata mendotae</u>	C	0	0	0	0	0	0	0	0	1	16	10	7	3	0.73	0.37
	T	2	3	2	1	0	0	0	0	11	6	5	4	3		
<u>Daphnia schødleri</u>	C	15	0	3	5	2	2	1	9	4	4	3	2	4	0.01	0.42
	T	0	1	0	0	0	0	0	0	0	0	0	0	0		
<u>Daphnia</u> juveniles	C	0	0	1	3	0	0	1	2	0	1	1	1	1	0.45	1.00
	T	0	0	0	0	0	1	0	0	0	2	1	0	0		
Copepoda[a]	C	14	6	6	36	36	42	26	14	16	33	20	22	22	0.39	0.07
	T	4	11	10	9	9	9	5	5	9	29	22	24	12		
<u>Diaptomus</u>	C	8	3	4	24	4	2	2	2	6	17	15	12	8	0.55	0.61
	T	3	7	7	4	4	3	1	1	4	15	14	13	6		
Nauplii	C	3	0	1	6	25	12	19	8	4	6	6	4	8	0.15	0.39
	T	0	2	0	0	1	2	1	2	2	14	4	8	3		
Rotifera[a]	C	0	19	110	110	110	60	12	9	5	0	0	1	36	0.55	0.04
	T	0	1	0	8	19	4	2	10	10	70	1	0	10		

[a] Includes unidentified and rare members of this group.

Table 4. Weighted lake means (number/liter) of zooplankton collected in Parvin Lake during control (C) and treatment (T) years (continued).

Group	Year	Weighted Mean												Mean	P of Sign Test	P of Run Test
		Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.			
Felinia	C	0	0	2	19	17	16	3	0	3	0	0	0	5	0.73	0.14
	T	0	1	0	3	8	1	1	10	8	0	0	0	3		
Keratella	C	0	12	35	46	86	40	8	9	0	0	0	0	20	0.07	0.11
	T	0	0	0	0	0	0	1	0	0	69	0	0	6		
Polyarthra	C	0	3	76	45	4	4	0	0	3	0	0	3	12	0.18	0.07
	T	0	0	0	0	1	2	0	0	2	1	1	0	1		

Table 5. Median depth (m) of zooplankters collected at Station IV in Parvin Lake during control (C) and treatment (T) years.

Group	Year	Median Depth												P of Sign Test
		Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	
Cladocera	C	n	n	9	9	n	n	n	n	9	2	3	5	
Daphnia galeata mendotae	T	5	6	4	4	9	n	n	n	2	4	5	7	0.68
Daphnia schødleri	C	3	n	8	8	6	9	4	3	4	4	2	4	
	T	5	5	5	3	n	n	n	n	3	n	7	n	0.50
Daphnia juveniles	C	n	n	8	8	n	n	7	5	3	n	4	4	
	T	n	n	n	n	n	6	n	5	n	5	4	1	0.50
Copepods	C	5	3	3	3	2	2	4	6	2	3	3	4	
Diaptomus	T	5	6	6	3	6	4	4	2	2	4	5	6	0.14
Nauplii	C	6	n	4	9	5	4	8	6	5	5	5	7	
	T	7	4	1	9	6	3	5	2	2	8	6	4	0.75
Rotifera	C	7	n	5	2	3	4	5	n	n	n	n	n	
Felinia	T	n	5	n	n	5	1	1	2	7	n	n	n	0.25
Keratella	C	n	3	3	4	3	5	6	46	n	n	n	n	
	T	n	n	n	n	n	n	5	n	n	69	n	n	0.50
Polyarthra	C	n	4	5	2	3	1	n	n	n	n	n	7	
	T	9	n	n	n	5	4	1	n	9	2	6	n	0.50

n = no organisms taken.

Vertical distribution was characterized by greatest numbers a few meters below the surface in summer and early fall and near the bottom in winter.

Weighted lake means of juvenile Daphnia are given in Table 4. No significant (sign test, $P > 0.45$) difference in weighted means or vertical distribution was observed.

Copepoda

Weighted lake means of all copepods (including developmental stages) are given in Table 4. Numbers were generally less during the treatment months (8 of 12), but not significantly (sign test, $P > 0.39$) less.

Diaptomus (represented by several species) followed a nearly identical annual cycle during control and treatment (Table 4). Diaptomus seemed to be found in deeper water during treatment but this was not significant (sign test, $P < 0.14$).

Nauplii are shown in Table 4 for both years. Nauplii density closely followed the density of total copepods and Diaptomus. Densities were not significantly lower (sign test, $P < 0.15$) during treatment.

Rotifera

Three genera of rotifer were common in Parvin Lake during this study: Felinia, Keratella, and Polyarthra. Weighted lake means/liter are given in Table 4 and median depth in Table 5. Densities were much less during the winter of the treatment year than during corresponding months of the control and this is reflected in a run test ($P < 0.04$).

Felinia weighted lake means are given in Table 4. During both years, densities were highest during winter and spring. Vertical distribution changes between years were not great (Table 5).

Data from 1952 (Boyd, 1953) showed peaks in May and August. Data from 1955 (Marshall, 1956) showed a peak in August and September, but no data were taken before June 15.

Keratella weighted lake means/liter are given in Table 4. Treatment year densities were lower (sign test, $P < 0.07$) than control densities. Vertical distribution followed no clear pattern (Table 5). Differences between stations were small.

Data from 1952 (Boyd, 1953) showed peaks in April and May with much smaller peaks in September and November. Data were not taken in winter. Marshall (1956) found peaks from June to September, 1955.

Polyarthra densities were generally lower during treatment but not significantly (sign test, $P < 0.18$) lower. Vertical distribution followed no clear pattern in either year (Table 5). Differences between stations were small.

Boyd (1953) found low densities (4-16/liter) in April and May, 1952, and nearly none during other months sampled. Samples were not taken from November to March. Marshall (1956) found none during the summer of 1955.

Benthic Community

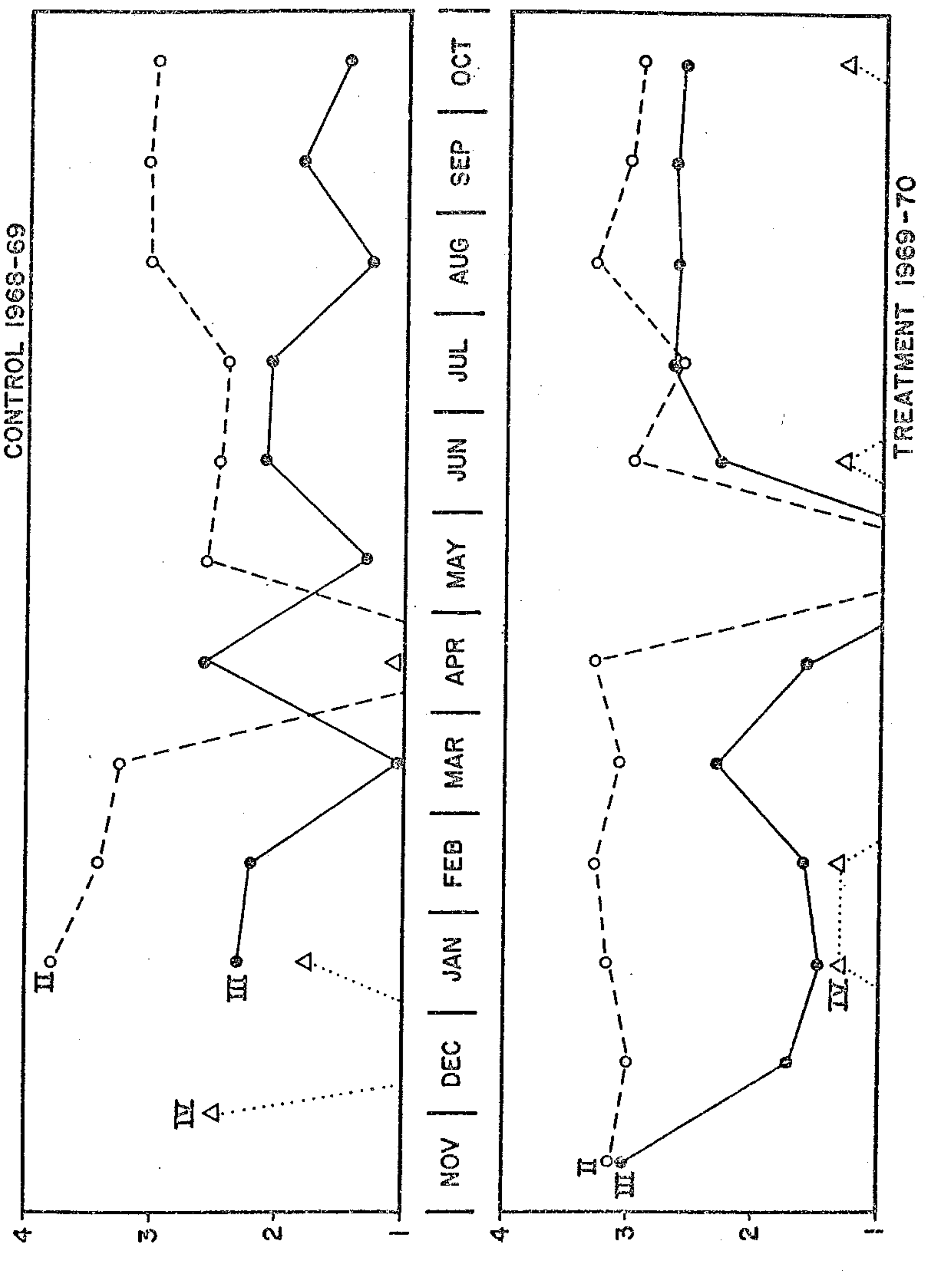
Asellus intermedius

Abundance of this isopod as weighted lake mean are shown in Table 6 and at lake stations in Figure 8. Total lake standing crop was not different between years (sign test, $P < 0.34$). The annual

Table 6. Weighted densities (number organisms/m^2) of benthic organisms collected in Parvin Lake during control (C) and treatment (T) years.

Group	Year	Weighted Mean												Mean	P of Sign Test
		Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.		
Asellus	C	----	----	2430	1220	692	153	106	178	161	443	472	443	630	0.34
	T	1000	417	6230	797	564	841	0	483	333	921	582	517	1060	
Chaoborus	C	----	----	272	230	1620	87	79	55	27	61	155	225	281	0.75
	T	360	233	159	473	448	311	50	124	75	14	74	73	200	
Chironomidae	C	----	----	878	1730	1920	2120	2500	805	725	757	579	898	1080	0.11
	T	757	1300	747	1210	1150	1010	19	461	337	132	1150	1900	848	
Hyalella	C	----	----	115	64	0	21	12	9	0	0	47	72	34	0.02
	T	260	115	119	285	136	191	0	247	30	81	254	174	158	
Lumbriculus	C	----	----	234	17	424	1130	100	285	580	3510	828	415	752	0.34
	T	591	770	1480	371	941	1090	110	1860	3770	1280	297	1900	1200	

Figure 8. *Asellus intermedius* (log of number of organisms/m^2) during control and treatment years. Stations are given in Roman numerals.


CONTROL 1968-69
TREATMENT 1969-70
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
4
3
2
1
II
III
IV
4
3
2
1
II
III
IV

cycle at Station II was quite similar in both years, except for the drop in April and May. Densities at Station III and IV were quite irregular and differences, if any, obscure.

Buscemi (1957) found maximum numbers of Asellus in June and July in Parvin Lake in 1954. No peaks during these months were observed in 1969 or 1970.

Chaoborus

Phantom midges were not greatly affected by destratification (Table 6). A nearly identical annual cycle was present at Station IV during both control and treatment (Figure 9). Densities at Stations II and III were lower during the treatment year.

Chironomidae

Midge larvae were common at all lake stations (Figure 10) and for the total lake in Table 6. About four or five chironomid species were common, although the taxonomy of this family is especially difficult in larval forms.

Mean weighted abundance of chironomids decreased (sign test, $P < 0.11$) somewhat. Stations II and III generally had more chironomids than Station IV during control year, but during the treatment year, this pattern dramatically reversed in May. The profundal (Station IV) generally had fewer chironomids during treatment.

Hyalella azteca

The amphipods increased (sign test, $P < 0.02$) in abundance during the treatment year in the total lake (Table 6). The greatest increase took place at Station II (Figure 11). Buscemi (1957) found these

Figure 9. *Chaoborus* (log of number of organisms/m^2) during control and treatment years. Stations are given in Roman numberals.

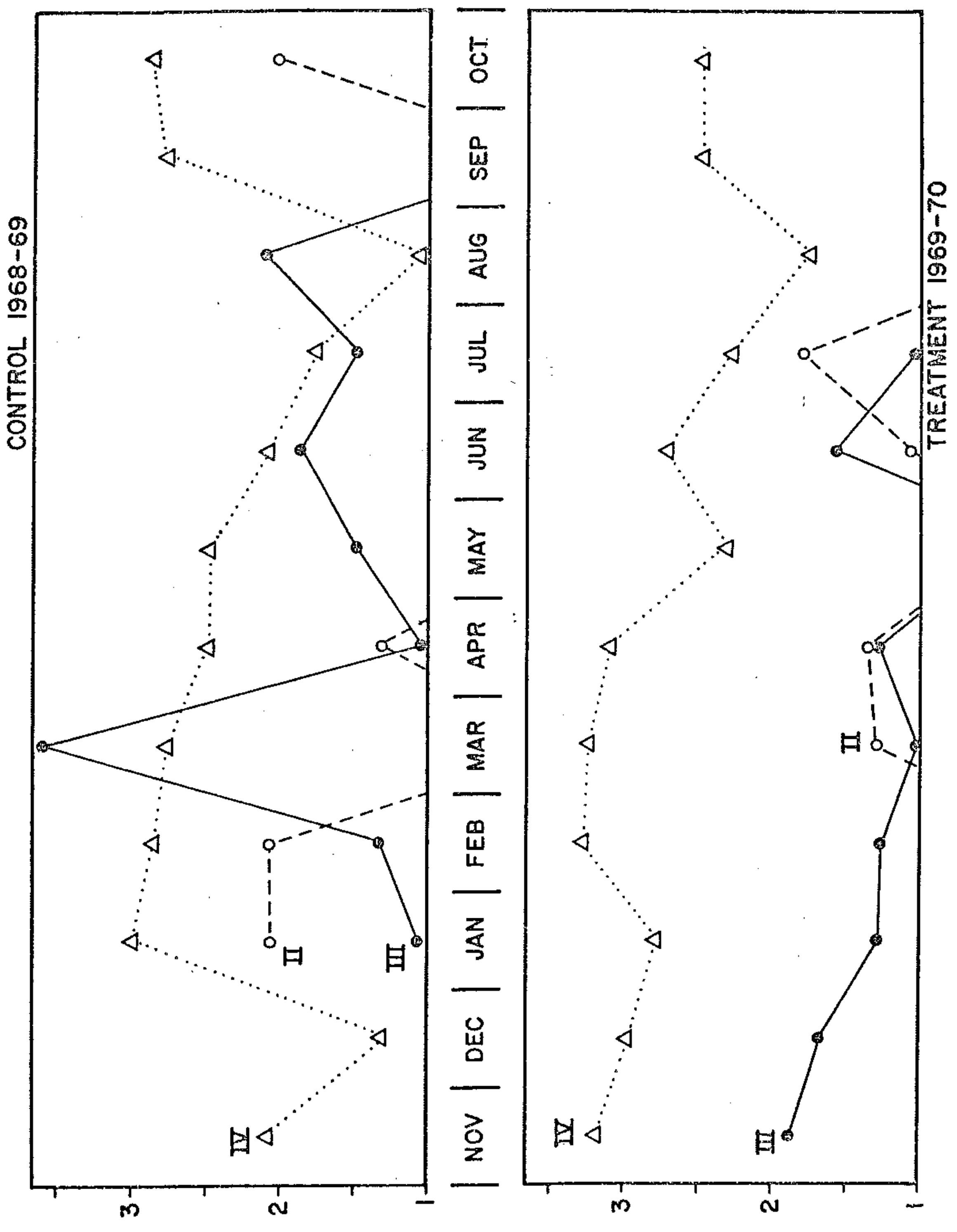

CONTROL 1968-69
TREATMENT 1969-70
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
1
2
3
II
III
IV

Figure 10. Chironomidae (log of number of organisms/m^2) during control and treatment years. Stations are given in Roman numerals.

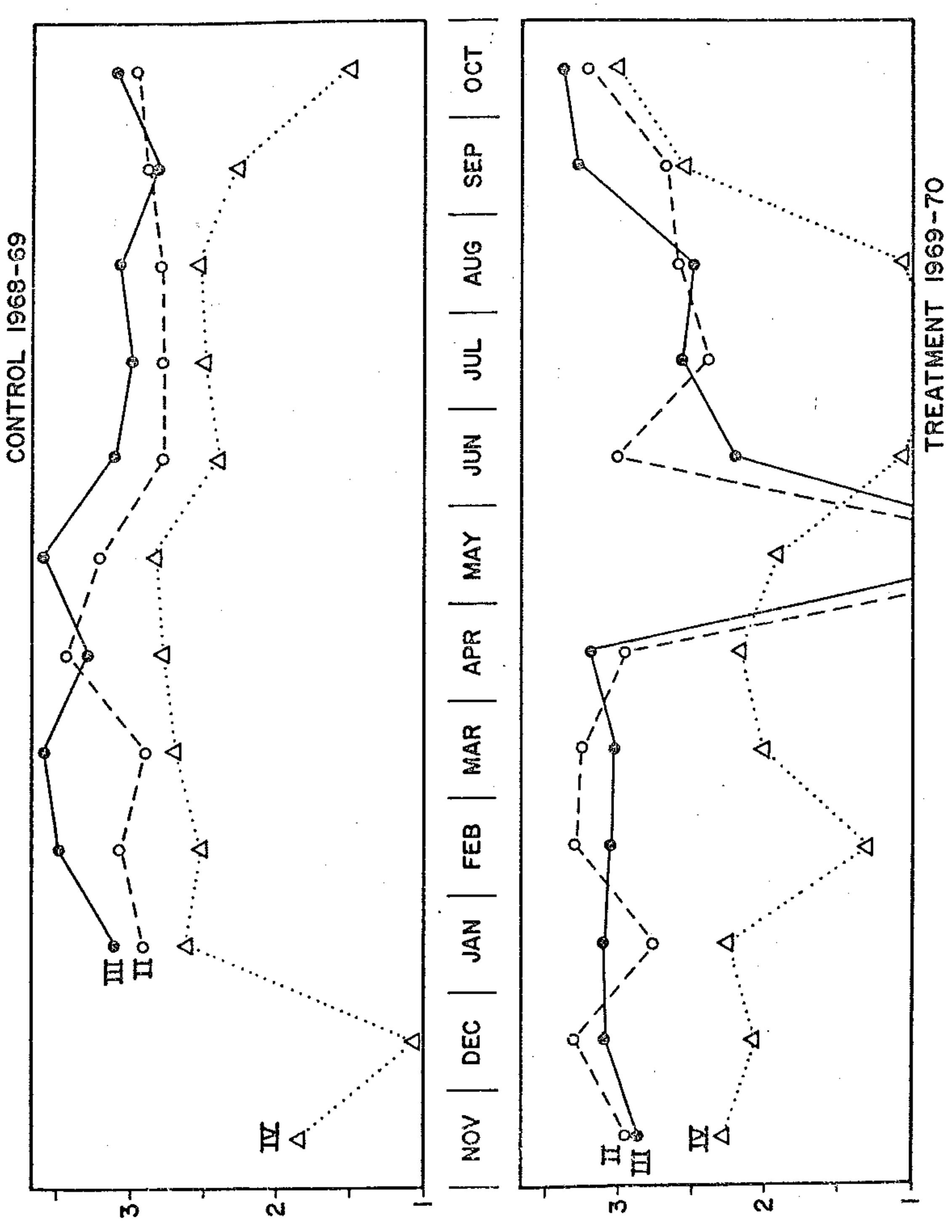
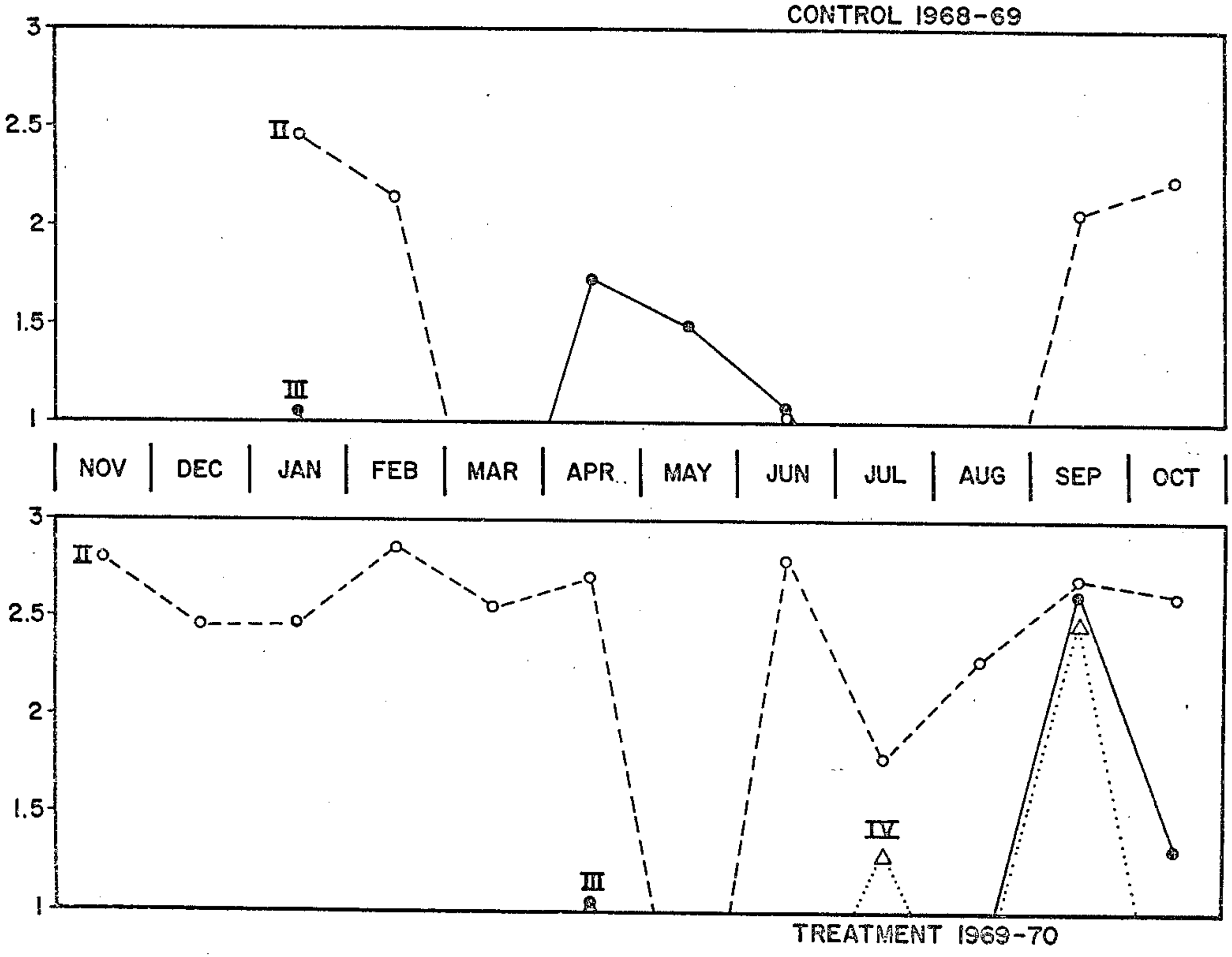

CONTROL 1968-69
TREATMENT 1969-70
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
3
2
1
II
III
IV

Figure 11. *Hyalella azteca* (log of number of organisms/m^2) during control and treatment years. Stations are given in Roman numerals.


CONTROL 1968-69
3
2.5
2
1.5
1
II
III
NOV
DEC
JAN
FEB
MAR
APR.
MAY
JUN
JUL
AUG
SEP
OCT
3
2.5
2
1.5
1
II
III
IV
TREATMENT 1969-70

animals most common in fall, winter, and spring. This pattern is somewhat similar to the control year, however, during treatment the species was generally abundant throughout the year.

Lumbriculus inconstans

This aquatic annelid was common, but highly variable in abundance (Table 6 and Figure 12). Station II densities were higher during treatment year, but both years were approximately the same for the remainder. Station III and IV were fairly similar in annual cycle.

Buscemi (1957) found Lumbriculus inconstans most abundant during fall, winter, and spring.

Fish Distribution

Rainbow trout (Salmo gairdneri) were characteristically found in the upper several meters in Parvin Lake in nontreatment (1959, 1960, 1961, and 1969) years (Table 7). This pattern was not altered by treatment.

Figure 12. *Lumbriculus inconstans* (log of number of organisms/m^2) during control and treatment years. Stations are given in Roman numerals.

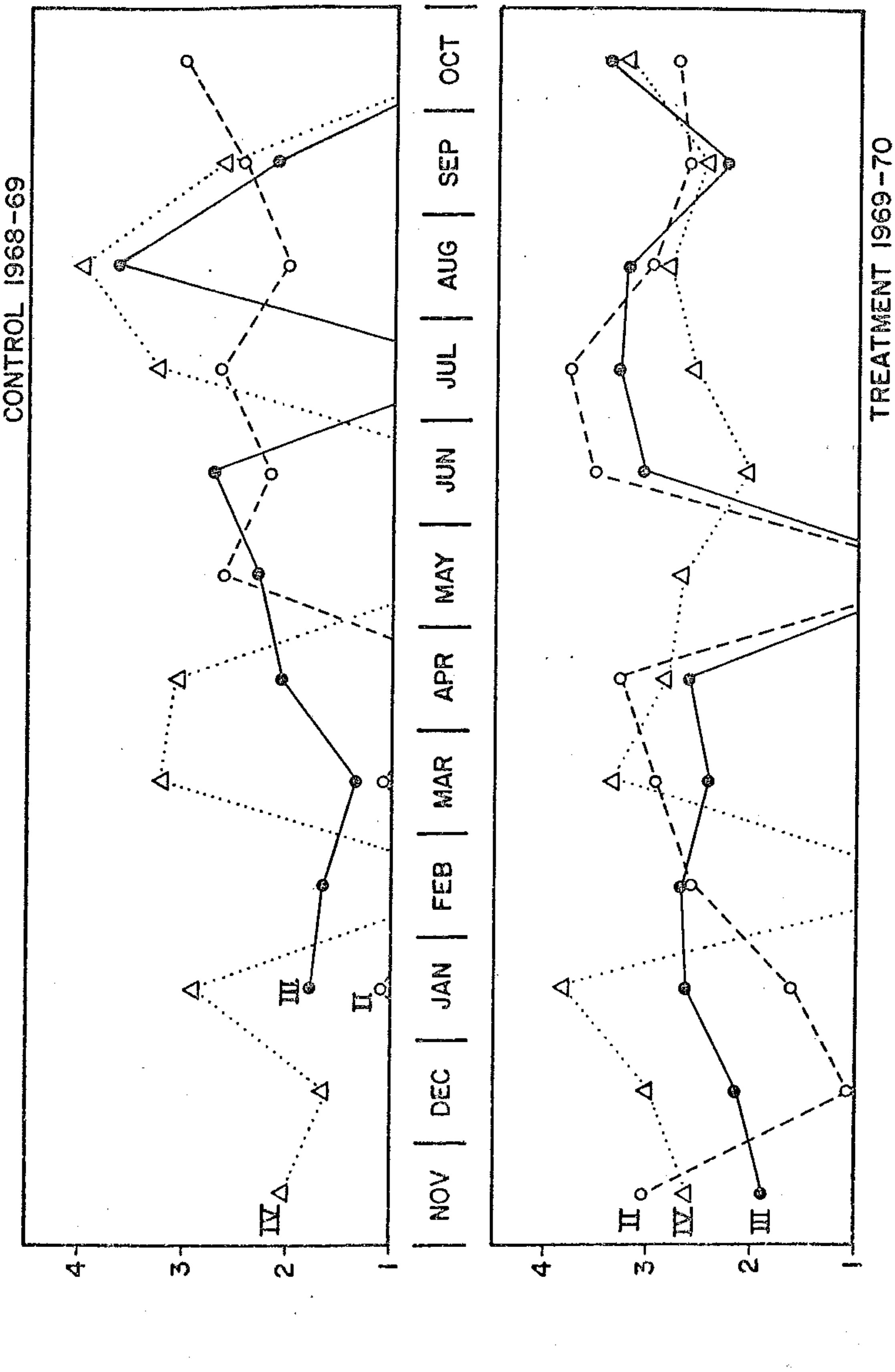

CONTROL 1968-69
TREATMENT 1969-70
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
1
2
3
4
II
III
IV

Table 7. Depth distribution of *Salmo gairdneri* collected in Parvin Lake at Station IV during the summers (June-August) of 1960, 1961, 1969 and 1970.

Depth (m)	Non-Treatment Year					Treatment Year
	1959[a]	1960[b]	1961[b]	1969	Mean	1970
0-2	10	8	126	3	37	19
2-4	1	7	32	1	10	7
4-6	1	1	17	1	5	3
6-8	0	0	5	1	2	0
8-10	0	0	2	1	1	2

[a] From Leik (1960).
[b] From Burkhard (1962).

V. DISCUSSION

Parvin Lake is a dimictic lake that develops low dissolved oxygen concentrations in winter and summer. Alkalinity, total residue, seston, calcium, magnesium, chloride, nitrate-N, and sulfate show little seasonal variation in concentration. Concentration of iron and manganese increase in winter and summer with oxygen loss.

The phytoplanktonic community in Parvin Lake is characterized by high numbers of diatoms in winter and blue-greens in summer. Green algae are found in low number throughout the year.

The zooplankton community normally consists of two species of _Daphnia_, perhaps five species of _Diaptomus_, and several species of rotifers. Many other zooplankters are found in low numbers. _Daphnia_ reach highest numbers from June to November. Copepods are found mainly during winter months.

The benthic population of Parvin Lake is composed of _Asellus_, _Chaoborus_, _Hyalella_, _Lumbriculus_, and several species of Chironomidae. _Hyalella_ is found irregularly throughout the year, but the other species are consistently taken with bottom samples.

General Physical-Chemical Parameters

Deep water in summer in Parvin Lake during destratification was markedly (4-6 C) warmer than typical temperatures. This phenomenon is typical of artificiallly destratified lakes (Riddick, 1957; Bryan, 1964; Kolbe, 1964; Bernhardt, 1967; Irwin, Symons, and Robeck, 1968; Wirth, Dunst, Uttormark, and Hilsenhoff, 1970; and others). The metalimnion normally insulates hypolimnion water from warming taking place at the air-water interface. Without this insulation the entire lake is warmer.

Summer surface water temperatures during destratification of Parvin Lake were not changed from control. Most destratification studies have shown a slight decline in surface temperatures (Koberg, 1964; Irwin, Symons, and Robeck, 1968; Fraser and Halsey, 1969; and others).

Operation of their destratification systems was limited to severe stratification only. If a highly stratified lake is quickly destratified, the mixing action tends to even out differences in epilimnion and hypolimnion temperatures rapidly. This was not the case in Parvin Lake, where stratification never developed and the entire mass of water was essentially being circulated.

Streiff (1955) and others have reviewed the benefits of reducing thermal stratification and lowering surface water temperatures. With reservoirs of much deep water, this is possible, but constant circulation of any water body will probably not affect summer surface temperature greatly.

Winter water temperatures in Parvin Lake during destratification were lower than normally found. This result is typical in artificially destratified lakes (Schmitz and Hasler, 1958; Patriarche, 1961; Wirth, Dunst, Uttormark, and Hilsenhoff, 1970; and others). The lowering of winter temperature is due to continued cooling of the air-water interface. Ice cover provides a degree of insulation which is partially eliminated during artificial destratification.

Oxygen concentration during summer in Parvin Lake during forced circulation remained near saturation except for slight decreases in deep water levels. Maintenance of high concentration of dissolved oxygen in mesotrophic lakes sensitive to thermal stratification and decreases in oxygen develop with slight thermal stratification. Other destratification projects have been able to maintain high summer dissolved oxygen concentrations by continuous mixing, but oxygen loss develops when aeration is curtailed (Koberg and Ford, 1965; Irwin, Symons, and Robeck, 1968; Wirth, Dunst, Uttormark, and Hilsenhoff, 1970). From a water management standpoint, this means that during summer, constant or at least systematic operation of a destratification system is needed. Developing a substantial reserve of oxygen by aeration does not seem possible.

Dissolved oxygen concentration in winter in Parvin Lake was always high during the treatment year. This result was found by Wirth, Dunst, Uttormark, and Hilsenhoff (1970), when they operated a destratification system year-around on a mesotrophic lake slightly larger than Parvin.

Parvin Lake seems to be very effectively buffered as an aquatic environment. Hydrogen ion concentration was very insensitive to artificial destratification. The pH showed no seasonal cycle during the control year and behaved in a similar way during the treatment year. Other workers (Koberg and Ford, 1965; Slack and Ehrlich, 1967) found little pH change during summer under destratified conditions on much larger reservoirs. Irwin, Symons, Robeck (1968), however, found that surface pH during summer months declined, but pH in deep water was unaffected in a Kentucky lake that is similar in size to Parvin.

Evidence of buffering was also found in the behavior of alkalinity in Parvin Lake. Concentrations were generally higher in winter and lower in summer for no apparent reason. Destratification appeared to have little or no effect on alkalinity.

Calcium concentration in Parvin Lake was slightly higher during the destratification year. Annual cycles, vertical gradients, or horizontal differences were not observed.

This increase is not readily explained. Forced circulation might be expected to keep more material suspended and result in increased calcium concentrations (because of unfiltered water samples), but total residue did not change and seston actually decreased during forced circulation. Further, treatment year inflow water generally contained less calcium than corresponding months of the control year.

Maintaining high dissolved oxygen concentration in deep water during winter and summer had important effects on chemical equilibria in Parvin Lake followed an annual cycle with distinct increases in deep water in winter and summer. Destratification essentially eliminated these increases.

Iron increases in lake water have been clearly correlated with oxygen depletion (Strum and Lee, 1960; Ruttner, 1963). Destratification of Parvin Lake eliminated oxygen depletion and iron concentration was kept low.

Such a decrease in deep water iron in summer during destratification has been observed by Riddick (1957), Wirth and Dunst (1967), Irwin, Symons, and Robeck (1968), and others.

Manganese followed the same annual pattern as iron. Destratification essentially eliminated Mn in winter and summer deep water.

Eliminating reducing conditions at the mud-water interface in Parvin Lake prevented Mn from going into solution.

Reduction of Mn in summer during destratification has been observed by Bernhardt (1967), Irwin, Symons, and Robeck (1968), Fast (1968), and Brezonik, Delfino, and Lee (1969). However, Brezonik, Delfino, and Lee (1969) found a slight buildup of Mn in winter during destratification.

Although not measured, phosphorous may have declined in concentration. Iron was mostly kept in the ferric state and this would keep phosphorous in a complex in the lake mud.

Phytoplanktonic Community

Changes in phytoplankton numbers are due in part to the species present as well as to various environmental factors. In Parvin Lake the treatment year total phytoplankton standing crop (number of individuals or colonies) was only about 40% of the control year. However, this decrease was due to a very substantial decrease in winter phytoplankton coupled with a proportionally smaller increase in summer.

Most summer studies have shown a general decrease in phytoplankton standing crop during forced circulation (Riddick, 1957; Slack and Ehrlich, 1967). Johnson (1966) found phytoplankton density to increase during summer circulation. Bella (1970) has shown that forced circulation increases the advantage of the higher sinking rate algae and, depending on the species present, could result in increase or decrease in overall algae numbers during destratification.

Green algae were present in most months of this study, but in low numbers. There was a clear decline during destratification and this change was so persistent from month to month that it probably reflects the influence of destratification.

Several factors may account for this decline in Parvin Lake green algae during destratification. Water temperatures were colder in winter and warmer in summer. Since the changes in numbers were not large in winter, the colder water temperature was probably not critical. Warmer summer water temperature may be important. Water column stability, although important, is difficult to correlate with decrease in green algae.

Ridley, Cooley, and Steel (1966) found that during summer, Chlorophyta decreased in abundance following destratification. Robinson, Irwin, and Symons (1968) operated a destratification system intermittently during two summers and found changes in green algae to be variable, but in general numbers decreased during forced circulation.

Planktonic diatoms and yellow-green algal species were most dominant in winter in Parvin Lake and decreased in abundance during the treatment winter. Decreased water temperature, increased sunlight (open water), or lack of water column stability may have hindered development. Nutrient limitations were probably not important because the parameters studied did not change drastically.

<u>Asterionella formosa</u> decreased during treatment and the pulse was limited to March through June. Fogg (1966) and Hutchinson (1967) have shown that temperature and light are important determinants of

population increases in this species, but no one factor is of overriding importance.

Decreased winter water temperature in Parvin Lake may well have depressed development. Temperatures were 1-3 C colder than normal. Increased light due to open water may have depressed population growth. Water column stability or nutrient concentrations may have been important.

Blue-green algae are very important from the standpoint of water quality. Hooper, Ball, and Tanner (1953) reported blue-greens increased in summer during destratification efforts. However, Bernhardt (1967) and Robinson, Irwin, and Symons (1968) found that blue-greens decreased in numbers during summer destratification. Blue-greens usually do not reach bloom proportion unless there has been depletion of nutrients (Ruttner, 1963).

Anabaena flos-aquae followed a similar pattern in both years. During the control year, this species was found from spring to early fall, but during treatment it was limited to summer months. Ridley, Cooley, and Steel (1966) found that *Anabaena* increased during summer destratification. Combined with Parvin Lake results, it appears that *Anabaena* may be fairly insensitive to destratification.

Aphanizomenon flos-aquae was more abundant during the treatment year. However, this species normally blooms in late summer in Parvin and the control year was unusual in this respect. In this case destratification did not grossly affect the normal bloom. Knoppert, Rook, Hoffker, and Oskam (1970) found that *Aphanizomenon flos-aquae* bloomed in late June and July in an artificially destratified lake.

Gomphosphaeria lacustris in Parvin Lake reached highest abundance in late summer and early fall. Treatment levels in these months were much higher than during control. Eliminating thermal stratification seems to have enhanced production of this species. Similar results were found with Gomphosphaeria aponina with a bloom developing in September (Knoppert, Rook, Hofker, and Oskam, 1970).

Zooplankton Community

The zooplankton community was generally adversely affected by thermal destratification. Although numbers were reduced, vertical differences were not changed. This reduction in zooplankton abundance may not be in the best interest of fisheries management by reducing available forage for young fish. However, Fast (1971) found that zooplankton extended their distribution in a destratified lake.

Daphnia schødleri was nearly eliminated during destratification, while D. galeata mendotae was not greatly affected. Since phytoplanktonic green algae had decreased in abundance, this may have had a negative effect on Daphnia. Water column instability and turbulence may have adversely affected D. schødleri.

Copepods declined (although not statistically significant) in mean abundance during treatment. Phytoplanktonic decline for food supply or alterations in water column stability are likely reasons for this decline. Riddick (1957), however, noted a four-fold increase in Cyclops and Diaptomus abundance following summer destratification.

Rotifers decreased (although not statistically significant) in abundance during treatment. This indicates that these organisms might be very sensitive to eliminating thermal stratification. Low winter water temperatures or water column stability are likely reasons for this change.

Benthic Community

Benthic populations in Parvin Lake remained at about the same level or increased during treatment. Attributing explanations to any changes in benthos is difficult. Ruttner (1963) and Hutchinson (1967) review major environmental parameters affecting benthic populations and point up the difficulty of extracting single causes for benthic changes.

Asellus intermedius followed a similar pattern during both years in Parvin Lake. Populations were fairly high in inshore samples except for April (control) and May (treatment). Ellis (1961) found this species breeds in April and May and then the adult population becomes much less abundant. This seems to account for the population drop off in Parvin Lake. Destratification had little effect on this life cycle.

The importance of Asellus as winter food for rainbow trout (Williams, 1954), brown trout (Berglund, 1968), and brook trout (Lackey, 1969) has been shown.

Chaoborus was also relatively unaffected by destratification. The distinct summer decline in abundance was present in both years. Wirth, Dunst, Uttormark, and Hilsenhoff (1970) found a dramatic shift in species composition of Chaoborus followed destratification. Hilsenhoff and Narf (1968) found Chaoborus typically of one-year life cycle and emerging in May and June.

Midge larvae are a very important component in the Parvin Lake ecosystem. Midge larvae did not change very much during destratification, except for the lower abundance in the profundal zone. This change might be due to changes in dissolved oxygen or temperature above the mud-water interface. Midge larvae will migrate away from unsuitable environments (Bay, Ingram, and Anderson, 1966). In Parvin Lake these conditions may have been higher than normal dissolved oxygen, colder temperatures (winter), or warmer temperatures (summer). Lake destratification has resulted in increases in chironomid abundance and their colonization in deeper (normally anaerobic part of the year) benthic areas (Wirth, Dunst, Uttormark, and Hilsenhoff, 1970; Inland Fisheries Branch, 1970).

Lubriculus inconstans was slightly more abundant during treatment in Parvin Lake. Winter changes were the greatest between years and this may be due to oxygen conditions at the mud-water interface during the treatment year. Nickerson (1961) noted an increase in worms with summer destratification. El Capitan Reservoir, California, had an oligochaete increase and an invasion of deeper benthic areas following destratifiction (Inland Fisheries Branch, 1970). Both papers concluded that increases in dissolved oxygen accounted for the population change.

Fish Community

Summer depth distribution of rainbow trout was unaffected by destratification. This is not surprising considering the lake's shallow (10 m) depth. Correlating depth distribution with temperature and dissolved oxygen has not been easy in normal years in Parvin Lake (Leik, 1960; Burkhard, 1962).

VI. CONCLUSIONS

Based on results from Parvin Lake, artificial destratification of lakes affects the ecosystem in ways that might be of use in water resource management.

Consumptive use of water for domestic or industrial purposes may be favorably affected by water quality improvement. In Parvin Lake reduction in iron and manganese and increases in dissolved oxygen were beneficial water quality changes.

Recreational use of lakes may be improved in some areas. In Parvin Lake most planktonic algae decreased (except for blue-greens). In addition, the summer surface temperature was not reduced which might have hindered recreational use.

Fisheries may be improved by higher dissolved oxygen under severe conditions. Indications from other components of the ecosystem, especially zooplankton and zoobenthos, are that food habits will not appreciably change. But, colder winter temperature may further retard growth rate.

The real question with destratification as an aquatic management tool is the effect on planktonic algae and especially blue-greens. In Parvin Lake blue-greens increased in abundance with destratification. If this proves to be a general phenomenon with this environmental alteration, its management potential would be greatly lessened.

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