ENTRAINMENT OF ZOOPLANKTON BY A ONCE-THROUGH COOLING SYSTEM ON WESTERN LAKE ERIE, 1974-1975

By

Roger Joshua Jones, Jr.

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Fisheries and Wildlife

1978

ABSTRACT

ENTRAINMENT OF ZOOPLANKTON BY A ONCE-THROUGH COOLING SYSTEM ON WESTERN LAKE ERIE, 1974-1975

By

Roger Joshua Jones

The once-through cooling system used by the Monroe Power Plant entrains large quantities of zooplankton through screens, pumps, and condensers. In addition to these mechanical stresses, organisms also were subjected to rapid temperature elevations and chlorination. Since zooplankton represent the trophic link between algae and fish, the impact of once-through cooling may be important.

In 1974, the mean annual densities of rotifers, copepods and cladocerans decreased from one-third to two-thirds in passage from the intake to the upper discharge canal. Biomass, and in most instances size, also varied in this manner. These results were not as evident in 1975.

Mortality studies at the site indicated that in the summer of 1975, lethal temperatures for many of the copepods and cladocerans were reached. At 38°C in the upper discharge canal, mortalities averaged 76% among three replicate samples. In 1976, observations were restricted to the largest zooplankter found during the study: *Leptodora kindtii*. The results showed an average of 60% of these organisms killed by passage through the plant.

ACKNOWLEDGMENTS

I would like to thank Dr. Richard Cole for his advice and especially for giving me the opportunity to become a member of the Lake Erie Project. Thanks also go to Donna Gates for assisting with the microscope work and to Drs. Niles Kevern and Richard Merritt for their manuscript reviews.

To my mother and father I am greatly indebted for wanting me to have something better than they had. Without their initial financial and moral support, a college career would not have been likely. Finally, I wish to express my deepest appreciation to my wife Teresa, and daughter Jessica, for their concern, good humor and love.

This study was funded by the U.S. Environmental Protection Agency.

TABLE OF CONTENTS

LIST OF TABLES

Table		Page

LIST OF FIGURES

INTRODUCTION

In densely populated areas, like that around the western end of Lake Erie, the demand for electric power plant cooling water has been doubling every ten years. This has led to the development of large fossil-fueled generating plants which produce 4 to 5 times more electricity than those built 20 years ago (Cairns, 1971). The once-through cooling systems utilized by such plants transport large quantities of zooplankton through screens, pumps, and condensers. The impact of once-through cooling is important since zooplankton serve as a trophic link between algae and the fishery resource. The purpose of this research was to quantify the passage of zooplankton through the cooling system of a steam-electric station on western Lake Erie and evaluate resulting impacts.

Plankton populations that are drawn through condenser systems experience various and nearly simultaneous stresses (Davies and Jensen 1974). The magnitude of these stress factors is determined by (1) ambient intake temperatures; (2) the rise in temperature (ΔT) during and after condenser passage; (3) the exposure time to these elevated temperatures; (4) physical damage resulting from turbulence and pressure changes within the system and (5) exposure of the organisms at certain times to chlorination used to prevent fouling of the condensers (by bacteria, algae, etc.).

The impact of once-through cooling upon zooplankton at the Monroe Power Plant was examined by collecting organisms from the plant intake and outfall areas and by measuring (1) numbers and biomass of the important taxa; (2) their size distribution; (3) their capacity to orient to normal vertical distributions and (4) their species diversity and (5) mortality resulting from plant passage.

MATERIALS AND METHODS

Study Area

The Monroe Power Plant occupies a 485-ha site adjacent to the City of Monroe, Michigan, where the Raisin River joins Lake Erie (Figure 1). It is owned and operated by the Detroit Edison Company. The plant began operating in May 1971, when the first of four 800-megawatt units started. With the remaining units completed in spring 1974, the plant can generate up to 3,150 megawatts. It is the largest coal-powered generating plant in the world and accounts for approximately one-third of Detroit Edison's electrical output. During capacity output, cooling water is required at a rate of 85 m^3/sec (Figure 2) and, depending on power generation and pumping rates, intake water is warmed up to 17^{o}C (Table 1).

The cooling water is drawn from the Raisin River and Lake Erie through an intake located about 1 km upstream from the mouth of the river (Figure 3). Almost all of the river water is drawn before any substantial makeup is drawn from the lake. The discharge of river water may be as high as 120 m^3/sec in the spring and as low as 3 m^3/sec in the late summer (Table 1). These fluctuations substantially influence the proportions of cooling water used from both sources. Since there are significant biological differences between the river and the lake, seasonal variations will also determine the amount of biological material contributed to the cooling system by each source.

After entering the intake, the water passes in sequence through a traveling screen with 1-cm diagonal openings, the condenser, a concrete

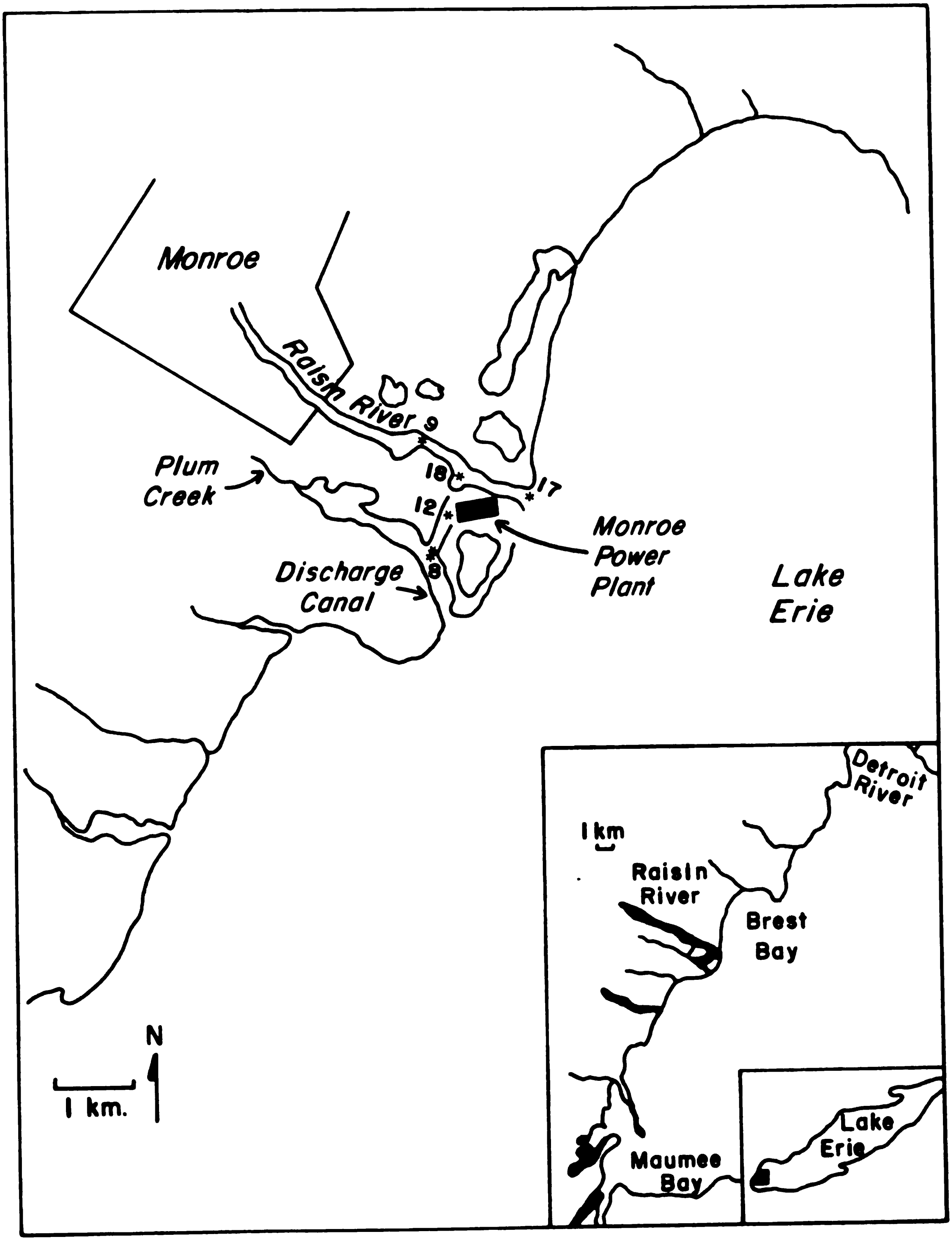

Figure 1. Map of the study area in the vicinity of the Monroe Power Plant.

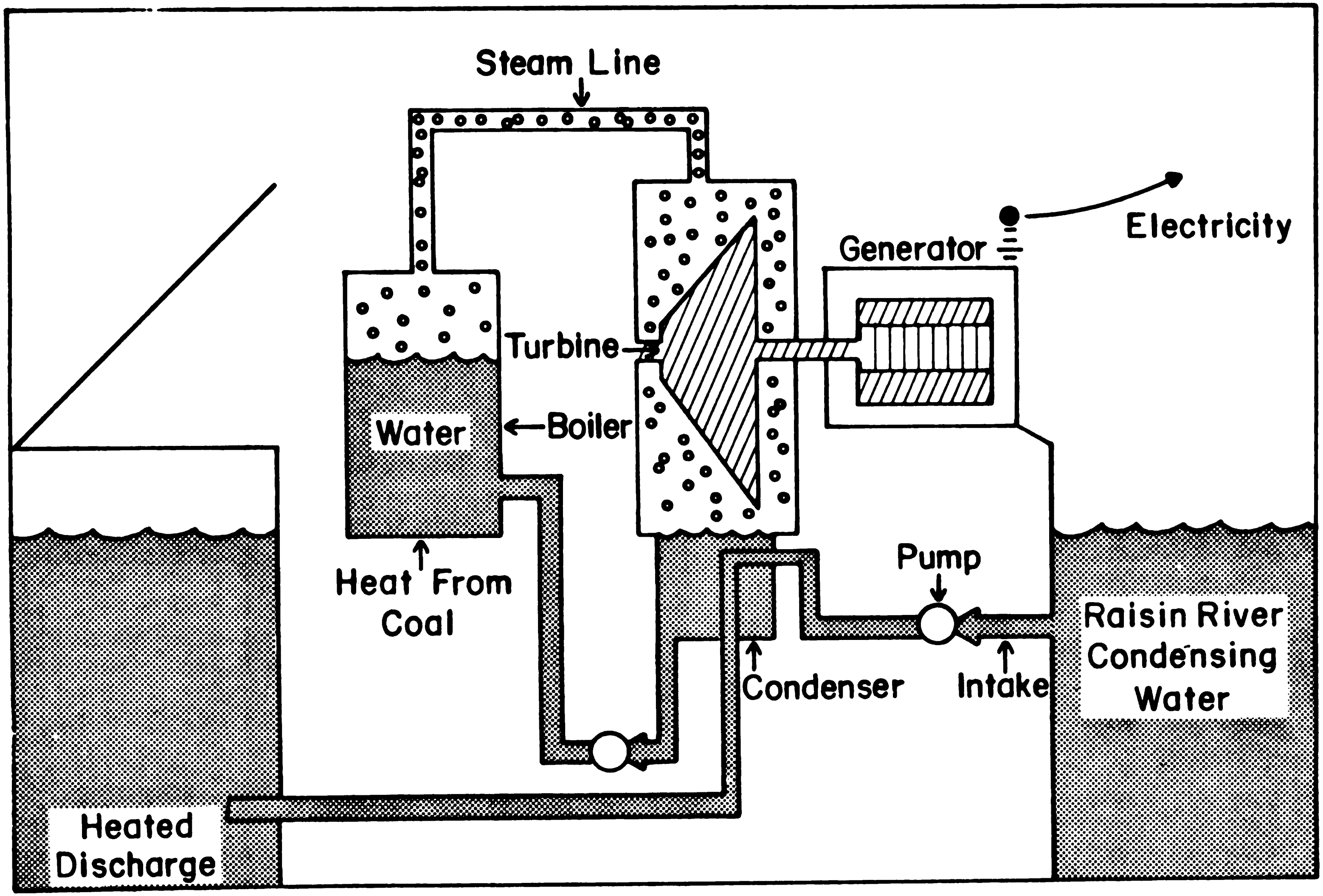

Figure 2. A generalized view of the steam-driven electrical power generating system.

Table 1. Amounts of river and lake water used to determine the concentrations of zooplankton at station 18 in the intake canal, velocities in the upper discharge, number of pumps in operation, water passage time through the canal, total chlorine, discharge temperature and temperature change (ΔT).

Date	River Water (m^3/sec)	Lake Water (m^3/sec)	Total Discharge (m^3/sec)	Velocity (cm/sec) U. Discharge	Number of Pumps in Operation	Passage Time Hours	Chlorine mg/liter	Discharge Temperature (c)	ΔT
9/9/72 (eve)	57.4	0	42	3.9	6	11.4	1.63	19.0	10
9/10/72 (aft)	52.0	0	42	3.9	6	11.4	1.63	15.0	6
1/18/73 (eve)	17.4	45.6	63	3.9	9	7.5	.83	14.0	9
1/24/73 (aft)	42.2	20.8	63	5.8	9	7.5	.83	7.0	3.5
3/30/73 (eve)	63.0	0	63	5.8	9	7.5	.83	16.0	6.5
4/5/73 (aft)	43.0	20.0	63	5.8	9	7.5	.83	17.0	9.0
6/11/73 (eve)	22.0	41.0	63	5.8	9	7.5	.9	27.0	5.0
6/12/73 (aft)	20.0	43.0	63	5.8	9	7.5	.9	26.0	6.0
8/8/73 (eve)	11.0	31.0	42	3.9	6	11.4	1.35	31.0	6.0
8/9/73 (aft)	10.5	31.5	42	3.9	6	11.4	1.35	30.0	4.0
9/28/73 (eve)	3.7	38.3	42	3.9	6	11.4	1.35	26.0	7.0
9/29/73 (aft)	5.0	37.0	42	3.9	6	11.4	1.35	27.0	8.5
12/12/73 (eve)	12.2	30.0	42	3.9	6	11.4	1.25	18.0	17.0
12/13/73 (aft)	12.8	29.4	42	3.9	6	11.4	1.25	17.0	13.5
1/31/74 (eve)	123.3	0	42	3.9	6	11.4	.75	11.0	6.0
2/1/74 (aft)	102.3	0	42	3.9	6	11.4	.75	14.0	8.0
4/7/74 (eve)	96.6	0	42	3.9	6	11.4	.75	16.0	5.0
4/8/74 (aft)	94.7	0	42	3.9	6	11.4	.75	14.0	5.0
6/11/74 (eve)	16.6	60.8	77	7.1	11	6.3	.41	30.0	8.0
6/12/74 (aft)	16.2	61.3	77	7.1	11	6.3	.41	29.5	7.0
8/14/74 (eve)	6.6	70.8	77	7.1	11	6.3	.41	35.5	5.5
8/15/74 (aft)	6.1	64.3	70	6.4	10	7.0	.45	34.0	8.0
10/19/74 (eve)	4.9	44.4	49	4.5	7	9.9	.64	21.5	9.0
10/21/74 (aft)	4.6	51.8	56	5.2	8	8.6	.56	21.0	11.0
1/24/75 (eve)	17.3	32.0	49	4.5	7	9.9	.64	15.2	10.0
1/25/75 (aft)	17.5	38.8	56	5.2	8	8.6	.56	15.0	9.0

Table 1 (cont'd.)

Date	River Water (m^3/sec)	Lake Water (m^3/sec)	Total Discharge (m^3/sec)	Velocity (cm/sec) U. Discharge	Number of Pumps in Operation	Passage Time Hours	Chlorine mg/liter	Discharge Temperature (c)	ΔT
3/15/75 (eve)	26.0	16.3	42	3.9	6	11.4	.75	20.0	15.0
3/16/75 (aft)	25.8	30.5	56	5.2	8	8.6	.56	16.5	14.0
5/16/75 (eve)	17.6	17.6	35	3.2	5	14.0	1.22	28.0	12.0
5/17/75 (aft)	16.7	17.6	35	3.2	5	14.0	1.22	28.0	11.5
7/27/75 (eve)	4.8	79.7	84	7.8	12	5.7	.38	33.3	8.9
7/28/75 (aft)	4.6	79.9	84	7.8	12	5.7	.38	35.0	8.3
9/15/75 (eve)	12.2	72.3	84	7.8	12	5.7	.38	26.4	10.4
9/16/75 (aft)	12.5	72.0	84	7.8	12	5.7	.38	26.0	8.5

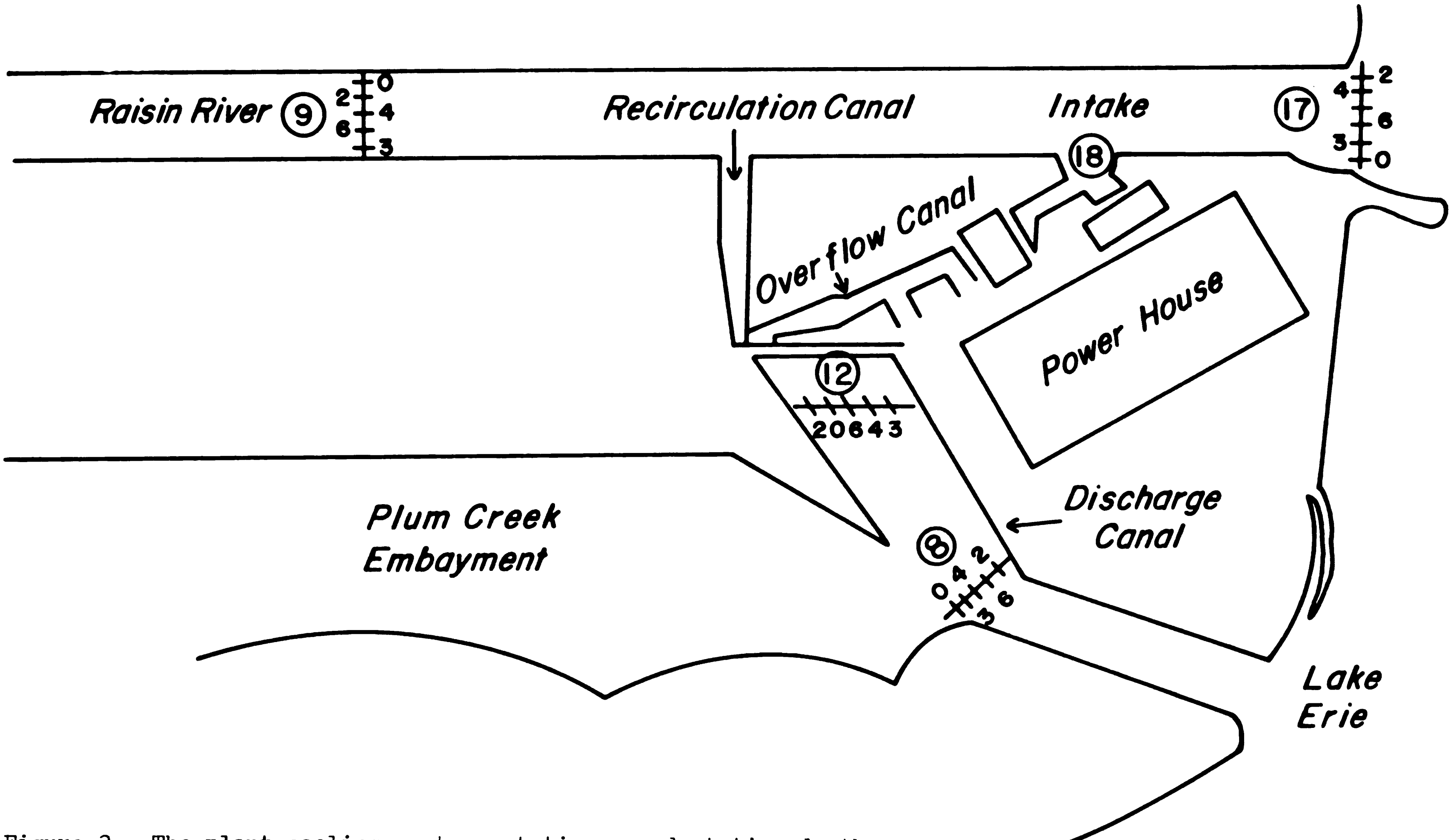

Figure 3. The plant cooling system, stations, and station depths in meters.

conduit, and the discharge canal. The condenser consists of 18,154 tubes each with a length of 17.6 m and a 2.54-cm outside diameter. Velocities during full operation within the condenser tubes are over 2 m/sec and decrease to about 1 m/sec in the 350 m long concrete conduit. The discharge canal averages 175 m wide, 7 m deep in the upper end, 3 m deep in the lower end and is 2000 m long. Velocities in the upper discharge canal approach 1 m/sec but are not uniform as a result of high velocity conduit water entering the west side of the discharge canal. This forms an eddy of slower water on the east side and adds to the variability in the residence time for the entrained organisms. During maximum output, water passage through the cooling system back to Lake Erie averages about 4.5 hours. Passage time through the individual parts of the cooling system are seven seconds through the condenser, 20 minutes through the concrete conduit, and four hours through the discharge canal.

Mass Transport Studies

In order to assess the impact of once-through cooling upon zooplankton, five stations were chosen for sampling in the vicinity of the plant (Figure 3). The intake was represented by a station upriver (9) from the plant, at the mouth of the river (17), and by an "artificial" station (18) calculated from the river and the lake contributions. Stations 17 and 9 were chosen from the intake region because the water at these points could be representatively sampled with relatively few samples. Since the water in the short intake canal was an incomplete mixture of river and lake water, theoretical concentrations at station 18 were calculated from data obtained at stations 17 and 9 in order to compare water at station 12 to the mixture from the two sources. This was done by proportioning plant cooling water demands from stations 17 and 9 using USGS measures of river discharges and records of Detroit Edison's pumping rates (Table 1). The outfall area consisted of a station immediately downstream from where the effluent enters the discharge canal (12) and a station about 1000 m downstream from this (8). Station 8 was sampled to evaluate the effects of prolonged exposures of organisms to the heated waters of the discharge canal.

Hydrology

Water samples collected in the intake and outfall areas were analyzed at the Michigan State University Lab to determine the concentrations of chloride and various forms of nitrogen. For the purposes of this study, chloride was measured in order to confirm mixing ratios in the intake (Table 2, 3). Chloride analyses were accomplished through the mercuric nitrate titration of a 25-milliliter sample to the diphenylcarbazone-mercury complex endpoint. These values then were indicative of the respective amounts of river and lake water used in the cooling process.

Zooplankton Sampling

Sampling began in November 1972, and continued until September 1975. The purpose of my study was to analyze data collected from December 1973 to September 1975, when the plant was operating with all four units. The findings, as well as having their own interpretation, could then be compared to the results of a 1972-73 study (Simons, 1977) when the plant had only two or three units functioning sporadically. Zooplankton samples were collected during the afternoon and evening over a two-day period every two months. The afternoon sampling began

Table 2. The distribution of mean total chloride (mg/liter) and mean temperature (°C) at all stations, June 11 through October 21, 1974.[1]

	Station									
	17		9		18		12		8	
Date	Cl	T°C	Cl	T°C	Cl	T°C	Cl	T°C	Cl	T°C
6/11/74 (eve)	20.3[2]	21.5	39.4	22.8	24.3	22.4	22.8	29.7	23.7	28.9
6/12/74 (aft)	20.1	22.5	35.3	24.0	23.3	22.8	20.6	29.4	22.7	29.0
8/14/74 (eve)	17.3	25.1	41.2	26.5	19.7	25.2	20.8	35.3	19.4	32.8
8/15/74 (aft)	16.5	25.7	42.5	27.6	18.7	25.9	18.0	34.0	19.2	32.5
10/19/74 (eve)	13.1	12.0	32.0	12.8	16.2	12.1	16.4	21.4	16.5	19.3
10/21/74 (aft)	13.7	10.0	32.2	11.8	18.9	10.1	19.5	17.6	18.6	17.7
Grand Mean	16.8		37.1		20.2		19.7		20.0	

[1] Dates selected for inclusion in this table were at times when zooplankton were abundant.

[2] Each value is the mean of 5 samples.

Table 3. The distribution of mean total chloride (mg/liter) and mean temperature (^{o}C) at all stations, May 16 through September 16, 1975.[1]

	Station									
	17		9		18		12		8	
Date	Cl	$T^{o}C$	Cl	$T^{o}C$	Cl	$T^{o}C$	Cl	$T^{o}C$	Cl	$T^{o}C$
5/16/75 (eve)	20.6[2]	15.5	29.0	---	24.7	---	23.6	28.0	26.7	25.2
5/17/75 (aft)	21.4	16.6	30.4	18.2	25.5	17.4	24.0	28.1	25.8	27.0
7/27/75 (eve)	14.6	24.4	30.2	23.9	15.5	24.4	15.4	33.3	15.6	33.3
7/28/75 (aft)	15.4	26.7	33.8	26.7	16.5	26.7	17.2	35.0	16.4	34.4
9/15/75 (eve)	21.2	16.5	29.0	16.5	22.3	16.5	22.4	26.3	23.0	25.5
9/16/75 (aft)	20.0	17.6	29.6	17.5	21.5	17.6	22.0	25.7	22.2	24.0
Grand Mean	18.9		30.3		21.0		20.8		21.6	

[1]Dates selected for inclusion in this table were at times when zooplankton were abundant.

[2]Each value is the mean of 5 samples.

at midday, while the evening samples were gathered promptly after sunset. During the evening period in the summer months was also when the plant cooling system was chlorinated. Sampling consisted of five replicates taken from randomly located depths at four stations (Figure 3). By using this sampling scheme any diurnal variability in the entrainment of organisms could be observed. Sampling at two-month intervals included the varying contributions of river and lake water to the cooling system and also changes in the dominant organisms.

Mortality Studies

The mortality of zooplankton in the cooling system was estimated by Simons in June 1974, and by myself in August 1975 and July 1976. Samples were collected from the intake and upper outfall areas usually at the same random depths used in the mass transport studies. The times of day chosen to sample represented extreme conditions for temperature change, chlorination and mechanical stress.

Laboratory and Statistical Analysis

During the long-term entrainment studies zooplankton were obtained using an 8.1-liter VanDorn water sampler. Once collected, each replicate was concentrated using a #25 Wisconsin plankton bucket and preserved in 5% formalin. The samples were then diluted to a known concentration (10-40 ml) and a 1-ml aliquot was extracted and placed in a Sedgewick-Rafter counting cell. The organisms were then counted, measured (using a Whipple micrometer), and identified to species when possible. From this information population densities, biomass, and species diversity indices were calculated.

Zooplankton volumes were estimated by using linear measurements of length and width to calculate the volume of a common geometric figure (Weast, 1968) that was similar to the shape of the organism. Dry weights were then estimated from the volumes by assuming that this measurement was 10% of the plankton wet weight (Cummins and Wuycheck, 1971).

Analysis of variance was conducted among stations (combining depth) on the density and biomass of the following taxa: Rotifera, Cladocera and Copepoda. To meet the conditions required for analysis of variance, the log (x + 1) transformation was employed. This was then followed by Tukey's test of paired comparisons if significant ($\alpha = 0.05$) differences existed (Sokal and Rohlf, 1969). Coefficients of linear regression were calculated to estimate the relationship of organisms to depth after they were subjected to the stresses of cooling system passage. The diversity of zooplankton at each station was determined by using the species diversity index $H = -\sum_{j=1}^{s}(Nj/N)\log_{10}(Nj/N)$ where Nj = the abundance of the jth species, N = the total abundance of all species and s = species (Pielou, 1969).

During the mortality studies of 1974 and 1975, zooplankton were collected with a 4-liter VanDorn water sampler at five random depths from the intake and discharge areas. The samples were pooled and concentrated to a 1-liter subsample, filtered, and placed on a separation dish. The organisms were examined under a dissecting microscope with numbers of dead and alive organisms being recorded. Death was signified by a lack of movement. The 1976 mortality study involved only the large cladoceran, *Leptodora kindtii*, which was collected from the intake and upper discharge with a 1-m (560μ-mesh) tow net.

RESULTS

Density and Species Composition

Twenty-nine taxa of Rotifera, nine taxa of Cladocera and seven taxa of Copepoda were identified from the samples collected in the plant's discharge and intake systems from December 1973 to September 1975 (Table 4). Although rotifers appeared on all of the sampling dates, they were most abundant from May through October (Figures 4, 5), with *Synchaeta*, *Keratella* and *Brachionus* represented by the greatest numbers (Table A1). *Bosmina* sp. and *Daphnia retrocurva* were the most common cladocerans from June through October, but were absent in January, March and April (Figures 6-11). Copepods were present in all months except January and were most common from May through October. Immature copepods (nauplii and calanoid and cyclopoid copepodites) were more common than adult copepods which were dominated by *Cyclops vernalis* (Figures 12-15). These results indicate that although zooplankton are drawn through the plant's cooling system throughout the year, the majority of them experience plant passage between May and October.

Day vs. Night Comparisons

Comparisons between afternoon and evening abundances showed that there was less variation over the short-term periods and no distinct relationship between abundance and time of the day sampled (Figures 6-15). There were occasions when densities found at different times of the day at each station varied up to 100% or more of each other, but

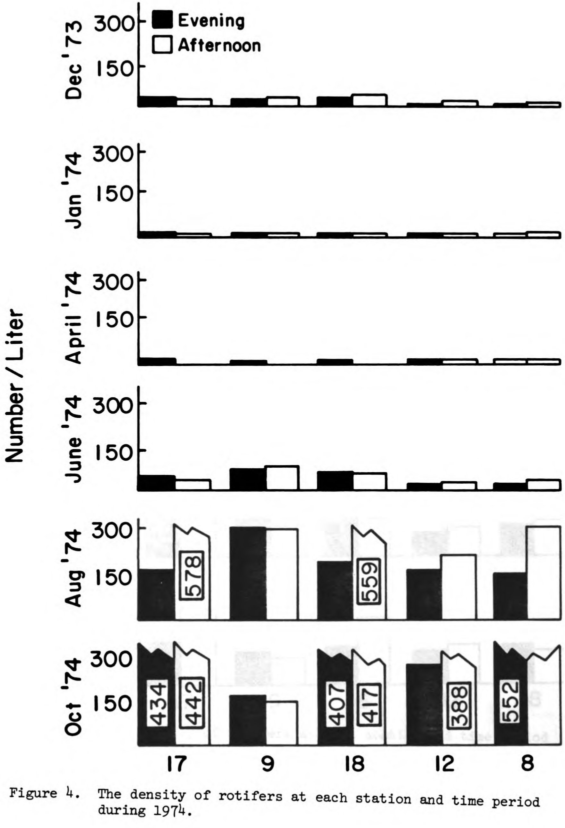

Figure 4. The density of rotifers at each station and time period during 1974.

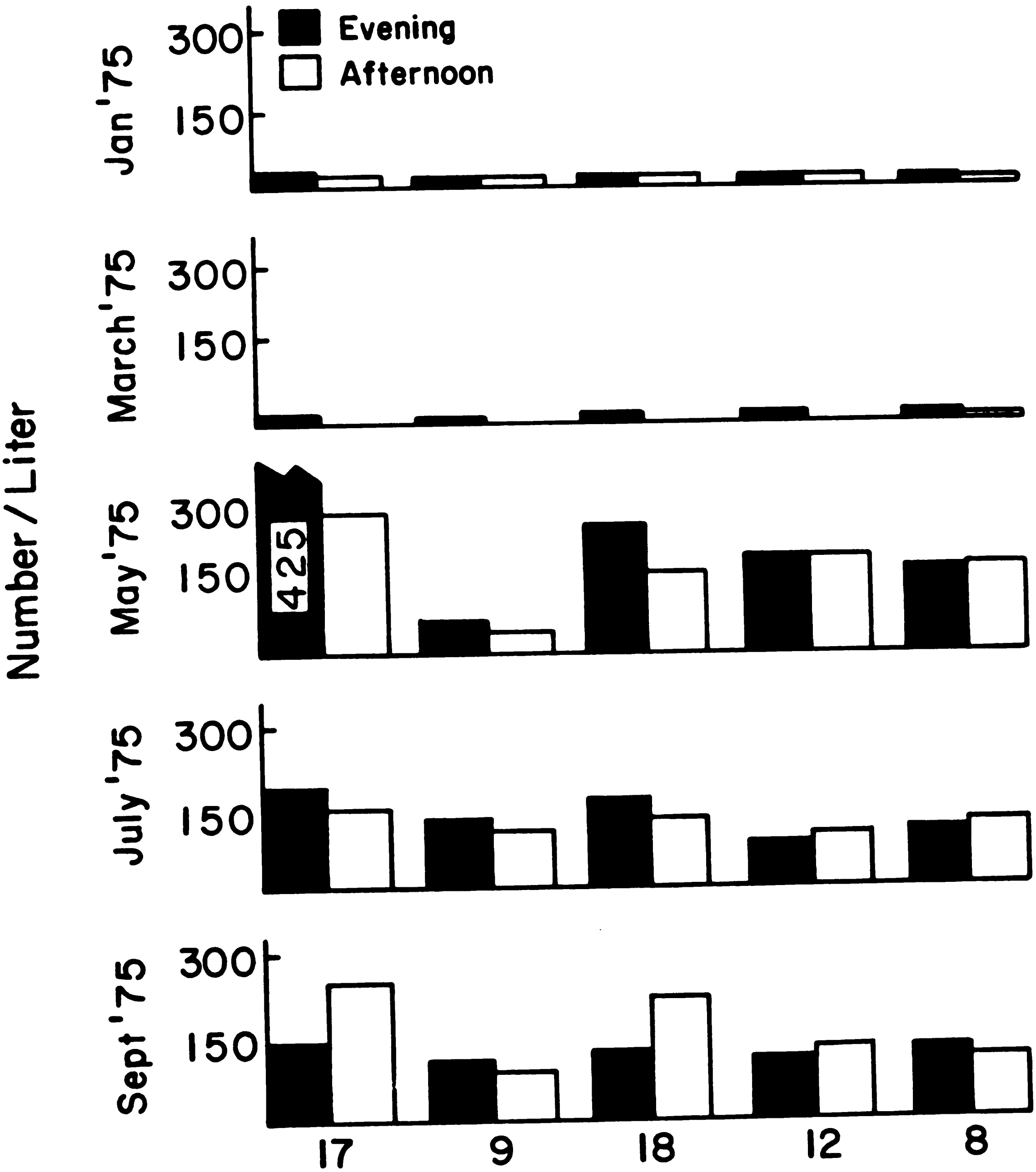

Figure 5. The density of rotifers at each station and time period during 1975.

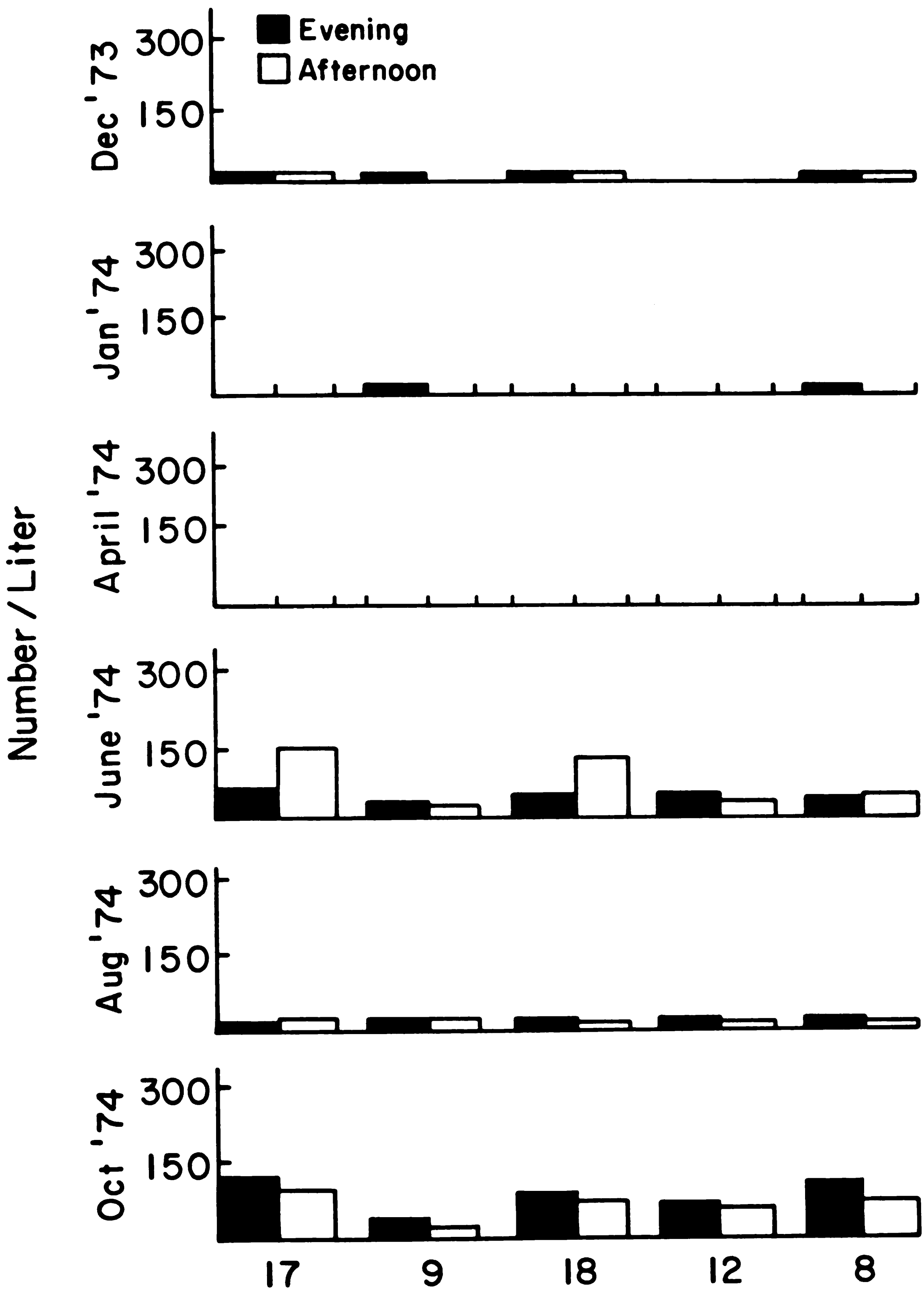

Figure 6. The density of cladocerans at each station and time period during 1974.

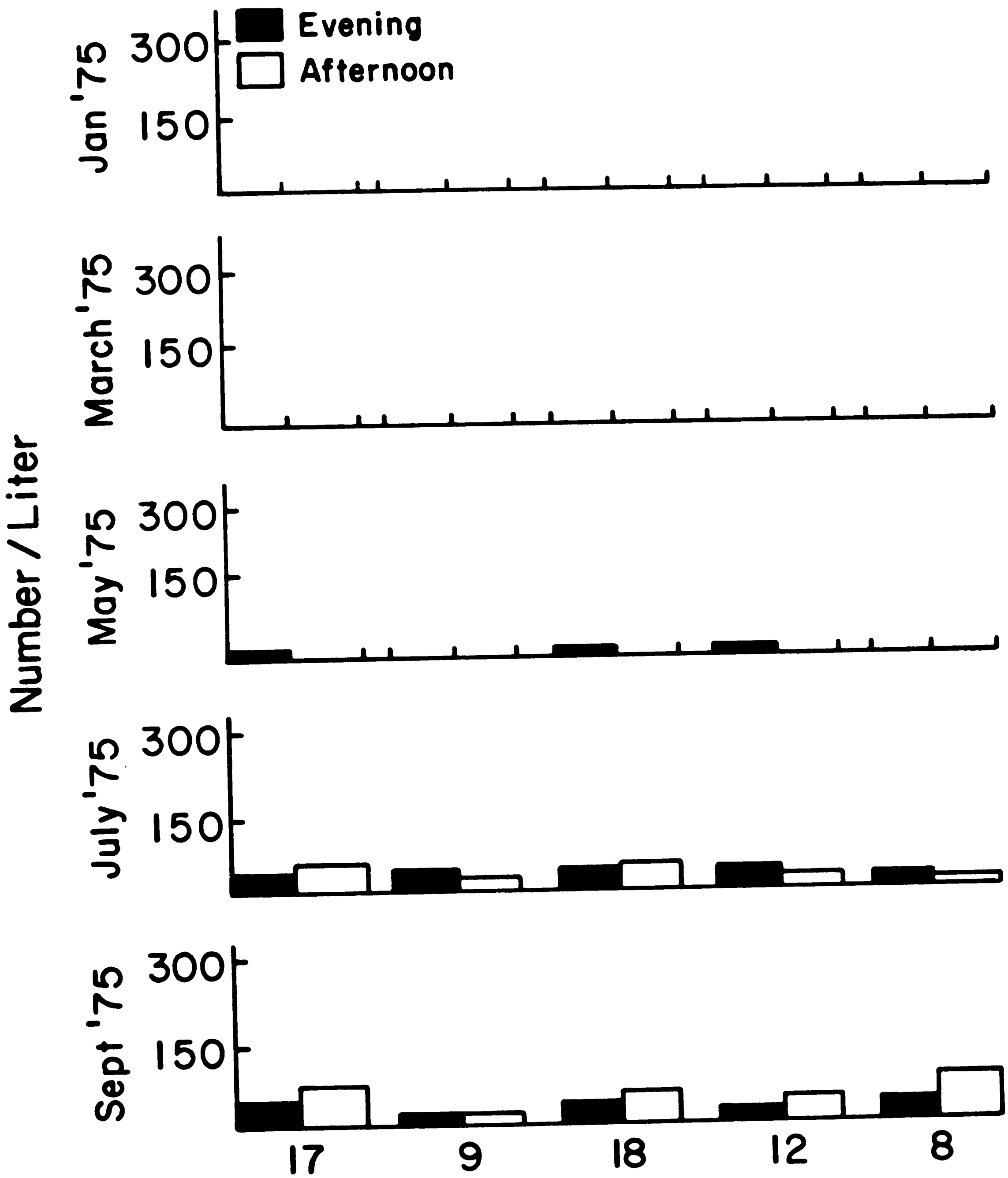

Figure 7. The density of cladocerans at each station and time period during 1975.

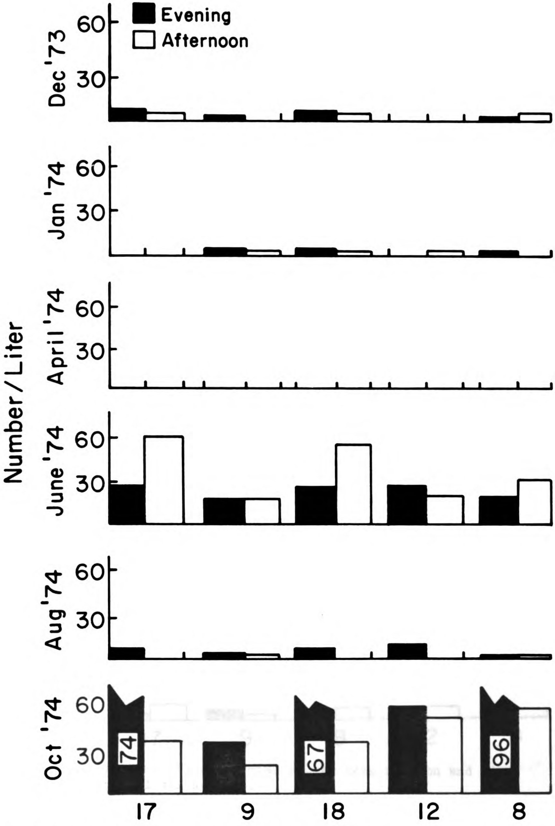

Figure 8. The density of *Bosmina* sp. at each station and time period during 1974.

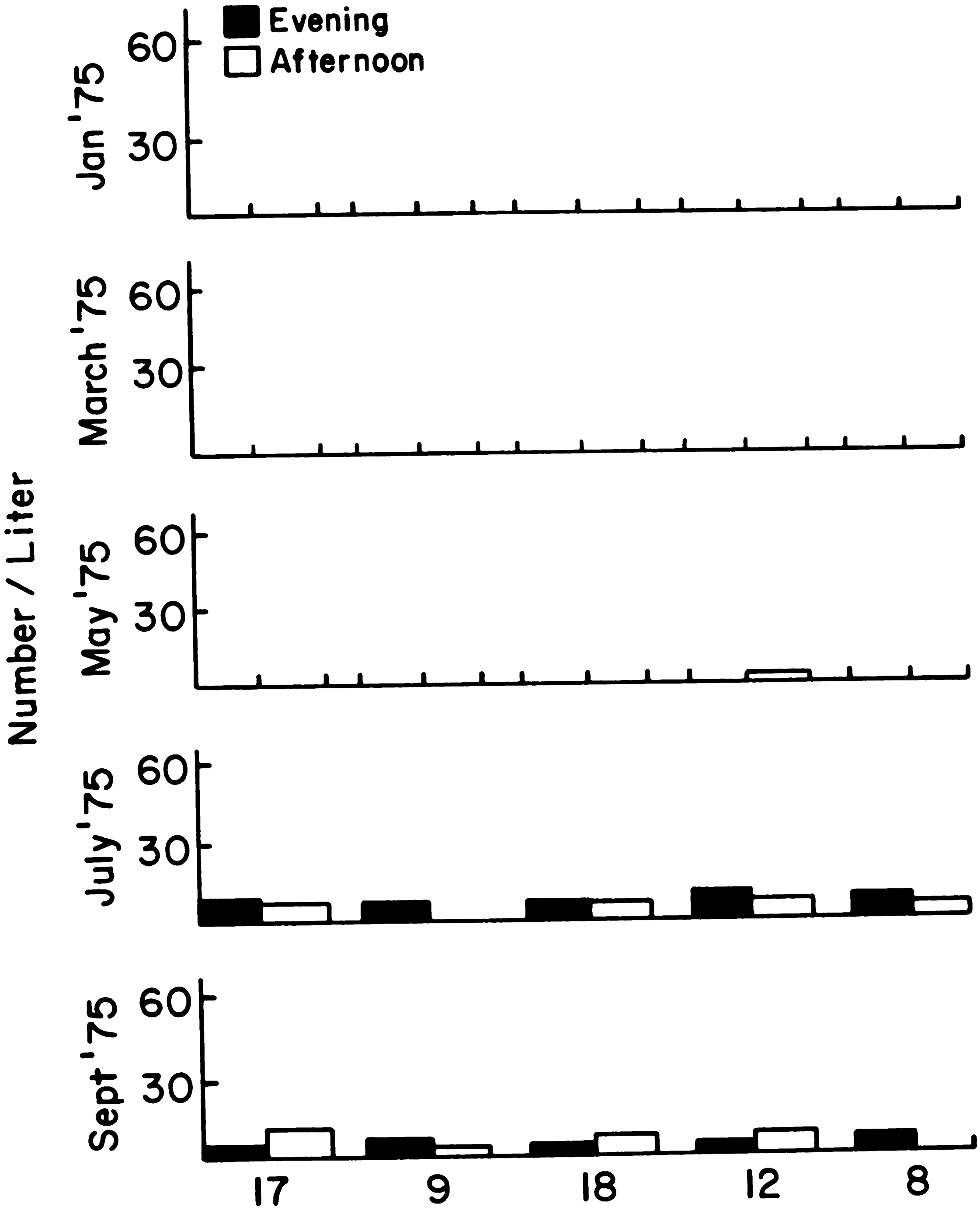

Figure 9. The density of *Bosmina* sp. at each station and time period during 1975.

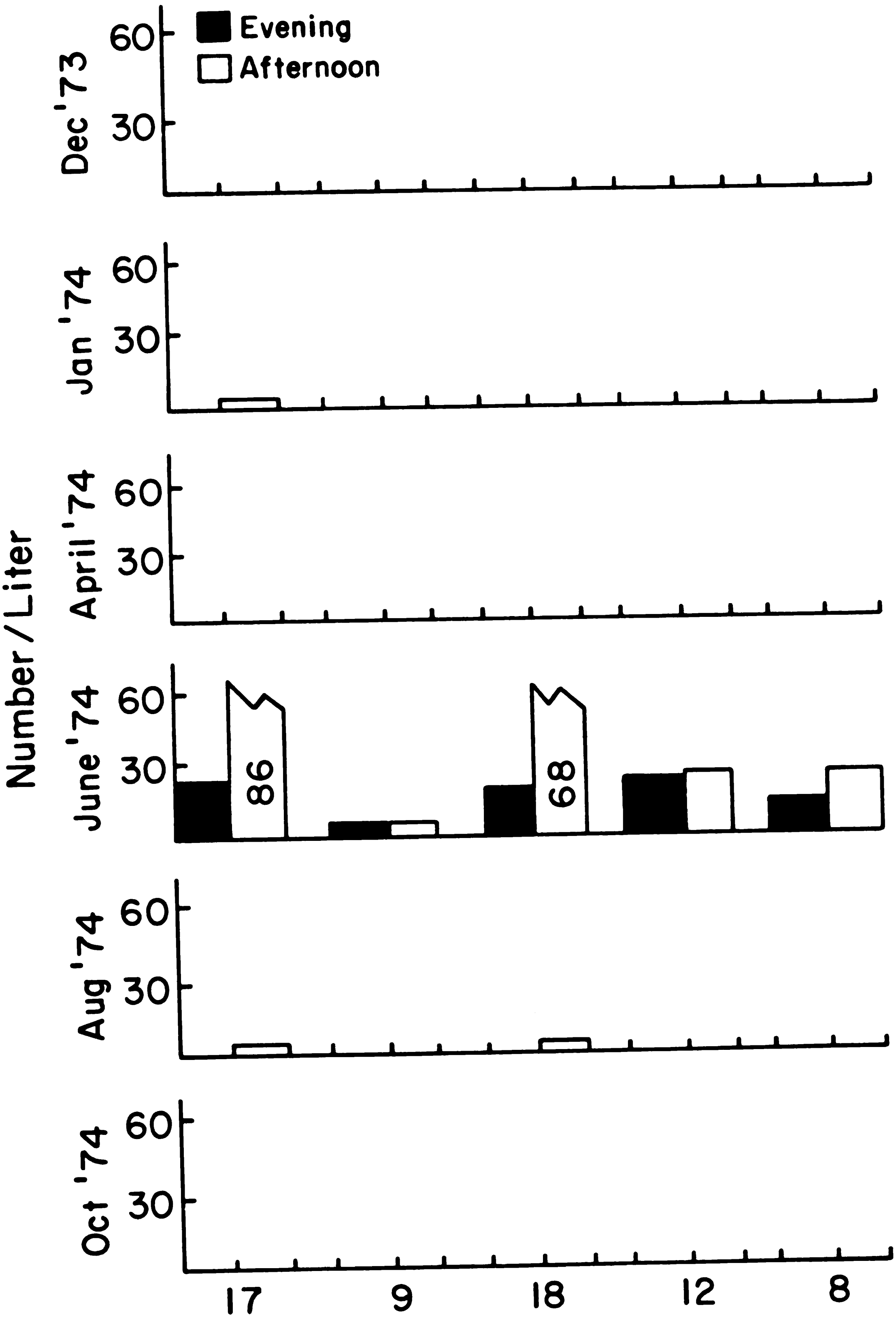

Figure 10. The density of *Daphnia retrocurva* at each station and time period during 1974.

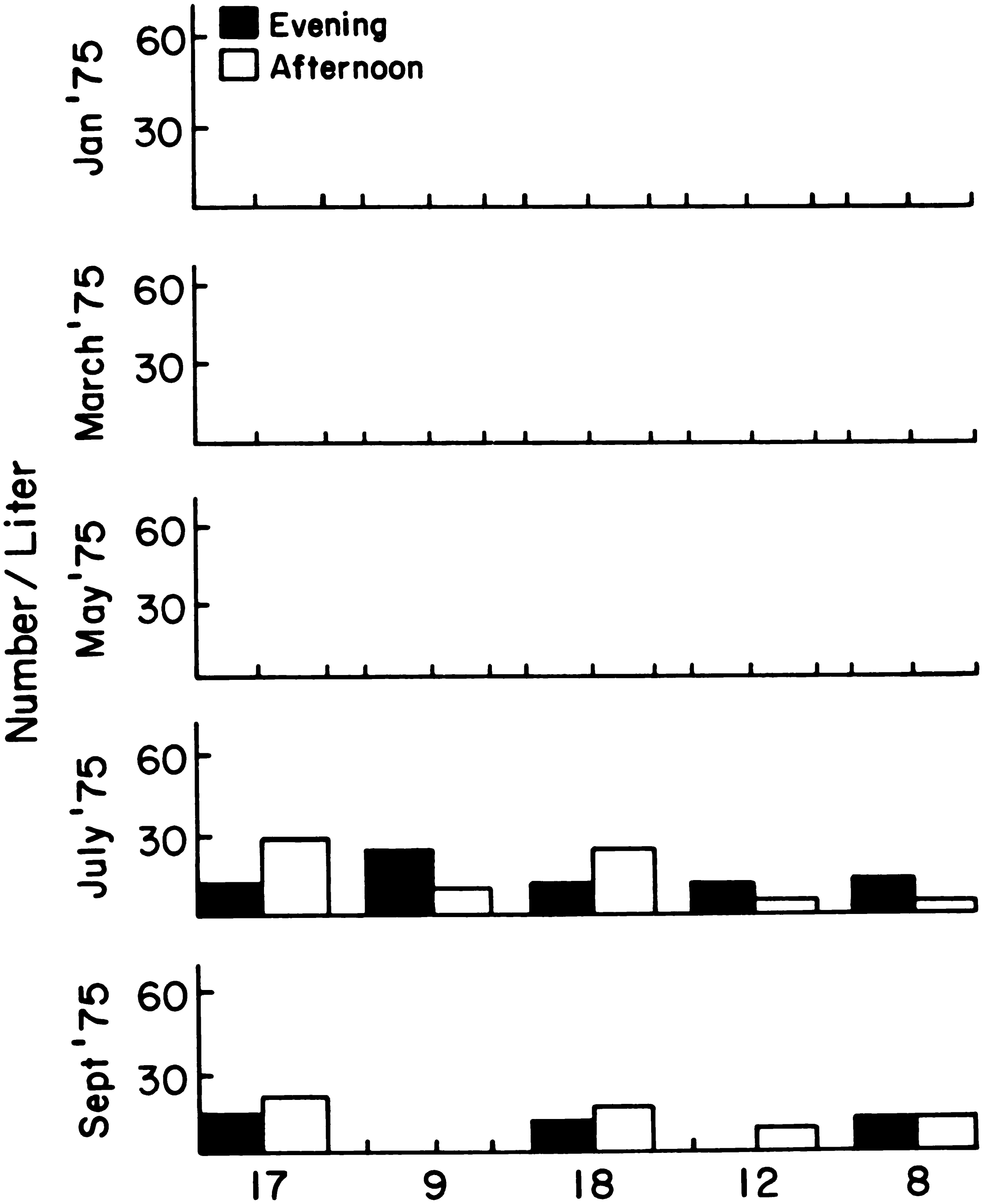

Figure 11. The density of *Daphnia retrocurva* at each station and time period during 1975.

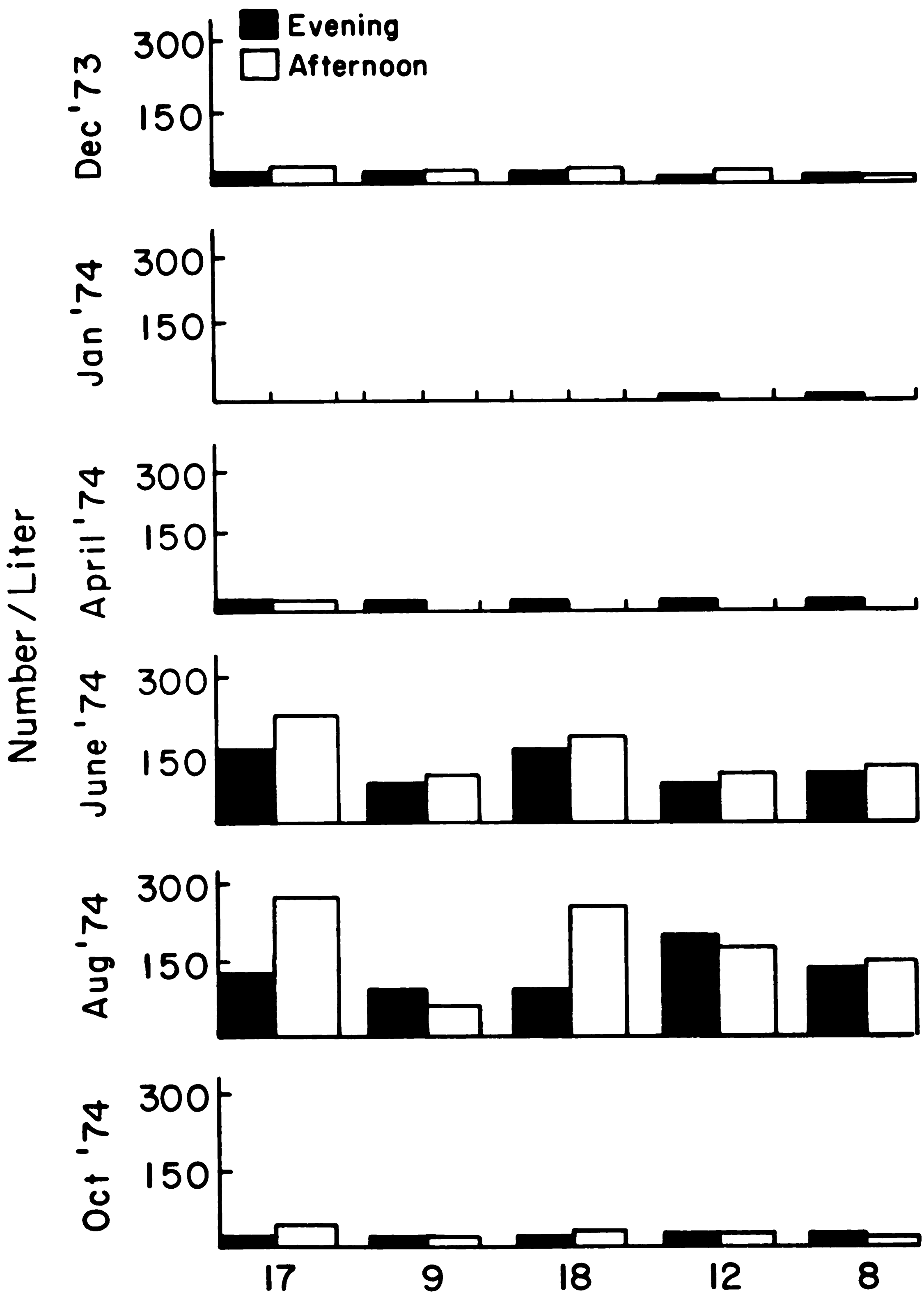

Figure 12. The density of copepods at each station and time period during 1974.

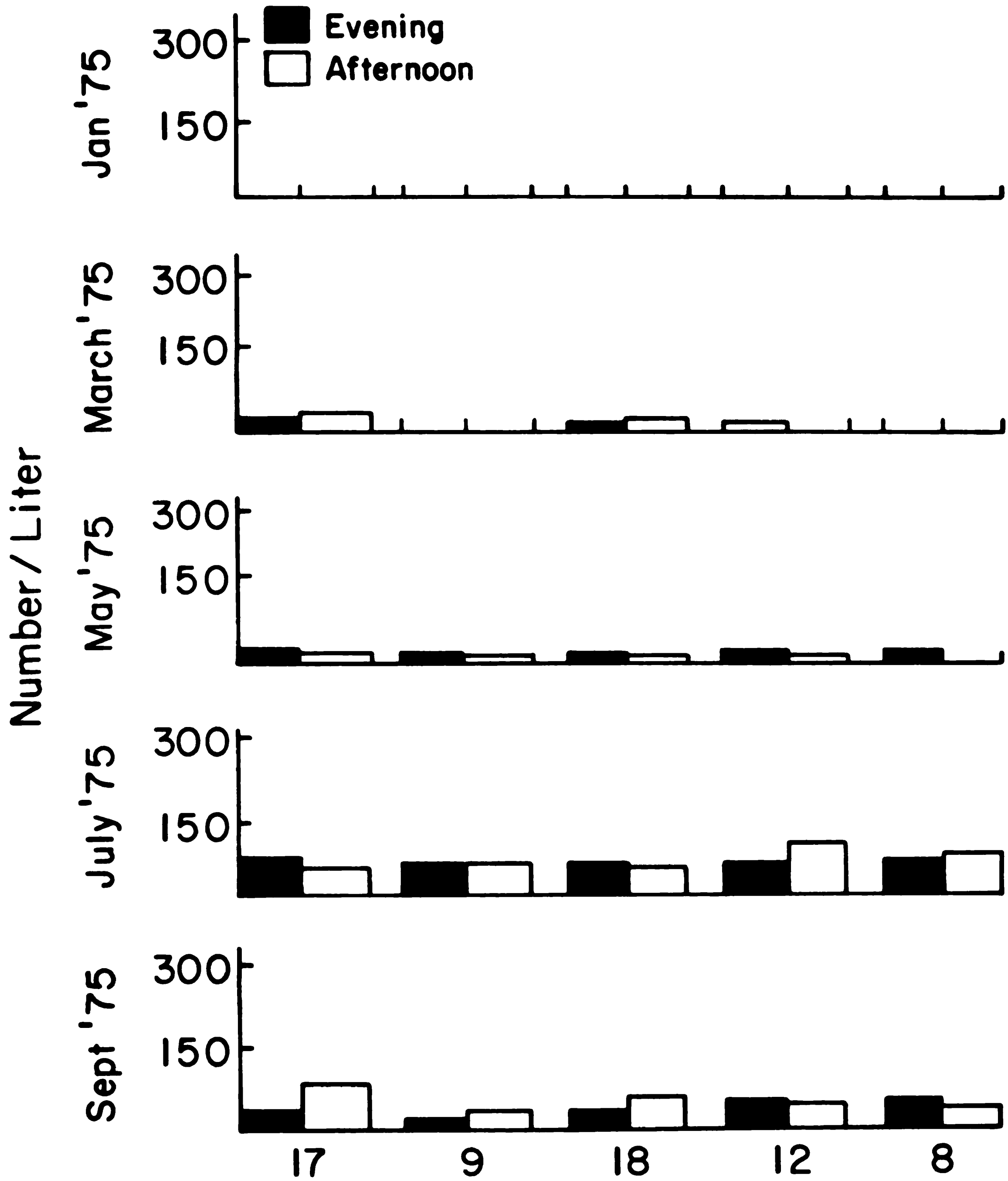

Figure 13. The density of copepods at each station and time period during 1975.

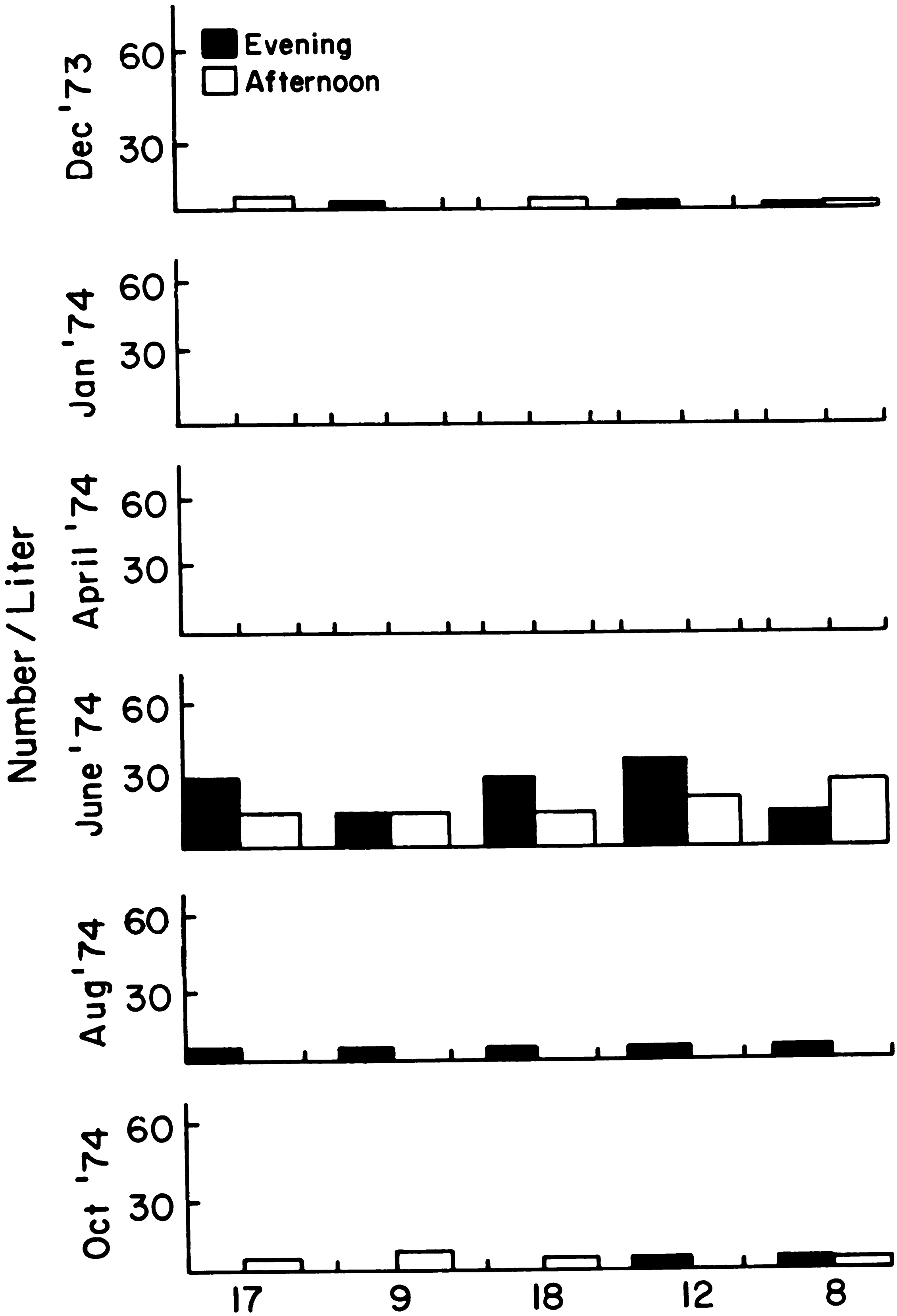

Figure 14. The density of *Cyclops vernalis* at each station and time period during 1974.

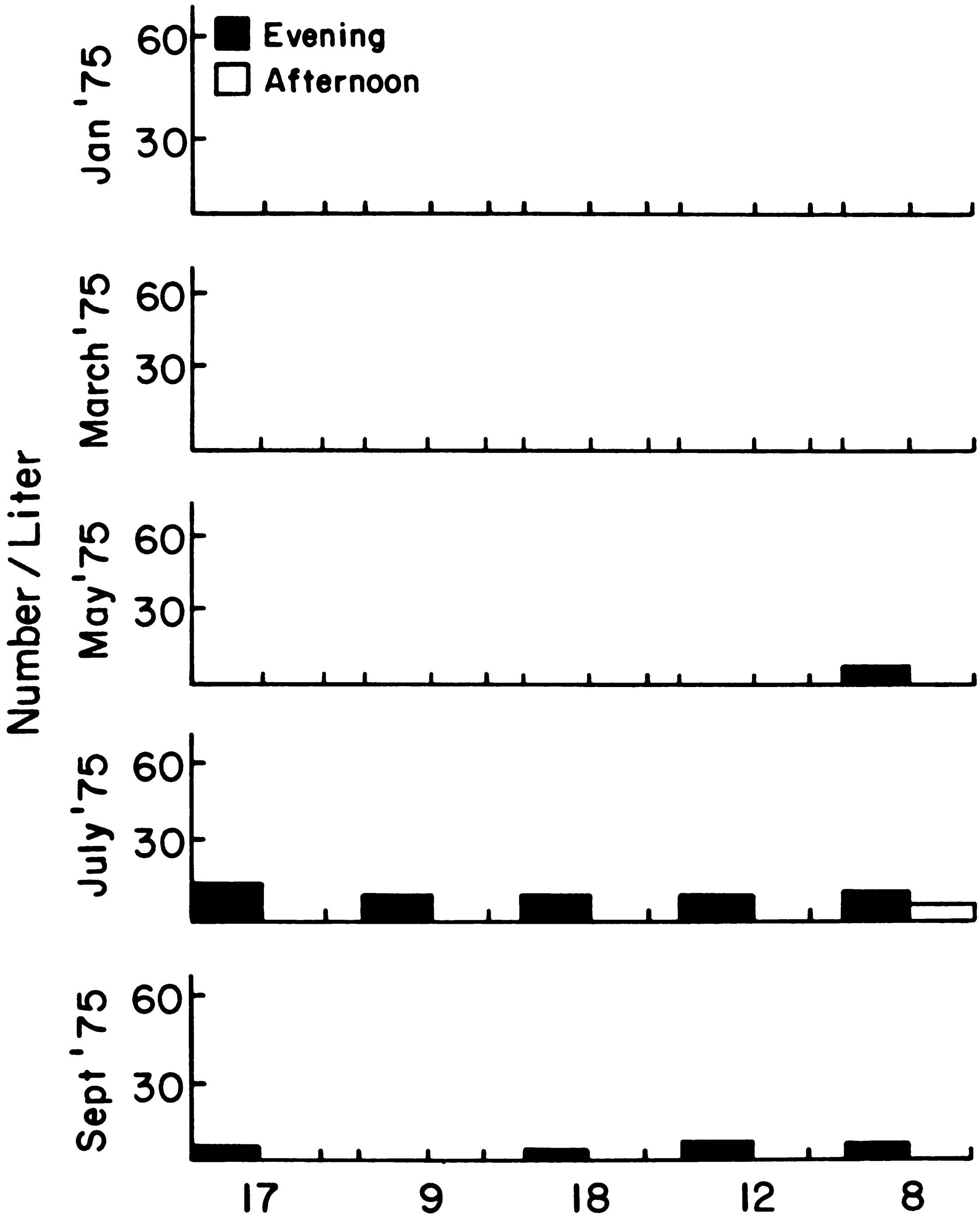

Figure 15. The density of *Cyclops vernalis* at each station and time period during 1975.

Table 4. Percent composition of the taxa encountered in 1974 and 1975.

Taxa	Percent 1974	Percent 1975
ROTIFERA		
Synchaeta sp.	32.6	16.0
Keratella cochlearis	3.8	14.8
Brachionus angularis	6.5	7.6
Keratella quadrata	1.4	10.5
Brachionus calyciflorus	4.5	3.2
Polyarthra sp.	3.5	5.9
Asplanchna sp.	3.4	1.3
Brachionus havanaensis	1.0	2.7
Trichocerca sp.	1.9	1.5
Pompholyx sp.	0.04	2.5
Brachionus budapestinensis	1.2	1.2
Chromogaster sp.	0.2	1.2
Brachionus caudatus	1.5	1.0
Keratella earlinae	0.5	0.16
Brachionus urceolares	0.16	0.78
Filinia longiseta	0.19	0.29
Brachionus quadridentata	0.16	0.31
Notholca sp.	0.18	0.36
Kellicottia longispina	0.28	0.05
Conochilus unicornis	0.18	0.02
Keratella valga	0.04	0.04
Rotaria neptunia	0.02	0.09
Euchlanis sp.	0.02	0.04
Gastropus sp.	0.02	0.04
Ploesoma sp.	0.02	0.02
Ascomorpha sp.	--	0.02
Keratella hiemalis	--	0.02
Lecane sp.	0.02	--
Cephalodella sp.	0.005	--
CLADOCERA		
Bosmina sp.	6.8	1.7
Chydorus sphaericus	1.6	4.2
Daphnia retrocurva	2.0	3.1
Diaphanosoma sp.	0.24	0.31
Leptodora kindtii	0.04	0.28
Daphnia galeata mendotae	0.02	0.04
Ceriodaphnia sp.	0.02	0.005
Alona sp.	0.02	0.005
Macrothrix sp.	--	0.005

Table 4 (cont'd.)

Taxa	Percent 1974	1975
COPEPODA		
Nauplii	19.9	13.4
Immature cyclopoids	2.8	2.2
Cyclops vernalis	1.9	1.3
Immature calanoids	0.22	0.76
Cyclops bicuspidatus	0.33	0.22
Diaptomus ashlandi	0.17	0.13
Diaptomus siciloides	0.22	0.18
Diaptomus sicilis	0.04	0.12
Eurytremora affinis	0.11	0.01
Diaptomus minutus	--	0.07
Diaptomus sp.	--	0.005

these fluctuations were outweighed by the similarity in afternoon and evening samples found at station 12. Because water at station 12 was thoroughly mixed it should have provided the most representative samples for detecting day and night numerical differences. Mean annual densities followed no consistent patterns related to time of day (Table 5). Although there were more organisms captured during 1974, afternoon and evening density differences for both years among major taxa and total organisms were generally less than 50 and 11%, respectively. The total zooplankton biomass also showed only minor, short-term temporal differences, but in this case, the evening samples in both years generally had the highest biomass (Table 6). Six of the nine zooplankton categories in 1974, and seven of nine in 1975, exhibited the greatest biomass in the evening samples; consequently, the mean size of the organisms was greatest at this time, especially in 1974 (Table 7).

Effects of Chlorine

Analysis of short- and long-term densities revealed no apparent effects from regular chlorine applications in the morning and evening (Figures 6-15; Table 5). Had chlorine been important, a decline of zooplankton abundances should have been observed at station 12 in the evening, and particularly in the afternoon at station 8. High velocities and turbulence may have masked the influence of the chemical on plankton concentrations at station 12, but its effects would have been noticed downstream at station 8 several hours later. Mean numbers of organisms found at the discharge stations in both years did not seem to follow a pattern that was determined by biocide applications.

Table 5. Mean density (numbers/liter) for the major taxa at each station and time period for 1974 and 1975.

Taxa	17				9				12				8			
	Afternoon		Evening		Afternoon		Evening		Afternoon		Evening		Afternoon		Evening	
	1974	1975	1974	1975	1974	1975	1974	1975	1974	1975	1974	1975	1974	1975	1974	1975
Rotifer	191.6	141.0	104.0	149.4	111.3	38.6	88.2	55.9	119.2	69.1	88.2	72.7	94.2	56.7	132.1	82.4
Cladocera	36.9	22.6	12.5	12.6	11.3	3.2	20.3	7.4	14.8	10.0	20.3	7.2	10.0	19.2	24.3	11.4
Daphnia sp.	14.7	8.6	.6	4.6	.3	1.2	2.6	3.6	3.3	1.2	2.6	1.6	3.0	2.0	1.3	3.8
Bosmina **sp.**	11.3	3.2	8.1	1.6	8.0	.34	13.6	1.3	10.5	2.8	13.6	2.8	6.3	.8	18.9	2.4
Adult Copepoda	4.2	2.0	3.9	3.6	3.2	.15	9.3	2.0	.5	1.5	9.3	4.2	7.0	1.8	5.3	4.7
Adult *C. vernalis*	3.4	.4	3.2	2.6	2.3	.05	6.7	2.0	.4	.4	6.7	3.2	4.4	1.2	3.3	3.4
Nauplii	73.8	19.3	20.6	11.9	24.1	11.6	37.6	11.5	40.9	17.2	37.6	14.4	48.2	19.5	36.3	15.7
Total Copepoda	78.0	21.3	24.5	15.5	27.3	11.7	46.9	13.5	41.4	18.7	46.9	18.6	55.2	21.3	41.6	20.4
Total	306.5	184.5	141.0	177.5	149.9	53.51	155.4	76.8	175.5	97.8	155.4	98.5	159.4	97.2	210.0	114.2

Table 6. Mean biomass (μg/liter) for the major taxa at each station and time period for 1974 and 1975.

Taxa	17				9				12				8			
	Afternoon		Evening		Afternoon		Evening		Afternoon		Evening		Afternoon		Evening	
	1974	1975	1974	1975	1974	1975	1974	1975	1974	1975	1974	1975	1974	1975	1974	1975
Rotifera	15.8	16.6	12.8	9.2	12.1	3.9	20.7	7.9	7.5	6.5	11.0	8.8	18.4	9.1	20.5	15.8
Cladocera	139.6	105.9	50.0	33.6	4.1	60.1	25.8	22.3	12.5	14.9	36.8	101.1	23.3	25.4	16.0	67.4
Daphnia sp.	131.1	55.1	35.7	27.5	0	17.2	8.5	22.5	6.9	9.1	31.2	97.1	16.5	17.9	5.8	63.6
Bosmina sp.	10.0	2.4	14.7	.88	2.7	.17	5.4	1.0	4.2	3.8	6.1	2.4	6.3	.5	9.0	2.5
Adult Copepoda	8.8	8.3	44.2	15.2	3.7	.20	15.1	6.6	2.3	10.1	26.7	11.9	24.7	4.0	19.2	17.0
Adult *C. vernalis*	7.0	.76	23.8	12.6	3.3	.41	11.2	6.6	.87	1.3	21.7	9.7	13.9	4.9	9.7	11.5
Nauplii	7.2	4.2	5.1	2.3	2.0	2.7	2.7	2.6	5.0	3.0	3.7	4.1	3.5	3.5	4.4	2.7
Total Copepoda	16.0	12.5	49.3	17.5	5.7	2.9	17.8	9.2	7.3	13.1	30.4	15.0	38.2	7.5	23.6	19.7
Total	171.4	135.0	112.1	60.3	21.9	66.9	64.3	39.4	27.3	34.5	78.2	124.9	79.9	42.0	60.1	102.9

Table 7. Mean biomass (μg/liter) and size/individual (μg) for the major taxa (combining stations) at the two daily time periods in 1974 and 1975.

	Afternoon				Evening			
	Biomass		Size		Biomass		Size	
Taxa	1974	1975	1974	1975	1974	1975	1974	1975
Rotifera	53.8	36.1	.10	.12	65.0	41.7	.14	.12
Cladocera	179.5	206.3	2.5	3.7	128.6	224.4	1.54	5.8
Daphnia sp.	154.5	99.3	7.2	7.6	81.2	210.7	10.4	15.5
Bosmina sp.	23.2	6.9	.64	.96	35.2	6.8	.58	.84
Adult Copepoda	39.5	22.6	2.6	4.1	105.2	50.7	4.0	3.5
Adult *C. vernalis*	25.1	7.4	2.4	3.6	66.4	40.4	3.6	3.6
Nauplii	17.7	13.4	.09	.20	15.9	11.7	.12	.22
Total Copepoda	67.2	36.0	.33	.49	121.1	61.4	.77	.90
Total	300.5	278.4	.33	.64	314.7	327.5	.44	.70

Statistical Comparisons

Although there were consistent trends in the comparisons of annual mean densities (Table 5), significant ($\alpha = 0.05$) differences were not common on the individual sampling dates (Table A2). On 11 of 36 occasions in 1974, and 7 of 36 in 1975, the difference among station means for the six zooplankton groups was significant. Concentrations of zooplankton collected at station 17 during both years were always greater than those found in the river at station 9, and on 12 of the 18 dates in 1974-75 when zooplankton were common, these differences were significant ($\alpha = 0.05$) for most of the taxa. The biomass of organisms collected at these stations varied similarly; biomass at station 17 was greater than station 9 on 15 of 18 dates when zooplankton were common. Again, on 12 of these 18 dates, the differences were real ($\alpha = 0.05$) for most of the taxa.

Comparisons between the densities at the intake and discharge stations revealed few statistical differences ($\alpha = 0.05$). Consistent depressions in abundances appeared as a result of cooling system passage from station 18 to 12 (Table 8), but only on three dates were these losses determined to be significant (Table A2). During both years stations 17, 18, 12 and 8 were not often different from each other while station 9 was usually much lower.

In 1974, the mean annual densities of all major zooplankton taxa decreased from one-third to two-thirds in passage from the intake to the upper discharge canal. Biomass, and in most instances size, also varied in this manner (Tables 9, 10). Passage from station 12 to station 8 showed a slight increase in mean annual numbers for all taxa except Cladocera and *Daphnia* sp. which decreased. Biomass fluctuated similarly

Table 8. Mean annual density of zooplankton at all stations (numbers/liter) in 1974 and 1975.

Taxa	17		9		18		12		8	
	1974	1975	1974	1975	1974	1975	1974	1975	1974	1975
Rotifera	162.1(181.2)*	145.2(183.0)	107.7(85.0)	47.3(35.5)	155.1(173.3)	109.0(129.2)	103.7(104.6)	70.9(77.1)	113.1(78.2)	69.6(71.2)
Caldocera	31.7(30.2)	17.6(11.0)	11.9(1313)	5.3(2.0)	28.4(27.3)	16.5(10.0)	17.6(11.0)	8.6(4.1)	17.2(5.8)	15.3(2.0)
Daphnia sp.	9.0(15.8)	6.6(2.0)	.5(0)	2.4(0)	7.2(6.7)	6.1(1.9)	3.0(0)	1.4(3.0)	1.8(1.7)	2.9(1.0)
Bosmina sp.	18.7(12.7)	2.4(4.0)	7.4(5.8)	.85(1.0)	16.2(11.7)	2.0(3.7)	12.1(9.4)	2.8(.12)	12.6(2.7)	1.6(1.0)
Adult Copepoda	6.1(8.5)	2.8(1.9)	3.6(.8)	1.1(.2)	5.2(5.8)	2.1(1.4)	4.9(5.0)	2.8(4.1)	6.2(5.0)	3.3(3.5)
Adult *C. vernalis*	4.2(5.8)	1.5(1.1)	2.7(.8)	1.0(.1)	3.6(5.6)	.9(1.0)	3.5(5.0)	1.8(4.0)	3.8(3.3)	2.3(3.5)
Nauplii	54.9(50.2)	15.6(19.4)	22.3(20.2)	11.5(2.5)	48.4(46.6)	14.1(16.3)	39.2(26.0)	15.8(8.4)	42.3(39.8)	17.6(16.6)
Total Copepoda	61.0(58.7)	18.4(21.3)	25.9(20.2)	12.6(2.5)	53.6(52.4)	16.2(17.7)	44.1(31.0)	18.6(12.5)	48.5(44.8)	20.9(20.1)
Total	254.8(270.0)	181.2(215.3)	145.5(118.5)	65.2(40.0)	237.1(253.0)	141.7(156.9)	165.4(146.6)	98.1(93.7)	178.8(128.8)	105.8(93.3)

*Represents surface numbers.

Table 9. Mean annual biomass of zooplankton at all stations (μg/liter) in 1974 and 1975.

Taxa	17		9		18		12		8	
	1974	1975	1974	1975	1974	1975	1974	1975	1974	1975
Rotifera	14.3(12.8)*	12.9(13.5)	16.4(11.3)	5.9(3.8)	15.0(12.6)	10.2(9.5)	11.8(12.9)	7.6(5.3)	19.4(8.7)	12.4(7.3)
Cladocera	94.8(182.8)	69.8(13.7)	15.0(4.1)	41.2(1.0)	77.3(145.8)	63.4(12.9)	24.7(4.7)	58.0(57.0)	19.6(10.6)	46.4(8.2)
Daphnia sp.	83.4(175.5)	41.3(9.3)	8.5(0)	19.9(0.0)	67.8(138.8)	38.8(8.8)	19.0(0)	53.1(54.7)	11.1(5.6)	39.7(7.8)
Bosmina sp.	12.3(6.9)	2.3(2.9)	4.1(1.0)	.12(.92)	10.7(6.1)	2.3(1.8)	5.2(4.1)	3.1(.05)	7.9(3.6)	1.5(.4)
Adult Copepoda	26.5(45.0)	11.7(10.6)	9.4(1.6)	3.5(.62)	22.9(36.8)	9.4(8.9)	14.5(12.2)	11.0(19.9)	22.0(18.1)	10.5(11.2)
Adult *C. vernalis*	15.4(18.7)	6.7(2.8)	7.2(1.6)	3.5(.3)	13.8(14.0)	6.3(2.2)	11.3(12.2)	5.5(14.8)	11.8(11.1)	8.2(8.6)
Nauplii	6.2(4.5)	3.2(3.4)	2.4(2.0)	2.7(.27)	5.5(4.1)	2.5(2.4)	4.9(5.9)	3.5(.94)	3.9(3.6)	3.1(3.6)
Total Copepoda	36.2(51.6)	16.7(15.3)	12.7(4.2)	7.4(4.5)	28.4(40.9)	11.9(11.3)	22.2(19.4)	16.8(24.4)	28.6(23.4)	15.1(15.6)
Total	145.3(247.2)	99.4(42.5)	44.1(19.6)	54.5(49.5)	120.7(199.3)	85.5(33.7)	587.7(37.0)	82.4(86.7)	67.6(42.7)	73.9(31.1)

*Represents surface numbers.

Table 10. Mean annual size/individual (μg) in 1974 and 1975.

Taxa	17		9		18		12		8	
	1974	1975	1974	1975	1974	1975	1974	1975	1974	1975
Rotifera	.09(.07)*	.09(.07)	.15(.09)	.12(.11)	1.(.07)	.09(.07)	.11(.17)	.11(.07)	.17(.11)	.18(.10)
Cladocera	3.0(6.0)	4.0(1.2)	1.3(.3)	7.8(.5)	2.7(5.3)	3.8(1.3)	1.4(.4)	6.7(13.9)	1.1(1.8)	3.0(4.1)
Daphnia sp.	9.3(11.1)	6.2(4.6)	17.0(0)	8.3(0)	9.4(20.7)	6.4(4.6)	6.3(0)	37.9(18.2)	6.2(3.3)	13.7(7.8)
Bosmina sp.	.7(.5)	.96(.72)	.5(.2)	.14(.92)	.7(.5)	1.1(.49)	.4(.4)	1.1(.42)	.6(1.3)	.93(.4)
Adult Copepoda	4.3(5.3)	4.2(5.6)	2.0(2.0)	3.2(3.1)	4.4(6.3)	4.5(6.4)	3.0(2.4)	3.9(4.8)	3.5(3.6)	3.2(3.2)
Adult *C. vernalis*	3.7(3.2)	4.5(2.5)	2.7(2.0)	3.5(3.0)	3.8(2.5)	7.0(2.2)	3.2(2.4)	3.0(3.7)	3.1(3.4)	3.6(2.4)
Nauplii	.11(.09)	.2(.17)	.11(.10)	.23(.11)	.11(.09)	.18(.14)	.12(.23)	.22(.11)	.09(.59)	.18(.94)
Total Copepoda	.60(.88)	.91(.72)	.49(.21)	.59(1.8)	.53(.78)	.73(.64)	.50(.63)	.90(1.9)	.59(.52)	.72(.78)
Total	.57(.91)	.55(.20)	.30(.16)	.83(1.2)	.51(.79)	.60(.21)	.35(.25)	.84(.92)	.38(.33)	.70(.33)

*Represents surface numbers.

with little trend in the mean size. The consistent, depressed abundances found in station 18 and 12 comparisons were not as apparent in 1975, but there were some species-related trends (Table 8). Analysis of biomass at these stations demonstrated a decrease in 50% of the major taxa and an increase in the remaining groups resulting in almost parallel size changes (Tables 9, 10). Rotifera and Cladocera decreased in total biomass and increased in mean size during passage from the intake to the upper discharge, while *Cyclops vernalis* decreased in both mean size and total biomass. Mean annual densities between the upper and lower discharge stations appeared to be somewhat similar. However, there was a minor net increase in numbers of certain species as they traveled through the discharge canal (Table 8), and in several taxa there was a decrease in total biomass and a corresponding reduction in mean size (Cladocera, *Daphnia* sp., *Bosmina* sp., adult Copepoda and nauplii).

Regression values based on afternoon and evening cladoceran and copepod distributions indicated no significant diurnal, vertical migrations; nor was there any real evidence of depth-related distributions (Figures 16 - 19). Patchy distributions of zooplankton and the lack of the intense sampling needed to quantify this variability may have been the cause for these results.

Mortality

The data suggest that lethal temperatures for many of the copepods and cladocerans were reached on August 2, 3 and 4th, 1975 (Table 11). On August 2nd, the temperature in the upper discharge was 38^{o}C and mortalities averaged 76% among the three replicate samples, while intake mortalities averaged only 12%. These percentages seemed to decrease as a function of temperature in the upper discharge and on August 3rd and 4th,

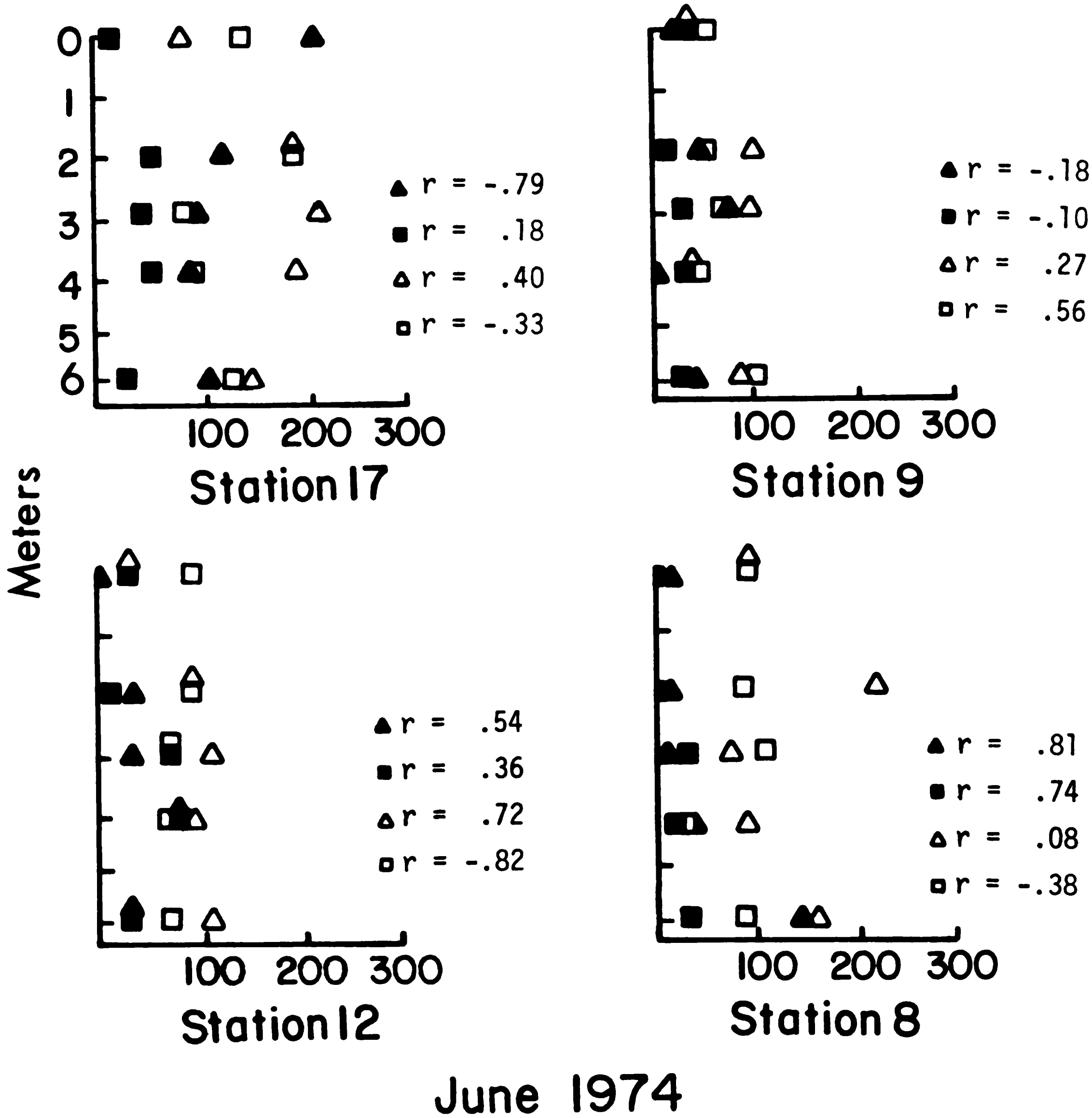

Figure 16. Mean densities (no./liter) of copepods (Δ = afternoon; □ = evening) and cladocerans (▲ = afternoon; ■ = evening) at all depths and regression values based on the density of each group at a particular depth in June 1974.

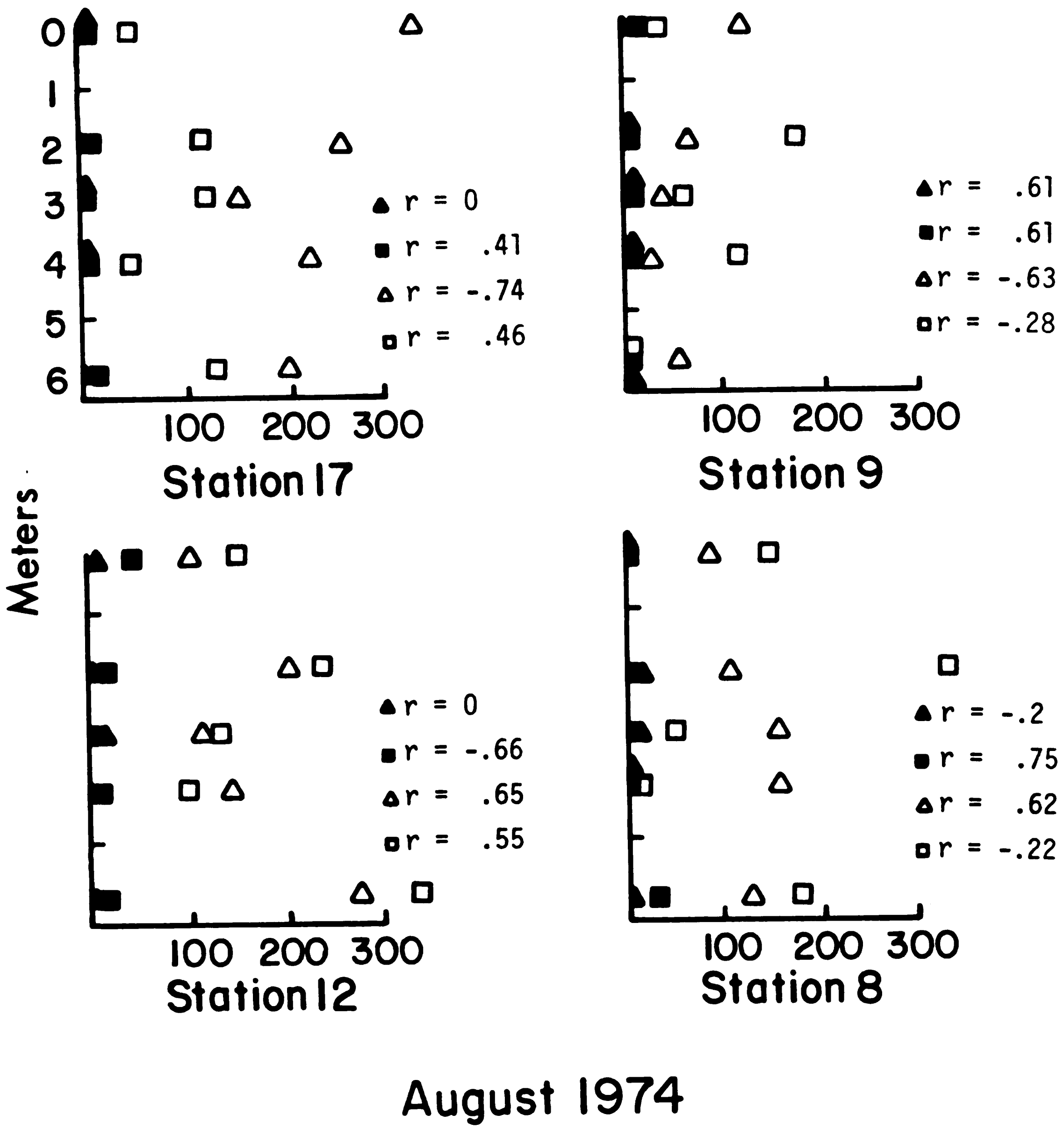

Figure 17. Mean densities (no./liter) of copepods (Δ = afternoon; □ = evening) and cladocerans (▲ = afternoon; ■ = evening) at all depths and regression values based on the density of each group at a particular depth in August 1974.

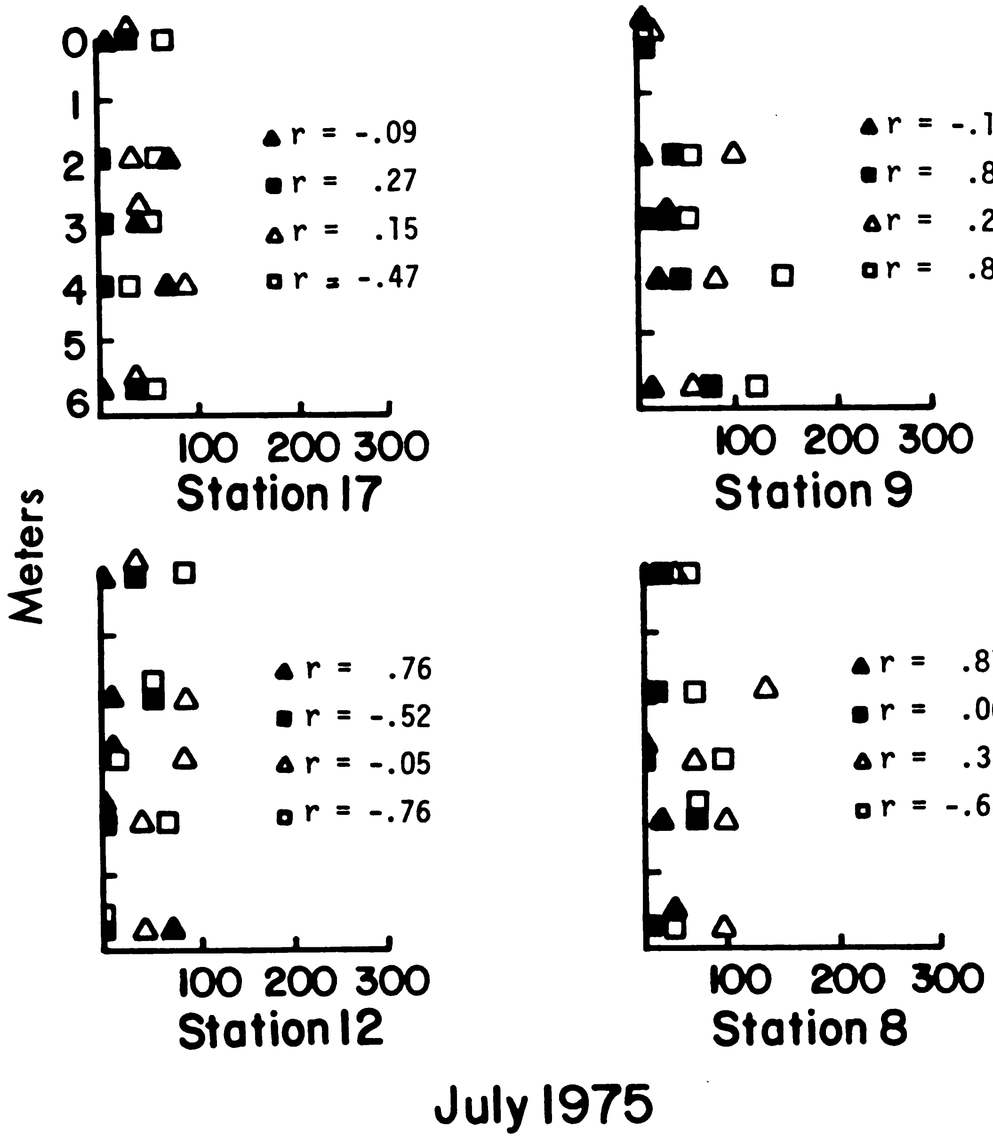

Figure 18. Mean densities (no./liter) of copepods (Δ = afternoon; □ = evening) and cladocerans (▲ = afternoon; ■ = evening) at all depths and regression values based on the density of each group at a particular depth in July 1975.

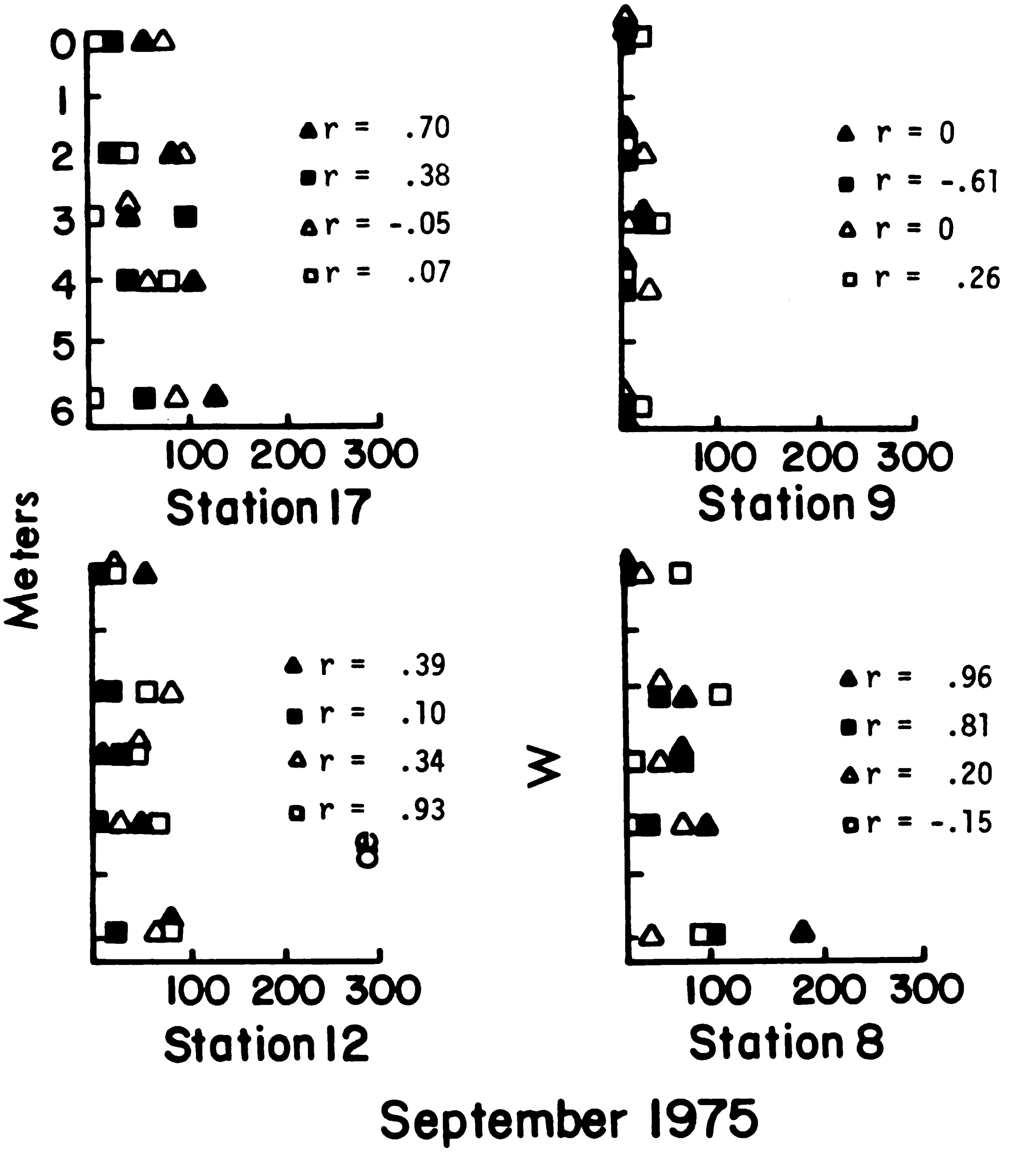

Figure 19. Mean densities (no./liter) of copepods (Δ = afternoon; □ = evening) and cladocerans (▲ = afternoon; ■ = evening) at all depths and regression values based on the density of each group at a particular depth in September 1975.

Table 11. Results of a three day mortality study involving copepods and cladocerans.

	Water Temperature (C°)	Chlorine Residual (mg/1)	Volume[1] Sampled (liters)	Number Alive	Number Dead	Mortality %	River Water (m^3/sec)	Lake Water (m^3/sec)	Total Discharge (m^3/sec)
Intake Sample #1	28.5(38)[2]	(0.5)	20				2.7	78.3	81
Daphnia retrocurva				48(1)	14(19)	23(95)			
Cyclops sp.				14(8)	1(10)	7(55)			
Diaptomus sp.				2(2)	1(3)	50(60)			
Leptodora kindtii				3(0)	0(2)	0(100)			
Diaphanosoma sp.				4 -	0 -	0 -			
Bosmina sp.				1(2)	0(4)	0(67)			
August 2, 1975 Intake Sample #2	28.5(38)	(0.5)	20				2.7	78.3	81
Daphnia retrocurva				44(1)	6(181)	12(99)			
Cyclops sp.				27(1)	0(1)	0(50)			
Leptodora kindtii				2 -	0 -	0 -			
Diaphanosoma sp.				1 -	1 -	50 -			
Bosmina sp.				4(0)	0(4)	0(100)			
Intake Sample #3	28.5(38)	(0.5)	20				2.7	78.3	81
Daphnia retrocurva				34(0)	4(244)	10(100)			
Cyclops sp.				18(4)	0(2)	0(33)			
Leptodora kindtii				1 -	0 -	0 -			
Eurytremora sp.				1 -	0 -	0 -			
Diaphanosoma sp.				1 -	0 -	0 -			
Bosmina sp.				7 -	0 -	0 -			

[1] Mortality rates were determined by observing all animals found in a 1-liter subsample.
[2] Numbers in parenthesis denote discharge canal values on the same day.

Table 11 (cont'd.)

August 3, 1975

	Water Temperature (C^o)	Chlorine Residual (mg/l)	Volume[1] Sampled (liters)	Number Alive	Number Dead	Mortality %	River Water (m^3/sec)	Lake Water (m^3/sec)	Total Discharge (m^3/sec)
Discharge Sample #1	36.0	(0.5)	20				3.1	77.9	81
Daphnia retrocurva				9	33	79			
Cyclops sp.				21	12	36			
Diaptomus sp.				1	0	0			
Leptodora kindtii				1	3	75			
Diaphanosoma sp.				6	10	62			
Bosmina sp.				3	10	77			
Discharge Sample #2	36.0	(0.5)	20				3.1	77.9	81
Daphnia retrocurva				11	15	58			
Cyclops sp.				24	7	23			
Diaptomus sp.				1	0	0			
Leptodora kindtii				2	1	33			
Diaphanosoma sp.				6	3	33			
Bosmina sp.				1	3	75			
Discharge Sample #3	36.0	(0.5)	20				3.1	77.9	81
Daphnia retrocurva				8	6	43			
Cyclops sp.				32	12	27			
Diaptomus sp.				0	1	100			
Leptodora kindtii				1	0	0			
Diaphanosoma sp.				4	3	43			
Bosmina sp.				0	4	100			

*Inclement weather prohibited sampling the intake on this date.

Table 11 (cont'd.)

August 4, 1975

	Water Temperature (C°)	Chlorine Residual (mg/l)	Volume Sampled (liters)	Number Alive	Number Dead	Mortality %	River Water (m^3/sec)	Lake Water (m^3/sec)	Total Discharge (m^3/sec)
Intake Sample #1	26.0(30.5)	(0)	20				3.1	77.9	81
Daphnia retrocurva				9(1)	1(3)	1(75)			
Cyclops sp.				13(13)	0(3)	0(19)			
Diaptomus sp.				2 -	0 -	0 -			
Leptodora kindtii				1(1)	0(0)	0(0)			
Diaphanosoma sp.				1(0)	0(1)	0(100)			
Intake Sample #2	26.0(30.5)	(0)	20				3.1	77.9	81
Daphnia retrocurva				4(3)	0(5)	0(62)			
Cyclops sp.				23(24)	0(2)	0(8)			
Diaptomus sp.				1 -	0 -	0 -			
Leptodora kindtii				1 -	0 -	0 -			
Diaphanosoma sp.				1(3)	0(1)	0(25)			
Bosmina sp.				-(0)	-(3)	-(100)			
Intake Sample #3	26.0(30.5)	(0)	20				3.1	77.9	81
Daphnia retrocurva				17 -	0 -	0 -			
Cyclops sp.				18(23)	0(2)	0(8)			
Diaptomus sp.				1 -	0 -	0 -			
Diaphanosoma sp.				1(3)	1(2)	50(40)			
Bosmina sp.				3(1)	0(0)	0(0)			

at temperatures of 36 and 30.5°C, the respective mortalities were 48 and 40%. Results of this study demonstrated that more cladocerans than copepods were killed after cooling system passage. Studies conducted in 1976 on the largest zooplankter, *Leptodora kindtii*, showed an average of 60% of these organisms were killed by passage through the plant; possibly because of mechanical factors (Table 12).

Diversity

Entrainment through the plant cooling system appeared to have little effect on zooplankton diversity (Table 13). The index used was influenced by the numbers of species found during the most productive months of the study and demonstrated that no major changes occurred from station to station during both years. There were also no consistent trends in diversity related to time of day. Afternoon and evening indices at each station showed minor variations, but this could have been attributed to spatial variability among samples collected from patchy zooplankton distributions.

Table 12. Results of a three day mortality study of *Leptodora kindtii* in 1976.

Date	Station	River Water (m^3/sec)	Lake Water (m^3/sec)	Total Discharge (m^3/sec)	Volume Sampled (m^3)	Water Temperature (C^o)	Chlorine Residual (mg/l)	Number Alive	Number Dead	Mortality %
July 6, 1976	Intake	13.6	63.4		4.0	24.0		1,539	0	0
	Upper Discharge			77.0	5.0	32.0	.02	598	3,155	84
July 7, 1976	Intake	16.3	60.7		3.3	24.0		1,341	372	22
	Upper Discharge			77.0	4.0	32.0	.03	402	565	58
July 8, 1976	Intake	13.8	63.2		4.7	24.0		850	71	8
	Upper Discharge			77.0	4.0	30.0	.07	1,250	1,250	50

Table 13. Diversity index values for zooplankton taxa captured in the cooling system. Diversity was calculated by:

$$H^{*} = -\sum_{j=1}^{s^{¶}} (Nj^{\dagger}/N^{\ddagger})\log_{10}(Nj/N)$$

1973	17	9	18	12	8
6/11	.53	.59	.53	.57	.59
6/12	.70	.51	.59	.73	.78
8/8	.42	.49	.45	.50	.43
8/9	.48	.69	.64	.40	.45
9/28	.84	.76	.92	.87	.95
9/29	.81	.83	.83	.93	.96
1974					
6/11	.98	1.08	1.00	.81	1.00
6/12	.70	1.08	.78	.94	.94
8/14	.63	.94	.67	.92	.82
8/15	.51	.90	.54	.72	.81
10/19	.66	.64	.66	.67	.67
10/21	.74	.60	.73	.65	.67
1975					
5/16	.59	.80	.67	.62	.84
5/17	.55	.78	.67	.76	.68
7/27	.72	.99	.73	.87	.80
7/28	.81	.92	.82	1.06	1.00
9/15	1.01	.59	.95	.94	1.00
9/16	.91	.89	.91	1.10	.86

* = Diversity

¶ = Number of Species

‡ = Total Abundance

† = Abundance of Each Species

DISCUSSION

Impact of Cooling System Passage

Analysis of the data in this study reveals many similarities to a 1972-73 investigation conducted by Simons (1977) when the plant had only two to three units functioning sporadically (Appendix B). Basically, the same materials and methods were used by Simons (1977) to demonstrate that short-term abundances (afternoon/evening) also varied less than those over the entire year, and that biomass and size showed only slight, short-term temporal differences. The evening samples, as in 1974-75, had the greatest biomass and size. Simons (1977) also found that chlorine applications had no measured impact on plankton numbers and biomass, but that the mean concentrations of organisms decreased significantly in passage from the intake to the upper discharge canal. The earlier study showed decreases in zooplankton size and an increase in numbers/liter as the plankton passed down the discharge canal from station 12 to station 8. This was also apparent in the present investigations. Diversity indices calculated in 1972-73 were similar to those of this study, while the mortality percentages differed substantially (possibly because the plant was not at full capacity during this period).

Examination of the mean annual densities of all major taxonomic zooplankton groups indicate that from November 1972 to September 1975, an average of 31% of the total number of animals disappeared from the water column between intake station 18 and upper discharge station 12. Entrainment through the plant and the resulting decreased abundances were not size-related in most cases. Although these declines seem to be consistent indicators of impact at the Monroe Power Plant, this result appears to be unusual when compared to the results obtained at other power plants. Carpenter et al. (1974) and Heinle (1976) report significant population losses in discharge areas, but at reference points downstream from the immediate source of the effluent.

The reductions in mean annual densities in the upper discharge canal may be caused by one or a combination of several factors. The apparent changes could have been caused by under- or overestimating the ratios of the cooling water sources and their respective biological composition in calculating intake station 18. However, USGS records of the Raisin River flow and plant pumping rates, used in conjunction with the chloride tracing, demonstrate that the mean annual calculated proportions of intake stations 17 and 9 (=station 18) were accurately estimated.

Between the intake and the upper discharge canal zooplankton pass through pumps and condensers at about 2 m/sec, then through the concrete overflow canal at about 0.75 m/sec. The losses that occurred and the mechanisms that caused them were realized before the water reached the upstream discharge station. Organisms may have been mechanically destroyed by the pressures and turbulence experienced in pump and condenser passage. Possible fish predators have never been sampled in the concrete conduit, but Cole (1976a) indicated that water velocities seemed too high (1 m/sec) and the canal too short to maintain large enough numbers of fish to have such an important impact.

Variations in zooplankton densities between times when the water was chlorinated and times when it was not chlorinated are not great enough to suspect chlorine as a major influence. Furthermore, even though chlorine may have been killing the animals, their carcasses would not have been destroyed by the chemical.

By the time water from the overflow canal (conduit) reached the upstream discharge station, dead or stunned organisms may have begun to settle out of the water column. Stavn (1971), while experimenting with Langmuir circulations and *Daphnia* distributions, showed that dead animals introduced to 30.5-cm deep chambers with currents of 2.0-8.8 cm/sec, sank to the bottom within a minute.

It is also possible that some of the more active zooplankters swam toward the bottom when they first entered the discharge canal. McLaren (1963) and Gehrs (1974) reported that certain species moved downward when they were exposed to higher temperatures. In waters of minimal turbulence, the copepods with swimming speeds up to 30 cm/sec (Allan, 1976) could accomplish this type of movement in the upper discharge canal. In this case the grouping of zooplankton below regular sampling depths would create a loss that was not real.

As the zooplankton moved down the discharge canal to station 8, there was little change in mean annual densities. However, there were obvious changes in the mean size of some taxa, especially the cladocerans and rotifers, which showed respective decreases and increases. Aside from the possibilities of settling out, emigrating from the water column, or size-related mortalities, predation could have caused the decrease in cladoceran size and a subsequent increase in the size of the rotifers. Brooks and Dodson (1965) indicate that intense predation will eliminate the larger species enabling the smaller types to predominate. Additionally, it was found that concentrations of fish in the discharge canal may have exceeded the seasonal mean density in the open lake by 10 times or more (Cole, 1976b) and that certain fish species caught in the vicinity of the power plant tended to be size-selective feeders (Kenaga and Cole, 1975). The mean size of nauplii and adult copepods did not fluctuate in a consistent pattern during passage, perhaps because of a uniformity of size among the individuals observed in the samples.

If the Monroe Power Plant had the greatest effect on the larger zooplankters, it was not apparent in the diversity indices. Since the formula used was influenced heavily by the total number of species, several taxa would have to be eliminated to detect a measurable impact by the plant.

Several explanations could be possible for the slight increase in mean annual densities which occurred as the zooplankton passed through the cooling system to station 8. If the organisms were not seriously injured after plant passage, increased reproduction could have resulted in the heated waters of the discharge canal. Allan (1976) reported that in the Rotifera, 1.25-1.75 days are required to go from egg to egg at 25°C, and 7-8 days for the Copepoda and Cladocera. It was also stated that during a lifetime of 5 days at this temperature, rotifers could produce a total of 15-25 offspring, while copepods and cladocerans generally produced 500-750 young in a 40-day lifetime. In the few hours it takes for the effluent and organisms to travel downstream, the impact of new smaller individuals upon the existing populations was probably not of great importance, but could have contributed slightly to a reduction in mean sizes. Increases in densities also may have resulted from the reorientation in the water column of recovered injured or shocked organisms which had settled out upstream. Vertical profiles constructed in the 1972-73 study indicate that the copepods and cladocerans had repositioned along depth-related gradients within a few hours after plant passage.

Mortality

The most tangible evidence that once-through cooling affects plankton was derived from the short-term mortality investigations. Many authors have indicated that the effects of suddent temperature changes, mechanical stresses and chlorine applications separately or together can be lethal to zooplankton. Coutant (1970) and Storr (1974) report heat-related deaths of 80 and 100% at 40 and 40.5°C, while Restaino *et al.* (1975), Benda and Gulvas (1976), and Carpenter *et al.* (1974) attribute respective mortalities of 15, 31 and 70% to mechanical stress. Direct mortalities caused by chlorine in the absence of temperature rise and mechanical stresses (condenser passage) are difficult to detect in the field; however, Heinle (1976) found that the percentage of living zooplankton collected during chlorination was reduced by some 60%. Extensive laboratory work reviewed by Brungs (1973) suggests that the total residual chlorine level in receiving waters should be 2 ppb or less for most aquatic organisms.

For most of the taxa collected at the Monroe Power Plant the temperature rise above ambient waters experienced in the condenser appeared to cause the greatest stress. None of the dead copepods or cladocerans examined during the 1975 mortality study showed signs of mechanical injuries and even though they were collected at the time the plant was chlorinating, no trace of the chemical was measured in the upper discharge area. The 76% mortality incurred at 38°C in the upper discharge canal seems to agree with Coutant and Storr's findings. In June 1974, Simons found the average mortality among copepods and cladocerans to be only 16.5% at a lower temperature of 29°C in the upper discharge canal, while in both years the intake dead averaged about 12.5%. That the mortality in 1974 and 1975 was taxon-selective, being especially high in the Cladocera, is also apparent in observations made by other researchers (Miller et al., 1976).

Although temperature had the greatest impact on most of the zooplankton, one species, *Leptodora kindtii*, suffered mechanical damage as well. Many of the specimens observed in the outfall area in 1976 were mangled, suggesting that pump and condenser passage may have been the cause. Since this organism is exceptionally large relative to the others, it appears to be influenced more by plant passage. Kenaga and Cole (1975) found that juvenile fish over 30 mm long selected *L. kindtii* as a preferred food item in the study area pointing out its importance as a forage species. Because the plant affects some of the zooplankton more than others, it may be viewed as an artificial predator in competition for specific types of organisms.

In summary, there is evidence that entrainment of zooplankton at the Monroe Power Plant affects their mean densities, mean sizes, distributions and mortality. Certain organisms decreased in number by nearly half before reaching the upper discharge station and decreased in size and increased slightly in density as they traveled down the discharge canal. On the site mortality studies revealed extensive deaths among the Cladocera, particularly *Leptodora kindtii*, during the hotter part of the year due to combined heat and mechanical stresses. For most of the species involved, however, the impact of the plant on total zooplankton may be outweighed by the productive nature of the western basin of Lake

Erie. Cole (1976a) estimated that even if all the zooplankton were killed during plant passage, the residual populations in this small part of the basin could turn over at least 2 to 4 times in the summer months based on a 2 to 4 week lifetime. But it should be emphasized that even though the waters surrounding the Monroe Power Plant are extremely productive, the biota they contain should not be considered inexhaustible. Some form of continuous monitoring should be required at the Monroe Power Plant to insure that the impact it has on receiving and discharge waters is not going to lead to damaging losses of any part of the aquatic community.

LITERATURE CITED

Allan, D. J. 1976. Life history patterns in zooplankton. Amer. Nat. 110(971):165-180.

Benda, R. S. and J. Gulvas. 1976. Effects of the Palisades Nuclear Power Plant on Lake Michigan. In Thermal Ecology II. Proceedings of a symposium held at Augusta, Georgia, April 2-5, 1975, pp. 243-250.

Brooks, J. L. 1965. Predation, body size and composition of plankton. Science 150:28-35.

Brungs, W. A. 1973. Effects of residual chlorine on aquatic life. J. Water Poll. Contr. Fed. 45(10):2180-2193.

Cairns, J. 1971. Thermal pollution - a cause for concern. J. Water Poll. Contr. Fed. 43(1):55-65.

Carpenter, E. S., B. B. Peck and S. J. Anderson. 1974. Survival of copepods passing through a nuclear power station on northeastern Long Island Sound, U.S.A., Marine Bio. 24:49-55.

Cole, R. A. 1976a. Entrainment at a once-through cooling system on western Lake Erie. Report to the Office of Research Development, U.S. Environmental Protection Agency, 165 pp.

Cole, R. A. 1976b. The impact of thermal discharge from the Monroe Power Plant on the aquatic community in western Lake Erie. Technical Report 32.6, Institute of Water Research, Michigan State University, East Lansing, Michigan, 571 pp.

Coutant, C. C. 1970. Biological aspects of thermal pollution. I. Entrainment and discharge canal effects. CRC Crit. Rev. Environ. Contr. 1(3):341-381.

Cummins, K. W. and J. C. Wuycheck. 1971. Caloric equivalents for investigations in ecological energetics. Int. Ass. of Theor. and Appl. Limnol., Pub. No. 18, 158 pp.

Davies, R. M. and L. D. Jensen. 1974. Effects of entrainment on zooplankton at three mid-Atlantic Power Plants, Report No. 10, Electric Power Research Institute, 76 pp.

Gehrs, C. W. 1974. Vertical movement of zooplankton in response to heated water. In Thermal Ecology. Proceedings of a symposium held in Augusta, Georgia, May 3-5, 1973, pp. 285-290.

Heinle, D. R. 1976. Effects of passage through power plant cooling systems on estuarine copepods. Environ. Pollut. 2(1):39-57.

Kenaga, D. E. and R. A. Cole. 1975. Food selection and feeding relationships of yellow perch *Perca flavescens* (Mitchell), white bass *Morone chrysops* (Rafinesque) and goldfish *Carassius auratus* (Linneaus) in western Lake Erie. Technical Report No. 32.5, Institute of Water Research, Michigan State University, East Lansing, Michigan, 61 pp.

McLaren, I. A. 1963. Effects of temperature on growth of zooplankton, and adaptive value of vertical migration. J. Fish. Res. Bd. Can. 20(3):685-727.

Miller, M. C., G. R. Hater, T. W. Federle and J. Reed. 1976. Effects of power plant operation on the biota of a thermal discharge channel. In Thermal Ecology II. Proceedings of a symposium held at Augusta, Georgia, April 2-5, 1975, pp. 251-258.

Pielou, E. C. 1969. An Introduction to Mathematical Ecology. Wiley, New York, 286 pp.

Restaino, A. L., D. G. Redmond and R. Otto. 1975. Entrainment study at Zion station. In Effects of Zio Station Operation on the Biota in Southwestern Lake Michigan, pp. 1-55.

Simons, M. 1977. Entrainment of zooplankton into a once-through cooling system on western Lake Erie. M.S. Thesis, Michigan State University, East Lansing.

Sokal, R. R. and F. J. Rohlf. 1969. Biometry. W. H. Freeman and Co., San Francisco, California, 776 pp.

Stavn, R. H. 1971. Hypothesis: Langmuir circulations and *Daphnia* distributions. Limnol. and Oceanogr. 16(2):453-466.

Storr, J. F. 1974. Plankton entrainment by the condenser systems of nuclear power stations on Lake Ontario. In Thermal Ecology. Proceedings of a symposium held in Augusta, Georgia, May 3-5, 1973, pp. 291-295.

Weast, R. C., Ed. 1968. Handbook of chemistry and physics. 49th ed. Chemical Rubber Co., Cleveland, Ohio, 2300 pp.

APPENDICES

APPENDIX A

Table A1. Zooplanktonic distribution (no./liter) in the cooling system (mean of five replicates).

	Station			
Species	17	9	12	8
12/12/73 (Night)				
Keratella cochlearis	0.5	0.2	-	0.2
Keratella earlinae	6.0	-	-	-
Keratella quadrata	4.5	0.5	2.0	1.0
Briochionus calyciflorus	8.0	1.5	-	-
Synchaeta sp.	4.5	4.0	-	-
Polyarthra sp.	8.5	2.0	-	-
Kellicottia longispina	0.5	-	-	-
Bosmina sp.	4.5	1.0	-	0.2
Chydorus sphaericus	0.5	-	-	-
Cyclops bicuspidatus	-	1.5	-	-
Cyclops vernalis	-	1.0	-	-
Immature cyclopoids	2.0	-	1.0	0.5
Nauplii	5.5	3.0	1.0	2.5
12/13/73 (Afternoon)				
Keratella cochlearis	1.5	8.0	2.5	2.0
Keratella earlinae	6.5	5.5	-	-
Keratella quadrata	2.0	1.5	-	-
Brachionus calyciflorus	2.5	1.0	1.0	0.5
Synchaeta sp.	12.0	8.0	-	0.5
Polyarthra sp.	3.5	11.0	2.0	1.0
Filinia longiseta	-	1.0	-	-
Asplanchna sp.	-	-	1.5	-
Bosmina sp.	2.0	-	-	2.0
Chydorus sphaericus	0.5	-	0.5	-
Cyclops vernalis	2.5	-	-	-
Immature cyclopoids	2.5	1.0	2.0	0.5
Nauplii	7.5	8.0	1.5	0.5
01/31/74 (Night)				
Keratella cochlearis	-	0.5	-	0.5
Keratella quadrata	1.0	-	1.0	1.0
Keratella earlinae	-	-	-	0.5
Brachionus calyciflorus	1.0	0.5	-	0.5
Brachionus urceolaris	-	-	15.0	-
Brachionus quadridentata	-	-	-	0.5
Brachionus angularis	-	0.5	-	-
Synchaeta sp.	-	1.5	-	0.5
Polyarthra sp.	3.0	2.0	-	0.5
Asplanchna sp.	-	-	15.0	-

Table A1 (cont'd.)

Species	Station 17	9	12	8
01/31/74 (Night) (cont'd.)				
Notholca sp.	-	-	-	9.5
Bosmina sp.	-	2.0	-	1.0
Chydorus sphaericus	-	-	-	0.5
Immature cyclopoids	-	1.0	0.5	1.0
Nauplii	1.0	-	1.0	3.0
02/1/74 (Afternoon)				
Keratella cochlearis	0.5	-	1.0	-
Keratella quadrata	-	0.5	-	0.5
Brachionus calyciflorus	-	-	-	0.5
Synchaeta sp.	-	2.0	-	1.5
Polyarthra sp.	-	0.5	2.0	0.5
Nitholea sp.	-	-	-	2.0
Kellicottia longispina	-	0.5	-	-
Rotaria neptunia	-	-	-	2.5
Bosmina sp.	0.5	1.0	1.0	-
Daphnia retrocurva	0.5	-	-	-
Cyclops bicuspidatus	0.5	-	-	-
Cyclops vernalis	-	-	0.5	-
Immature cyclopoids	0.5	-	0.5	-
Nauplii	-	-	0.5	0.5
04/07/74 (Night)				
Keratella quadrata	-	-	0.5	-
Brachionus calyciflorus	2.0	-	1.0	1.0
Brachionus urceolaris	-	0.5	-	0.5
Brachionus angularis	5.5	0.5	-	-
Polyarthra sp.	-	0.5	0.5	-
Filinia longiseta	1.5	-	-	-
Asplanchna sp.	1.0	-	-	-
Notholca sp.	1.0	2.0	0.5	1.0
Kellicottia longispina	0.5	-	-	-
Cephalodella sp.	-	15.0	-	-
Cyclops vernalis	0.5	-	-	-
Diaptomus ashlandi	0.5	-	-	-
Immature cyclopoids	-	0.5	0.5	-
Nauplii	3.0	2.5	2.5	2.5

Table A1 (cont'd.)

Species	Station 17	9	12	8
04/08/74 (Afternoon)				
Keratella quadrata	-	0.5	-	-
Brachionus calyciflorus	0.5	-	-	1.5
Brachionus urceolaris	-	-	-	1.0
Brachionus caudatus	-	0.5	-	-
Brachionus sp.	-	-	0.5	-
Synchaeta sp.	-	-	0.5	0.5
Filinia longiseta	-	0.5	-	-
Notholca sp.	-	0.5	-	-
Euchlanis sp.	-	-	-	0.5
Gastropus sp.	0.5	-	-	-
Cyclops bicuspidatus	-	-	0.5	-
Diaptomus ashlandi	0.5	-	-	-
Immature cyclopoids	0.5	-	-	-
Nauplii	1.0	1.0	1.5	0.5
06/11/74 (Night)				
Keratella cochlearis	4.0	4.0	4.0	2.0
Keratella quadrata	8.0	-	4.0	2.0
Keratella earlinae	2.0	-	-	-
Brachionus calycifloris	-	6.0	-	4.0
Brachionus angularis	2.0	18.0	-	-
Brachionus caudatus	-	2.0	-	-
Brachionus havanaensis	-	10.0	-	-
Brachionus budapestinensis	-	2.0	-	2.0
Synchaeta sp.	2.0	-	-	-
Polyarthra sp.	4.0	2.0	2.0	4.0
Asplanchna sp.	-	18.0	-	-
Kellicottia longispina	4.0	4.0	10.0	2.0
Trichocerca sp.	8.0	-	2.0	-
Conochilus sp.	-	2.0	-	2.0
Bosmina sp.	22.0	12.0	22.0	14.0
Daphnia retrocurva	20.0	4.0	16.0	8.0
Daphnia galeata mendotae	-	-	2.0	-
Diaphanosoma sp.	-	10.0	-	-
Leptodora kindtii	2.0	-	-	-
Immature *daphnia* sp.	-	2.0	2.0	2.0
Cyclops bicuspidatus	6.0	2.0	-	4.0
Cyclops vernalis	28.0	12.0	34.0	14.0
Immature cyclopoids	12.0	6.0	8.0	10.0
Diaptomus ashlandi	-	4.0	2.0	4.0
Diaptomus siciloides	10.0	-	2.0	4.0
Immature calanoids	6.0	-	-	-
Nauplii	84.0	42.0	36.0	68.0

Table A1 (cont'd.)

Species	17	Station 9	12	8
06/12/74 (Afternoon)				
Keratella cochlearis	4.0	4.0	4.0	8.0
Keratella quadrata	4.0	-	6.0	-
Brachionus calycifloris	-	8.0	-	-
Brachionus angularis	2.0	20.0	8.0	10.0
Brachionus havanaensis	-	16.0	2.0	-
Brachionus urceolaris	-	8.0	-	-
Synchaeta sp.	-	-	-	2.0
Polyarthra sp.	12.0	12.0	2.0	2.0
Asplanchna sp.	-	12.0	2.0	2.0
Filinia longiseta	-	6.0	-	-
Kellicottia longispina	-	-	4.0	-
Trichocerca sp.	2.0	2.0	4.0	2.0
Conochilus sp.	6.0	-	-	6.0
Lecane sp.	-	2.0	-	-
Bosmina sp.	56.0	16.0	14.0	32.0
Daphnia retrocurva	86.0	2.0	18.0	20.0
Chydorus sphaericus	-	4.0	-	-
Diaphanosoma sp.	-	4.0	-	-
Leptodora kindtii	2.0	-	-	-
Ceriodaphnia sp.	-	-	2.0	-
Cyclops bicuspidatus	4.0	2.0	-	8.0
Cyclops vernalis	12.0	10.0	2.0	26.0
Immature cyclopoids	12.0	-	10.0	6.0
Diaptomus ashlandi	-	-	2.0	2.0
Diaptomus sicilis	-	-	-	4.0
Immature calanoids	-	-	2.0	2.0
Nauplii	160.0	64.0	82.0	96.0
08/14/74 (Night)				
Keratella cochelaris	8.0	36.0	10.0	16.0
Keratella quadrata	-	2.0	2.0	-
Keratella earlinae	4.0	-	-	2.0
Brachionus calyciflorus	-	32.0	10.0	8.0
Brachionus angularis	60.0	60.0	48.0	48.0
Brachionus caudatus	-	50.0	-	2.0
Brachionus havanaensis	-	6.0	-	-
Brachionus urceolaris	-	4.0	-	-
Brachionus budapestinensis	18.0	6.0	8.0	2.0
Synchaeta sp.	100.0	74.0	60.0	54.0
Polyarthra sp.	-	-	2.0	-
Asplanchna sp.	-	22.0	10.0	2.0
Filinia longiseta	-	2.0	-	2.0
Trichocerca sp.	56.0	18.0	20.0	16.0

Table A1 (cont'd.)

Species	Station 17	9	12	8
08/14/74 (Night) (cont'd.)				
Pompholyx sp.	-	-	-	2.0
Chromogaster sp.	2.0	2.0	2.0	-
Bosmina sp.	4.0	2.0	8.0	2.0
Chydorus sphaericus	-	2.0	6.0	6.0
Cyclops bicuspidatus	-	-	2.0	-
Cyclops vernalis	2.0	4.0	4.0	2.0
Immature cyclopoids	12.0	10.0	16.0	20.0
Diaptomus siciloides	-	-	4.0	-
Eurytremora affinis	2.0	-	-	-
Immature calanoids	-	-	2.0	-
Nauplii	84.0	66.0	178.0	106.0
08/15/74 (Afternoon)				
Keratella cochlearis	16.0	8.0	34.0	30.0
Keratella quadrata	2.0	2.0	-	-
Keratella earlinae	4.0	-	-	-
Keratella volga	-	-	-	4.0
Brachionus calyciflorus	2.0	14.0	10.0	20.0
Brachionus angularis	96.0	76.0	48.0	76.0
Brachionus caudatus	-	64.0	10.0	6.0
Brachionus havanaensis	-	44.0	-	6.0
Brachionus budapestinensis	28.0	24.0	8.0	6.0
Brachionus quadridentata	-	14.0	-	-
Synchaeta sp.	390.0	90.0	114.0	116.0
Polyarthra sp.	4.0	2.0	-	2.0
Asplanchna sp.	4.0	14.0	2.0	4.0
Trichocerca sp.	28.0	4.0	24.0	32.0
Pompholyx sp.	-	-	-	2.0
Chromogaster sp.	4.0	-	4.0	4.0
Ploesoma sp.	-	2.0	-	-
Gastropus sp.	-	2.0	-	-
Bosmina sp.	-	2.0	-	2.0
Daphnia retrocurva	2.0	-	-	-
Diaphanosoma sp.	2.0	-	2.0	2.0
Immature cyclopoids	16.0	4.0	30.0	30.0
Nauplii	248.0	54.0	144.0	110.0

Table A1 (cont'd.)

Species	Station 17	9	12	8
10/19/74 (Night)				
Keratella cochlearis	36.0	4.0	10.0	14.0
Keratella quadrata	14.0	2.0	8.0	14.0
Keratella earlinae	-	-	-	2.0
Brachionus calyciflorus	32.0	10.0	40.0	58.0
Brachionus havanaensis	2.0	-	-	-
Synchaeta sp.	284.0	118.0	196.0	370.0
Polyarthra sp.	42.0	10.0	12.0	46.0
Asplanchna sp.	26.0	16.0	16.0	44.0
Filinia longiseta	-	-	-	4.0
Euchlanis sp.	-	-	2.0	-
Bosmina sp.	74.0	32.0	52.0	96.0
Chydorus sphaericus	14.0	8.0	16.0	20.0
Diaphanosoma sp.	-	-	-	2.0
Alona sp.	2.0	-	-	-
Cyclops vernalis	-	2.0	6.0	4.0
Immature cyclopoids	6.0	-	2.0	2.0
Eurytremora affinis	-	4.0	2.0	-
Immature calanoids	-	-	-	8.0
Nauplii	10.0	10.0	8.0	16.0
10/21/74 (Afternoon)				
Keratella cochlearis	34.0	4.0	16.0	14.0
Keratella quadrata	8.0	2.0	18.0	16.0
Keratella earlinae	12.0	-	-	2.0
Brachionus calyciflorus	44.0	8.0	28.0	46.0
Brachionus angularis	-	-	4.0	-
Synchaeta sp.	262.0	118.0	258.0	284.0
Polyarthra sp.	44.0	6.0	34.0	44.0
Asplanchna sp.	34.0	16.0	28.0	26.0
Trichocerca sp.	2.0	-	2.0	2.0
Chromogaster sp.	2.0	-	-	2.0
Bosmina sp.	36.0	16.0	48.0	52.0
Chydorus sphaericus	34.0	10.0	10.0	16.0
Cyclops vernalis	2.0	4.0	-	2.0
Immature cyclopoids	14.0	-	6.0	-
Eurytremora affinis	-	2.0	-	-
Nauplii	26.0	16.0	16.0	10.0

Table A1 (cont'd.)

Species	Station 17	9	12	8
01/24/75 (Night)				
Keratella cochlearis	2.5	-	-	-
Keratella quadrata	6.7	2.5	6.1	4.5
Keratella earlinae	-	0.25	-	-
Keratella hiemalis	1.0	-	-	-
Brachionus calyciflorus	-	-	0.25	-
Brachionus angularis	-	-	-	0.25
Synchaeta sp.	0.25	0.5	1.0	1.0
Polyarthra sp.	-	0.25	0.25	-
Asplanchna sp.	0.5	-	-	-
Notholca sp.	-	-	-	0.25
Kellicottia longispina	-	-	-	0.25
Ascomorpha sp.	0.5	-	-	-
Bosmina sp.	-	0.75	0.25	-
Alona sp.	-	0.25	-	-
Ceriodaphnia sp.	-	0.25	-	-
Cyclops bicuspidatus	0.25	-	-	0.5
Cyclops vernalis	-	-	0.25	-
Eurytremora affinis	-	-	-	0.25
Nauplii	0.25	1.0	0.5	1.0
01/25/75 (Afternoon)				
Keratella cochlearis	0.25	0.25	0.25	0.5
Keratella quadrata	4.7	1.0	3.0	5.0
Keratella earlinae	0.25	-	-	-
Brachionus calyciflorus	0.25	-	-	0.5
Brachionus urceolaris	-	0.25	-	-
Synchaeta sp.	0.25	0.5	-	0.5
Polyarthra sp.	0.5	-	-	-
Asplanchna sp.	1.0	-	-	-
Kellicottia longispina	-	-	0.25	-
Rotaria neptunia	-	5.0	-	-
Ascomorpha sp.	0.25	-	-	-
Bosmina sp.	-	-	0.25	0.25
Macrothrix sp.	0.25	-	-	-
Cyclops bicuspidatus	-	0.25	-	-
Cyclops vernalis	-	0.25	-	-
Diaptomus siciloides	-	0.25	-	-
Diaptomus ashlandi	-	-	0.75	-
Diaptomus sicilis	0.25	-	-	-
Nauplii	0.5	0.75	-	1.25

Table A1 (cont'd.)

Species	Station 17	9	12	8
03/16/75 (Night)				
Keratella cochlearis	-	-	0.25	-
Keratella quadrata	0.5	-	0.25	-
Keratella earlinae	-	0.25	-	-
Brachionus calyciflorus	0.5	-	-	0.5
Brachionus angularis	-	0.25	0.75	2.5
Brachionus caudatus	-	-	-	0.75
Synchaeta sp.	0.5	-	-	-
Asplanchna sp.	2.2	-	-	-
Notholca sp.	-	0.25	-	-
Chromogaster sp.	-	-	-	-
Cyclops bicuspidatus	0.75	-	-	0.75
Cyclops vernalis	-	-	-	-
Immature cyclopoids	0.5	-	0.25	0.25
Diaptomus sicilis	1.0	-	-	-
Diaptomus minutus	0.25	-	-	-
Nauplii	3.5	0.75	0.5	0.5
03/15/75 (Afternoon)				
Keratella cochlearis	-	0.25	-	-
Keratella quadrata	0.25	-	-	-
Brachionus calyciflorus	-	-	-	0.25
Brachionus angularis	0.25	0.5	-	1.2
Synchaeta sp.	-	0.25	-	0.5
Notholca sp.	-	0.25	0.5	0.75
Chromogaster sp.	0.25	-	-	-
Cyclops bicuspidatus	2.0	-	0.5	0.25
Immature cyclopoids	1.0	-	-	0.25
Diaptomus ashlandi	1.5	-	0.75	-
Diaptomus minutus	0.5	-	-	-
Nauplii	5.2	0.75	1.2	1.2
05/16/75 (Night)				
Keratella cochlearis	9.0	3.0	-	3.0
Keratella quadrata	159.0	13.0	76.0	58.0
Keratella earlinae	-	1.0	-	-
Brachionus calyciflorus	39.0	4.0	16.0	25.0
Brachionus angularis	5.0	6.0	8.0	19.0
Brachionus caudatus	1.0	-	-	-
Brachionus urceolaris	5.0	-	7.0	13.0
Brachionus quadridentata	2.0	2.0	5.0	1.0
Synchaeta sp.	197.0	6.0	59.0	32.0

Table A1 (cont'd.)

Species	Station 17	9	12	8
05/16/75 (Night) (cont'd.)				
Polyarthra sp.	5.0	-	-	2.0
Filinia longiseta	2.0	-	-	1.0
Asplanchna sp.	1.0	-	1.0	2.0
Kellicottia longispina	-	1.0	-	-
Notholca sp.	4.0	1.0	2.0	3.0
Daphnia retrocurva	1.0	-	-	1.0
Chydorus sphaericus	2.0	-	-	-
Cyclops bicuspidatus	-	-	7.0	3.0
Cyclops vernalis	1.0	-	-	3.0
Immature cyclopoids	1.0	1.0	4.0	6.0
Diaptomus ashlandi	-	-	-	1.0
Immature calanoids	-	-	-	2.0
Nauplii	8.0	2.0	5.0	5.0
05/17/75 (Afternoon)				
Keratella cochlearis	11.0	3.0	5.0	6.0
Keratella quadrata	17.0	5.0	47.0	63.0
Keratella earlinae	1.0	-	1.0	1.0
Brachionus calyciflorus	27.0	2.0	33.0	23.0
Brachionus angularis	3.0	10.0	3.0	9.0
Brachionus urceolaris	7.0	1.0	1.0	1.0
Brachionus quadridentata	-	-	1.0	3.0
Synchaeta sp.	165.0	4.0	68.0	35.0
Polyarthra sp.	6.0	-	1.0	2.0
Filinia longiseta	2.0	1.0	3.0	1.0
Asplanchna sp.	3.0	1.0	2.0	-
Kellicottia longispina	1.0	-	-	-
Notholca sp.	-	-	3.0	1.0
Conochilus sp.	1.0	-	-	-
Ploesoma sp.	-	-	1.0	-
Bosmina sp.	-	-	1.0	-
Daphnia retrocurva	1.0	-	-	-
Chydorus sphaericus	-	-	1.0	-
Cyclops bicuspidatus	-	-	-	1.0
Immature cyclopoids	2.0	2.0	-	-
Diaptomus sp.	-	1.0	-	-
Nauplii	2.0	2.0	5.0	5.0
07/27/75 (Night)				
Keratella cochlearis	98.0	8.0	40.0	58.0
Keratella valga	2.0	-	-	-

Table A1 (cont'd.)

Species	17	Station 9	12	8
07/27/75 (Night) (cont'd.)				
Brachionus calyciflorus	-	18.0	-	-
Brachionus angularis	12.0	4.0	2.0	-
Brachionus caudatus	-	20.0	-	-
Brachionus havanaensis	-	24.0	-	-
Brachionus budapestinensis	-	34.0	4.0	2.0
Synchaeta sp.	6.0	5.0	-	2.0
Polyarthra sp.	16.0	4.0	4.0	10.0
Asplanchna sp.	2.0	2.0	4.0	8.0
Trichocerca sp.	-	-	-	8.0
Pompholyx sp.	2.0	-	4.0	2.0
Chromogaster sp.	18.0	-	8.0	-
Gastropus sp.	-	2.0	-	-
Bosmina sp.	6.0	4.0	10.0	8.0
Daphnia retrocurva	8.0	20.0	8.0	10.0
Diaphanosoma sp.	-	2.0	2.0	-
Leptodora kindtii	-	-	2.0	-
Cyclops vernalis	14.0	10.0	12.0	12.0
Immature cyclopoids	10.0	14.0	6.0	2.0
Immature calanoids	4.0	-	2.0	6.0
Nauplii	28.0	30.0	30.0	36.0
07/28/75 (Afternoon)				
Keratella cochlearis	82.0	22.0	26.0	38.0
Brachionus calyciflorus	-	12.0	8.0	4.0
Brachionus angularis	6.0	8.0	10.0	16.0
Brachionus caudatus	-	14.0	4.0	2.0
Brachionus havanaensis	-	-	12.0	2.0
Brachionus budapestinensis	-	8.0	6.0	2.0
Synchaeta sp.	4.0	4.0	6.0	-
Polyarthra sp.	20.0	2.0	8.0	14.0
Asplanchna sp.	2.0	2.0	-	-
Filinia longiseta	-	-	2.0	-
Trichocerca sp.	4.0	-	4.0	8.0
Pompholyx sp.	12.0	-	6.0	16.0
Chromogaster sp.	8.0	-	-	10.0
Euchlanis sp.	-	-	-	2.0
Bosmina sp.	6.0	-	6.0	4.0
Daphnia retrocurva	24.0	6.0	4.0	4.0
Diaphanosoma sp.	2.0	4.0	2.0	-
Leptodora kindtii	4.0	2.0	-	2.0
Immature *Leptodora kindtii*	4.0	-	-	-
Cyclops vernalis	-	-	-	6.0

Table A1 (cont'd.)

Species	Station 17	9	12	8
07/28/75 (Afternoon) (cont'd.)				
Immature cyclopoids	2.0	12.0	12.0	4.0
Diaptomus sicilis	-	-	2.0	-
Diaptomus ashlandi	-	-	-	2.0
Immature calanoids	-	-	2.0	-
Nauplii	36.0	44.0	54.0	64.0
09/15/75 (Night)				
Keratella cochlearis	20.0	30.0	34.0	34.0
Brachionus calyciflorus	2.0	4.0	-	-
Brachionus angularis	32.0	22.0	14.0	30.0
Brachionus caudatus	-	-	4.0	-
Brachionus havanaensis	14.0	8.0	10.0	8.0
Synchaeta sp.	10.0	12.0	16.0	12.0
Polyarthra sp.	28.0	20.0	18.0	14.0
Trichocerca sp.	12.0	-	4.0	4.0
Pompholyx sp.	14.0	2.0	6.0	8.0
Chromogaster sp.	6.0	-	-	6.0
Rotaria sp.	-	-	2.0	2.0
Bosmina sp.	2.0	4.0	2.0	4.0
Chydorus sphaericus	26.0	4.0	12.0	16.0
Daphnia retrocurva	10.0	-	-	8.0
Daphnia galeata mendotae	2.0	-	-	-
Cyclops vernalis	2.0	-	4.0	4.0
Immature cyclopoids	-	-	6.0	-
Diaptomus sp.	-	-	-	2.0
Immature calanoids	4.0	-	2.0	2.0
Nauplii	20.0	8.0	36.0	36.0
09/16/75 (Afternoon)				
Keratella cochlearis	76.0	22.0	12.0	16.0
Keratella earlinae	-	-	2.0	-
Brachionus calyciflorus	-	4.0	-	-
Brachionus angularis	62.0	18.0	16.0	24.0
Brachionus havanaensis	-	6.0	18.0	20.0
Synchaeta sp.	40.0	10.0	14.0	4.0
Polyarthra sp.	46.0	16.0	18.0	8.0
Asplanchna sp.	-	-	2.0	6.0
Trichocerca sp.	10.0	6.0	2.0	4.0
Pompholyx sp.	18.0	2.0	12.0	10.0
Chromogaster sp.	2.0	2.0	10.0	6.0
Bosmina sp.	8.0	2.0	8.0	-

Table A1 (cont'd.)

Species	Station 17	9	12	8
09/16/75 (Afternoon) (cont'd.)				
Chydorus sphaericus	44.0	-	20.0	66.0
Daphnia retrocurva	18.0	-	6.0	10.0
Diaphanosoma sp.	-	2.0	-	-
Leptodora kindtii	2.0	-	2.0	-
Cyclops bicuspidatus	2.0	-	-	-
Cyclops vernalis	-	-	2.0	-
Immature cyclopoids	4.0	-	4.0	2.0
Diaptomus siciloides	-	-	8.0	-
Diaptomus sicilis	2.0	-	-	-
Immature calanoids	-	-	2.0	4.0
Nauplii	54.0	10.0	26.0	26.0

Table A2. Tukey's post-hoc comparison for mean zooplankton density[1] in 1974 and 1975.

Rotifera	6/11/74					
	Station[2]	9	18	17	12	8
	Mean	1.8550	1.6556	1.5744	1.3918	1.0936
	10/19/74					
	Station	8	17	18	12	9
	Mean	2.7068	2.6789	2.6487	2.4801	2.1251
	10/20/74					
	Station	12	17	18	8	9
	Mean	2.5829	2.5770	2.5544	2.3237	2.1233
Cladocera	10/19/74					
	Station	17	8	18	12	9
	Mean	2.0277	1.9981	1.8308	1.8008	1.5267

[1]Means are corrected for heterogeneity by log (x + 1) transformation.

[2]17 = River Mouth; 18 = Intake; 9 = Upper River; 12 = Upper Discharge; 8 = Lower Discharge.

Table A2 (cont'd.)

Cladocera	10/21/74					
	Station	8	17	18	12	9
	Mean	1.9385	1.7899	1.7702	1.7640	1.4351
Copepoda	6/11/74					
	Station	17	18	8	12	9
	Mean	2.1519	2.0991	2.0159	1.9125	1.8160
	8/15/74					
	Station	17	18	12	8	9
	Mean	2.4066	2.3760	2.2053	2.1605	1.7102
Bosmina sp.	6/12/74					
	Station	17	18	8	9	12
	Mean	1.7485	1.6891	1.2983	1.1504	0.8048

Table A2 (cont'd.)

Daphnia sp.	6/12/74 Station	17	18	8	12	9
	Mean	1.8865	1.7877	1.2308	0.8481	0.2083
Cyclops sp.	6/12/74 Station	8	17	18	9	12
	Mean	1.3565	1.2661	1.2287	0.9231	0.2083
Bosmina sp.	10/19/74 Station	17	18	8	12	9
	Mean	1.9220	1.8928	1.8617	1.6774	1.3853
Rotifera	5/16/75 Station	17	18	8	12	9
	Mean	2.5740	2.3119	2.2203	2.2025	1.4940

Table A2 (cont'd.)

Rotifera	5/17/75					
	Station	17	12	8	18	9
	Mean	2.3170	2.2065	2.0930	2.0845	1.4048
	9/16/75					
	Station	17	18	12	8	9
	Mean	2.4174	2.3690	2.0116	1.9746	1.8435
Cladocera	9/16/75					
	Station	17	18	8	12	9
	Mean	1.8298	1.7643	1.5474	1.4509	0.2644
Copepoda	5/16/75					
	Station	8	12	17	18	9
	Mean	1.2130	0.9722	0.9160	0.7207	0.4669

Table A2 (cont'd.)

Copepoda	9/15/75					
	Station	12	8	17	18	9
	Mean	1.6558	1.5357	1.0965	1.0556	0.5066
	9/16/75					
	Station	17	18	12	8	9
	Mean	1.7835	1.7246	1.5788	1.4825	0.7372

Table A3. Tukey's post-hoc comparison for mean zooplankton biomass[1] in 1974 and 1975.

Rotifera	8/14/74					
	Station[2]	9	12	8	18	17
	Mean	1.6009	1.2381	0.9963	0.8998	0.8525
	10/21/74					
	Station	8	17	18	12	9
	Mean	1.8187	1.8158	1.7911	1.7037	1.2943
Cladocera	6/12/74					
	Station	17	18	8	12	9
	Mean	2.7250	2.6260	1.6268	1.3658	1.0140
	10/19/74					
	Station	8	17	18	12	9
	Mean	1.6137	1.5456	1.5175	1.3135	0.8463

[1]Means are corrected for heterogeneity by log (x + 1) transformation.

[2]17 = River Mouth; 18 = Intake; 9 = Upper River; 12 = Upper Discharge; 8 = Lower Discharge.

Table A3 (cont'd.)

Cladocera	10/21/74					
	Station	8	17	12	18	9
	Mean	1.3557	1.2716	1.2266	1.2403	0.4095
Copepoda	6/12/74					
	Station	8	17	18	12	9
	Mean	2.0828	1.8206	1.7504	1.3456	1.2782
Copepoda	8/15/74					
	Station	17	18	8	12	9
	Mean	1.3765	1.3482	1.3228	1.3171	0.5643
	10/21/74					
	Station	17	18	12	9	8
	Mean	0.9473	0.9197	0.8251	0.2241	0.2204

Table A3 (cont'd.)

Bosmina sp.	6/12/74					
	Station	17	18	8	9	12
	Mean	1.5940	1.5212	1.0860	0.8515	0.5748
Daphnia sp.	6/12/74					
	Station	17	18	8	12	9
	Mean	2.7170	2.6159	1.5350	1.0753	0.2462
Cyclops sp.	6/12/74					
	Station	8	17	18	9	12
	Mean	1.9672	1.5898	1.5354	1.0779	0.2797
Bosmina sp.	10/21/74					
	Station	12	17	18	8	9
	Mean	1.1499	1.0668	1.0364	0.9756	0.2885

Table A3 (cont'd.)

Rotifera	5/16/75					
	Station	17	12	8	18	9
	Mean	1.4739	1.3989	1.2636	1.0802	0.6729
	5/17/75					
	Station	17	12	8	18	9
	Mean	1.2260	1.2120	1.0555	1.0275	0.5252
	7/27/75					
	Station	9	8	18	17	12
	Mean	1.2680	1.2452	0.9049	0.6295	0.4571
Cladocera	9/15/75					
	Station	17	18	8	12	9
	Mean	1.5536	1.2307	0.9045	0.5970	0.3643

Table A3 (cont'd.)

Cladocera	9/16/75					
	Station					
	Mean	1.7001	1.6360	1.5582	1.4703	0.2576
Copepoda	5/16/75					
	Station	8	12	17	18	9
	Mean	1.3076	0.6478	0.5176	0.4164	0.2553
	7/28/75					
	Station	12	8	9	18	17
	Mean	1.4251	1.2820	1.0623	0.6941	0.6389
	9/15/75					
	Station	12	8	17	18	9
	Mean	1.3008	1.0396	0.8355	0.7926	0.0932

Table A3 (cont'd.)

Copepoda	9/16/75					
	Station	17	12	18	8	9
	Mean	1.3387	1.3344	1.2758	0.9338	0.2210

Figure A1. The majority of zooplanktonic types captured in the vicinity of the Monroe Power Plant during the 1973-75 studies.

1. *Asplanchna* sp.
2. *Brachionus urceolaris*
3. *Brachionus budapestinensis*
4. *Brachionus calyciflorus*
5. *Brachionus caudatus*
6. *Brachionus havanaensis*
7. *Brachionus quadridentata*
8. *Brachionus angularis*
9. *Platyias patulus*
10. *Keratella cochlearis*
11. *Keratella quadrata*
12. *Polyarthra* sp.
13. *Synchaeta* sp.
14. *Kellicottia longispina*
15. *Notholca acuminata*
16. *Conochilus* sp.
17. *Trichotria* sp.
18. *Trichocerca* sp.
19. *Rotaria neptunia*
20. *Monostyla* sp.
21. *Euchlanis* sp.
22. *Filinia longiseta*
23. *Bosmina* sp.
24. *Chydorus sphaericus*
25. *Alona* sp.
26. *Daphnia retrocurva*
27. *Daphnia galeata mendotae*
28. *Diaphanosoma* sp.
29. *Diaptomus* sp.
30. *Leptodora kindtii*
31. *Ceriodaphnia* sp.
32. *Filinia brachiata*
33. Nauplii
34. *Canthocamptus* sp.
35. *Hexarthra* sp.
36. *Lepadella* sp.
37. *Ploesoma* sp.
38. *Chromogaster* sp.
39. *Cyclops bicuspidatus*
40. *Pompholyx* sp.

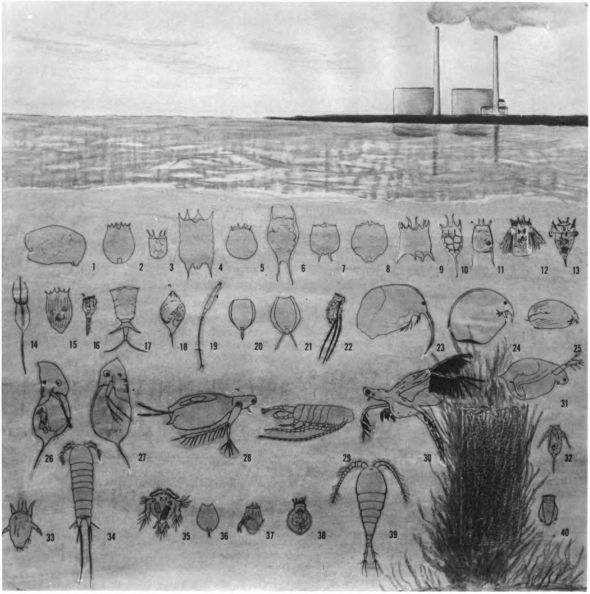

Figure A1. The majority of zooplanktonic types captured in the vicinity of the Monroe Power Plant during the 1973-75 studies.

APPENDIX B

Table B1. Mean annual size/individual (μg) from November 1972 to September 1973 (From Simons, 1977).

Taxa	Station 17	9	18	12	8
Rotifera	0.11(.13)*	0.16(.18)	0.12(.10)	0.12(.13)	0.15(.17)
Cladocera	6.1(4.8)	2.2(.63)	5.1(4.7)	11.8(4.9)	6.8(4.7)
Daphnia sp.	9.9(12.0)	14.0(5.7)	11.6(11.0)	10.7(16.6)	9.8(5.7)
Bosmina sp.	1.6(5.3)	0.84(.82)	1.1(.65)	0.81(.67)	0.60(1.0)
Adult Copepoda	3.6(3.1)	4.3(9.5)	3.8(3.4)	3.9(3.6)	2.5(3.3)
Adult *C. vernalis*	2.7(3.0)	4.0(9.9)	3.2(3.3)	3.4(3.5)	2.7(3.2)
Nauplii	0.17(.17)	0.21(.19)	0.11(.11)	0.10(.10)	0.09(.09)
Total Copepoda	2.5(2.2)	2.8(2.6)	2.7(2.2)	2.9(2.8)	1.7(2.0)
Total	2.1(1.7)	1.7(.85)	2.1(1.5)	2.7(1.9)	1.6(1.2)

*Represents surface numbers

Table B2. Mean annual biomass of zooplankton at all stations (μg/liter) from November 1972 to September 1973 (From Simons, 1977).

			Station		
Taxa	17	9	18	12	8
Rotifera	8.6(7.1)*	7.0(7.7)	7.1(5.3)	5.4(6.6)	9.2(9.2)
Cladocera	175.7(79.3)	49.8(14.0)	138.7(61.5)	136.1(56.0)	98.2(24.6)
Daphnia sp.	134.8(74.6)	44.9(6.9)	119.1(56.1)	38.7(41.5)	54.9(19.0)
Bosmina sp.	17.1(28.9)	4.2(7.0)	10.2(4.7)	5.0(3.6)	4.3(4.6)
Adult Copepoda	219.7(148.0)	133.0(47.7)	209.5(107.4)	171.9(170.8)	134.1(103.2)
Adult *C. vernalis*	153.8(109.9)	107.1(47.4)	170.2(89.4)	148.1(138.2)	111.0(93.3)
Nauplii	4.4(3.6)	3.9(2.7)	2.6(1.9)	1.7(1.4)	2.3(1.9)
Total Copepoda	224.1(151.6)	136.9(50.4)	212.1(109.3)	173.6(172.2)	136.4(105.1)
Total	408.4(238.0)	193.7(72.1)	357.9(176.1)	315.1(234.8)	243.8(138.9)

*Represents surface numbers

Table B3. Mean annual density at all stations (numbers/liter) from November 1972 to September 1973 (From Simons, 1977).

Taxa					
Rotifera	76.3(56.1)*	43.0(43.3)	65.7(51.6)	45.0(51.1)	60.4(54.4)
Cladocera	28.8(16.5)	22.3(22.3)	27.0(13.2)	11.5(11.5)	14.5(5.2)
Daphnia sp.	13.6(6.2)	3.2(1.2)	10.3(5.1)	3.6(2.5)	5.6(3.3)
Bosmina sp.	10.9(5.4)	5.0(8.5)	9.1(7.2)	6.2(5.4)	7.2(4.4)
Adult Copepoda	61.6(48.1)	31.2(5.0)	54.4(31.8)	44.0(47.5)	52.6(30.8)
Adult *C. vernalis*	57.7(36.7)	27.0(4.8)	52.3(27.4)	43.5(39.2)	40.8(28.7)
Nauplii	26.4(20.7)	18.3(14.0)	24.3(16.7)	16.1(13.5)	25.6(22.1)
Total Copepoda	88.0(68.8)	49.5(19.0)	78.8(48.5)	60.1(60.7)	78.2(52.9)
Total	193.1(141.4)	114.8(84.6)	171.5(113.3)	116.6(123.3)	153.1(112.5)

*Represents surface numbers

Table B4. Mean density (numbers/liter) for the major taxa at each station and time period from November 1972 to September 1973 (From Simons, 1977).

Taxa	17		9		12		8	
	Afternoon	Evening	Afternoon	Evening	Afternoon	Evening	Afternoon	Evening
Rotifera	100.2	80.7	46.2	39.9	53.0	58.4	78.0	42.8
Cladocera	43.7	25.5	10.0	7.9	8.4	14.7	12.2	17.7
Daphnia sp.	18.2	7.7	3.6	3.3	14.7	12.2	3.7	7.5
Bosmina sp.	13.3	8.1	6.0	3.7	3.6	7.1	6.9	8.4
Adult Copepoda	73.3	56.7	42.3	28.1	57.1	40.3	43.6	49.7
Adult *C. vernalis*	62.6	52.8	30.2	22.0	51.8	35.8	42.7	42.9
Nauplii	26.7	110.6	25.0	11.6	21.7	9.5	31.4	20.7
Total Copepoda	100.0	167.3	67.3	39.7	78.8	49.8	75.0	70.4
Total	243.9	273.5	123.5	87.5	140.2	122.9	165.2	130.9