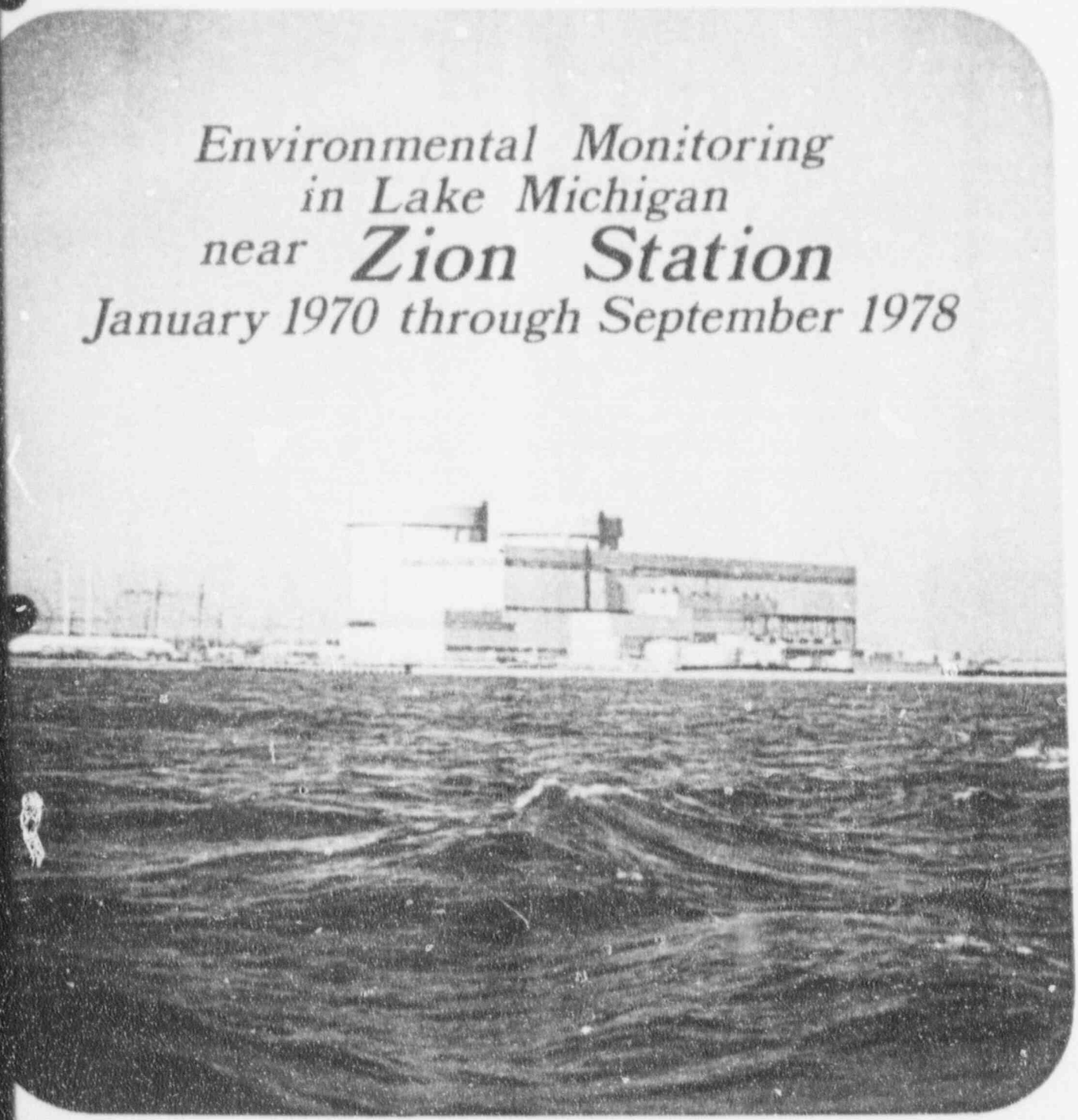
Summary Report to:
COMMONWEALTH EDISON COMPANY
CHICAGO, ILLINOIS

Environmental Monitoring in Lake Michigan near Zion Station

January 1970 through September 1978



9111110071 780930
PDR NUREG
1437 C PDR

HAZLETON
ENVIRONMENTAL SCIENCES CORPORATION

HAZLETON
ENVIRONMENTAL SCIENCES CORPORATION
1500 FRONTAGE ROAD, NORTHBROOK, ILLINOIS 60062, U.S.A.

SUMMARY REPORT TO

COMMONWEALTH EDISON COMPANY

CHICAGO, ILLINOIS

ENVIRONMENTAL MONITORING IN LAKE MICHIGAN NEAR ZION STATION JANUARY 1970 THROUGH SEPTEMBER 1978

PREPARED AND SUBMITTED
BY
HAZLETON ENVIRONMENTAL SCIENCES

Report Approved by:

G. P. Czajkowski, B.A.
Project Manager
Environmental Sciences

G. W. Wadley

G. W. Wadley, Ph.D.
Scientific Director
Environmental Sciences

1 June 1979

PHONE (312) 564-0700 • TELEX 28-9483 (HAZES NBRK)

TABLE OF CONTENTS

Chapter		Page
	Acknowledgements	v
	Foreward	vii
1.	Executive Summary	1
2.	Plant Operation	21
3.	Current Measurements	41
4.	Thermal Plume Studies	47
5.	Water Quality Studies	105
6.	Phytoplankton Studies	143
7.	Zooplankton Studies	209
8.	Periphyton Studies	271
9.	Benthos Studies	295
10.	Fish Egg and Larvae Studies	373
11.	Adult Fish Monitoring Studies	419
12.	Fish Impingement and Entrainment Studies	477
	Appendix	
	A. Illustrations of Sampling Locations, Analytical Methods, and Sampling Schedule for 1972 Water Quality Studies, Zion Station, February 1970 through September 1978	A-1
	B. Phytoplankton Species List	A-33
	C. Bibliography of Zion Related Publications	A-55

ACKNOWLEDGEMENTS

The following experts in their respective fields have contributed a significant amount to the design and implementation of these studies. We are pleased to acknowledge their advice and assistance.

Mr. Harry Carter Plume Predictions	Johns Hopkins University
Dr. Shelby Gerking Adult Fish	Arizona State University
Dr. Donald McCaughran Biostatistics	Independent Consultant
Dr. Donald C. McNaught Zooplankton Ecology	State University of New York
Dr. Robert G. Otto Fish Eggs and Larvae	Johns Hopkins University
Dr. Wesley O. Pipes Benthic Ecology	Drexel University
Dr. Don Pritchard Plume Predictions	Johns Hopkins University
Dr. Jacob Verduin Phytoplankton Ecology	Southern Illinois University

We would particularly like to acknowledge the efforts of Mr. Rudy Kunshek, Commonwealth Edison Company, whose close attention to this project has been most beneficial.

FOREWARD

Studies summarized in this report were conducted for Commonwealth Edison Company from approximately 1970 through 1978 by Hazleton Environmental Sciences Corporation (HES), formerly known as NALCO Environmental Sciences (NALCO ES) and Industrial BIO-TEST Laboratories (IBT). Annual and semi-annual reports for the Zion monitoring program are referenced as follows: IBT from 1970 to 1974, NALCO ES from 1974 to 1978 and HES from 1978 to 1979. A bibliography of Zion related publications is presented in Apperdix C of this report.

Data presented over the nine years of monitoring in the vicinity of the Waukegan and Zion Generating Stations have been routinely checked throughout the program for errors in calculations, transcription and typing. Other than minor data transcription errors, a limited number of computer calculations of species diversity and factorial analysis of variance were in error. In some cases, where warranted, the data were recalculated. These cases are discussed in the methods sections of the applicable chapters. It should be noted that the interpretation of the data presented in any prior report is not affected by the result of any discovered error.

Chapter 1

EXECUTIVE SUMMARY

SUMMARY REPORT OF ENVIRONMENTAL MONITORING
IN LAKE MICHIGAN NEAR ZION STATION
January 1970 through September 1978

EXECUTIVE SUMMARY

General

Environmental studies, consisting of preoperational and operational monitoring in Lake Michigan near Zion Generating Station, were conducted over approximately an eight-year period. The studies included: current measurements, thermal plume studies, water quality, phytoplankton, zooplankton, periphyton, benthos, fish eggs and larvae, adult fish, and fish impingement and entrainment. In addition, Hydrocon Inc. reported plant operating data in conjunction with thermal plume studies conducted in Lake Michigan near Zion Station. The purpose of these studies was to evaluate the effect of station operation on Lake Michigan. Specifically, the objectives were to (1) detect the natural seasonal patterns for physical, chemical and biological parameters and (2) to measure any effects of station operation upon these parameters.

Station Operation

Units 1 and 2 at the Zion Station have operated at 1% or greater capacity for 81% and 88% of the time, respectively, since they started operating in 1973. Monthly generation averaged between 67% and 80% for both units throughout the period of study. Plant operating data as it related to specific sampling days for both biological and chemical parameters were reported in annual and special reports.

Current Measurements

Beginning in December 1972 and continuing through January 1974,

Hydrocon, Inc. collected continuous current speed and direction data near Zion Station. Wind speed and direction data were also recorded. Models were developed for stratified lake conditions (summer) and for unstratified conditions (winter). Predictions made with these models were compared with the measured data.

A current study in support of the biological and chemical sampling programs was conducted from August 1974 through June 1978. Current meters were deployed 55 hours preceding sample collection and removed after sample collection. This study provided information which was used in the interpretation of the chemistry and plankton data.

Current speeds were generally between 0.0 ft/ sec and 1.5 ft/ sec from August 1974 to June 1978. Current direction varied from month to month moving in either a northerly or southerly direction, parallel to the local shoreline. The average net displacement varied between 19423 ft and 22144 ft.

Thermal Plume

A total of 20 thermal plumes were studied by Hydrocon, Inc. The study period began in December 1973 and continued through January 1977. Of these 20 studies, 4 were conducted in late fall, 8 in winter, 4 in summer, and 4 in spring. The results of these surveys were used to refine predictive plume models.

With the exception of the winter plume, the thermal plume was generally limited to the surface and to water less than 12 m deep. The plume's far field influence (extent of the 2°F T isotherm) was generally limited to 2 km north and south of the Station. This

area encompasses most of the sampling locations selected to evaluate the Station's influence (Zion zones). Sampling locations within the area of the plume include most of the adult fish sampling locations near the Station and all of the shallow (less than 12 m) locations. Fish egg and larvae locations near the Station, the 3 m and 9 m water quality sampling locations within the Zion zones and the 3 m south control location for water quality are also influenced. The winter plume occurs near the bottom and is generally found between the shore and the 15 m contour. This normally extends 4 km north and south of the Station. The winter plume influences all benthos sampling locations in the Zion zones, and most of the south control locations. The water quality sampling locations influenced included the 3 m and 9 m locations of the Zion zones as well as the 9 m south control location. All adult fish sampling locations in the Zion zone except the 18 m gillnet location were influenced by the winter plume.

Water Quality

Spatial variations for certain water quality constituents were observed in the study area and were related to water depth at the sampling locations. Turbulence due to wind action frequently resuspended sediments causing higher turbidity, total suspended solids) and total phosphorus concentrations at shallower locations near the shore. In addition, on sampling dates when weather was stormy these constitents were present at increased levels throughout the study area. Seasonal changes due to biological activity and

circulation of Lake Michigan waters were observed. These included cyclic patterns in nutrient concentrations, water temperature, and dissolved oxygen concentrations.

A four-year study was conducted to assess water quality differences between the Station's intake and discharge waters. Water temperature, and dissolved oxygen concentration were the only parameters to reveal measurable effects of Station operation. Release of the neutralizing tank contents to the discharged water did not consistently affect any of the constituents measured, although total dissolved solids concentrations were increased for a seven-month period in 1974. Most of the water quality constituents showed slight random variations which could not be attributed to Zion Station operation.

Phytoplankton

Phytoplankton analyses resulted in the indentification of seven algal divisions including 140 genera and almost 600 species and varieties. Members of the division Bacillariophyta (diatoms) were by far the most abundant phytoplankters and composed the greatest number of taxa. Members of the divisions Chlorophyta (green algae), Cyanophyta (blue-green algae) and Chysophyta (golden-brown algae) were the other most commonly encountered algae. The seasonal composition and abundance patterns of the phytoplankton community were similar between the preoperational and operational periods. There were no major shifts in dominant taxa over these periods. During operational monitoring, there was no consistant pattern of significant differences in any of the respective algal

components between the control and experimental locations. The operation of Zion Station has not produced any apparent changes in the phytoplankton community of this area of southwestern Lake Michigan.

Carbon fixation rates and chlorophyll *a* concentrations of phytoplankton collected near Zion Station exhibited a typical bimodal periodicity pattern with spring and fall maxima. A high degree of natural spatial and temporal variability was observed in phytoplankton carbon fixation rates and chlorophyll *a* concentrations at all depth contours and among all locations. Generally both carbon fixation rates and chlorophyll *a* concentrations decreased as depth increased. This was probably due to higher water temperatures and increased nutrients inshore.

Statistical analyses applied to the productivity data did not detect consistently significant ($p \leq 0.05$) differences in annual trends between experimental and control locations. Occasionally statistically significant differences between experimental and control locations existed, however, these differences were detected both during preoperational and operational periods. The occurrence of these differences can be attributed to natural variability and the larger number of statistical tests conducted which by chance alone would result in some significant differences being found.

Condenser passage of phytoplankton entrained during the 1973-1974 study at Zion Station resulted in an annual mean reduction in chlorophyll *a* concentration of about 2%. Effects on chlorophyll *a*

concentration were mechanical in nature, results being unaffected by the presence or magnitude of ΔT. Mechanical aspects of condenser passage had no apparent effect on the ability of phytoplankton to fix carbon, the annual mean reduction of 5.5% corresponding with a decrease in abundance. Presence of ΔT caused an approximate doubling of the reduction in carbon fixation rate, the annual mean decrease being 12%.

Both lake control and plume locations were added to the 1976-1977 entrainment study to assess recovery of the phytoplankton community after passage through the Station. Carbon fixation rates, chlorophyll a concentrations, and phytoplankton densities collected near Zion Station exhibited a typical bimodal periodicity pattern with spring and fall maxima. Carbon fixation rates and chlorophyll a concentrations occasionally reflected some immediate and delayed responses to entrainment which were generally minimized by the mixing of plume organisms with the ambient lake community. Phytoplankton seasonal dynamics and abundance of entrained organisms appeared to be minimally perturbed by passage through Zion Station probably due to quick re-introduction into and mixing with ambient Lake Michigan waters.

Zooplankton

Zooplankton densities were greatest in the late summer and fall and declined significantly in the winter and early spring. Cladocera and Rotifera, the main components of the fall zooplankton community, were rare in winter and early spring. Copepods were

also abundant in the fall, but remained so during the winter.

Locations of maximum density varied between depth contours with cladocerans and rotifers found primarily at inshore locations with copepods more prevalent at offshore locations. Densities of major taxa at 3, 9 and 18 m locations were not consistently significantly different between control and experimental locations or preoperational and operational periods. No major changes in species composition were observed after Station operation commenced.

Entrainment studies were conducted to determine effects of condenser passage on zooplankton. Immotilities averaged 8.7% and ranged from 2.8% to 15.5% of the total collected. Immotilities and mortalities were noted as being affected by mechanical and/or thermal stresses. Mechanical rather than thermal factors were found to be the main cause of zooplankton mortalities. Species size apparently affected survival while time of day or magnitude of the ΔT were unrelated.

Zooplankton population and zooplankton entrainment studies over these years have shown that the Zion Station has not significantly affected the zooplankton populations in this area of Lake Michigan. Differences between locations or years have not been consistent and are apparently due to natural variability in the sampling area.

Periphyton

Green algae were the major components of the periphytic algal community observed. Most common were species of Ulothrix (primarily

U. zonata) and Cladophora glomerata. Secondary components were usually diatoms. Most of the major algal taxa reported during all monitoring programs were typical constituents of shoreline periphyton communities in Lake Michigan.

Cladophora glomerata was generally most abundant during the late summer and fall; whereas, Ulothrix was most abundant in the spring and early summer. There were some deviations from this normal seasonal cycle between Ulothrix and Cladophora at some locations throughout all studies. Substrate scouring by wave action and sand was the most common non-seasonal factor which affected the abundance and type of periphyton growth. A successional growth pattern after scouring was observed when Cladophora was normally the dominant alga form. The succession usually required a two to four week growth period and began with a community dominated by diatoms, followed by one of Ulothrix domination, and finally Cladophora. This pattern was also observed when uncolonized areas of shoreline substrates were brought into the "splash zone" as water levels changed. There were also vertical gradations in periphyton growth. Ulothrix, diatoms, blue-green algae and Bangia atropurpurea (a red alga) were observed growing at different splash zone depths. As a result of sampling these different stages of succession or splash zone depths there were often fluctuations in the standing crop and species composition of the periphyton community over a relatively short period of time.

Biovolume, biomass and chlorophyll a concentrations tended to

be highest during periods of Cladophora predominance. These relatively large crops were fairly consistent in size throughout the monitoring program. Fluctuations in crop size were not attributable to any effect of Zion Station start-up or to the Station's increase in operating capacity during mid-1976. Diversity and evenness indices were generally highest when diatoms were the dominant algal form.

Statistical tests reflected no consistent trends throughout the January 1973 - June 1977 study period. There was no evident growth inhibition or stimulation of any shoreline periphytic algal taxon attributable to the operation of Zion Station.

Benthos

The benthic macroinvertebrate collections contain 136 invertebrate taxa which comprised 12 classes within 10 phyla. The majority of the benthic community was composed of four classes of organisms: Crustacea, Oligochaeta, Pelecypoda and Insecta.

There has been a general increase in the density of total benthos during sampling within the study area. This appears to be a lakewide trend rather than a local effect. All sampling zones have exhibited this same increase at each depth indicating that this increase is not related to Station operation. Seasonal trends have also been noted especially at the 3, 6 and 9 m locations. Peak abundance was usually observed from June to October and lowest numbers reported in February. There was also a general trend of increased abundance with increased depth observed at all zones.

Pontoporeia affinis was the most abundant species collected. It accounted for over 20% of the benthos at most locations throughout the years and often exceeded 70% of the total. P. affinis exhibited definite seasonal trends at all locations although at 18 m the seasonal peaks were not as pronounced. Peak abundances occurred during the summer and early fall with lowest numbers usually reported in February.

Oligochaeta was composed predominantly of tubificids and the lumbriculid, Stylodrilus heringianus. Potamothrix moldaviensis was the dominant tubificid at the inshore locations while Potamothrix vejdovskyi and Limnodrilus hoffmeisteri were the major species at the 12 and 18 m locations. There were large increases in numbers of Tubificidae at the 3 and 6 m locations after August 1976 but this was not attributed to Station operation because the increase was observed at both test and control locations. Since there was an increase at all zones, it was apparently due to natural variation.

Sphaerium striatinum, Sphaerium nitidum and Pisidium spp. were the dominant Sphaerids collected. Pisidium spp. comprised the majority of the Sphaeriidae at all locations at all depths. After August 1976 there was a general increase in the density of the sphaeriids at all locations. Numbers of sphaeriids increased with increased depth, with greatest abundances usually found at those locations with silty substrate.

The Chironomidae were the major component of the class Insecta. Very few chironomids were reported from the inshore locations prior

to June 1974. Since this time there has been a gradual increase in abundance of chironomids at most locations. There was a general trend of peak chironomid abundance in late summer and fall and a trend toward increased densities with increased depth.

Very few statistical differences were observed in abundances of selected taxa or groups of organisms between the two Zion zones and the two control zones. Also, few differences were noted over time between the Zion locations and the control locations. There has been a continuing shift in community composition during the study. This shift has been toward more eutrophic forms but is disguised somewhat by the concurrent increase in overall density and is a general or lakewide phenomenon.

Fish Eggs and Larvae

Intensive studies assessing the seasonal abundance and distribution of larval fish and eggs were conducted on a continuous basis since 1972. Data obtained from these studies have provided information on seasonal patterns of distribution among those species whose early life stages inhabit the Zion-Waukegan sampling area. Emphasis was directed towards the rainbow smelt and alewife, since numerically, they represented the two most abundant species which spawn in the sampling area.

The seasonal occurrence of early life stages of fish within the Zion sampling zone varied slightly with normal seasonal warming patterns.

Large fluctuations in annual abundance of early life stages

occurred for several species. These fluctuations may have been related to differences in adult abundance and spawning activity. No trends over years in the abundance of fish eggs, larvae or young-of-year were apparent.

Rainbow smelt and alewife were the only species whose early life stages were collected in large enough numbers to determine any patterns of distribution within the sampling area. Greatest concentrations of eggs, larvae and young-of-year of both species generally occurred inshore at the 10 to 30 foot depth contours. Distributional patterns among transects were not apparent for larval or young-of-year alewife and rainbow smelt. Higher concentrations of smelt eggs and occasionally greater numbers of alewife eggs occurred along transects commonly influenced by Zion's plume. This was the only evidence of possible Station operating effects on the distribution of early life stages of fish. Higher concentrations of smelt and alewife eggs in the vicinity of Zion's plume may have, in part, been the result of attraction of adult smelt and alewife to the area during their spawning seasons, though other factors such as purging of eggs by impinged females or accumulations of eggs due to current patterns may have also contributed.

Adult Fish

A total of 1010198 fish, comprised of 37 species and 2 hybrids, was collected from 1971 through 1978. Alewife and rainbow smelt have dominated fish collections, though an additional 13 species have commonly contributed to each annual catch. Changes in species

composition were limited to occasional small catches of species not common to Lake Michigan or not common to the Zion zone. Species listed as threatened in the Illinois waters of Lake Michigan that have occurred or occasionally occur in the vicinity of Zion Station are lake herring, lake whitefish and longnose sucker.

Catches were analyzed to determine whether Station operation affected seasonal movements or distribution of species within the sampling area. Year-round sampling failed to detect any measurable changes in the normal seasonal movement of abundant species. Distributional differences within the sampling area were highly variable for several species. Statistically significant differences in distribution based on trawl catches, were not uncommon; however, no distinct patterns or trends have been apparent. Occasional indications of attraction of alewife, smelt and salmon to the thermal plume area during the early stages of their normal seasonal migrations was the only evidence of Station operating effects on fish distribution. Extensive laboratory studies of tolerance of temperature change (increase and decrease), temperature preference and avoidance and other associated physiological factors were conducted using these and other locally occurring species prior to the initiation of station operation. No adverse effects on the local fisnery were predicted on the basis of these studies. Subsequent operational field studies have confirmed these predictions.

Age determinations were made for lake trout and yellow perch, and special age and growth studies were conducted on alewife. The

age composition of lake trout and yellow perch catches have not changed appreciably throughout the monitoring period. Growth of alewives within the study area was almost identical between sampling zones.

Food habit studies of lake trout, lake perch and slimy sculpin were conducted and condition factors were calculated for all species collected by gill net and trawl. No detectable changes in the feeding habits of these species have occurred throughout the monitoring period. Statistical comparisons of condition factors between zones for individual species of different size groups, during each month, resulted in few significant differences. No biologically important differences in the body condition of fish inhabiting the study area have occurred since Zion Station began operation.

Fecundity estimates for alewife and smelt were compared over time by calculation of the number of eggs produced per gram of body weight. Changes in these values suggested compensatory responses in relation to fluctuations in population levels of these species. Changes in fecundity values could not be attributed to operation of Zion Generating Station.

Considerable differences in the abundance of several principle species have been detected throughout the eight year monitoring period. No change, however, could be attributed to operation of Zion Station. Most notable have been changes in the abundance of alewife, rainbow smelt and bloater. Increased abundance of some salmonid species was attributed to increased stocking efforts.

Changes in the abundance of alewife, smelt and bloater have not been restricted to the Zion sampling zone. Lakewide fluctuations in populations of these species have occurred that generally agree with those changes detected by these monitoring studies. Interactions between the alewife and several species may have affected changes in the abundance of these species during this monitoring period, though other factors have, undoubtedly, contributed to these population fluctuations.

Fish Impingement and Entrainment

Fish impinged at Zion Station were comprised almost entirely of alewife (98.9 percent), a small percentage of rainbow smelt (1.0 percent), and 34 other species contributing very little to the total. The percentage composition of the impingement catch was very similar to the community composition in the lake near the Station. Seasonal occurrence of fish species in the lake and seasonal occurrence of fish species in impingement results were similar, but masked somewhat by forebay residence. Total numbers of fish impinged were not related to Station intake flow. It appeared an intake barrier net was effective in limiting alewife impingement. Total numbers of fish impinged did, however, reflect seasonal movements of alewife onshore in the spring, peak abundance near the Station for spawning, and gradual offshore movement during the fall. The maximum number of fish impinged coincided with maximum abundance near the Station. Young-of-year fish were also impinged at ratios similar to their occurrence and relative abun-

dance near the Station. Comparisons of total impingement with lake biomass estimates, commercial and sport landings, and plantings showed impingement to equal small fractions of each. Under normal Station operating conditions it is anticipated that the estimated impingement losses of alewife and rainbow smelt would not exceed 0.1% of their respective lakewide biomass.

Entrainment of ichthyoplankton at Zion Station was primarily limited to alewife and rainbow smelt. The early life stages of alewife and rainbow smelt, particularly eggs and larvae, were most abundant and widely distributed in the study area and were concentrated along inshore depth contours where they were susceptible to entrainment by the Zion Station intake. Both alewife and smelt eggs were entrained through Zion Station, but egg losses due to impingement of ripe females was several times greater than losses through entrainment of lake-spawned eggs. Alewife and rainbow smelt larvae were also entrained in Zion Station cooling water flow.

With the exception of eggs released by females entrapped in the forebay, the seasonal distributions and relative abundances of alewife and smelt larvae collected in the Zion Station forebay were similar to seasonal distributions and relative abundances in the lake near Zion Station. Comparisons of losses of alewife and rainbow smelt larvae with estimates of larval standing crops in the vicinity of the Station indicated entrainment losses were a small fraction of larval production in the vicinity of the Zion Station.

Estimated losses of alewife and rainbow smelt through impinge-

nent and entrainment at Zion Station when compared to their populations in Lake Michigan are sufficiently small that adverse effects on these species would not be anticipated. There have been no measurable changes in the adult fish populations which are restricted to the vicinity of Zion Station that could be attributed to Station operation.

Conclusions

The information provided by these studies demonstrates that potential problem areas related to station operation originally discussed in the licensing phase of this Station are not a concern. No detectable change in dissolved oxygen concentrations, chemical oxygen demand levels and concentrations of other chemical constituents in Lake Michigan have occurred. Based upon comparisons within the study area there is no evidence of seasonal biological events occurring at different times in the area of thermal influence. No significant changes in algal growth or community composition occurred. The macroinvertebrate community which serve as food items for fish has remained unaffected. There has been no displacement of cold water fish or changes in seasonal migrational patterns of indigenous fish species.

Impingement and entrainment studies demonstrate that certain aquatic organisms undergo short intervals of thermal stress. In some cases mortality results due to a combination of mechanical, hydrodynamic and thermal effects. These losses are, however, minimal in relation to the standing crop of the populations effected.

Based upon the results of the studies summarized in this report, the operation of Commonwealth Edison Company's Zion Generating Station has not produced a measurable change in the water quality or aquatic communities of Lake Michigan.

Chapter 2

PLANT OPERATION

by

William P. Skibbe

SUMMARY REPORT OF ENVIRONMENTAL MONITORING
IN LAKE MICHIGAN NEAR ZION STATION

January 1970 through September 1978

TABLE OF CONTENTS

		Page
	List of Figures	25
	List of Tables	27
I.	Introduction	29
II.	Methods and Materials	31
III.	Results and Discussion	33
IV.	References Cited	39

LIST OF FIGURES

No.	Title	Page
1	Schematic of Station water use.....	34

LIST OF TABLES

No.	Title	Page
1	Zion Station cooling water system.....	35
2	Zion Station monthly capacity factors.....	36
3	Summary of temperature occurrences above 20°F ΔT at Zion Station, 1 February - 30 September, 1978.....	38

I. Introduction

Zion Station is a two unit nuclear fueled electric generating plant. Unit 1 began operating in July 1973 and Unit 2 became operational in December 1973. Prior to 25 June 1976, the operating license for the Station was restricted to 85% of design thermal power. After 25 June 1976 the station was allowed to operate up to 100% of design thermal power (3250 MW thermal per unit). On 25 April 1978 the Nuclear Regulatory Commission amended the Zion Station Environmental Technical Specification. This amendment removed the thermal restriction on the discharge water which eliminated the 20°F ΔT limitation and 55°F recirculation temperature limit with regard to ice meltation.

Throughout the environmental monitoring program, which ended in September 1976, plant operating data used in the various studies were supplied by Commonwealth Edison Company. A summary of these data are presented in this chapter.

II. Methods and Materials

The information for this chapter was obtained by reviewing all available literature prepared for the environmental monitoring program from 1969 through 1978. The data reported by Hydrocon, Inc. are presented in Chapter 4, Table 1.

III. Results and Discussion

Both Units 1 and 2 have a design power rating of 1085 MW electrical and 3250 MW thermal (Hydrocon 1974). The design heat rejection rate for each unit operating at 100% power is 7.38×10^9 BTU/hr, with a maximum temperature increase of approximately 20°F.

Steam generated by the Station is cooled by water drawn from Lake Michigan. The once through cooling system utilizes 6 circulating water pumps giving a total maximum design flow of 1.68 million GPM (Figure 1). The intake structure is located 2600 ft offshore in 22 feet of water. The twin discharge structures extend 760 ft into the lake, 154 ft on either side of the intake. The discharge jet is directed away from the shoreline and intake line at a 45° angle by vanes on the discharge louvers. The cooling water has a residence time of approximately 8.9 minutes (IBT, 1975 p. 2). A list of the structures through which the cooling water passes, and the approximate flow rate is presented in Table 1. The flow rates given are the design values used when the plant is operating at 100% capacity. The capacity of the plant is the design thermal power rating of the units.

Table 2 presents average monthly operating loads as percentages of design load for the period November 1973 through September 1978. During the 63 month period between July 1973 and September 1978, Unit 1 has operated at 1% or greater capacity for 51 months and has been out of service or operating at less than 1% capacity for 12 months. For the 58 month period between December 1973 and September 1978, Unit 2 has operated at 1% or greater capacity for

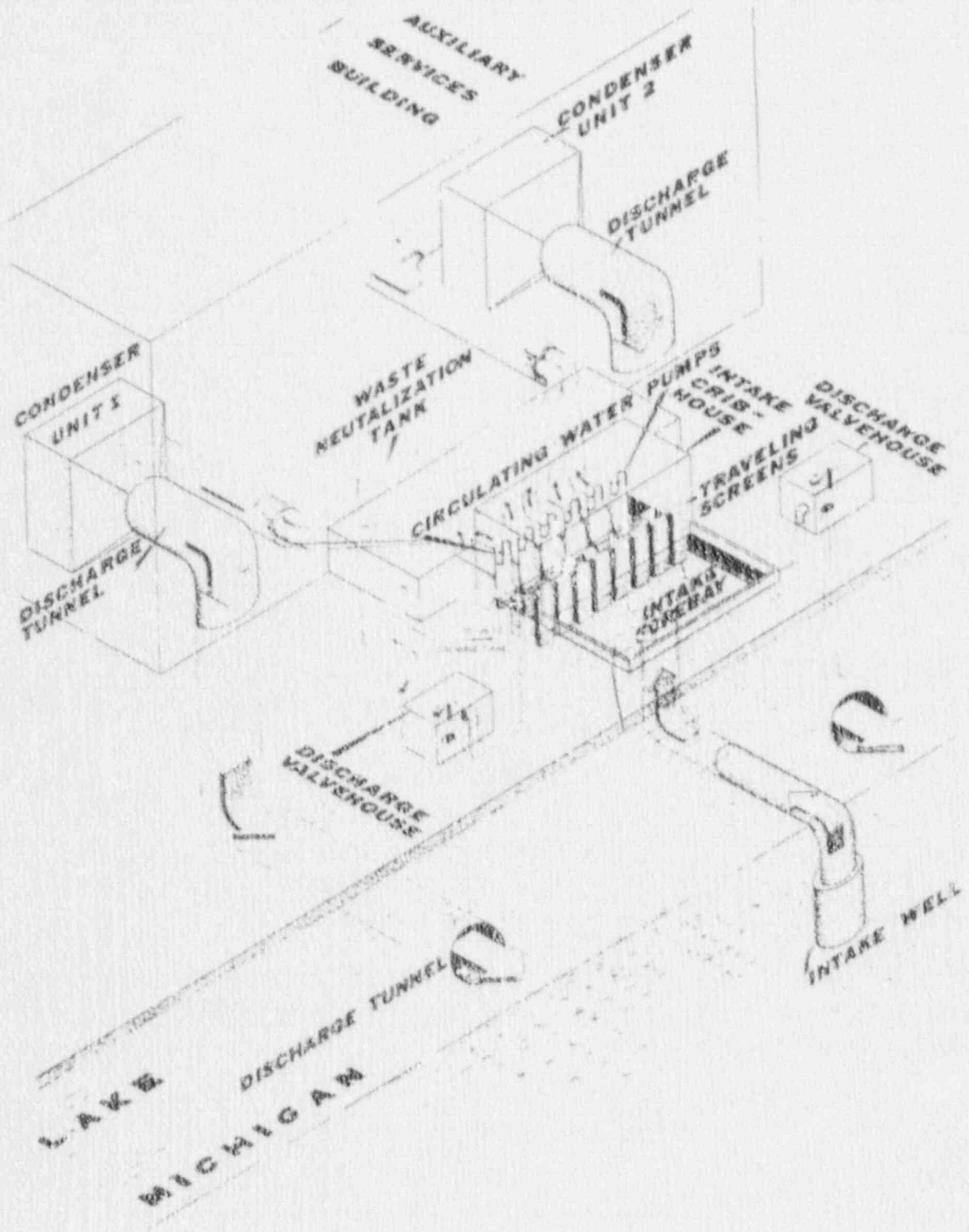


Figure 1. Schematic of Station water use.

Table 1. Zion Station [illegible] system.

Structure	Dimensions	Description	Capacity (gallons)	Average Flow Rate ft/sec
Intake Structure	30 x 104 ft dia	Concrete and Steel Pan	1.9×10^6	0.9
Intake Pipe	16 x 2600 ft	Steel Pipe (3)	3.9×10^6	8.7
Intake Forebay	N.A.	Concrete Box	5×10^6	1-2
Condenser Feed Line	12 ft dia	Steel Pipe (2)	N.A.	6
Condenser	54 ft long	Stainless Steel Tubing (2)	N.A.	8
Discharge Tunnel	16 x 16 x 324 ft	Square Concrete Tunnel (2)	6.2×10^5	N.A.
Offshore Discharge Line	14 x 760 ft	Steel Pipe (2)	8.8×10^5	N.A.
Discharge Structure	30 x 75 x 19 ft	Box (2)	3.2×10^5	8

Table 2. Zion Station monthly capacity factors

	1973		1974		1975		1976		1977		1978	
	U-1	U-2	U-1	U-2	U-1	U-2	U-1	U-2	U-1	U-2	U-1	U-2
Jan.	---	---	0	0.2	66.4	46.9	89.2	32.1	97.2	14.5	98.4	75.2
Feb.	---	---	0	10.6	51.8	33.6	97.5	45.6	92.9	0	98.0	6.2
[illegible]	---	---	0	21.1	8.1	51.1	12.9	99.8	74.9	4.2	95.4	0
April	---	---	20.0	5.4	72.0	52.2	0.0	1.1	70.0	78.1	91.5	36.5
May	---	---	41.9	0	57.4	77.1	0.0	64.0	70.9	94.3	72.3	96.8
June	---	---	54.3	0	0.0	12.6	10.2[a]	47.6[a]	60.7	86.5	92.4	94.8
Aug.	---	---	56.3	1.6	76.0	68.5	88.3	67.6	52.5	97.3	79.7	97.7
Sept	---	---	42.8	23.8	49.9	18.4	72.9	43.6	11.0	98.9	21.6	95.2
Oct.	---	---	68.3	23.5	76.0	68.4	26.9	3.5	0	93.6		
Nov.	52.0	---	61.1	64.1	76.4	70.4	87.1	92.8	0	92.5		
Dec.	5.1	---	78.0	30.4	71.7	66.4	88.5	72.6	73.9	83.0		

[a] Operating License was restricted to 85% of design thermal power prior to June 25, 1976.

[b] Unit 1 started operation.

51 months and has been out of service or operating at less than 1% capacity for 7 months. The greatest average monthly operating load for Unit 1 was 98.4% (January 1978). The greatest average monthly operating load for Unit 2 was 99.8% (March 1976). On 25 April 1978 Nuclear Regulatory Commission amended the Environmental Technical Specification which limited the discharge temperature to the station design maximum heat rejection and water usage capacity. The environmental monitoring program was extended for 3 months to provide data relating to these new plant operating conditions. Since the amendment, temperatures above 20°F ΔT have been infrequent and generally short. The longest period lasted 11 hours. The highest reported temperature was 29.5°F (NALCO, 1978 p. viii). Table 3 presents a summary of these temperatures.

Table 3. Summary of temperature occurrences above 20°F Δ T at Zion Station, 1 February - 30 September, 1978.

Date	Temperature ΔT (°F)	Duration of Occurrences (Minutes)	Cause of Occurrences	Power Output at Time of Occurrences	Power Reduction
3 May	20.5	5	Condenser Fouling	99%	1.1%
20 May	20.8	30	Condenser Fouling	100%	0%
20 May	20.8	660	Condenser Fouling	100%	0%
20 May	25.6	30	Circ. Water Pump Trip	100%	0%
21 May	24.8	35	Circ. Water Pump Trip	100%	0%
21 May	20.8	150	Condenser Fouling	100%	0%
6 July	21.6	15	Unknown	100%	N.A.[a]
2 August	29.5	240	Circ. Water Pump Outage (Wastewater Treatment Plant tied into System)	100%	N.A.
6 September	21.0	480	Unknown	100%	N.A.

[a] Data not available.

IV. References Cited

Hydrocon, Inc., and Pritchard-Carpenter, Consultants. 1974. The Distribution of Excess Temperature From the Zion Generating Station on Lake Michigan Fall Study Period (December 1973). Report to Commonwealth Edison Company, Chicago, Illinois. Reference 114.

Industrial BIO-TEST Laboratories, Inc. 1975. Operational Environmental Monitoring in Lake Michigan near Zion Station July 1974 through December 1974. Semi-annual Report Commonwealth Edison Company, Chicago, Illinois. V.I.

NALCO Environmental Sciences. 1978. Operational Environmental Monitoring in Lake Michigan near Zion Station July through September 1978. Supplemental Report to Commonwealth Edison Company, Chicago, Illinois.

Chapter 3

CURRENT MEASUREMENTS

by

William P. Skibbe

SUMMARY REPORT OF ENVIRONMENTAL MONITORING
IN LAKE MICHIGAN NEAR ZION STATION

January 1970 through September 1978

TABLE OF CONTENTS

		Page
	List of Figures	45
	List of Tables	47
I.	Introduction	49
II.	Materials and Methods	51
III.	Results and Discussion	57
IV.	References Cited	75

LIST OF FIGURES

No.	Caption	Page
1	ENDECO Type 105 current meter.....	52
2	Current meter locations used by Hydrocon, Inc., in southwestern Lake Michigan near Zion, Illinois, December 1972 through January 1974...	53
3	Current meter mooring configuration used by Hydrocon, Inc., in southwestern Lake Michigan near Zion, Illinois, December 1972 through January 1974.....	54
4	Current meter locations used by Hazleton Environmental Sciences, in southwestern Lake Michigan near Zion, Illinois, August 1974 through June 1978.....	55

LIST OF TABLES

No.	Title	Page
1	Comparison of water displacement among current meter stations at Zion Station, August 1974 through June 1975	58
2	Comparison of water displacement among current meter stations at Zion Station, July 1975 through June 1976	62
3	Comparison of water displacement among current meter stations at Zion Station, July 1976 through June 1977	66
4	Comparison of water displacement among current meter stations at Zion Station, July 1977 through June 1978	70

I. Introduction

The purpose of monitoring currents in the vicinity of Zion Station was two-fold. Initially, currents in Lake Michigan and wind speed and direction in the vicinity of the Station were monitored continuously to determine ambient conditions. This work was performed by Hydrocon, Inc., Baltimore, Maryland between December 1972 and January 1974 (Hydrocon, 1975). Hydrocon correlated the ambient current and wind data and developed two current circulation models.

The second phase of current monitoring started in July 1974 when Hazleton Environmental Sciences (HES) began monitoring the current structure of Lake Michigan in the vicinity of Zion Station (NALCO Environmental Sciences 1975, 1976, 1977 and 1978). The HES monitoring program was designed to monitor lake current prior to and concurrent with biological sampling and to determine the net displacement, direction of net displacement and mean current speed for the 55-hour period prior to each monthly plankton sampling day and for the sampling day itself. The program was terminated in June 1978.

II. Methods and Materials

A. Current Measurements

Current speed and direction in the vicinity of Zion Station were monitored by Hydrocon and Hazleton Environmental Sciences using ENDECO Type 105 Current Meters. The ENDECO current meter, illustrated in Figure 1, is a ducted-impeller recording current meter designed for use in the nearshore zone. Analog data of current speed and direction were continuously recorded on 16 mm film at 30-minute intervals during the Hydrocon and HES studies.

The position of current meter moorings used in the vicinity of Zion Station during the Hydrocon study is shown in Figure 2. A single current meter was moored six feet below the surface at Locations A and B. Two current meters were moored at depths of six and fifteen feet at Locations C and D. The configuration of the mooring used at each location is shown in Figure 3.

Continuous current meter measurements were made each month by HES at three locations near Zion Station. A single current meter was moored at Locations LR, C and D at approximately six feet below the surface as shown in Figure 4. The current meters were installed approximately two days prior to biological sampling and removed after the completion of the monthly sampling activities. Hence, current speeds and directions averaged over every thirty minutes during the sampling period (an average of 14 days per month) were determined prior to and concurrent with biological sampling.

Time series data for hourly vector averages of current speed and direction were used to construct plots of speed and

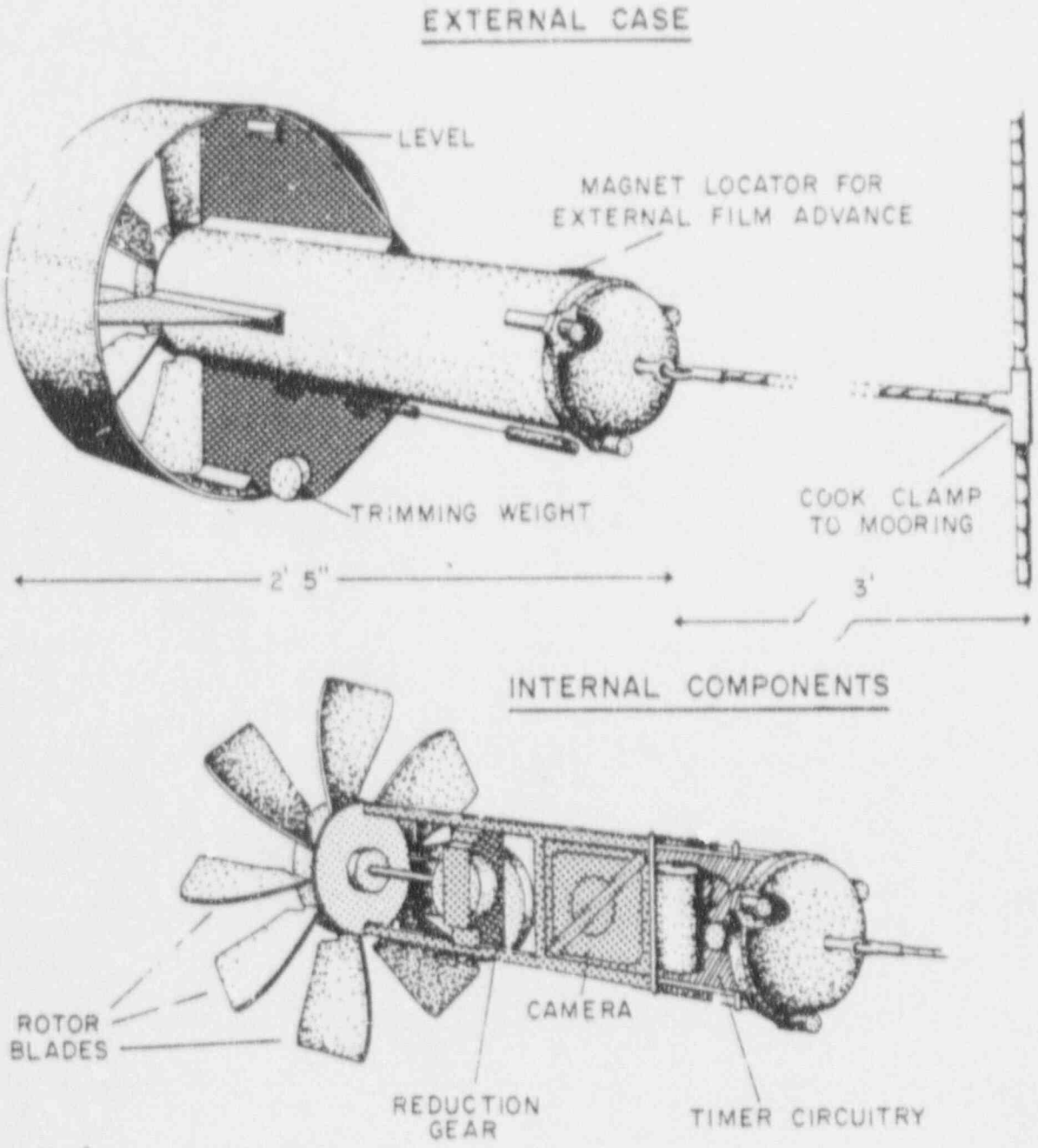


Figure 1. ENDECO type 105 current meter.

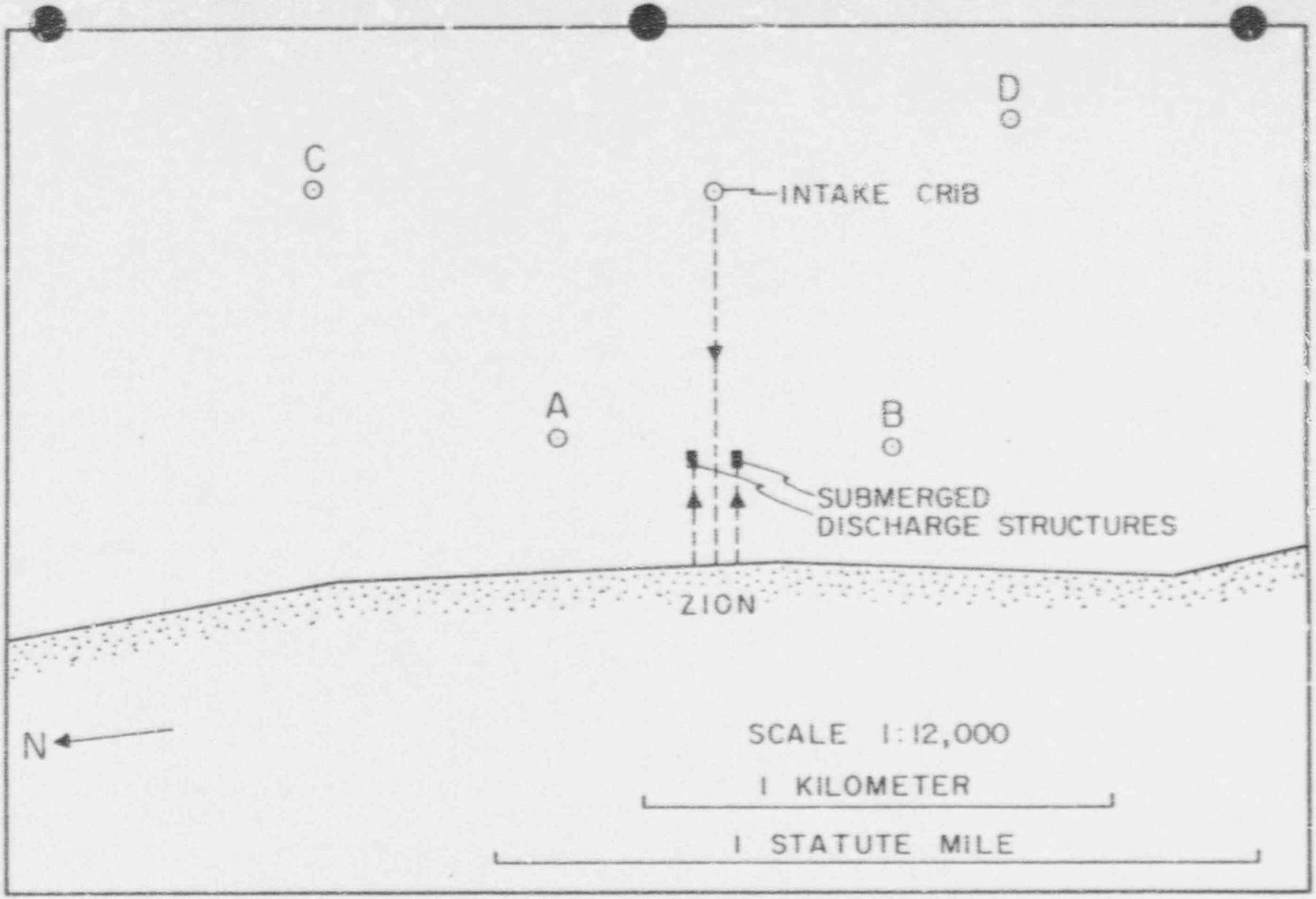


Figure 2. Current meter locations, used by Hydrocon, Inc., in southwestern Lake Michigan near Zion, Illinois, December 1972 through January 1974 (Hydrocon, 1975).

HAZLETON ENVIRONMENTAL SCIENCES

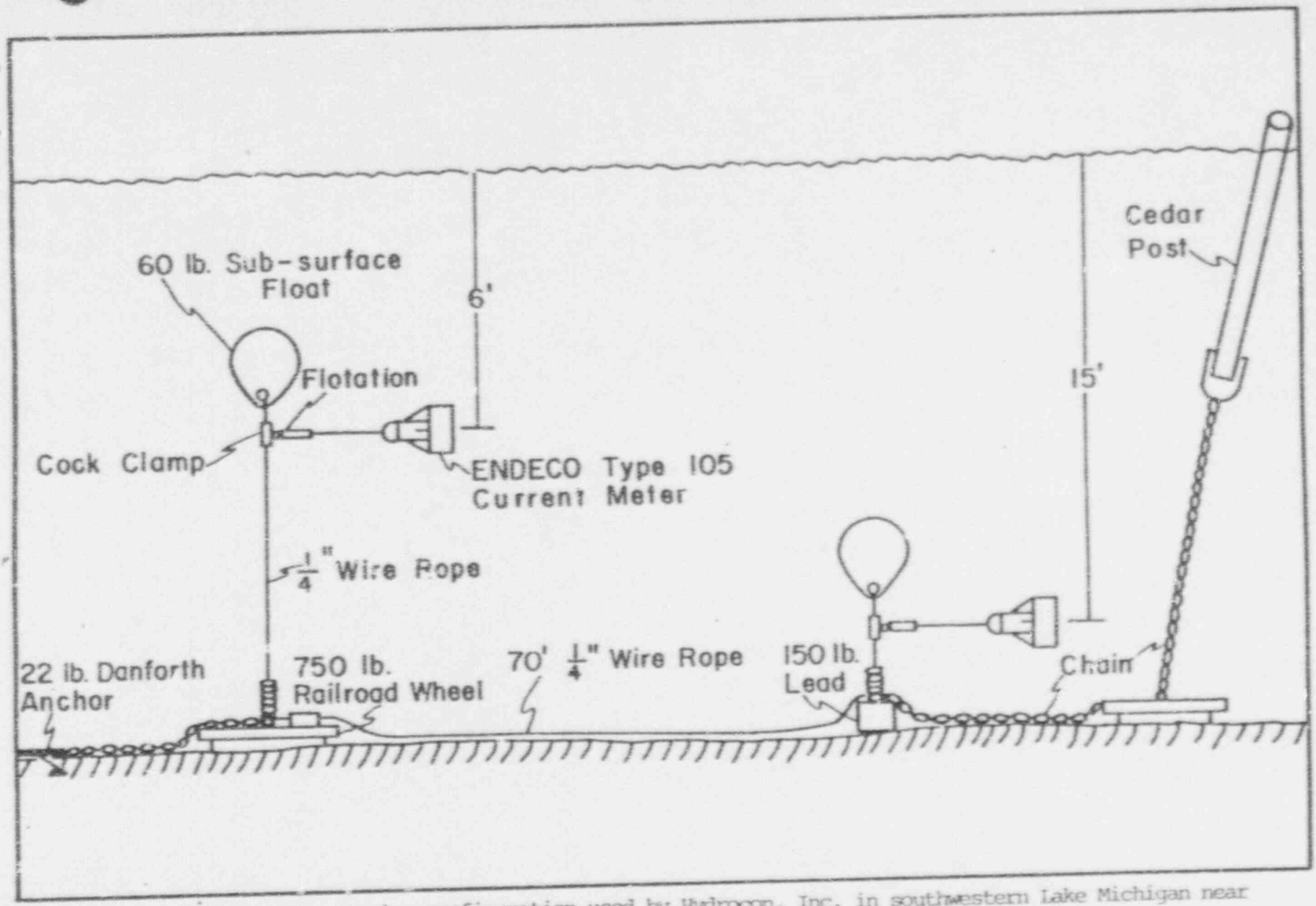


Figure 3. Current meter mooring configuration used by Hydrocon, Inc. in southwestern Lake Michigan near Zion, Illinois, December 1972 through January 1974 (Hydrocon, Inc. 1975).

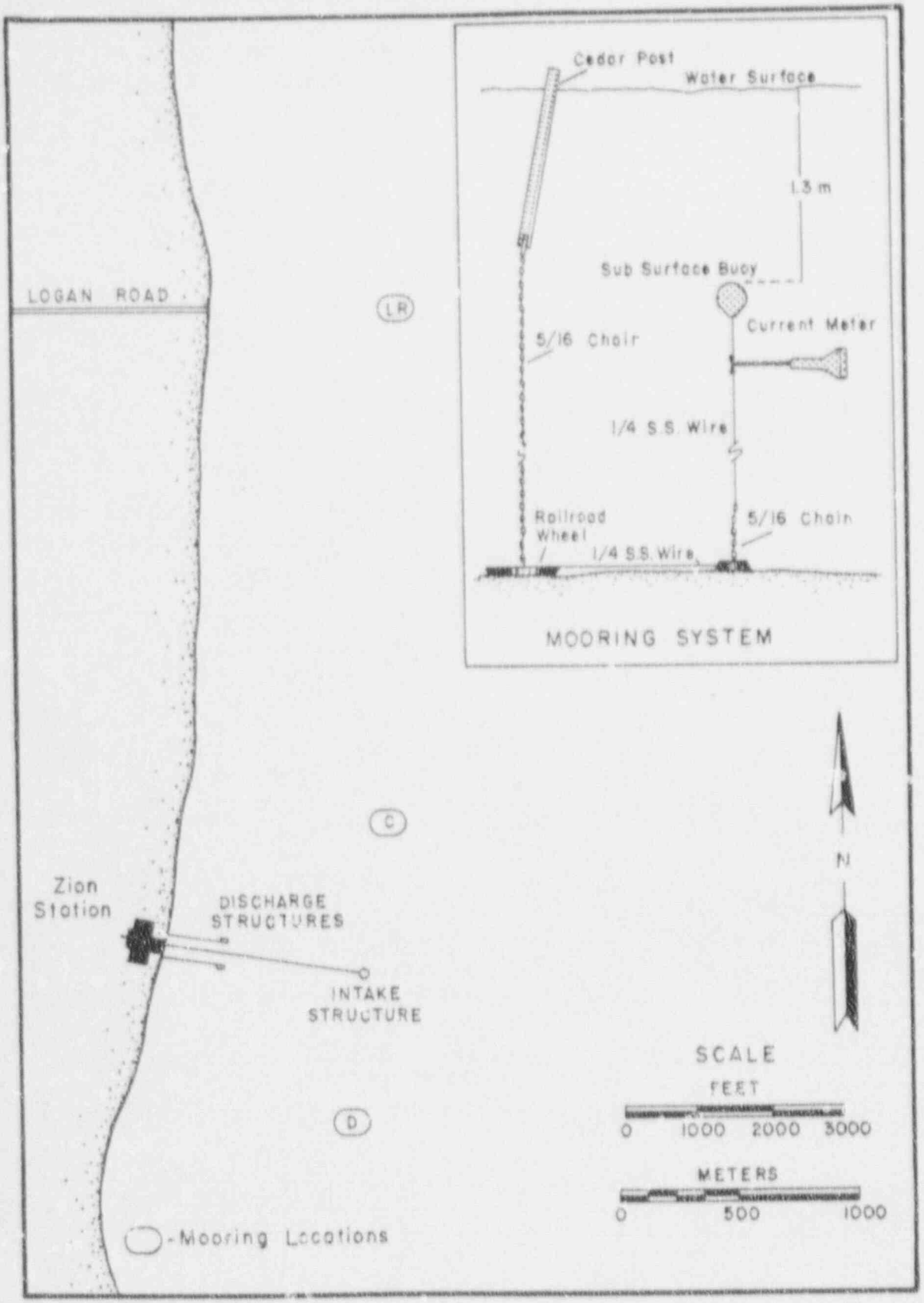


Figure 4. Current meter locations in southwestern Lake Michigan near Zion, Illinois, August 1974 through June 1978.

direction versus time and progressive vector diagrams (PROVECS). PROVEC's were formed by connecting the time series of current vectors from a current meter record to produce diagram that depicts the motion of a water particle past a single point. Net water displacement, direction of displacement and average speed were determined for a period (approximately 55 hours) prior to plankton sampling and for the day when sampling took place (0800-2400 hours).

B. Wind Measurements

The wind measurement program at Zion Station was performed by Hydrocon, Inc. Wind speed and direction were measured at elevations of 35, 125 and 250 feet above the ground. Belfort Type L transmittters located on platforms at the above elevations transmitted wind speed and direction to Belfort Type M recorders. Wind measurements made at the 35-foot elevation were used in correlating with the currents.

The current and wind data collected by Hydrocon, Inc. were statistically analyzed to determine the correlation between (1) the alongshore components of wind and current at a depth of six feet, (2) offshore components of wind and current at a depth of six feet, (3) alongshore component of current at a depth of six feet with the alongshore and offshore components of wind, (4) offshore component of current at a depth of six feet with the alongshore and offshore components of wind and (5) currents at depths of six and fifteen feet with each other.

II. Results and Discussion

A. Current Measurements

Results of the multiple correlation of currents and winds by Hydrocon, Inc. showed that the current circulation in Lake Michigan near Zion Station was best described by two models. Hydrocon, Inc. recommended that between late fall and early spring, when Lake Michigan is unstratified with respect to temperature, that the following model be applied:

$$\langle u(t)\rangle_5 = 3.48 \times 10^{-2} \quad \langle U(t-3)\rangle_5$$

where: t is the time in hours
u is the alongshore component of current,
U is the alongshore component of wind,
$\langle\ \rangle_t$ is the running average over time t in hours.

When Lake Michigan is stratified, between late spring and early fall, Hydrocon, Inc. recommended that the following model be used:

$$\langle u(t)\rangle_5 = 4.60 \times 10^{-2} \langle U(t-3)\rangle_{144} + 3.82 \times 10^{-2} \quad \delta U(t-3)$$

where

$$\delta U(t-3) = \langle U(t-3)\rangle_5 - \langle U(t-3)\rangle_{144}$$

Hydrocon's analysis of current meter records from Station C at a depth of six feet showed that for the period between 19 December 1972 and 11 January 1974 the currents were generally towards the north. The current velocity ranged from 0 to more than 1 ft/sec; the average was 0.3 to 0.4 ft/sec (Hydrocon 1975).

A comparison of the water displacement, determined by Hazleton Environmental Sciences, at current meter Locations LR, C and D from August 1974 to June 1978 is shown in Tables 1 through 4 (NALCO 1975, 1976, 1977, 1978). The net displacement, the

Table 1. Comparison of water displacement among current meter stations at Zion Station, August 1974 through June 1975.

Station	Time	Net Displacement (feet)	Direction of Net Displacement (° True)	Mean Speed (ft/sec)
LR	Aug. 3 0100	a	a	a
C	to	b	b	0.48
D	Aug. 5 0800	43,480	32	0.50
LR	Aug. 5 0800	a	a	a
C	to	b	b	0.27
D	Aug. 5 2400	18,870	175	0.36
LR	Sept. 1 0100	36,700	163	0.39
C	to	39,627	200	0.36
D	Sept. 3 0800	52,535	187	0.47
LR	Sept. 3 0800	25,700	159	0.44
C	to	32,086	171	0.54
D	Sept. 3 2400	31,391	173	0.56
LR	Oct. 6 0100	b	b	0.42
C	to	54,750	10	0.43
D	Oct. 8 0800	40,110	67	0.28
LR	Oct. 8 0800	b	b	0.44
C	to	33,830	359	0.64
D	Oct. 8 2400	30,570	14	0.53
LR	Nov. 2 0100	35,600	167	0.20
C	to	c	c	c
D	Nov. 4 0800	a	a	a

HAZLETON ENVIRONMENTAL SCIENCES

Table 1. (continued).

Station	Time		Net Displacement (feet)	Direction of Net Displacement (° True)	Mean Speed (ft/sec)
LR	Nov. 4	0800	19,750	164	0.34
C	to		c	c	c
D	Nov. 4	2400	a	a	a
LR	Dec. 1	0100	332,000	264	1.76
C	to		321,600	314	1.66
D	Dec. 3	0800	d	14	d
LR	Jan. 6	0100	18,560	17	0.26
C	to		25,030	335	0.36
D	Jan. 7	0800	27,280	14	0.38
LR	Jan. 7	0800	15,360	19	0.28
C	to		18,060	325	0.37
D	Jan 7	2400	14,370	14	0.30
LR	Feb. 9	0100	51,440	8	0.30
C	to		68,000	314	0.37
D	Feb. 11	0800	50,800	20	0.35
LR	Feb. 11	0800	908	174	0.10
C	to		8,450	268	0.19
D	Feb. 11	2400	17,500	136	0.37
LR	Mar. 4	0100	22,400	317	0.32
C	to		86,600	55	0.61
D	Mar. 6	0800	76,300	29	0.38

Table 1. (continued).

Station	Time		Net Displacement (feet)	Direction of Net Displacement (° True)	Mean Speed (ft/sec)
LR	Mar. 6	0800	15,500	312	0.32
C	to		48,600	54	0.92
D	Mar. 6	2400	16,600	30	0.30
LR	Apr. 12	0100	7,330	338	0.12
C	to		11,000	197	0.11
D	Apr. 14	0800	10,300	120	0.05
LR	Apr. 14	0800	12,000	171	0.24
C	to		11,200	148	0.21
D	Apr. 14	2400	e	e	0.09
LR	May 3	0100	24,600	37	0.28
C	to		50,200	140	0.32
D	May 5	0800	21,100	249	0.14
LR	May 5	0800	2,300	126	0.43
C	to		12,100	162	0.46
D	May 5	2400	17,700	260	0.34
LR	May 31	0100	26,420	275	0.14
C	to		38,914	40	0.31
D	June 2	0800	17,646	350	0.23

Table 1. (continued).

Station	Time	Net Displacement (feet)	Direction of Net Displacement (° True)	Mean Speed (ft/sec)
LR	June 2 0900	16,100	327	0.27
C	to	24,500	19	0.42
D	June 2 2400	21,900	6	0.37

[a]Data lost due to jammed film cartridge.
[b]No valid direction data due to stuck compass.
[c]Data lost in film processing.
[d]Incomplete valid data due to loss of buoy.
[e]Currents were less than threshold of meter.

HAZLETON ENVIRONMENTAL SCIENCES

Table 2. Comparison of water displacement among current meter stations at Zion Station, July 1975 through June 1976.

Station	Time			Net Displacement (feet)	Direction of Net Displacement (° True)	Mean Speed (ft/sec)
LR	July	7	0030	70480	353	0.42
C		to		a	a	a
D	July	8	0800	66770	10	0.39
LR	July	8	0800	18740	185	0.41
C		to		a	a	a
D	July	8	2400	24230	270	0.44
LR	Aug.	2	0030	59840	347	0.38
C		to		76780	11	0.46
D	Aug.	4	0800	55180	39	0.47
LR	Aug.	4	0800	23740	341	0.44
C		to		26000	8	0.49
D	Aug.	4	2400	37500	159	0.41
LR	Sept.	1	0030	42140	32	0.42
C		to		46190	197	0.36
D	Sept.	3	0800	b	b	b
LR	Sept.	3	0800	17320	295	0.32
C		to		3867	223	0.23
D	Sept.	3	2400	b	b	b
LR	Oct.	4	0900	c	c	c
C		to		69060	15	0.50
D	Oct.	6	0800	57060	21	0.47
LR	Oct.	6	0900	c	c	c
C		to		25740	17	0.49
D	Oct.	6	2400	29110	9	0.55

Table 2. (continued)

Station	Time			Net Displacement (feet)	Direction of Net Displacement (° True)	Mean Speed (ft/sec)
LR	Nov.	1	1100	31980	34	0.30
C		to		23440	101	0.38
D	Nov.	3	0800	48910	150	0.42
LR	Nov.	3	0900	24170	326	0.45
C		to		26940	25	0.50
D	Nov.	3	2400	27300	21	0.50
LR	Dec.	1	0030	31050	341	0.36
C		to		33830	232	0.54
D	Dec.	2	0700	58210	13	0.54
LP	Dec.	2	0800	16950	57	0.28
C		to		17390	26	0.33
D	Dec.	2	2400	19530	181	0.39
LR	Jan.	12	0030	72270	285	0.48
C		to		57370	341	0.61
D	Jan.	14	0700	36920	20	0.61
LR	Jan.	14	0800	8383	264	0.17
C		to		17050	47	0.42
D	Jan.	14	2400	6343	45	0.19
LR	Feb.	7	0100	19680	301	0.40
C		to		d	d	d
D	Feb.	9	0700	39440	327	0.46
LR	Feb.	9	0800	40080	331	0.70
C		to		d	d	d
D	Feb.	9	2400	29480	302	0.73

HAZLETON ENVIRONMENTAL SCIENCES

Table 2. (continued)

Station	Time			Net Displacement (feet)	Direction of Net Displacement (° True)	Mean Speed (ft/sec)
LR	March	1	0100	53910	251	0.92
C		to		d	d	d
D	March	3	0700	d	d	d
LR	March	3	0800	23800	169	0.42
C		to		d	d	d
D	March	3	2400	d	d	d
LR	Apr.	26	0100	73890	64	0.59
C		to		58740	182	0.66
D	Apr.	28	0700	e	e	e
LR	Apr.	28	0800	9151	52	0.16
C		to		12560	168	0.23
D	Apr.	28	2400	e	e	e
LR	May	11	0100	38520	343	0.35
C		to		23720	75	0.47
D	May	13	0700	21740	312	0.40
LR	May	13	0800	12810	29	0.30
C		to		29400	27	0.51
D	May	13	2400	24850	15	0.44
LR	June	15	0000	37950	2	0.27
C		to		113000	23	0.57
D	June	17	0700	82890	7	0.43

Table 2. (continued)

Station	Time			Net Displacement (feet)	Direction of Net Displacement (° True)	Mean Speed (ft/sec)
LR	June	17	0800	8376	328	0.16
C		to		36420	26	0.62
D	June	17	2400	27130	13	0.47

[a]Data lost due to jammed film cartridge.
[b]Data lost due to broken current meter.
[c]No current meter installed due to lost mooring.
[d]Data missing due to lost current meter.
[e]Data missing due to instrument malfunction.

HAZLETON ENVIRONMENTAL SCIENCES

Table 3. Comparison of water displacement among current meter stations at Zion Station, July 1975 through June 1977.

Station	Time		Net Displacement (feet)	Direction of Net Displacement (°True)	Mean Speed (ft/sec)
LR	June 29	0200	53080	325	0.31
C	to		53760	164	0.37
D	July 1	0800	50410	286	0.48
LR	July 1	0800	14150	255	0.24
C	to		23080	022	0.41
D	July 1	2400	10440	058	0.42
LR	Aug. 2	0200	47280	295	0.25
C	to		27680	105	0.43
D	Aug. 4	0800	57110	147	0.42
LR	Aug. 4	0800	21100	270	0.36
C	to		37400	045	0.64
D	Aug. 4	2400	28190	035	0.54
LR	Sep. 5	0200	76540	295	0.46
C	to		31950	075	0.61
D	Sep. 7	0800	30050	096	0.61
LR	Sep. 7	0800	28030	331	0.49
C	to		34980	348	0.80
D	Sep. 7	2400	46360	008	0.79
LR	Oct. 24	0200	106700	260	0.55
C	to		88620	159	0.48
D	Oct. 26	0800	75690	177	0.44
LR	Oct. 26	0800	44670	246	0.76
C	to		38890	156	0.56
D	Oct. 26	2400	33890	182	0.58

HAZLETON ENVIRONMENTAL SCIENCES

Table 3. (continued)

Station	Time	Net Displacement (feet)	Direction of Net Displacement (°True)	Mean Speed (ft/sec)
LR	Nov. 6 0200	a	a	a
C	to	49330	135	0.47
D	Nov. 8 0800	59470	155	0.48
LR	Nov. 5 0800	a	a	a
C	to	18120	300	0.46
D	Nov. 6 2400	15610	346	0.50
LR	Dec. 4 0200	b	b	b
C	to	30060	057	0.37
D	Dec. 6 0800	38590	075	0.44
LR	Dec. 6 0800	b	b	b
C	to	7330	022	0.42
D	Dec. 6 2400	9129	072	0.44
LR	Jan. 22 0200	37230	359	0.23
C	to	c	c	c
D	Jan. 24 0800	41940	015	0.29
LR	Jan. 24 0800	d	336	d
C	t	c	c	c
D	Jan. 24 2400	d	005	d
LR	Feb. 7 0200	19910	269	0.24
C	to	c	c	c
D	Feb. 9 0800	38680	026	0.34
LR	Feb. 9 0800	11860	246	0.22
C	to	c	c	c
D	Feb. 9 2400	14890	020	0.25

Table 3. (continued)

Station	Time			Net Displacement (feet)	Direction of Net Displacement (°True)	Mean Speed (ft/sec)
LR	Mar.	5	0200	13190	206	0.18
C		to		20950	183	0.25
D	Mar.	7	0800	31820	152	0.31
LR	Mar.	7	0800	6989	001	0.17
C		to		11210	337	0.25
D	Mar.	7	2400	1274	008	0.22
LR	Apr.	11	0200	79850	358	0.43
C		to		88290	356	0.67
D	Apr.	13	0800	48790	013	0.46
LR	Apr.	13	0800	11900	168	0.37
C		to		413	027	0.38
D	Apr.	13	2400	7631	158	0.36
LR	May	3	0200	31770	178	0.21
C		to		57920	317	0.33
D	May	5	0800	65910	195	0.37
LR	May	5	0800	13570	019	0.24
C		to		25630	348	0.44
D	May	5	2400	16700	057	0.38
LR	June	13	0200	90410	195	0.47
C		to		92080	173	0.49
D	June	15	0800	c	c	c

HAZLETON ENVIRONMENTAL SCIENCES

Table 3. (continued)

Station	Time		Net Displacement (feet)	Direction of Net Displacement (°True)	Mean Speed (ft/sec)
LR	June 13	0800	20770	194	0.36
C	to		19850	172	0.35
D	June 15	2400	c	c	c

a Data missing, no current meter installed due to lost mooring.
b Data missing due to lost current meter and temporary mooring.
c Data lost due to instrument failure.
d Data are not presented because the instruments apparently jammed with ice.

HAZLETON ENVIRONMENTAL SCIENCES

Table 4. Comparison of water displacement among current meter stations at Zion Station, July 1977 through June 1978.

Station	Time		Net Displacement (feet)	Direction of Net Displacement (° True)	Mean Speed (ft/sec)
LR	Jul. 9	0200	15060	357	0.43
C	to		49660	194	0.44
D	Jul. 11	0800	77520	177	0.49
LR	Jul. 11	0800	9337	52	0.17
C	to		13430	24	0.33
D	Jul. 11	2400	20700	77	0.42
LR	Jul. 30	1200[a]	43230	256	0.30
C	to		56730	35	0.39
D	Aug. 1	0800	36780	44	0.30
LR	Aug. 1	0800	b	b	b
C	to		22990	15	0.44
D	Aug. 1	2400	1299	147	0.22
LR	Sept. 10	0200	2171	271	0.28
C	to		21730	50	0.39
D	Sept. 12	0800	26930	314	0.29
LR	Sept. 12	0800	23430	354	0.40
C	to		24030	30	0.43
D	Sept. 12	2400	27140	8	0.47
LR	Oct. 8	0200	78130	291	0.52
C	to		79090	318	0.55
D	Oct. 10	0800	108700	347	0.62
LR	Oct. 10	0800	44560	75	0.74
C	to		21790	28	0.74
D	Oct. 10	2400	42950	348	0.72

HAZLETON ENVIRONMENTAL SCIENCES

Table 4. (continued).

Station	Time	Net Displacement (feet)	Direction of Net Displacement (° True)	Mean Speed (ft/sec)
LR	Nov. 12 0200	8524	122	0.53
C	to	63650	179	0.49
D	Nov. 14 0800	37040	242	0.62
LR	Nov. 14 0800	25270	205	0.48
C	to	10290	313	0.38
D	Nov. 14 2400	29240	342	0.51
LR	Dec. 17 0200	68520	358	0.36
C	to	79930	357	0.48
D	Dec. 19 0800	54690	19	0.47
LR	Dec. 19 0800	11420	10	0.20
C	to	22000	359	0.45
D	Dec. 19 2400	13040	48	0.31
LR	Jan. 21 0200	c	c	c
C	to	c	c	c
D	Jan. 23 0800	d	136	d
LR	Jan. 23 0800	c	c	c
C	to	c	c	c
D	Jan. 23 2400	d	51	d
LR	February 0200	e	e	e
C	to	e	e	e
D	February 0800	e	e	e
LR	February 0800	e	e	e
C	to	e	e	e
D	February 2400	e	e	e

Table 4. (continued).

Station	Time	Net Displacement (feet)	Direction of Net Displacement (° True)	Mean Speed (ft/sec)
LR	March 0200	e	e	e
C	to	e	e	e
D	March 0800	e	e	e
LR	March 0800	e	e	e
C	to	e	e	e
D	March 2400	e	e	e
LR	Apr. 18 0200	21620	264	0.45
C	to	18220	222	0.32
D	Apr. 20 0800	28670	254	0.38
LR	Apr. 20 0800	53540	164	0.42
C	to	42330	189	0.72
D	Apr. 20 2400	47530	20	0.81
LR	May 7 0930[a]	42600	341	0.33
C	to	37160	342	0.31
D	May 9 0800	26710	23	0.36
LR	May 9 0800	4250	352	0.16
C	to	12850	345	0.27
D	May 9 2400	15710	5	0.30
LR	June 3 1000[a]	11730	274	0.15
C	to	17420	291	0.22
D	June 5 0800	20070	64	0.28

HAZLETON ENVIRONMENTAL SCIENCES

Table 4. (continued).

Station	Time	Net Displacement (feet)	Direction of Net Displacement (° True)	Mean Speed (ft/sec)
LR	Jun. 5 0800	12460	185	0.22
C	to	15700	176	0.29
D	Jun. 5 2400	8470	247	0.18

[a]Due to poor weather conditions current meters were not in-situ 55 hours prior to biological sampling.
[b]Data not presented due to instrument failure.
[c]Data missing, instrument lost due to severe weather and ice conditions
[d]Data not presented due to instrument damage
[e]Data missing, current meters not installed because of severe weather and ice conditions.

HAZLETON ENVIRONMENTAL SCIENCES

direction of net displacement, and the mean current have been computed for the the 55-hour period previous to each monthly plankton sampling day and for the sampling day itself (0800 hours to 2400 hours). On the sampling days the mean speed at each location was generally between 0.16 ft/sec and 0.80 ft/sec. The maximum mean speed of 1.76 ft/sec was recorded in December 1974. Current speeds were generally between 0.0 ft/sec and 1.5 ft/sec from August 1974 to June 1978. The maximum speed recorded during the entire study period was 3.3 ft/sec in April 1976.

The current records indicate that the general direction of flow was relatively stable at each location during the monthly biological sampling periods. While the current direction was not the same from month to month, it was generally either northerly or southerly, consistent with the north-south orientation of the local shoreline. The minimum net displacement during a biological sampling day was 413 ft on 13 April 1977 at location C. The maximum net displacement was 53540 ft on 20 April 1978 at location LR. The average net displacement during the study was 20842 ft. Progressive vector plots and speed-direction plots of the results are presented in previous annual reports (NALCO Environmental Sciences 1975, 1976, 1977, and 1978).

V. References Cited

Hydrocon. 1975. Lake currents in the temperature zone of Lake Michigan near the Zion Nuclear Generating Station. A research report prepared for Commonwealth Edison Company, Chicago, Illinois, by Hydrocon, Inc., Baltimore, Maryland. Reference 119: 1-35.

NALCO Environmental Sciences. 1975. Current measurement study. IN Operational environmental monitoring in Lake Michigan Zion Station, July 1974 through June 1975. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. I: 1-270.

NALCO Environmental Sciences. 1976. Current measurement study. IN Operational environmental monitoring in Lake Michigan near Zion Station. July 1975 through June 1976. Annual report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol I: 1-410.

NALCO Environmental Sciences. 1977. Current measurement study. IN Operational environmental monitoring in Lake Michigan near Zion Station. July 1976 through June 1977. Annual report to Commonwealth Edison Company, Chicago, Illinois by NALCO Environmental Sciences. Vol. I: 1-373.

NALCO Environmental Sciences. 1978. Current measurement study. IN Operational environmental monitoring in Lake Michigan near Zion Station. July 1977 through June 1978. Annual report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. I: 1-328.

Chapter 4

THERMAL PLUME STUDIES

by

WILLIAM P. SKIBBE

SUMMARY REPORT OF ENVIRONMENTAL MONITORING
IN LAKE MICHIGAN NEAR ZION STATION

January 1970 through September 1978

TABLE OF CONTENTS

		Page
	List of Figures	81
	List of Tables	83
I.	Introduction	85
II	Methods and Materials	87
III.	Results and Discussion	93
IV.	References Cited	103

LIST OF FIGURES

No.	Caption	Page
1	Sampling locations used during adult fish studies overlayed on the 2°F ΔT isotherm at the surface compiled from thermal plumes surveyed in spring (dashed line) and summer and fall (solid line) in southwestern Lake Michigan near Zion Station.....	94
2	Sampling locations used during adult fish studies overlayed on the 2°F ΔT isotherm at the surface compiled from thermal plumes surveyed in winter in southwestern Lake Michigan near Zion Station.....	95
3	Sampling locations used during adult fish studies overlayed on the 2°F ΔT isotherm on the bottom compiled from thermal plumes surveyed in winter in southwestern Lake Michigan near Zion Station.....	96
4	Sampling locations used during egg and larvae studies overlayed on the 2°F ΔT isotherm at the surface compiled from thermal plumes surveyed in spring (dashed line) and summer and fall (solid line) in southwestern Lake Michigan near Zion Station.....	97
5	Sampling locations used during benthos studies overlayed on the 2°F ΔT isotherm on the bottom compiled from thermal plumes surveyed in winter in southwestern Lake Michigan near Zion Station.....	98
6	Sampling locations used during water quality studies overlayed on the 2°F ΔT isotherm at the surface compiled from thermal plumes surveyed in spring (dashed line) and summer and fall (solid line) in southwestern Lake Michigan near Zion Station.....	99
7	Sampling locations used during water quality studies overlayed on the 2°F ΔT isotherm at the surface compiled from thermal plumes surveyed in winter in southwestern Lake Michigan near Zion Station.....	100
8	Sampling locations used during water quality studies overlayed on the 2°F ΔT isotherm on the bottom compiled from thermal plumes surveyed in winter in southwestern Lake Michigan near Zion Station.....	101

LIST OF TABLES

No.	Title	Page
1	Average daily generation at Zion Station, Units 1 and 2.....	102

I. Introduction

Five thermal plume studies were conducted near Zion Station between 1973 and 1977 by Hydrocon, Inc., Baltimore, Maryland. The purpose of the studies was to define the three-dimensional structure of the thermal plumes resulting from heated water being discharged into Lake Michigan. In addition, the data were used to verify results of the predictive model developed by D.W. Pritchard.

The first plume study was conducted in December 1973 to determine the distribution of excess temperature in isothermal waters. The distribution of excess temperature in stratified waters was determined in July, 1974. A sinking plume study was conducted in February, 1975 and a thermal bar study was performed two months later in April 1975. The fifth plume study was conducted in late December 1976 and January 1977 to assess the size of the thermal plume when Units 1 and 2 were operating at full power. The results of the five plume studies are presented in detail in five Hydrocon, Inc. reports (Hydrocon, Inc., 1974, 1975a, 1975b, 1975c, 1977).

II. Methods and Materials

Because of the difficulty in separating excess temperature from ambient temperature, Hydrocon used a dye tracer technique to simulate the distribution of excess temperature resulting from the discharge of thermal effluent into Lake Michigan at the Zion Station. During each thermal plume study a 20% solution of Rhodamine WT dye was injected into the cooling water on the discharge side of selected circulating pumps.

Measurements of dye concentration and water temperature in Lake Michigan were made from two boats. During the thermal plume studies of December 1973, July 1974, April 1975 and December 1976 - January 1977 one boat sampled continuously near the surface while the other boat sampled vertically at discrete depths. Because the plume study conducted in February 1975 was designed to measure a sinking plume both boats sampled vertically.

Aboard the sampling vessels dye samples were pumped from the intake through a Turner Model 111 Fluorometer equipped with a flow-through door. One-half inch diameter clear polyethylene (Poly-Flo) tubing was used for all piping. Temperature was monitored continuously in a flow cell by a thermistor probe connected to an M&F Engineering Fluorescence-Temperature Indicator (FTI) specially designed and built for these studies. This instrument was interfaced with the fluorometer, a Motorola Mini-Ranger Navigation System, a Model 656 Anadex Printer and a Model 3400 Rustrak Dual Channel Recorder. The FTI also digitally displayed both fluorescence

and temperature. The printer was keyed by the Mini-Ranger to print fluorescence, fluorometer scale, alternate navigation channels, and temperature at a rate of 1 line per second. Temperature and fluorescence were recorded on the Rustrak Dual Channel Recorder for backup.

The following relationships between the dye concentrations and excess temperatures were taken from Hydrocon Report No. 114. (Hydrocon 1974). The temperature under heated conditions (plant operating) at any point x, y, z and time t if we neglect surface cooling is given by

$$T_h(x,y,z,t) = \frac{1 \cdot T_{h,o} + n_1 T_{n_1} + n_2 T_{n_2} + n_3 T_{n_3} \cdots N T_N}{1 + \sum_{i=1} n_i} \qquad (1)$$

where $T_{h,o}$ is the temperature of the cooling water at discharge and $1 + \sum_{i=1}^{i=N} n_i$ is the volume into which a unit volume of temperature $T_{h,o}$ is considered to be mixed. T_{n_i} are the temperatures of the various components that make up the mixture whose temperature is T_h.

Equation (1) may be rewritten as

$$T_h(x,y,z,t) = \frac{T_{h,o} + \bar{T}_n \sum_{i=1}^{i=N} n_i}{1 + \sum_{i=1}^{i=N} n_i} \qquad (2)$$

where

$$\bar{T}_n = \frac{1}{\sum_{i=1}^{i=N} n_i} \sum_{i=1}^{i=N} n_i \, T_{n_i} \qquad (3)$$

For any tracer injected into the same flow and at the same state of equilibrium we can write a similar relation, that is

$$C_d(x,y,z,t) = \frac{1 \cdot (C_d)_o}{1 + \sum_{i=1}^{i=N} n_i} \tag{4}$$

where now the contributions from the various species are zero since the background dye concentration of the receiving waters is negligible.

Combining (2) and (4) we have

$$T_h(x,y,z,t) - \bar{T}_n = (T_{h,o} - \bar{T}_n)\frac{C_d}{(C_d)_o} \tag{5}$$

From the foregoing point of view, $\bar{T}_n$ is an equivalent background or natural temperature of the receiving waters. Therefore

$$T_h(x,y,z,t) - \bar{T}_n = \theta = \theta_o\frac{C_d}{(C_d)_o} \tag{6}$$

which is the required scaling relation between dye concentration C_d and excess temperature θ. It remains, however, to determine θ_o and $\bar{T}_n$.

From equation (5) it may be seen that if we plot T_h versus $\frac{C_d}{(C_d)_o}$, then the temperature at which the regression of T_h on $\frac{C_d}{(C_d)_o}$ intercepts the line $\frac{C_d}{(C_d)_o} = 0$ is $\bar{T}_n$ and the intercept with the line $\frac{C_d}{(C_d)_o} = 1$ is $T_{h,o}$.

Dye concentrations, $\frac{C_d}{(C_d)_o}$, from both vertical stations and horizontal runs were then scaled to excess temperatures by equation

(6) and the concurrently measured temperature field converted to excess temperature by subtracting $\bar{T}_n$. The result is two separate realizations of the field of excess temperature, one based on measured dye concentrations and the other on the measured temperature field. The field of excess temperature based on the measured temperature field depends primarily on our estimation of $\bar{T}_n$, the T_h intercept, whereas the field of excess temperature based on dye tracer depends on $T_{h,o} - \bar{T}_n$ or the slope of our regression line. Consideration of the fact that our measured temperatures probably reach $\bar{T}_n$ sooner than the tracer concentrations reach zero due to surface cooling, leads to the conclusion that the method produces an estimate of $\bar{T}_n$ that is too low and of $T_{h,o} - \bar{T}_n$ that is too high. As a result both fields will be too large for a given isotherm or conservative. The field derived from the measured temperatures and $\bar{T}_n$ is probably the more nearly correct at low excess temperatures, however, since it includes, at least to the first order, the effect of surface cooling.

A word about θ_o. θ_o is not simple T_c, the temperature rise across the condensers, but is ΔT_c reduced by the temperature difference between ambient, $\bar{T}_n$, and intake, T_{intake}. That is,

$$\theta_o = T_c - (\bar{T}_n - T_{intake}).$$

With recirculation such that $T_{intake} > \bar{T}_n$, $\theta_o > \Delta T_c$. For a deep intake without recirculation, if $T_{intake} < \bar{T}_n$ then $\theta_o < \Delta T_c$. This may be seen more clearly by considering the following simple example. Assume, that $\Delta T_c = 3°F$, $T_{int} = 40°F$ and $\bar{T}_n = 43°F$. In

this event $\theta_o = \theta$ since the water discharged will be the same temperature as the receiving water. This, of course, presumes an infinite supply of diluting water for the discharged heat with no vertical mixing to the point of intake and may be a trivial example but does serve to illustrate the meaning of θ_o. It should be noted that in subsequent Hydrocon reports detailing the excess temperature distribution in Lake Michigan the ambient water temperature, $\bar{T}_n$, was determined as a function of position. It was assumed that the ambient temperature did not change significantly with time during the plume measurements.

During the first four plume studies ENDECO Type 105 current meters were installed in Lake Michigan by Hydrocon personnel. During the fifth plume study personnel from Hazleton (formerly NALCO) Environmental Sciences installed the current meters. The current meters were deployed in Lake Michigan to determine how ambient current in the vicinity of the Zion Station affected the position of the centerline of the thermal plume.

The areas of influence of the thermal plumes were determined by overlaying each plume of the same type and at the same scale and outlining the area enclosed by the 2°F ΔT isotherm.

III. Results and Discussion

During the years that Hydrocon conducted thermal plume studies Hazleton Envionmental Science did monthly chemical and biological monitoring in the vicinity of Zion Station. The areal extent of the thermal plumes measured during these studies has provided information used to evaluate the effects of station operation on chemical and biological sampling locations.

Diagrams of the maximum surveyed extent of the thermal plume at the surface during spring, summer and fall, winter, and on the bottom during winter are shown overlayed on the appropriate sampling location maps in Figures 1-8. Table 1 presents a summary of Station operating conditions during the 20 thermal plume surveys. As indicated in the figures the surface plume during the summer and fall would affect only those stations between the shore and the 8 m contour approximately 2 km north and south of the station. The spring surface plumes have a larger area of influence, extending as far as the 12 m contour and south to the Waukegan Generating Station. The winter surface plumes influence a similar size area, though their northerly extent is greater and they are more restricted to the south. The offshore extent in one case reached the 15 m contour.

The bottom winter plumes influenced the largest area, extending approximately 5 km both north and south of the station and as far offshore as the 18 m contour.

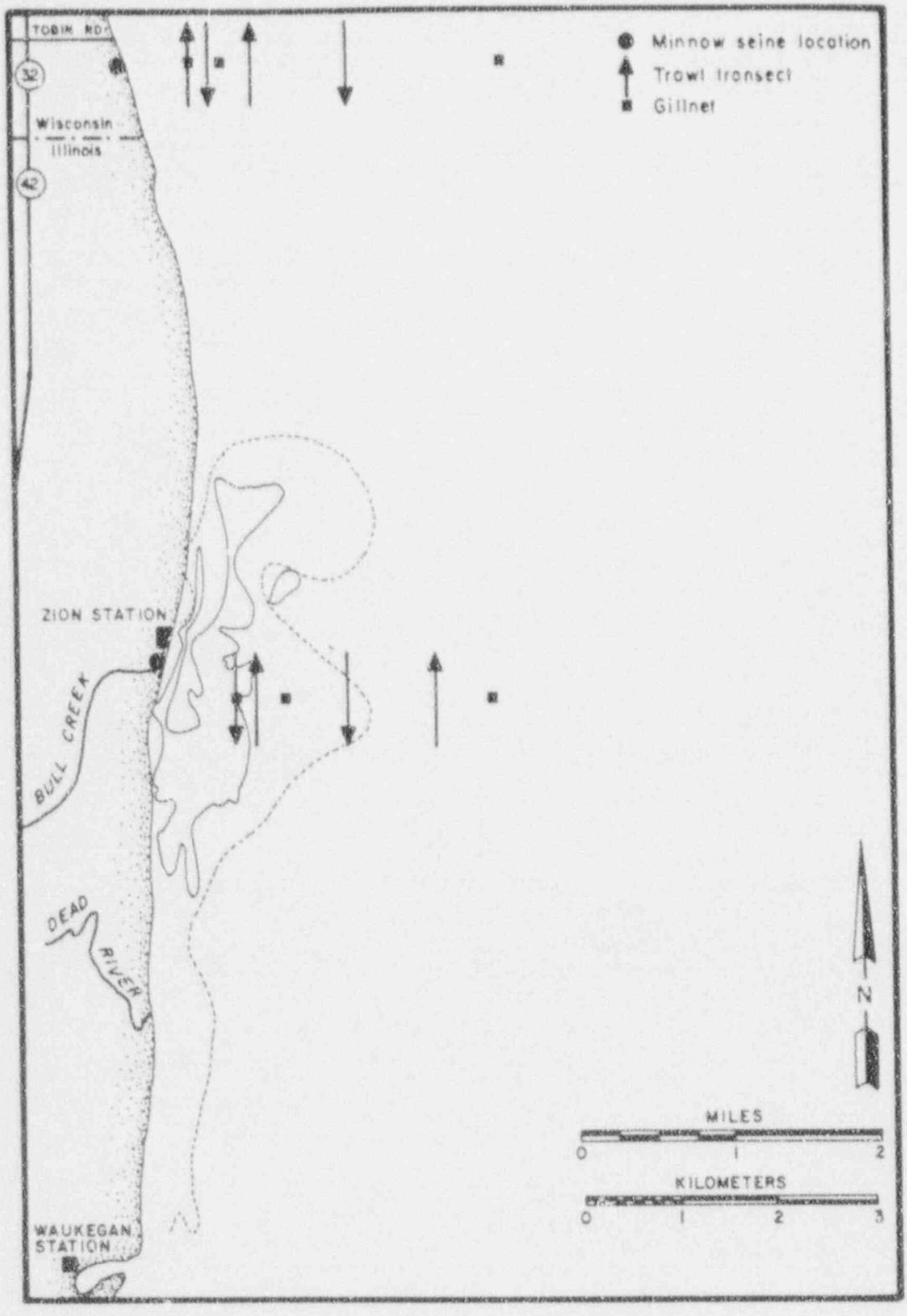


Figure 1. Sampling locations used during adult fish studies overlayed on the 2°F ΔT isotherm at the surface compiled from thermal plumes surveyed in the spring (dashed line) and summer and fall (solid line) in southwestern Lake Michigan near Zion Station.

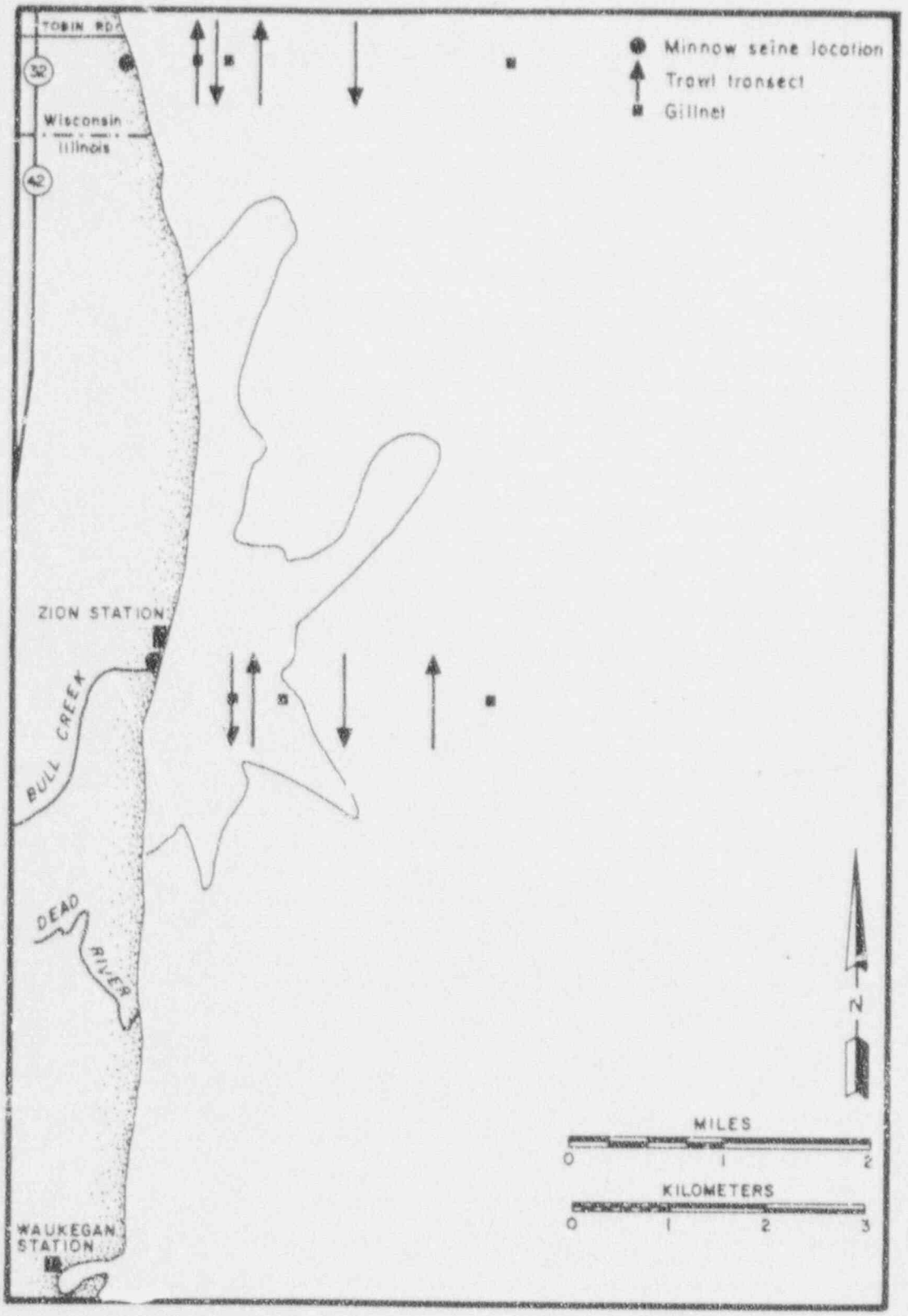


Figure 2. Sampling locations used during adult fish studies overlayed on the 2°F ΔT isotherm at the surface compiled from thermal plumes surveyed in winter in southwestern Lake Michigan near Zion Station.

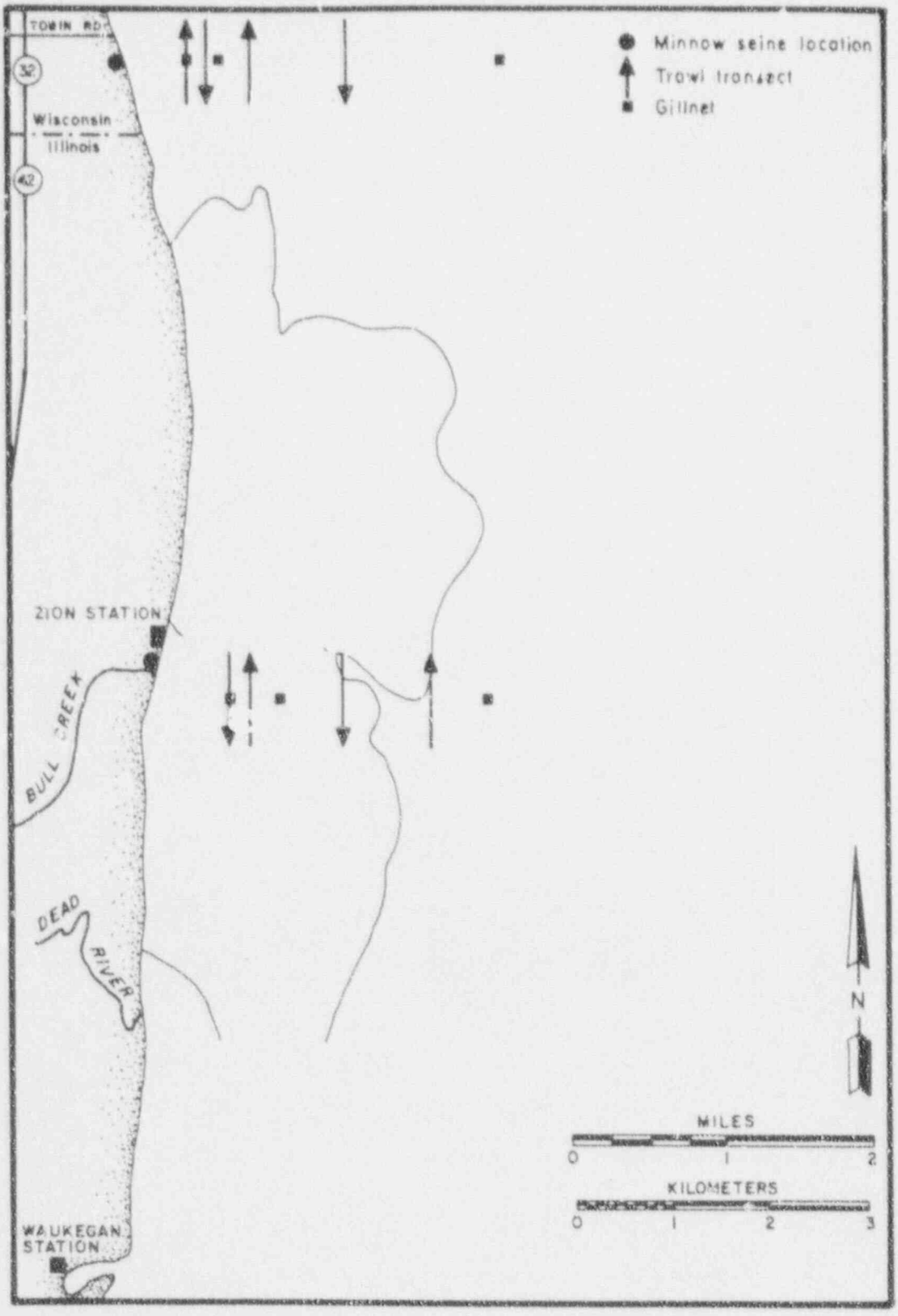


Figure 3. Sampling locations used during adult fish studies overlayed on the 2°F ΔT isotherm on the bottom compiled from thermal plumes surveyed in winter in southwestern Lake Michigan near Zion Station.

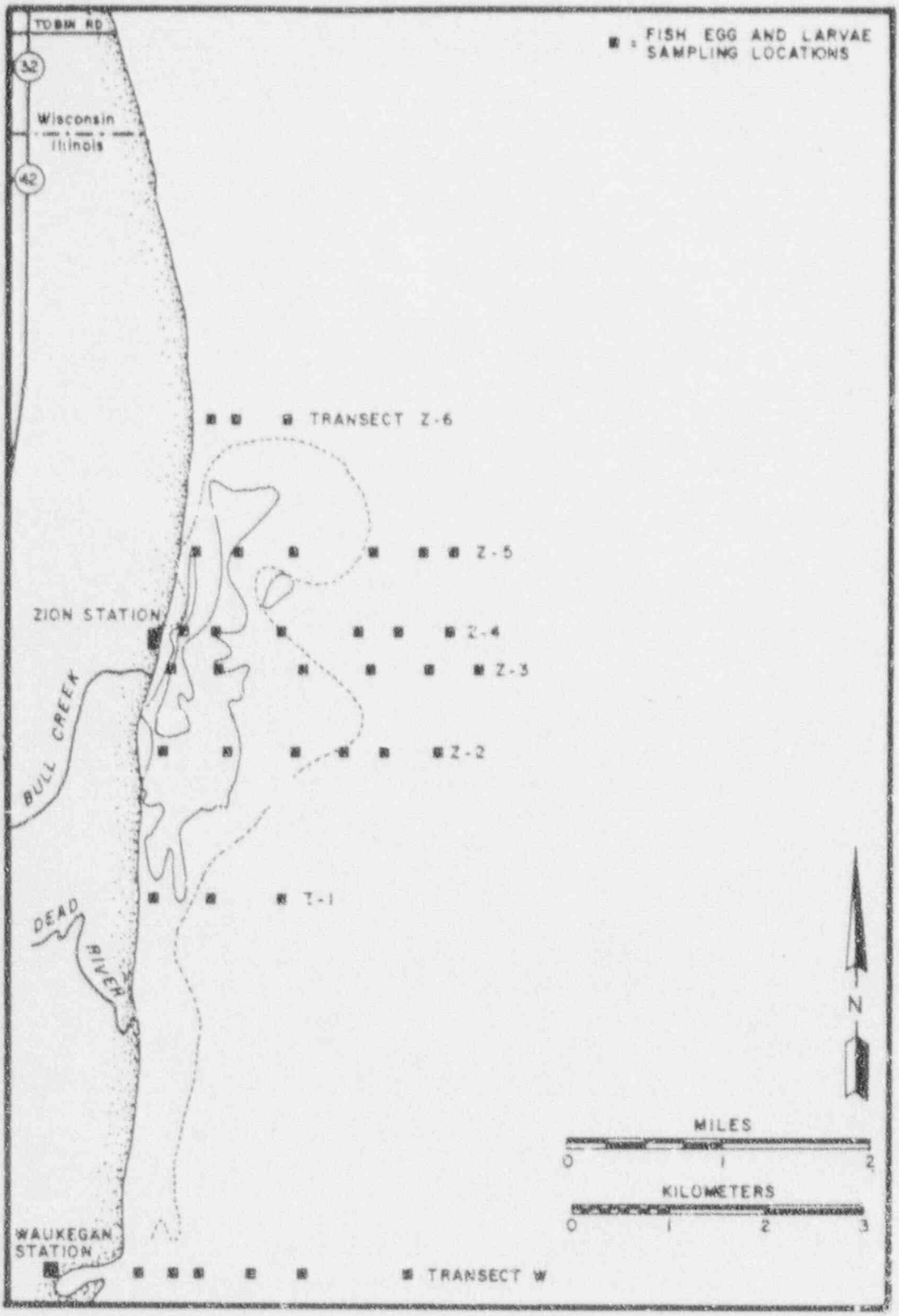


Figure 4. Sampling locations used during egg and larvae studies overlayed on the 2°F ΔT isotherm at the surface compiled from thermal plumes surveyed in spring (dashed line) and summer and fall (solid line) in southwestern Lake Michigan near Zion Station.

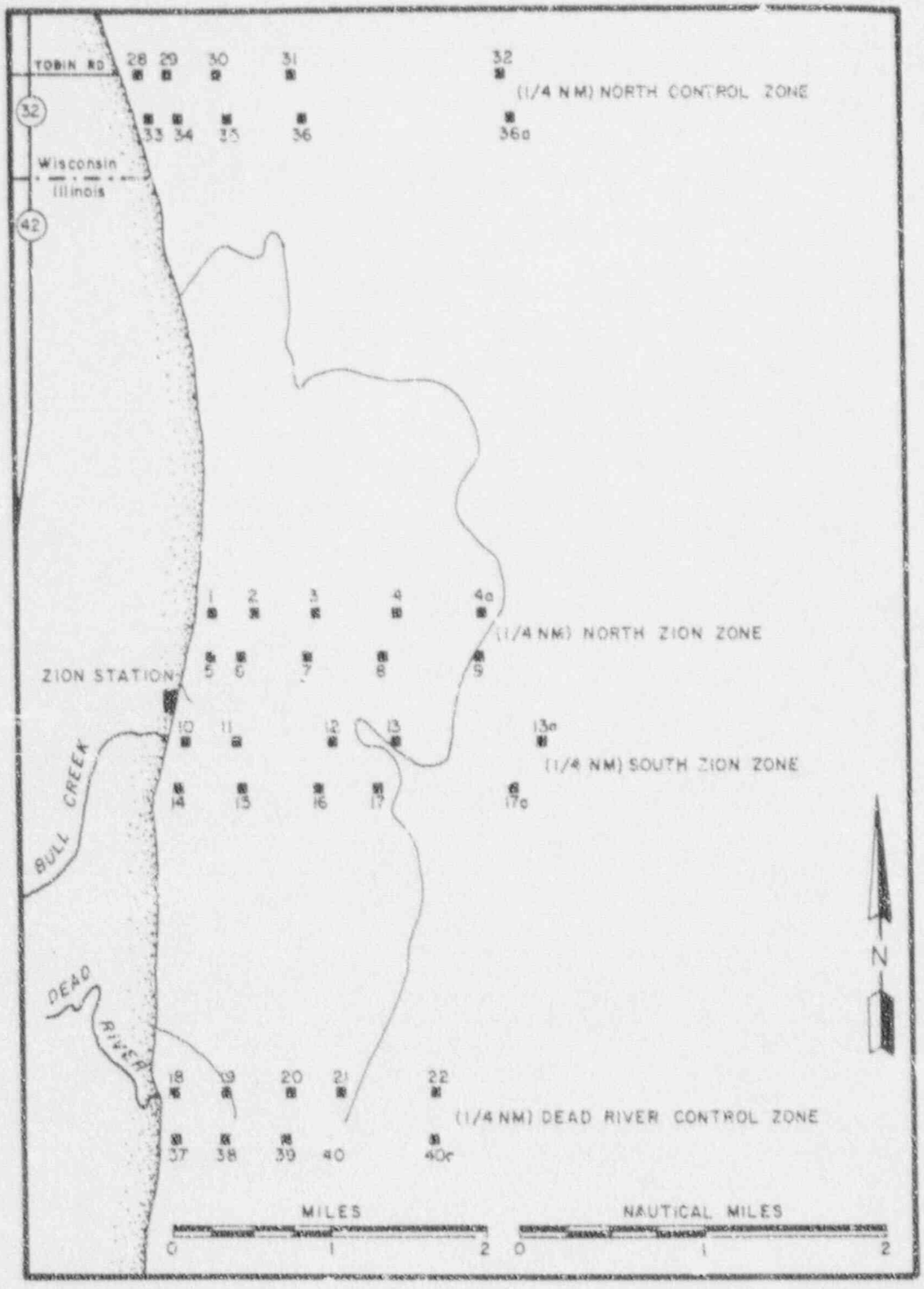


Figure 5. Sampling locations used during benthos studies overlayed on the 2°F ΔT isotherm on the bottom compiled from thermal plumes surveyed in winter in southwestern Lake Michigan near Zion Station.

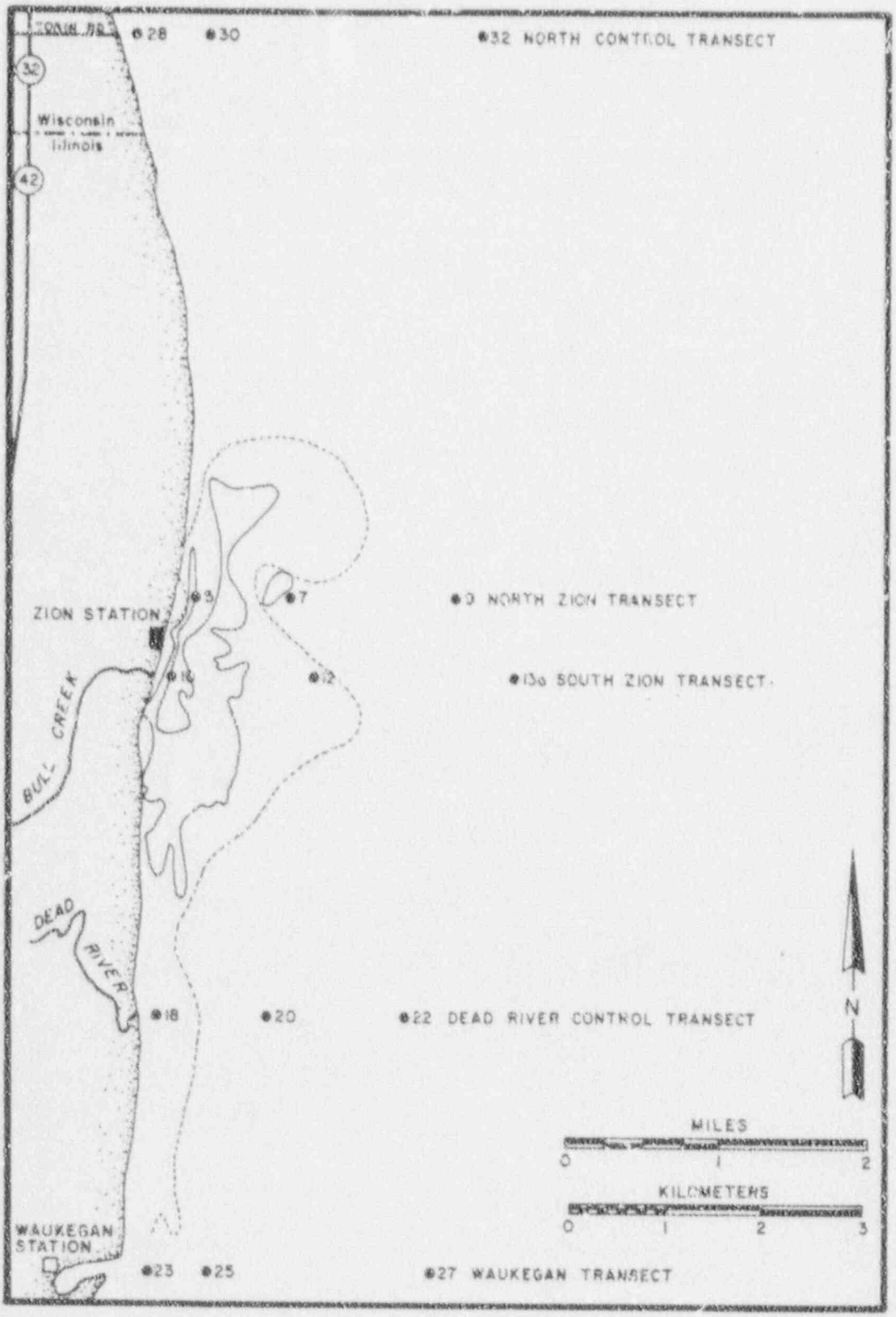


Figure 6. Sampling locations used during water quality studies overlayed on the 2°F ΔT isotherm at the surface compiled from thermal plumes surveyed in spring (dashed line) and summer and fall (solid line) in southwestern Lake Michigan near Zion Station.

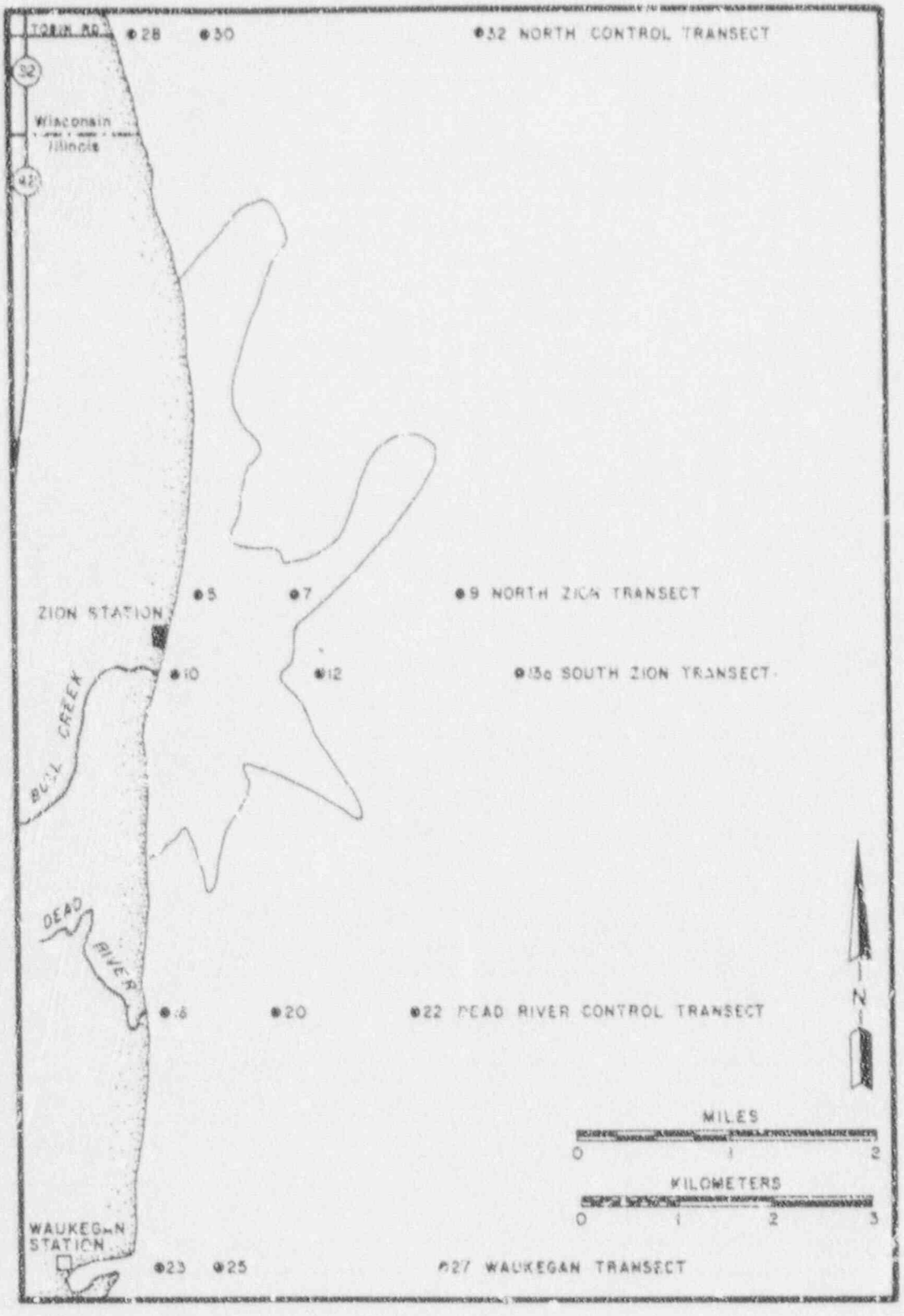


Figure 7. Sampling locations used during water quality studies overlayed on the 2°F ΔT isotherm at the surface compiled from thermal plumes surveyed in winter in southwestern Lake Michigan near Zion Station.

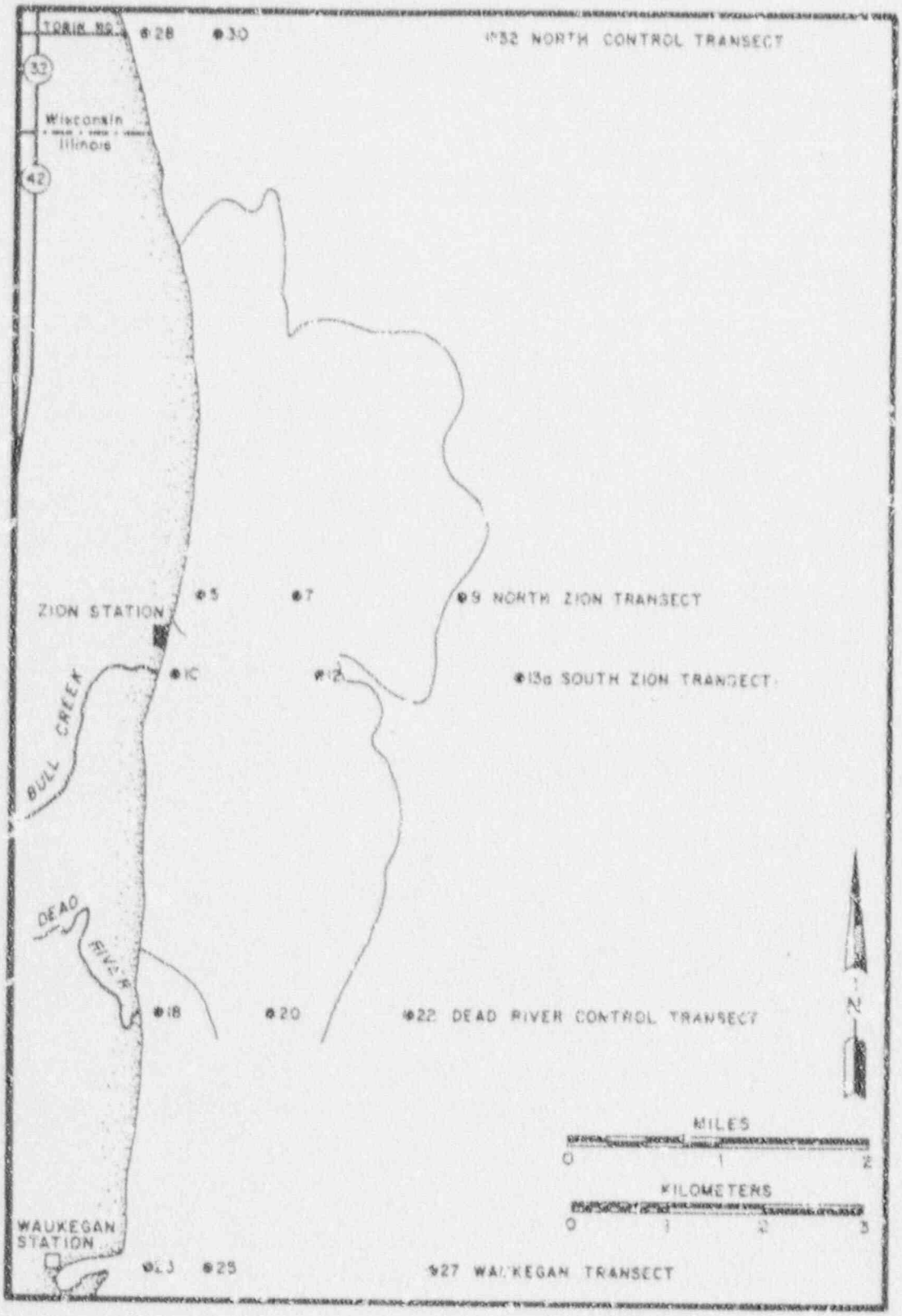


Figure 8. Sampling locations used during water quality studies overlayed on the 2°F ΔT isotherm on the bottom compiled from thermal plumes surveyed in winter in southwestern Lake Michigan near Zion Station.

Table 1. Average daily generation of Zion Station Units 1 and 2[a].

DATE	Unit 1 Gross Gen. (MWe)	Unit 1 % of RATED Output	Unit 2 Gross Gen. (MWe)	Unit 2 % of RATED Output	# of Plumes Surveyed
1 Dec 73	-[b]	52.9	*[c]	*	2
8 Dec 73	-	63.3	*	*	1
9 Dec 73	-	57.6	*	*	1
25 Jul 74	859.5	79.2	*	*	1
26 Jul 74	861.8	79.4	*	*	1
27 Jul 74	857.0	79.0	*	*	1
28 Jul 74	854.1	78.7	*	*	1
25 Feb 75	32.8	3	601.8	55	1
26 Feb 75	*	*	631.2	58	1
27 Feb 75	*	*	776.8	72	1
28 Feb 75	*	*	847.5	78	1
25 Apr 75	610.2	56	843.5	78	2
27 Apr 75	890.8	83	878.6	81	1
29 Apr 75[d]	893.8	82	855.9	79	1
29 Dec 76	1046.0	96	774.0	71	1
31 Dec 76	1048.0	97	753.0	69	1
2 Jan 77	1046.0	96	712.0	66	1
3 Jan 77	1055.0	97	711.0	66	1

[a]Data compliled from Hydrocon Report No.s, 114,118,121, and 125.
[b]No data due to equipment malfunction.
[c]Unit out of service.
[d]Temperature plume only - Excess temperatures were not determined.

IV. References Cited

Hydrocon Inc., and Pritchard - Carpenter, Consultants. 1974. The Distribution of Excess Temperature from the Zion Generating Station on Lake Michigan Fall Study Period (December 1973). Report to Commonwealth Edison Company, Chicago, Illinois. Reference 114.

_____. 1975. The Distribution of Excess Temperature from the Zion Generating Station on Lake Michigan Summer Study Period (July 1974). Report to Commonwealth Edison Company, Chicago, Illinois. Reference 118.

Hydrocon, Inc., 1975. The Distribution of Excess Temperature from the Zion Generating Station on Lake Michigan Winter (Sinking Plume) Study Period (February 1975). Report to Commonwealth Edison Company, Chicago, Illinois. Reference 120.

_____. 1975. The Distribution of Excess Temperature from the Zion Generating Station on Lake Michigan Spring (Thermal Bar) Study Period (April 1975). Report to Commonwealth Edison Company, Chicago, Illinois. Reference 121.

_____. 1977. The Distribution of Excess Temperature from the Zion Generating Station on Lake Michigan Winter (Sinking Plume) Study Period (December 1976/January 1977). Report to Commonwealth Edison Company, Chicago, Illinois. Reference 125.

Chapter 5

WATER QUALITY STUDIES

by

Gayle L. Shipley

SUMMARY REPORT OF ENVIRONMENTAL MONITORING
IN LAKE MICHIGAN NEAR ZION STATION

January 1970 through September 1978

TABLE OF CONTENTS

		Page
	List of Figures	109
	List of Tables	111
I.	Introduction	113
II.	Methods and Materials	115
	A. Study Area	115
	B. Field Procedures	115
	C. Analytical Procedures	121
	D. Data Handling Procedures	121
III.	Results and Discussion	123
	A. Zion Station Operating Conditions	123
	B. Water Temperature, Dissolved Oxygen and Light Penetration	123
	C. General Water Quality Constituents	125
	D. Aquatic Nutrients	129
IV.	References Cited	139

LIST OF FIGURES

No.	Caption	Page
1	Total alkalinity concentrations along the 9 meter depth contour in Lake Michigan, 1971 through 1978.....	126
2	Values of pH along the 9 meter depth contour in Lake Michigan, 1971 through 1978.....	127
3	Turbidity values along the 9 meter depth contour in Lake Michigan, 1971 through 1978.....	128
4	Nonfiltrable residue concentrations (total suspended solids) along the 9 meter depth contour in Lake Michigan, 1971 through 1978..	130
5	Filtrable residue concentrations (total dissolved solids) along the 9 meter depth contour in Lake Michigan, 1971 through 1978.....	131
6	Ammonia concentrations along the 9 meter depth contour in Lake Michigan, 1971 through 1978.....	132
7	Nitrate concentrations along the 9 meter depth contour in Lake Michigan, 1971 through 1978.....	133
8	Soluble orthophosphate concentrations along the 9 meter depth contour in Lake Michigan, 1971 through 1978.....	134
9	Total phosphorus concentrations along the 9 meter depth contour in Lake Michigan, 1971 through 1978.....	135
10	Soluble silica concentrations along the 9 meter depth contour in Lake Michigan, 1971 through 1978.....	137

LIST OF TABLES

No.	Title	Page
1	Summary of study designs for water quality monitoring in southwestern Lake Michigan near Zion, Illinois, 1970 through 1978.....	116
2	Water quality constituents measured in southwestern Lake Michigan near Zion, Illinois, 1971 through 1978.....	118

I. Introduction

Water quality studies have been conducted in southwestern Lake Michigan near the Zion Generating Station from February 1970 through September 1978. These monitoring studies encompassed the construction phase (prior to July 1973) and the operational phase (after the Zion Station began operation in July 1973). Numerous reports which presented data and discussions of short-term variations in water quality have been prepared (Sheehan et al. 1972a, 1972b; Huh et al. 1973; Briars 1974a, 1974b, 1974c; Ellis 1975, 1976, 1977, 1978; and Shipley 1979).

The main purpose of the presented work is to bring the findings from previous reports together into a single discussion. The specific objectives are:

1. to determine, by evaluating the concentrations of a number of constituents in or near areas influenced by the station's thermal discharge and also in reference areas, if the operation of Zion Station has had an effect on the chemical water quality of Lake Michigan; and

2. to assess natural variability in water quality over time, as well as spatially, giving special consideration to possible effects from Zion Station operation.

II. Methods and Materials

A. Study Area

Water quality data were collected from the locations listed in Table 1 (see also Appendix A, Figures A-1 through A-5). Beginning in April 1971, water quality monitoring locations were arrayed in a grid of up to five transects in Lake Michigan in the vicinity of Zion Generating Station. Each transect consisted of Locations at the 3, 9, and 18 meter depth contours. From January 1970 through April 1971, locations were sampled either very close to shore or at 30 to 50 meter depths, and they did not correspond to the sampling design instituted in 1971.

The North Zion Transect (Locations 5, 7 and 9) and the South Zion Transect (Locations 10, 12 and 13a) were within or near the predicted area of major thermal influence from Zion Station (Pritchard 1977). The Dead River Control Transect (Locations 18, 20, and 22) was approximately 2.5 mi south of Zion Station; the North Control Transect (Locations 28, 30, and 32) was situated approximately four miles north of Zion Station. From May 1971 through June 1974, an additional transect was included in the sampling program: the Waukegan Transect (Locations 23, 25 and 27) was located approximately four miles south of Zion Station near the Waukegan Generating Station.

B. Field Procedures

The depth of sampling, number of replicates, frequency of monitoring, sampling method, and number of parameters monitored are presented in Table 1. In general, duplicate water samples were

Table 1. Summary of study designs for water quality monitoring in southwestern Lake Michigan near Zion, Illinois, 1970 through 1978.

Date	Locations	Depths	Replicates	Frequency	Parameters	Sampling Method	References
Feb 1970	2(5F,6F)[a]	Surface, mid	1	Monthly	19	Lucite Kemmerer	Sheehan et al. 1972a
Mar 1970	4(3F,4F,7F,8F)[a]	Surface, mid, bottom	1	Monthly	23	Lucite Kemmerer	
Apr 1970	6(1,2,3,4,5,6)[a]	Surface, mid, bottom	1	Monthly	21	Lucite Kemmerer	
May-Jul 1970	3(1,3,5)[a]	Surface, mid, bottom	2	Twice per mo.	29	Lucite Kemmerer	
Aug 1970-Apr 1971	3(1,3,5)[a]	Surface, mid, bottom, above and below thermocline, if present	2	Monthly	36	Lucite Kemmerer	
Jan-Apr 1970	5(K,ZB,WI,WD,NC)[b]	One meter below surface or top	1	Bi-weekly	25	Lucite Kemmerer or tap	Sheehan et al. 1972b
May 1970-Apr 1971	5(K,ZB,WI,WD,NC)[b]	One meter below surface or top	3	Monthly	38	Lucite Kemmerer or tap	
May 1971-Mar 1972[c]	9(5,7,9,10,20,22,23,25,27)	1 meter below surface 1 meter above bottom	2 2	Monthly Monthly	12 2	Kemmerer	Hunt et al. 1973
Apr-Dec 1972[c]	15(5,7,9,10,12,13a,18,20,22,23,25,27,28,30,32)	1 meter below surface 1 meter above bottom Profiles	1 or 2 1 or 2 1	Monthly Monthly Monthly	66 13 1 or 2	5-1 Kemmerer or Van Dorn 24 1 Composite	Briarn 1974a
Jan-Jun 1973[c]	15(5,7,9,10,12,13a,18,20,22,23,25,27,28,30,32)	1 meter below surface Profiles	2 1	Monthly Monthly[d]	14 2	6-1 Kemmerer or Van Dorn 24 1 Composite	Briarn 1974b
Jul 1973-Jun 1974	15(5,7,9,10,12,13a,18,20,22,23,25,27,28,30,32)	1 meter below surface profiles	2 1	Monthly Monthly	14 2	6-1 Kemmerer or Van Dorn 24 1 Composite	Briarn 1974c
Jul 1974-Jun 1975 Jul 1975-Jun 1976 Jul 1976-Jun 1977 Jul 1977-Jun 1978	12(5,7,9,10,12,13a,18,20,22,28,30,32)	1 meter below surface Profiles Light penetration @ 1m	2 1 1	Monthly Monthly Monthly	13 2 1	6-1 Kemmerer or Van Dorn 24 1 Composite	Ellis 1975 Ellis 1976 Ellis 1977 Ellis 1978
Jul 1978-Sep 1978	12(5,7,9,10,12,13a,18,20,22,28,30,32)	1 meter below surface Profiles	2 1	Monthly Monthly	11 1	6-1 Kemmerer or Van Dorn 24 1 Composite	Shipley 1979

[a] Locations are from 30 to 50 m depth and do not correspond to locations sampled later.
[b] Locations are: Kenosha (K), Zion Beach (ZB), Waukegan Station Intake (WI), Waukegan Station Discharge (WD),and North Chicago (NC), and do not correspond to locations sampled later.
[c] Sediment samples also collected.
[d] From January to June 1973, profiles were also taken bi-monthly at other locations.

HAZLETON ENVIRONMENTAL SCIENCES

collected monthly at a sampling depth of one meter below the surface. Kemmerer or VanDorn samplers were always used. In addition, from April 1972 through September 1978 each sample consisted of 24 liters of water which were collected concurrently by multiple casts of a sampler and composited in a polyethylene carboy. Individual sample bottles were filled from the carboy, preserved as necessary, packed in ice and returned to the analytical laboratory.

The water quality constituents monitored between May 1971 and September 1978 are shown in Table 2. (Information for studies prior to May 1971 was not included in the summary table because locations sampled in the early work were not comparable to those in the sampling design initiated in 1971.) Thirteen constituents were monitored most frequently throughout the study period, and they have been selected for emphasis in the text of this report. In 1972, the study plan became more complex. Table A-8 in Appendix A provides further clarification of the study plan after 1972.

Vertical profiles of water temperature and dissolved oxygen concentrations were taken at one meter depth intervals monthly between May 1971 and September 1978, except when dissolved oxygen was not profiled at times in 1972 and from July through September 1978. Water temperatures were taken in situ with a Whitney thermistor-thermometer (Model TC-5) or a Hydrolab TDO-2 or Surveyor 6D. Dissolved oxygen concentrations were measured in situ with a Weston and Stack oxygen analyzer (Model A15), a Beckman oxygen analyzer (Model 39552) or one of the Hydrolab units described above.

Table 2. Water quality constituents measured in southwestern Lake Michigan near Zion, Illinois, 1971 through 1978.

Parameter	Study Period[a] MAY 71 to MAR 72	APR 72 to DEC 72	JAN 73 to JUN 74	JUL 74 to JUN 78	JUN 78 to SEPT 78
Alkalinity, total	M	M	M	M	M
Ammonia	M	M	M	M	M
Nitrate	M	M	M	M	M
Orthophosphate, soluble	M	M	M	M	M
Oxygen, dissolved	MP	M some P	MP	MP	
Oxygen, saturation	MP	M some P	MP	MP	
pH	M	M	M	M	M
Phosphorous, total	M	M	M	M	M
Residue, filtrable (total dissolved solids)		M	M	M	M
Residue, nonfiltrable (total suspended solids)		SA	M	M	M
Silica, soluble	M	M	M	M	M
Temperature	MP	MP	MP	MP	MP
Turbidity	M	M	M	M	M
Chlorine, total residual		M	M		
Aluminum		M			
Arsenic		SA			
Bacteria,					
total coliform	M	M			
fecal coliform	M	M			
fecal streptococcus	M	M			
standard plate count		SA			
Barium		SA			
Beryllium		SA			
Biochemical oxygen demand	M	M			
Boron		M			
Cadmium		M			
Calcium		M			
Cesium		SA			
Chemical oxygen demand		M			
Chloride		M			
Chromium, hexavalent		M			
Chormium, trivalent		M			
Cobalt		SA			

Table 2. (continued)

Parameter	Study Periods[a] MAY 71 to MAR 72	APR 72 to DEC 72	JAN 73 to JUN 74	JUL 74 to JUN 78	JUN 78 to SEPT 78
Color, true	M	M			
Conductance, specific	M	M			
Copper	M	M			
Cyanide		SA			
Fluoride		M			
Hardness, total		M			
Hexane soluble materials		SA			
Iron	M	M			
Lead		M			
Lithium		SA			
Magnesium	M	M			
Manganese	M	M			
Mercury	M	M			
Methylene blue-active substances		M			
Molybdenum		SA			
Nickel		M			
Nitrite	M	SA			
Odor, threshold		M			
Organic carbon, total	M	M			
Organic nitrogen, total	M	M			
Organic nitrogen, soluble		M			
Phenols		SA			
Potassium	M	M			
Residue, total (total solids)		M			
Residue, total volatile	M	SA			
Residue, suspended volatile		SA			
Selenium		SA			
Silver		SA			
Sodium		M			
Sulfate		M			
Strontium		SA			
Sulfide, total		SA			

Table 2. (continued)

Parameter	Study Periods[a] MAY 71 to MAR 72	APR 72 to DEC 72	JAN 73 to JUN 74	JUL 74 to JUN 78	JUN 78 to SEPT 78
Tin		SA			
Vanaduim		SA			
Zinc		M			

[a] M = indicates generally monthly sampling
SA = indicates semi-annual sampling
P = indicates vertical profiles were taken; some P indicates vertical profiles were sometimes taken.

Light penetration measurements were taken at the surface, one meter depth, three meters depth, and three meter intervals thereafter at each water quality location from July 1974 through June 1978. A Kahlsico submarine photometer (Model 286WA310) was used.

C. Analytical Procedures

The water samples were analyzed for water quality constituents according to the methods presented in Appendix A, Tables A-1 through A-7. Most analytical techniques followed Standard Methods for the Examination of Water and Wastewater (A.P.H.A et al. 1971 and 1976) or Chemical Analysis of Water and Wastes (U.S.E.P.A 1974).

D. Data Handling Procedures

Data were compiled and statistical analyses were performed as described in previous reports to Commonwealth Edison Company.

Statistical evaluations of water quality data between January 1972 and June 1977 were performed using a program which generated very slightly incorrect results, based upon a comparison of the hand-calculated and computer-calculated values. However, the magnitude of the difference was so minute that the results presented in reports were essentially correct.

Between August 1974 and December 1975, silica data, which were reported in units of milligrams per liter as SiO_2, were really calculated in the units, milligrams per liter as Si Corrections of these data to milligrams per liter as SiO_2 have been published in reports to Commonwealth Edison Company in 1976.

III. Results and Discussions

This discussion is limited to an evaluation of the 13 parameters monitored both prior to and during the period of operation of Zion Station to meet the objectives described in the introduction. Throughout the previous studies, these parameters remained part of the monitoring program. Data obtained for other constituents measured prior to station start up were, in general, typical for Lake Michigan waters, although effects relating to the proximity to shore were also observed.

A. Zion Station Operating Conditions

Operation of both generating units at the Zion Station required an estimated intake of 1.704 million gallons per minute of Lake Michigan water. The majority (94%) of this water was used for condenser cooling, but a portion of it was demineralized and used in the steam generation system at the station. Periodically, the demineralizers were regenerated and the discharge from this process was stored in a 100,000 gallon neutralizing tank before release into the Unit 1 or Unit 2 condensing water.

On sampling dates from October 1973 through September 1978, water was circulated through the station, although on several sampling dates in 1973, 1974, and 1975 the station was shut down or very little power was produced. Temperature increases in the Unit 1 and Unit 2 condensing water reached 12.5C.

B. Water Temperature, Dissolved Oxygen and Light Penetration

Water temperatures followed normal seasonal trends in Lake

Michigan. Thermoclines were usually present in the late summer, especially at the deep 18 meter locations. Stratification ended in the fall and waters were usually well mixed throughout the winter and spring.

Water temperatures were frequently variable throughout the study area on any sampling date. Higher temperatures were sometimes observed along the Dead River Transect (south control) than at the other transects because it was sampled later in the morning when solar input became significant. Naturally occurring temperature variations also occurred between locations in shallower and deeper waters due to solar input and circulation patterns.

No notable effects on water temperature from operation of Zion Station were observed. In March 1978, one instance of a temperature increase was discerned at the bottom of the water columns at the 9 meter depth contour along the South Zion Transect. Although the thermal regime exhibited the characteristics of a sinking plume, the reason for the temperature increase remains unclear. During this period, Unit 2 was not operational, which indicates that the reason for the increase was probably from a source other than the station.

Dissolved oxygen (DO) concentrations also followed normal seasonal trends. In the summer, when thermal stratification was present, zones of slightly increased DO concentrations and oxygen saturations were observed well below the surface just below the thermocline. These zones were probably related to photosynthetic oxygen production which occurred in the metalimnion. Because of

density stratification, the oxygen could not transfer into the overlying waters, resulting in naturally occurring zones of higher DO levels.

Light penetration measurements indicated that the euphotic zone usually extended to over one meter depth and in the summer frequently extended into the metalimnion or hypolimnion.

C. General Water Quality Constituents

Total alkalinity concentrations varied little during the study. Concentrations sometimes decreased with distance from shore and were usually somewhat higher in the winter and early spring (December through April) (Figure 1). Although the highest alkalinity values along the 9 meter depth contour were sometimes observed at the North and South Zion Transects, differences in alkalinity levels appeared random.

Values of pH were frequently higher during the summer months concurrent with higher temperatures (Figure 2). Few spatial differences in pH were observed.

Levels of both pH and alkalinity, as well as other constituents measured, were more variable during 1971 and 1972 than in later studies. This was related to anayltical variability and not to natural variability of Lake Michigan water.

Turbidity levels were generally highest closest to shore due to resuspension of bottom sediments from wind-related turbulence. During sampling periods when winds were strong and waters were turbulent, turbidity levels increased at all locations as illustrated in Figure 3 by levels at the 9 meter depth contour on December 1974, April 1976, and October 1977.

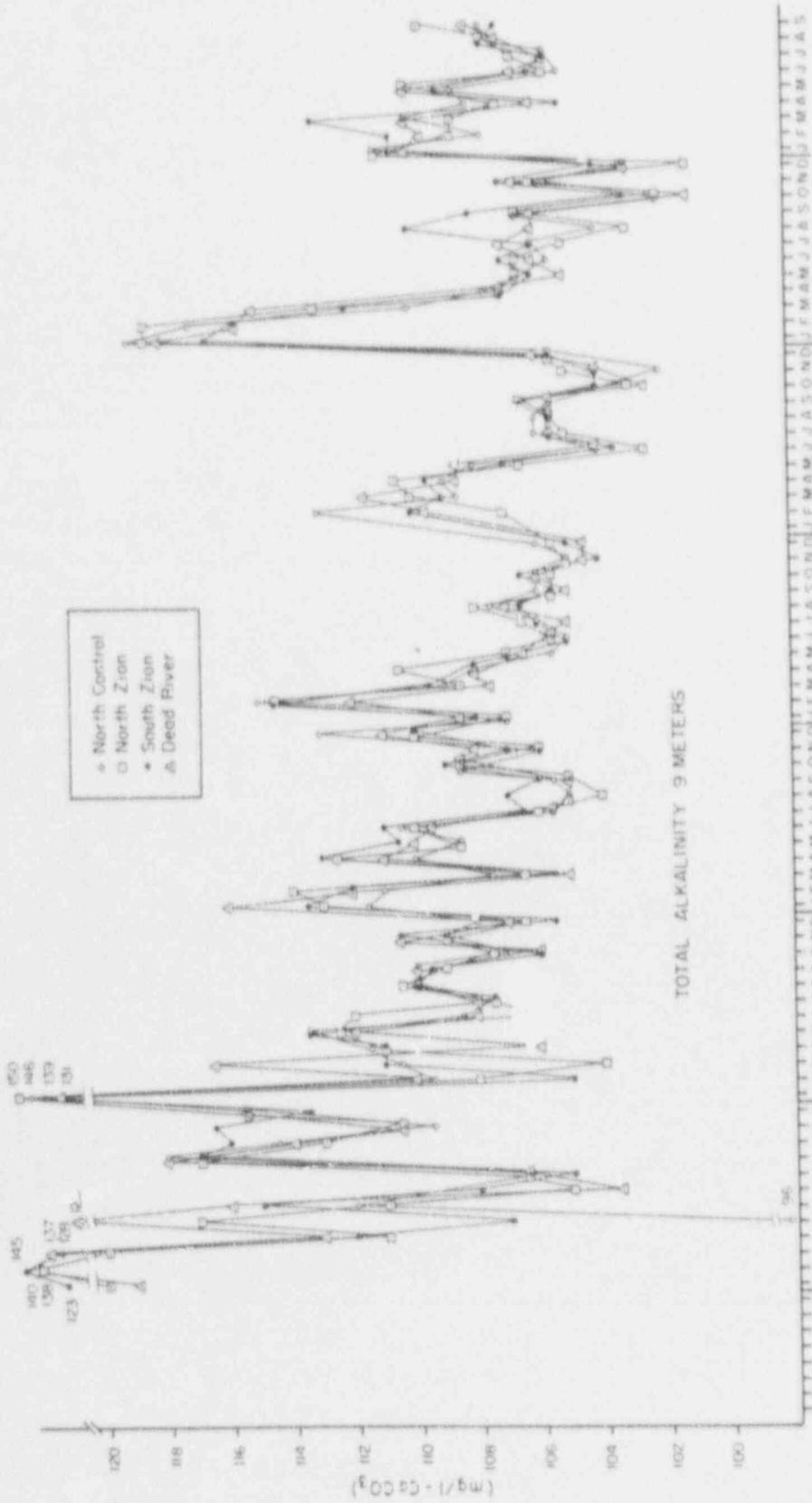


Figure 1. Total alkalinity concentrations along the 9 meter depth contour in Lake Michigan, 1971 through 1978.

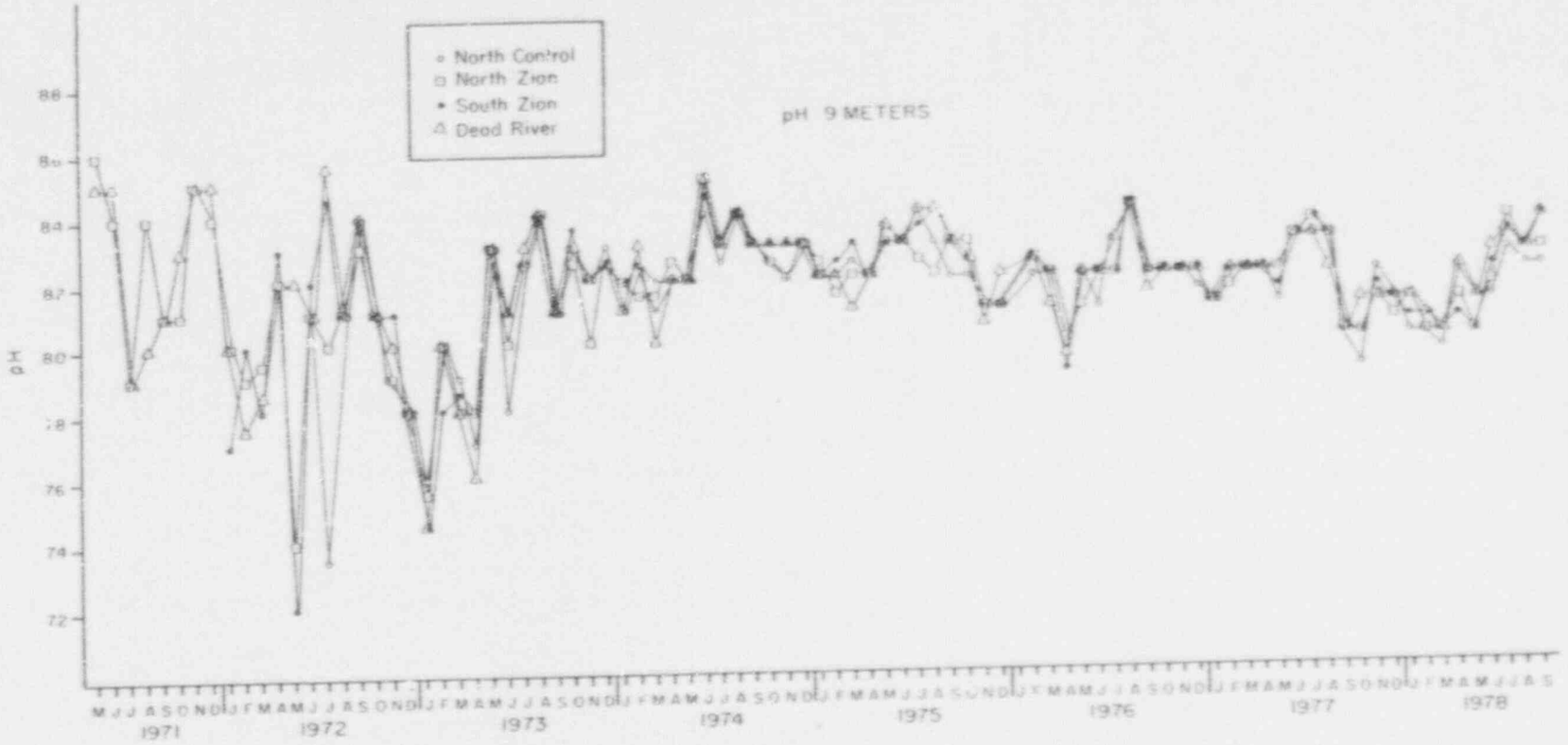


Figure 2. Values of pH along the 9 meter depth contour in Lake Michigan, 1971 through 1978.

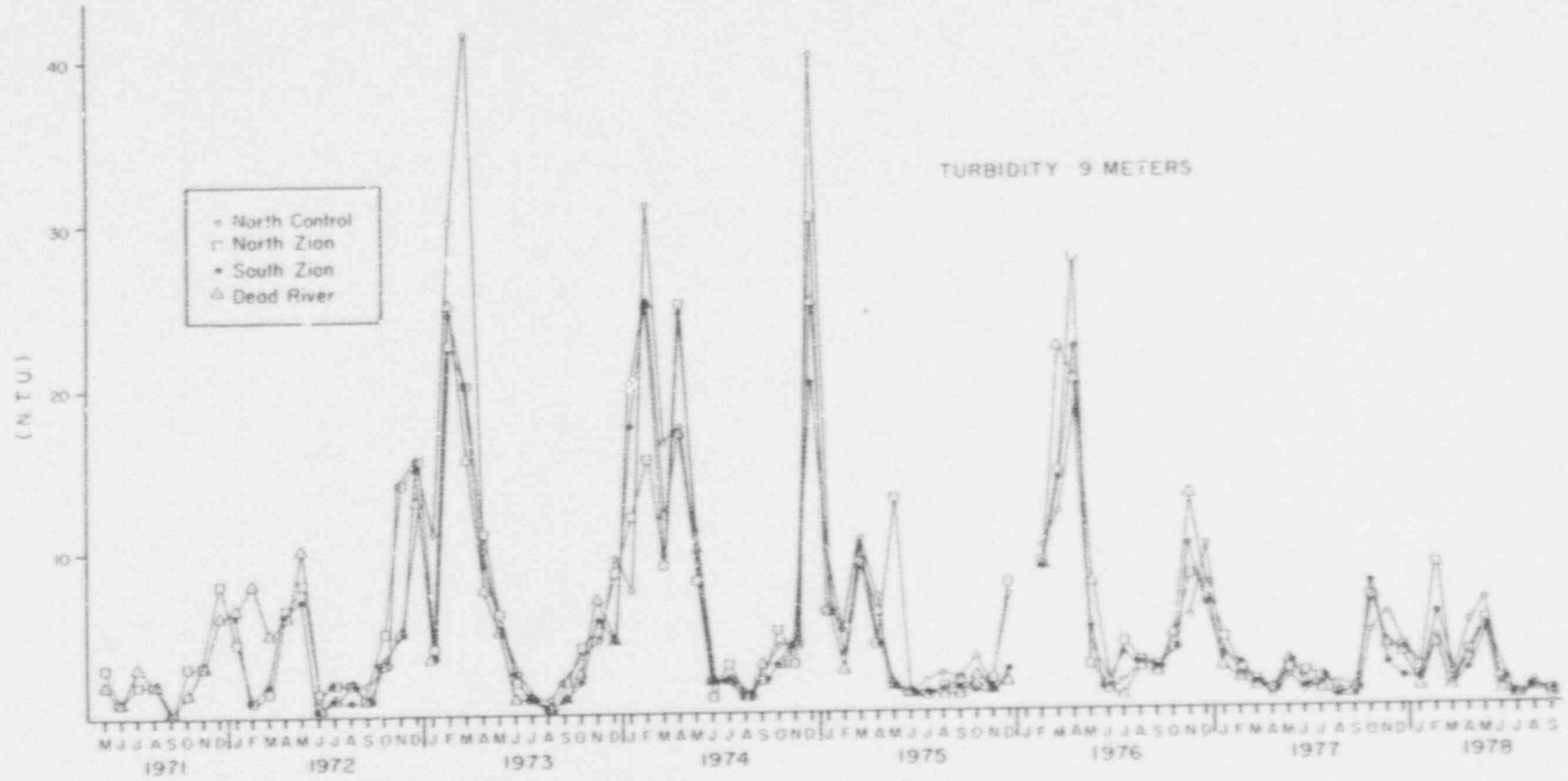


Figure 3. Turbidity values along the 9 meter depth contour in Lake Michigan, 1971 through 1978.

Nonfiltrable residue concentrations (total suspended solids) followed a trend very similar to that of turbidity (Figure 4) since both parameters are a measure of particulates in water.

Filtrable residue concentrations (total dissolved solids) varied randomly throughout the study (Figure 5) and indicated general homogeneity in this part of Lake Michigan.

D. Aquatic Nutrients

Ammonia concentrations were generally low and close to the detection limit (Figure 6). Very slightly higher concentrations were sometimes observed in the late winter and early spring. Although concentrations were sometimes higher at the Zion transects than at control locations, this effect appeared random.

Concentrations of nitrate were variable and sometimes higher in the winter and early spring than during the summer months (Figure 7).

Soluble orthophosphate concentrations were usually close to or below the analytical detection limit (Figure 8). In the winter and early spring, soluble orthophosphate concentrations were sometimes at slightly higher levels.

Total phosphorus concentrations, as for many of the other nutrients, appeared lower during the summer period of increased biological activity (Figure 9). However, total phosphorus concentrations also reflected changes in levels of particulate materials and were higher in months when turbidity and nonfiltrable residue levels were increased. Total phosphorus levels were slightly higher near the shore than in deeper waters because of the effect of particulate resuspension.

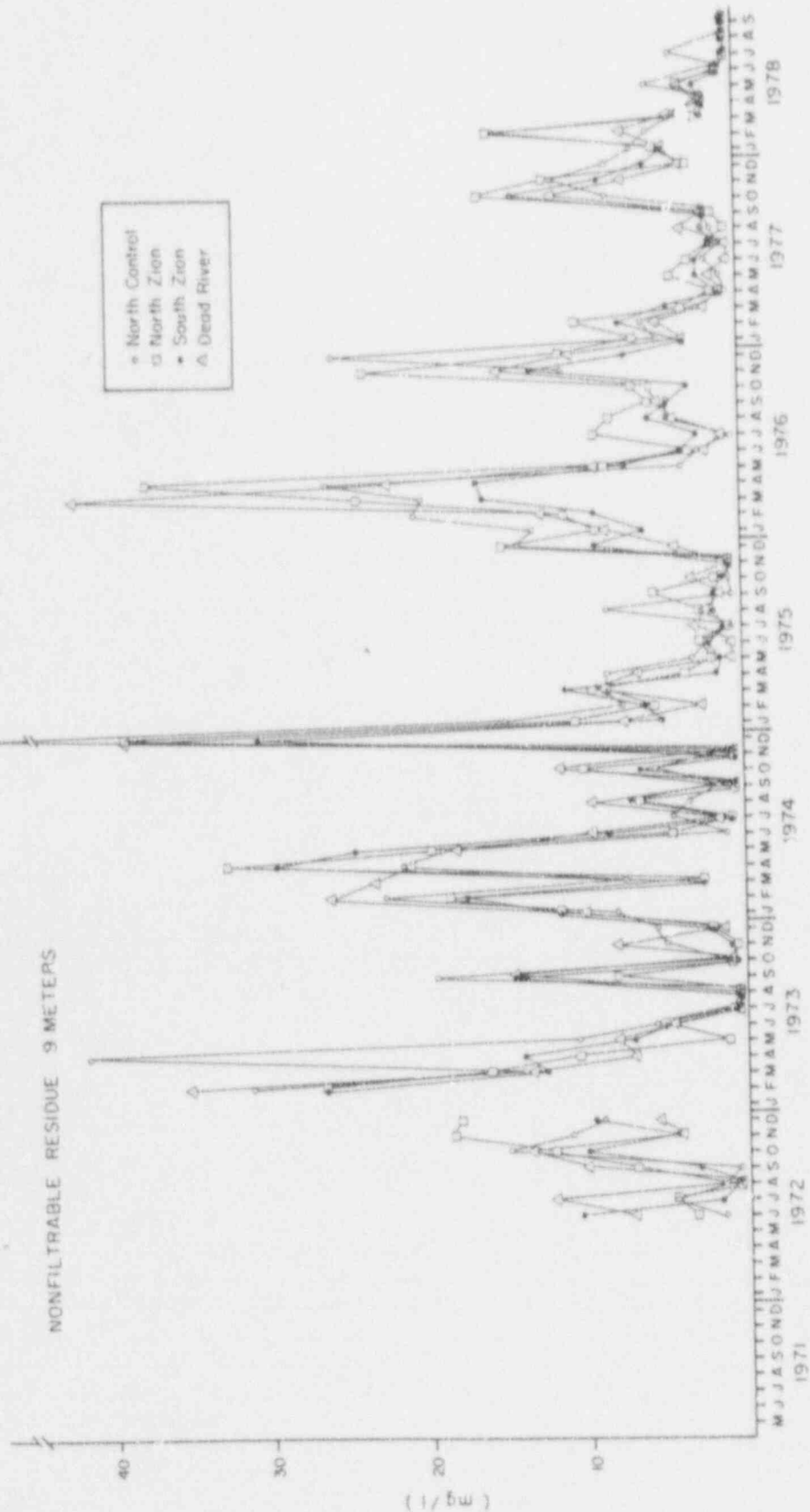


Figure 4. Nonfiltrable residue concentrations (total suspended solids) along the 9 meter depth contour in Lake Michigan, 1971 through 1978.

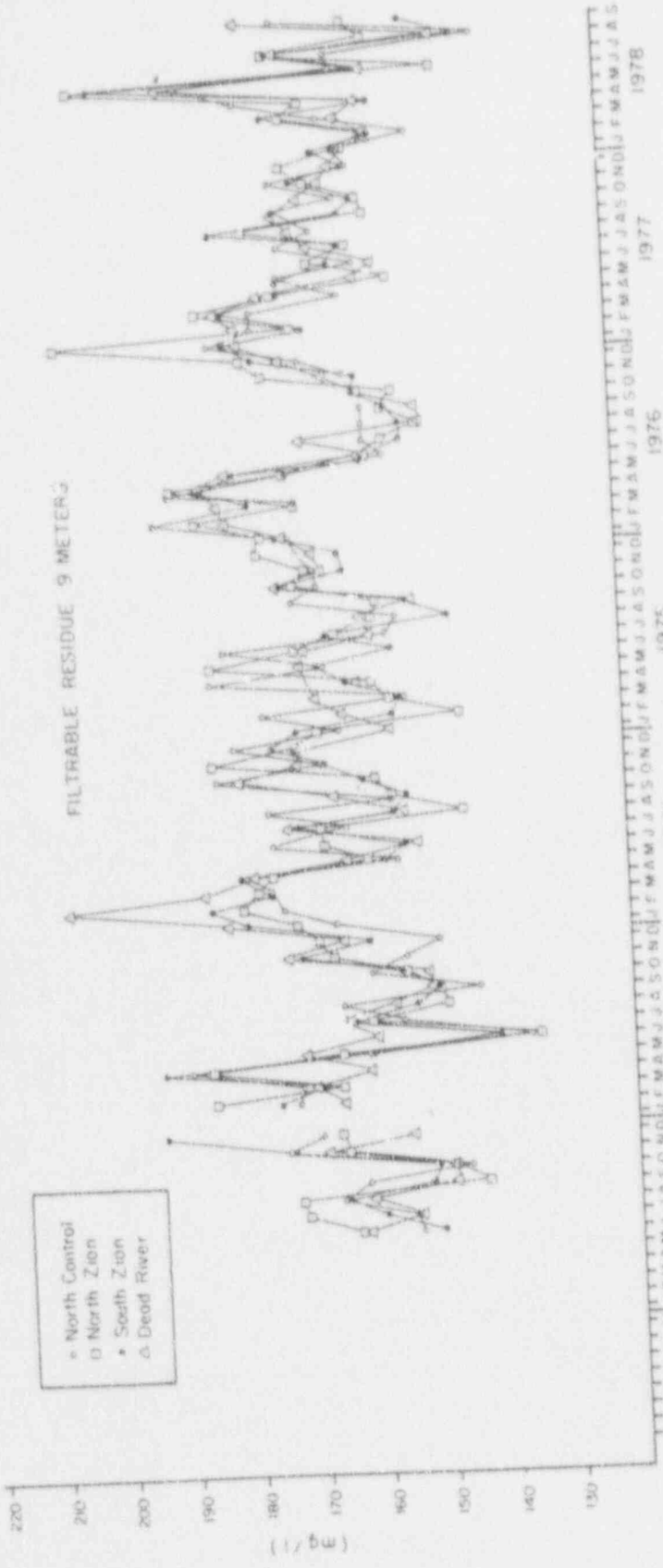


Figure 5. Filtrable residue concentrations (total dissolved solids) along the 9 meter depth contour in Lake Michigan, 1971 through 1978.

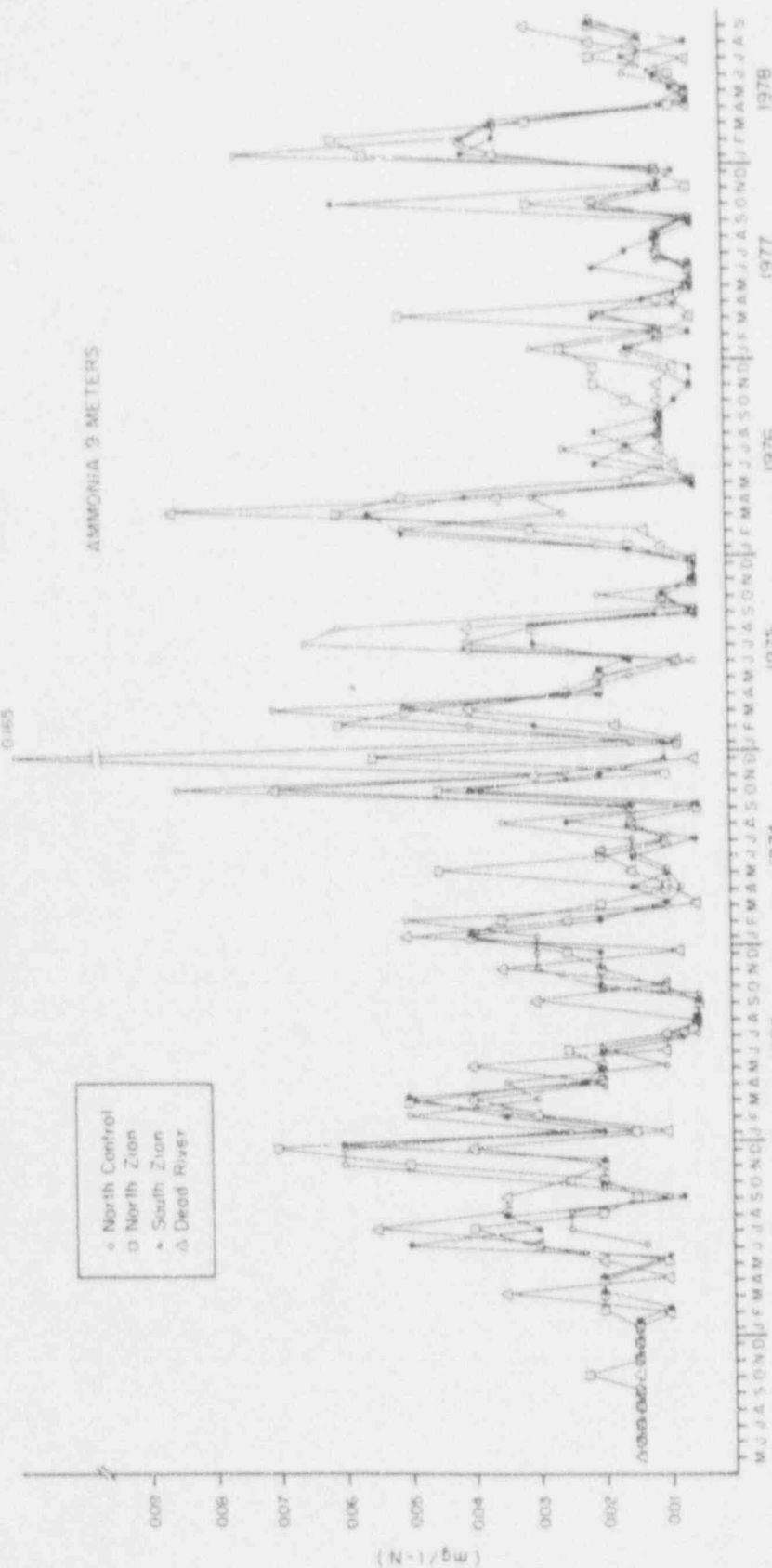


Figure 6. Ammonia concentrations along the 9 meter depth contour in Lake Michigan, 1971 through 1978.

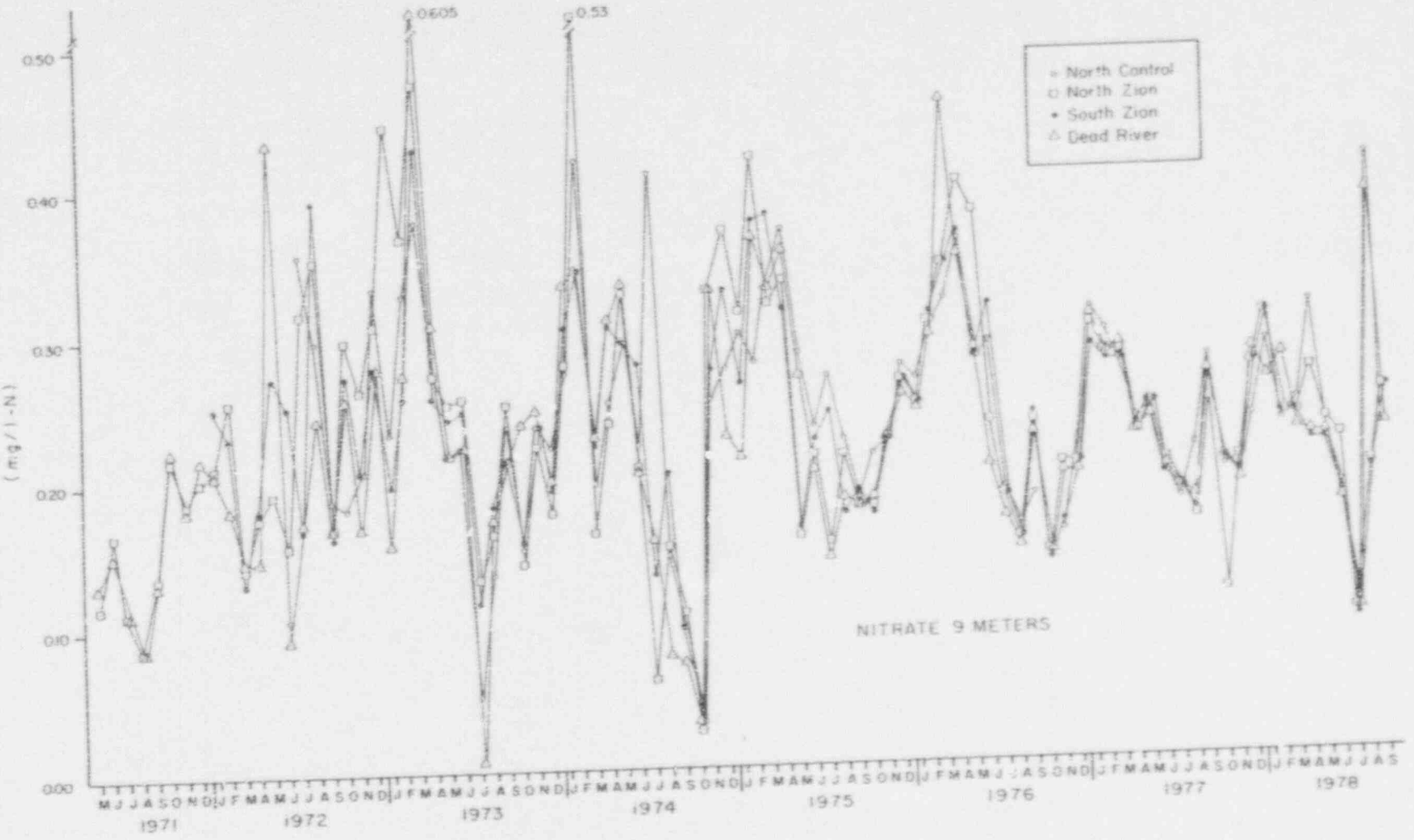


Figure 7. Nitrate concentrations along the 9 meter depth contour in Lake Michigan, 1971 through 1978.

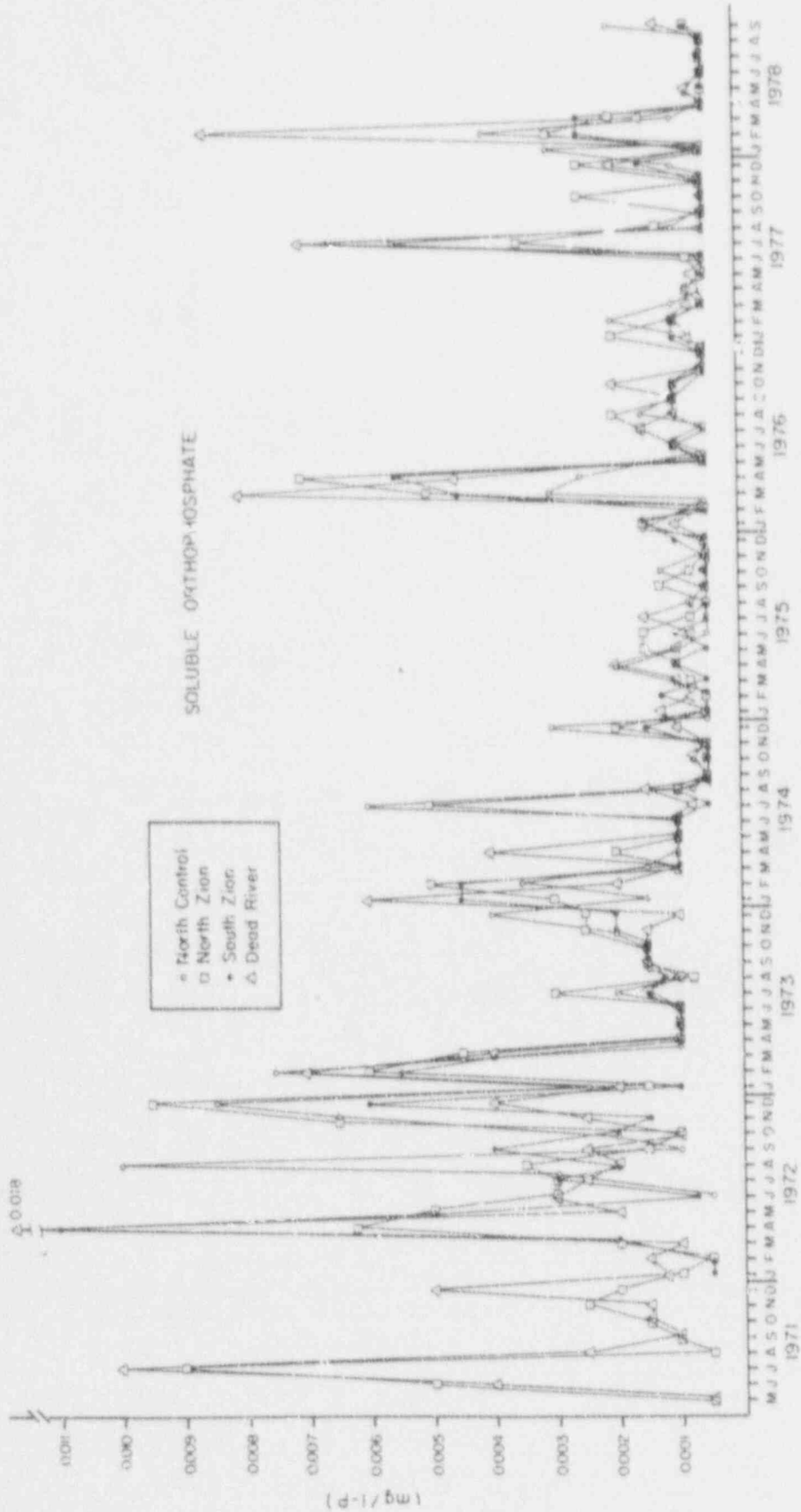


Figure 8. Sclible orthophosphate concentrations along the 9 meter depth contour in Lake Michigan, 1971 through 1978.

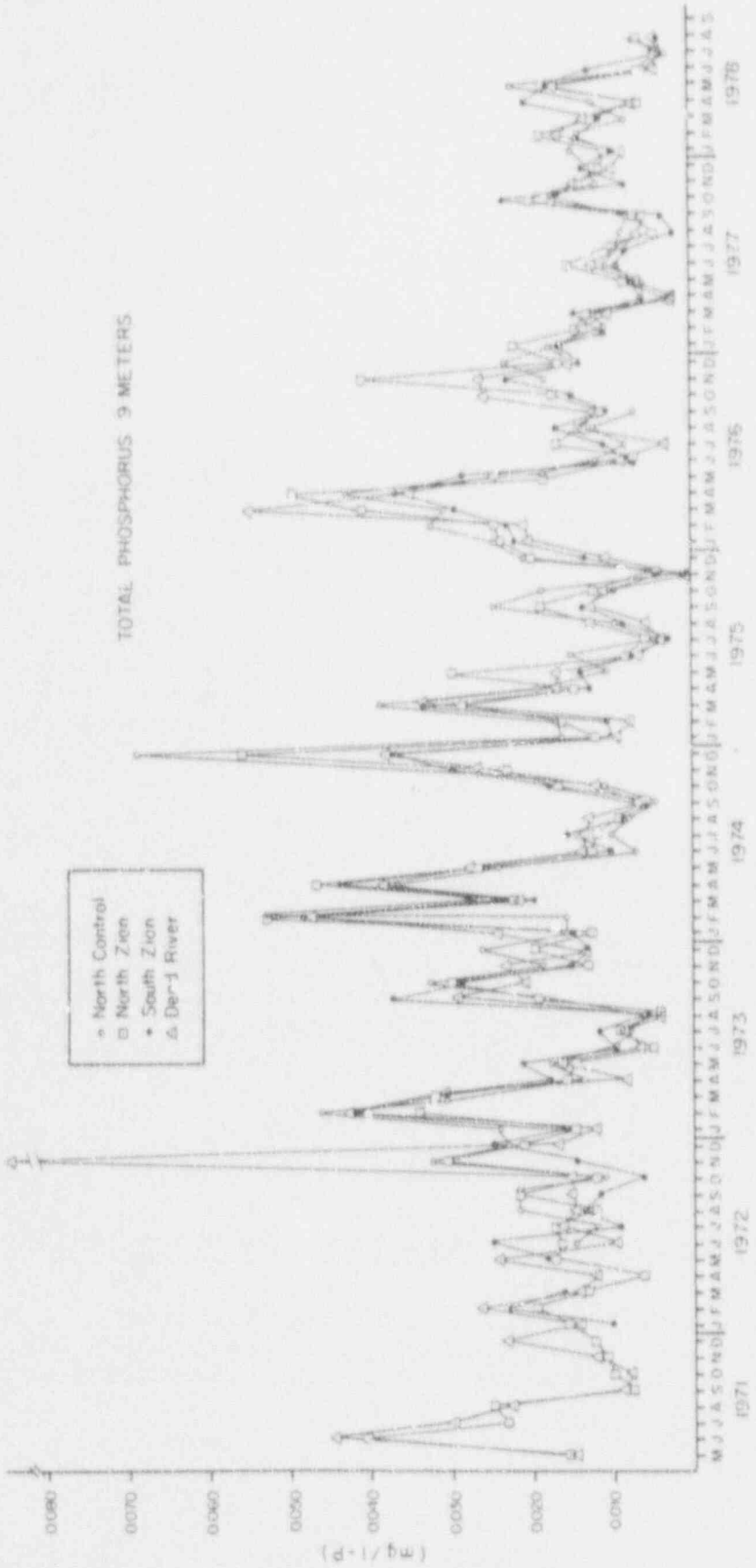


Figure 9. Total phosphorus concentrations along the 9 meter depth contour in Lake Michigan, 1971 through 1978.

Soluble silica concentrations varied widely throughout the seasonal cycle and levels were lower during the summer period (Figure 10) because of increased biological activity. On occasion, levels were sometimes higher at the transects near Zion Station; however, these differences were random.

The concentrations of water quality constituents: dissolved oxygen, pH, total alkalinity, turbidity, nonfiltrable residue, filtrable residue, ammonia, nitrate, soluble orthophosphate, total phosphorus, and soluble silica, showed no effects related to Zion Station operation. In general, changes in parameter concentrations were random, due to natural variability of Lake Michigan.

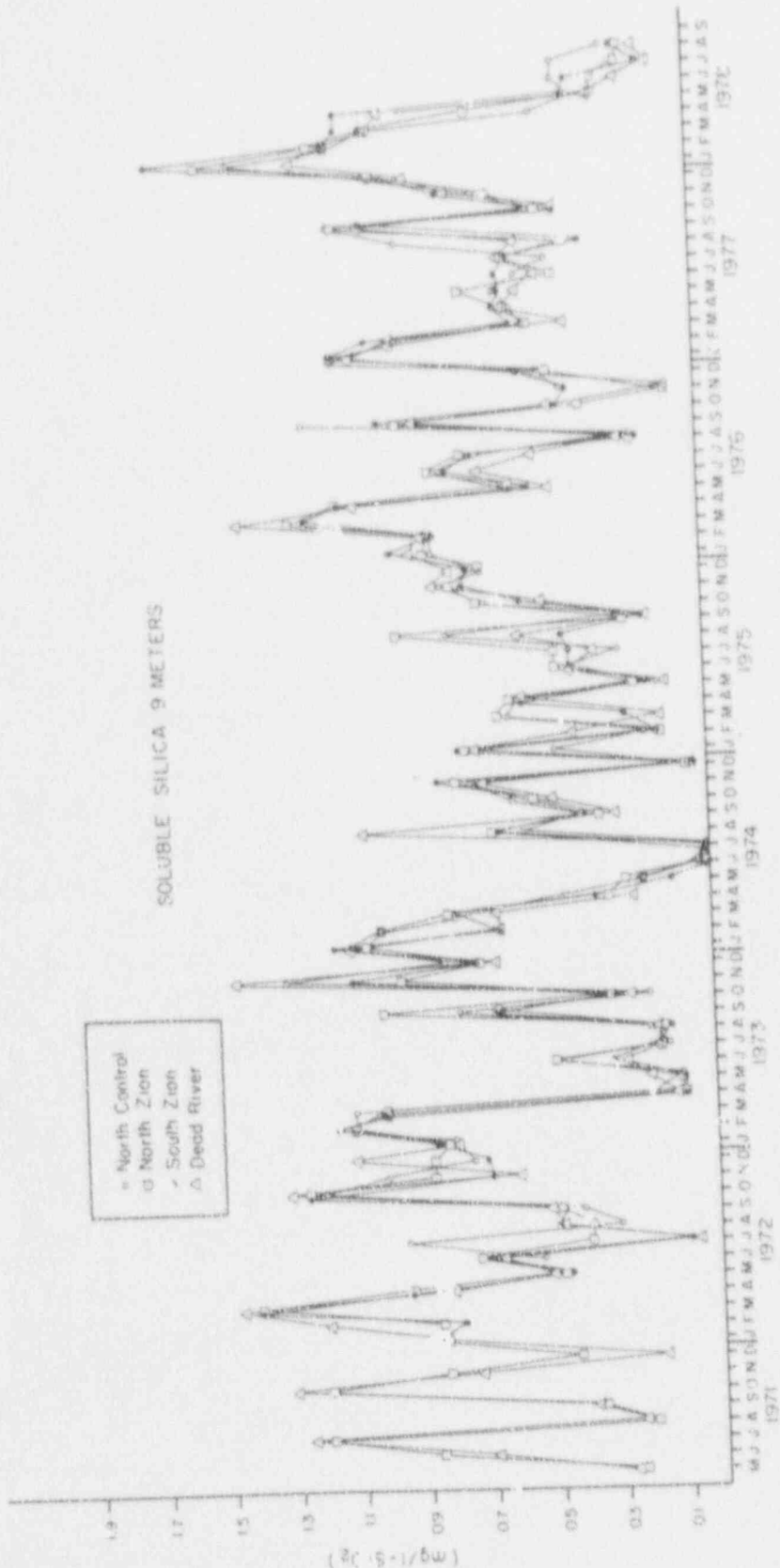


Figure 10. Soluble silica concentrations along the 9 meter depth contour in Lake Michigan, 1971 through 1978.

IV. References Cited

A.P.H.A., A.W.W.A., and W.P.C.F. 1971. Standard methods for the examination of water and wastewater. 13th ed. Amer. Public Health Assn., Washington, D.C. 874 p.

A.P.H.A., A.W.W.A., and W.P.C.F. 1976. Standard methods for the examination of water and wastewater. 14th ed. Amer. Public Health Assn., Washington, D.C. 1193 p.

Briars, R.P. 1974a. Water quality monitoring in Lake Michigan in the vicinity of the Zion and Waukegan Generating Stations, January 1972 through December 1972. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. 1: 197-343.

_____. 1974b. Field chemistry study. IN Environmental monitoring in Lake Michigan near Zion and Waukegan Generating Stations, January 1973 through June 1973. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. n.p.

_____. 1974c. Field chemistry study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through June 1974. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories,Inc. Vol. III: 1-74.

Ellis, D.B. 1975. Field chemistry study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1974 through June 1975. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. I: 271-396.

_____. 1976. Field chemistry study. IN Operation environmental monitoring in Lake Michigan near Zion Station, July 1975 through June 1976. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. II: 1-178.

_____. 1977. Field chemistry study. IN Operational environmental monitoring in Lake Michigan near Zion Station. July 1976 through June 1977. Annual report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. II: 1-170.

_____. 1978. Field chemistry study. IN Operational environmental monitoring in Lake Michigan near Zion Station. July 1977 through June 1978. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences, Vol. II: 1-170.

Referencer Cited (continued)

Howe, L.H., III, and C.W. Holley. 19[illegible]. Comparisons of mercury (II) chloride and sulfuric acid as preservatives for nitrogen forms in water samples. Environ. Sci. Technol. 3:478-481.

Huh, H., L. Everhart, C. Kondrat, J. Lingle and J. Urry. 1973. Field study program of Lake Michigan in the vicinity of the Waukegan and Zion Generating Stations, April 1971-March 1972. Project X. IN Evaluation of thermal effects in southwestern Lake Michigan 1971-1972. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I: 131 p. plus Appendix C, Vol. III.

Hydrolab Corporation. 1973. Instructions for operating the Hydrolab Surveyor Model 6D in situ water quality analyzer. Austin, Texas. 146 p.

Pritchard, D.W. 1977. The distribution of excess temperatures in Lake Michigan resulting from the discharge of condenser cooling water from the Zion and Waukegan Power Stations for various seasons and environmental conditions. Testimony for Commonwealth Edison Company, Chicago, Illinois. 30 p.

Ryden, J.C., J.K. Syers, and R.F. Harris. 1972. Sorption of organic phosphate by laboratory ware. Implications in environmental phosphorus techniques. Analyst. 97:903-908.

Sheehan, W., E. Skepnek, W. Bauszek and J.J. Delfino. 1972a. Inshore water quality evaluation, January 1970-April 1971. Project II, Part A - Chemistry. IN Evaluation of thermal effects in southwestern Lake Michigan (January 1970-April 1971). Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I: IIA-1 to IIA-23 plus Appendix A.

_____. 1972b. Field sampling, February 1970-April 1971. Project VII, Part D - Offshore Water Quality. IN Evaluation of thermal effects in southwestern Lake Michigan (January 1970-April 1971). Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. II: VII-1 to VII-20, plus Appendix A.

Shipley, G.L. 1979. Field chemistry study. IN Operational environmental monitoring in Lake Michigan near Zion Station. July 1978 through September 1978. Report to Commonwealth Edison Company, Chicago, Illinois, by Hazleton Environmental Sciences.

References Cited (continued)

Strickland [illegible].H., and T. R. Parsons. 1972. A practical handbook of seawater analysis. Bull. Fish. Res. Board of Canada 167. 310 p.

Technicon Industrial Systems. 1974. Technicon auto analyzer II continuous-flow analytical instrument manual. Technical Publications No. UA 4-0170C00 n.p.

Thomas, R. F. , and R. L. Booth. 1973. Selective electrode measurement of ammonia in water and wastes. Environ. Sci. Technol. 7:523-526.

U.S. Environmental Protection Agency. 1974. Methods for chemical analysis of water and wastes. EPA-625-16-74-003. Washington, D.C. 298 p.

Chapter 6

PHYTOPLANKTON STUDIES

by

Chris C. Altstaetter
and
Patricia S. Bartholomew

SUMMARY REPORT OF ENVIRONMENTAL MONITORING
IN LAKE MICHIGAN NEAR ZION STATION

January 1970 through September 1978

TABLE OF CONTENTS

		Page
	List of Figures	147
	List of Tables	151
I.	Introduction	153
II.	Methods and Materials	
	A. Populations	
	1. Sampling Locations	154
	2. Sample Collection	157
	3. Analytical Methods	157
	4. Statistical Analysis	158
	B. Primary Productivity	
	1. Field Procedures	159
	2. Laboratory Procedures	159
	3. Statistical Analyses	160
	C. Phytoplankton Entrainment	
	1. Field Methods	161
	2. Laboratory Methods	163
	3. Statistical Analyses	163
III.	Results and Discussion	
	A. Populations	165
	B. Primary Productivity	187
	C. Phytoplankton Entrainment	198
	1. Immediate Effects	198
	2. Delayed Effects	202
IV.	Literature Cited	205

LIST OF FIGURES

No.	Caption	Page
1	Sampling locations in southwestern Lake Michigan near Zion, Illinois	155
2	Mean density of total phytoplankton at the 3 meter locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978	166
3	Mean density of total phytoplankton at the 9 meter locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978	167
4	Mean density of total phytoplankton at the 18 meter locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978	168
5	Mean density of the division Bacillariophyta at the 3 meter locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978	169
6	Mean density of the division Bacillariophyta at the 9 meter locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978	170
7	Mean density of the division Bacillariophyta at the 18 meter locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978	171
8	Mean density of the division Chlorophyta at the 3 meter locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978	172
9	Mean density of the division Chlorophyta at the 9 meter locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978	173
10	Mean density of the division Chlorophyta at the 18 meter locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978	174

LIST OF FIGURES (continued)

No.	Caption	Page
11	Mean density of the division Cyanophyta at the 3 meter locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978	175
12	Mean density of the division Cyanophyta at the 9 meter locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978	176
13	Mean density of the division Cyanophyta at the 18 meter locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978	177
14	Mean density of the division Chrysophyta at the 3 meter locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978	178
15	Mean density of the division Chrysophyta at the 9 meter locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978	179
16	Mean density of the division Chrysophyta at the 18 meter locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978	180
17	Carbon fixation rates of phytoplankton collected at the 3 meter depth contour in southwestern Lake Michigan near Zion, Illinois, July 1972 through September 1978	190
18	Carbon fixation rates of phytoplankton collected at the 9 meter depth contour in southwestern Lake Michigan near Zion, Illinois, July 1972 through September 1978	191
19	Carbon fixation rates of phytoplankton collected at the 18 meter depth contour in southwestern Lake Michigan near Zion, Illinois, July 1972 through September 1978	192
20	Chlorophyll a concentrations of phytoplankton collected at the 3 meter depth contour in southwestern Lake Michigan near Zion, Illinois, July 1972 through September 1978	193

LIST OF FIGURES (continued)

No.	Caption	Page
21	Chlorophyll a concentrations of phytoplankton collected at the 9 meter depth contour in southwestern Lake Michigan near Zion, Illinois, July 1972 through September 1978 ...	194
22	Chlorophyll a concentrations of phytoplankton collected at the 18 meter depth contour in southwestern Lake Michigan [illegible]r Zion, Illinois, July 1972 through [illegible]ember 1978 ...	195

LIST OF TABLES

No.	Title	Page
1	Summary of the ... and methods used to sample ... communi... and production ... rn Lake Michigan near Zion, ... 1977	156
2	Des... ...ocations for phyto- ... studies near the Zion ... through July 1977	162
3	Domi... ...d as percent of the total ...ity at each location within ... contour in southwestern ...r Zion, Illinois, July 1972	181

I. Introduction

This report is a summarization of a long-term phytoplankton monitoring program of southwestern Lake Michigan near Zion, Illinois. The program, initiated in 1970 and continued through 1978, resulted in the preparation of numerous semi-annual and annual data presentations. The purpose of this summarization is not to present any new or previously undiscussed data; but, rather to bring together, in a single document, the most salient data trends and conclusions.

The monitoring program was accomplished during the preoperational and operational (after July 1973) periods of Zion Station. The objectives of the study were:

1. to qualitatively and quantitatively determine spatial and temporal fluctuations of the populations and productivity patterns in the phytoplankton community; and

2. to assess whether the operation of Zion Station has produced any apparent changes in the primary productivity and population dynamics of the phytoplankton community at the experimental locations.

II. Methods and Materials

A. Populations

1. Sampling Locations

Phytoplankton samples for microscopical analyses were collected monthly from 3 locations in southwestern Lake Michigan in the vicinity of Zion, Illinois, from May 19[illegible] through March 1971 (Figure 1). These locations were Lake County (LC), North Zion (NZ), and Zion Beach (ZB) (Gulo and Lamble, 1972). Locations 5, 7, and 9 (North Zion Transect) near the proposed Zion Generating Station and Locations 18, 20, and 22 south of Zion near the Dead River area were sampled monthly from April 1971 through March 1972 (Figure 1) (Huh, et al., 1973). From January 1972 through September 1978 samples were collected monthly at North Zion Transect (Locations 5, 7, and 9), and South Zion Transect (Locations 10, 12, and 13a) which were within or near the predicted area of major thermal influence from Zion Station. The Dead River Transect (Locations 18, 20, and 22) and North Control Transect (Locations 28, 30, and 32 which were not added until April 1972) served as southern and northern control areas respectively (Figure 1 and Table 1). Samples were also taken at these same locations for primary productivity monitoring from July 1972 through September 1978.

Sampling locations along the 3m depth contour (Locations 5, 10, 18, and 28) were called "inshore", those along the 9m depth contour (Locations 7, 12, 20, and 30) were called "middle", and those along the 18m depth contour (Locations 9, 13a, 22, and 32) were designated as "offshore" locations.

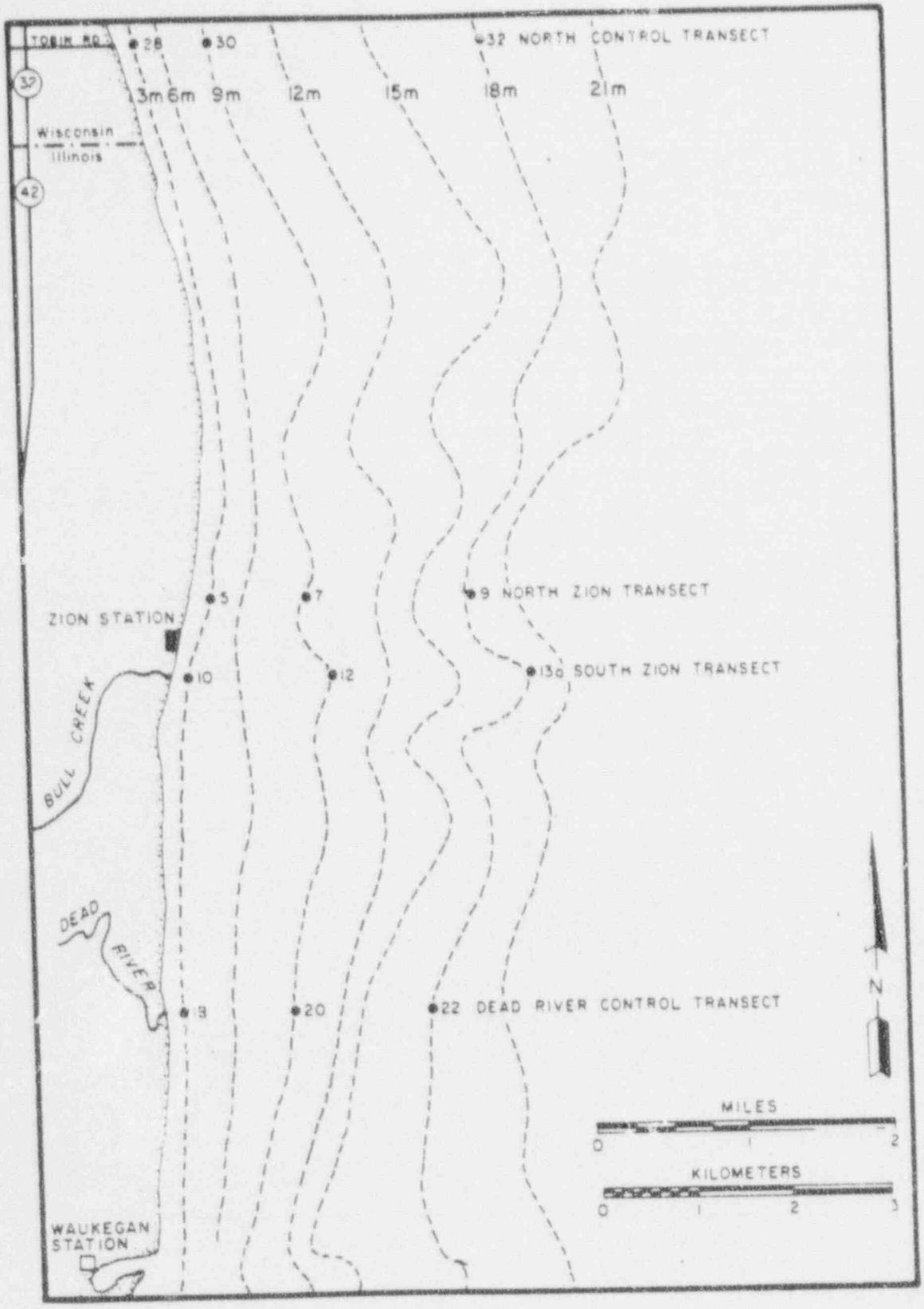


Figure 1. Sampling locations in southwestern Lake Michigan near Zion, Illinois.

Table 1. Summary of material and methods used to sample phytoplankton community and production in southwestern Lake Michigan near Zion, Illinois, 1970-1978.

Year	Number of Locations	Locations	Frequency of Sampling	Number of Replicates	Preservative	Report Reference
1970 May- 1971 March	3	Lake County (LC) Zion Beach (ZB) North Zion (NZ)	Monthly	3	3% Formalin	Gulo & Lamble 1972
1971 Apr- 1972 Mar	6	Locations 5,7,9, 18,20,22	Monthly	2	3% Formalin	Huh, et al. 1973
1972 Jan-Dec	12	Locations 5,7,9,10, 12,13a,18,20,22 Jan-Dec, plus 28,30,32 Apr-Dec	Monthly	2	3% Formalin	Mayhew 1974 Bremer 1974
1973-74 Jan 74-Jun 74	12	Locations 5,7,9,10, 12,13a,18,20,22,28, 30,32	Monthly	2 Jan-Mar 73; 4 Apr-Jun 74	3% Formalin Jan 73-Jun 73; M^3 fixative Jul 73-Jun 74	Mayhew 1974 Mayhew & Barber 1974 Redmond 1974
1974-75 Jul 74-Jun 75	12	Locations 5,7,9,10, 12,13a,18,20,22,28, 30,32	Monthly	4	M^3 fixative	Barber & Redmond 1975
1975-76 Jul 75-Jun 76 All categories same as 74-75.						Barber & Redmond 1976
1976-77 Jul 76-Jun 77 All categories same as 74-75.						Barber & Redmond 1977
1977-78 Jul 77-Jun 78 All categories same as 74-75.						Festin & Redmond 1978
1978 Jul 78-Sep 78 All categories same as 74-75 except Replicates				2		Festin & Bartholomew 1979

2. Sample Collection

Samples were collected at each location from a 1-meter depth using 6-liter water samplers. Triplicate samples were collected from May 1970 through March 1971 by taking one bottle cast per replicate. Duplicate composite samples were collected from April 1971 through March 1973, four composite samples from April 1973 to June 1978 and duplicate samples from July through September 1978 (Table 1). Each composite sample consisted of 24 liters of water from four water bottle casts. Through June 1972 a 1.9-liter portion was withdrawn from each composite sample and preserved at the time of collection. After June 1972, when the primary productivity monitoring program began (see Section B of Methods and Materials), a 4-liter subsample from each composite was maintained at ambient lake temperature and returned to the laboratory for chlorophyll a and carbon fixation measurements. In addition, a 1.9-liter portion of these subsamples was preserved and used for phytoplankton identification, enumeration and biovolume measurements. The preservative used through June 1973 was a 3% formalin solution, thereafter Meyer's M^3 fixative was utilized (Table 1).

3. Analytical Methods

Diatoms were cleaned with concentrated nitric acid-potassium dichromate solution and collected on 0.45 µm porosity filters. A portion of the filter was mounted on a slide, cleared with immersion oil and examined under phase contrast at 1000 or 1250 X magnification. The size of the slide area to be analyzed

was established for each depth contour such that a minimum of 400 diatom valves was counted from each sample, or if organisms were very sparse, a maximum area of 3.60 mm^2 was examined on each slide.

Eight hundred and seventy-five milliliter subsamples were processed for analysis of phytoplankton other than diatoms. The subsamples were settled overnight with detergent and successively condensed to a 200:1 concentration. A 0.1 ml aliquot of the concentrate was then examined under 400 or 500 X magnification using the microtransect method. Enumeration of the organisms was limited to a minimum of 400 reporting units or if the density was low, a maximum area of 88 mm^2 was examined on each slide.

Phytoplankton were identified to the lowest positive taxonomic level, either genus, species or variety utilizing appropriate taxonomic keys. Algal densities were reported in units per milliliter. A reporting unit consisted of an individual cell or frustule for unicellular forms, a 100 m length for filamentous forms and four cells for all colonial forms other than Aphanocapsa, Aphanothece, and Microcystis which had 50 cells comprising a reporting unit. Biovolume measurements were taken from June 1972 to June 1978 and were expressed in microliters per liter (µl/l).

4. Statistical Analyses

Statistical comparisons on densities of total phytoplankton, major divisions and dominant species within each depth contour were conducted with a monthly one-way analysis of variance to detect significant ($p \leq 0.05$) differences between locations. If any significant differences did occur, Tukey's multiple

comparison procedure was used to isolate the differences. In addition, yearly factorial ANOVAs (locations x sampling dates) with an associated multiple comparison procedure were employed to detect significant ($p \leq 0.05$) differences in densities of total phytoplankton, divisions and dominant taxa. The diversity and redundancy values of the phytoplankton community were calculated monthly for each sampling location.

Due to an error in the calculation of Tukey's W values, data run on the SUPERFAC program contained possible errors. The SUPERFAC program was used on data from two annual reporting periods: July 1973 - June 1974; and July 1974 - June 1975. The errors do not constitute a change in the interpretation of the data presented in the annual reports.

B. Primary Productivity

1. Field Procedures

Duplicate samples were collected during the July 1972-March 1973 sampling periods. Quadruplicate samples were collected during the April 1973-September 1978 sampling periods. The sampling locations were the same as described for population studies (Table 1 and Figure 1).

2. Laboratory Procedures

Three 250-ml subsamples were analyzed from each 24-liter composite sample for chlorophyll *a* during July 1972-March 1973 and one 250-ml subsample was analyzed from each 24-liter composite sample during April 1973-September 1978. Chlorophyll *a* concentrations were determined using fluorometric techniques and

were expressed as milligrams chlorophyll a per cubic meter of water (mg chl a/m^3).

Primary productivity (rate of carbon fixation) was estimated with the light-dark bottle ^{14}C method. Four 50-ml aliquots were taken from each composite sample during July 1972-March 1973 and one 50-ml aliquot was taken from each composite sample during April 1973-September 1978. Each aliquot was inoculated with 4-5 microcuries of aqueous ^{14}C solution, agitated and incubated in a constant light and temperature incubator at a light intensity of 1000 foot-candles. Upon completion of the incubation period (usually 3-4 hours) each aliquot was filtered through a 47-mm diameter, 0.45 µm porosity filter. The filters were dried, exposed to fumes of concentrated HCl for 10 minutes and placed in low-potassium glass scintillation vials. Seventeen milliliters of scintillation fluid were added and the activity determined on a refrigerated liquid scintillation counter. The rate of carbon fixation was expressed as milligrams of carbon fixed per cubic meter per hour (mg C/m^3 per hr).

3. Statistical Analyses

Phytoplankton carbon fixation rates and cholorophyll a concentrations from 1972 through 1978 were compared at all depth contours using an analysis of variance. Significant differences ($p \leq 0.05$) between locations were determined and an appropriate multiple comparison test (Scheffe's or Tukey's) was applied. Whenever interaction among months and locations was detected, a computer plot was generated to depict the interaction.

Due to an error in the calculation of Tukey's W values, data run on the SUPERFAC program contained possible errors. SUPERFAC was used on July 73 - June 74 annual data. The errors do not constitute a change in the interpretation of the data presented in the annual reports.

C. Phytoplankton Entrainment

1. Field Methods

Entrainment effects on the phytoplankton near the Zion Station were examined monthly from July 1973 to September 1974 (except December 1973 due to plant shut-down) and from August 1976 to July 1977. Intake forebay and the discharge tunnels were sampled during 1973 and 1974. Locations sampled during 1976-1977 are described in Table 2. During both study periods all locations except the plant discharge were sampled with a six-liter Kemmerer. In-plant discharge tunnel samples were collected with a pump without passage of the water sample through the impellers. All samples were cooled and maintained at ambient lake temperature until analysis.

During 1973 and 1974 only the intake bay and the two discharge tunnel locations were sampled. Two 24-liter composite samples were collected simultaneously from the forebay and discharge tunnel locations from July through November 1973. Four 24-liter composite samples were collected from January through September 1974. The intake bay, discharge tunnel, in the lake plume (experimental) and control locations were sampled from August 1976 to July 1977 when plant operation was greater than 70%

Table 2. Description of sampling locations for phytoplankton entrainment studies near the Zion Station, August 1976 through July 1977.

Sampling Location	Description
1 T and B	Intake area, surface and bottom of the lake.
2	Forebay.
3	Discharge tunnel for Unit 1 or 2.
4 T	Immediate area of discharge for the unit generating greater power.
5 T and B	Area of plume from Unit 1 or 2 for which the temperature is equal to the forebay temperature plus 25% of the ΔT.
6 T and B	Area of plume from Unit 1 or 2 for which the temperature is equal to the forebay temperature plus 10% of the ΔT.
7 T and B	Reference location four miles north of Zion Station and at same depth as samples collected at Location 5.
8 T and B	Reference location four miles north of Zion Station and at same depth as samples collected at sampling Location 6.
9 T	Immediate area of discharge for the unit generating lower power.

T = surface samples
B = bottom samples

(Table 2). Plume locations were determined each month by plume measurement and calculation. Duplicate 24-liter composite samples were collected at each location during the 1976-1977 study.

2. Laboratory Methods

Subsamples from each composite water sample were analyzed for chlorophyll a concentration at 7, 24, 48, and 72 hrs after collection following procedures outlined in the previous section. During both studies triplicate subsamples were taken from each replicate except January through September 1974 when one subsample was removed from each replicate.

Carbon fixation rates were estimated by the light-dark bottle ^{14}C method as described previously. Triplicate subsamples were employed to estimate carbon fixation except during January through September 1974 when one subsample was analyzed from each replicate.

Phytoplankton abundance and composition was also examined during the 1976-1977 study. Phytoplankton were enumerated after processing for both the acid-cleaned and the inverted microscope method. Nutrient chemical analyses were also taken at 7 and 72 hour periods in an attempt to correlate availability of certain nutrients and phytoplankton productivity.

3. Statistical Analyses

Student's "t" tests were performed to compare both carbon fixation rates and chlorophyll a concentrations of forebay and discharge tunnel samples at 7, 24, 48, and 72 hrs after collection for samples collected during 1973 and 1974. All testing was done at $p \leq 0.05$.

A nested one-way analysis of variance and Tukey's multiple comparison procedure was applied monthly to both carbon fixation and chlorophyll *a* data to detect significant differences between locations at 7, 24, 48, and 72 hrs for each sampling period during 1976 and 1977. All testing was performed at $p \leq 0.05$.

III. Results and Discussion

Phytoplankton analyses resulted in the indentification of seven algal divisions and approximately 140 genera and almost 600 species and varieties (Table B-1 in Appendix B). Members of the division Bacillariophyta (diatoms) were the most abundant phytoplankters (Figures 2 through 7) and composed the greatest number of taxa. Members of the divisions Chlorophyta (green algae) (Figures 8 through 10), Cyanophyta (blue-green algae) (Figures 11 through 13) and Chrysophyta (golden-brown algae) (Figures 14 through 16) were the other most commonly encountered algae (Table 3).

A. Populations

May 1970 - March 1971

Maximum phytoplankton abundance occurred in June; a smaller secondary peak was recorded during late fall and winter (Gulo and Lamble 1972, p. IIB-7). Diatoms were the predominant phytoplankters throughout the study period and were primarily represented by Stephanodiscus (hantzschii-tenuis), Cyclotella sp., Fragilaria crotonensis, F. capucina and Tabellaria flocculosa (Gulo and Lamble 1972, p. IIB-12).

Other less abundant members of the phytoplankton community were green algae (Chlorophyta), blue-greens, (Cyanopohyta), and golden-brown algae (Chrysophyta) (Gulo and Lamble 1972, pp. 19-20).

April 1971 - March 1972

Diatoms were again the predominant phytoplankton organisms and reached their seasonal maximum during April through June

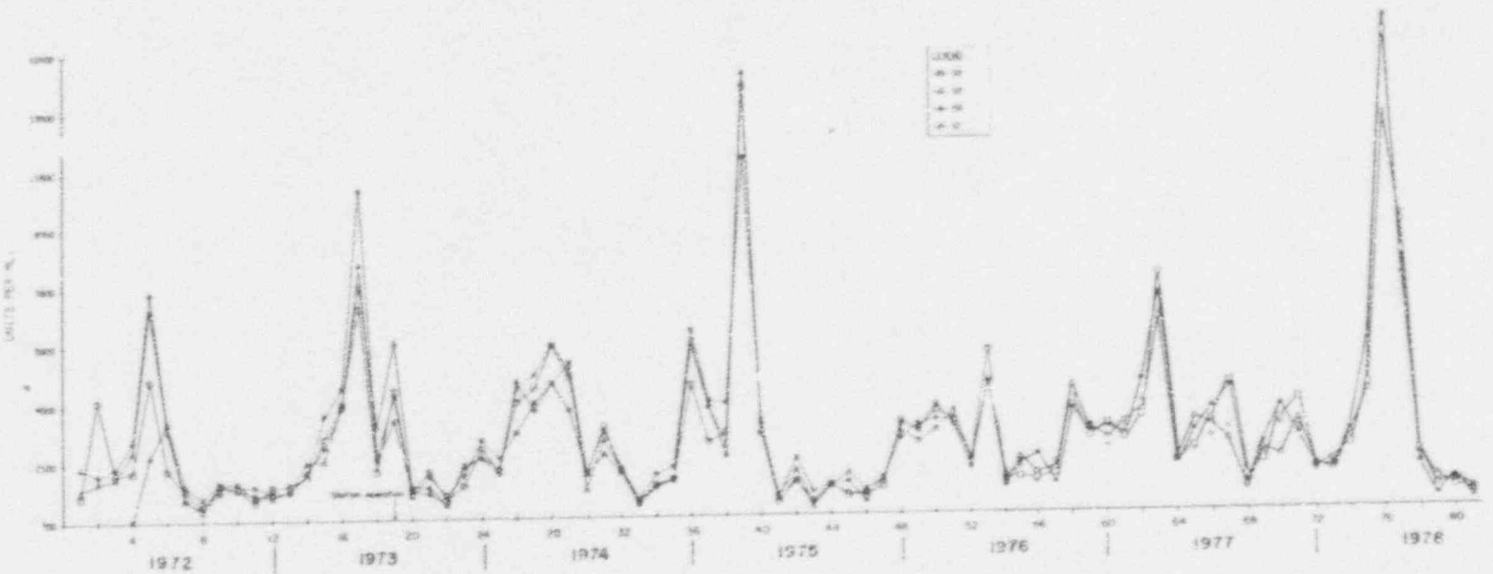


Figure 2. Mean density of total phytoplankton at the 3 meter locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978.

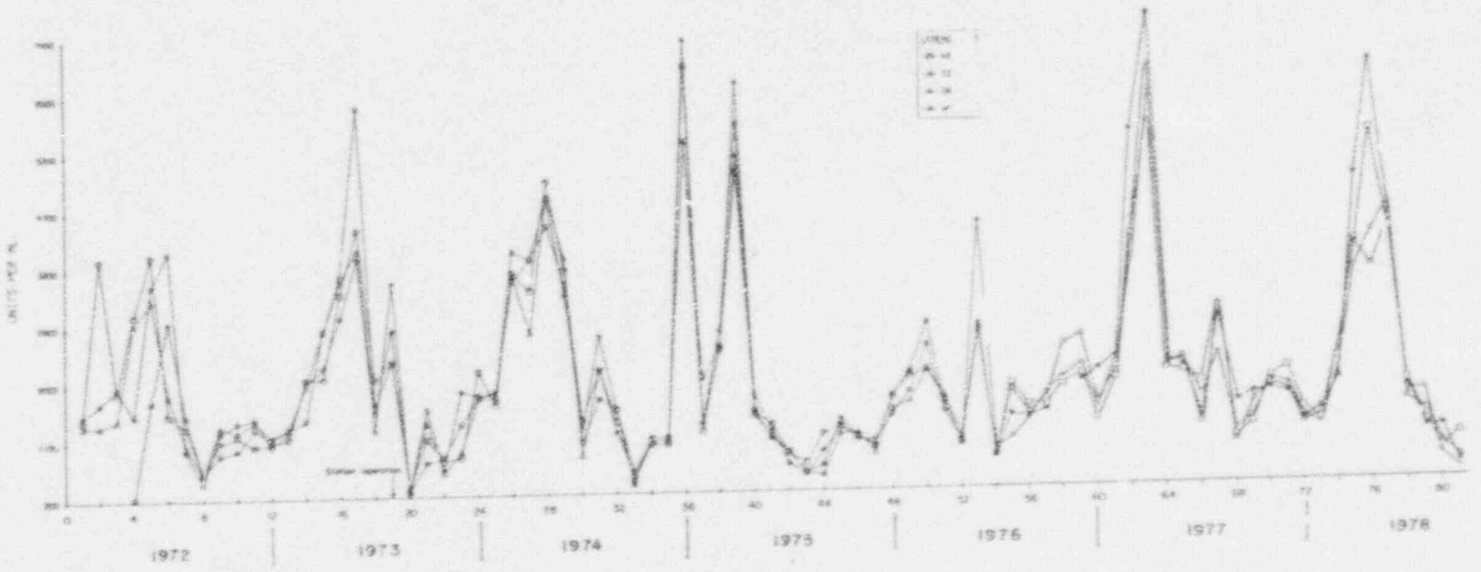


Figure 3. Mean density of total phytoplankton at the 9 meter locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978.

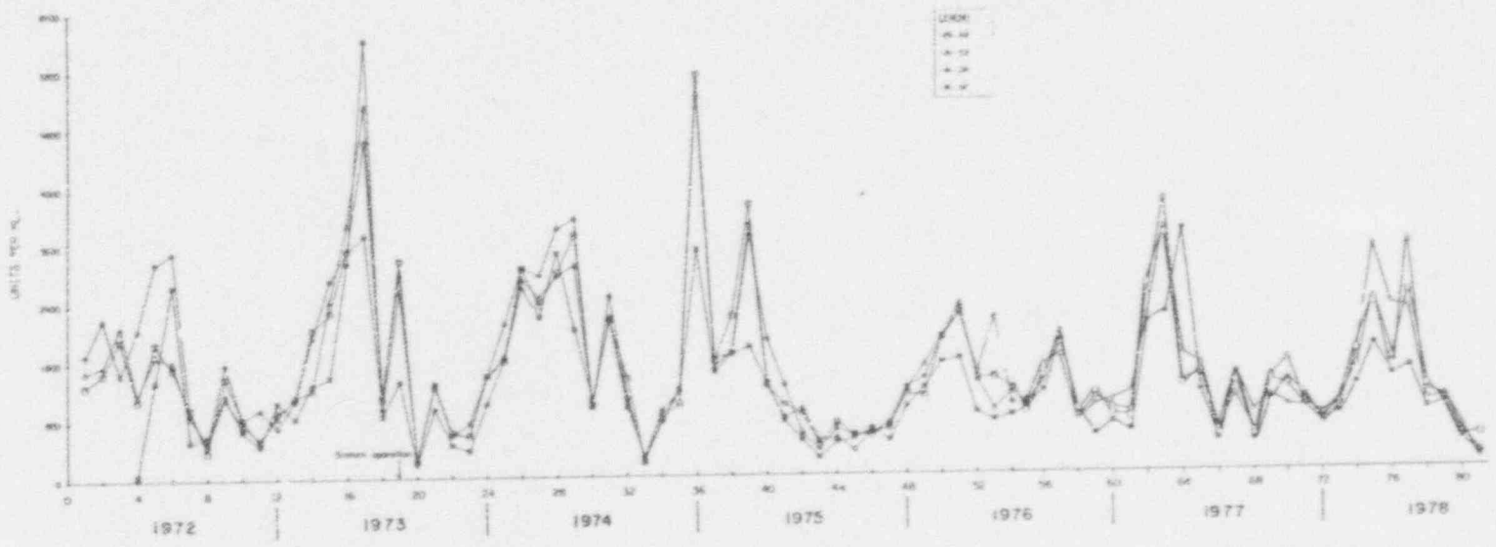


Figure 4. Mean density of total phytoplankton at the 18 meter locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978.

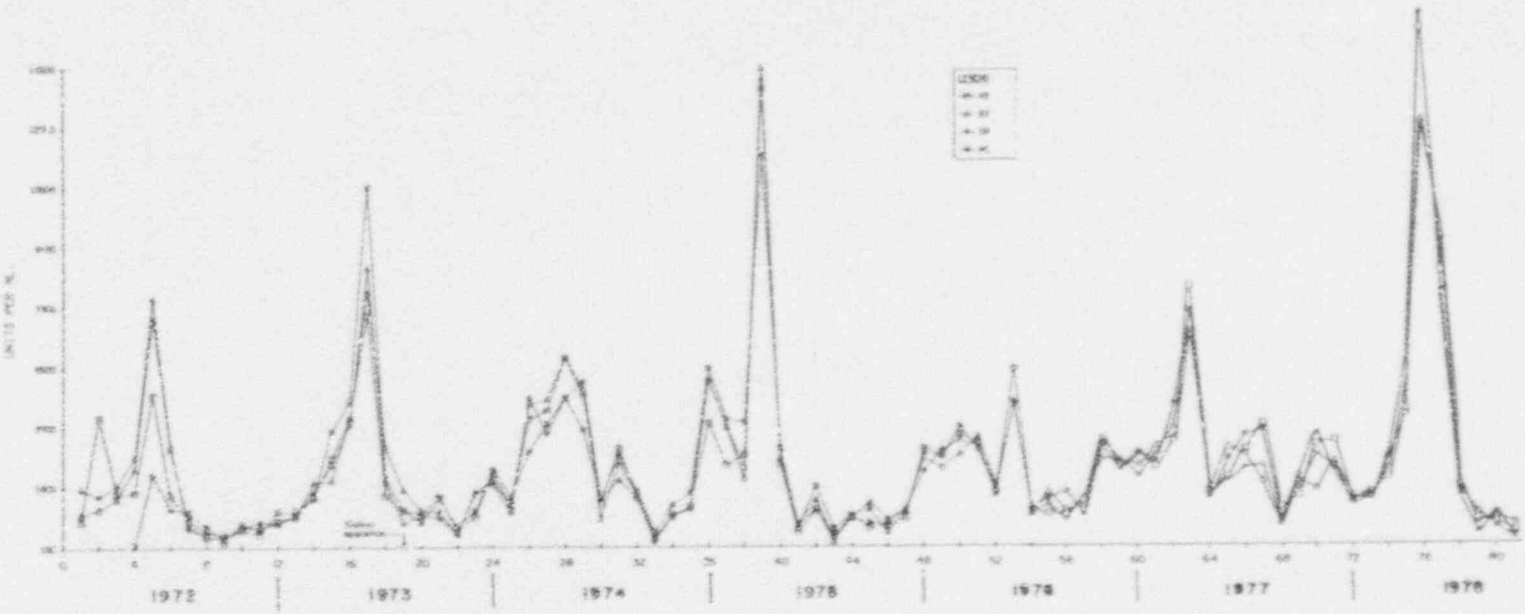


Figure 5. Mean density of the division Bacillariophyta at the 3 meter locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978.

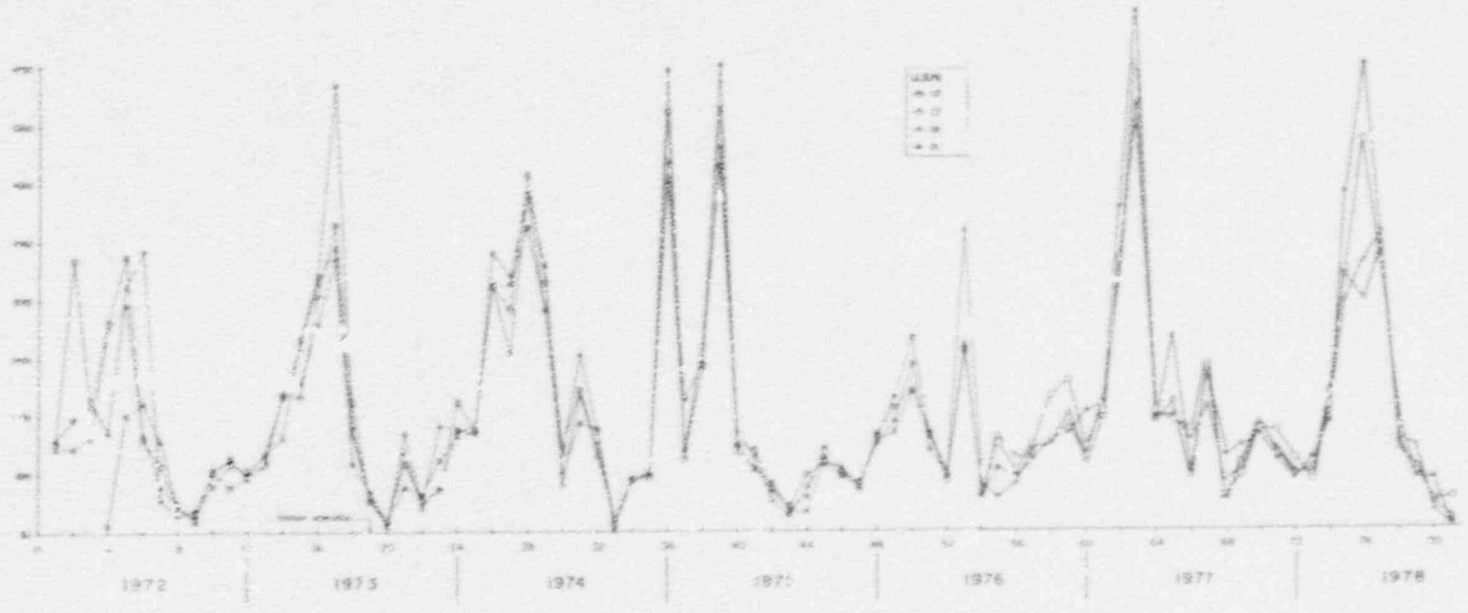


Figure 6. Mean density of the division Bacillariophyta at the 9 meter locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978.

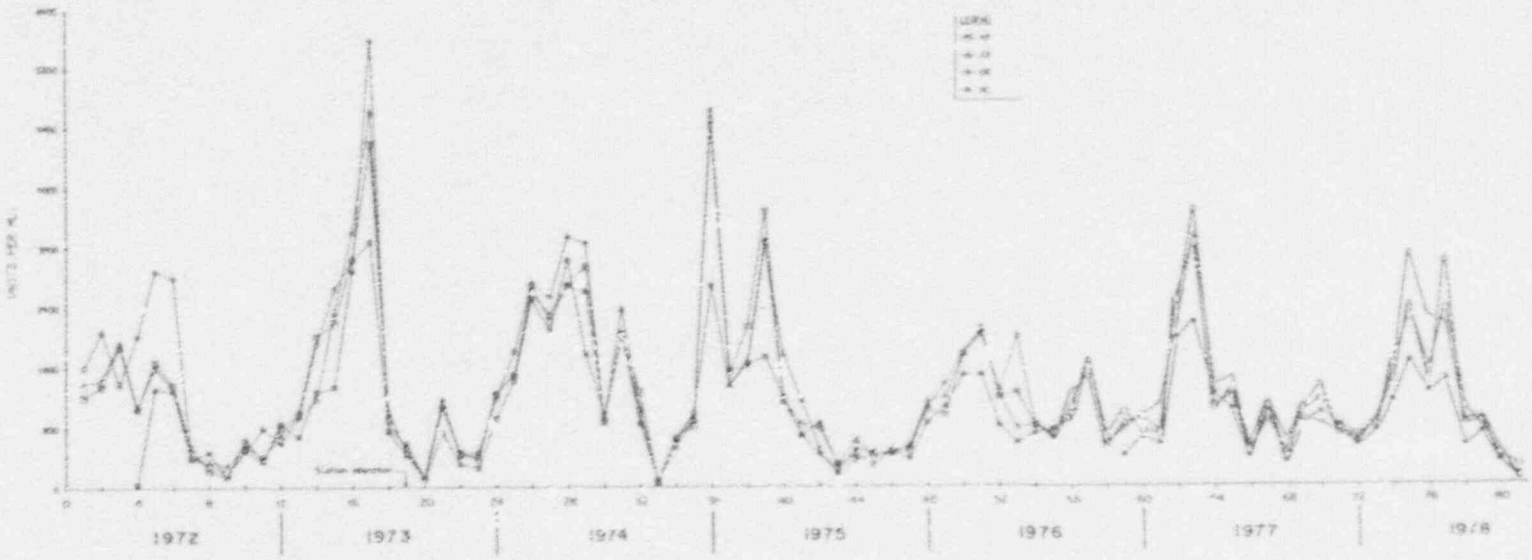


Figure 7. Mean density of the division Bacillariophyta at the 18 meter locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978.

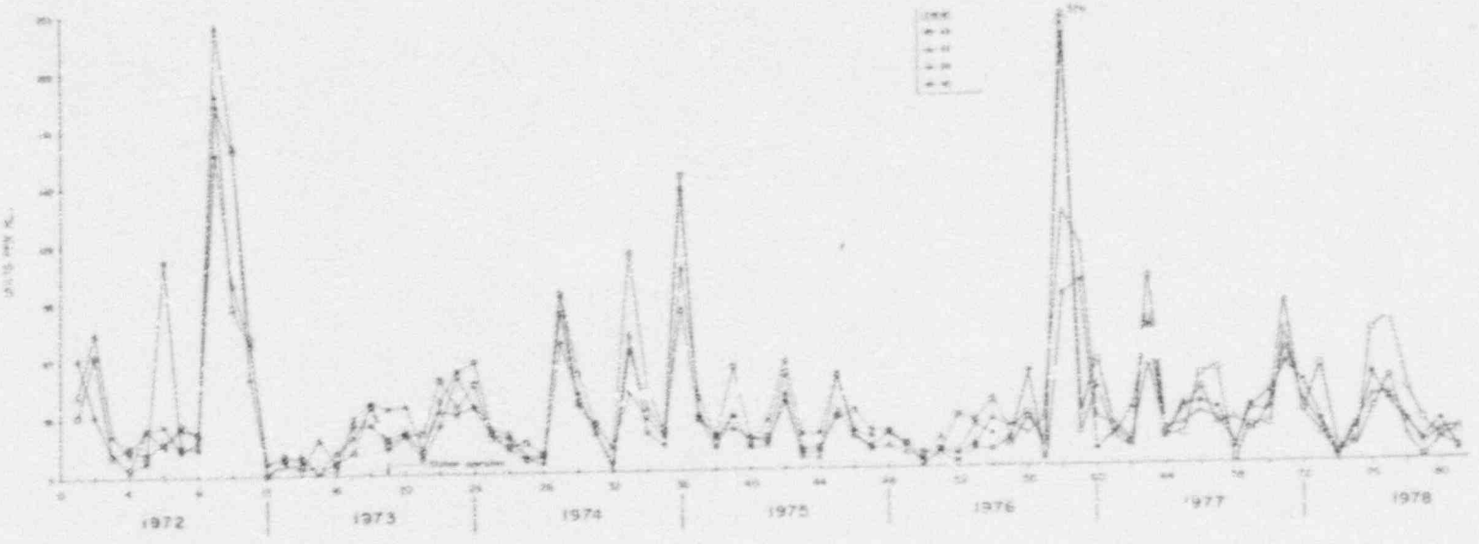


Figure 8. Mean density of the division Chlorophyta at the 3 meter locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978.

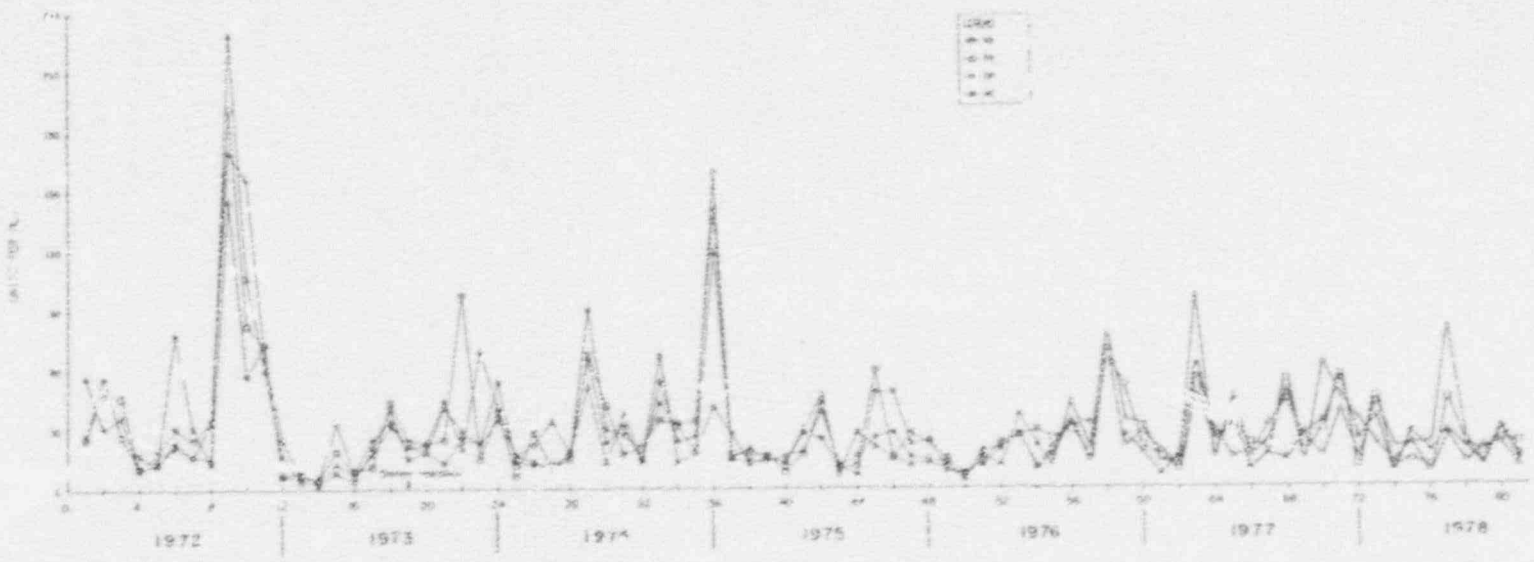


Figure 9. Mean density of the division Chlorophyta at the 9 meter locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978.

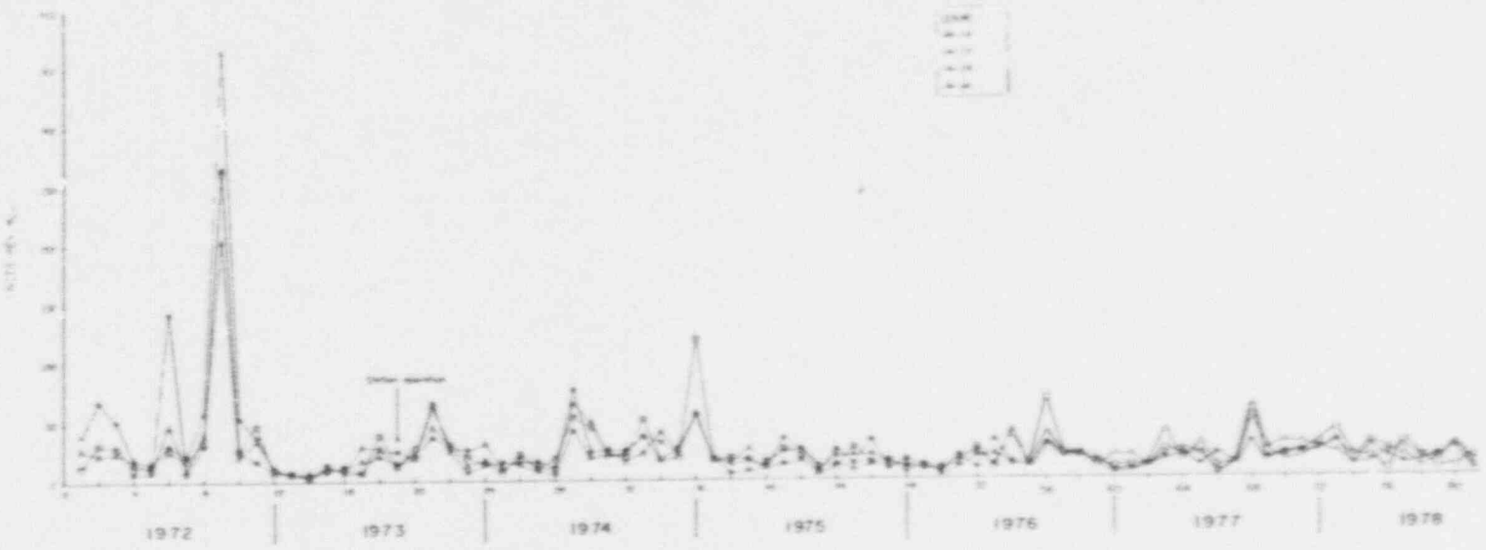


Figure 10. Mean density of the division Chlorophyta at the 18 meter locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978.

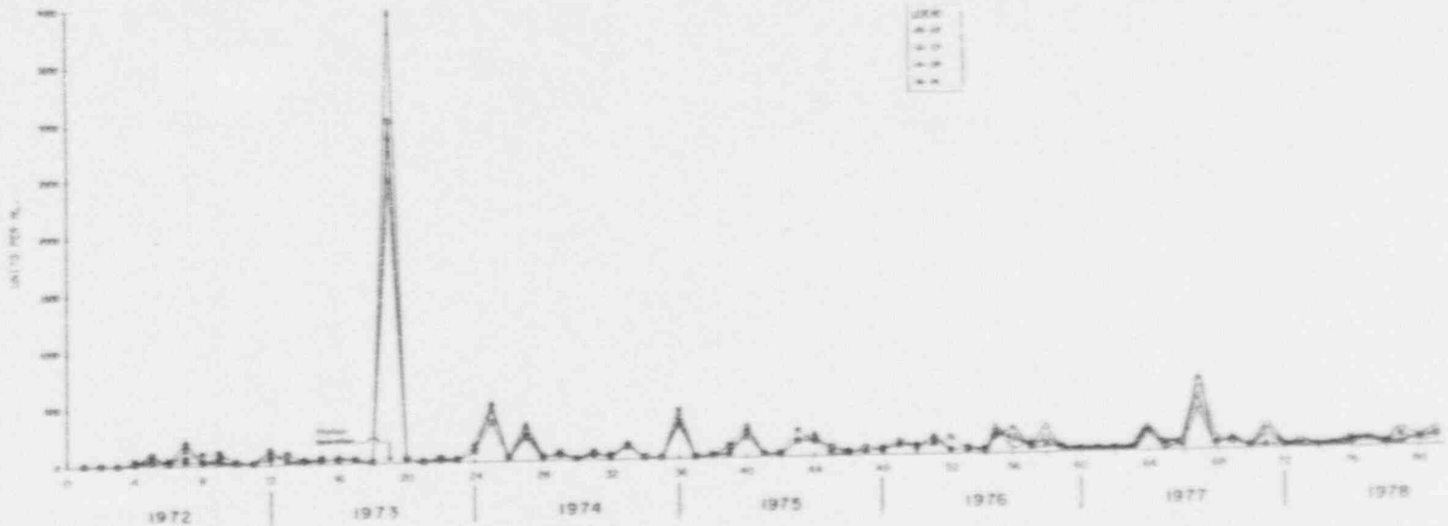


Figure 11. Mean density of the division Chrysophyta at the 3 meter locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978.

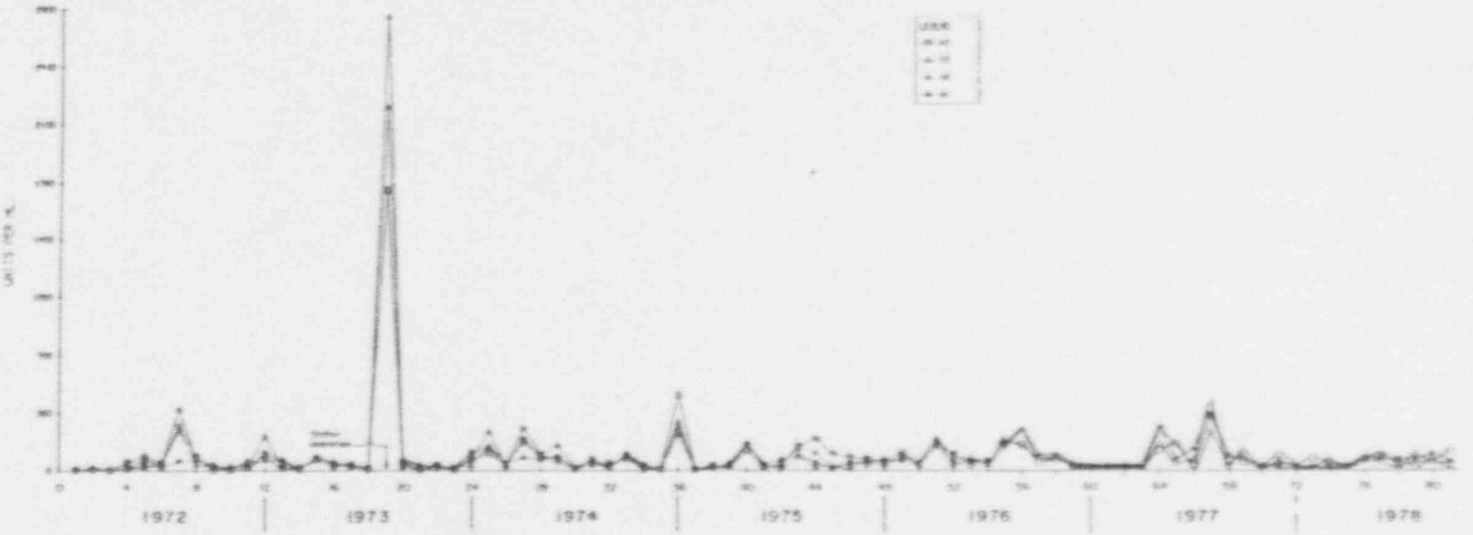


Figure 12. Mean density of the division Chrysophyta at the 9 meter locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978.

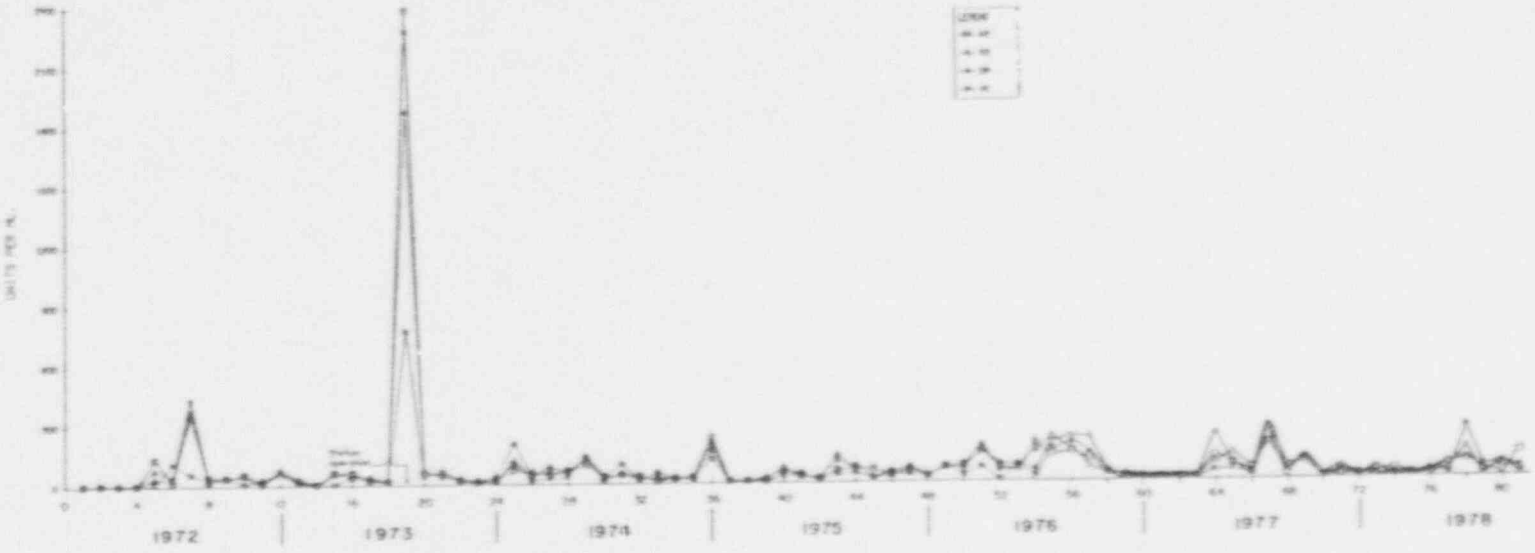


Figure 13. Mean density of the division Chrysophyta at the 18 meter locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978.



Figure 14. Mean density of the division Cyanophyta at the 3 meter locations in southwestern Lake Michigan near Zion, Illinois. January 1972 through September 1978.

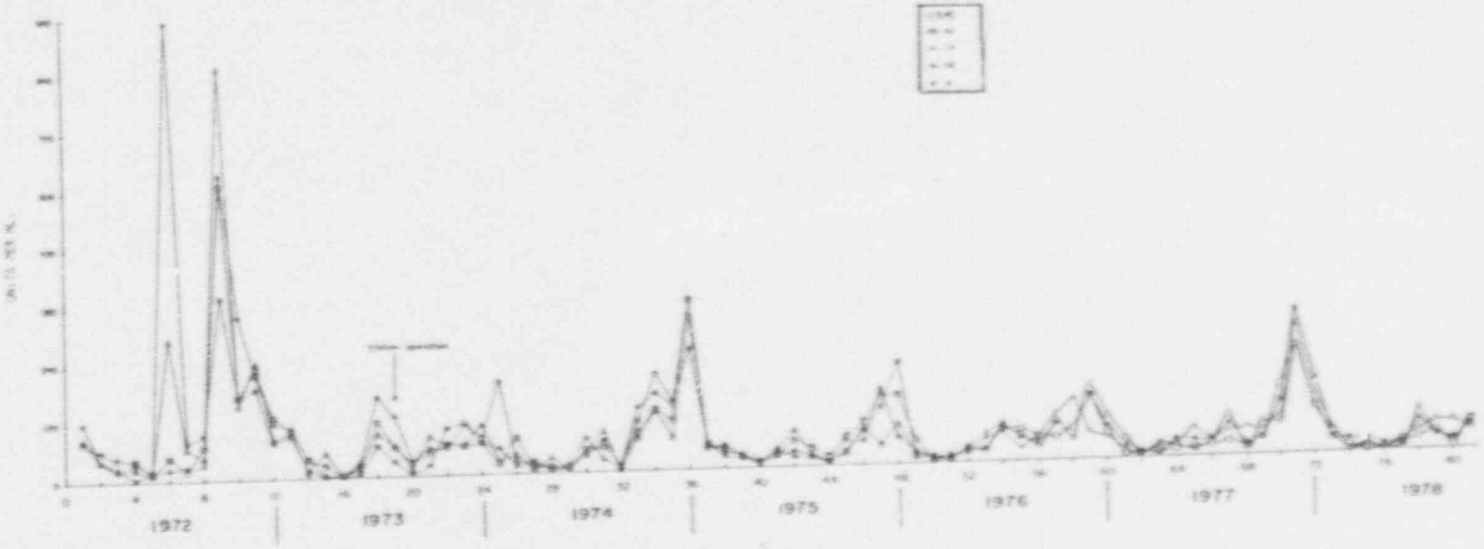


Figure 15. Mean density of the division Cyanophyta at the 9 meter locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978.

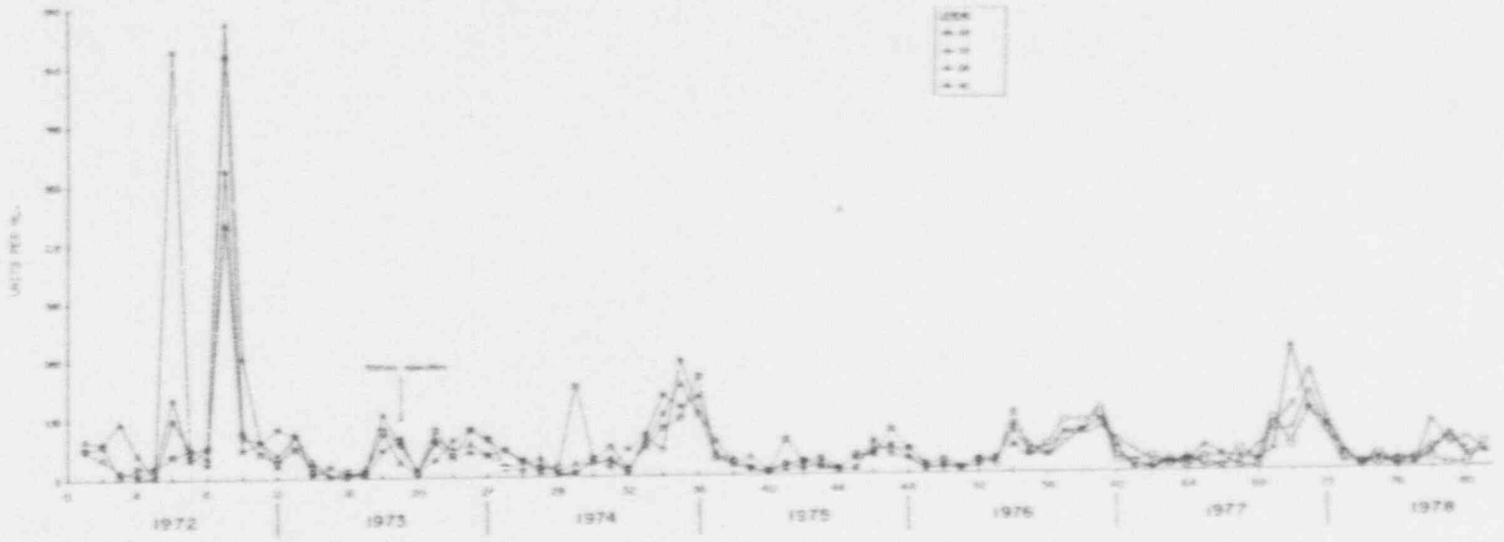


Figure 16. Mean density of the division Cyanophyta at the 18 meter locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978.

Table 3 Dominant algal taxa ranked as percent of the total phytoplankton density (D) at each location within the 9 meter depth contour in southwestern Lake Michigan near Zion, Illinois, July 1972 through June 1978.

July 1972-June 1973		July 1973-June 1974		July 1974-June 1975	
Taxa	%D	Taxa	%D	Taxa	%D
North Control (Location 30)		North Control (Location 30)		North Control (Location 30)	
Stephanodiscus sp.	27	Stephanodiscus sp.	20	Stephanodiscus binderanus	26
Tabellaria flocculosa	7	Stephanodiscus minutus	14	Stephanodiscus sp.	10
Melosira islandica	7	Fragilaria crotonensis	7	Stephanodiscus minutus	9
Fragilaria crotonensis	7	Dinobryon divergens	6	Tabellaria flocculosa	6
Stephanodiscus sp. 2	5	Stephanodiscus astraea	6	Fragilaria crotonensis	6
Stephanodiscus astraea	4	Tabellaria flocculosa	4	Stephanodiscus astraea	4
Rhizosolenia eriensis	3	Melosira islandica	3		
North Zion (Location 7)		North Zion (Location 7)		North Zion (Location 7)	
Stephanodiscus sp.	22	Stephanodiscus sp.	17	Stephanodiscus binderanus	22
Melosira islandica	8	Stephanodiscus minutus	16	Stephanodiscus minutus	10
Fragilaria crotonensis	7	Stephanodiscus astraea	7	Stephanodiscus sp.	9
Tabellaria flocculosa	7	Fragilaria crotonensis	6	Fragilaria crotonensis	8
Rhizosolenia eriensis	3	Dinobryon divergens	5	Tabellaria flocculosa	6
		Tabellaria flocculosa	4	Stephanodiscus astraea	4
		Melosira islandica	4		
South Zion (Location 12)		South Zion (Location 12)		South Zion (Location 12)	
Stephanodiscus sp.	21	Stephanodiscus sp.	19	Stephanodiscus binderanus	27
Tabellaria flocculosa	8	Stephanodiscus minutus	16	Stephanodiscus minutus	10
Fragilaria crotonensis	7	Stephanodiscus astraea	7	Stephanodiscus sp.	9
Melosira islandica	7	Fragilaria crotonensis	7	Fragilaria crotonensis	6
Coelosphaerium naegelianum	5	Dinobryon divergens	7	Tabellaria flocculosa	6
Stephanodiscus astraea	4	Tabellaria flocculosa	5	Stephanodiscus astraea	4
Rhizosolenia eriensis	2	Melosira islandica	3		
Dead River (Location 20)		Dead River (Location 20)		Dead River (Location 20)	
Stephanodiscus sp.	19	Stephanodiscus sp.	18	Stephanodiscus binderanus	29
Tabellaria flocculosa	8	Stephanodiscus minutus	14	Stephanodiscus sp.	9
Melosira islandica	7	Dinobryon divergens	7	Stephanodiscus minutus	8
Fragilaria crotonensis	6	Fragilaria crotonensis	7	Fragilaria crotonensis	7
Stephanodiscus sp. 2	5	Stephanodiscus astraea	7	Tabellaria flocculosa	6
Coelosphaerium naegelianum	5	Tabellaria flocculosa	5	Stephanodiscus astraea	4
Rhizosolenia eriensis	2	Melosira islandica	3		
		Dinobryon sociale			

Table 3 (continued).

July 1975-June 1976		July 1976-June 1977		July 1977-June 1978	
Taxa	%D	Taxa	%D	Taxa	%D
North Control (Location 30)		North Control (Location 30)		North Control (Location 30)	
Stephanodiscus sp.	17	Stephanodiscus minutus	16	Stephanodiscus minutus	26
Stephanodiscus minutus	16	Fragilaria crotonensis	13	Fragilaria crotonensis	12
Fragilaria crotonensis	10	Cyclotella kutzingiana		Cyclotella kutzingiana	
Asterionella formosa	5	var. radiosa	10	var. radiosa	4
Stephanodiscus binderanus	5	Synedra filiformis	6	Asterionella formosa	6
Melosira italica	5	Stephanodiscus sp.	3	Cyclotella stelligera	5
Melosira islandica	4	Stephanodiscus binderanus	3	Tabellaria flocculosa	5
Stephanodiscus astracea	4	Asterionella formosa	4	Synedra filiformis	3
Tabellaria flocculosa	3	Tabellaria flocculosa	4	Coelosphaerium naegelianum	3
North Zion (Location 7)		North Zion (Location 7)		North Zion (Location 7)	
Stephanodiscus sp.	15	Stephanodiscus minutus	16	Stephanodiscus minutus	24
Stephanodiscus minutus	14	Fragilaria crotonensis	13	Cyclotella kutzingiana	
Fragilaria crotonensis	10	Cyclotella kutzingiana		var. radiosa	11
Asterionella formosa	7	var. radiosa	10	Fragilaria crotonensis	10
Stephanodiscus binderanus	5	Synedra filiformis	6	Cyclotella stelligera	6
Melosira islandica	5	Stephanodiscus binderanus	4	Asterionella formosa	5
Tabellaria flocculosa	4	Asterionella formosa	4	Tabellaria flocculosa	5
Stephanodiscus astraea	3	Tabellaria flocculosa	4		
South Zion (Location 12)		South Zion (Location 12)		South Zion (Location 12)	
Stephanodiscus minutus	15	Stephanodiscus minutus	17	Stephanodiscus minutus	24
Stephanodiscus sp.	15	Fragilaria crotonensis	12	Cyclotella kutzingiana	
Fragilaria crotonensis	10	Cyclotella kutzingiana		var. radiosa	13
Asterionella formosa	7	var. radiosa	12	Fragilaria crotonensis	9
Stephanodiscus binderanus	6	Synedra filiformis	6	Cyclotella stelligera	7
Melosira islandica	5	Stephanodiscus sp.	5	Asterionella formosa	5
Tabellaria flocculosa	4	Asterionella formosa	4	Tabellaria flocculosa	4
Stephanodiscus astraea	3	Stephanodiscus binderanus	3		
		Tabellaria flocculosa	3		
Dead River (Location 20)		Dead River (Location 20)		Dead River (Location 20)	
Stephanodiscus sp.	14	Stephanodiscus minutus	15	Stephanodiscus minutus	24
Stephanodiscus minutus	13	Cyclotella kutzingiana	12	Cyclotella kutzingiana	
Fragilaria crotonensis	12	var. radiosa		var. radiosa	12
Stephanodiscus binderanus	9	Fragilaria crotonensis	12	Fragilaria crotonensis	9
Asterionella formosa	6	Synedra filiformis	6	Cyclotella stelligera	7
Melosira italica	5	Stephanodiscus sp.	4	Asterionella formosa	5
Melosira islandica	4	Stephanodiscus binderanus	4	Tabellaria flocculosa	5
Tabellaria flocculosa	3	Asterionella formosa	4	Synedra filiformis	3
Stephanodiscus astraea	3	Cyclotella stelligera	4	Coelospherium naegelianum	3
Rhizosolenia eriensis	2	Diatoma tenue var. elongatum	3		
		Tabellaria flocculosa	3		

(Huh, et al. 1973, p. 22). A smaller secondary peak of diatoms was also recorded in February. The most commonly encountered dominant taxa were Fragilaria crotonensis, Tabellaria flocculosa, Stephanodiscus (hantzschii-tenuis), S. binderanus and Asterionella formosa (Huh, et al. 1973, pp. 16, 22).

The peak abundance of blue-green algae from September through December and their occasional dominance of the community during this period was not recorded during the previous monitoring program (Huh, et al. 1973, p. 37). No unusual chemical or physical differences between monitoring years was noted; therefore, the blue-green abundance patterns were attributed to normal population fluctuations (Huh, et al. 1973, p. 37).

Inshore to offshore phytoplankton assemblage differences were noted throughout the year. Diatom densities decreased from inshore to offshore; whereas, diversity values increased from inshore to offshore (Huh, et al. 1973, p. 16).

January - December 1972

A relatively small February peak of total phytoplankton was followed by a large May peak (Mayhew 1974, pp. 18, 30). Diatoms comprised the majority of both of the total phytoplankton peaks and were the predominant algae throughout the year except during September and October (Mayhew 1974, p. 34). The September and October populations were dominated by blue-green algae and, to a lesser extent, green algae (Mayhew 1974, pp. 46, 49).

The dominant diatoms were Stephanodiscus spp., S. binderanus, S. (hantzschii-tenuis), Asterionella formosa, Rhizosolenia eriensis, Fragilaria crotonensis, and Tabellaria flocculosa (Mayhew 1974, p. 34).

The most apparent trend in the data was the inshore to offshore differences for most phytoplankton assemblage components. As reported in the previous monitoring program, total phytoplankton and most of the diatoms were less abundant offshore than at the inshore locations (Mayhew 1974, pp. 58, 60, 67-88). Results of statistical analyses also supported the inshore to offshore data trends. There were also significant differences ($p \leq 0.05$) between locations along the same depth contour in densities of some phytoplankton taxa. The differences were not reflective of any consistent or biologically meaningful separation of the North Control, North Zion, South Zion, and Dead River monitoring areas.

January - June 1973

Total phytoplankton was most abundant in May (Mayhew 1973). Diatoms dominated throughout the six-month period and were primarily represented by Melosira islandica, M. italica, Rhizosolenia eriensis, Stephanodiscus spp. and Fragilaria crotonensis (Mayhew 1973).

July 1973 - June 1974

Total phytoplankton generally decreased from July to the low of August through October; this was followed by an increase to the peak densities of May (Mayhew and Barber 1974, pp. 12, 13). Diatoms dominated throughout the year except during July when species

of Dinobryon (Chrysophyta) dominated (Mayhew and Barber 1974, pp. 12, 22-23). Green algae were generally minor constituents of the phytoplankton and were most abundant during May (Mayhew and Barber 1974, p. 19). Blue-green algae were most abundant during June, July, and November (Mayhew and Barber 1974, p. 21).

The most commonly encoutered dominant diatoms were Melosira islandica, Rhizosolenia eriensis, Stephanodiscus astraea, S. minutus, S. spp., Asterionella formosa, and Fragilaria crotonensis (Mayhew and Barber 1974, p. 12).

Results of statistical analysis on total phytoplankton generally reflected differences in diatom densities (Mayhew and Barber 1974, p. 28). There were no apparent differences in assemblage components between the experimental and control locations which could be attributed to this first year of Zion Station operation.

July 1974 - June 1975

Population peaks of total phytoplankton were during July, December, and March; whereas, lowest densities were generally recorded in September (Barber and Redmond 1974, p. 22).

Diatoms were the major components of total phytoplankton except during September (Barber and Redmond 1974, pp. 24, 26). The most commonly occurring dominant diatoms were Stephanodiscus spp., S. binderanus, S. minutus, Asterionella formosa, Tabellaria flocculosa, and Fragilaria crotonensis (Barber and Redmond 1975, p. 29).

Green algae, blue-green algae, and chrysophytes exhibited peaks during the winter months (Barber and Redmond 1974, pp. 39, 41, 44). These groups also shared dominance over the usually dominant diatoms during September.

Phytoplankton density decreased from inshore to offshore at all transects (Barber and Redmond 1974, p. 19). Results of statistical analyses did not follow a general trend of control locations being significantly different from experimental locations (Barber and Redmond 1975, p. 19). The operation of Zion Station did not apparently significantly affect the composition of the phytoplankton community in the vicinity of Zion Station (Barber and Redmond 1975, p. 67).

July 1975 - June 1976

The phytoplankton data from this years' monitoring program were combined with previous monitoring program data in order to compare the phytoplankton community over preoperational and operational periods. The July 1975 through June 1976 phytoplankton data did not vary substantially from previous data.

From January 1972 through June 1976 the sizes of the seasonal peak densities were somewhat variable; however, the March-May seasonal maxima and the somewhat smaller late fall/early winter seasonal peak were fairly consistent (Barber and Redmond 1976, p. 53).

Diatoms usually dominated from January 1972 through June 1976 and followed the same general patterns as total phytoplankton (Barber and Redmond 1976, p. 55). The most commonly occurring

species were Stephanodiscus spp., S. minutus, S. astraea, S. binderanus, Melosira islandica, Rhizosolenia eriensis, Asterionella formosa, Fragilaria crotonensis, and Tabellaria flocculosa (Barber and Redmond 1976, p. 27.)

Densities of green algae did not follow distinct seasonal patterns, however, they were generally most abundant from May through December (Barber and Redmond 1976, p. 72).

Maximum densities of blue-green algae generally occurred during September through December and June and July (Barber and Redmond 1976, p. 74).

There were no changes in total phytoplankton or in any of the assemblage components over time or between sampling areas which were attributable to effects of Zion Station operation (Barber and Redmond 1976, pp. 55, 56, 69-74).

July 1976 - June 1977

Total phytoplankton was most abundant in March and exhibited a somewhat smaller peak in October (Barber and Redmond 1976, p. 22). Densities decreased from inshore to offshore. There were no apparent consistent differences in total phytoplankton between control and experimental sampling areas (Barber and Redmond 1976, p. 22).

Diatoms again dominatd the community and followed the same general trend as total phytoplankton (Barber and Redmond 1976, p. 25). The dominant species compared favorably with those reported from previous programs (Barber and Redmond 1976, pp. 25-35).

Green algae reached peak densities in the spring and the fall; whereas, blue-green algae reached peak densities during the fall only (Barber and Redmond 1976, pp. 35, 41).

There were no apparent trends in the data which were attributable to any effect of Zion Station operation.

July 1977 - June 1978

The spring peak in total phytoplankton occurred in April; the fall peak was smaller than usual and not very apparent (Festin and Redmond, 1978, p. 22). The diatoms dominated the phytoplankton and followed the same seasonal trend (Festin and Redmond 1978, p. 25). The most commonly encountered diatoms were Stephanodiscus minutus, Cyclotella kutzingiana v. radiosa, C. stelligera, Asterionella formosa, Fragilaria crotonensis, and Tabellaria flocculosa (Festin and Redmond 1978, p. 19).

Densities of green algae were not very consistent and reflected a not very discernable spring and fall pulse (Festin and Redmond 1978, pp. 36-39). Blue-green algae were most abundant in November (Festin and Redmond 1978, p. 42).

There were no consistent trends in the respective algal components which reflected any difference between control and experimental sampling areas.

July - September 1978

In general, total phytoplankton densities decreased slightly from July to September (Festin and Bartholomew 1979, p. 196). Diatoms were the dominant algae and were primarily represented by Cyclotella kutzingiana v. radiosa, Fragilaria crotonensis,

and Tabellaria flocculosa (Festin and Bartholomew 1979, p. 197). There were no considerable differences between months in densities of green algae, blue-green algae and the other algal divisions (Festin and Bartholomew 1979, pp. 197, 198). No trends were apparent in the data which reflected any difference between control and experimental sampling areas.

B. Primary Productivity

Primary productivity data were collected monthly from July 1972 through September 1978 at the same stations sampled for phytoplankton abundance and corposition (Figures 17 - 22). The phytoplankton assemblage in the study area generally exhibited a bimodal periodicity pattern indicating spring and fall peaks in carbon fixation rates and chlorophyll a concentrations. Chlorophyll a concentrations also displayed pulses in the summers of 1973 and 1974. This periodicity pattern is common and is typical of most of Lake Michigan as well as other temperate midwest lakes. Large temporal fluctuations in primary productivity were characteristic of the entire study area throughout the seven sampling years. Phytoplankton carbon fixation rates and chlorophyll a concentrations, in general, followed patterns of temporal fluctuation which resembled the patterns observed in total phytoplankton abundance as documented earlier in this report.

Physical factors such as water temperature, availability of nutrients, speed and direction of both lake currents and surface winds as well as total insolation share a high degree of responsibility as causes of heterogeneous ("patchy") phytoplankton

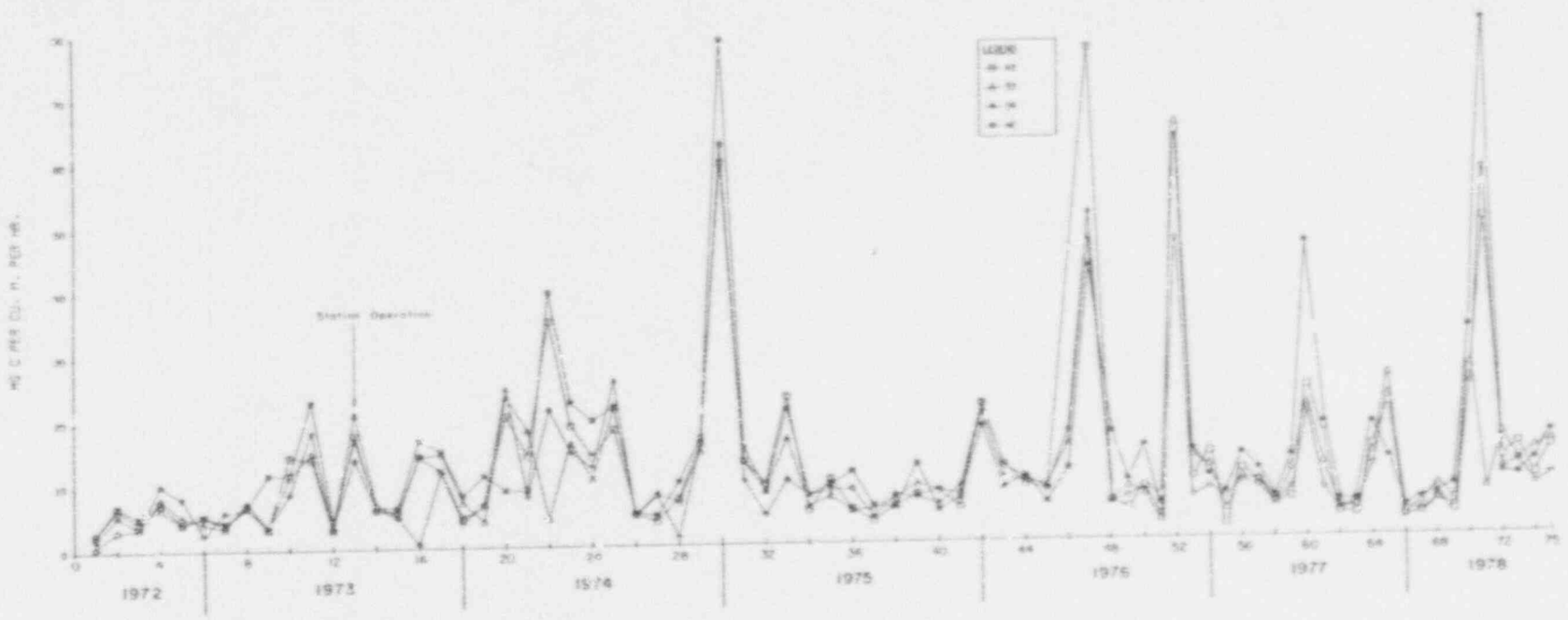


Figure 17. Carbon fixation rates (mg C/m^3 per hr) of phytoplankton collected at the 3m depth contour in southwestern Lake Michigan near Zion, Illinois, July 1972 through September 1978.

HAZLETON ENVIRONMENTAL SCIENCES

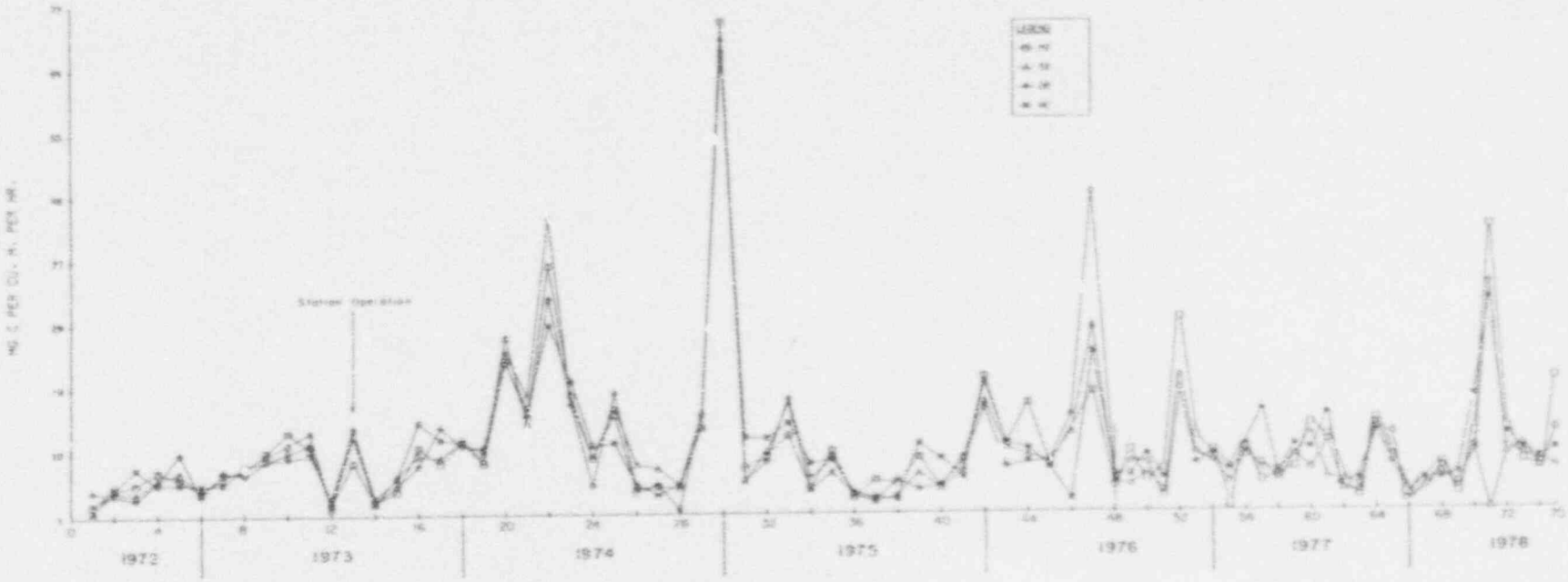


Figure 18. Carbon fixation rates (mg C/m^3 per hr) of phytoplankton collected at the 9m depth contour in southwestern Lake Michigan near Zion, Illinois, July 1972 through September 1978.

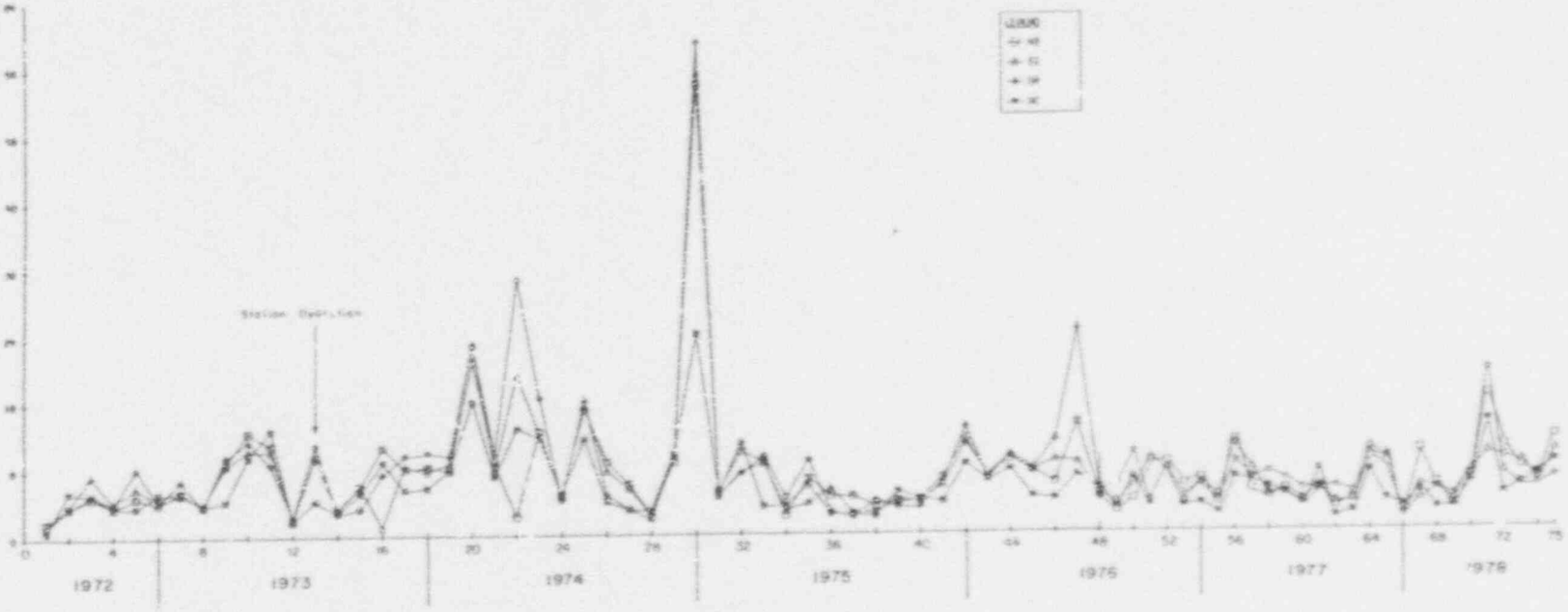


Figure 19. Carbon fixation rates (mg C/m^3 per hr) of phytoplankton collected at the 18m depth contour in southwestern Lake Michigan near Zion, Illinois, July 1972 through September 1978.

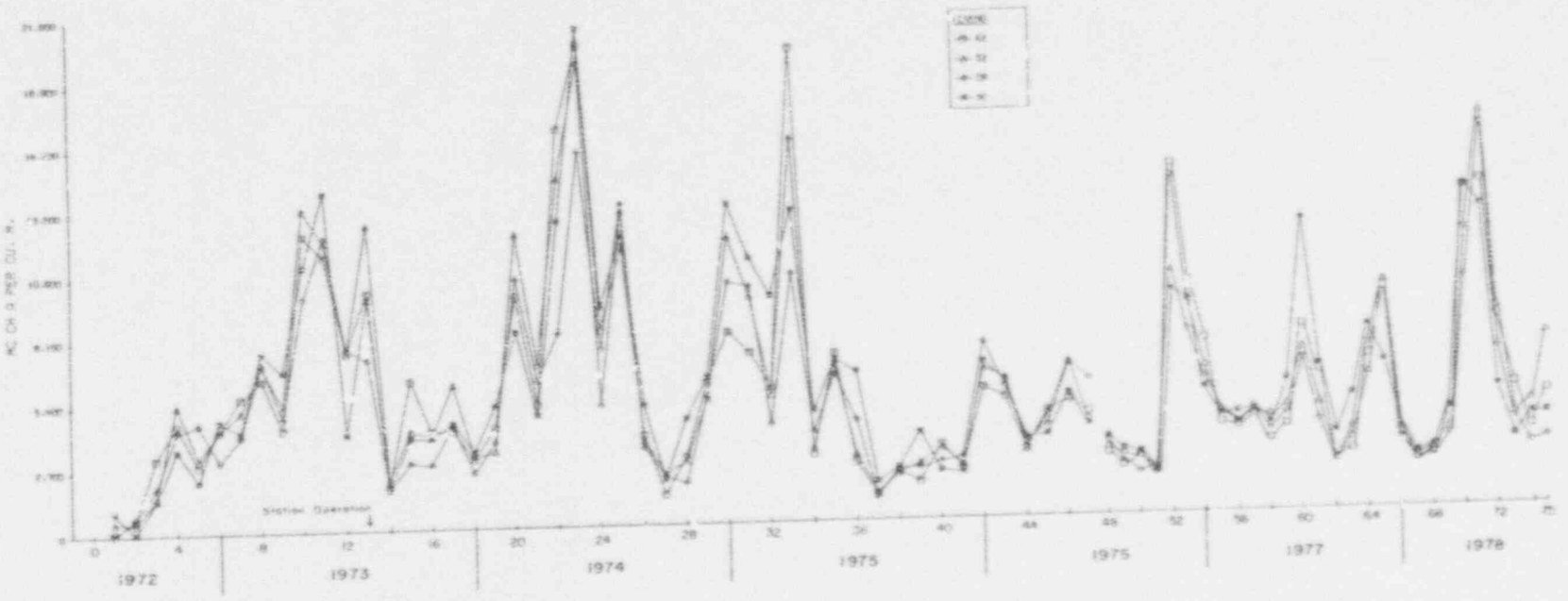


Figure 20. Chlorophyll a concentrations (mg chl a/m^3) of phytoplankton collected at the 3m depth contour in southwestern Lake Michigan near Zion, Illinois, July 1972 through September 1978.

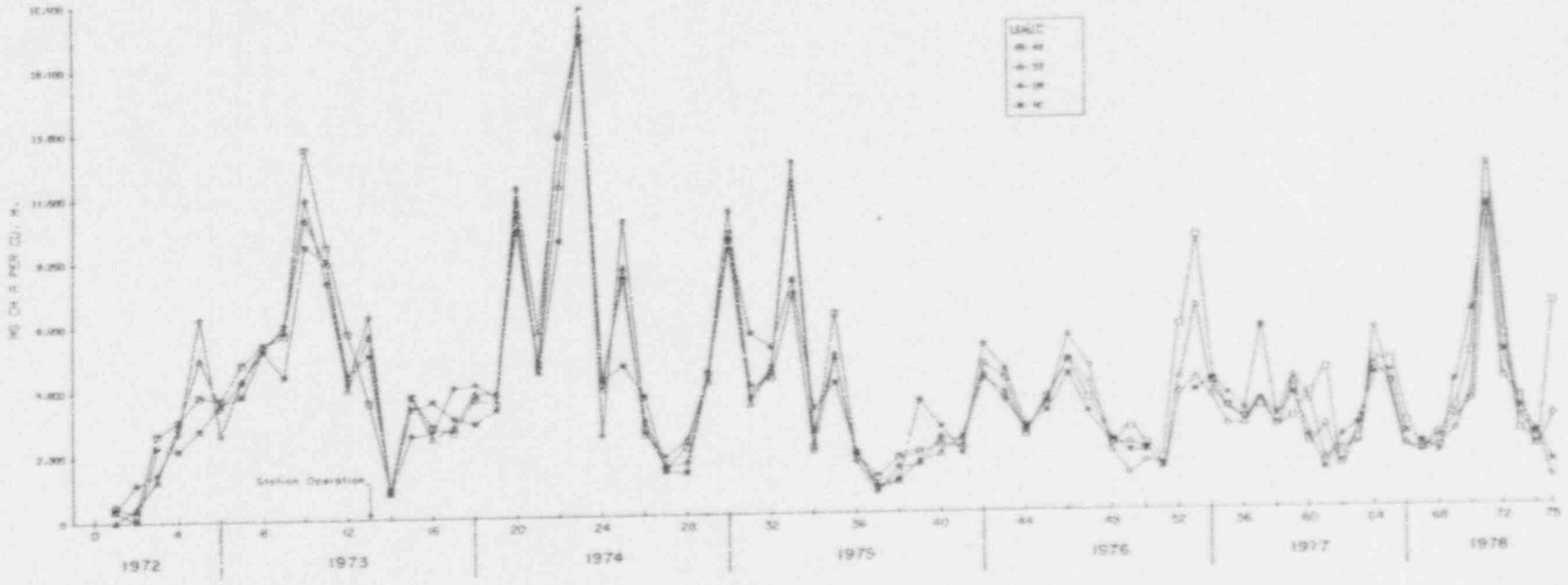


Figure 21. Chlorophyll a concentrations (mg chl a/m^3) of phytoplankton collected at the 9m depth contour in southwestern Lake Michigan near Zion, Illinois, July 1972 through September 1978.

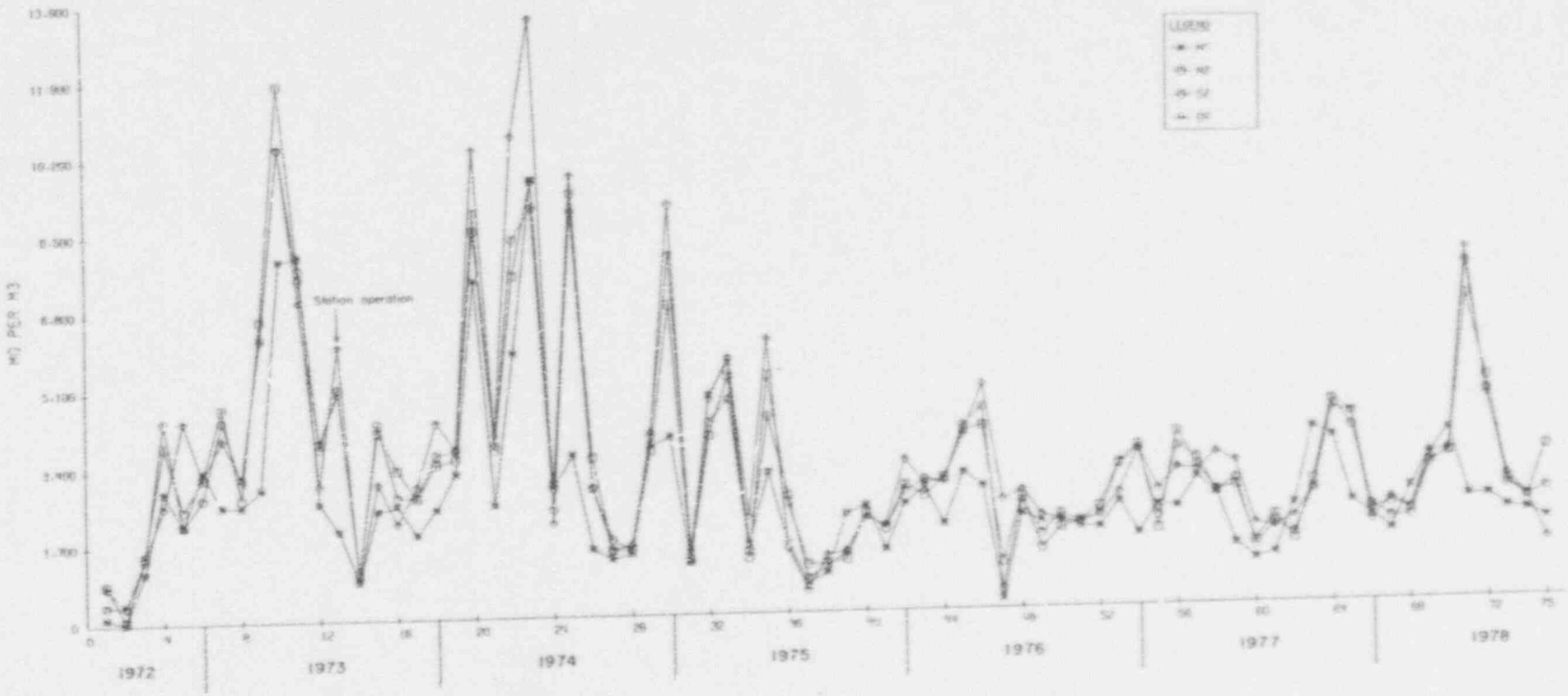


Figure 22. Chlorophyll a concentrations (mg chl a/m^3) of phytoplankton collected at the 18m depth contour in southwestern Lake Michigan near Zion, Illinois, July 1972 through September 1978.

distribution. This uneven distribution of the phytoplankton assemblage undoubtedly contributed to the large temporal fluctuations in primary productivity dat documented in this report.

July 1972 to December 1972

Carbon fixation values and chlorophyll a concentrations were the highest during October and November during this sampling year (Bremer 1973, p. 157). These peaks were related to corresponding high phytoplankton population densities. Carbon fixation rates ranged from 0.17 to 10.04 mg C/m^3 per hr. Mean chlorophyll a concentrations during July through December ranged from 0.02 to 7.20 mg chl a/m^3. Generally, offshore locations exhibited reduced carbon fixation rates and chlorophyll a values when compared to midshore locations (Bremer 1973, p. 160). Transect comparisons at each depth contour had similar values for the productivity parameters measured.

January 1973 to June 1973

Mean carbon fixation rates ranged from 1.76 to 22.9 mg C/m^3 per hr while chlorophyll a concentrations ranged from 2.55 to 14.20 mg chl a/m^3 (Redmond and Bremer 1973). Peak va. . in productivity parameters were observed in the spring pulse in phytoplankton populations. January and June had the lowest carbon fixation rates and chlorophyll a concentrations measured during the six month period. Monthly factorial analyses of variance showed no apparent trends between transects or depth contours in either productivity parameter.

July 1973 to June 1974

Chlorophyll a concentrations and carbon fixation rates were the lowest at the 3m depth contour in December (Redmond 1974, p. 331). The highest carbon fixation rates and chlorophyll a values at the 3m depth contour locations were during April and May, respectively (Redmond 1974, p. 329). Mean carbon fixation rates and chlorophyll a concentrations ranged from 0.58 to 39.48 mg C/m^3 per hr and from 0.86 to 35.50 mg chl a/m^3, respectively. Seasonal fluctuations of each of these parameters followed much the same pattern at each of the three depth contours through the year. Except during December, January and February the inshore location values were greater than the offshore.

July 1974 to June 1975

Peak carbon fixation rates and chlorophyll a concentrations were measured during December and March. Physical factors such as wind speed and direction, water temperature, availability of nutrients and insolation are responsible, in part, for the temporal fluctuations documented in this report. The high carbon fixation rates measured in December, for example, were probably a result of strong northeasterly winds encountered for several days prior to sampling. Both productivity parameters measured followed temporal patterns which generally resembled those observed in total phytoplankton abundance. Highest carbon fixation rates and chlorophyll a concentrations were measured at 3m locations and the lowest values were measured at 18m locations. The mean ranges for carbon fixation rates and chlorophyll a concentrations

were 1.16 to 78.39 mg C/m^3 per hr and 1.21 to 19.90 mg chl *a*/m^3, respectively (Barber and Redmond 1975, p. 50-53).

July 1975 to June 1976

Peak primary productivity values were bimodal occurring during December and May in this sampling period as previously recorded during the past four year. The highest carbon fixation rates and chlorophyll *a* concentrations occurred during May 1976. Mean values for carbon fixation rates and chlorophyll *a* concentrations ranged from 1.90 to 76.45 mg C/m^3 per hr and from 0.48 to 17.80 mg chl *a*/m^3, respectively (Barber and Redmond 1976, pp. 76-87).

July 1976 to June 1977

Bimodal peaks of phytoplankton productivity typically found in temperate northern lakes were documented during this study period and in other previous studies. Pulses of carbon fixation rates and chlorophyll *a* concentrations were documented during October and June and corresponded to peaks in phytoplankton biovolumes recorded at the same time. Mean carbon fixation rates ranged from 1.94 to 64.56 mg C/m^3 per hr while chlorophyll *a* concentrations measured between 1.26 and 14.70 mg chl *a*/m^3 during the sampling period (Barber and Redmond 1977, p. 44). Both productivity parameters displayed the recurrent offshore decline in values. Statistical analyses as presented in the past reports and in this report (Barber and Redmond 1977, pp. 56-57) were not consistent enough to produce significant trends in the experimental vs. control location. Occasional monthly statistics sometimes

revealed significant differences, but were not consistent. Prior to July 1976 the Zion operating license was restricted to 85% of the thermal power (Table 2, Chapter 2). Additional increase in power generation and therefore thermal discharge after July 1976 did not significantly effect the differences in the parameters between experimental and control locations.

July 1977 to [illegible] 78

As documented [illegible] revious years the typical bimodal peak in phytoplankton productivity recurred, being evident in November 1977 and May 1978. As in past studies, maxima in both parameters occurred in the spring with a smaller peak in the fall which generally corresponded to phytoplankton density and bio-volume patterns. A trend of decreasing carbon fixation rates and chlorophyll a concentrations was evident as water depth increased from 3 to 18 meters. These differences were probably a result of higher water temperatures and greater nutrient loads of nearshore waters compared with offshore waters. Mean carbon fixation rates ranged from [illegible].09 to 79.63 mg C/m^3 per hr (both occurring in May 1978) while average chlorophyll a concentrations ranged from 0.96 to 16.53 mg chl a/m^3 (Festin and Redmond 1978, p. 46).

The carbon fixation rate during May at the South Zion 9m location was 0.00 mg C/m^3 per hr. The North Control, North Zion and Dead River 9m locations had carbon fixation rates of 31, 39 and 33 mg C/m^3 per hr (Festin and Redmond 1978, p. 52). This large difference in values was statistically significant

and an identical trend at the 3m transect was also statistically significant (Festin and Redmond 1978, p. 57). No consistent differences could be detected in the parameters which may effect productivity, e.g., temperature, pH, dissolved oxygen or nutrients. Immediate variations in chlorophyll a concentrations did not correlate with reduced levels of primary production, however, this would not be expected as discussed in Section C.

July 1978 to September 1978

An additional three months of sampling was continued through September 1978. During the three month period carbon fixation rates ranged from 5.11 to 19.49 mg C/m^3 while chlorophyll a concentrations ranged from 1.92 to 7.24 mg chl a/m^3 (Festin and Bartholomew, 1979, p. 199). Decreasing carbon fixation rates and chlorophyll a concentrations occurred from the 3m to the 18m depth contour except during September along the North Zion transect. An increase in productivity at the 9m North Zion location compared to the 3m location followed an increase in phytoplankton densities at the 9m North Zion location also. Again there were statistically significant differences between experimental and control locations, but with no consistent trend.

C. Phytoplankton Entrainment

1. Immediate Effects

During the 1973 and 1974 entrainment study, discharge tunnel samples were compared to simultaneously collected intake forebay samples. Concurrent instantaneous collections were an attempt to help minimize the widespread effect of plankton patchiness in

Lake Michigan. Chlorophyll a concentrations were reduced during seven of the ten sampling periods for which there was no temperature increase (ΔT) across the condenser suggesting mechanical effects, and six of the ten samplings for which there was a measured ΔT. Changes in chlorophyll a concentrations following condenser passage followed no apparent seasonal trend. There was no consistent relationship to presence or magnitude of a ΔT. Reductions in abundance ranged from 3% to 26% during samplings of no ΔT (mechanical effects only). Slightly smaller reductions were noted during periods when a ΔT was present with values ranging from 2% to 3% (Restaino et al., 1975, p. 21). The wide variability of results and apparently random pattern of fluctuations resulted from natural variation in abundance and the difficulty of sampling the same water mass before and after plant passage rather than from plant effects. The best estimate of plant effects on chlorophyll is, therefore, the grand mean of all observations which yields a reduction in abundance of just over 2%.

Carbon fixation rates, like chlorophyll a concentrations, were generally reduced immediately following condenser passage. Reduced carbon fixation rates were observed at the discharge relative to the intake on fifteen of the twenty samplings conducted during the study period. Seven of these reductions or inhibitions occurred during periods when there was no ΔT, eight occurred when a ΔT was present. Increases in carbon fixation rate occurred on five occasions. Two of these (October 1973 and September 1974) were observed during periods of power production (ΔT = 9 and 7.3 C).

The data suggest no consistent seasonal aspect to the immediate effects of condenser passage on carbon fixation rates. Although relatively large inhibitions occurred during the months of March, April, and May with reductions ranging from 13% to 47%, a similar reduction (22%) was measured in July 1974 (Restaino et al. 1975, p. 24). No incidence of stimulation or increased carbon fixation rate was noted during these periods. The reductions in carbon fixation rate during the periods of no ΔT tended to be smaller than those noted when heat was applied. In the former case (no ΔT), values ranged from 1% to 22% inhibition while the reductions in carbon fixation rate when ΔT was present ranged from <1 to 47%.

No apparent correlation between differences in carbon fixation rate and the magnitude of ΔT was noted for ΔT values ranging from 4.5 C to 11.0 C. The smallest reduction (<1%) occurred during February when the minimum ΔT (4.5 C) was recorded. However, stimulations of 25% and 4% were noted in October 1973 and September 1974 with ΔT values of 9 C and 7.3 C, respectively. Values for ΔT ranging from 6.4 C to 9.2 C measured during other sampling periods had corresponding inhibitions that ranged from 10% to 47% (Restaino et al. 1975, p. 25.)

During the 1976 and 1977 entrainment study, whenever the ambient water temperature was greater than 8 C, the carbon fixation rates were inhibited, i.e., carbon rates at the plant discharge location were less than those at the intake forebay (Bartholomew and Redmond 1977, pp. 34-35). Conversely, when the ambient lake water temperature fell below 8 C the carbon fixation rates showed

stimulation at the discharge tunnel. Two exceptions to this trend occurred during May and June when the differences between the intake forebay and discharge tunnel were less than 10%. Statistical analyses showed these differences not to be significant unless the differences were greater than 15%. During August 1976 carbon fixation rates measured at plume locations decreased sharply from the rates recorded at the two lake control locations, and this was a statistically significant difference. At this time Unit One was operating at 98% turbine capacity (power) (Bartholomew and Redmond 1977 p. 10). Chlorophyll *a* concentrations observed at Locations 4, 5, and 6 were also less than Locations 7 and 1T during August (Bartholomew and Redmond 1977, p. 40). The reduced chlorophyll values ranged from 12% to 25% lower and reflected a similar trend found for carbon fixation rates.

The chlorophyll *a* concentrations at the plant intake and discharge tunnel did not respond to entrainment as much as the carbon fixation rates. Generally, the chlorophyll *a* concentrations also were larger or smaller at the discharge depending upon the lake water temperature. However, the chlorophyll values were higher at the discharge in October which may have been the delay factor involved in chlorophyll *a* production. Carbon fixation is a process that is continually occurring in a cell, and an immediate response may be measured because it is a rate; whereas, chlorophyll *a* concentrations are products of a metabolic process and may lag behind productivity rate changes. Thus delayed changes in chlorophyll *a* concentrations are not surprising. The only statis-

tically significant difference in chlorophyll a levels between intake and discharge samples was during August when the discharge concentration was 20% less than the intake chlorophyll concentration.

Fluctuations in phytoplankton abundances measured in samples from plume locations were generally as variable as fluctuations observed in discharge abundances. There were no consistent trends of increased or decreased abundances at the discharge relative to the intake. The plume locations responded as variably as the plant location.

2. Delayed Effects

Plant Entrainment

The effects of storage and possible delayed condenser effects at Zion Station were evaluated using the ratio of the 72-hour data to the corresponding 7-hour data for chlorophyll a concentration and ^{14}C uptake rate. Studies conducted at the fossil fueled Waukegan Generating Station had shown increasing effects on the carbon fixation rate of discharge samples when samples were stored and analyzed at the above intervals.

The ratios calculated for chlorophyll a concentrations during 1973-1974 showed no appreciable loss in that parameter during the 72-hour holding period. The carbon fixation rates demonstrated declines during storage in both the forebay and non-thermal (mechanical) discharge categories.

These data suggest that the evidence of delayed photosynthetic inhibition encountered in the Waukegan experiments was not present in the Zion data. The best estimate of the total

effect of condenser passage at Zion Station is the immediate 12% reduction in the carbon fixation rate observed in thermal discharge samples.

Values for both carbon fixation and chlorophyll a were measured at the extended time periods during 1976 and 1977 to assess any possible delayed effects. During January, February, March, April, and June 1977 the 72-hr analysis continued to show increased carbon fixation rates which averaged (at the discharge) greater than 27% increase over the intake values. Even though the carbon fixation rates remained statistically greater at Location 2 (intake bay) than at Location 3 (discharge tunnel) during August and September, the percent difference between locations decreased over the time period. Chlorophyll a concentrations analyzed at the 72-hr time period showed a trend toward recovery during 6 of the 12 months tested (Bartholomew and Redmond 1977, p. 41).

Plume Entrainment (1976-1977)

Differences in carbon fixation rates and chlorophyll a concentrations found between plume and lake control samples during 1976-1977 were usually minimal. However, occasional large changes in carbon fixation rates were measured between plume and control locations over the 72-hr period. An example was during August when discharge Location 4 had one-fourth of the carbon fixation rates of the lake control location and differences were statistically significant. The 25% ΔT location (5) had 28% lower carbon fixation rates than Location 7b and the 10% ΔT location (6) rate was 23% lower than rates measured at Location 7 (Bartholomew and

Redmond 1977, p. 42). All of these differences were statistically significant.

Chlorophyll a concentrations generally exhibited as high a degree of variability over the 72-hour period as did the carbon fixation rates. However samples from Location 4 analyzed during August, for example, had less than half the concentrations measured at Location 7. Location 5 (23% ΔT) concentrations were 38% lower than values measured at Location 7. Values from Location 6 nearly approximate values measured at control Location 7. These differences were present consistently throughout the 72-hours and statistical tests revealed that most of these differences between plume and control locations were significant.

During April, May, and June chlorophyll a concentrations showed differences between plume and control locations that were generally not minimized by mixing toward the edge of the plume. An extreme example was during June when chlorophyll a levels at Locations 4, 5, and 6 were 38%, 30%, and 39% lower, respectively, than the chlorophyll levels measured at the lake control locations. The 72-hr phytoplankton community samples generally reflected trends observed in the 7-hr samples, increasing or decreasing in much the same way as the 7-hr samples. Overall the abundances observed in the 72-hr samples were usually slightly higher than those measured in the 7-hr samples except for December and March. These increases in abundance were most likely due to bottle effects.

IV. References Cited

Barber, B.E., and D.G. Redmond. 1975. Phytoplankton study. IN Operational environmental monitoring in Lake Michigan near Zion Station. July 1974 through June 1975. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. II: 1-352.

_____ 1976. Phytoplankton study. IN Operational environmental monitoring in Lake Michigan near Zion Station. July 1975 through June 1976. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. III: 1-696.

_____ 1977. Phytoplankton study. IN Operational environmental monitoring in Lake Michigan near Zion Station. July 1976 through June 1977. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. III: 1-375.

Bartholomew, P.S., and D.G. Redmond. 1977. Phytoplankton Entrainment Study. IN Operational monitoring in Lake Michigan near Zion Station. July 1976 through June 1977. Annual report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. IV: 1-477.

Bremer, K. 1974. Phytoplankton productivity study. IN Environmental monitoring in Lake Michigan near Zion and Waukegan Generating Stations, January 1972 through December 1972. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. II: 149-166.

Festin, J.B., and P.S. Bartholomew. 1979. Phytoplankton study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July through September 1978. Hazleton Environmental Sciences for Commonwealth Edison Company, Chicago, Illnois.

Festin, J.B., and D. Redmond. 1978. Phytoplankton study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1977 through June 1978. NALCO Environmental Sciences for Commonwealth Edison Comany, Chicago, Illinois.

Gulo, J.E., and M.O. Lamble. 1972. Inshore water quality evaluation, Project II, Part B - Phytoplankton, May 1970 - March 1971. IN Evaluation of thermal effects of southwestern Lake Michigan (January 1970 - April 1971). Industrial BIO-TEST Laboratories, Inc., for Commonwealth Edison Company, Chicago, Illinois.

Huh, H., L. Everhart, C. Kondrat, J. Lingle, and J. Urry. 1973. Field study program of Lake Michigan in the vicinity of the Waukegan and Zion Generating Stations, April 1971-March 1972. Project X. IN Evaluation of thermal effects in southwestern Lake Michigan 1971-1972. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I: 13b p.

Mayhew, E. 1974. Phytoplankton study. IN Environmental monitoring in Lake Michigan near Zion and Waukegan Generating Stations, January 1972 through December 1972. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. II: 1-148.

_____ 1973. Phytoplankton study. IN Environmental monitoring in Lake Michigan near Zion and Waukegan Generating Stations, January 1973 through June 1973. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories Inc. Unpublished.

Mayhew, E., and B. Barber. 1974. Phytoplankton study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through June 1974. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I. 1-318.

Redmond, D.G. 1974. Primary productivity study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through June 1974. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I: 319-338.

Redmond, D.G., and K. Bremer. 1973. Primary productivity study. IN Environmental monitoring in Lake Michigan near Zion and Waukegan Generating Stations, January 1973 through June 1973. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Unpublished.

Restaino, T., D.G. Redmond, and R.G. Otto. 1975. Entrainment study at Zion Station. IN Compilation of special reports on the effects of Zion Station operation on the biota in Southwestern Lake Michigan. Special Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc.

Chapter 7

ZOOPLANKTON STUDIES

by

Deb Dvorak

SUMMARY REPORT OF ENVIRONMENTAL MONITORING
IN LAKE MICHIGAN NEAR ZION STATION

June 1970 through September 1978

TABLE OF CONTENTS

Page

List of Figures .....

List of Tables .....

I. Introduction .....

II. Material and Methods

A. Zooplankton
1. Sampling Locations .....
2. Sample Collection .....
3. Sample Analysis .....
4. Data Analysis .....

B. Zooplankton Entrainment
1. Sampling Locations .....
2. Sample Collection .....
3. Sample Analysis .....
4. Data Analysis .....

III. Results and Discussion

A. Zooplankton
1. January through December 1972 .....
2. January 1973 through June 1973 .....
3. July 1973 through June 1974 .....
4. July 1974 through June 1975 .....
5. July 1975 through June 1976 .....
6. July 1976 through June 1977 .....
7. July 1977 through June 1978 .....
8. July 1978 through September 1978 .....

B. Zooplankton Entrainment
1. Seasonal Abundance .....
2. Entrainment Effects .....

IV. References Cited .....

LIST OF FIGURES

Number	Caption	Page
1	Zooplankton sampling locations, southwestern Lake Michigan near Zion, Illinois	
2	Monthly mean density of total zooplankton at 3 m locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978	
3	Monthly mean density of total zooplankton at 9 m locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978	
4	Monthly mean density of total zooplankton at 18 m locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978	
5	Monthly mean density of total Copepoda at 3 m locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978	
6	Monthly mean density of total Copepoda at 9 m locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978	
7	Monthly mean density of total Copepoda at 18 m locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978	
8	Monthly mean density of total Cladocera at 3 m locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978	
9	Monthly mean density of total Cladocera at 9 m locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978	
10	Monthly mean density of total Cladocera at 18 m locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978	

LIST OF FIGURES (continued)

Number	Caption	Page
11	Monthly mean density of total Rotifera at 3 m locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978	
12	Monthly mean density of total Rotifera at 9 m locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978	
13	Monthly mean density of total Rotifera at 18 m locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978	

LIST OF TABLES

Number	Title	Page
1	Summary of material and methods used to sample zooplankton in southwestern Lake Michigan near Zion, Illinois, 1970-1978	
2	Description of sampling locations for zooplankton entrainment studies near the Zion Station, August 1976 through July 1977	
3	List of zooplankton taxa collected in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978	
4	Mean quarterly abundance of zooplankton at 9 m locations with dominant species ranked in order of abundance in southwestern Lake Michigan near Zion, Illinois, January-March 1972-1978	
5	Mean quarterly abundance of zooplankton at 9 m locations with dominant species ranked in order of abundance in southwestern Lake Michigan near Zion, Illinois, April-June 1972-1978	
6	Mean quarterly abundance of zooplankton at 9 m locations with dominant species ranked in order of abundance in southwestern Lake Michigan near Zion, Illinois, July-September 1971-1978	
7	Mean quarterly abundance of zooplankton at 9 m locations with dominant species ranked in order of abundance in southwestern Lake Michigan near Zion, Illinois, October-December 1971-1977	

I. Introduction

This chapter summarizes the zooplankton data from a seven year monitoring program initiated in 1970 in southwestern Lake Michigan near Zion Illinois. The data summary presented herein is a description of the zooplankton populations offshore from the Zion Station during preoperation and operational phases of the Station which became operational in July 1973. The preoperational data will be compared with data collected after operations had begun. The study was also part of an operational monitoring program for Waukegan Generating Station, located 4.5 miles south of the Zion Station. Planned experimental locations near Zion served as control locations for Waukegan prior to Zion operation.

This chapter will also evaluate the effects of plant condenser passage on zooplankton. These effects have been divided into two categories: mechanical effects related to the physical passage through pumps and condenser tubes prior to being released back into the lake, and thermal effects resulting from the sudden increase in water temperatures which occurs in the condenser tubes.

The main objectives of the study program were:

1. To characterize the zooplankton populations in southwestern Lake Michigan in the Zion area. This included seasonal occurrence of species, distribution as related to water depth and natural fluctuations among transects;

2. To assess the effect of heated effluents on the zooplankton populations in the lake following start-up of the Zion Station;

3. To assess the immediate and delayed effects of Station entrainment on zooplankton; and

4. To determine the delayed effects of plume entrainment on zooplankton in the lake.

II. Material and Methods

A. Zooplankton

1. Sampling Locations

Zooplankton samples were collected monthly from three locations (Waukegan Station discharge plume, Waukegan nearshore and Zion nearshore) near Zion and Waukegan, Illinois, from June through October 1970 (Table 1) (Lamble 1972, p. 3). From this initial sampling program only one location, Location 3, corresponds to a present location, Location 5.

Samples were collected from one location each in the intake and discharge canals of the Waukegan Generating Station from December 1970 through March 1971 (Lamble 1972, p. 3). A second location was sampled in the intake canal after December.

Four replicate zooplankton samples were collected monthly from each of ten locations from May 1971 through March 1972, and six of those correspond to present sampling locations (Huh, et al. 1973, p. 9). Three of the ten sampling locations were situated on a transect near Waukegan Generating Station but were discontinued in May 1974.

Fifteen sampling locations (5, 7, 9, 10, 12, 13a, 18, 20, 22, 23, 25, 27, 28, 30 and 32) were established in the vicinity of the Zion and Waukegan Stations in January 1972 (Hunt 1974a, p. 174). Six of these locations (Locations 5, 7, 9, 10, 12 and 13a) were within or near the predicted area of major thermal influence from Zion Station (Pritchard-Carpenter Consultants, 1970). Three locations (Locations 23, 25 and 27) were offshore

Table 1. Summary of material and methods used to sample zooplankton in southwestern Lake Michigan near Zion, Illinois, 1970-1978.

Year	Number of Sampling Sec.	Locations corresponding to 1973 locations	Sampling Device	Method of Sampling	Depths Sampled	Frequency of Sampling	Replicates	Preservative	Identification Procedure	Treatment of Sample	Source/ References
1970 June-Oct	1	Location 1 corresponds to location 5, 1973 Location 1 corresponds to location 25, 1973.	Miller Plankton Sampler #20 mesh	One minute oblique tow from bottom to surface.		Weekly	12	5% Formalin	Micro-crustacea identified to species except for Cyclops (copepoda and Cercaia (ostracoda) (genuses) Tows.	Sample volume adjusted to 100 ml with at least two #1 ml subsamples counted	Gamble 1972
1970 Dec- 1971 March	3	None	Miller Plankton Sampler #10 mesh	Ten minute tows 0.5m below the surface.		Once /	3-Dec 6-Jan-Mar	5% Formalin	Micro-crustacea identified as in 1970.	Technique as used in 1970-Oct. 1970.	Gamble 1972
1971 May- 1972 March	27	Locations 5, 7, 9, 19, 20, 22, 24, 25 and 27.	Wilge Closing Net 12 cm Diameter #25 mesh	Vertical tow Where thermocline present, vertical tows divided into 2 portions; bottom to thermocline, thermocline to surface.	Locations 5, 19 and 24 - 2 meter to surface. Location 7, 20 and 25 - 8 meter to surface. Locations 9, 22 and 27 - 18 meter to surface	1 - Weekly	4	5% Formalin	Micro-crustacea identified as in 1970.	Sample volume adjusted to 80-100 ml with one to ware 1-10 ml subsamples counted.	Hoh, et al. 1973
1972 Jan-Dec	24	Locations 5, 7, 9, 19, 12, 13a, 14, 20, 22, 23, 25, 27, 24 Dec and 28, 30, 32 April-Oct.	Simple conical Zooton Net 35 cm Diameter #12 mesh	Vertical tow.	All locations - 2 Meter to surface. Locations 5, 9, 12, 13a, 20, 22, 25, 27, 30 and 32 - 9 meter to surface. Location 19 - 18 meter to surface.	Monthly	3	5% Formalin	Micro-crustacea identified as in 1970. Rotifers identified as total Rotifera.	Sample volume adjusted to 50-200 ml with one to seven subsamples counted until a minimum of 100 of the 2 or 3 most abundant taxa had been counted, with the sample counted in total if necessary. Sample volumes and subsample volumes were held constant during individual at each location.	Hunt 1974
1973-74 Jan '73-Jan 74	15	Locations 1, 5, 9, 19, 12, 13a, 14, 20, 22, 23, 25, 27, 24, 30 and 32	Simple Conical Plankton Net 35 cm Diameter #12 mesh	Vertical tow.	Location 5, 12, 19 23, 30 - 3 meter to surface. Locations 1, 13, 20, 25 and 32 - 9 meter to surface. Location 9 13a, 22, 27 and 32 - 18 meter surface.	Monthly	4 composite replicates, each a one minute of 4 vertical tows.	5% Formalin	Micro-crustacea identified as in 1970. Rotifers identified to most cases, to genus.	Procedure the same as in 1972 except sample volumes and subsample volumes were held constant among all replicates for all samples taken along each depth contour (nearshore, midlake, offshore).	Hunt 1974 Richards & Gannon 1974
1974 May Mechanic Station dredged.	12	Locations 5, 7, 9, 19, 12, 13a, 14, 20, 22, 24, 25 and 27.									

HAZLETON ENVIRONMENTAL SCIENCES

Table 1. (continued)

Year	Number of Sampling Sec	Location corresponding to 1977 locations	Sampling Device	Method of Sampling	Aspects Sampled	Frequency of Sampling	Replicates	Preservative	Identification Procedure	Treatment of Sample	Report Reference
10/2/75 Jul 75-Jun 76 All categories same as 73-74 except treatment of Sample.										HCl_2 was added to samples to yield pH, neutralize the zinc chloride from Reg chemical Sec 35, then not enough Sec saturated weather water was used, formalin was added later in lab.	Jensen 1975
1975-76 Jul 75-Jun 76 All categories same as 73-74 except Treatment of of Sample.										Saturated ammonia water used to weather the soil. Soil Profile was 2 - 10 later in lab.	Jensen 1976
1976-77 Jul 76-Jun 77 All categories same as 75-76.											Jensen 1977
1977-78 Jul 77-Jun 78 All categories same as 75-75.											Wolfarth & Jensen 1978
1978 Jul 78-Sep 78 All categories same as 75-76.											Jensen 1979

HAZLETON ENVIRONMENTAL SCIENCES

of the Waukegan Station and three (Locations 18, 20 and 22) were offshore Dead River. The locations near Dead River, approximately midway between Zion and Waukegan, served as a southern control area. The North Control transect (Locations 28, 30 and 32), approximately four miles north of Zion, was added in April 1972, as an additional control area. Both of the Zion transects were also used in 1972 as control transects for the Waukegan Station since Zion Station was not operational during this study.

The 15 locations established in 1972 have remained the same through September 1978, except as previously noted, the Waukegan transect being discontinued in May 1974 (Figure 1).

For clarity, the four established transects will be referred to as North Control (NC) (Locations 28, 30 and 32); North Zion (NZ) (Locations 5, 7 and 9); South Zion (SZ) (Locations 10, 12 and 13a) and Dead River (DR) (Locations 18, 20 and 22). Sampling locations on each transect were at depths of 3, 9 and 18 m.

One exception to the monthly sampling of all locations occurred in October, 1976. Adverse weather conditions caused cancellation of sampling after all but the middle and offshore locations of North Control had been sampled. Data are therefore missing from Locatons 30 and 32 in October of that year.

2. Sample Collection

For each sampling period from June through October 1970, 12 one-minute oblique tows were made from the bottom to

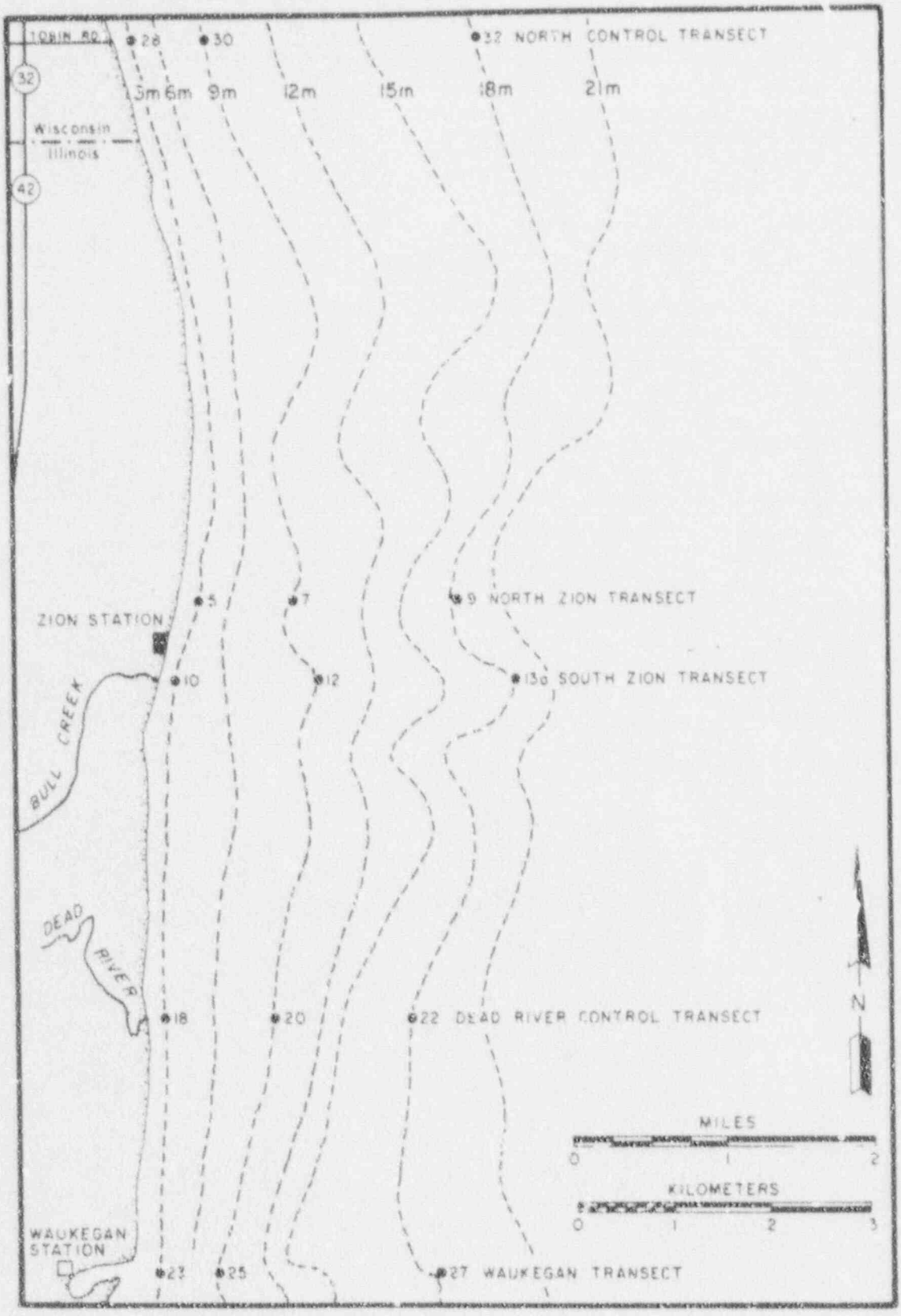


Figure 1. Zooplankton sampling locations, southwestern Lake Michigan near Zion, Illinois.

surface using a flowmeter-equipped Miller Plankton Sampler (#10 nitex net, 153 µm aperture) (Lamble 1972, p. 3). Water temperatures were measured before and after each tow.

All collections from December 1970 through March 1971 were also made using the Miller Plankton Sampler (Lamble 1972, p. 3). The sampler was suspended 0.5 m below the surface for three successive 10-minute periods January through March.

Samples were collected from May 1971 through March 1972 using a Birge closing net (12.0 cm diameter, #20 mesh) towed vertically from the bottom to the surface (Huh, et al. 1973, p. 9). At those locations where the thermocline was evident, each of the vertical hauls was divided into two portions; a haul was taken from the bottom to the thermocline, and another through the thermocline to the surface.

From January 1972 through December 1972 samples were collected monthly using a 30 cm diameter conical plankton net constructed of #12 (120 µm aperture) nitex (Hunt 1974a, p. 174). Duplicate vertical samples were collected at all 15 of the sampling locations from depth of 3 m to the surface. Additional samples were taken in duplicate from 9 m to the surface at the 10 deeper locations and from 18 m to the surface at the five deepest locations.

Beginning in January 1973 through September 1978, four replicate samples were collected using the same size net as in 1972 with each replicate consisting of four vertical tows collected from 3 m to the surface at the inshore locations, from

9 m to the surface at the middle locations and from 18 m to the surface at the offshore locations. These four tows were collected simultaneously at each location by four biologists, and later composited in the laboratory.

A small amount of "sparkling water" (CO_2) was added to the samples in the field from May through September 1975 to anesthetize the zooplankton and aid in rotifer identification (Dvorak, 1975, 1976). From October 1975 through September 1978, saturated menthol water was used instead of CO_2. Formalin was added to the samples as a preservative several hours later in the laboratory.

3. Sample Analysis

Preceding analysis, each composited sample was concentrated or diluted, depending on the density of zooplankters and/or debris in the sample. To do this, one sample for each location was thoroughly mixed and a subsample was withdrawn and placed in a Bogorov counting chamber. The subsample was scanned to determine the approximate density of organisms in each selected sample. The sample with the lowest density for a particular depth contour was used to determine the appropriate proportion to be subsampled. An appropriate subsample volume was then selected such that the subsample volume to be counted contained a minimum total of 300 of the two or three most abundant crustacean taxa. Once an appropriate subsample volume was determined, all Crustacea and Rotifera present in the subsample were counted using a binocular dissecting microscope. Only the Crustacea were identified in

samples from January 1970 through December 1971. Rotifers were enumerated as total Rotifera, January 1972 through January 1973, after which they were identified, in most cases, to genus. Crustacea were identified to species with the exception of immature copepods which were identified as nauplii or calanoid or cyclopoid copepodites. Population densities were calculated from the number of organisms per taxon enumerated, subsample volume, sample volume and total volume of water sampled. Densities of all organisms were reported as numbers per cubic meter (No./m^3) of water sampled.

Identifications were made using taxonomic keys by Brooks (1957), Czaika and Robertson (1968), Frey (1959), Megard (1967), Ruttner-Kolisko (1974), Smirnov (1974) and Edmondson (1959).

4. Data Analysis

The population densities of major taxa and dominant species at sampling locations of similar depth were compared each month with a one-way analysis of variance. A nested ANOVA was performed on data from 1972 through June 1973. In 1972 the analysis of variances was conducted on the two replicates from the two deepest hauls at each location. Prior to analysis, raw data was transformed to stabilize the variance by using either a square root or log to the base 3 transformation. Upon finding a significant difference ($p \leq 0.05$) among locations compared, Tukey's multiple comparison procedure was used to determine which, if any, locations differed significantly ($p \leq 0.05$).

A Kruskal-Wallis non-parametric ANOVA was used to compare species diversity indices at locations of similar depth.

As with the one-way analysis of variance, any significant differences detected were examined with appropriate comparison tests.

Species diversity (calculated using log to the base 2) and redundancy values were calculated for each replicate. The mean diversity per location was calculated by the formula of Shannon (1948):

$$H' = -\sum_{i=1}^{s} \frac{ni}{N} \log_2 \frac{ni}{N}$$

where n_i was the number of individuals in the i^{th} category, N is the total number of all species and s is the number of species. The index is dimensionless and may range from 0 to H' max. Redundancy was calculated from the formula (Shannon 1948):

$$R = \frac{H'max - H'}{H'max - H'min}$$

A mean redundancy value was also calculated for each location. The values were calculated using all adult taxa and not the immature forms.

B. Zooplankton Entrainment

1. Sampling Locations

Samples collected for zooplankton entrainment studies from October 1973 through September 1974 were collected from three locations. Intake samples were collected near the

northeast corner of the forebay. Discharge samples from Unit 1 and Unit 2 were collected through 7.6 cm (3 in) inside diameter polyvinylchloride (PVC) lined pipes that extended approximately 7.6 m (25 ft) down to the center of the discharge tunnel for each unit (Nestaino, Redmond and Otto 1975, p.4). The opening of the pipe pointed into the flow.

During the sampling period of August 1976 through July 1977, samples taken in the Station were collected off a floating platform near the northeast section of the intake forebay (Location 2) and through a pipe that extended down to the center of the discharge tunnel of Units 1 or 2 (Location 3) (Table 2). Lake samples were collected near the surface and bottom at Location 1, and at Locations 4 through 9. Zion entrainment sampling coincided with zooplankton field sampling carried out in the vicinity of the Zion Station.

2. Sample Collection

From October 1973 through September 1974, four replicate samples at the forebay and duplicate samples at the discharge tunnel locations were collected monthly during the day (0900) and night (2300) with a filter-pump system similar to that described by Icanberry (1972). A #10 mesh net (153 µm aperture size, October through March) and a #12 mesh net (120 µm aperture size, April through September) were used in the filter-pump system. Mesh size was changed to permit sampling of rotifer populations during the latter period. Each sample was concentrated to a 200 ml volume and transferred immediately to an environmental

Table 2. Description of sampling locations for zooplankton entrainment studies near the Zion Station, August 1976 through July 1977.

Sampling Location	Description
1 T and B	Intake area, surface and bottom of the lake.
2	Forebay.
3	Discharge tunnel for Unit 1 or 2.
4 T	Immediate area of discharge for the unit generating greater power.
5 T	Area of plume from Unit 1 or 2 for which the temperature is equal to the forebay temperature plus 25% of the ΔT.
6 T	Area of plume from Unit 1 or 2 for which the temperature is equal to the forebay temperature plus 10% of the ΔT.
7 T	Reference location four miles north of Zion Station and at same depth as samples collected at Location 5.
8 T	Reference location four miles north of Zion Station and at same depth as samples collected at sampling Location 6.
9 T	Immediate area of discharge for the unit generating lower power.

T = surface samples
B = bottom samples

chamber where it was maintained at ambient lake temperature. Discharge samples were cooled to within 2C of ambient temperature within 10 minutes of collection, according to anticipated temperature decay rates at Zion Station.

Duplicate zooplankton entrainment samples were collected monthly from August 1976 through July 1977 at 10 locations when at least one unit of Zion Station was operating near full power (>85%). Duplicate night samples were also collected at the intake and discharge, approximately 12 hours after each monthly day collection. A filter-pump system like that described above with a #10 mesh net insert (153 µm aperture), was used again during this sampling period. The volume of water sampled was measured using a calibrated in-line water meter.

3. Sample Analysis

After collection subsamples were drawn with an automatic pipette from each concentrated sample and released into a partitioned Petri dish. The volume of subsamples taken was dependent upon the density of organisms present in the concentrated sample.

Zooplankton were separated live from dead under a stereozoom microscope at 4 and 24 hours after sample collection. Samples collected at the intake and discharge were also analyzed for live-dead at 0 hours (within 20 minutes after sample collection). Zooplankton observed at 0 hours at the intake and discharge were recorded as motile and immotile rather than live and dead to account for possible recovery from temporary shock after condenser

passage. Immotility was defined as the absence of appendicular and visceral movement upon probing. The term mortality denotes those organisms which failed to recover (become motile) after the 4 and 24 hour observations. A minimum of 150 organisms were separated from each replicate (300 organisms per location) during each of the 0, 4 and 24 hour observation periods. The percent immotile or dead zooplankters at each location was calculated using the following formula:

$$\frac{\text{Number of immotile or dead zooplankton/sample}}{\text{Total zooplankton/sample}} \times 100 = \text{Percent Immotility or Mortality}$$

Zooplankton were preserved in 3% formalin at the conclusion of each survival analysis and later identified to the lowest positive taxon using keys by Brooks (1957), Edmondson (1959) and Smirnov (1974).

Zooplankton populations were determined at Locations 2 (day and night collections) 5, 6, 7 and 8. Population densities for each replicate were calculated using the following information: Total number of organisms separated during the 4 and 24 hour survival analyses, subsample volume recorded during those observations, sample volume (200 ml) and total volume of water pumped. Populations of all organisms were reported in numbers per cubic meter (No./m^3) of water sampled.

4. Data Analysis

Chi square analyses were performed to test whether the proportions of dead zooplankton were similar among locations. In 1976-1977 Cal-Comp plots of the data were generated to display

the proportion of dead zooplankters with the associated 95% confidence intervals for each time period (4 and 24 hours) (Snee 1974).

The population densities of major taxa and dominant species at Locations 2, 5, 6, 7 and 8 were compared monthly from August 1976 through July 1977 with a one-way analysis of variance. All analyses were calculated using log to the base e transformation. Upon finding a significant difference ($p \leq 0.05$) among the locations compared, Tukey's multiple comparison procedure was used to determine which, if any, locations differed significantly ($p \leq 0.05$). Day-night population density differences ($p \leq 0.05$) at the intake were determined using a Student's "t" test.

Binomial regression analyses (linear model analyses for categorical data), comparing zooplankton immotility against species size, and additional regression analyses, comparing zooplankton condenser immotility and/or mortality rate differences between day and night collections were conducted from October 1973 through September 1974.

During the zooplankton study a minor error was detected in the portion of the zooplankton computer program that calculates species diversity. Crustacea, are enumerated by gender and immature stages. The computer program handled these immature stages and gender distinctions as separate species thus increasing the number in individuals (N) in the calculation resulting in values for H' (diversity) which were lower than the correct values. This problem was evident in diversity data reported from July 1973 through

December 1976. All incorrect data was rerun and incorporated into new tables. The interpretation of the data was not affected because any discussion of the data described only relative differences between locations.

Due to errors in the calculation of Tukey's W values, data run on the SUPERFAC program contained possible errors. SUPERFAC was used to compare July 1973 through June 1974 annual data. From July 1974 through June 1975, FAC3:2 which is related to SUPERFAC was used in comparisons at 3 and 9 m locations. This data, if rerun, would not change the interpretation presented in the annual reports.

III Results and Discussion

A. Zooplankton

All taxa collected during the study period are listed in Table 3. Quarterly ranking tables have been constructed for dominant organisms encountered at 9 m locations (Tables 4 through 7). The 9 m transect was selected because of its possible plume influence and being less affected by lake weather conditions than the 3 m locations. The ranking tables depict the yearly seasonal variations for dominant species, and as shown illustrate no major changes in species composition after Station operation commenced.

1. January through December 1972

Zooplankton densities were minimal from January through May (Figures 2, 3, 4). The populations then increased almost eight-fold from over 2,000 organisms/m^3 in April to a maximum of 170,000 organisms/m^3 in August (Hunt 1974a, p. 178).

Copepods constituted 83 to 100% of all organisms encountered in the winter and spring samples when zooplankton densities were less than 11,000 organisms/m^3 (Hunt 1974a, p. 184) (Figures 5, 6, 7). Nauplii densities were low January through April then increased significantly during the spring and summer to a seasonal maximum in August. Cyclopoid copepodites, the dominant copepod taxon, were most abundant from July to November, when densities over 10,000 organisms/m^3 were maintained. The most abundant adult copepods collected during this study period were Cyclops bicuspidatus thomasi, Diaptomus ashlandi, D. minutus, D. oregonensis, and D. sicilis. The adult taxa maintained higher

Table 3. List of zooplankton taxa collected in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978.

Crustacea
- Copepoda
  - nauplii
  - calanoid copepodites
  - cyclopoid copepodites
  - Cyclops bicuspidatus thomasi S.A. Forbes
  - C. varicans rubellus Lilljeborg
  - C. vernalis Fischer
  - Diaptomus ashlandi (female) Marsh
  - D. ashlandi (male) Marsh
  - D. clavipes (male) Schacht
  - D. minutus (female) Lilljeborg
  - D. minutus (male) Lilljeborg
  - D. oregonensis (female) Lilljeborg
  - D. oregonensis (male) Lilljeborg
  - D. sicilis (female) S.A. Forbes
  - D. sicilis (male) S.A. Forbes
  - Epischura lacustris S.A. Forbes
  - Eucyclops agilis (Koch)
  - E. prionophorus Kiefer
  - E. speratus (Lilljeborg)
  - Eurytemora affinis (Poppe)
  - Limnocalanus macrurus Sars
  - Mesocyclops edax (S.A. Forbes)
  - Orthocyclops modestus (Herrick)
  - Paracyclops fimbriatus poppei (Rehberg)
  - Tropocyclops prasinus (Fischer)
  - Tropocyclops prasinus mexicanus Kiefer
- Cladocera
  - Alona affinis (Leydig)
  - A. barbulata (Megard)
  - A. circumfimbriata Megard
  - A. costata Sars
  - A. guttata Sars
  - A. quadrangularis (O.F. Muller)
  - Biapertura intermedia Sars
  - Bosmina longirostris (O.F. Muller)
  - Camptocercus rectirostris Schodler
  - Ceriodaphnia lacustris Birge
  - C. quadrangula (O.F. Muller)
  - Chydorus sphaericus (O.F. Muller)
  - Daphnia galeata mendotae Birge
  - D. longiremis Sars
  - D. parvula Fordyce

Table 3. (continued)

D. pulex Richard
D. retrocurva Forbes
D. schodleri Sars
Diaphanosoma leuchtenbergianum Fischer
Disparalona rostrata Koch
Eubosmina coregoni (Baird)
Eurycercus lamellatus (O.F. Muller)
Holopedium gibberum Zaddach
Ilyocryptus sordidus (Lieven)
Leptodora kindtii (Focke)
Leydigia leydigi Schoedler
L. quadrangularis (Leydig) (name changed to L. leydigi)
Macrothrix hirsuticornis Norman and Brady
M. laticornis (Jurine)
Moina micrura Kurz
Polyphemus pediculus (Linne)
Simocephalus expinosus Koch

Rotifera

Asplanchna spp. Gosse
bdelloid Rotifera spp.
Brachionus spp. Pallas
Cephalodella spp. Bory de St. Vincent
Collotheca spp. Harring
Conochiloides spp. Hlava
Conochilus spp. Hlava
Encentrum spp. Ehrenberg
Euchlanis spp. Ehrenberg
Filinia spp. Bory de St. Vincent
Gastropus spp. Imhof
Kellicottia spp. Ahlstrom
Keratella spp. Bory de St. Vincent
Lecane spp. Nitzsch
Monostyla spp. Ehrenberg
Notholca spp. Gosse
Philodina spp. Ehrenberg
Platyias spp. Harring
Ploesoma spp. Herrick
Polyarthra spp. Ehrenberg
Synchaeta spp. Ehrenberg
Trichocerca spp. Lamarck
Trichotria spp. Bory de St. Vincent

Table 4. Mean quarterly abundance of zooplankton at 9 m locations with dominant species ranked in order of abundance in southwestern Lake Michigan near Zion, Illinois, January-March 1972-1978.

Year	North Control			North*			South Zion			Coal Ridge		
	Organism	Density	%	Organism	Density	%	Organism	Density	%	Organism	Density	%
1972	A			cyclopoid copepodites	2558	36	cyclopoid copepodites	1404	29	cyclopoid copepodites	748	33
				Diaptomus spp. (female)	777	14	Diaptomus spp. (female)	851	16	Diaptomus spp. (female)	595	26
				Cyclops bicuspidatus thomasi	609	9	D. ashlandi (male)	516	12	D. ashlandi (male)	283	12
				D. ashlandi (male)	502	11	nauplii	468	9	Cyclops bicuspidatus thomasi	202	7
				nauplii	481	8	Cyclops bicuspidatus thomasi	287	6	D. oregonensis (male)	178	6
										nauplii	116	6
1973	cyclopoid copepodites	1303	34	cyclopoid copepodites	1230	32	cyclopoid copepodites	1228	38	cyclopoid copepodites	1561	39
	Diaptomus spp. (female)	706	21	Diaptomus spp. (female)	636	20	Diaptomus spp. (female)	657	20	Diaptomus spp. (female)	870	23
	D. ashlandi (male)	445	13	D. ashlandi (male)	349	11	D. ashlandi (male)	424	10	D. ashlandi (male)	606	22
	nauplii	259	11	nauplii	287	14	nauplii	278	14	nauplii	303	12
							D. minutus (male)	235	6	D. minutus (male)	156	5
1974	cyclopoid copepodites	2810	59	cyclopoid copepodites	2686	58	cyclopoid copepodites	2889	58	cyclopoid copepodites	4282	58
	Cyclops bicuspidatus thomasi	401	8	Cyclops bicuspidatus thomasi	350	7	Cyclops bicuspidatus thomasi	297	7	Cyclops bicuspidatus thomasi	471	6
	Diaptomus ashlandi (female)	316	5	Diaptomus ashlandi (female)	375	6	Diaptomus ashlandi (male)	213	6	Diaptomus oregonensis (female)	386	5
	D. ashlandi (male)	213	5	D. ashlandi (male)	240	6	D. ashlandi (female)	200	5	D. ashlandi (male)	309	5
										D. ashlandi (female)	309	5
1975	cyclopoid copepodites	6431	30	cyclopoid copepodites	4540	31	cyclopoid copepodites	2827	25	cyclopoid copepodites	3424	27
	Nothoica spp.	2472	11	Diaptomus ashlandi (female)	1471	10	Diaptomus ashlandi (female)	1792	12	Nothoica spp.	1938	16
	Diaptomus ashlandi (female)	1686	11	D. ashlandi (male)	1456	10	Nothoica spp.	1362	12	Diaptomus ashlandi (female)	1317	11
	D. ashlandi (male)	1411	10	Nothoica spp.	1421	10	D. ashlandi (male)	1317	12	nauplii	1240	10
	nauplii	1652	9	nauplii	1240	9	nauplii	1130	10	D. ashlandi (male)	1178	10
	Cyclops bicuspidatus thomasi	1028	5	D. oregonensis (female)	916	6						
	D. oregonensis (female)	962	5	Cyclops bicuspidatus thomasi	900	6						
				D. oregonensis (male)	781	5						
1976	cyclopoid copepodites	1638	37	cyclopoid copepodites	1401	37	cyclopoid copepodites	1320	37	cyclopoid copepodites	1112	25
	nauplii	540	15	nauplii	686	15	nauplii	635	15	nauplii	529	12
	Diaptomus ashlandi (male)	370	8	Diaptomus ashlandi (male)	529	8	Diaptomus ashlandi (male)	368	8	Diaptomus ashlandi (male)	264	6
	D. ashlandi (female)	306	7	Limnocalanus macrurus	314	7	D. ashlandi (female)	283	7	calanoid copepodites	198	7
	D. oregonensis (female)	286	6	D. ashlandi (female)	265	6	Limnocalanus macrurus	234	5	D. ashlandi (female)	290	6
	Cyclops bicuspidatus thomasi	235	6	Cyclops bicuspidatus thomasi	218	5	D. oregonensis (female)	205	5			
							calanoid copepodites	180	5			
1977	cyclopoid copepodites	936	27	Diaptomus ashlandi	595	23	cyclopoid copepodites	715	28	cyclopoid copepodites	677	25
	Limnocalanus macrurus	726	21	cyclopoid copepodites	580	25	Diaptomus ashlandi	607	23	Diaptomus ashlandi	453	16
	Diaptomus ashlandi	637	19	Limnocalanus macrurus	473	19	Limnocalanus macrurus	472	19	Limnocalanus macrurus	539	20
	nauplii	317	13	nauplii	190	8	nauplii	288	9	nauplii	240	7
	Diaptomus minutus	218	6	Diaptomus minutus	155	6	Diaptomus minutus	198	7	Diaptomus minutus	201	7
				calanoid copepodites	108	5	Diaptomus sicilis	137	5	calanoid copepodites	186	5
				Diaptomus oregonensis	107	5	calanoid copepodites	133	5	Diaptomus oregonensis	122	5
							Diaptomus oregonensis	92	5			
1978	cyclopoid copepodites	880	25	cyclopoid copepodites	2952	27	Diaptomus ashlandi	1432	25	Diaptomus ashlandi	1576	27
	Diaptomus ashlandi	706	22	Diaptomus ashlandi	2161	20	cyclopoid copepodites	1506	24	cyclopoid copepodites	1165	21
	Limnocalanus macrurus	522	21	Limnocalanus macrurus	1236	23	Limnocalanus macrurus	630	20	Limnocalanus macrurus	682	16
	nauplii	426	12	Diaptomus oregonensis	695	7	Diaptomus minutus	455	9	Diaptomus sicilis	468	10
	Diaptomus minutus	370	8	Diaptomus minutus	643	7	Diaptomus oregonensis	367	6	nauplii	450	9
	Diaptomus sicilis	171	6	nauplii	516	7	nauplii	261	6	Diaptomus minutus	390	8
				Diaptomus sicilis	245	5	Diaptomus sicilis	269	7	Diaptomus oregonensis	282	5

* North Control not added to program until April 1972.

Table 5. Mean quarterly abundance of zooplankton at 9 m locations with dominant species ranked in order of abundance in southwestern Lake Michigan near Zion, Illinois, April-June 1972-1978.

Year	North Control			North Zion			South Zion			Dead River		
	Organism	Density	%	Organism	Density	%	Organism	Density	%	Organism	Density	%
1972	nauplii	2999	26	nauplii	3139	27	nauplii	2087	29	nauplii	1823	27
	cyclopoid copepodites	485	5	calanoid copepodites	547	6	cyclopoid copepodites	689	5	cyclopoid copepodites	515	6
	Diaptomus spp. (female)	751	13	Diaptomus spp. (female)	384	16	Diaptomus spp. (female)	276	13	Diaptomus spp. (female)	3.6	10
	D. minutus (male)	155	14	cyclopoid copepodites	350	6	D. minutus (male)	126	7	D. ashlandi (male)	181	7
										D. minutus (male)	157	5
1973	nauplii	7964	43	nauplii	6596	42	nauplii	6553	39	nauplii	6496	32
	calanoid copepodites	3970	15	calanoid copepodites	3577	16	calanoid copepodites	4361	16	calanoid copepodites	5649	15
	cyclopoid copepodites	2224	7	Notholca spp.	1912	15	cyclopoid copepodites	2748	8	cyclopoid copepodites	3435	7
	Notholca spp.	2168	14	cyclopoid copepodites	1206	5	Notholca spp.	1500	13	Notholca spp.	1848	15
	Diaptomus spp. (female)	1011	7	Diaptomus spp. (female)	1045	8	Diaptomus spp. (female)	1004	8	Diaptomus spp. (female)	1794	10
	D. ashlandi (male)	753	5							D. ashlandi (male)	870	5
1974	nauplii	7538	33	nauplii	8669	39	nauplii	8483	32	nauplii	8362	34
	Notholca spp.	4610	14	Notholca spp.	3837	10	Notholca spp.	3550	9	Notholca spp.	3545	9
	cyclopoid copepodites	943	8	cyclopoid copepodites	2113	9	cyclopoid copepodites	2312	10	cyclopoid copepodites	4123	11
	Cyclops bicuspidatus thomasi	545	11	calanoid copepodites	1946	6	calanoid copepodites	2089	8	calanoid copepodites	3122	7
				Cyclops bicuspidatus thomasi	250	8	Cyclops bicuspidatus thomasi	480	10	Cyclops bicuspidatus thomasi	351	8
1975	Synchaeta spp.	6330	20	Synchaeta spp.	3051	24	Synchaeta spp.	4113	17	nauplii	2920	46
	nauplii	6875	40	nauplii	2605	38	nauplii	3645	41	Synchaeta spp.	1946	16
	calanoid copepodites	1985	11	calanoid copepodites	680	8	calanoid copepodites	2293	13	calanoid copepodites	1109	12
	Diaptomus ashlandi (male)	115	7	Diaptomus ashlandi (male)	57	6	Diaptomus ashlandi (male)	73	5	Diaptomus ashlandi (male)	75	6
				D. ashlandi (female)	84	5						
1976	nauplii	5398	45	nauplii	8450	42	nauplii	9991	52	nauplii	2098	19
	Synchaeta spp.	6203	32	Synchaeta spp.	4650	29	calanoid copepodites	3435	18	Synchaeta spp.	5255	22
	calanoid copepodites	1417	8	calanoid copepodites	1871	12	Synchaeta spp.	2320	15	calanoid copepodites	3836	41
				Notholca spp.	971	5						
1977	nauplii	4454	43	nauplii	4035	54	nauplii	5007	48	nauplii	4111	49
	cyclopoid copepodites	3816	10	Synchaeta spp.	2487	10	calanoid copepodites	3185	11	Synchaeta spp.	1771	19
	calanoid copepodites	3708	10	calanoid copepodites	1586	8	Synchaeta spp.	2269	7	calanoid copepodites	2645	8
	Synchaeta spp.	2610	8	Kellicottia spp.	1099	5	cyclopoid copepodites	1782	6	cyclopoid copepodites	2226	6
	Kellicottia spp.	1694	5	Diaptomus ashlandi	310	5	Kellicottia spp.	1545	6	Kellicottia spp.	1519	5
	Cyclops bicuspidatus thomasi	715	7				Diaptomus ashlandi	543	8	Diaptomus ashlandi	427	8
	Diaptomus ashlandi	472	6				Cyclops bicuspidatus thomasi	343	5			
1978	nauplii	25483	67	nauplii	35947	67	nauplii	29970	59	nauplii	2936	60
	calanoid copepodites	4431	9	cyclopoid copepodites	6064	5	cyclopoid copepodites	4142	6	cyclopoid copepodites	8630	8
	cyclopoid copepodites	3827	5	calanoid copepodites	7126	7	Synchaeta spp.	5934	5	calanoid copepodites	5514	7
	Diaptomus ashlandi	1091	5	Diaptomus ashlandi	1248	6	calanoid copepodites	4425	6	Diaptomus ashlandi	1038	7
							Diaptomus ashlandi	1725	8			

HAZLETON ENVIRONMENTAL SCIENCES

Table 6. Mean quarterly abundance of zooplankton at 9 m locations with dominant species ranked in order of abundance in southwestern Lake Michigan near Zion, Illinois, July-September 1971-1978.

Year	North Control			North Zion			South Zion			Dead River		
	Organism	Density	%	Organism	Density	%	Organism	Density	%	Organism	Density	%
1971	*			Bosmina longirostris	35806	27	*			Bosmina longirostris	45780	29
				nauplii	18769	32				nauplii	21751	22
				cyclopoid copepodites	12057	16				cyclopoid copepodites	8861	11
				calanoid copepodites	8296	12				calanoid copepodites	6980	14
1972	Bosmina longirostris	41971	27	Bosmina longirostris	73091	40	Bosmina longirostris	47816	35	Bosmina longirostris	42347	39
	cyclopoid copepodite	31450	8	calanoid copepodites	17641	10	nauplii	8623	10	calanoid copepodites	13987	17
	nauplii	9596	7	cyclopoid copepodites	9935	7	calanoid copepodites	10647	11	nauplii	12586	10
	calanoid copepodites	8431	9	nauplii	9654	6	cyclopoid copepodites	7852	7	cyclopoid copepodites	10553	9
1973	Bosmina longirostris	87199	36	Bosmina longirostris	47911	26	Bosmina longirostris	50753	26	Bosmina longirostris	21983	26
	cyclopoid copepodites	30145	14	calanoid copepodites	31035	17	calanoid copepodites	16878	14	calanoid copepodites	25370	20
	calanoid copepodites	17494	13	cyclopoid copepodites	8398	6	Kellicottia spp.	16071	8	cyclopoid copepodites	12619	10
	nauplii	10507	8	nauplii	7696	14	cyclopoid copepodites	15174	8	Keratella spp.	11957	5
	Kellicottia spp.	8179	5				nauplii	6860	7	nauplii	6839	8
							Tropocyclops prasinus mexicanus	5496	6			
1974	nauplii	7538	53	nauplii	6868	39	nauplii	8881	32	nauplii	8302	36
	Notholca spp.	4835	14	Notholca spp.	3837	10	Notholca spp.	3559	9	Notholca spp.	3545	9
	cyclopoid copepodites	843	8	cyclopoid copepodites	2633	9	cyclopoid copepodites	2312	10	cyclopoid copepodites	3137	11
	Cyclops bicuspidatus thomasi	585	11	calanoid copepodites	1548	6	calanoid copepodites	2089	8	calanoid copepodites	2110	7
				Cyclops bicuspidatus thomasi	256	8	Cyclops bicuspidatus thomasi	890	10	Cyclops bicuspidatus thomasi	952	8
1975	Kellicottia spp.	239850	12	Bosmina longirostris	186213	26	Bosmina longirostris	237671	28	Bosmina longirostris	5585.5	39
	Keratella spp.	190575	10	Kellicottia spp.	155705	8	nauplii	91847	11	cyclopoid copepodites	11351.	8
	Bosmina longirostris	96854	29	Keratella spp.	131385	8	Conochilus spp.	83038	9%	nauplii	6861?	5
	cyclopoid copepodites	72609	7	nauplii	129991	12	cyclopoid copepodites	57479	8	Conochilus spp.	6737	4
	nauplii	52262	7	cyclopoid copepodites	76371	8	Synchaeta spp.	38740	4	Synchaeta spp.	6855	6
	calanoid copepodites	35462	7	Synchaeta spp.	36350	7	calanoid copepodites	27836	10	calanoid copepodites	2787?	6
	Synchaeta spp.	32377	5	calanoid copepodites	23367	9						
	Conochilus spp.	18994	6	Conochilus spp.	20852	8						
1976	Bosmina longirostris	57123	29	Bosmina longirostris	65319	33	Bosmina longirostris	43828	30	Bosmina longirostris	29566	37
	nauplii	30252	15	nauplii	33917	15	nauplii	26525	15	nauplii	10696	14
	calanoid copepodites	8798	21	cyclopoid copepodites	31287	10	calanoid copepodites	11496	28	calanoid copepodites	2?154	29
	cyclopoid copepodites	6933	11	calanoid copepodites	20699	21	cyclopoid copepodites	8985	10	cyclopoid copepodites	5061	6
	Keratella spp.	4148	6	Keratella spp	7586	6	Kellicottia spp.	5985	7	Keratella spp.	5307	6
	Kellicottia spp.	3679	8	Kellicottia spp.	4182	7	Keratella spp.	2594	5			
1976	Bosmina longirostris	23122	19	Bosmina longirostris	40317	13	Bosmina longirostris	83424	30	Bosmina longirostris	29566	37
	nauplii	20752	15	nauplii	33917	13	nauplii	26525	15	nauplii	10696	14
	calanoid copepodites	8798	21	cyclopoid copepodites	31287	10	calanoid copepodites	11496	28	calanoid copepodites	2?154	29
	cyclopoid copepodites	6933	11	calanoid copepodites	20699	21	cyclopoid copepodites	8985	10	cyclopoid copepodites	5061	6
	Keratella spp.	4148	6	Keratella spp.	7586	6	Kellicottia spp.	5985	7	Keratella spp.	5307	6
	Kellicottia spp.	3679	8	Synchaeta spp.	5112	5	Keratella spp.	2594	5			
				Kellicottia spp.	4182	7						
1977	Bosmina longirostris	15219	26	Bosmina longirostris	16567	29	Bosmina longirostris	13789	28	Bosmina longirostris	69075	43
	Kellicottia spp.	14876	21	nauplii	12493	19	Kellicottia spp.	11 467	18	Kellicottia spp.	12958	17
	nauplii	8294	13	Kellicott[illegible]a spp.	11476	14	nauplii	10210	20	nauplii	10965	14
	cyclopoid copepodites	5566	9	cyclopoid copepodites	7545	13	cyclopoid copepodites	6351	12	cyclopoid copepodites	7154	9
	Keratella spp.	5411	8	Keratella spp.	5232	6	Conochilus spp.	3818	8	calanoid copepodites	5598	7
	calanoid copepodites	3675	7	Conochilus spp.	3257	5	calanoid copepodites	3778	6	Synchaeta spp.	2757	3
				calanoid copepodites	3073	5	Keratella spp.	1395	5	Keratella spp.	2753	5
							Synchaeta spp.	2721	4			
1978	Bosmina longirostris	28157	58	Bosmina longirostris	46351	66	Bosmina longirostris	19419	35	Bosmina longirostris	37012	33
	cyclopoid copepodites	17498	17	cyclopoid copepodites	17199	25	cyclopoid copepodites	12687	21	Daphnia retrocurva	13548	18
	Daphnia retrocurva	10809	11	Daphnia retrocurva	4069	6	Daphnia retrocurva	5862	10	cyclopoid copepodites	10798	14
	nauplii	8802	10	nauplii	5685	8	nauplii	4218	7	nauplii	7172	6
	calanoid copepodites	4927	6				Kellicottia spp.	2818	4	Synchaeta spp.	6318	5
	Kellicottia spp.	4807	6				calanoid copepodites	2003	6	calanoid copepodites	5423	5
	Keratella spp.	4151	5				Conochilus spp.	1967	5	Conochilus spp.	4863	5

* Sampling locations do not correspond to present locations.

Table 7. Mean quarterly abundance of zooplankton at 9 m locations with dominant species ranked in order of abundance in southwestern Lake Michigan near Zion, Illinois, October-December 1971-1977.

Year	North Control			North Zion			South Zion			Dead River		
	Organism	Density	%	Organism	Density	%	Organism	Density	%	Organism	Density	%
1971	a			nauplii	19291	32	a			nauplii	16312	32
				cyclopoid copepodites	16831	36				cyclopoid copepodites	15531	35
				calanoid copepodites	5332	8				calanoid copepodites	4058	8
				Daphnia retrocurva	1914	7				Daphnia retrocurva	2114	5
1972	Bosmina longirostris	17323	71	Bosmina longirostris	11497	20	calanoid copepodites	11796	20	Bosmina longirostris	14670	19
	calanoid copepodites	8246	15	cyclopoid copepodites	10641	30	cyclopoid copepodites	11750	31	cyclopoid copepodites	12347	31
	cyclopoid copepodites	7572	25	calanoid copepodites	8937	29	Bosmina longirostris	9801	17	calanoid copepodites	9064	17
	Diaptomus spp. (female)	605	6							Diaptomus spp. (female)	869	5
1973	cyclopoid copepodites	9433	33	cyclopoid copepodites	9789	32	cyclopoid copepodites	11100	34	cyclopoid copepodites	10816	35
	Bosmina longirostris	7224	12	Bosmina longirostris	6092	16	Bosmina longirostris	7224	15	Bosmina longirostris	5736	19
	calanoid copepodites	3442	11	calanoid copepodites	5191	17	calanoid copepodites	6162	17	calanoid copepodites	5287	14
	Daphnia retrocurva	2584	8	Daphnia retrocurva	1838	6	Daphnia retrocurva	2244	6			
1974	cyclopoid copepodites	11350	35	cyclopoid copepodites	13636	38	cyclopoid copepodites	14045	35	cyclopoid copepodites	13544	38
	Bosmina longirostris	8020	16	Bosmina longirostris	5590	11	nauplii	5237	13	nauplii	4178	11
	nauplii	3645	10	nauplii	4293	11	calanoid copepodites	5663	11	Bosmina longirostris	3959	9
	calanoid copepodites	1894	6	calanoid copepodite	3036	8	Bosmina longirostris	4093	7	Nothelca spp.	2535	6
	Nothelca spp.	1470	5	Nothelca spp.	2653	7	Nothelca spp.	2551	7	calanoid copepodites	2582	7
1975	cyclopoid copepodites	5403	28	cyclopoid copepodites	7296	24	cyclopoid copepodites	7820	27	Bosmina longirostris	9645	17
	Bosmina longirostris	5004	18	Bosmina longirostris	7243	21	Bosmina longirostris	35.7	14	cyclopoid copepodites	7098	25
	nauplii	2540	10	calanoid copepodites	3918	11	calanoid copepodites	3239	13	calanoid copepodites	4043	13
	calanoid copepodites	2049	11	nauplii	3216	7	nauplii	2324	9	nauplii	2820	7
	Daphnia retrocurva	809	5	Tropocyclops prasinus mexicanus	2056	7	Tropocyclops prasinus mexicanus	1358	5	Tropocyclops prasinus mexicanus	2427	7
				Daphnia retrocurva	1700	6	Daphnia retrocurva	1349	6	Daphnia retrocurva	1733	6
				Diaptomus oregonensis (male)	819	6						
1976	cyclopoid copepodites	6929	36	cyclopoid copepodites	9090	33	cyclopoid copepodites	9513	40	cyclopoid copepodites	10190	38
	calanoid copepodites	3299	17	Bosmina longirostris	5742	16	calanoid copepodites	4036	16	Eubosmina coregoni	5020	16
	Diaptomus oregonensis	1789	7	Eubosmina coregoni	5243	14	Eubosmina coregoni	3169	12	calanoid copepodites	3225	11
	Eubosmina coregoni	1241	6	calanoid copepodites	2485	8	Bosmina longirostris	1731	6	Bosmina longirostris	3144	10
	Bosmina longirostris	1019	5	Diaptomus oregonensis	1050	5	Diaptomus oregonensis	1261	6			
197	cyclopoid copepodites	13197	39	cyclopoid copepodites	12964	41	cyclopoid copepodites	10737	39	cyclopoid copepodites	10954	38
	calanoid copepodites	7073	17	Bosmina longirostris	5664	9	calanoid copepodites	5331	15	calanoid copepodites	4856	13
	nauplii	1308	5	calanoid copepodites	4256	13	Bosmina longirostris	1948	6	Bosmina longirostris	3625	6
	Diaptomus ashlandi	1259	11	Diaptomus ashlandi	1231	9	nauplii	1353	5	nauplii	1649	6
							Diaptomus ashlandi	1021	10	Kellicottia spp.	1355	6
							Kellicottia spp.	971	5	Diaptomus ashlandi	1172	11

[a] Sampling locations do not correspond to present locations.

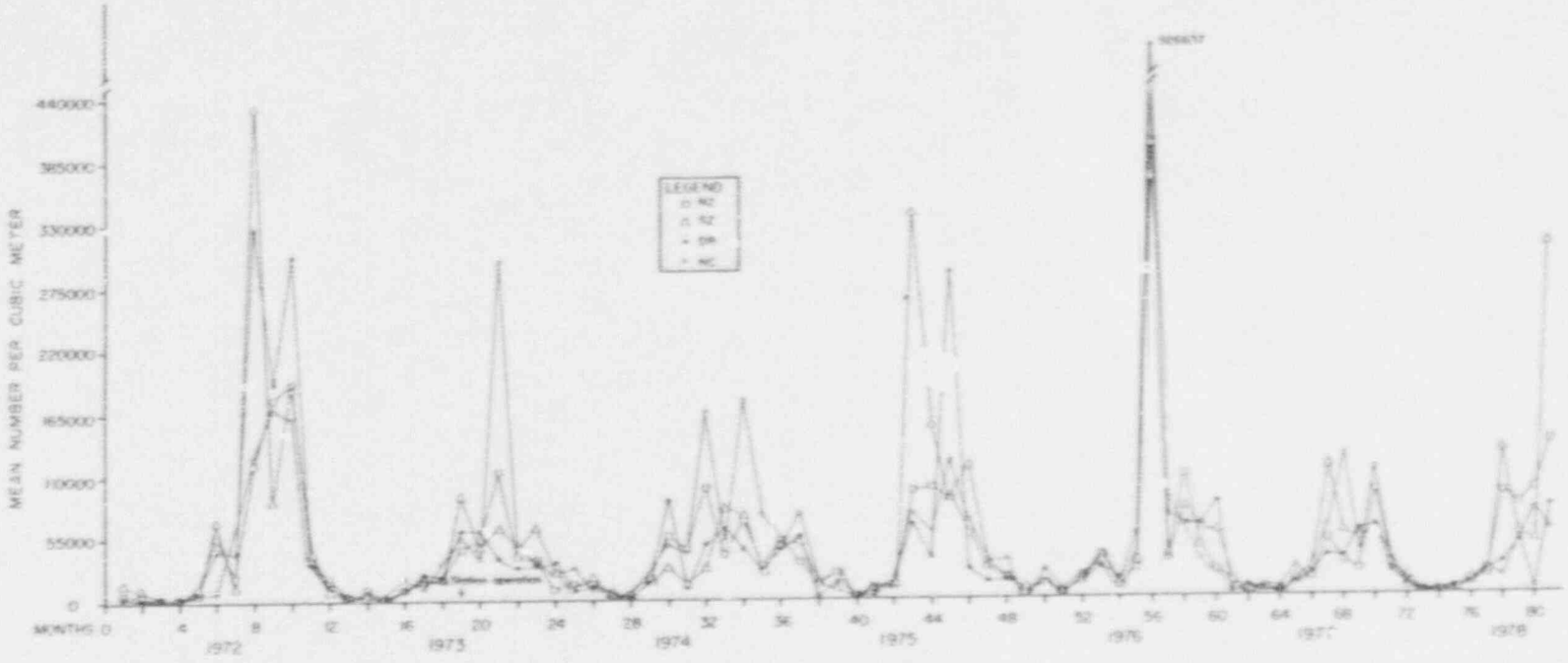


Figure 2. Monthly mean density (No./m^3) of total zooplankton at 3 m locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978.

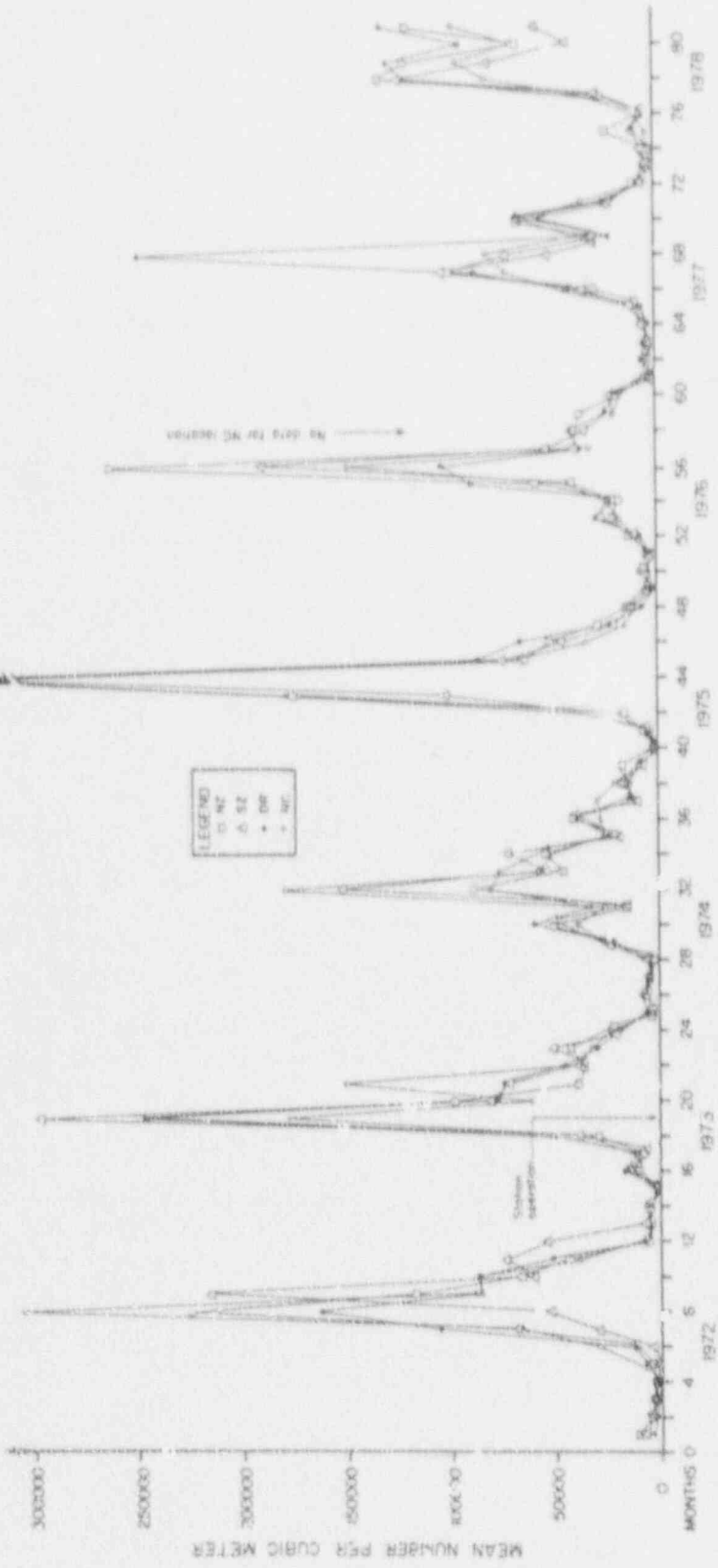


Figure 3. Monthly mean density (No./m^3) of total zooplankton at 9 m locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978.

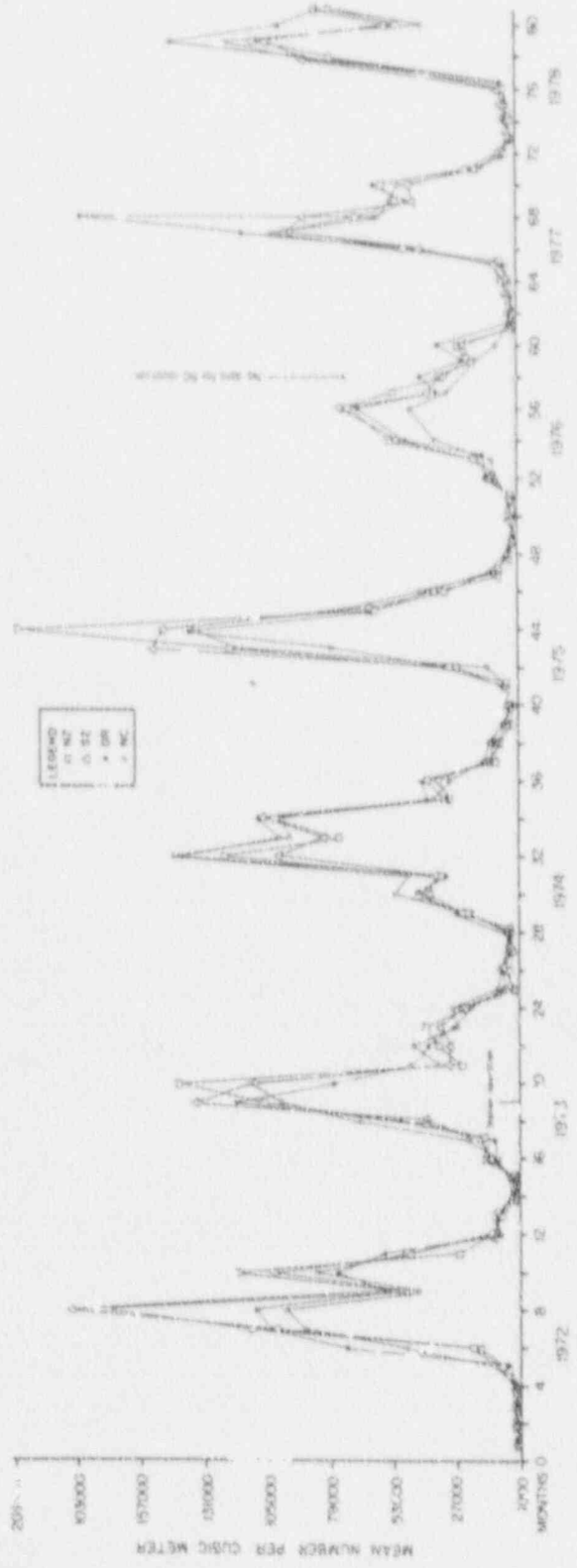


Figure 4. Monthly mean density (No./m^3) of total zooplankton at 18 m locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978.

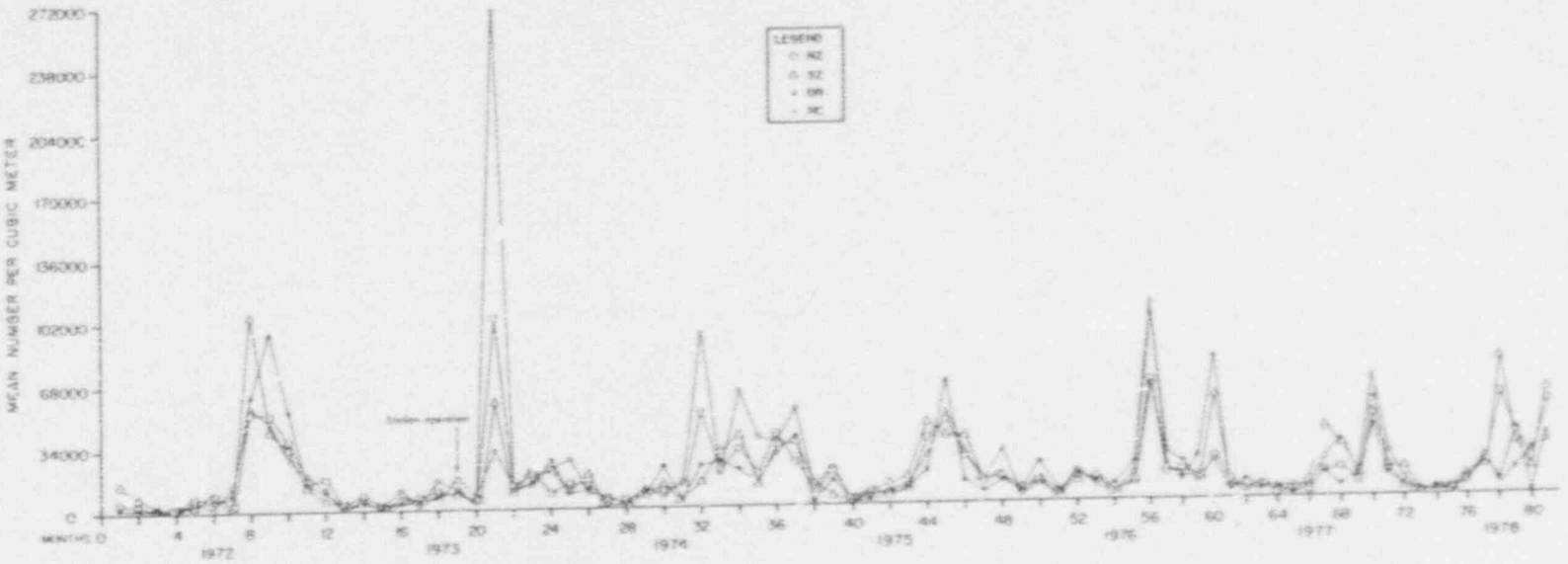


Figure 5. Monthly mean density (No./m^3) of total Copepoda at 3 m locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978.

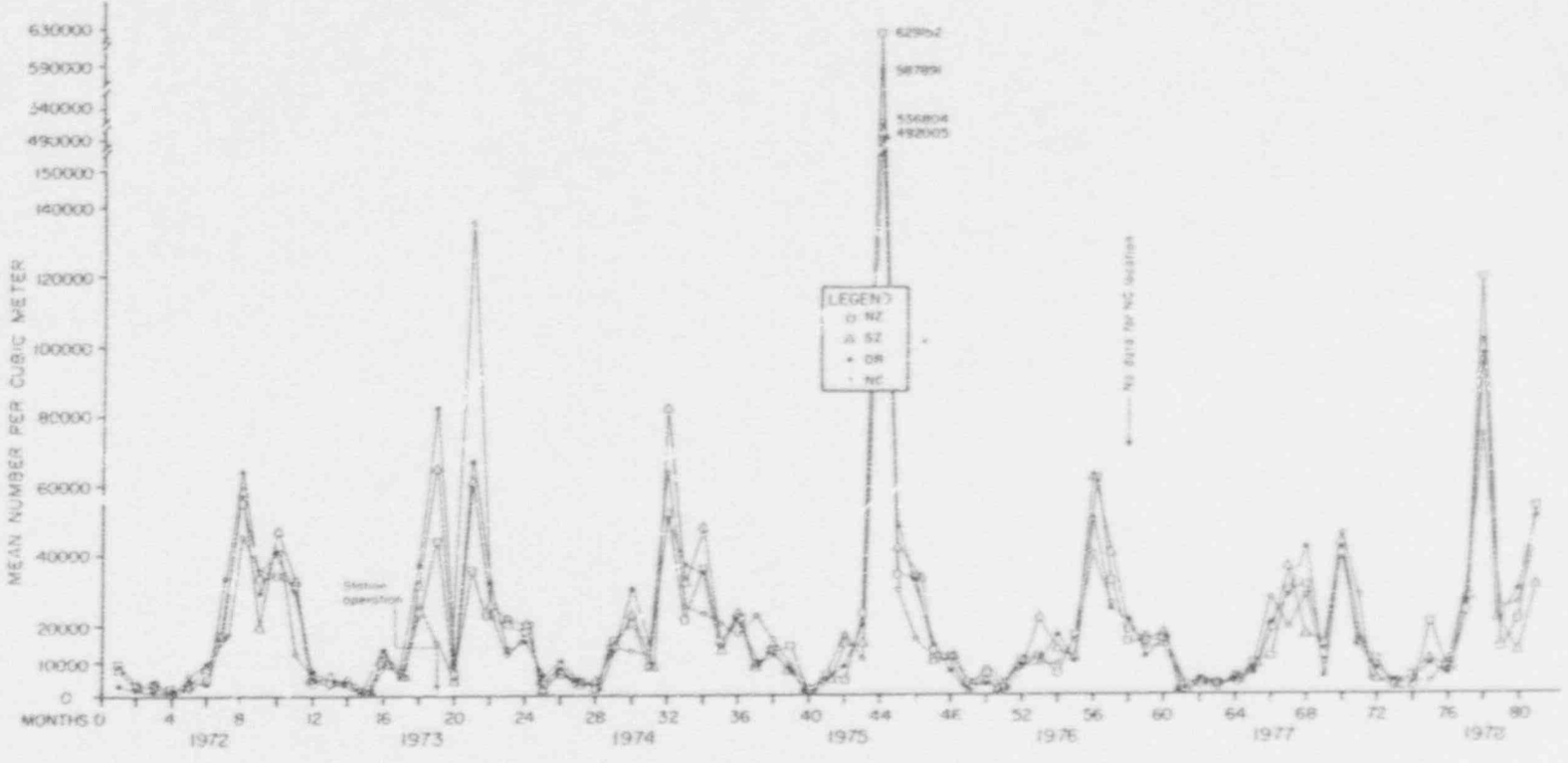


Figure 6. Monthly mean density (No./m^3) of total Copepoda at 9 m locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978.

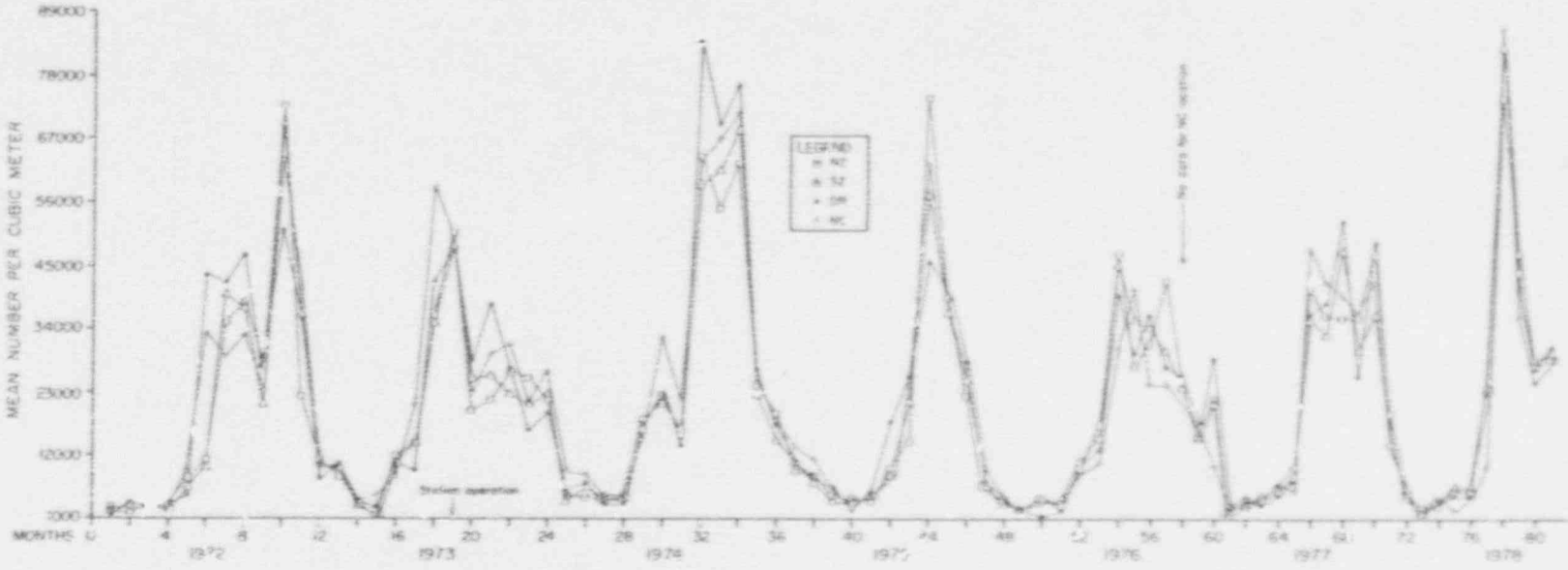


Figure 7. Monthly mean density (No./m^3) of total Copepoda at 18 m locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978.

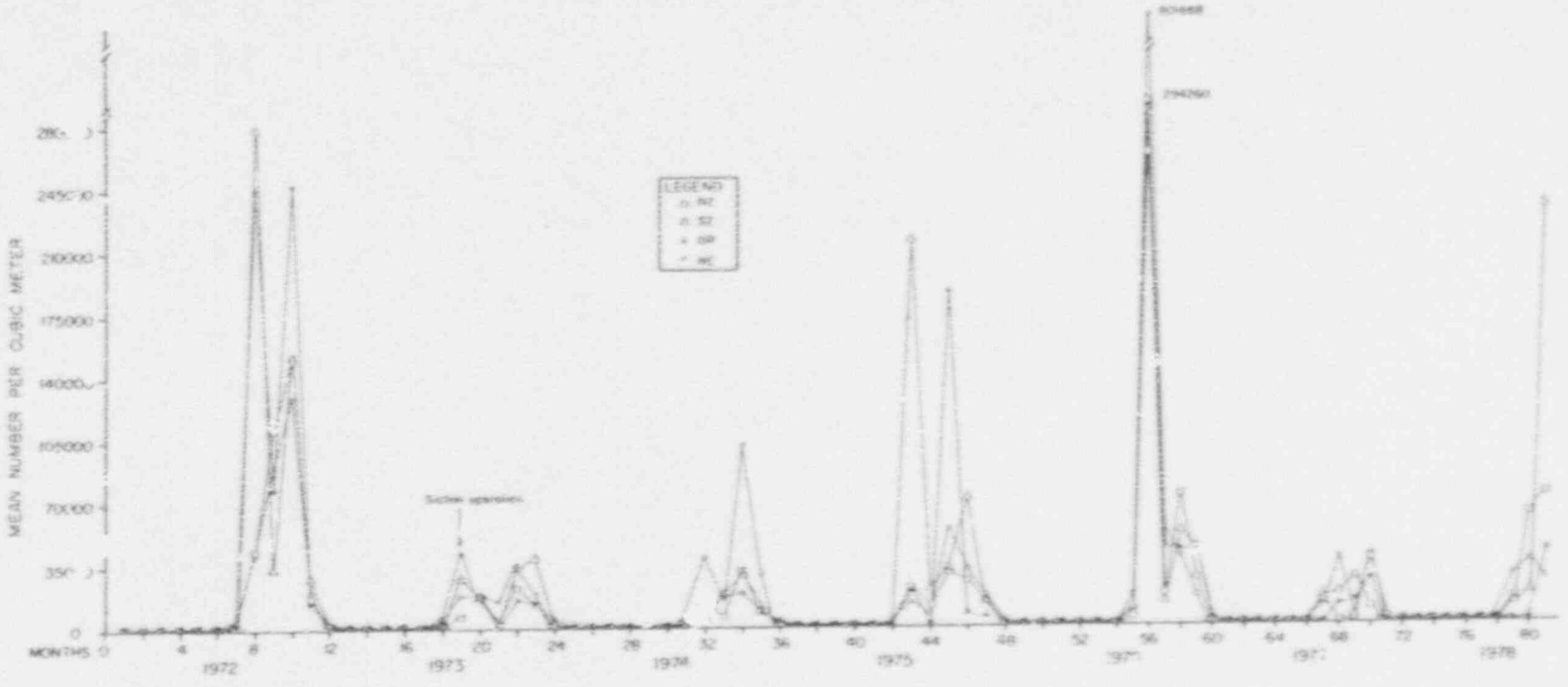


Figure 8. Monthly mean density (No./m^3) of total Cladocera at 3 m locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978.

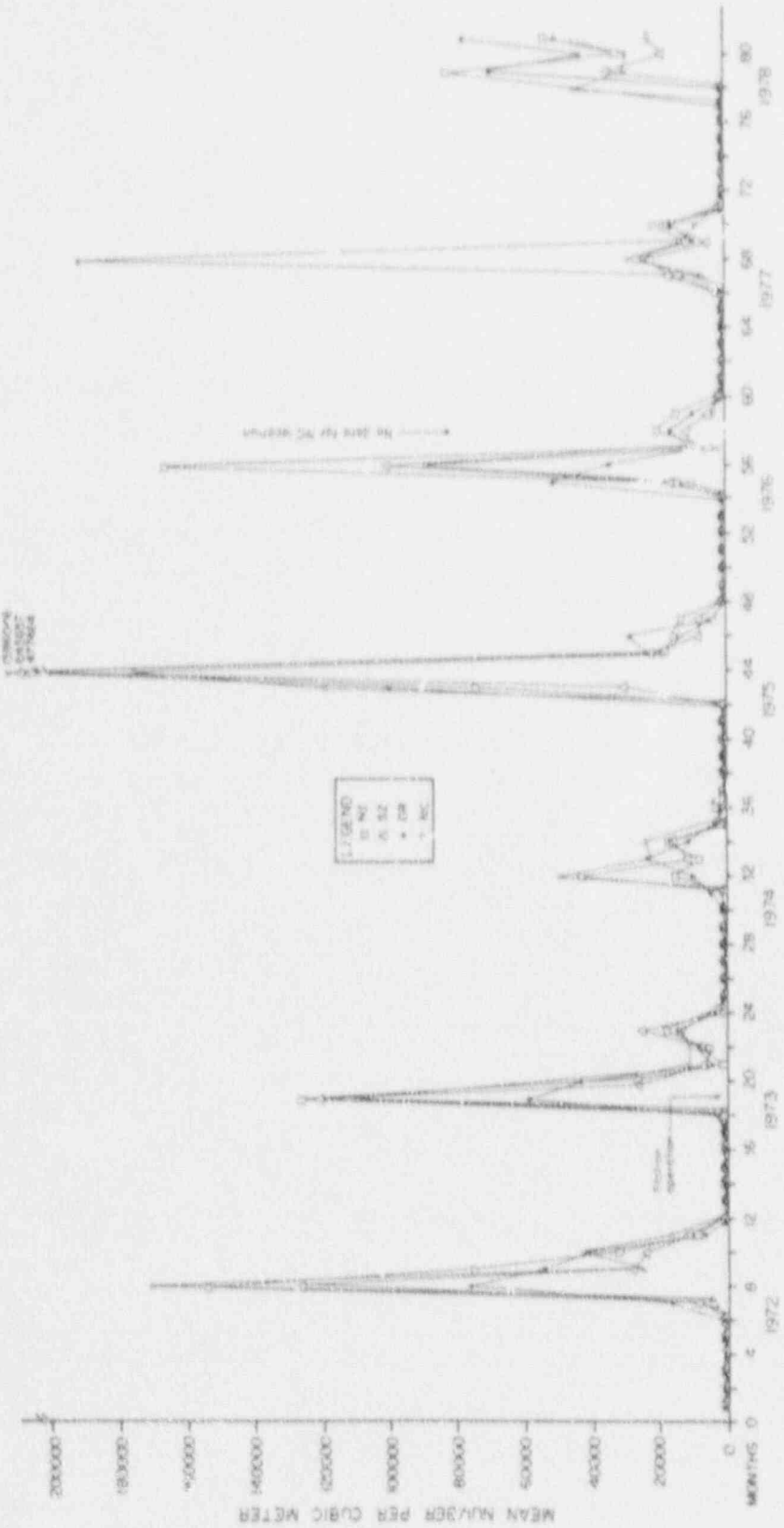


Figure 9. Monthly mean density (No./m^3) of total Cladocera at 9 m locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978.

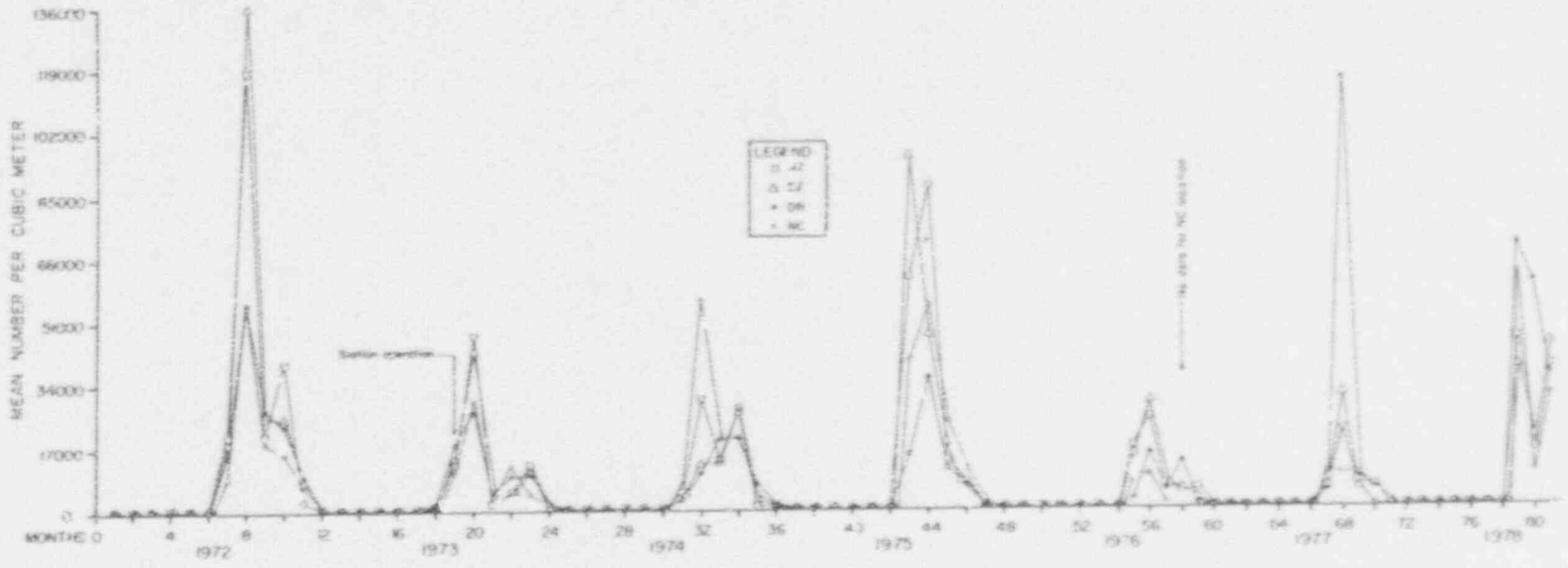


Figure 10. Monthly mean density (No./m^3) of total Cladocera at 18 m locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978.

densities through the fall and winter than in the spring and summer. In general copepods were more abundant at the offshore locations.

Fall populations of Cladocera were generally more abundant than during the winter and spring (Figures 8, 9, 10). Their numbers increased from less than 5 organisms/m^3 in April to over 100,000 organisms/m^3 in August (Hunt 1974a, p. 197). During August and September over one-half of all zooplankton enumerated and identified were cladocerans. The most predominant cladoceran collected in 1972 was Bosmina longirostris. The seasonal occurrence and distribution of this species was therefore very similar to that of total cladocerans. The second most abundant cladoceran, Daphnia retrocurva, also exhibited density patterns similar to Bosmina longirostris and total Cladocera. In months of peak density cladocerans were most numerous at 3 m locations.

Rotifers, enumerated only as major group totals, were low in density during the winter and spring, after which populations increased to a peak period from June through August (Figures 11, 12, 13). At this time they composed up to 88% of the total zooplankton community. Locations of greatest density for rotifers varied between depth contours.

2. January 1973 through June 1973

During this study period total zooplankton abundance declined through March, then began to rise significantly through June due to increases in all three major groups. Copepoda increased from approximately 2000 organisms/m^3 in March to nearly 37,000 organisms/m^3 in June primarily due to the rise in number of

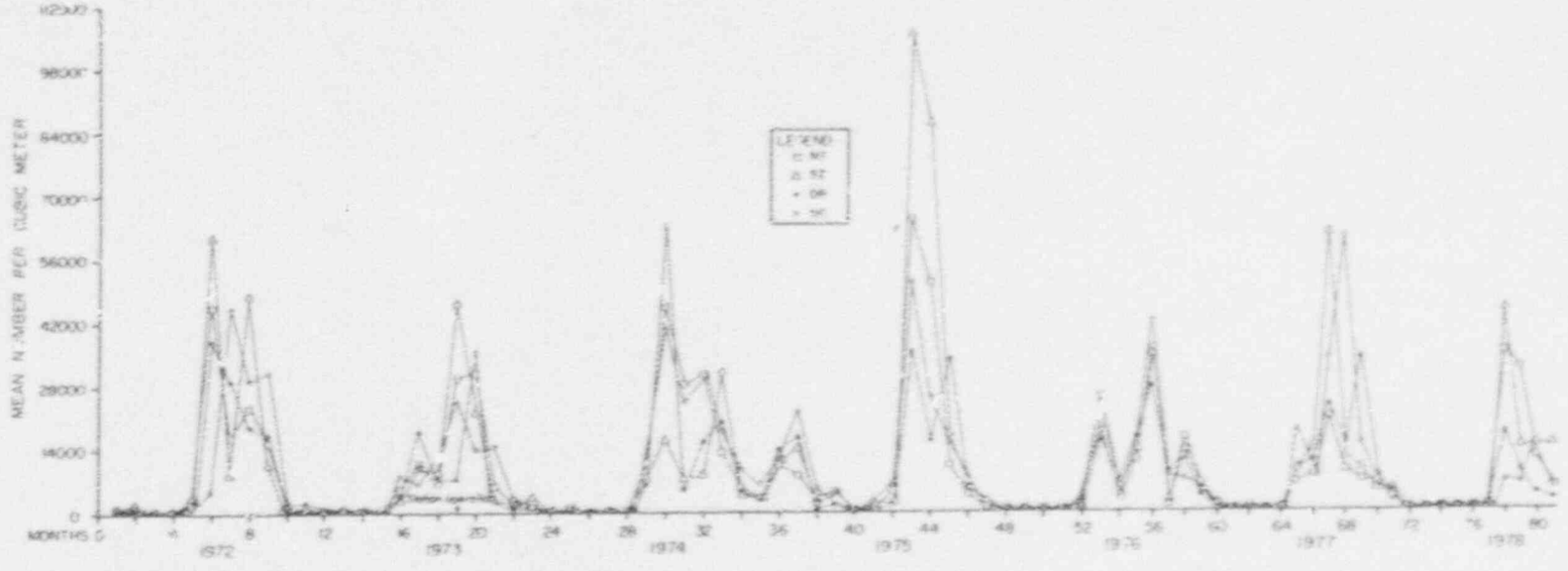


Figure 11. Monthly mean density (No./m^3) of total Rotifera at 3 ... locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1976.

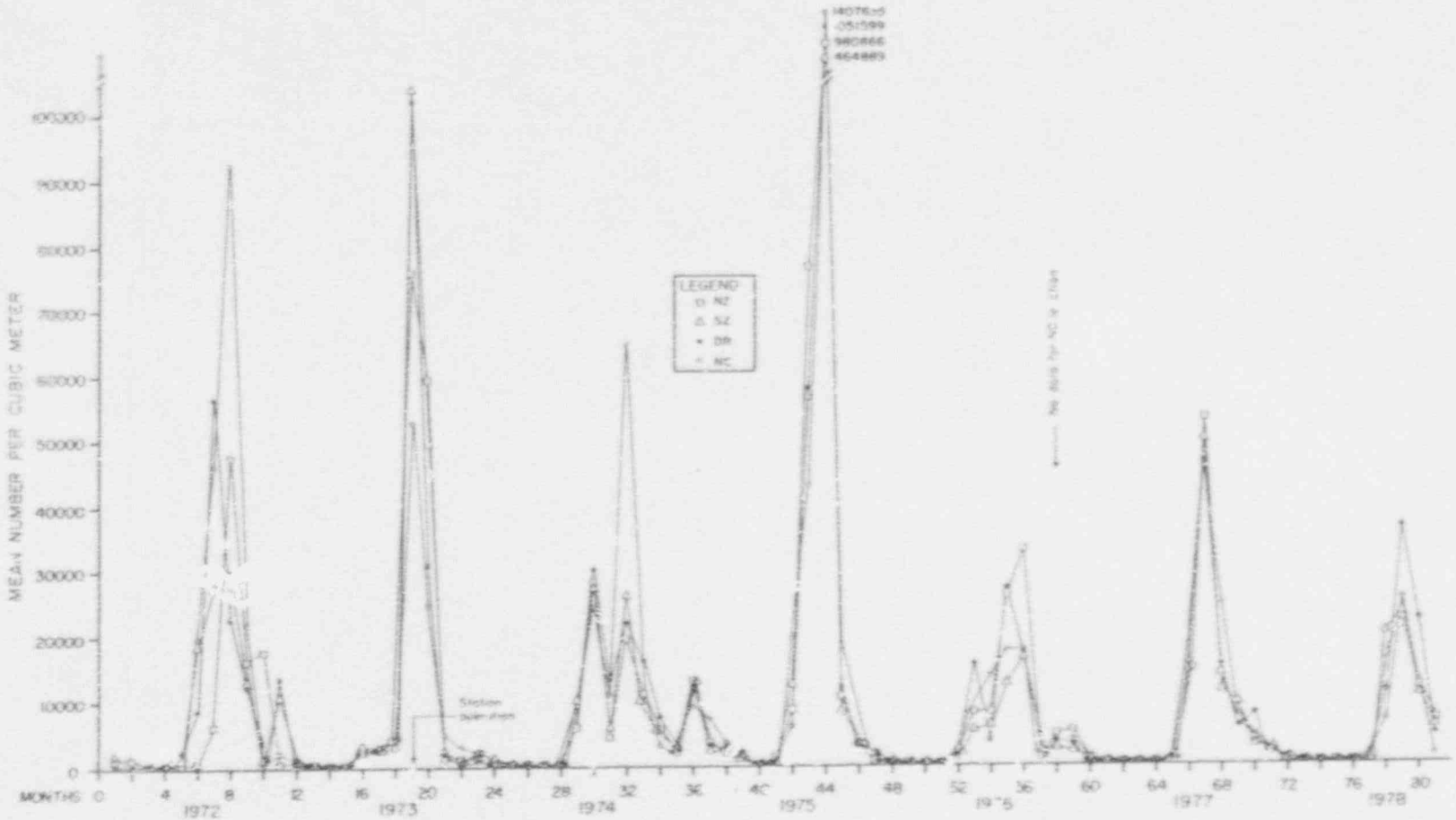


Figure 12. Monthly mean density (No./m^3) of total Rotifera at 3 m locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978.

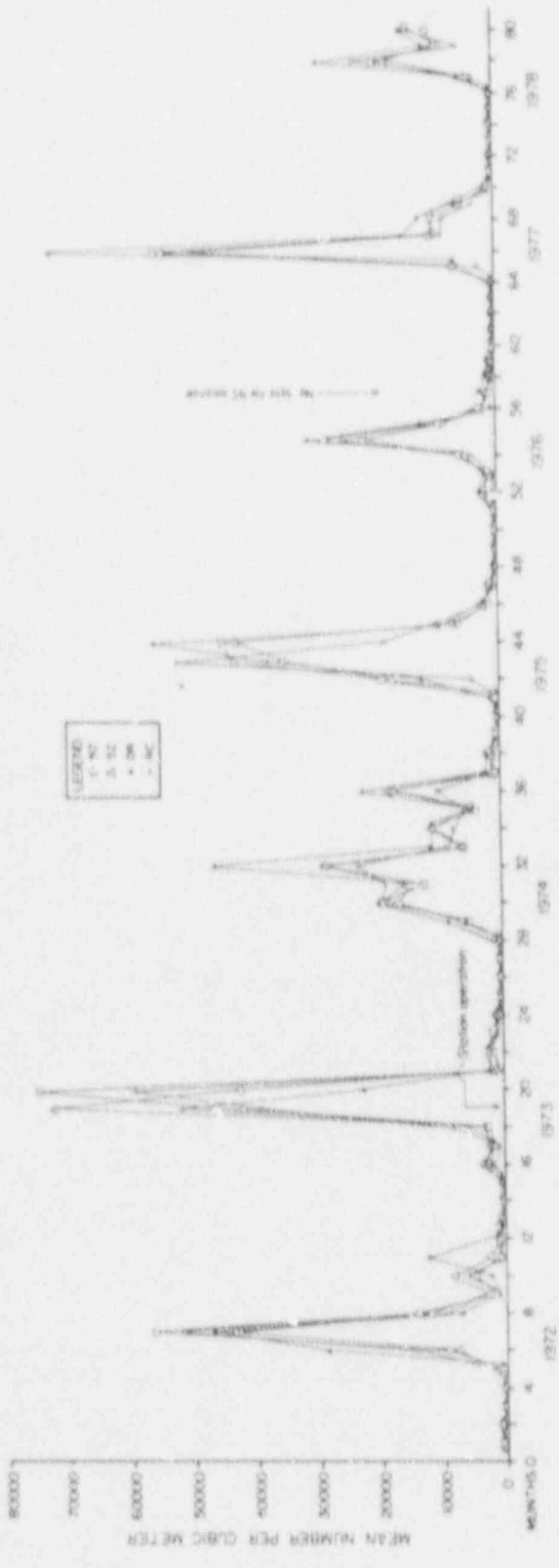


Figure 13. Monthly mean density (No./m^3) of total Rotifera at 18 m locations in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978.

immatures (Hunt 1974b, unpaged). Total zooplankton and copepods were more abundant at the 18 m locations. Adult taxa remained relatively common throughout this period. Cladocera, rare in February and March, increased considerably in June. This increase is attributable to Bosmina longirostris which composed 99% of the total Cladocera. Rotifera also increased from a seasonal low in February to maximum densities in June when Notholca, Kellicottia and Keratella comprised the major portion of the rotifer population. Cladocerans and rotifers were more concentrated at the 3 m depth in months of their occurrence.

3. July 1973 through June 1974

Total zooplankton and total Crustacea densities were greatest during summer and early fall but decreased by half in the winter months (McGrath and Dvorak 1974, p. 84). The summer increase of total zooplankton was due to the increase in the numbers of Cladocera and Rotifera species. Their maximum densities were also reached in the summer and early fall months.

Total Copepoda populations were low January through April after which densities began to increase toward maximum abundance in September. Percent composition was also high during this month when cladoceran blooms usually overshadow the concurrent increase in Copepoda abundance. The high percentage was due to Cladocera peaking in July and August, before the Copepoda peak. Maximum abundances of copepods varied between depth contours.

Immature forms, the major component of the copepod population, accounted for the high densities in September. Densi-

ties for nauplii, calanoid and cyclopoid copepodites were low during the winter and early spring increasing toward their fall maximum. Nauplii also experienced a later peak in May when they composed up to 68% of the zooplankton at one location. Cyclops bicuspidatus thomasi and Diaptomus species were also common during the fall and remained so during the winter months.

Cladocera were scarce in winter and spring though becoming very abundant in the fall. This increase was due primarily to the densities of Bosmina longirostris and Daphnia retrocurva.

B. longirostris was most abundant July to November while D. retrocurva occurred most frequently in October and November. When densities began to increase toward a fall peak, the 3 m locations contained the greatest density of cladocerans.

Densities of Rotifera were also low in the winter and spring, but increased to half of the total zooplankton in July and August 1973 and June 1974 (McGrath and Dvorak 1974, p. 88). The abundance of Keratella was highest in July when mean densities exceeded 17,000 organisms/m^3. Notholca and Synchaeta, however, became most abundant in May and June. During months of high density, rotifers occurred most frequently at the inshore locations.

4. July 1974 through June 1975

During this study period zooplankton densities fluctuated between months with the largest density occurring in August and the smallest in April (Dvorak 1975, p. 364). Density was high in the fall due to large numbers of taxa in all divisions, and high in the winter because of Copepoda dominance. The

number of organisms declined in April and May but increased in June due to the rise in abundance of Cladocera and Rotifera species.

Total Copepoda abundance was low during the summer months and highest during the fall and winter at offshore locations. During the fall and winter the copepods, primarily immature forms, accounted for the majority of the zooplankton. The most abundant adult copepods were Cyclops bicuspidatus thomasi and Diaptomus species.

The maximum cladoceran densities in August and October were due primarily to Bosmina longirostris and Daphnia retrocurva. The mean numbers of Cladocera decreased from approximately 27,000 organisms/m^3 in August to 3 organisms/m^3 in March and April (Dvorak 1975, p. 367). B. longirostris was rarely encountered in samples collected from January through April following which densities increased toward a fall peak. Densities were generally greatest at the inshore locations.

Densities of total Rotifera paralleled those of Cladocera with low numbers in the winter and spring, increasing to a maximum density in August. In June, rotifers composed over one half of the zooplankton. Kellicottia and Keratella were the most prevalent rotifer taxa in the fall accounting for the high total rotifera numbers in these months. Subdominant species included Notholca and Synchaeta.

5. July 1975 through June 1976

The zooplankton community near Zion Station during this study period was dominated by immature copepods and Bosmina

longirostris in late summer and early fall. The lowest levels of abundance occurring January through April reflected the marked decrease in densities of Cladocera and Rotifera during the winter.

The dominant Copepoda taxon, cyclopoid copepodites, reached their highest number of the entire study program in August 1975 with over 300,000 organisms/m^3 at one location (Dvorak 1976, p. 180). Yet due to the large numbers of rotifers and cladocerans also occurring at this time, they composed only 10% of the total zooplankton. Subdominant copepod taxa encountered included Cyclops bicuspidatus thomasi, Diaptomus ashlandi, D. minutus, and D. oregonensis.

Cladocera were rare or absent from samples collected in winter and spring. Densities gradually increased to a seasonal peak in early fall, during which they composed nearly one-half of all zooplankton. The maximum and minimum values for total Cladocera can be directly correlated to the Bosmina longirostris density fluctuations. The cladocerans were dominated by B. longirostris composing up to 69% of the total zooplankton in July (Dvorak 1976, p. 23). Total Cladocera varied little between depth contours in winter and spring but densities were generally greatest at the inshore locations when the community was more abundant.

Populations of rotifers fluctuated somewhat as seasonal successions of species occurred but the general trend was low densities in the winter and spring increasing toward a maximum in summer and early fall. The greatest fall densities in July and August were attributed to high densities of Conochilus, Kellicottia

and Keratella. Other dominant rotifer taxa included Synchaeta and Notholca.

6. July 1976 through June 1977

Zooplankton densities during this study period increased from July to August, reaching a maximum of nearly 142,000 organisms/m^3, decreased steadily through January, then began to increase again in the spring (Dvorak 1977, p. 393).

The species richness of each of the major zooplankton groups differed between months. The low number of species found in February and March reflected the marked decrease in densities of Cladocera and Rotifera during the winter. A greater number of Copepoda occurred in December although densities were highest in August due to large numbers of immature forms. Cladocerans were more diverse in September; however, maximum densities were reached the previous month. The greatest number of rotifer species occurred in the summer and early fall with the highest abundance occurring in July. Maximum densities at the three depth contours varied between months and locations with no consistent pattern evident.

In all months except August, the most abundant zooplankton group was the Copepoda accounting for 30-90% of the mean total zooplankton. The largest percentage of copepods during the fall were immature forms, dominated by cyclopoid copepodites. Immature forms increased during the summer to their greatest abundance in August. Nauplii and calanoid copepodites tended to follow this same pattern. Cyclops bicuspidatus thomasi, Diaptomus ashlandi, D. minutus, and D. oregonensis were the four predominant

adult copepod taxa collected. Maximum densities of C. bicuspidatus thomasi, the dominant adult copepod, varied between depths and months with no apparent peak period occurring. The Diaptomus species were most abundant during December through March. Copepods were found to be more prevalent in offshore waters.

Mean densities of total Cladocera decreased from nearly 83,000 organisms/m^3 in August to zero in March 1977 (Dvorak 1977, p. 401). As with total Cladocera, Bosmina longirostris, the dominant cladoceran, was rarely collected in the winter and spring collections, after which they increased in abundance towards a fall peak. Other cladocerans which occurred as subdominants included Eubosmina coregoni and Daphnia retrocurva.

Populations of rotifers followed the same general pattern as Cladocera with low densities in the winter and spring increasing toward greatest numbers in summer and early fall, primarily at 3 m locations. Whenever a maximum occurred for rotifers it was usually reflective of a dominant genus. During the peaks in July and August the most abundant rotifers were Kellicottia and Keratella.

7. July 1977 through June 1978

As in previous study periods, certain taxa recurred more frequently and dominated the total zooplankton. Yet the majority of the taxa could be classified as uncommon with only 14 or 15 taxa occurring as dominants or subdominants. Reflecting these dominant species, zooplankton densities increased from July to August, decreased through January, and then began to increase again in the

spring (McGrath and Dvorak 1978, p. 393). As found in other years, the greatest number of species occurred in months of high densities.

Except for late summer (July, August, September) the most abundant zooplankton group was the Copepoda accounting for 26-99% of the mean total zooplankton (McGrath and Dvorak 1978, p. 396). The largest percentage of copepods during the fall were immature forms, composed primarily of nauplii and cyclopoid copepodites. Cyclopoid copepodites increased through the summer and early fall to their maximum in October 1977. Nauplii had a later peak in June 1978 when they composed up to 60% of the total zooplankton when cladoceran abundance was still low. Cyclops bicuspidatus thomasi, Diaptomus ashlandi, D. minutus, D. oregonensis and D. sicilis were the five predominant adult copepod taxa collected. Although each taxon usually occurred in every month, seasonal pulses were more common. Limnocalanus macrurus, a cold-water species, became quite abundant January through March but was seldom found in other months. Data from this study show copepods to be generally more abundant at offshore locations.

Mean densities of total Cladocera decreased from 191,000 organisms/m^3 in August to none in March 1978 (McGrath and Dvorak 1978, p. 403). The maximum and minimum values for total Cladocera can be directly related to the Bosmina longirostris density fluctuations. The cladocerans were always dominated by Bosmina longirostris, composing as much as 76% of the total zooplankton in August.

The general pattern followed by rotifers was low densities in the winter and spring increasing toward a maximum in summer and early fall. Maximum abundances for rotifers were usually reflective of a dominant genus. During high abundances in July and August the predominant taxa were Keratella and Kellicottia, respectively. Another prevalent rotifer, Synchaeta, reached its highest abundance in June. During peak months, maximum densities varied between depth contours.

8. July 1978 through September 1978

The last sampling interval in the study program was conducted from July through September 1978. Densities of total zooplankton reached their peak in July when Cladocera and Rotifera taxa were most abundant. Copepoda decreased from a peak in June, but still remained very abundant through September. Densities of total Cladocera, Bosmina longirostris and Daphnia retrocurva all increased from the spring and peaked during this sampling period. Rotifer densities increased significantly from June to their maximum in July. Dominant fall rotifers included Kellicottia, Keratella, Conochilus and Synchaeta.

B. Zooplankton Entrainment

1. Seasonal Abundance

a. October 1973 through September 1974

The zooplankton exhibited wide fluctuations in density and composition in this study. Densities ranged from 91,531 organisms/m^3 in July to 1754 organisms/m^3 in February (Restaino, Redmond, Otto 1975, p. 32).

Copepods, most commonly observed as immature forms (nauplii and calanoid and cyclopoid copepodites), reached their highest abundance in August and September. Cyclops bicuspidatus thomasi was the most common adult copepod in the fall. Other adult copepods became abundant in February and continued to dominate the identifiable fraction of the zooplankton through May with Diaptomus and Cyclops species being the predominant taxa. During the summer adult copepods were present in very low numbers.

Cladocera were either absent or present in very low numbers during the winter and spring but became quite numerous in fall. The most abundant species to appear at any one time was Bosmina longirostris which constituted 69% of all Cladocera collected during the sample period (Restaino, Redmond, Otto 1975, p. 35).

Rotifers accounted for 64% of the total zooplankton community in June and 75% in July (Restaino, Redmond, Otto 1975, p.35). Nothoica, the most abundant rotifer, was first collected in April and reached a maximum mean density in June when it constituted 66% of the rotifer population and 10% of the total zooplankton. Keratella, the most common summer rotifer, reached a maximum density in August when it constituted 80% of the rotifer poplation.

The mean density of total zooplankton in the Zion forebay was significantly greater during the day than at night in October, November and March. Night populations were significantly more abundant than during the day in August and September.

b. August 1976 through July 1977

Zooplankton abundance underwent large seasonal fluctuations during the year. Densities were greatest in August averaging over 140,000 organisms/m^3 and declined to a low in April (Restaino and Morse 1977, p. 489).

Copepod densities reached a high in August when the immature forms (nauplii and copepodites) accounted for over 80% of the Copepoda. Tropocyclops prasinus mexicanus was the most abundant copepod in September and reached its peak abundance in October. Cyclops bicuspidatus thomasi was the dominant copepod in August, October and November and peaked in December.

The extremely high densities in August were due to a seasonal peak of the cladoceran, Bosmina longirostris. The Cladocera continued through November as the most abundant zooplankters with B. longirostris and Eubosmina coregoni sharing dominance in October and November. The short-lived Cladocera declined sharply in December and January and no cladocerans were observed in February. Cladocera recurred in March and gradually increased in the spring and summer as temperatures and phytoplankton abundance increased.

Differences in zooplankton densities between day and night samples in the intake forebay, tested with the Student's "t" test, detected eleven instances when taxa were significantly more abundant at night whereas in only three instances taxa were significantly more abundant during the day.

2. Entrainment Effects

a. Mechanical

The mechanical effect of condenser passage on entrained zooplankton was determined from January through June and August and September 1974, when at least one unit of Zion Station was operating at 0% turbine capacity (no ΔT). During that period, entrained zooplankton immotilities ranged from 3.2% to 14.9% (Restaino, Redmond, Otto 1975, p. 39).

Mechanical effects alone could not be measured during the 1976 through 1977 study due to station operation and subsequent ΔT.

b. Thermal and Mechanical

The combined effects of thermal and mechanical factors during condenser passage on zooplankton were determined from October and November 1973, and February through September 1974. Although differences in immotilities between intake and discharge samples were significant throughout the study with individual values ranging from 2.8% to 15.5%, there appeared to be no direct correlation between increases in temperature across the condensers (ΔT) and zooplankton immobilities (Restaino, Redmond, Otto 1975, p. 39). Discharge water temperatures did not exceed upper lethal temperatures for entrained zooplankton. Immotility differences between day and night populations followed no apparent pattern.

The combined thermal and mechanical factors of condenser passage during the period from August 1976 through July 1977 resulted in day immotilities ranging from 5.2% to 22.5%

(Restaino and Morse 1977, p. 503). Differences in mortalities (24 hrs) between the intake forebay (Location 2) and discharge (Location 3) were significantly ($p \leq 0.05$) higher at the discharge in ten of twelve sampling periods. Day and night populations for total zooplankton had similar condenser immotilities and mortalities. During nine of twelve months sampled, day and night condenser mortality differences over 24 hours averaged less than 1%.

A size-immotility relationship was observed for zooplankton passing through the condensers during the day and night at Zion Station. Entrained organisms which exceeded 0.98 mm in length (e.g., Diaptomus ashlandi, D. oregonensis and Limnocalanus macrurus) had a 14.2% higher immotility than non-entrained organisms while organisms 0.4 mm or less (e.g., nauplii, Bosmina longirostris and Eubosmina coregoni) had only 6.5% greater immotility (Restaino and Morse 1977, p. 510). This indicates that mechanical factors were primarily responsible for the observed effects of condenser passage, effecting mostly the larger-bodied species.

The percent zooplankton mortalities (4 and 24 hrs) measured in the plume were lower than those measured at the discharge tunnel. Plume mortalities primarily represented dead organisms discharged from the Station. Rapid dilution of discharge water with ambient lake water and settling out of dead zooplankters discharged from the Station were the most important factors for the decreased percent mortality measured within the plume.

IV. References Cited

Brooks, J. L. 1957. The systematics of North American Daphnia. Mem. Connecticut Acad. Arts and Sci. 13: 180 p.

Czaika, S. C. and A. Robertson. 1968. Identification of the Copepodites of the Great Lakes species of Diaptomus (Calanoida, Copepoda). Proc. 11th Conf. Great Lakes Res., Intern. Assoc. Great Lakes Res. 39-60.

Dvorak, D. 1975. Zooplankton study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1974, through June 1975. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. II: 353-491.

_____. 1976. Zooplankton study. IN Operational environmental monitoring in Lake Michigan near Zion Station. July 1975 through June 1976. Annual report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. IV: 1-416.

_____. 1977. Zooplankton study. IN Operational monitoring in Lake Michigan near Zion Station. July 1976 through June 1977. Annual report to Commonwealth Edison Company, Chicago, Illinois by NALCO Environmental Sciences. Vol. III: 377-573.

Edmondson, W. T. (Ed.) 1959. Ward and Whipple - Freshwater Biology. John Wiley & Sons, Inc. New York. 1248 p.

Frey, D. G. 1959. The taxonomic and phylogenetic significance of the head pores of the Chydoridae (Cladocera). Int. Revue ges. Hydrobiol. 44: 27-50.

Huh, H., L. Everhart, C. Kondrat, J. Lingle and J. Urry. 1973. Field study program of Lake Michigan in the vicinity of the Waukegan and Zion Generating Stations, April 1971 - March 1972. Project X. IN Evaluation of thermal effects in southwestern Lake Michigan 1971-1972. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I: 131 p.

Hunt, G. 1974a. Zooplankton study. IN Environmental monitoring in Lake Michigan near Zion and Waukegan Generating Stations, January 1972 through December 1972. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. II: 167-226.

_____. 1974b. Zooplankton study. IN Environmental monitoring in Lake Michigan near Zion and Waukegan Generating Stations, January 1973 through June 1973. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Unpublished.

Icanberry, J. W. 1972. Quantitative sampling of live zooplankton with a filter-pump system. Presented at Amer. Soc. Limnol. Oceanogr., Inc., Thirty-fifth Annual Meeting, Florida State University, Tallahassee, Florida, March 19-22, 1972.

Lamble, M. 1972. Zooplankton study, August 1970 - March 1971. Project VIII. IN Evaluation of thermal effects in southwestern Lake Michigan (January 1970 - April 1971). Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. II: 60 p.

McGrath, M. and D. Dvorak. 1974. Zooplankton study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through June 1974. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. II: 75-232.

_____. 1978. Zooplankton Study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1977 through June 1978. Annual Report to Commonwealth Edison Company, Chicago, Illinois. by Industrial BIO-TEST Laboratories, Inc. Vol. III: 377-558.

Megard, R. O. 1967. Three new species of Alona (Cladocera, Chydoridae) from the United States, Int. Revue ges. Hydrobiol. 52(1): 37-50.

Pritchard-Carpenter Consultants. 1970. Predictions of the distribution of excess temperatures in Lake Michigan resulting from the discharge of condenser cooling water from the Zion Nuclear Power Station. Commonwealth Edison Company, Chicago, Illinois, 68 p.

Restaino, A., D. G. Redmond and R. G. Otto. 1975. Entrainment study at Zion Station. IN Compilation of special reports on the effects of Zion Station operation on the biota in southwestern Lake Michigan. Special Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc.

Restaino, A. and T. Morse. 1977. Zooplankton Entrainment Study. IN Operational Monitoring in Lake Michigan near Zion Station. July 1976 through June 1977. Annual report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. IV: 479-652.

Ruttner-Kolisko, A. 1974. Plankton Rotifers, Biology and Taxonomy. IN Die Binnengewasser, Vol. XXVI/1 Supplement. E. Schweizerbart'sche Verlagsbuchhandlung. Stuttgard. 146 p.

Shannon, C. E. 1948. A mathematical theory of communication. Bell System Tech. J. 27: 349-423.

Smirnov, N. N. 1974. Chydoridae. Fauna of the USSR. Crustacea. Vol. 1, No. 2. (Transl. from Russian by A. Mercado, Israel Program for Scientific Translations). Acad. Sci. USSR. New Series No. 101. 644 p.

Snee, Ronald D. 1964. Graphical display of two-way contingency tables. The American Statistician. 48(1): 9-12.

Chapter 8

PERIPHYTON STUDIES

by

M.Y. Phillips

SUMMARY REPORT OF ENVIRONMENTAL MONITORING
IN LAKE MICHIGAN NEAR ZION STATION

April 1970 through June 1977

TABLE OF CONTENTS

		Page
	List of Figures	275
	List of Tables	277
I.	Introduction	279
II.	Materials and Methods	
	A. Field Procedures	281
	B. Laboratory Procedures	283
	C. Data Analysis	285
III.	Results and Discussion	
	A. Yearly Results	
	1. April 1970 - March 1971	287
	2. January - June 1973	287
	3. July 1973 - June 1974	288
	4. July 1974 - June 1975	289
	5. July 1975 - June 1976	290
	6. July 1976 - June 1977	291
IV.	References Cited	293

LIST OF FIGURES

No.	Caption	Page
1	Shoreline periphyton sampling locations in southwestern Lake Michigan near Zion, Illinois	282

LIST OF TABLES

No.	Title	Page
1	Summary of the monitoring programs of periphyton collected from natural shoreline substrates in southwestern Lake Michigan near Zion, Illinois, April 1970 - June 1977	283

Introduction

This report is a summary of data generated during the April 1970 through March 1971 and January 1973 through June 1977 periphyton studies of southwestern Lake Michigan near Zion Station, Zion, Illinois.

The objectives of the monitoring programs were:

1. to identify and document the periphyton community of this area prior to Zion Station operation;

2. to determine whether differences existed in the abundance of total periphyton, species composition, biomass and chlorophyll a concentrations between locations near or under the potential influence of the thermal plume and control locations outside the plume area; and

3. to assess any effect of Zion Station operation on the periphyton community.

II. Methods and Materials

A. Field Procedures

The basic periphyton monitoring program was established at three zones; North Control, North Zion, and South Zion (Figure 8.1). The initial program was based on samples collected during June, July, August and October 1970 from Locations 31 (near North Control), 25 (North Zion) and 24 (South Zion) (Figure 8.1) (Industrial BIO-TEST Laboratories, Inc. 1972, p. V-3 through V-5). Samples were collected from steel pilings at Locations 24 and 31 and from a rock breakwater at Location 25.

The January 1973 through the 1977 monitoring program was established at the same basic locations; however, the sampling was twice monthly except during the winter months when ice covered the substrates. (Flores 1974; Altstaetter 1974, p.5; 1975, p.8; Altstaetter and Phillips, 1976, p. 11; Phillips 1977, p. 179). Samples were collected from rock or cement slabs in the splash zone at Location 28 (North Control), Location 1 (North Zion), Location 14 (south edge of South Zion) and from a steel outfall pipe, the only substrate available, at Location 10 (north edge of South Zion zone) (Figure 8.1).

Samples for species identification, biomass and chlorophyll a determinations were collected throughout all years (Table 8.1). All algae samples for species identifications were preserved at the time of collection (Industrial BIO-TEST Laboratories, Inc. 1972, p. V-7; Flores 1974; Altstaetter 1974, p. 5; Altstaetter 1975, p. 8; Altstaetter and Phillips 1976, p. 11; Phillips 1977, p. 181).

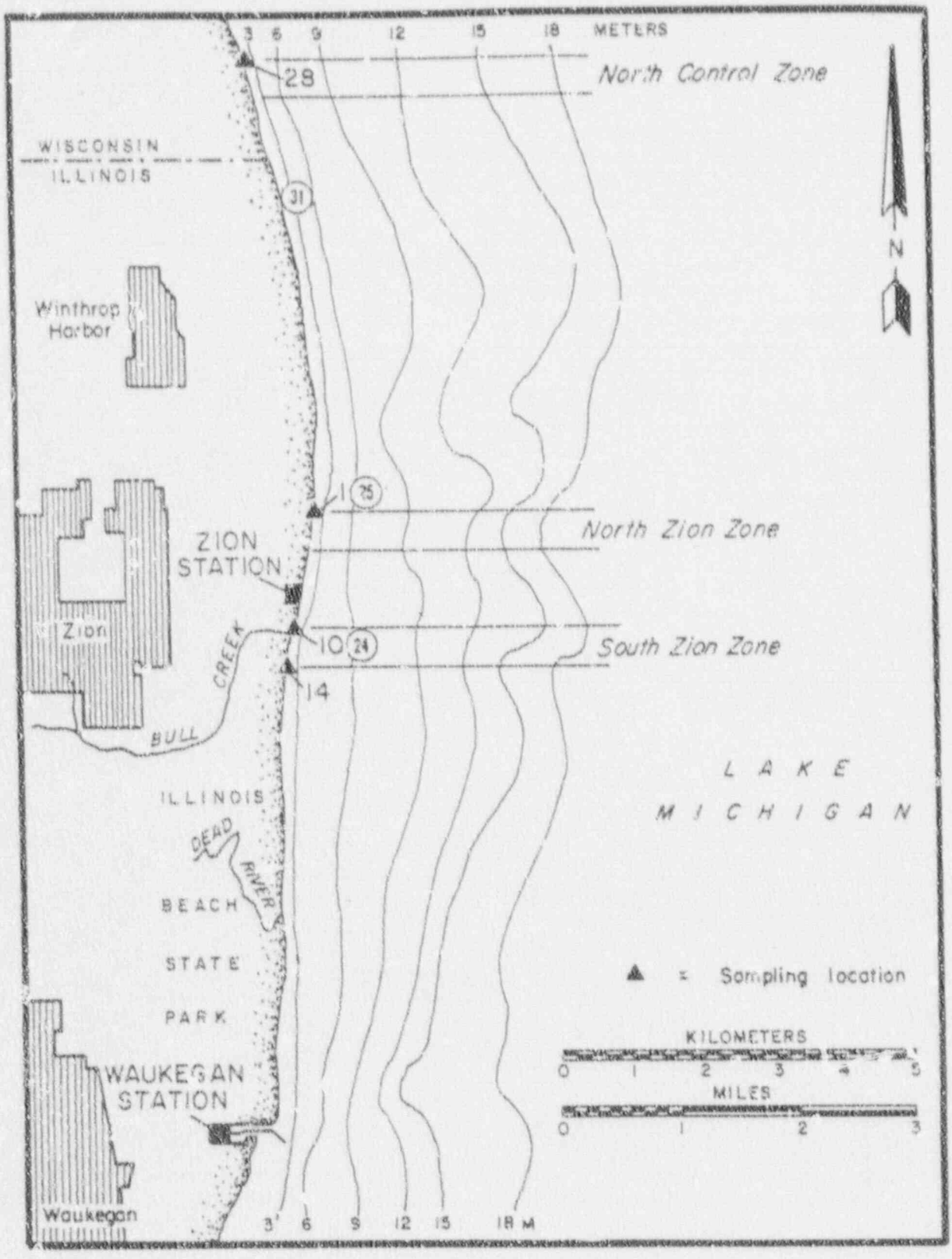


Figure 1. Shoreline periphyton sampling locations in southwestern Lake Michigan near Zion, Illinois.

Table 1. Summary of the monitoring programs of periphyton collected from natural substrates in southwestern Lake Michigan near Zion, Illinois, April 1970 through June 1977.

Collection Period	Locations	Number of Replicates/Location and Frequency						Report
		Identification		Biomass		Chlorophyll a		
		No.	Freq.	No.	Freq.	No.	Freq.	
April 1970 - March 1971	24,25 & 31	1	M[a]	4	M	3	M	Industial BIO-TEST Laboratories, Inc. 1972
January - June 1973	1,10,14 & 28	4	B[b]	6	B	6	M	Flores, 1974
July 1973 - June 1974	1,10,14 & 28	4	B	6	B	6	M	Altstaetter, 1974
July - November 1974, April - June 1975	1,10,14 & 28	4	B	6	B	6	M	Altstaetter, 1975
July - November 1975, April - June 1976	1,10,14 & 28	4	B	6	B	6	M	Altstaetter and Phillips 1976
July - November 1976, April - June 1977	1,10,14 & 28	4	B	6	B	6	M	Phillips, 1977

[a] Samples collected monthly.
[b] Samples collected twice monthly.

HAZLETON ENVIRONMENTAL SCIENCES

B. Laboratory Procedures

Diatoms were cleaned with a nitric acid/potassium dichromate solution, diluted and subsamples were mounted using Hyrax mounting medium. Samples for algal analysis other than diatoms were mixed in a blender, diluted and subsamples were mounted as semi-permanent wet mounts (Industrial BIO-TEST Laboratories 1972, p. V-7; Flores 1974; Altstaetter 1974, p. 5; Altstaetter 1975, p. 8; Altstaetter and Phillips 1976, p. 11; Phillips 1977, p. 181). Results of sample analysis from the April 1970 - March 1971 study were qualitatively expressed as relative abundance (Industrial BIO-TEST Laboratories, Inc. 1972, p. V-7). The January 1973 through June 1977 monitoring program techniques were quantitative with data expressed as units/cm^2 (Flores 1974; Altstaetter 1974, p.5; Altstaetter 1975, p. 8; Altstaetter and Phillips 1976, p. 13; Phillips 1977, p. 181). In addition, biovolumes were calculated and expressed as microliters/square decimeter ($\mu l/dm^2$) for the January 1973 - June 1977 studies (Flores 1974; Altstaetter 1974, p.5; Altstaetter 1975, p. 9, 10; Altstaetter and Phillips 1976, p. 13; Phillips 1977, p. 181). Biomass and chlorophyll a determinations were accomplished in accordance with standard methodologies (Industrial BIO-TEST Laboratories, Inc. 1972, p. V-6; Flores 1974; Altstaetter 1974, p.7; Altstaetter 1975, p. 10; Altstaetter and Phillips 1976, p. 13; Phillips 1977, p. 181). Biomass values were reported as milligrams ash-free

dry weight per square decimeter (mg/dm^2) and chlorophyll a concentrations were reported as micrograms per square decimeter ($\mu g/dm^2$).

C. Data Analysis

Shannon's diversity and evenness indices were calculated and used to estimate the difference in community structure between sampling locations for the January 1973 - June 1977 studies (Flores 1974; Altstaetter 1974, p. 7; Altstaetter 1975, p. 10; Altstaetter and Phillips 1976, p. 14; Phillips 1977, p. 181).

Statistical tests performed on the periphyton data included: monthly one-way analysis of variance and Tukey's multiple comparison procedures on biomass and chlorophyll a values for the April 1970 - March 1971 and January - June 1973 studies (Industrial BIO-TEST Laboratories, Inc. 1972, p. V-6; Flores 1974); a factorial analysis of variance and Tukey's multiple comparison procedure on biomass and chlorophyll a values for the April 1970 - March 1971 study (Industrial BIO-TEST Laboratories, Inc. 1972, p. V-6); and, a factorial analysis of variance and associated multiple comparison procedure on dominant taxa, major divisions, total periphyton, biomass and chlorophyll a for the June 1973 through June 1976 studies (Altstaetter 1974, p. 7; Altstaetter 1975, p. 10; Altstaetter and Phillips 1976, p. 13).

Due to an error in the calculation of Tukey's W values, data run on the SUPERFAC program contained possible errors. The SUPERFAC program was used on data from three annual

reporting periods: July 73 - June 74; July 74 - June 75; and July 75 - June 76. The errors did not constitute a change in the the interpretation of the data presented in the annual reports.

III. Results and Discussion

A. Yearly Results

1. April 1970 - March 1971

The periphyton community collected from natural substrates was dominated by Ulothrix zonata in June and Cladophora glomerata in July, August and October. Representatives of the diatom genera, Cocconeis, Cymbella, Diatoma and Rhoicosphenia were also common. The dominance of U. zonata and C. glomerata of the algal communities in southern Lake Michigan is common and this seasonal succession was correlated to seasonal water temperatures (Industrial BIO-TEST Laboratories, Inc. 1972, p. V-8).

2. January - June 1973

The periphyton community collected from natural shoreline substrates was dominated by Ulothrix species (primarily U. zonata and U. variabilis) in January, February and June. Cladophora glomerata was dominant by biovolume in February only. The diatoms Achnanthes, Fragilaria, Gomphonema, Navicula and Nitzschia were the dominant algae during April and May. Blue-green algae, primarily Phormidium tenue, P. uncinatum and Oscillatoria tenuis were occasionally abundant (Flores 1974).

Biomass and chlorophyll a values were highest in June during Ulothrix predominance and lowest in April when diatoms were predominant. Biomass and chlorophyll a values were significantly greater at Location 28 than Locations 1 and 14. Substrates at Locations 1 and 14 were more susceptible to scouring and did not support the growth of the filamentous forms

as well as those at Location 28. Diversity values were highest in June and lowest in January (Flores 1974).

3. July 1973 - June 1974

The periphyton community was dominated by Ulothrix zonata and diatoms (primarily Achnanthes, Diatoma Fragilaria and Rhoicosphenia) in July 1973 and April-June 1974. Cladophora glomerata dominated during August 1973 through January 1974. Bangia atropurpurea (a red alga) was also occasionally dominant throughout the study (Altstaetter 1974, p. 12, 13).

Ulothrix zonata and C. glomerata densities were generally higher at Location 28 than Locations 1, 10 and 14; whereas, diatom densities at Location 28 were generally lower than at the other locations (Altstaetter 1974, p. 16 17).

Biomass and chlorophyll a values varied among locations but a general trend of higher values during the summer months was evident. Biomass and chlorophyll a concentrations at Location 28 were usually greater than at Locations 1, 10 and 14 (Altstaetter 1974, p. 18, 73, 74).

Substrates at Locations 1, 10 and 14 were more often scoured from sand and wave action than Location 28 substrates. Location 28 afforded a more protected area for the growth of the filamentous forms over the diatoms. These natural physical factors were sufficient to cause the observed variations of the periphyton community.

Statistical tests indicated few consistent significant trends among the respective algal components. Algal

assemblages at the experimental Locations (1, 10 and 14) were occasionally different from those of Location 28; however, the differences were similarly noted during the previous monitoring year prior to station start-up.

Diversity values were similar to those reported in the January - June 1973 study (Flores 1974; Altstaetter 1974, p. 51, 52).

4. July 1974 - June 1975

Green algae composed the bulk of the densities, biovolume, biomass and chlorophyll a concentrations during the July 1974 - June 1975 study. Ulothrix was generally most abundant in the spring and early summer; Cladophora glomerata was most abundant in late summer and early fall. The diatoms Diatoma, Gomphonema, Nitzschia and Rhoicosphenia were also common constituents of the periphyton community. Dominant populations of Lyngbya aerugineo - caerulea (blue-green alga) and Bangia atropurpurea (red alga) occasionally occurred throughout the year (Altstaetter 1975, p. 12, 13). THe periphyton community was generally higher at Locations 28 and 14 than Locations 1 and 10 (Altstaetter 1975, p. 48-56).

Biomass and chlorophyll a concentrations were similar to those reported in the previous year's study. Biomass and chlorophyll a values were generally higher at Location 28 than Locations 1, 10 and 14.

Diversity va.ues were within the range of those of the July 1973 - June 1974 study.

There were no differences in the abundance of the respective algal components among the control and experimental locations that were attributable to an effect of Zion Station operation (Altstaetter 1975, p. 20).

5. July 1975 - June 1976

The periphyton community was dominated by Ulothrix in the spring and early summer and by Cladophora glomerata in the late summer. Diatoms (mainly Achnanthes and Fragilaria) were the dominant algal group during October and November. Bangia atropurpurea was also a common constituent of the periphyton community; whereas, blue-green algae were of minor importance (Altstaetter and Phillips 1976, p. 15-17).

Biomass and chlorophyll a values were similar to those reported in previous years (Altstaetter and Phillips 1976, p. 70). Diversity values also fell within the range of previous years (Altstaetter and Phillips 1976, p. 80, 81).

Results of statistical tests indicated significant differences among sampling dates in densities of Cladophora glomerata and Ulothrix species that corresponded with the previously mentioned seasonal trends. Biomass, chlorophyll a concentrations and total periphyton densities were also significantly higher during months of Cladophora dominance (Altstaetter and Phillips 1976, p. 19)

The seasonal growth and distribution patterns of the respective algal components were a result of natural temporal and spatial variability and not Zion Station operation.

6. July 1976 - June 1977

Periphyton samples were primarily collected from Location 28. Locations 1, 10 and 14 were sampled only intermittently throughout the study period due to lack of suitable substrates, resultant of relatively low lake levels and scouring (Phillips 1977, p. 179).

The green algae were the primary constituents of the periphyton community. Ulothrix zonata was the dominant alga during April through June 1977; whereas, Cladophora glomerata was dominant from July through November 1976. Bangia atropurpurea was occasionally a dominant member of the periphyton assemblage. Blue-green algae and the diatoms, Diatoma, Fragilaria and Rhoicosphenia, were also dominant at various times throughout the sampling period (Phillips 1977, p. 183, 184).

There was a general seasonal trend of largest standing crops, i.e., biomass, chlorophyll a concentrations and biovolume values, being recorded from July through November 1976. This coincided with the seasonal Cladophora glomerata dominance at the various locations (Phillips 1977, p. 185, 198-205). In general the algal components were most abundant at Location 28. Biomass and chlorophyll a concentrations fell within the ranges of previous years' studies.

IV. References Cited

Altstaetter, C. C. 1974. Periphyton study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through June 1974. Annual report to Commonwealth Edison Company, Chicago, Illinois.

_____. 1975. Periphyton study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1974 through June 1975. Annual Report to Commonwealth Edison Company, Chicago, Illinois.

_____ and M. Y. Phillips. 1976. Periphyton study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1975 through June 1976. Annual report to Commonwealth Edison Company, Chicago, Illinois.

Flores, M. 1974. Periphyton study. IN Environmental monitoring in Lake Michigan near Zion and Waukegan Generating Stations, January 1973 through June 1973. Report to Commonwealth Edison Company, Chicago, Illinois.

Industrial BIO-TEST Laboratories, Inc. 1972. Field studies on periphyton, April 1970 through March 1971. Project V. IN Evaluation of thermal effects in southwestern Lake Michigan (January 1970 through April 1971). Report to Commonwealth Edison Company, Chicago, Illinois.

Phillips, M. Y. 1977. Periphyton study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1976 through June 1977. Annual report to Commonwealth Edison Company, Chicago, Illinois.

Chapter 9

BENTHOS STUDIES

by

Dean F. Geers

SUMMARY REPORT OF ENVIRONMENTAL MONITORING
IN LAKE MICHIGAN NEAR ZION STATION

January 1970 through September 1978

TABLE OF CONTENTS

		Page
	List of Figures	299
	List of Tables	303
I.	Introduction	305
II.	Methods and Materials	
	A. Sampling Locations	307
	B. Benthos Collections	311
	C. Taxonomy	312
	D. Physical Measurements	314
	E. Statistical Analysis	314
IV.	Results	
	A. Benthic Macroinvertebrate Collections	317
	B. Ichthyoplankton Collections	326
	C. Summary	327
V.	References Cited	369

LIST OF FIGURES

No.	Caption	Page
1	Benthos sampling locations in southwestern Lake Michigan near Zion, Illinois, January 1973 through August 1978	320
2	Mean number/m^2 of total benthos at the 3 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1971-August 1978	337
3	Mean number/m^2 of total benthos at the 6 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1971-August 1978	338
4	Mean number/m^2 of total benthos at the 9 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1970-August 1978	339
5	Mean number/m^2 of total benthos at the 12 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1970-August 1978	340
6	Mean number/m^2 of total benthos at the 18 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1970-August 1978	341
7	Mean number/m^2 of Pontoporeia affinis at the 3 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1971-August 1978	342
8	Mean number/m^2 of Pontoporeia affinis at the 6 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1971-August 1978	343
9	Mean number/m^2 of Pontoporeia affinis at the 9 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1970-August 1978	344
10	Mean number/m^2 of Pontoporeia affinis at the 12 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1970-August 1978	345
11	Mean number/m^2 of Pontoporeia affinis at the 18 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1970-August 1978	346
12	Mean number/m^2 of total Tubificidae at the 3 meter locations in southwestern Lake Michigan near Zion, Illinois, February 1972-August 1978	348

LIST OF FIGURES (continued)

No.	Caption	Page
13	Mean number/m^2 of total Tubificidae at the 6 meter locations in southwestern Lake Michigan near Zion, Illinois, February 1972-August 1978	349
14	Mean number/m^2 of total Tubificidae at the 9 meter locations in southwestern Lake Michigan near Zion, Illinois, February 1972-August 1978	350
15	Mean number/m^2 of total Tubificidae at the 12 meter locations in southwestern Lake Michigan near Zion, Illinois, February 1972-August 1978	351
16	Mean number/m^2 of total Tubificidae at the 18 meter locations in southwestern Lake Michigan near Zion, Illinois, February 1972-August 1978	352
17	Mean number/m^2 of Stylodrilus heringianus at the 9 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1970-August 1978	354
18	Mean number/m^2 of Stylodrilus heringianus at the 12 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1970-August 1978	355
19	Mean number/m^2 of Stylodrilus heringianus at the 18 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1970-August 1978	356
20	Mean number/m^2 of total Sphaeriidae at the 3 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1971-August 1978	357
21	Mean number/m^2 of total Sphaeriidae at the 6 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1971-August 1978	358
22	Mean number/m^2 of total Sphaeriidae at the 9 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1970-August 1978	359
23	Mean number/m^2 of total Sphaeriidae at the 12 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1970-August 1978	360
24	Mean number/m^2 of total Sphaeriidae at the 18 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1970-August 1978	361

LIST OF FIGURES (continued)

No.	Caption	Page
25	Mean number/m^2 of total Chironomidae at the 3 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1971-August 1978	362
26	Mean number/m^2 of total Chironomidae at the 6 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1971-August 1978	363
27	Mean number/m^2 of total Chironomidae at the 9 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1970-August 1978	364
28	Mean number/m^2 of total Chironomidae at the 12 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1970-August 1978	365
29	Mean number/m^2 of total Chironomidae at the 18 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1970-August 1978	366

LIST OF TABLES

No.	Title	Page
1	Summary of sampling locations and methods used for benthos collections in southwestern Lake Michigan near Zion, Illinois, February 1970 through August 1978	308
2	Taxonomic list of benthic macroinvertebrates encountered in southwestern Lake Michigan near Zion, Illinois, April 1970-August 1978	328
3	Annual means and percent occurrence of the dominant benthic macroinvertebrates collected from southwestern Lake Michigan near Zion, Illinois, January 1972 through June 1978	333

Introduction

A long term monitoring program was initiated in February 1970 to determine possible effects of cooling water use by Zion Station on the benthic community in the adjacent area of Lake Michigan. This is a summary report of the results drawn from the macroinvertebrate data as presented in previous reports. This report covers data presented for the preoperational period February 1970 through June 1973 and the operational period August 1973 through August 1978.

The main objectives throughout these studies have been:

1. To characterize the benthos in southwestern Lake Michigan in the Zion area. This included seasonal occurrence of species, distribution as related to water depth and natural benthos population fluctuations among zones;

2. To analyze the benthic community for changes in species composition or abundance of the major components of the benthic community; and

3. To analyze the data so that an assessment could be made of the effect of heated effluents on the benthic populations due to operation of Zion Station.

II. Method and Materials

A. Sampling Locations

The benthic sampling program was initiated in February 1970. Initially 103 sampling locations were established in radiating concentric patterns from the location of the intake and discharge structures. This plan, however, was abandoned in April 1970 because of difficulty in relocating sampling locations. None of the locations sampled during this inital survey correspond to present sampling locations. For the period April 1970 through March 1971, a grid-type sampling pattern with 63 locations was established, seven of these correspond to present sampling locations (Table 1). In April 1971, eighteen locations on three transects perpendicular to the shore were sampled and eight of these correspond to present sampling locations (Table 1). For the period June 1971 to April 1972, 22 locations were sampled, all of which correspond to present locations. Four locations were added in April 1972 and eight more locations were added in June 1972. The 18-m locations were established in February 1973.

A total of 40 locations were sampled continuously from February 1973 through June 1978 (Figure 1). Thirty-six of the 40 locations were sampled in August 1978, a reduction of four 18 m locations (36a, 4a, 17a, and 40a). The 40 locations were divided into four zones. Two zones, North Zion (N.Z.) and South Zion (S.Z.), with 10 locations in each were established within or near the predicted area of major thermal influence from Zion Station (Pritchard-Carpenter, Consultants 1970). Ten locations were established off

Table 1. Summary of sampling locations and methods used for benthos collections in southwestern Lake Michigan near Zion, Illinois, February 1970 through August 1978.

Year	Month	Total Number of Sampling Locations	Number of Locations Corresponding to 1976 Locations	Depths Sampled	Sampling Device	Number of Replicates	Number of Collecting Trips/Month	Preservative Used	Treament of Samples	Reference
1970	Feb.	103	0	2-50m	Ponar	1	1	70% Ethanol	Sieved in Lab	Industrial BIO-TEST Lab. 1972
	April	63	7	2-50m	Ponar	1	1	70% Ethanol	Sieved in Lab	Industrial BIO-TEST Lab. 1972
	June	63	7	2-50m	Ponar	1	2	70% Ethanol	Sieved in Lab	Industrial BIO-TEST Lab. 1972
	Aug.	63	7	2-50m	Ponar	1	1	70% Ethanol	Sieved in Lab	Industrial BIO-TEST Lab. 1972
	Oct.	63	7	2-50m	Ponar	1	1	70% Ethanol	Sieved in Lab	Industrial BIO-TEST Lab. 1972
	Dec.	63	7	2-50m	Ponar	1	1	70% Ethanol	Sieved in Lab	Industrial BIO-TEST Lab. 1972
1971	Feb.	63	7	2-50m	Ponar	1	1	70% Ethanol	Sieved in Lab	Huh et. al. 1973
	April	18	8	3,6,9,12,18 28,37m	Ponar	1	1	70% Ethanol	Sieved in Lab	Huh et. al. 1973
	June	22	22	3,6,9,12m	Ponar	3	1	70% Ethanol	Sieved in Lab	Huh et. al. 1973
	Aug.	22	22	3,6,9,12m	Ponar	3	1	70% Ethanol	Sieved in Lab	Huh et. al. 1973
	Oct.	22	22	3,6,9,12m	Ponar	3	1	70% Ethanol	Sieved in Lab	Huh et. al. 1973
	Dec.	22	22	3,6,9,12m	Ponar	3	1	70% Ethanol	Sieved in Lab	Huh et. al. 1973
1972	Feb.	22	22	3,6,9,12m	Ponar	3	1	70% Ethanol	Sieved in Lab	Barbour 1974
	April	26	26	3,6,9,12m	Ponar	2	1	70% Ethanol	Sieved in Lab	Barbour 1974
	June	34	34	3,6,9,12m	Ponar	2	1	70% Ethanol	Sieved in Lab	Barbour 1974
	Aug.	34	34	3,6,9,12m	Ponar	2	1	70% Ethanol	Sieved in Lab	Barbour 1974
	Oct.	34	34	3,6,9,12m	Ponar	2	1	70% Ethanol	Sieved in Lab	Barbour 1974
	Dec.	34	34	3,6,9,12m	Ponar	2	1	70% Ethanol	Sieved in Lab	Barbour 1974
1973	Feb.	40	40	3,6,9,12,18m	Ponar	2	1	10% Form	Sieved in Field	Unpublished
	April	40	40	3,6,9,12,18m	Ponar	2	1	10% Form	Sieved in Field	Unpublished
	June	40	40	3,6,9,12,18m	Ponar	2	1	10% Form	Sieved in Field	Unpublished
	Aug.	40	40	3,6,9,12,18m	Ponar	2	1	10% Form	Sieved in Field	Stimpson & Brice 1974
	Oct.	40	40	3,6,9,12,18m	Ponar	2	1	10% Form	Sieved in Field	Stimpson & Brice 1974
	Dec.	40	40	3,6,9,12,18m	Ponar	2	1	10% Form	Sieved in Field	Stimpson & Brice 1974
1974	Feb.	40	40	3,6,9,12,18m	Ponar	2	1	10% Form	Sieved in Field	Stimpson & Brice 1974
	April	40	40	3,6,9,12,18m	Ponar	2	1	10% Form	Sieved in Field	Stimpson & Brice 1974
	June	40	40	3,6,9,12,18m	Ponar	2	1	10% Form	Sieved in Field	Stimpson & Brice 1974
	Aug.	40	40	3,6,9,12,18m	Ponar	2	1	10% Form	Sieved in Field	Stimpson & Brice 1975
	Oct.	40	40	3,6,9,12,18m	Ponar	2	1	10% Form	Sieved in Field	Stimpson & Brice 1975
	Dec.	40	40	3,6,9,12,18m	Ponar	2	1	10% Form	Sieved in Field	Stimpson & Brice 1975
1975	Feb.	40	40	3,6,9,12,18m	Ponar	2	1	10% Form	Sieved in Field	Brice 1976
	April	40	40	3,6,9,12,18m	Ponar	2	1	10% Form	Sieved in Field	Brice 1976
	June	40	40	3,6,9,12,18m	Ponar	2	1	10% Form	Sieved in Field	Brice 1976
	Aug.	40	40	3,6,9,12,18m	Ponar	2	1	10% Form	Sieved in Field	Brice 1976
	Oct.	40	40	3,6,9,12,18m	Ponar	2	1	10% Form	Sieved in Field	Brice 1976
	Dec.	40	40	3,6,9,12,18m	Ponar	2	1	10% Form	Sieved in Field	Brice 1976

HAZLETON ENVIRONMENTAL SCIENCES

Table 1. (continued)

Year	Month	Total Number of Sampling Locations	Number of Locations Corresponding to 1976 Locations	Depths Sampled	Sampling Device	Number of Replicates	Number of Collecting Trips/Month	Preservative Used	Treament of Samples	Reference
1975	Feb.	40	40	3,6,9,12,18m	Ponar	2	1	10% Form	Sieved in Field	Brice 1976
	April	40	40	3,6,9,12,18m	Ponar	2	1	10% Form	Sieved in Field	Brice 1976
	June	40	40	3,6,9,12,18m	Ponar	2	1	10% Form	Sieved in Field	Brice 1976
	Aug.	40	40	3,6,9,12,18m	Ponar	2	1	10% Form	Sieved in Field	Geers 1977
	Oct.	40	40	3,6,9,12,18m	Ponar	2	1	10% Form	Sieved in Field	Geers 1977
	Dec.	40	40	3,6,9,12,18m	Ponar	2	1	10% Form	Sieved in Field	Geers 1977
1977	Feb.	40	40	3,6,9,12,18m	Ponar	2	1	10% Form	Sieved in Field	Geers 1977
	April	40	40	3,6,9,12,18m	Ponar	2	1	10% Form	Sieved in Field	Geers 1977
	June	40	40	3,6,9,12,18m	Ponar	2	1	10% Form	Sieved in Field	Geers 1978
	Aug.	40	40	3,6,9,12,18m	Ponar	2	1	10% Form	Sieved in Field	Geers 1978
	Oct.	40	40	3,6,9,12,18m	Ponar	2	1	10% Form	Sieved in Field	Geers 1978
	Dec.	40	40	3,6,9,12,18m	Ponar	2	2[a]	10% Form	Sieved in Field	Geers 1978
1978	Feb.	40	40	3,6,9,12,18m	Ponar	2	2[a]	10% Form	Sieved in Field	Geers 1978
	April	40	40	3,6,9,12,18m	Ponar	2	2[a]	10% Form	Sieved in Field	Geers 1978
	June	40	40	3,6,9,12,18m	Ponar	2	1	10% Form	Sieved in Field	Geers 1979
	August	36	36	3,6,9,12,18m	Ponar	2				

[a]Second trip each month was for additional samples collected at 3 and 6m North and South Zion locations.

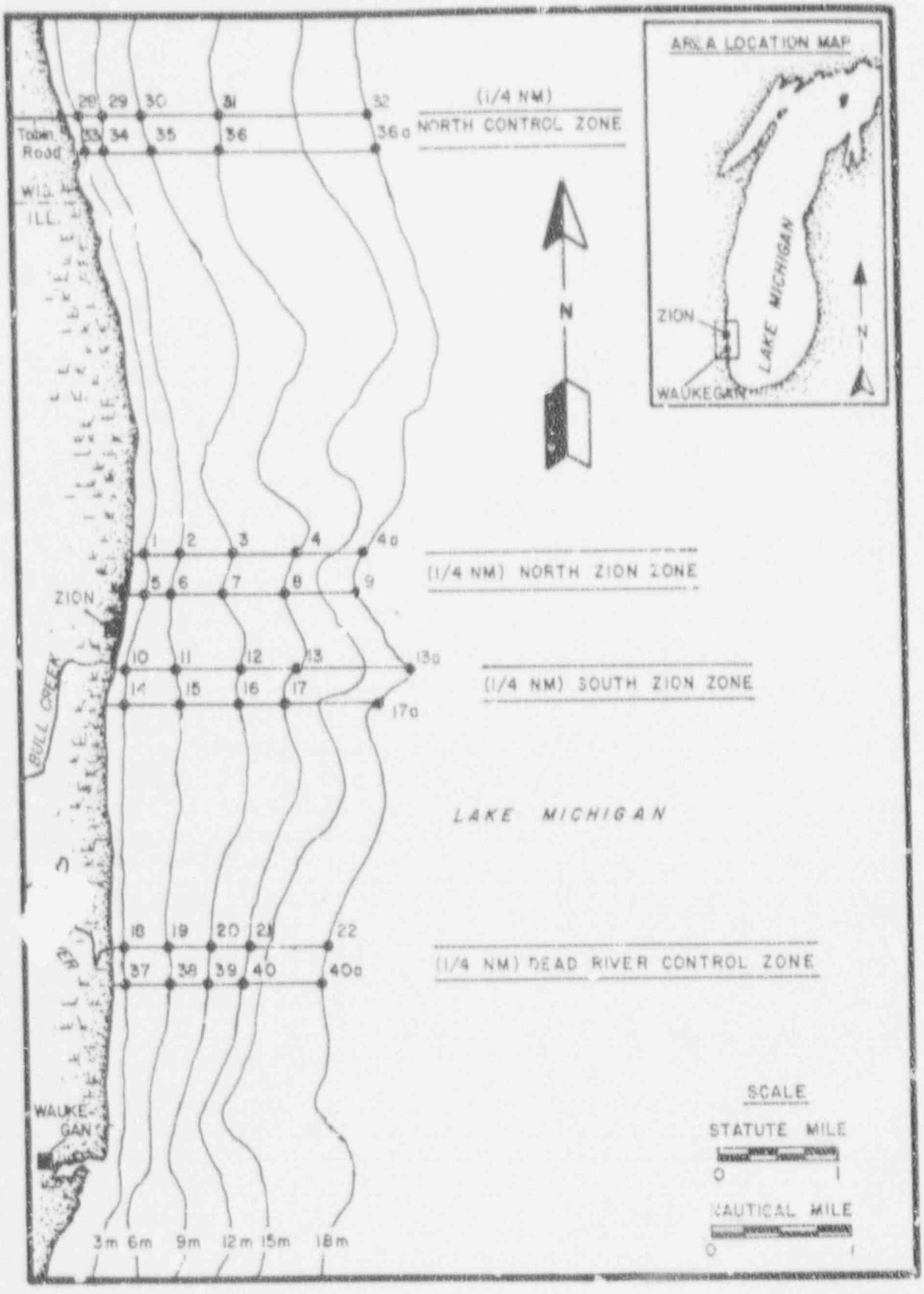


Figure 1. Benthos sampling locations in southwestern Lake Michigan near Zion, Illinois, January 1973 through August 1978.

shore of Dead River (Dead River Zone designated D.R.) to serve as a control area. Ten additional sampling locations were situated approximately four miles (6.4 km) north of Zion and served as a second control area (North Control Zone designated N.C.). Each zone consisted of two transects, 1/4 mile (0.4 km) apart, each with five sampling locations. Sampling locations on each transect were at depths of 3, 6, 9, 12 and 18 m. Sampling locations were located by means of shipboard radar and fathometer.

B. Benthos Collections

Benthic samples have been collected every other month since April 1970 using a Ponar grab sampler (530 sq cm). From April 1972 to August 1978, two replicate samples were collected at each location; prior to this, the number of samples varied from one to three replicates (Table 1).

Samples were washed in the field through a U.S. Standard No. 30 mesh sieve (.595 mm aperture). From August 1978 to February 1973, organisms retained on the screen were fixed and preserved in 10% formalin. Prior to February 1973 samples were returned to the laboratory to be sieved and the organisms were then preserved in 70% ethanol.

All macroinvertebrate organisms were enumerated as they were separated from the sample residue in the laboratory using a binocular dissecting microscope (10-70 x). Identification of all organisms, except oligochaetes and chironomids, was made during the separation process. Oligochaetes and chironomids were mounted in a non-resinous clearing media on glass slides. They were then

identified using a binocular compound microscope with magnification of 40-1000 x.

From April 1971 to March 1972 only selected organisms were identified to species (Industrial BIO-TEST 1973). For the April 1971-March 1972 period five selected species (Pontoporeia affinis, Stylodrilus heringianus, Monodiamesa tuberculata, Sphaerium striatinum and Valvata perdepressa) were counted and the total number of organisms in each sample recorded. From June 1972 to August 1979 all organisms were identified to the lowest positive taxon. When the 18 m locations were added to the sampling program it was discovered that frequently more than 1000 oligochaetes were collected in one grab sample from locations at this depth. This necessitated a subsampling procedure. The oligochaetes present were first counted (total oligochaetes), then composited by combining the four replicates from the two transects in a zone. A random subsample of 500 was withdrawn from each composited sample. All oligochaetes in the subsample were identified to the lowest positive taxon.

C. Taxonomy

Cook and Johnson (1974) in their review of Great Lakes benthos noted the advances made in the taxonomy of benthic organisms in the last decade. As a result of these improved capabilities, the species composition of the macrobenthos of Lake Michigan has become much better known (Hiltunen 1967, Mozely and Garcia 1972, Stimpson et al. 1975). The list of species collected from the Zion area has also been considerably expanded since initiation of the

present study (Industrial BIO-TEST Laboratories, Inc. 1972, Stimpson and Brice 1974, Geers 1978).

The taxonomy of the Oligochaeta followed that of Hiltunen (1967), Brinkhurst and Jamieson (1971) and Sperber (1950). Enchytraeidae, Lumbriculidae, Naididae and some Tubificidae were identified at all stages of maturity based upon external characteristics. Other Tubificidae were identified by internal organs and structures present only when sexually mature. The Tubificidae identifiable at all stages of maturity were: all species of Aulodrilus, Peloscolex multisetosus, Potamothrix vejdovskyi, and Tubifex ignotus. All other tubificids were identifiable only when mature. Specimens of this group which were sexually immature and could not be identified were divided into two groups; unidentifiable immatures with capilliform chaetae and unidentifiable immatures without capilliform chaetae.

The description of Pontoporeia affinis follows that of Bousfield (1958). A number of subspecies or variety names have been applied to freshwater material of both North American and European origin, however, according to Bousfield all North American material should be referred to simply as Pontoporeia affinis Lindstrom until more taxonomic information is available. Segerstrale (1977) has recently reopened this nomenclature issue with the recommendation that P. hoyi Smith 1874 should be reinstated for North American populations. The nomenclature suggested by Hamilton, Saether, and Oliver (1969) was used for the Chironomidae. The taxonomy and nomenclature of the Hirudinea follows that of

Klemm (1972). The Gastropoda identifications were based on descriptions by Walter and Burch (1957) and the Sphaeriidae were identified according to Burch (1972).

D. Physical Measurements

Temperature profiles were recorded at each location from February 1973 to August 1978 using a Whitney underwater thermometer or a bathythermograph. Weather and lake conditions were noted on each collection date.

Substrates from each location were visually characterized at the time of collection as to texture (i.e. gravel, coarse sand, fine sand, mud, or clay). Duplicate sediment samples for particle size analysis (P.S.A.) were first collected in October 1972, thereafter samples were collected twice each year using a Ponar grab sampler (530 sq cm). Collections for P.S.A. analysis were made annually in April or June and again in August except in 1978 when collections were only taken in April.

E. Statistical Analysis

A one-way analysis of variance utilizing log + 1 transformed data was performed on macroinvertebrate data within each depth contour during each sampling period for those taxa that composed 5% or more of the benthic community. Where significant differences ($P \leq 0.05$) were found Tukey's multiple comparison procedure was employed to test for differences in abundances of selected taxa among zones at each depth.

A 6 x 4 (6 months by 4 zones) factorial analysis of variance (ANOVA) using untransformed data with Tukey's multiple

comparison procedure was employed to test for differences ($P \leq 0.05$) in abundance of selected taxa between zones at each depth and between months at each depth. In the 1975 and 1976 benthos summary reports a factorial analysis of variance was also employed to test for differences in abundance of selected taxa between years (Brice 1975 and 1976).

Diversity for each replicate at each location was calculated according to Brillouin (1956) where:

$$H = \frac{1}{N} \log \left(\frac{N!}{n_1!, n_2! \ldots . n_i!} \right)$$

and where n_i is the number of individuals in the i^{th} category, i is the individual species, and N is the total number of all species.

Due to errors in the calculation of Tukey's W values, data run on the SUPERFAC program contained possible errors. SUPERFAC was used to compare cell effects in the January 1972 through June 1976 data. This data, if rerun, would not change the interpretation presented in the interpretive reports since the cell effects were not compared in either of these reports.

IV. Results

A. Benthic Macroinvertebrate Collections

April 1970 - March 1971

Pontoporeia affinis was the most abundant organism collected in 1970 averaging 61.7% of the benthos (IBT 1972 p. 30). Total numbers of benthic macroinvertebrates increased with depth throughout the year except during June and July when high numbers of juvenille P. affinis were encountered along the shallow contours.

Oligochaetes were the second most abundant group encountered of which Stylodrilus heringianus was one of the most commonly collected. Tubificids were also encountered in large numbers especially at the deeper locations (41-90 ft range) which contained high percentages of clay and silt. Due to natural variability and apparent substrate perference of the tubificids, considerably higher numbers were collected from the deep water locations south of the Zion Station than were collected from locations north of the Zion Station (IBT 1972 p. 39)

Sphaeriids were ocassionally a major component of the benthos especially at depths of less than 30 feet. Chironomids and gastropods were also common throughout the study area but were never found in large numbers.

April 1971 - March 1972

Mean abundance of total benthos was affected by depth, time of year and substrate. Total benthos generally increased with depth with the highest mean abundance recorded at the 9 m locations. Differences were observed between transects with significantly

fewer organisms collected at South Zion than any other transect during the year. This was probably due to the variability of the substrate (Huh et al. 1973, p. 55).

Pontoporeia affinis was the dominant organism throughout the study exhibiting peak abundance in August and September. Greatest mean densities of P. affinis were recorded from the 6 and 9 m locations. Natural variability of the substrate and population densities could explain the significant differences observed by Huh in mean abundance of P. affinis among the four Zion Transects (Huh et al. 1973, p. 60).

Oligochaetes, the second most abundant group of organisms encountered, also exhibited significant differences in densities among the Zion transects.

January 1972 - December 1972

Mean abundance of the total benthos during the 1972 study increased with depth and was usually greatest at the Dead River zone. Differences were observed in total numbers of organisms among the four zones with the two Zion zones generally intermediate between North Control and Dead River. Seasonal variations were also noted with peak abundances usually occurring in late summer or fall (Barbour 1974, pp. 273, 280).

Pontoporeia affinis, the most abundant organism collected, probably accounted for the greatest percentage of seasonal variation of the total benthos. Numbers of P. affinis collected were highest in June, August and October (Barbour 1974, pp. 283, 285 and 286). This summer and fall peak can be attributed to recruitment of the juvenile P. affinis.

Oligochaetes were dominated by the families Tubificidae and Lumbriculidae. Potamothrix moldaviensis and Limnodrilus hoffmeisteri were the most abundant tubificids collected from all depths and were generally most abundant during the summer (Barbour 1974, pp. 287, 289 and 290). The lumbriculid, Stylodrilus heringianus, was most abundant during August and October but unlike the tubificids was only abundant at the 9 and 12 m locations (Barbour 1974, pp. 291, 193).

Other macroinvertebrates commonly collected were the sphaeriids: Pisidium, spp., Sphaerium striatinum and Sphaerium nitidum, and the chironomids: Monodiamesa tuberculata and Procladius sp.

January 1973 - June 1973

Benthic populations at all depths increased in April from the low numbers found in February and then declined slightly in June. Pontoporeia affinis was the dominant macroinvertebrate at the 3, 6 and 9 m locations and at 12 and 18 m North Control. Numbers of P. affinis were generally highest in April which contributed to the high number of total benthos in April (Brice and Stimpson, 1974 unpublished).

Olilgochaetes were the most abundant organisms at 12 and 18 m North and South Zion and Dead River, with greatest numbers at those locations with siltly substrates.

Pisidium spp. and Sphaerium nitidum were the principle sphaeriids with their greatest densities occurring at the 18 m South Zion and Dead River locations.

July 1973 - June 1974

Pontoporeia affinis was the most abundant benthic macroinvertebrate collected accounting for over 50% of the benthos at some locations and often exceeding 80% of the total (Stimpson and Brice 1974, p. 245). Densities of P. affinis increased with depth from the 3 to 12 m locations but were slightly lower at the 18 m than the 12 m locations (Stimpson and Brice 1974, pp. 249-250). Significant differences were observed between zones at each depth but no one zone had consistently greater densities than any other zone. The period of highest densities of P. affinis occurred during late spring and early summer and was the same for all zones (Stimpson and Brice 1974, p. 251).

Oligochaetes were composed predominantly of Stylodrilus heringianus and the tubificids, Limnodrilus hoffmeisteri, Potamothrix moldaviensis and Potamothrix vejdovskyi. Stylodrilus heringianus occurred in very low numbers along the 3 and 6 m contours but was much more abundant at the deeper locations. Yearly mean abundances of S. heringianus at the 9 and 12 m locations generally increased from North Control southward to Dead River. Numbers of S. heringianus were usually significantly lower at North Control than any other zone, while no consistent significant differences existed between the two experimental zones (North and South Zion) and Dead River (Stimpson and Brice 1974, p. 253). Seasonal variations in densities of S. heringianus were apparent with significantly greater densities reported from the late summer and fall collections (Stimpson and Brice 1974, p. 255).

Numbers of tubificids were generally significantly lower at South Zion along the 3 and 6 m locations than at any other zones. This did not appear to be substrate related since the substrate was uniform between all zones (Stimpson and Brice 1974, pp. 258-259). The tubificids increased in number with depth at all zones and were most abundant at the silty 18 m locations. The tubificids exhibited well defined seasonal fluctuations in density with mature individuals most abundant during the summer. This summer peak was observed in each zone and no empirical or statistical differences between zones were apparent (Stimpson and Brice 1974, p. 263).

Pisidium spp. was the most abundant Sphaeriid collected at all locations. Pisidium spp. generally increased in abundance with increased depth, greatest densities were recorded at the silty 18 m locations. Sphaerium nitidum was also most abundant at the silty 18 m locations (Stimpson and Brice 1974, p. 266). All species of Sphaeridae increased in abundance in late summer and early fall with seasonal abundances similar at all locations (Stimpson and Brice 1974, p. 267).

Chironomidae generally increased in numbers with increased depth at all zones. Monodiamesa tuberculata, which was most abundant at the shallower locations, was most frequently collected in June and August. Procladius sp., which was most abundant at the 12 and 18 m locations, was most abundant in February and April. No apparent seasonal differences between the control and experimental zones were observed (Stimpson and Brice 1974, p. 271).

July 1974 - June 1975

The data and results of analysis of the benthic community for July 1974 through June 1975 are included in a summary report comparing preopertional and opertional data. The benthic community during this time period was very similar to that of previous years with the same seasonal and depth related variations observed (Brice 1975, p. 109). Benthic production at the 3 m locations was significantly higher during the operational period than during the preoperation period. This was probably indicative of natural flucuations since all locations followed the same trend during the operational period (Brice 1975, p. 110).

Pontoporeia affinis, the most abundant organism, generally increased with depth to the 9 m locations. The density of P. affinis was variable at the 12 and 18 m locations with much lower numbers recorded at these locations containing large amounts of silt (Brice 1975, p. 137).

Oligochaetes were the second most abundant group of organisms observed. Numbers of oligochaetes generally increased with depth with greatest numbers recorded from the 12 and 18 m locations with silty substrates.

Sphaeriids and chironomids were the other two groups of organisms most frequently encountered. The family Sphaeriidae was represented by Pisidium spp., Sphaerium striatinum and Sphaerium nitidum. Chironomids were most frequently collected from the 12 and 18 m locations with Procladius sp., Heterotrissocladius p. and Micropsectra sp. the most common midges.

July 1975 - June 1976

All benthic macroinvertebrate data for the period July 1975 through June 1976 are included in a summary report comparing preoperational and operational data. In comparing data collected from February 1970 through June 1976, Brice (1976, p. 121) observed no apparent changes in the composition or relative abundance of the benthic community. As in previous studies, Pontoporeia affinis, oligochaetes, sphaeriids and chironomids composed the majority of the benthos at the sandy locations while the Tubificidae (Oligochaeta) dominated the silty deep water locations.

July 1976 - June 1977

Densities of total benthos increased with increased depth from 3 m to 18 m in most portions of the study area. Pontoporeia affinis, oligochaetes, sphaeriid clams, and chironomids composed the majority of the benthic community.

Pontoporeia affinis was the most abundant single species collected. This species composed the majority of the benthos in all 6 and 9 m locations and in the sand bottom locations of 12 and 18 m (Geers 1977, p. 75). Abundance of P. affinis was higher during this sampling period than had been previously reported (Geers 1977, p. 33).

Three families of Oligochaeta: Lumbriculidae, Naididae and Tubificidae constituted the second most abundant group of organisms (Geers 1977, p. 75). The lumbriculid, Stylodrilus heringianus, was often the most abundant oligochaete and was one of the few species to make-up greater than 5% of the benthos at

any location during the sampling period (Geers 1977, p. 27). Densities of S. heringianus generally increased at each succeeding depth contour.

The most abundant species of Tubificidae were Limnodrilus hoffmeisteri, Potamothrix moldaviensis and P. vejdovskyi. Samples collected from silty substrates had the highest numbers and greatest diversity of tubificid species. Seasonal density of mature tubificids was greatest in summer collections. This summer peak was observed in each zone and no empirical or statistical differences between control and experimental zones were apparent (Geers 1977, p. 59).

Pisidium spp., Sphaerium nitidum and S. striatinum constituted the Sphaeriidae. S. striatinum was most abundant at locations with higher proportions of sand. Numbers of Pisidium spp. and S. nitidum generally paralleled the percentage of silt in the sediments. Chironomidae generally composed only small percentages of the benthos (Geers 1977, p. 28). Monodiamesa tuberculata and Procladius sp. were the most abundant chironomids collected.

July 1977 - June 1978

The majority of the benthic community during this time period was composed of four classes of organisms: Crustacea, Oligochaeta, Pelecypoda, and Insecta.

Pontoporeia affinis was the single most abundant species collected often exceeding 50% of the benthos (Geers 1978, p. 21). Annual mean densities of P. affinis were lowest at all

9 m locations and generally highest at the 9 m locations. Peak abundance of P. affinis occurred in June due primarily to the recruitment of young of the year.

Stylodrilus heringianus, a lumbriculid, and the tubificids were the primary constituents of the class Oligochaeta. Both were generally most abundant in late summer and early fall (Geers 1978, pp. 39, 48). There was also direct relationship with depth and densities of S. heringianus and the tubificids. Generally greater densities were encountered at each succeeding depth contour (Geers 1978, pp. 37 and 48-51).

Sphaeriids were ocassionally a major component of the benthos especially at the 18 m locations with silty substrate.

Chironomids were also common throughout the study area but were only present in large numbers at the 18 m silty locations.

July - September 1978

Pontoporeia affinis was the single most abundant species collected in August 1978. Greatest densities were recorded from the two Zion zones which had substrates that were predominantly fine sand. (Geers 1979, p. 360).

Potomathrix moldaviensis was the dominant oligochaete at the inshore locations while Stylodrilus heringianus, Limnodrilus hoffmeisteri and Potamothrix vejdovskyi were the dominant oligochaetes at the 12 and 18 m locations (Geers 1979, pp. 361, 363-364).

Pisidium spp., the major component of the sphaeriids at all locations, was most abundant at the 18 m locations (Geers

1979, p. 365).

Chironomidae, represented predominantly by Microp-sectra sp. and Monodiamesa tuberculata, increased with depth to a maximum at the 9 m locations (Geers 1979, p. 366).

B. Ichthyoplankton Collections

A special summary report was issued that documented the occurrence of Mysis relicta and Pontoporeia affinis in ichthyoplankton samples collected during 1975 and 1976 (Cima 1977).

Mysis relicta were more abundant during winter and spring months than during summer and fall. Peak abundances occurred in February and in June and July. The majority of the M. relicta were collected from the 40 to 60 foot depth contours in 1975 and 1976 with the largest total catch taken at the 50 foot contour (Cima 1977, p. 9).

Greatest densities of P. affinis were collected in July. After July, numbers of P. affinis continued to decline until sampling was terminated in October. The majority of the organisms were collected from the 20 foot contour in 1975 and in general were evenly distributed from the 30 to 60 foot contours in 1976 (Cima 1977, p. 18). However, in both years, Transect Z-4 produced the highest number of P. affinis.

C. Summary

The near shore macroinvertebrate community of southwestern Lake Michigan near Zion Station was comprised of 136 taxa (Table 2). Members of the classes Crustacea, Oligochaeta, Insecta and Pelecypoda were the pricipal components of this near shore benthic community. Abundance tables were prepared for data of those taxa that made up 5% or more of the benthic community at the 3, 6, and 9 m locations from 1972 through 1978. These tables were then used as an aid in evaluating any long term major changes in the community composition (Table 3).

In general there has been an increase in densities of benthic invertebrates through time (Figures 2, 3, 4, 5 and 6). This long term increase in densities was evident at all zones and was most noticeable at the 3 through 12m depth contours. Other trends included increased abundances with increased depth, annual or seasonal peaks occurring from early summer through early fall and generally higher densities at Dead River and South Zion 18m locations.

The burrowing amphipod, Pontoporeia affinis was the single most abundant species collected from the study area. It accounted for over 20% of the benthos at most locations throughout the years and often exceeded 70% of the total (Table 3). It should be noted that the proportion of the benthic community occupied by P. affinis (i.e. percent composition) at the 3m locations has decreased through time (Table 3). P. affinis exhibited seasonal trends at all locations although at the 18m locations the seasonal peaks were not as pronounced (Figures 7, 8, 9, 10 and 11) as at the shallower loca-

Table 2. Taxonomic list of benthic macroinvertebrates encountered in Southwestern Lake Michigan, near Zion, Illinois, April 1970 - August 1978.

Porifera
  Demospongea
    Haplosclerina
      Spongillidae
        Spongilla fragilis (Leidy) June 1973[a]
Acanthocephala Sug. 1976
Cnidaria
  Hydrozoa
    Hydroida
      Hydridae
        Hydra sp. (Linnaeus) Dec. 1972
Platyhelminthes
  Turbellaria
    Tricladida
      Planariidae
        Dugesia sp. Girand Dec. 1977
        Dugesia tigrina (Girand) Oct. 1976
    Rhabdocoela June 1973
Rhynchocoela Dec. 1972
Aschelminthes
    Nematoda Dec. 1972
Ectoprocta
  Phylactolaemata
    Ctenostomata
      Paludicellidae
        Paludicella articulata (Ehrenberg) Dec. 1974
  Phylactolaemata
    Plumatellina
      Plumatellidae
        Plumatella sp. (Hancock) Feb. 1978
        Plumatella repens Oct. 1975
        Fredericella sp. Gerris Oct. 1975
    Cristatellidae
      Cristatella mucedo Cuvier April 1978
Annelida
  Oligochaeta
    Plesiopora
      Enchytraeidae Dec. 1972
      Naididae
        Amphichaeta leydigii Tauber June 1974
        Chaetogaster diaphanus (Gruithuisen) June 1973
        Chaetogaster limnaei Von Baer Oct. 1977
        Dero digitata (Muller) June 1973
        Nais barbata Muller 1975
        Nais bretscheri Michaelson June 1973
        Nais communis Piquet June 1974
        Nais elinguis (Muller) June 1973

Table 2. (continued)

Nais pardalis Piquet June 1973
Nais simplex Piquet August 1977
Nais sp. Muller Dec. 1972
Ophidonais serpentina Muller June 1974
Paranais frici Hrabe June 1973
Piguetiella michiganensis Hiltunen Dec. 1972
Pristina foreli (Piguet) Oct. 1977
Slavina appendiculata d'Udekem Feb. 1973
Specaria josinae (Vejdovsky) Apr. 1974
Stylaria lacustris (Linnaeus) Dec. 1972
Uncinais uncinata (Orstedt) Mar. 1971
Vejdovskyella intermedia (Bretscher) Dec. 1972

Tubificidae
Unidentifi immature with capilliform chaetae Mar. 1971
Unidentified immature without capilliform chaetae Mar. 1971
Aulodrilus americanus Brinkhurst and Cook Mar. 1971
Aulodrilus limnobius Bretscher Feb. 1973
Aulodrilus pluriseta (Piguet) Mar. 1971
Ilyodrilus templetoni (Southern) Mar. 1971
Limnodrilus angustipeni- Brinkhurst and Cook Apr. 1970
Limnodrilus cervix Brinkhurst Apr. 1970
Limnodrilus cervix variant Mar. 1971
Limnodrilus claparedeianus Ratzel Apr. 1970
Limnodrilus hoffmeisteri Claparede Apr. 1970
Limnodrilus hoffmeisteri variant Claparede Mar. 1971
Limnodrilus profundicola (Verril) Apr. 1970
Limnodrilus spiralis Eisen Apr. 1970
Limnodrilus udekemianus Claparede Mar. 1971
Peloscolex freyi Brinkhurst Mar. 1971
Peloscolex multisetosus longidentus Brinkhurst and Cook Mar. 197[illegible]
Peloscolex multisetosus multisetosus Smith Mar. 1971
Peloscolex superiorensis (Brinkhurst and Cook) Aug. 1973
Peloscolex variegatus Leidy Mar. 1971
Potamothrix bedoti (Piguet) Dec. 1976
Potamothrix moldaviensis Vejdovsky and Mrazek Apr. 1970
Potamothrix vejdovskyi (Hrabe) Mar. 1971
Tubifex ignotus Stole Apr. 1970
Tubifex tubifex Muller Apr. 1970

Prosopora
Lumbriculidae
Stylodrilus heringianus Claparede Apr. 1970

Opisthopora
Glossoscolecidae
Sparganophilus sp. Benham Apr. 1974

Table 2. (continued)

- Hirudinea
  - Rhynchobdellida
    - Glossiphoniidae
      - Glossiphonia complanata (Linnaeus) Apr. 1970
      - Helobdella stagnalis (Linnaeus) Mar. 1971
    - Pisicolidae
      - Pisicola geometra (Linnaeus Apr. 1970
      - Pisicola milneri (Verrill) Oct. 1977
  - Pharyngobdellida
    - Erpobdellidae
      - Dina microstoma Moore Mar. 1971
      - Dina parva Moore Dec. 1972
      - Nephelopsis obscura Verrill Feb. 1974
      - Mocreobdella microstoma Moore June 1977
- Mollusca
  - Gastropoda
    - Mesogastropoda
      - Amnicolidae
        - Amnicola sp. Gould and Haldeman Mar. 1971
        - Somatogyrus sp. Gill Apr. 1970
      - Valvatidae
        - Valvata bicarinata Lea June 1973
        - Valvata perdepressa Walker Apr. 1970
        - Valvata sincera Say Apr. 1970
        - Valvata tricarinata Gould Dec. 1972
        - Valvata sp. Lamarck Aug. 1976
    - Basomatophora
      - Lymnaeidae
        - Lymnaea auricularia Linnaeus Apr. 1970
        - Lymnaea megasoma Say Mar. 1971
        - Lymnaea sp. Lamark Aug. 1976
      - Physidae
        - Physa sp. Draparnaud Mar. 1971
  - Pelecypoda
    - Heterodonta
      - Sphaeriidae
        - Pisidium sp. Pfeiffer Apr. 1970
        - Sphaerium nitidum Clessin Apr. 1970
        - Sphaerium striatinum (Lamarck) Apr. 1970
        - Sphaerium transversum (Say) Feb. 1977
- Arthropoda
  - Crustacea
    - Ostracoda Dec. 1972
    - Mysidacea
      - Mysidae
        - Mysis relicta Loven Mar. 1971

Table 2. (continued)

- Amphipoda
  - Gammaridae
    - Gammarus fasciatus Say Oct. 1976
    - Gammarus pseudolimnaeus Mar. 1971
  - Haustoriidae
    - Pontoporeia affinis Lindstrom Mar. 1970
  - Talitridae
    - Hyallela azteca (Saussure) Dec. 1972
- Isopoda
  - Asellidae
    - Asellus sp. Geoffrey St. Hillaire Mar. 1971
    - Lirceus sp. Rafinesque Aug. 1973
- Arachnida
- Acari Feb. 1974
- Insecta
  - Coeloptera
    - Dytiscidae Aug. 1976
    - Elmidae
      - Dubiraphia sp. Sanderson Dec. 1972
  - Ephemeroptera
    - Caenidae Dec. 1973
    - Ephemeridae Aug. 1976
    - Heptageniidae Dec. 1973
  - Hemiptera Dec. 1972
  - Tricoptera
    - Hydropsychidae
      - Hydropsyche recurvata Banks Oct. 1976
      - Hydropsyche sp. Pictet Dec. 1972
    - Phryganeidae
      - Agrypnia improba (Hagen) Oct. 1976
      - Agrypnia straminea Hagen Oct. 1976
      - Agrypnia sp. Curtis June 1977
      - Banksiola sp. Martynov April 1977
  - Diptera
    - Ceratopogonidae
    - Chironomidae
      - Chironomus sp. Walker 1970
      - Cladotanytarsus sp. Kieffer Dec. 1972
      - Coelotanypus sp. Kieffer Oct. 1977
      - Cricotopus bicinctus sp. (Van der Wulp) Feb. 1976
      - Cricotopus (s.s.) sp. (Van der Wulp) Aug. 977
      - Cryptochironomus sp. Kieffer Apr. 1970
      - Cryptochironomus cf. monstrosus Chernovskii Feb. 1977
      - Cryptochironomus cf. rolli Kirpitshenko Oct. 1976
      - Cryptocladopelma sp. Lenz Dec. 1972
      - Demicryptochironomus sp. Lenz Oct. 1976
      - Dicrotendipes sp. Kieffer Feb. 1973
      - Epoicocladius sp. Kieffer April 1978

Table 2. (continued)

Eukiefferiella sp. Thienemann Aug. 1976
Glyptotendipes sp. Kieffer Oct. 1976
Glyptotendipes (Phytotendipes) sp. Geotghebuer Aug. 1977
Heterotrissocladius sp. Sparck Apr. 1970
Micropsectra sp. Kieffer Apr. 1970
Microtendipes Kieffer Aug. 1975
Monodiamesa tuberculata Saether Dec. 1972
near Demicryptochironomus sp. Feb. 1976
Parachironomus sp. Lenz Dec. 1972
Paracladopelma sp. Harnisch Apr. 1970
Parakiefferiella sp. Thienemann Dec. 1972
Paratanytarsus sp. Kieffer June 1973
Paratendipes sp. Kieffer Oct. 1977
Polypedilum (s.s.) convictum type Kieffer Apr. 1977
Polypedilum (s.s.) fallax group Kieffer Dec. 1972
Polypedilum (s.s.) scalaenum type Kieffer June 1977
Polypedilum (s.s.) simulans type Kieffer Oct. 1977
Polypedilum (s.s.) sp. Kieffer
Pottastia sp. (Kieffer) Dec. 1972
Procladius sp. Skuse Apr. 1970
Stictochironomus sp. Kieffer Jun. 1976
Tanytarsus sp. Van der Wulp Dec. 1972
Thienemanniella group Fitkau Dec. 1972
Trissocladius sp. Kieffer Aug. 1975

a. Date first encountered

Table 3. Annual means and percent occurrence of the dominant benthic macroinvertebrates collected from southwestern Lake Michigan near Zion, Illinois, January 1972 through June 1978.

Zone	Depth	Taxa	1972-1973		1973-1974		1974-1975		1975-1976		1976-1977		1977-1978	
			Mean/m²	%	Mean/m²	%	Mean/m²	%	Mean/m²	%	Mean/m²	%	Mean/m²	%
North Control	3 m	Pontoporeia affinis	565	59	272	37	221	11	366	33	296	26	350	13
		Immature tubificids w/o capilliforms	294	31	154	21	480	25	103	9	689	39	1309	47
		Potamothrix moldaviensis	28	3	38	5	13	1	[illegible]	1	74	4	421	15
		Piguetiella michiganensis	4	<1	4	1	83	4	204	19	121	9	128	5
		Uncinais uncinata	0	0	0	0	0	0	198	18	10	1	228	8
		Stylaria lacustris	13	1	191	26	126	7	3	<1	1	<1	26	1
		Nais elinguis	0	0	8	0	20	1	25	2	3	0	0	0
		Nais sp.	0	0	2	<1	22	1	10	1	7	1	9	<1
		Chironomus sp.	1	<1	12	2	808	42	71	6	21	2	22	1
		Cryptochironomus sp.	9	1	5	1	26	1	15	1	104	8	26	1
		Fisidium spp.	2	<1	4	1	0	0	2	<1	9	1	20	1
		Undetermined Nematoda	0	0	6	1	22	1	6	1	10	1	27	1
	6 m	Pontoporeia affinis	3020	89	2009	75	2792	66	2229	73	3096	56	4854	72
		Immature tubificids w/o capilliforms	245	7	421	16	583	14	421	14	752	21	805	12
		Potamothrix moldaviensis	23	1	54	2	35	1	77	3	139	4	309	5
		Piguetiella michiganensis	2	<1	35	1	358	9	82	3	268	7	158	2
		Stylaria lacustris	4	<1	13	1	199	5	0	0	1	<1	1	<1
		Stylodrilus heringianus	8	<1	3	<1	4	<1	4	<1	15	<1	13	<1
		Fisidium spp.	13	<1	20	1	7	<1	46	2	39	2	123	2
	9 m	Pontoporeia affinis	4875	84	4608	77	4380	66	4686	78	4086	64	7938	80
		Immature tubificids w/o capilliforms	467	8	680	11	991	15	649	11	695	12	428	4
		Piguetiella michiganensis	2	<1	47	1	52	1	71	1	400	7	80	1
		Stylodrilus heringianus	28	1	261	4	41	1	72	1	92	1	140	1
		Fisidium spp.	91	2	51	1	83	1	63	1	91	1	193	2

Table 3. (continued)

Zone	Depth	Taxa	1972-1973 Mean/m²	%	1973-1974 Mean/m²	%	1974-1975 Mean/m²	%	1975-1976 Mean/m²	%	1976-1977 Mean/m²	%	1977-1978 Mean/m²	%
North Zion	3 m	Pontoporeia affinis	246	44	458	53		45	602	48	470	27	813	23
		Immature tubificids w/o capilliforms	213	38	203	22	8	4	83	7	610	37	1357	38
		Potamothrix moldaviensis	16	3	12	1	1	<1	10	1	126	8	302	8
		Piguetiella michiganensis	21	4	21	2		4	243	19	146	10	228	6
		Uncinais uncinata	0	0	0	0	2	<1	117	9	33	2	325	9
		Stylaria lacustris	19	3	150	17	175	12	0	0	0	0	2	<1
		Nais elinguis	0	0	6	1	86	6	2	<1	6	0	0	0
		Nais sp.	3	0	2	<1	135	9	2	<1	0	0	6	<1
		Chironomus sp.	0	0	6	1	223	15	105	8	23	1	60	2
		Cryptochironomus sp.	14	3	16	2	32	2	14	1	76	5	17	1
		Pisidium spp.	2	<1	2	<1	2	<1	9	1	39	2	110	3
		Undetermined Nematoda	2	<1	1	<1	17	1	11	1	4	<1	23	1
	6 m	Pontoporeia affinis	3244	88	3552	75	3274	55	4149	71	3352	49	7900	68
		Immature tubificids w/o capilliforms	229	6	529	11	647	13	1017	17	1496	22	1410	12
		Potamothrix moldaviensis	50	1	96	2	154	3	157	3	505	7	532	5
		Piguetiella michiganensis	5	<1	89	2	468	8	80	1	391	6	98	1
		Stylaria lacustris	6	<1	34	1	192	4	0	0	9	<1	7	<1
		Stylodrilus heringianus	9	<1	28	1	9	<1	5	<1	62	1	72	1
		Pisidium spp.	26	1	191	4	60	1	82	1	339	5	792	7
	9 m	Pontoporeia affinis	4747	72	5629	68	4763	68	5118	68	6628	57	10105	62
		Immature tubificids w/o capilliforms	444	7	583	7	396	6	543	7	788	7	799	5
		Piguetiella michiganensis	43	1	40	1	193	3	56	1	131	1	53	<1
		Stylodrilus heringianus	376	6	993	12	702	10	702	9	2217	20	2076	16
		Pisidium spp.	260	4	371	5	335	5	367	5	1062	9	1551	10

Table 3. (continued)

Zone	Depth	Taxa	1972-1973 Mean/m²	%	1973-1974 Mean/m²	%	1974-1975 Mean/m²	%	1975-1976 Mean/m²	%	1976-1977 Mean/m²	%	1977-1978 Mean/m²	%
South Zion	3 m	Pontoporeia affinis	452	54	813	86	917	50	807	48	491	20	987	25
		Immature tubificids w/o capilliforms	276	33	32	3	219	12	228	13	1249	54	933	24
		Potamothrix moldaviensis	29	4	4	<1	2	<1	28	2	213	9	397	10
		Piguetiella michiganensis	8	1	3	<1	32	2	283	17	148	10	199	5
		Uncinais uncinata	0	0	0	0	7	<1	71	4	70	3	402	10
		Stylaria lacustris	13	2	50	5	168	9	1	<1	2	<1	66	2
		Nais elinguis	0	0	0	0	60	3	2	<1	0	0	14	<1
		Nais sp.	0	0	2	<1	59	3	0	0	17	1	135	4
		Chironomus sp.	0	0	1	<1	257	14	135	8	7	<1	15	<1
		Cryptochironomus sp.	22	3	10	1	38	2	31	2	32	2	11	<1
		Pisidium spp.	5	<1	0	0	2	<1	6	<1	9	<1	43	1
		Undetermined Nematoda	9	1	5	1	16	1	14	1	12	1	67	2
			3019	92	2730	52	3153	81	2607	73	6735	59	7775	77
	6 m	Pontoporeia affinis	110	3	117	4	183	5	542	15	959	21	910	9
		Immature tubificids w/o capilliforms	18	1	13	<1	11	<1	43	1	223	3	380	4
		Potamothrix moldaviensis	4	<1	28	1	113	3	92	3	461	7	218	2
		Piguetiella michiganensis	2	<1	16	1	134	3	2	<1	3	<1	0	0
		Stylaria lacustris	13	<1	7	<1	47	1	6	<1	47	1	17	<1
		Stylodrilus heringianus	17	1	3	<1	8	<1	28	1	171	3	169	2
		Pisidium spp.	4088	63	8473	76	4955	62	5365	62	2407	48	8043	53
	9 m	Pontoporeia affinis	222	3	346	3	290	4	461	5	681	6	607	4
		Immature tubificids w/o capilliforms	5	<1	13	<1	80	1	72	1	150	1	43	<1
		Piguetiella michiganensis	1106	17	1440	13	1562	20	1430	16	3026	28	3819	25
		Stylodrilus heringianus	308	5	579	5	391	5	667	8	1466	12	1716	11
		Pisidium spp.												

Table 3. (continued)

Zone	Depth	Taxa	1972-1973 Mean/m²	%	1973-1974 Mean/m²	%	1974-1975 Mean/m²	%	1975-1976 Mean/m²	%	1976-1977 Mean/m²	%	1977-1978 Mean/m²	%
Dead River	3 m	Pontoporeia affinis	738	91	1094	66	1862	62	788	44	729	26	825	19
		Immature tubificids w/o capilliforms	32	4	325	20	318	11	323	18	594	28	1767	41
		Potamothrix moldaviensis	4	1	31	2	16	1	48	3	214	8	332	8
		Piguetiella michiganensis	1	<1	44	3	155	5	290	16	60	4	133	1
		Uncinais uncinata	0	0	0	0	6	<1	36	2	70	3	212	5
		Stylaria lacustris	0	0	71	4	280	9	1	<1	1	<1	0	0
		Nais elinguis	1	<1	3	<1	46	2	2	<1	0	0	3	<1
		Nais sp.	0	0	0	0	33	1	6	<1	4	<1	32	1
		Chironomus sp.	1	<1	13	1	117	4	61	3	24	1	65	2
		Cryptochironomus sp.	7	1	26	2	60	2	24	1	50	3	28	1
		Pisidium spp.	3	<1	17	1	21	1	39	2	78	4	343	8
		Undetermined Nematoda	2	<1	4	<1	15	1	19	1	19	1	15	<1
	6 m	Pontoporeia affinis	3977	78	4297	68	5095	75	4690	71	4643	51	6884	59
		Immature tubificids w/o capilliforms	135	3	431	7	634	9	543	8	818	11	824	7
		Potamothrix moldaviensis	2	<1	10	<1	48	1	54	1	157	2	273	2
		Piguetiella michiganensis	6	<1	295	5	214	3	200	3	280	4	118	1
		Stylaria lacustris	1	<1	56	1	116	2	4	<1	0	0	9	<1
		Stylodrilus heringianus	24	1	57	1	42	1	116	2	710	11	699	6
		Pisidium spp.	313	6	284	5	283	4	462	7	946	15	2022	17
	9 m	Pontoporeia affinis	3264	42	3949	46	3122	42	3973	45	4831	45	4624	34
		Immature tubificids w/o capilliforms	1330	17	1288	15	959	13	578	7	1103	10	680	5
		Piguetiella michiganensis			13	<1	5	<1	16	<1	6	<1	6	<1
		Stylodrilus heringianus	2075	26	1428	26	1962	27	2326	27	3648	33	4749	35
		Pisidium spp.	335	4	685	8	764	10	1089	12	1581	14	2048	15

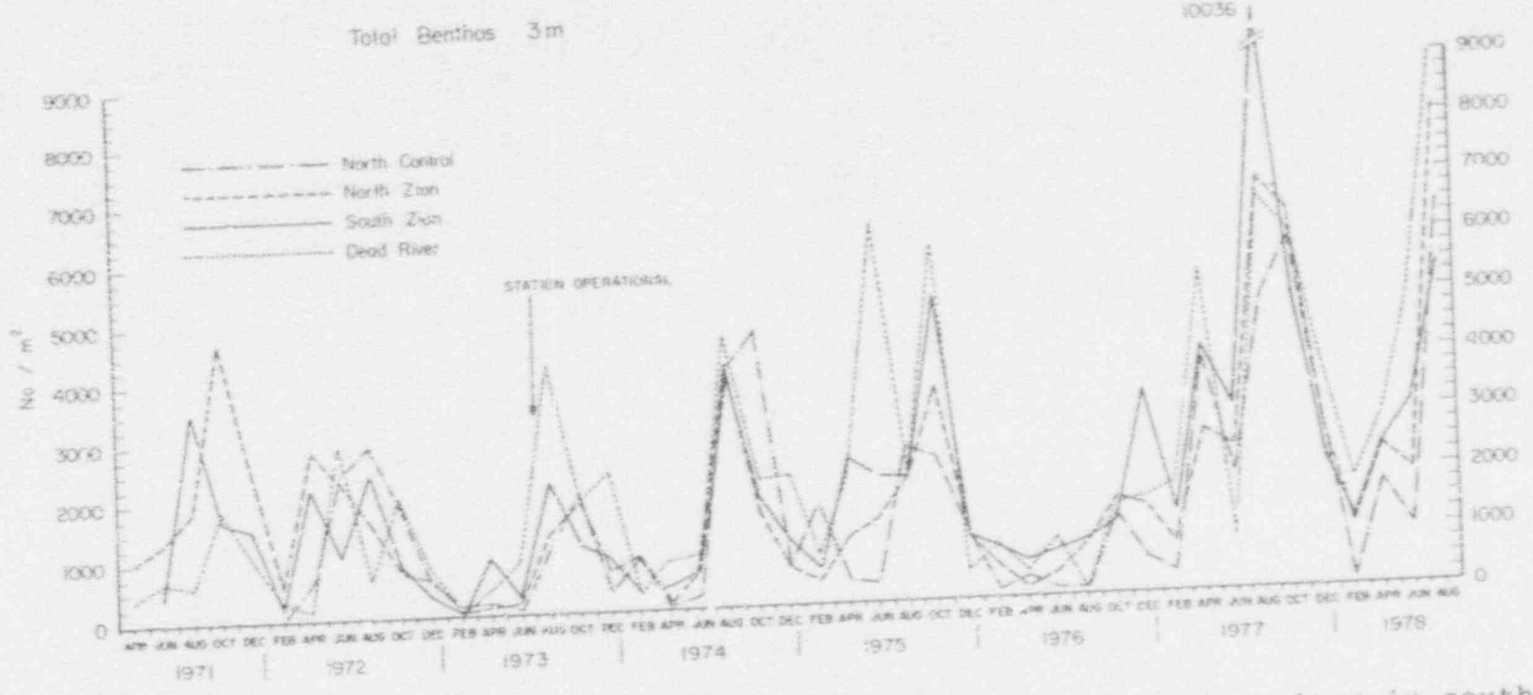


Figure 2. Mean number/m^2 of total total benthos at the 3 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1971-August 1978.

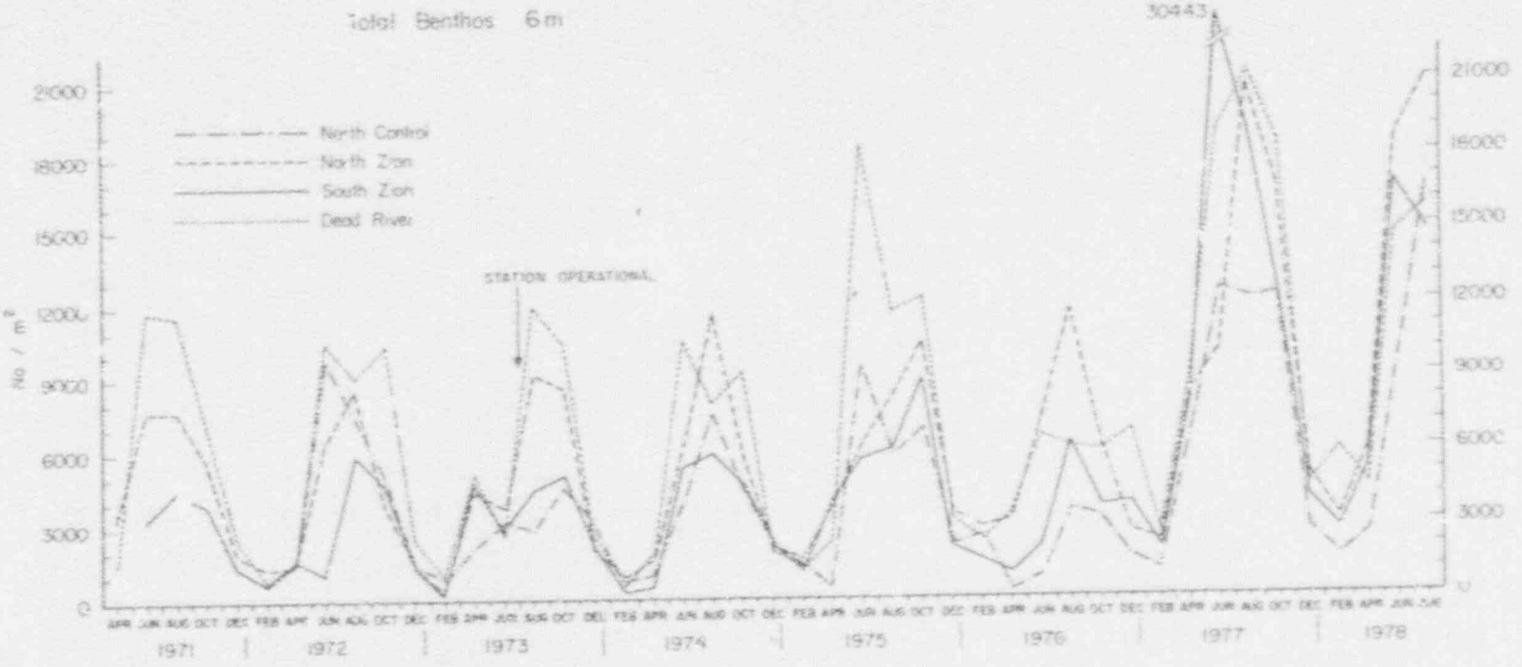


Figure 3. Mean number/m^2 of total total benthos at the 6 meter locations in southwestern lake Michigan near Zion, Illinois, April 1971-August 1978.

HAZLETON ENVIRONMENTAL SCIENCES

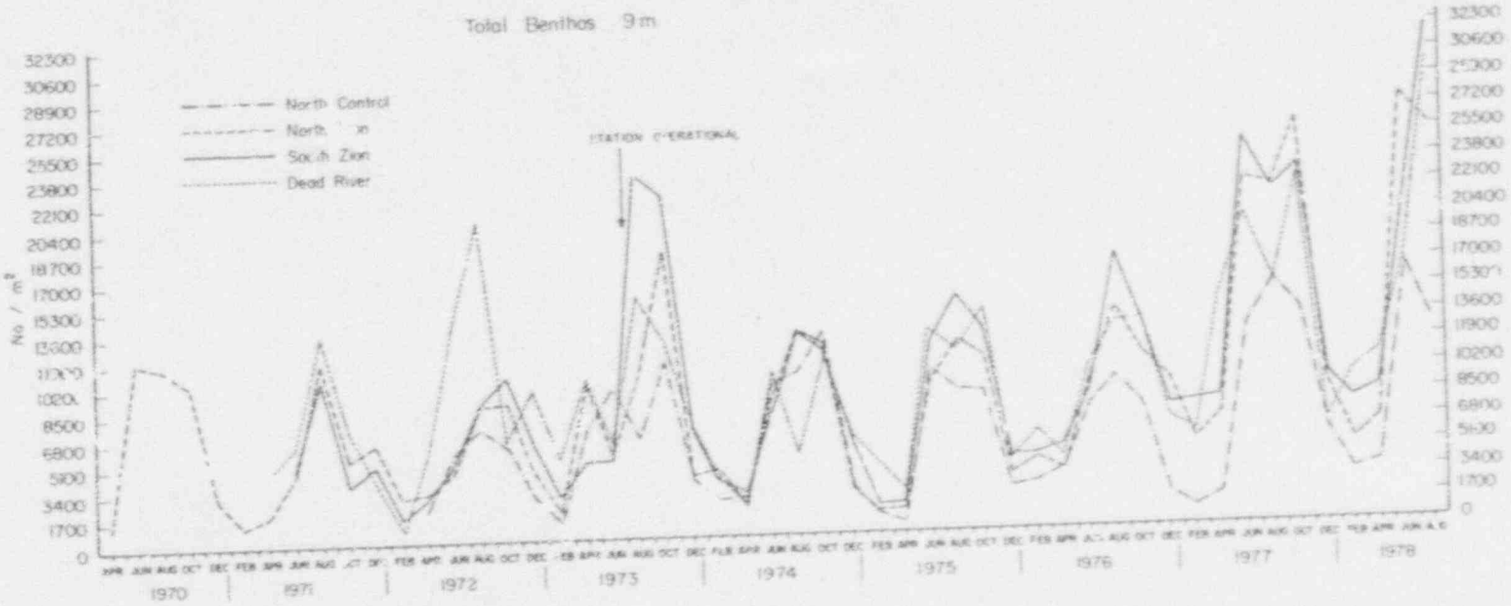


Figure 4. Mean number/m^2 of total total benthos at the 9 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1970-August 1978.

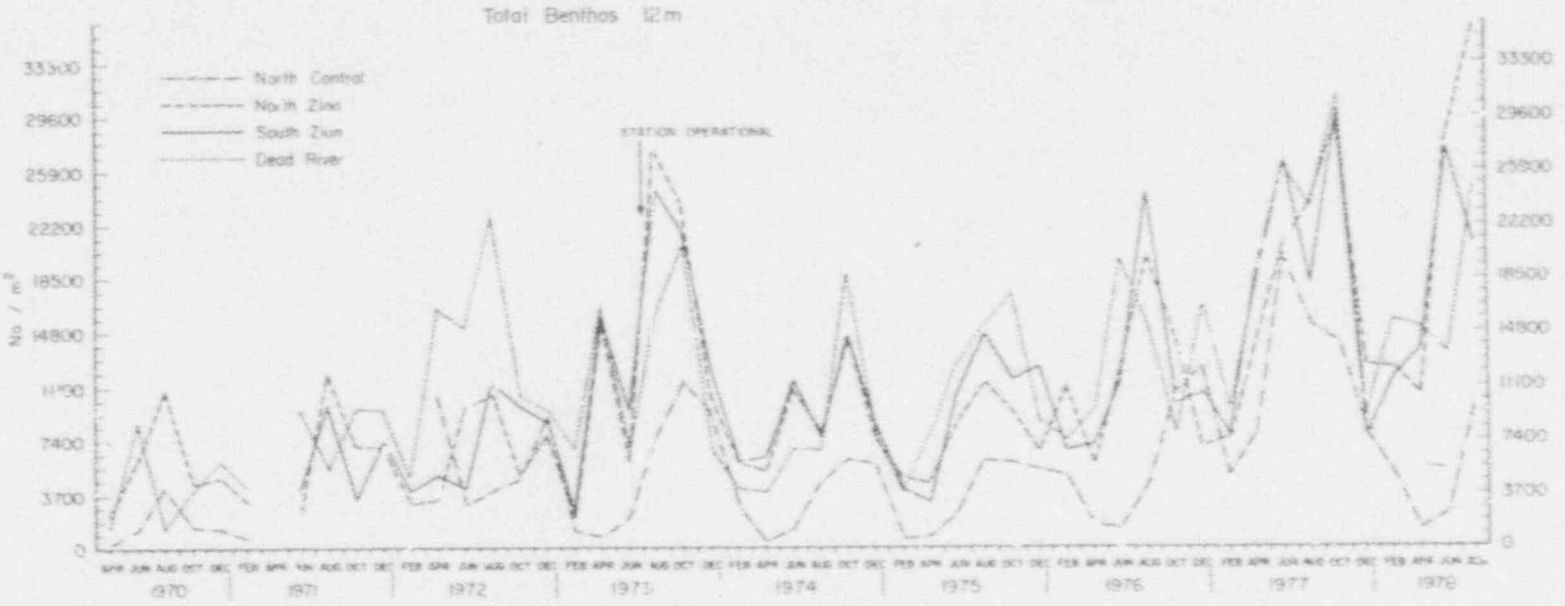


Figure 5. Mean number/m^2 of total total benthos at the 12 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1970-August 1978.

HAZLETON ENVIRONMENTAL SCIENCES

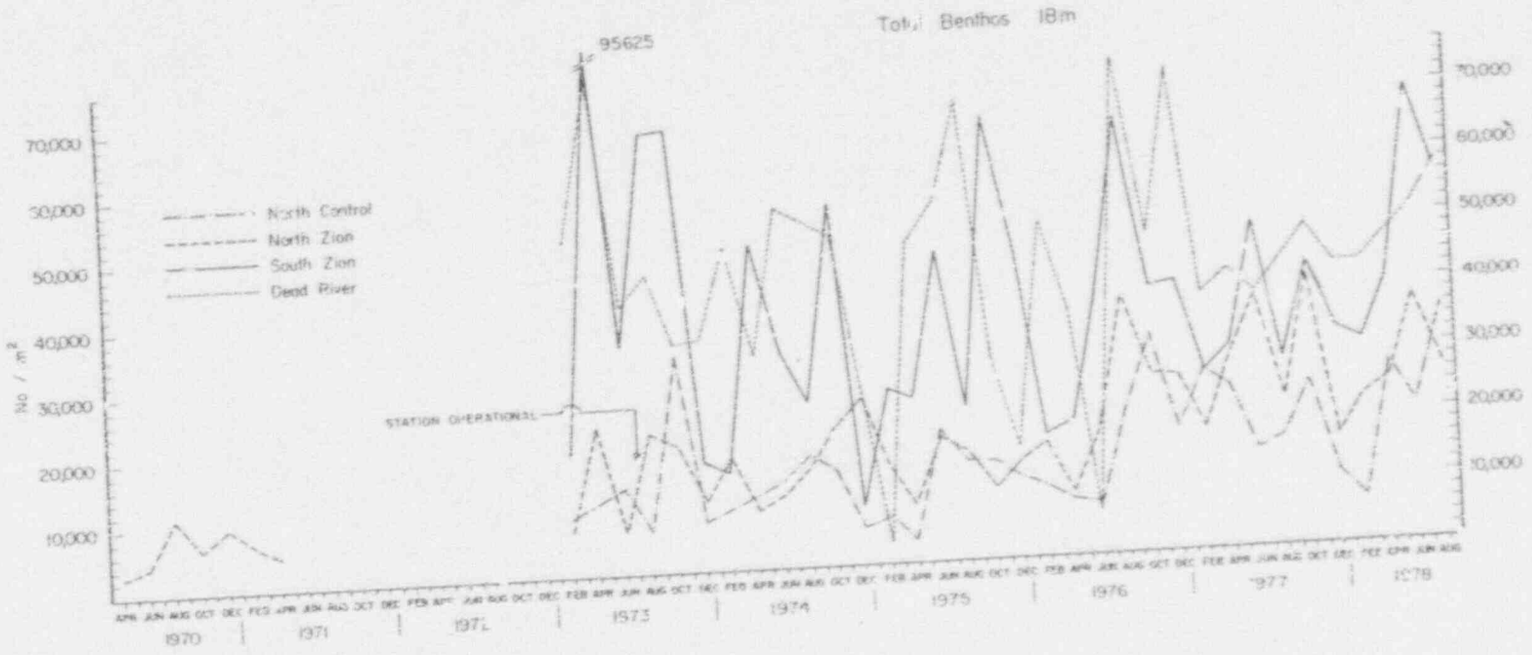


Figure 6. Mean number/m^2 of total total benthos at the 18 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1970-August 1978.

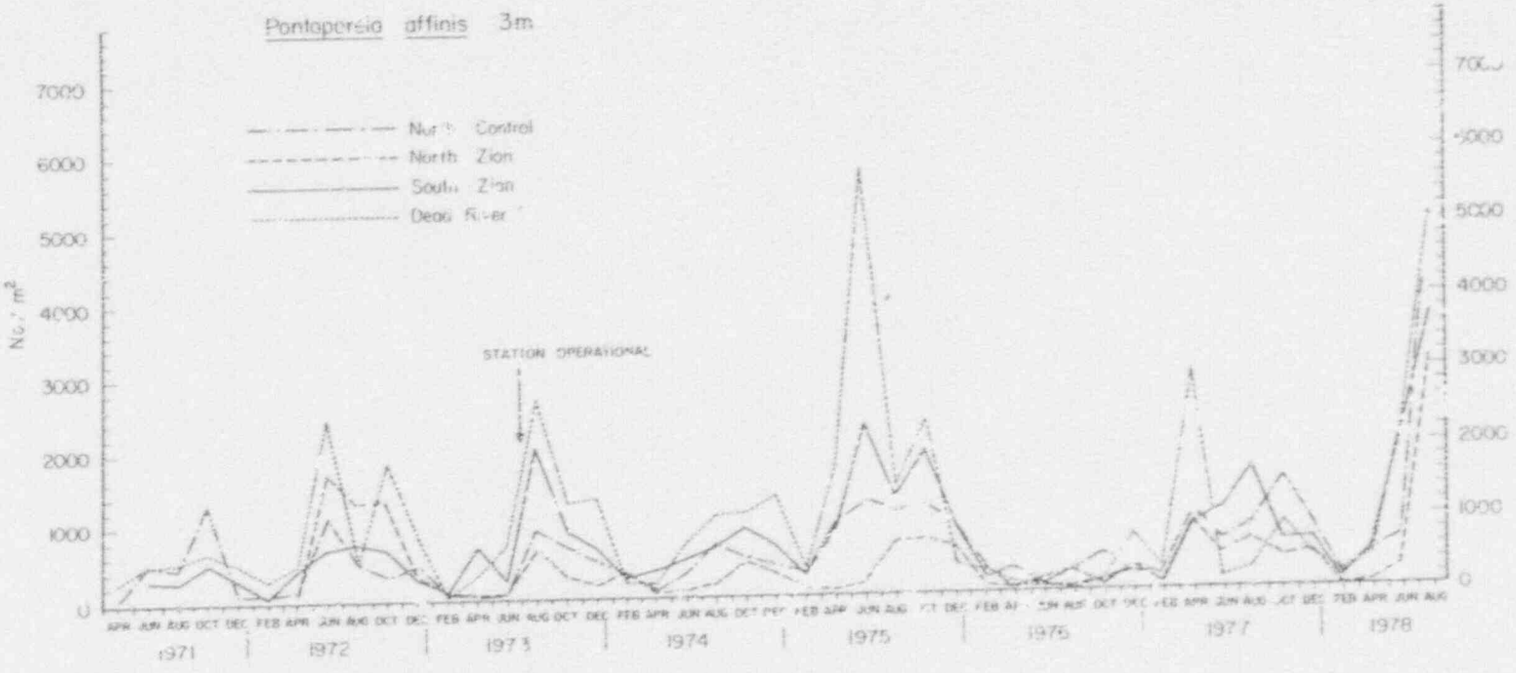


Figure 7. Mean number/m^2 of Pontoporeia affinins at the 3 meter locations in southsestern Lake Michigan near Zion, Illinois, April 1971-August 1978.

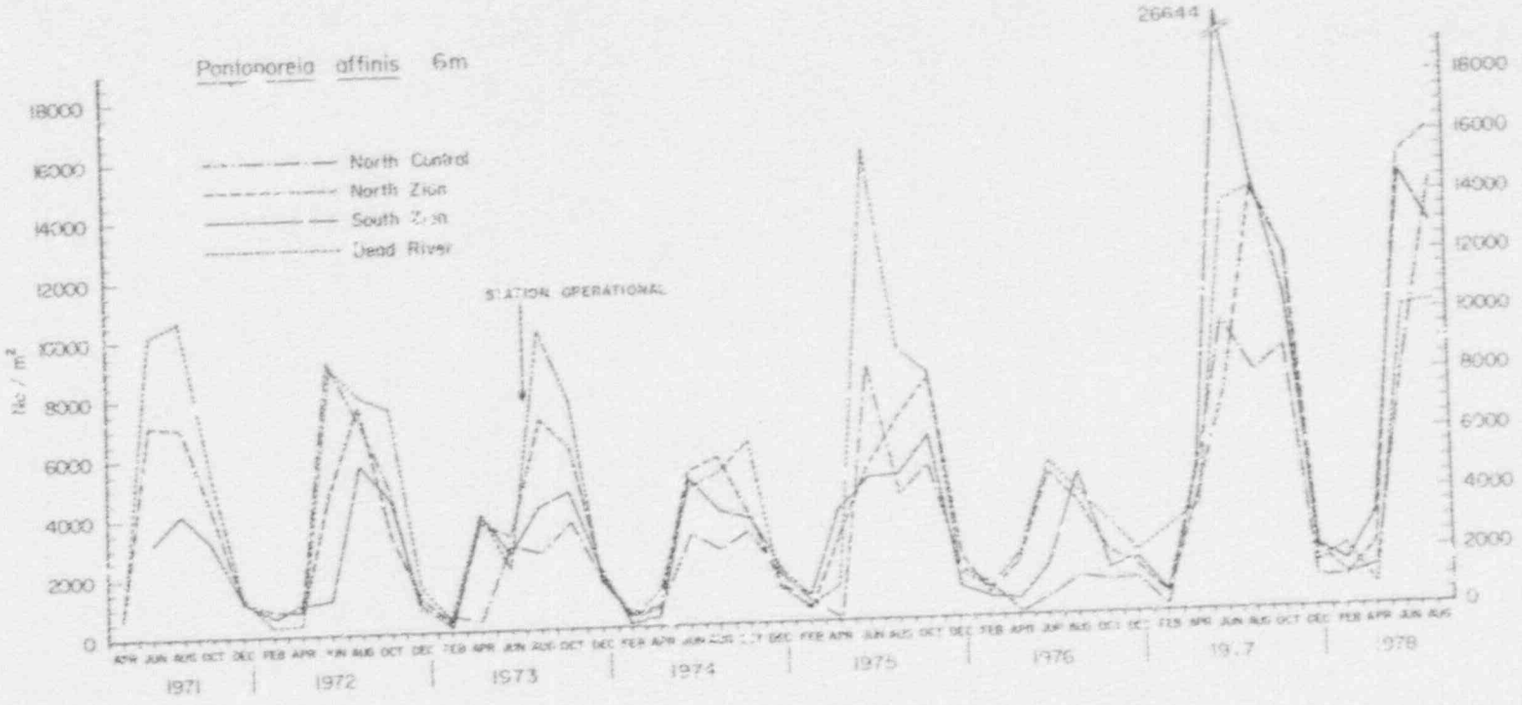


Figure 8. Mean number/m^2 of Pontoporeia affinis at the 6 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1971-August 1978.

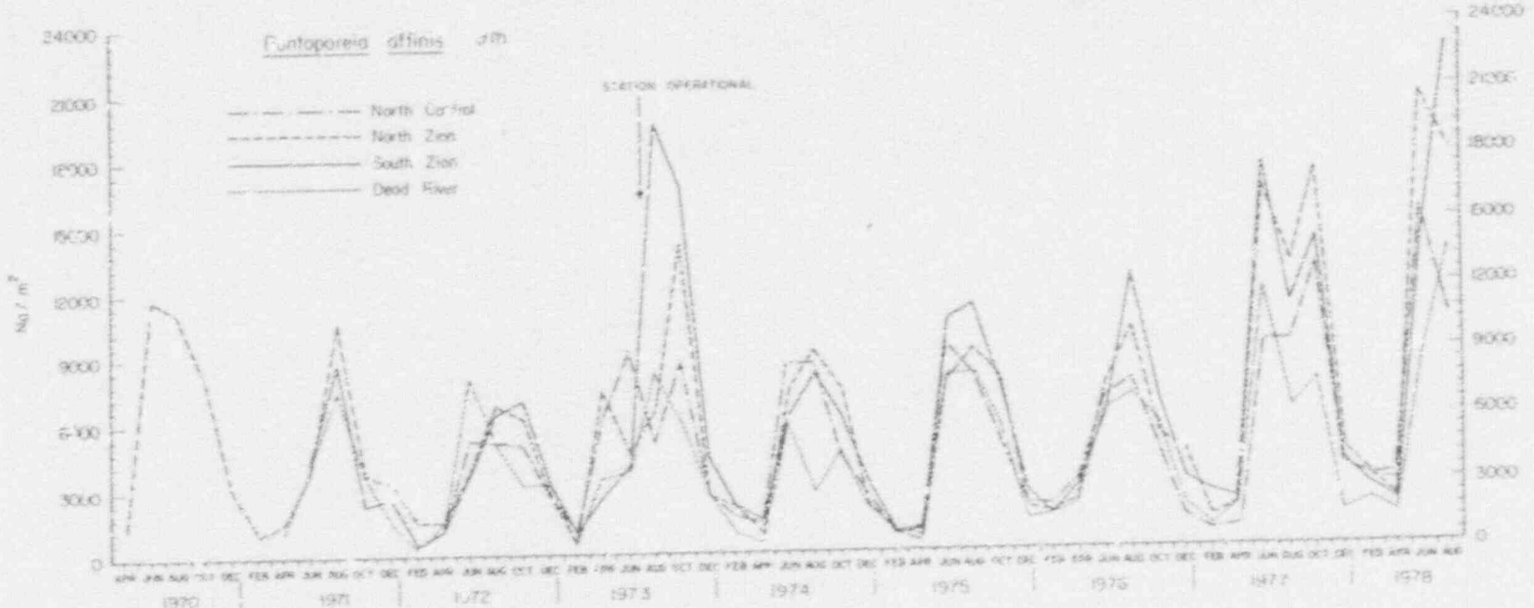


Figure 9. Mean number/m^2 of Pontoporeia affinis at the 9 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1970-August 1978.

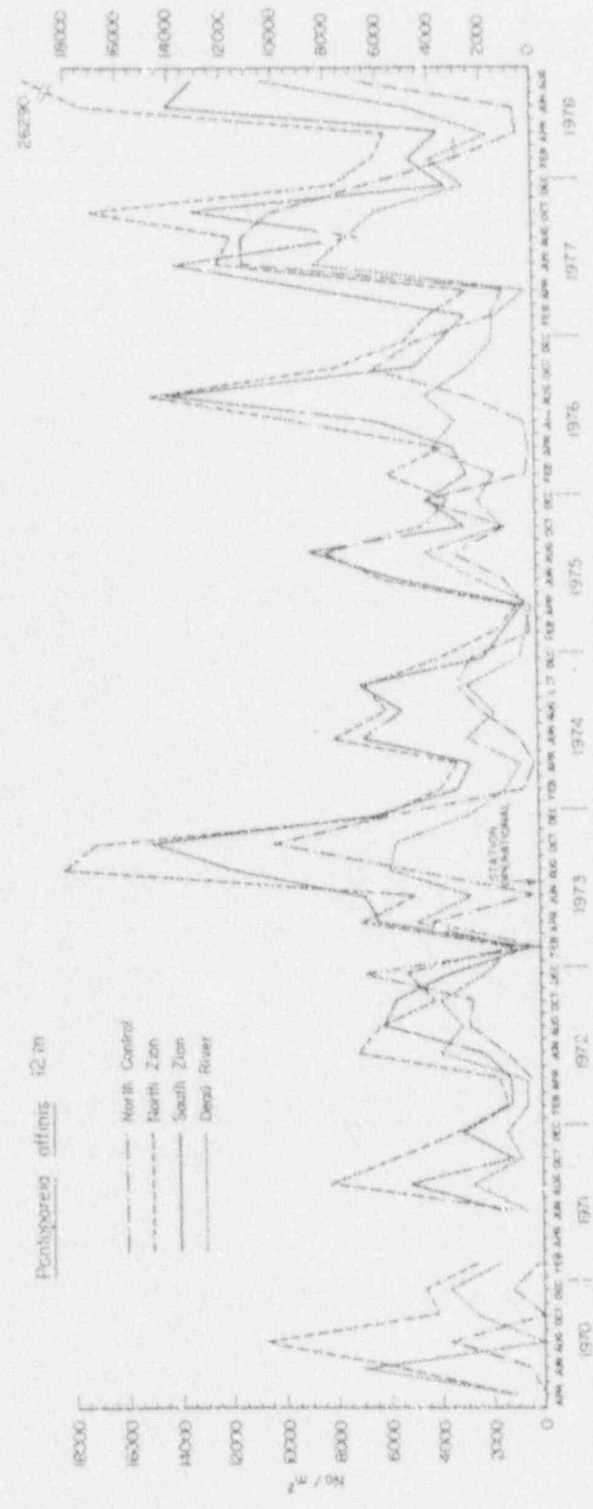


Figure 10. Mean number/m^2 of Pontoporeia affinis at the 12 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1970-August 1978.

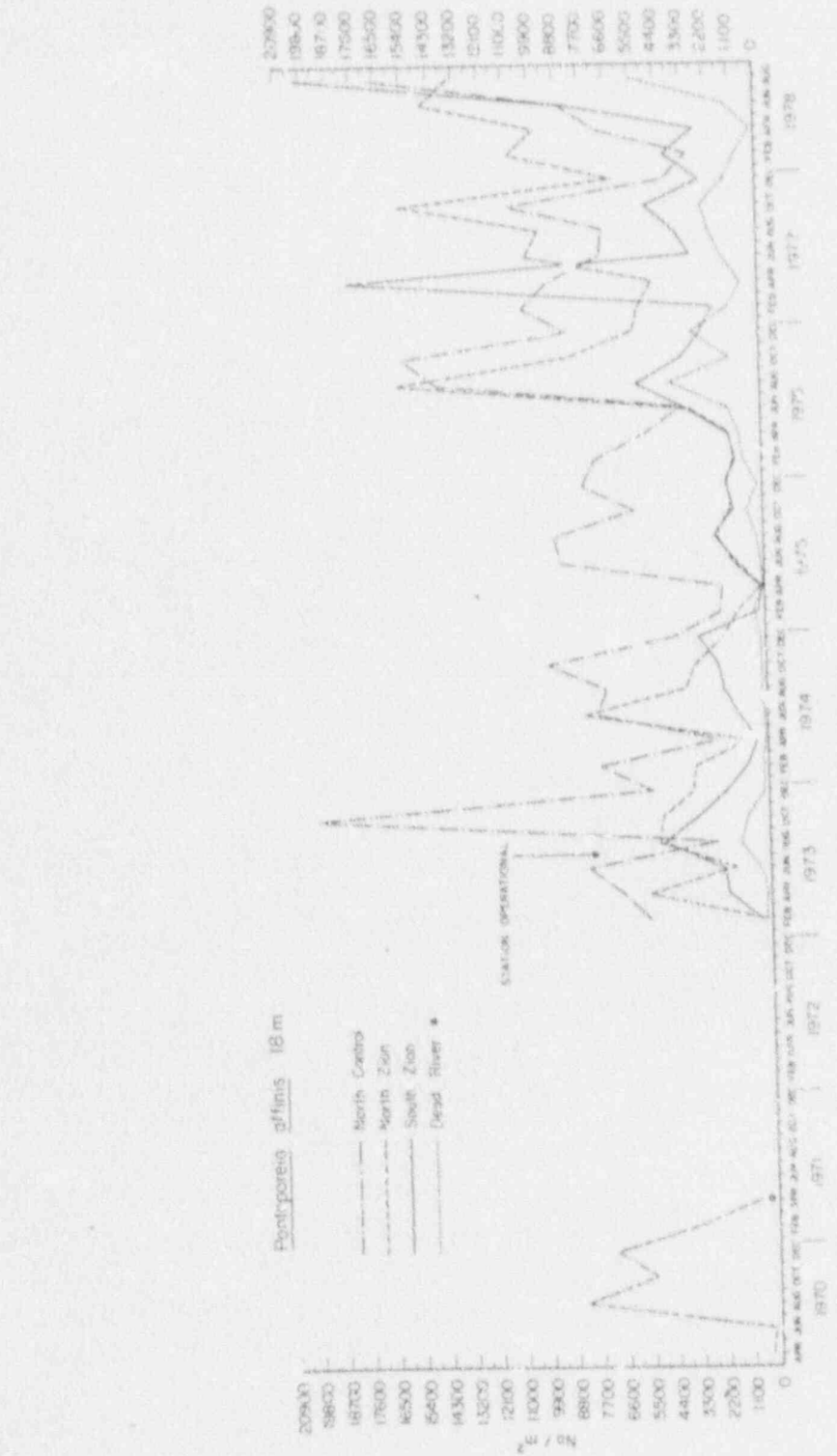


Figure 11. Mean number/m² of total Pontoporeia affinis at the 18 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1970-August 1978.

tions. Peak abundances occurred during the summer and early fall with lowest numbers usually reported in February.

There has been a general increase in abundance of P. affinis throughout the study. However in 1976 there was a decline in numbers of P. affinis but this decline was followed by large increases in 1977 and 1978. Densities of P. affinis generally increased with depth to 9m where peak abundances were usually reported from South Zion.

Oligochaeta was composed predominantly of tubificids and the lumbriculid, Stylodrilus heringianus. Potamothrix moldaviensis was the dominant tubificid at the inshore locations while Potamothrix vejdovskyi and Limnodrilus hoffmeisteri were the major species at the 12 and 18 m locations. There were large increases in numbers of Tubificidae at the 3 and 6 m locations after August 1976 (Table 2 and Figures 1. and 13). This could have been influenced by Zion Station, at the Zion zones, which was no longer restricted to 85% of capacity. But since there was an increase at all zones it was apparently due to natural variation. Cook and Johnson (1974) have suggested that cultural eutrophication in southern Lake Michigan has increased benthic production at an accelerated rate. Numbers of tubificids were usually greatest at Dead River Zone at the 9, 12 and 18 m locations (Figures 14, 15 and 16). This may have been related to the high amount of silt in the substrate at those locations.

Peak densities were observed in the fall at the 3, 6, 9 and 12 m locations and occasionally in the spring at the 9 and 12 m

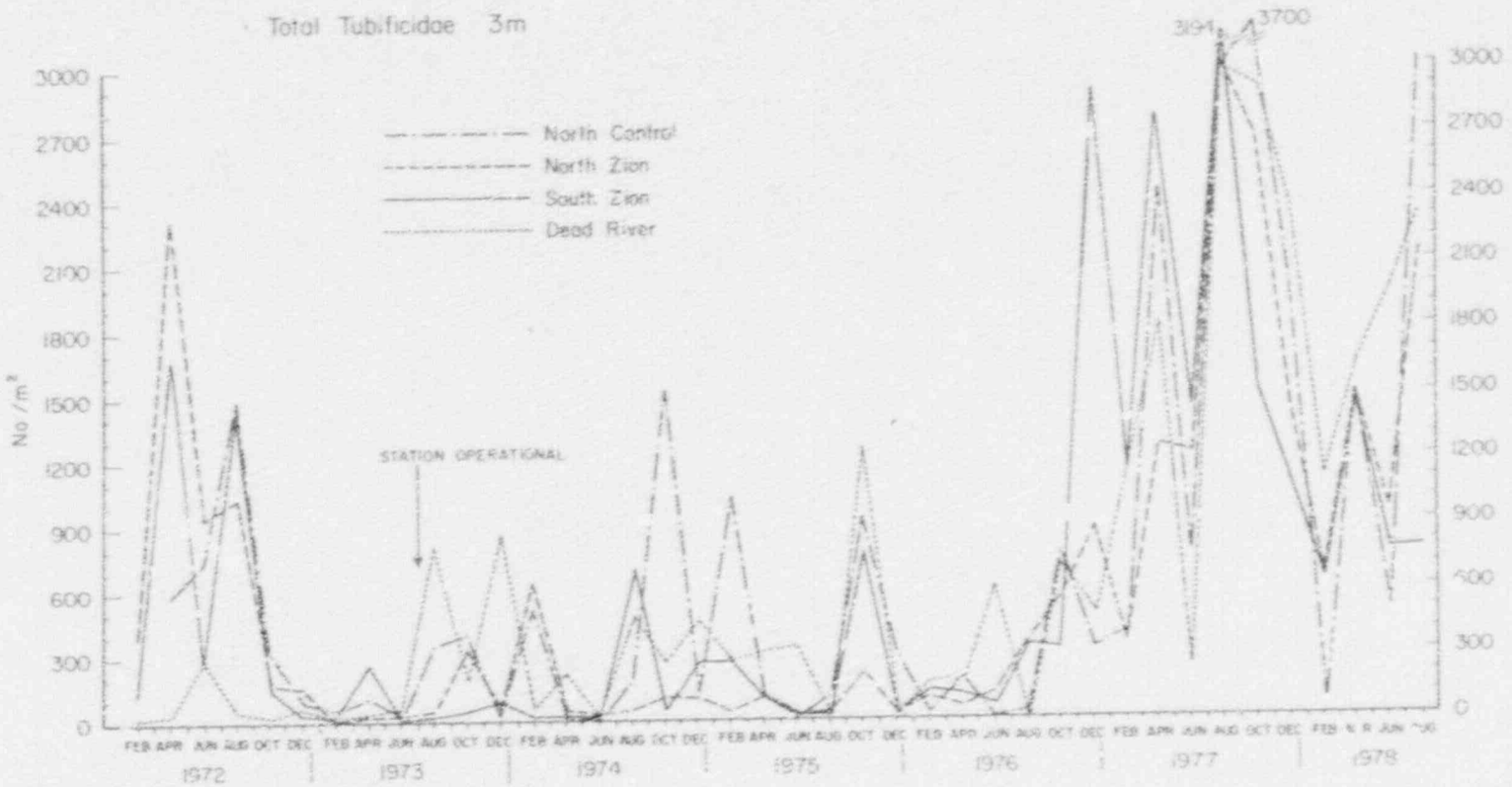


Figure 12. Mean number/m^2 of total Tubificidae at the 3 meter locations in southwestern Lake Michigan near Zion, Illinois, February 1972 - August 1978.

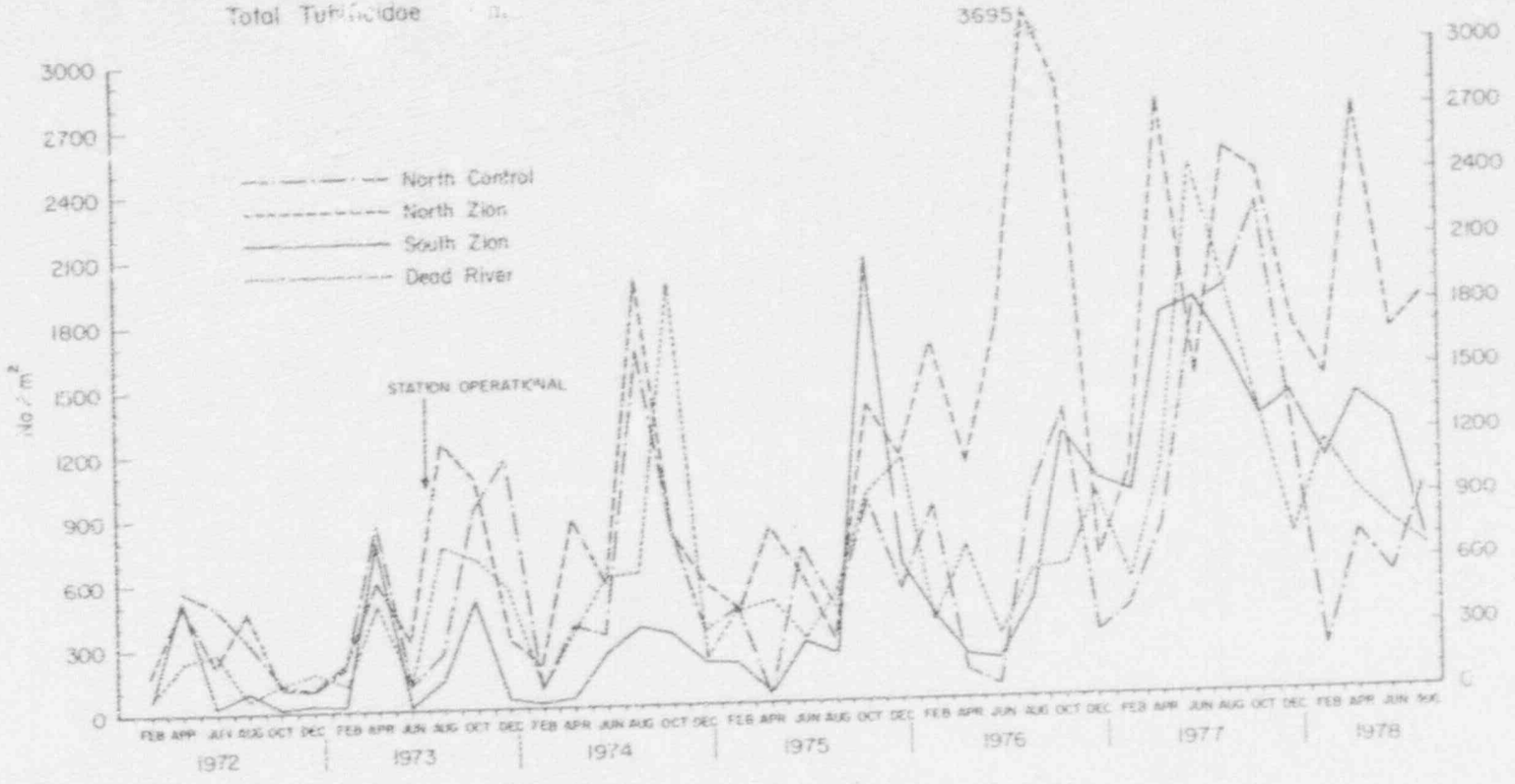


Figure 13. Mean number/m^2 of total Tubificidae at the 6 meter locations in southwestern Lake Michigan near Zion, Illinois, February 1972 - August 1978.

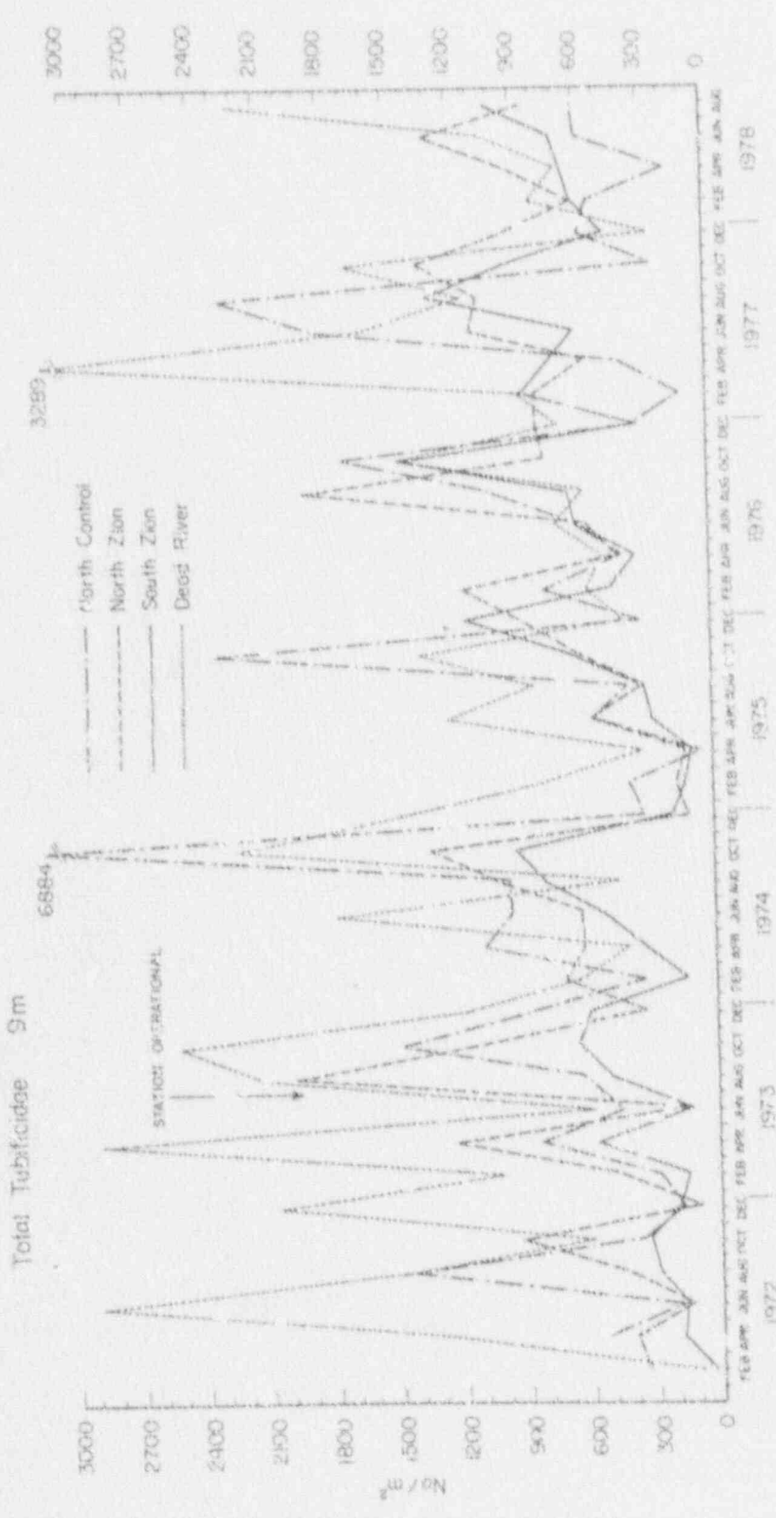


Figure 14. Mean number/m² of total Tubificidae at the 9 meter locations in southwestern Lake Michigan near Zion, Illinois, February 1972 - August 1978.

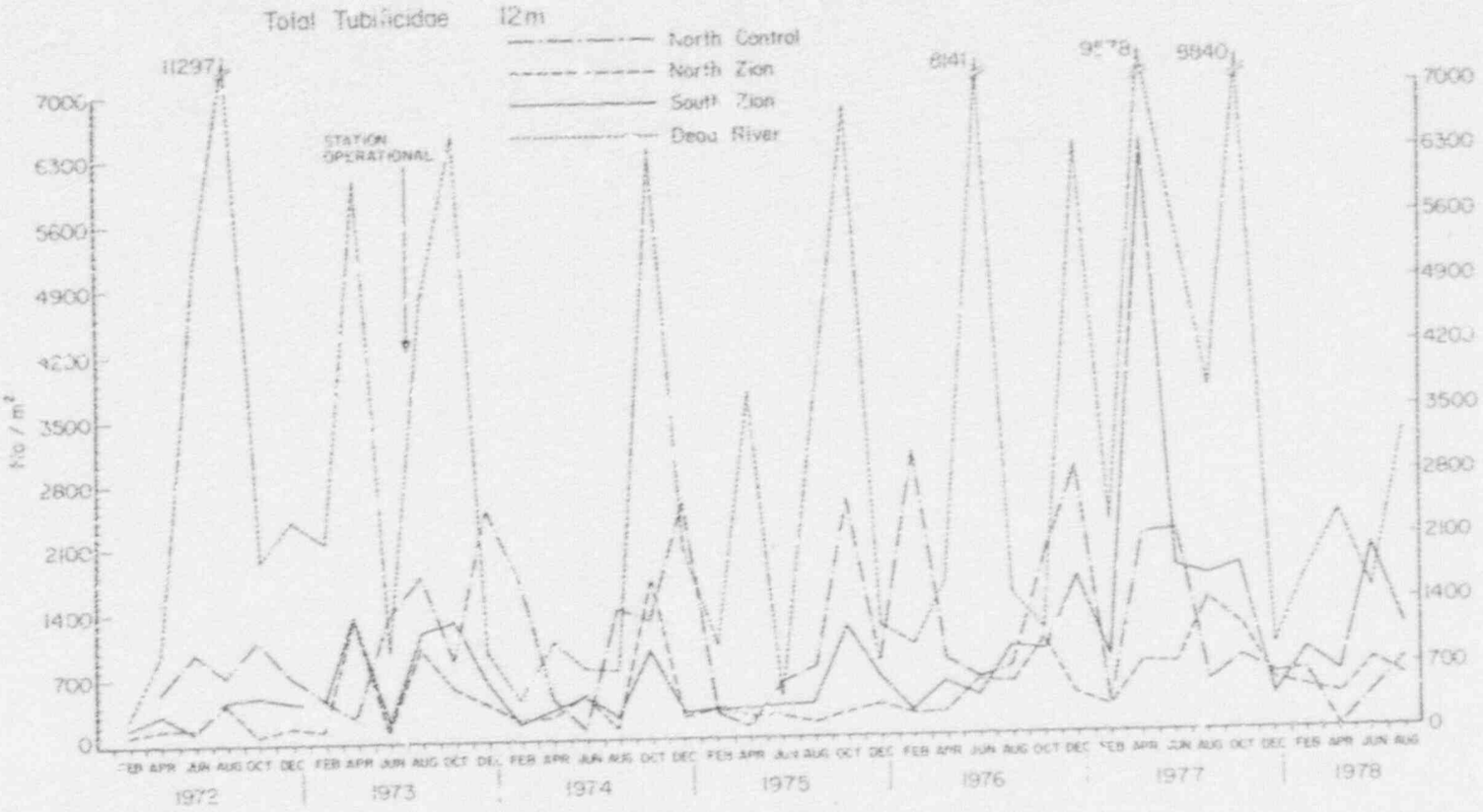


Figure 15. Mean number/m^2 of total Tubificidae at the 12 meter locations in southwestern Lake Michigan near Zion, Illinois, February 1972 - August 1978.

HAZLETON ENVIRONMENTAL SCIENCES

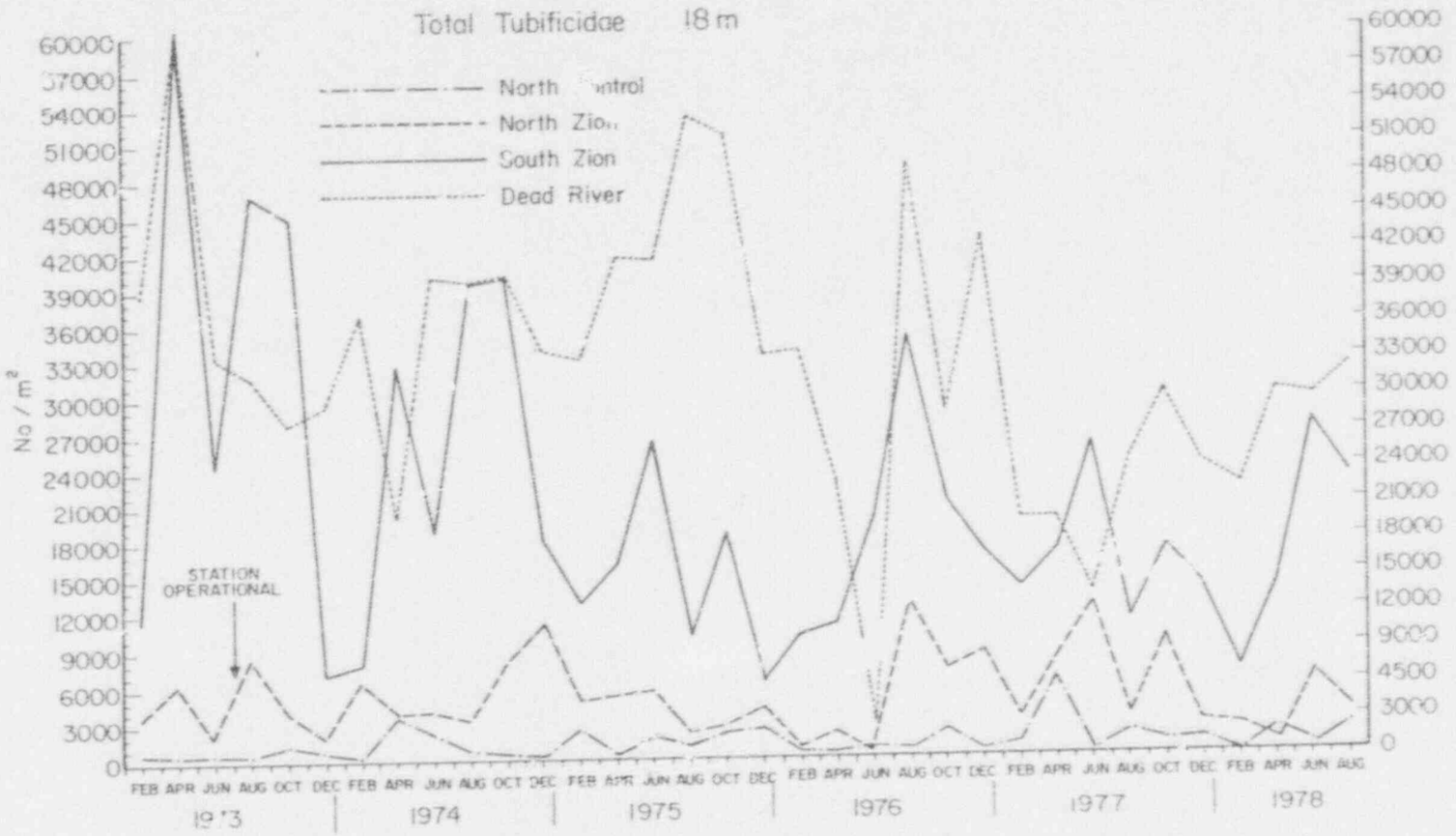


Figure 16. Mean number/m^2 of total Tubificidae at the 18 meter locations in southwestern Lake Michigan near Zion, Illinois, February 1972 - August 1978.

locations. No consistent seasonal trends were observed at the 18m location.

Stylodrilus heringianus was collected in very low numbers at the 3 and 6 m locations. The only differences observed between zones along a depth contour were the much lower numbers at North Control 9 and 12 m locations and the lower numbers at 18 m Dead River (Figures 17, 18 and 19). These differences are probably due to the differences in substrates at these locations.

Sphaerium striatinum, Sphaerium nitidum and Pisidium spp. were the dominant Sphaeriids collected. The Pisidium species group comprised the majority of the Sphaeriidae at all locations except Dead River until August 1976 (Figures 20 and 21). After August 1976 there was a general increase in the density of the sphaeriids at all locations, including Dead River.

Numbers of sphaeriids increased with increased depth, greatest abundances were usually reported from those locations with silty substrate. Densities at 9, 12 and 18 m locations were generally greatest at Dead River and lowest at North Control throughout the study (Figures 22, 23 and 24).

The Chironomidae were the major component of the class Insecta. Very few chironomids were reported from the inshore locations prior to June 1974. Since this time there has been a gradual increase in abundance of chironomids at most locations. Few differences were observed between zones at the inshore locations but at the 12 and 18 m locations numbers of chironomids were usually highest at Dead River (Figures 25, 26, 27, 28 and 29). Two

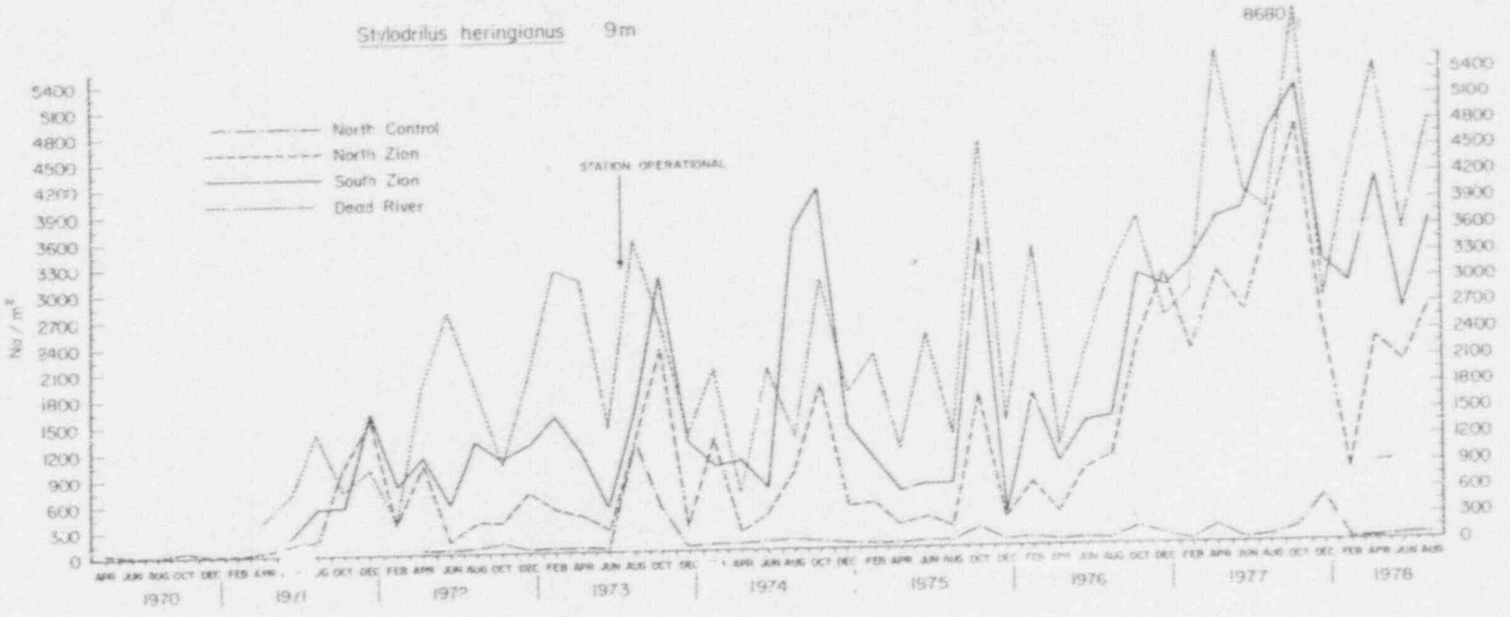


Figure 17. Mean number/m^2 of Stylodrilus heringianus at the 9 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1970 - August 1978.

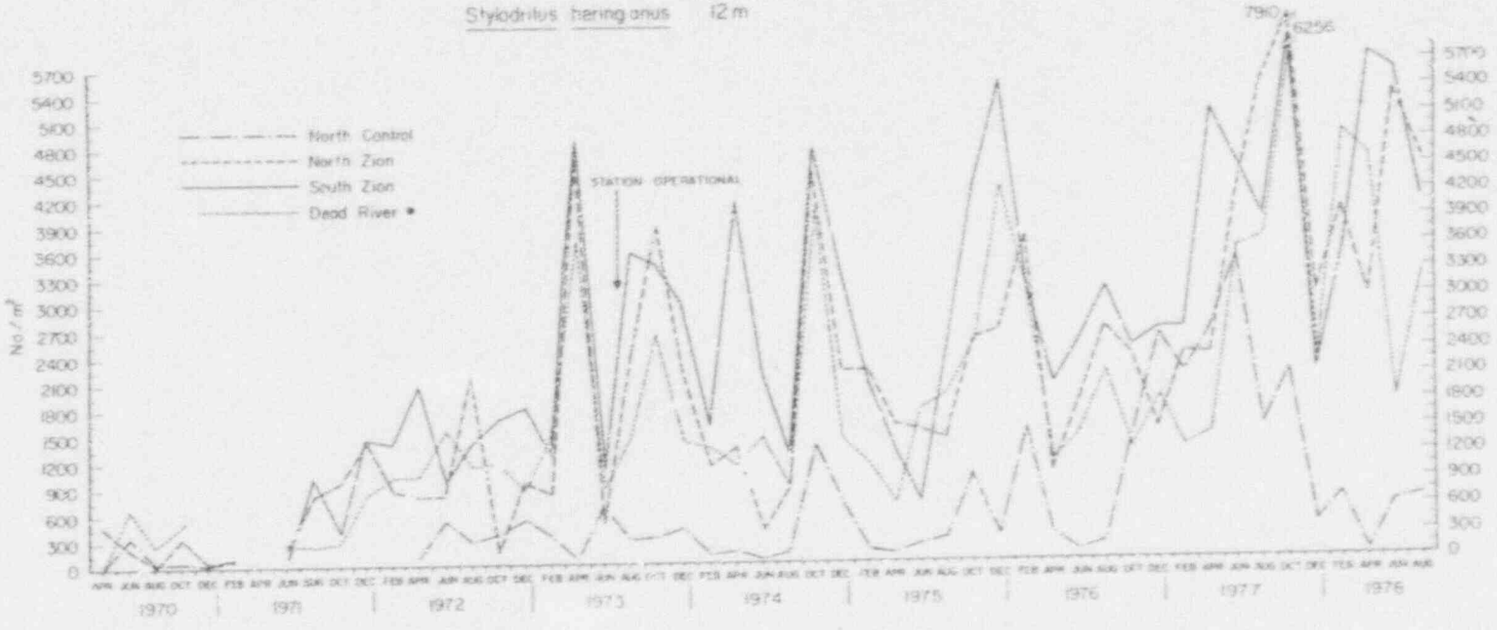


Figure 18. Mean number/m^2 of Stylodrilus heringianus at the 12 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1970 - August 1978.

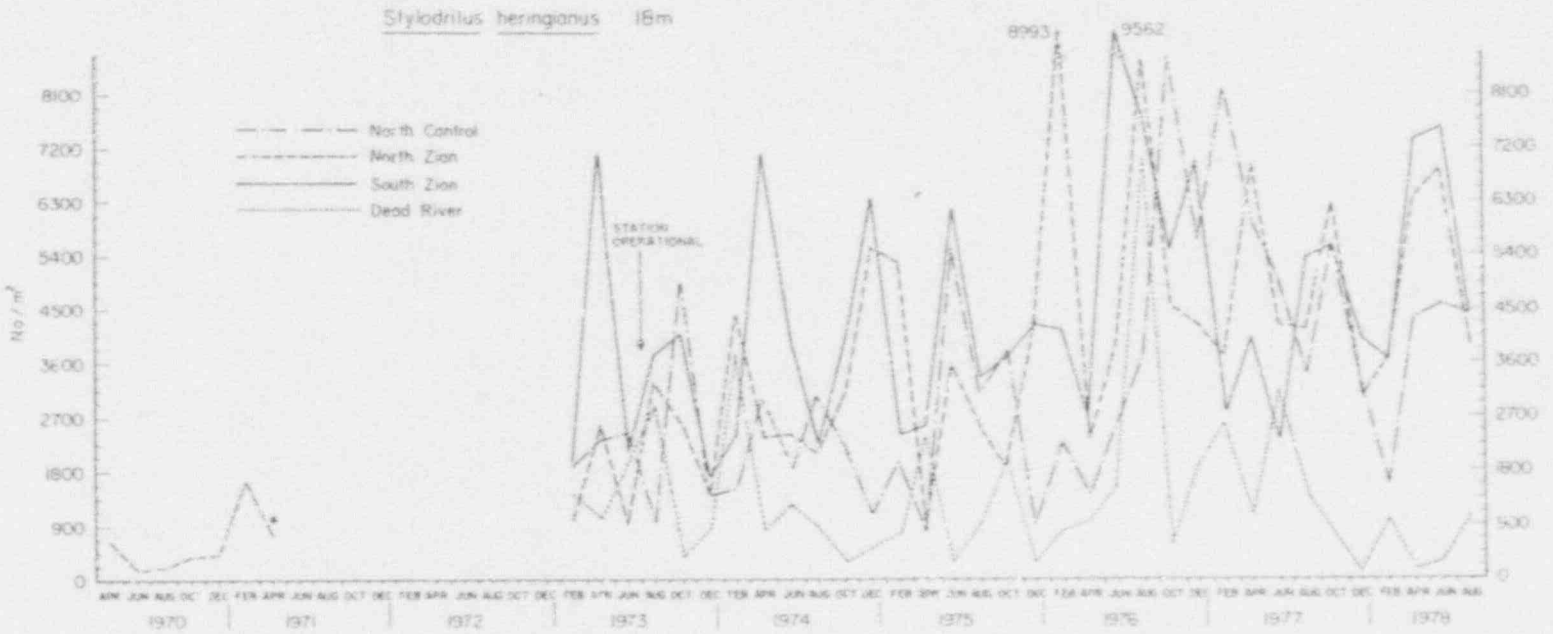
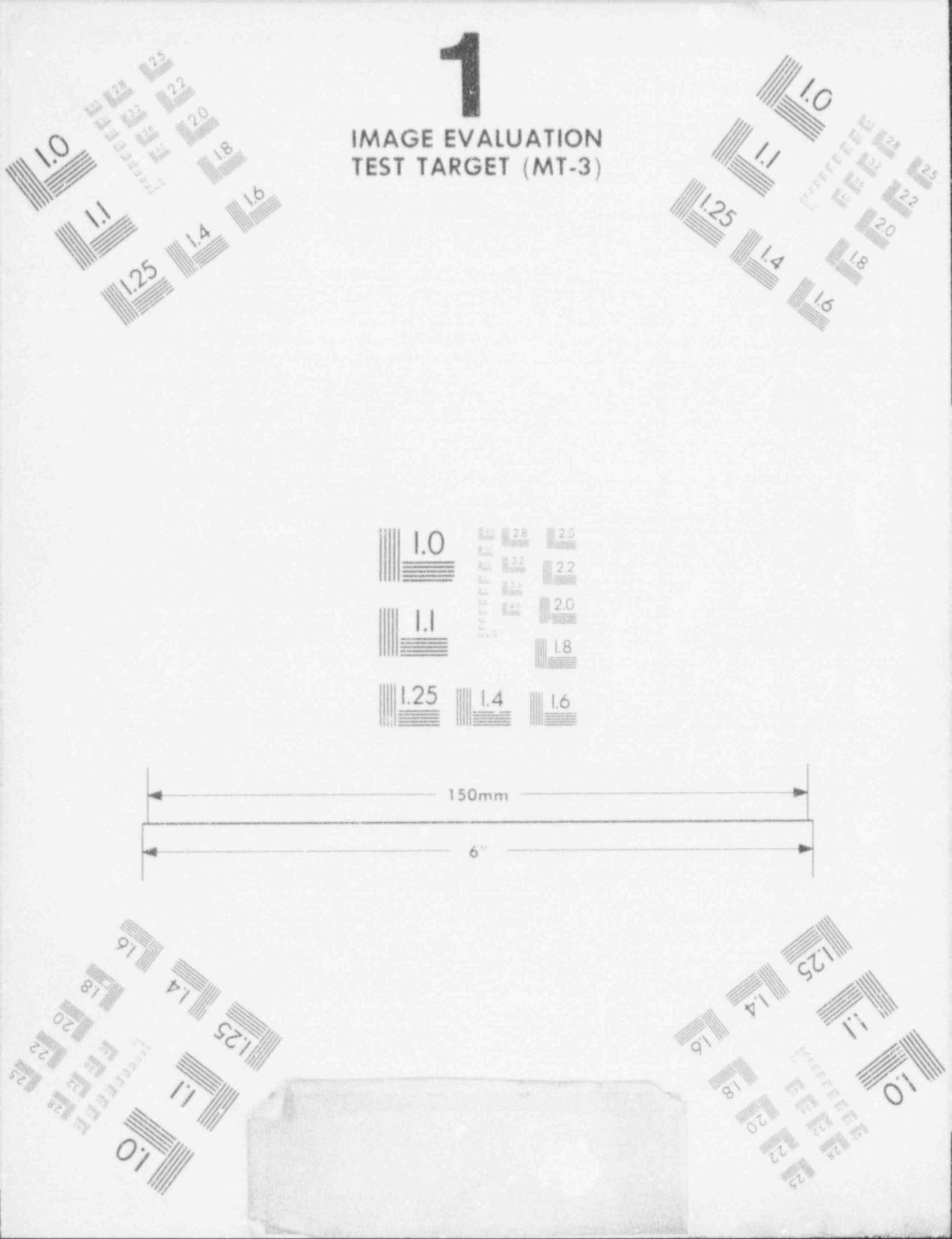
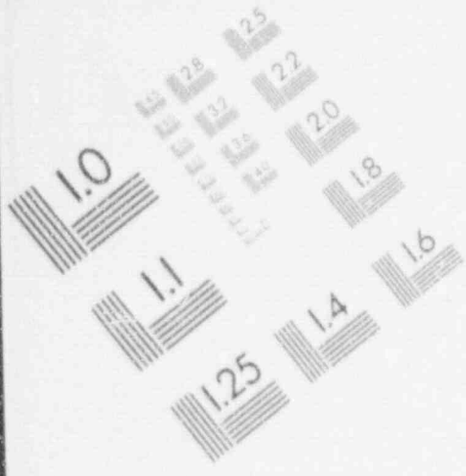


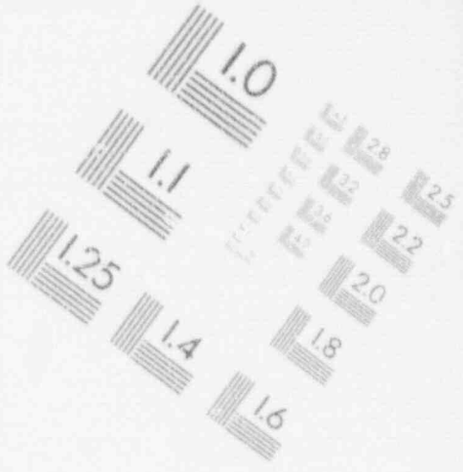
Figure 19. Mean number/m^2 of Stylodrilus heringianus at the 18 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1970 - August 1978.


1
IMAGE EVALUATION
TEST TARGET (MT-3)
1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.5
4.0
150mm
6"

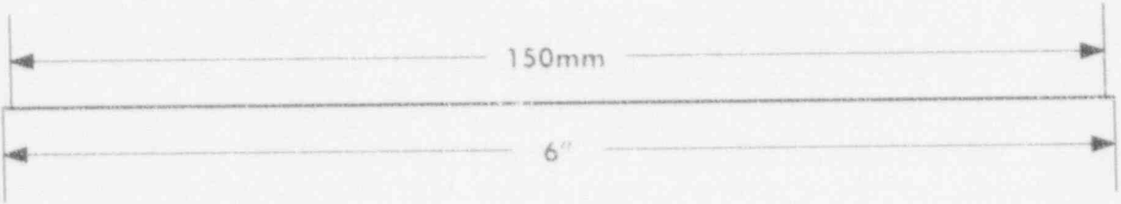
1

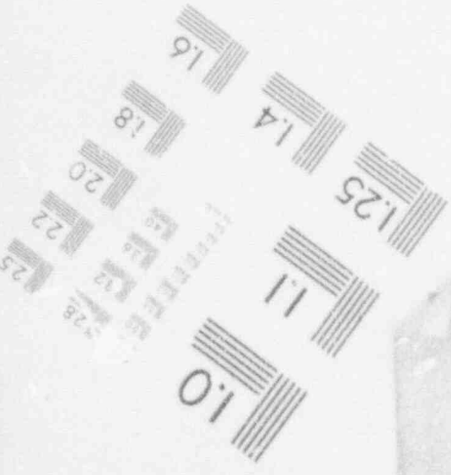
IMAGE EVALUATION TEST TARGET (MT-3)

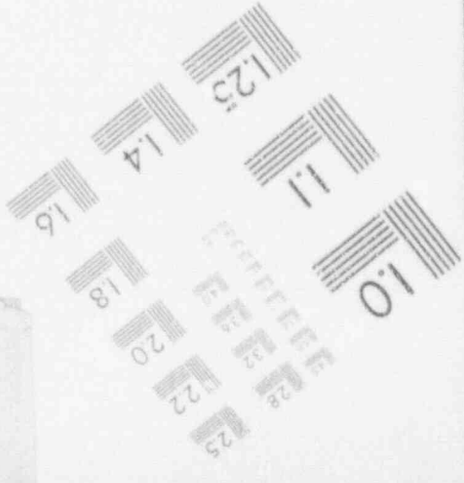


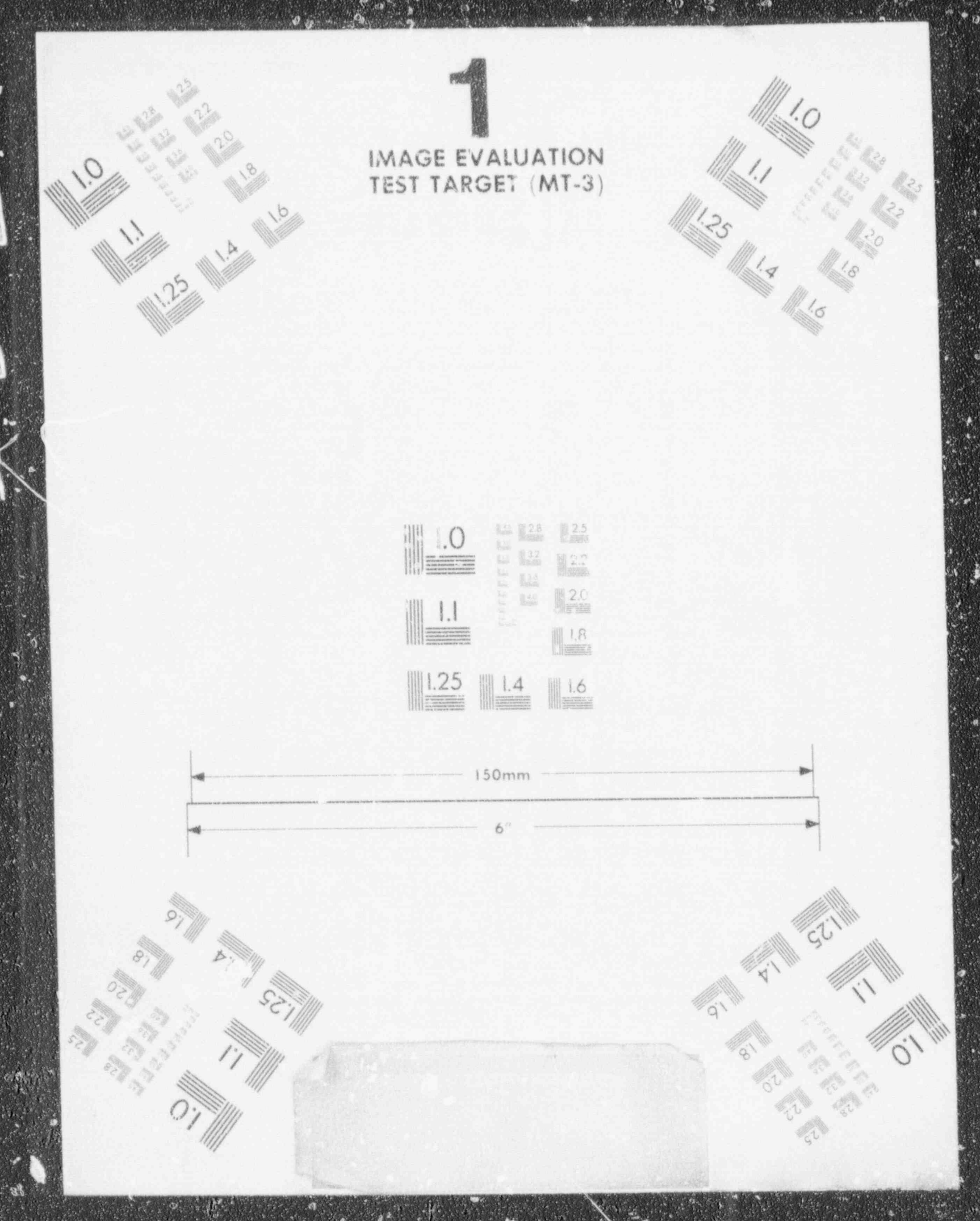











1
IMAGE EVALUATION
TEST TARGET (MT-3)
1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
150mm
6"

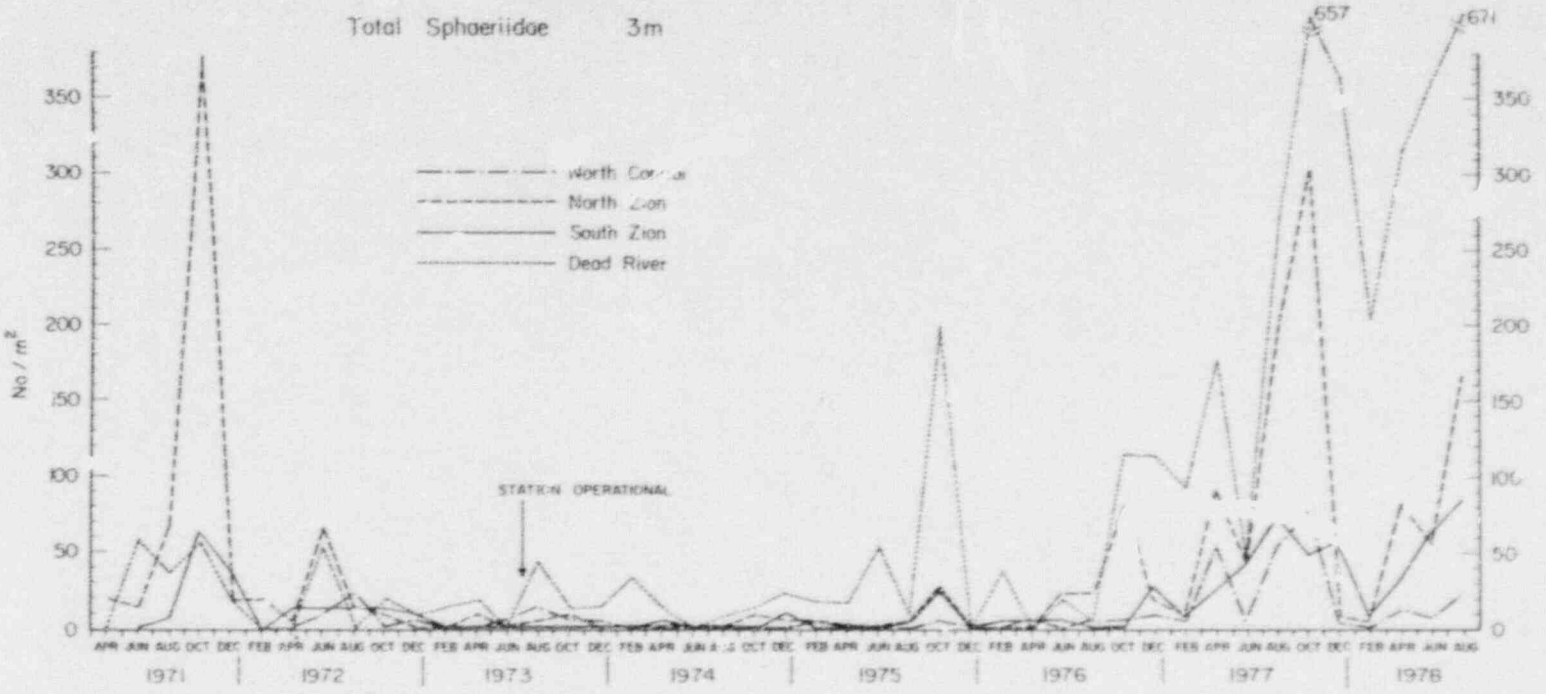


Figure 20. Mean number/m^2 of total Sphaeriidae at the 3 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1971-August 1978.

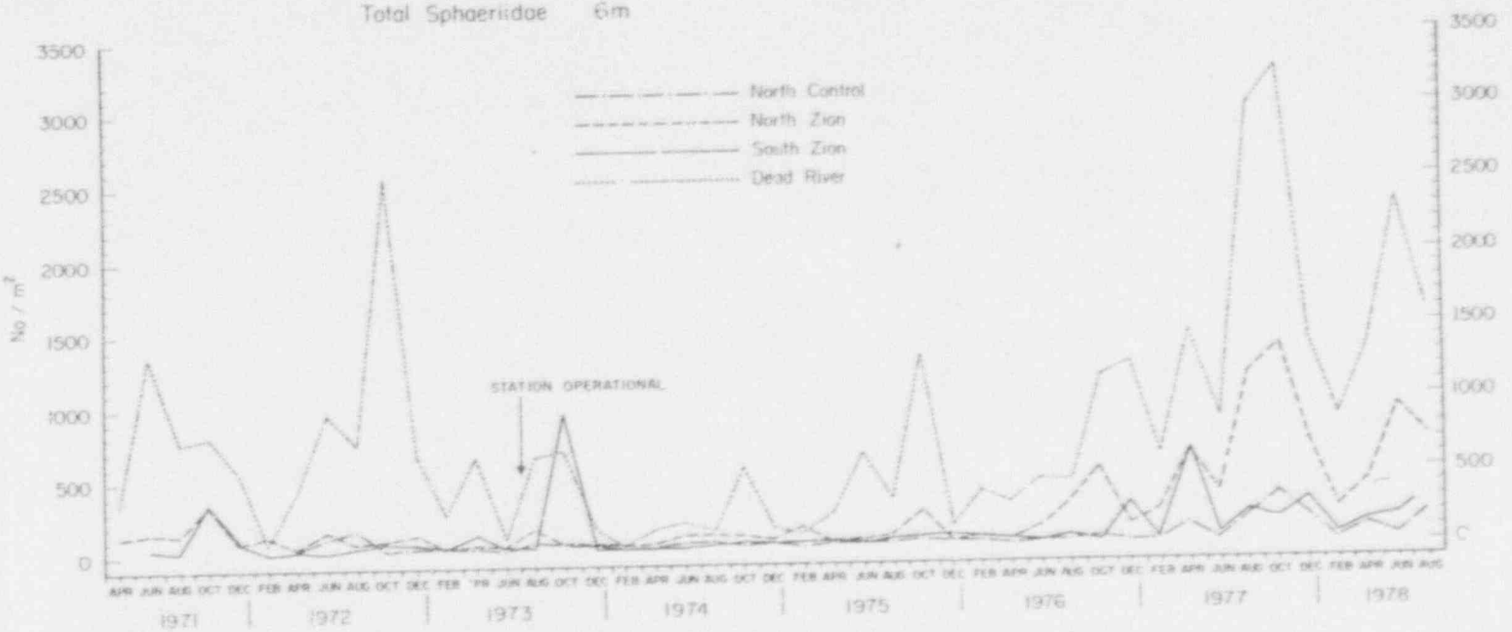


Figure 21. Mean number/m^2 of total Sphaeriidae at the 6 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1971-August 1978.

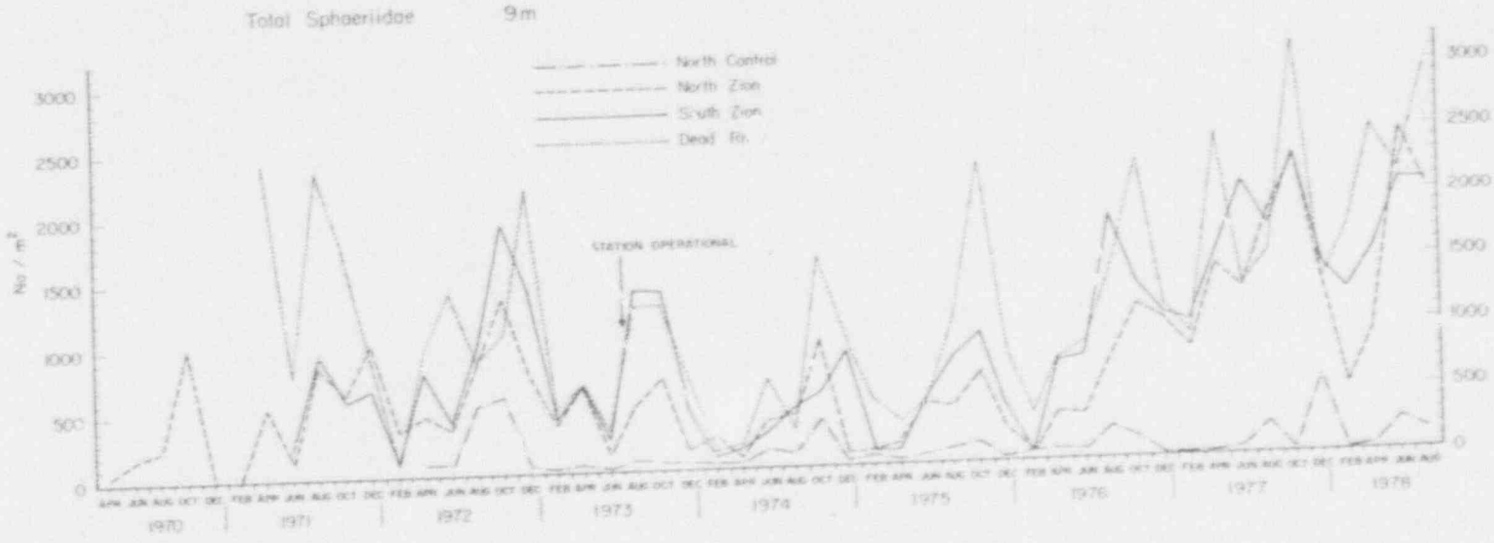


Figure 22. Mean number/m^2 of total Sphaeriidae at the 9 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1970-August 1978.

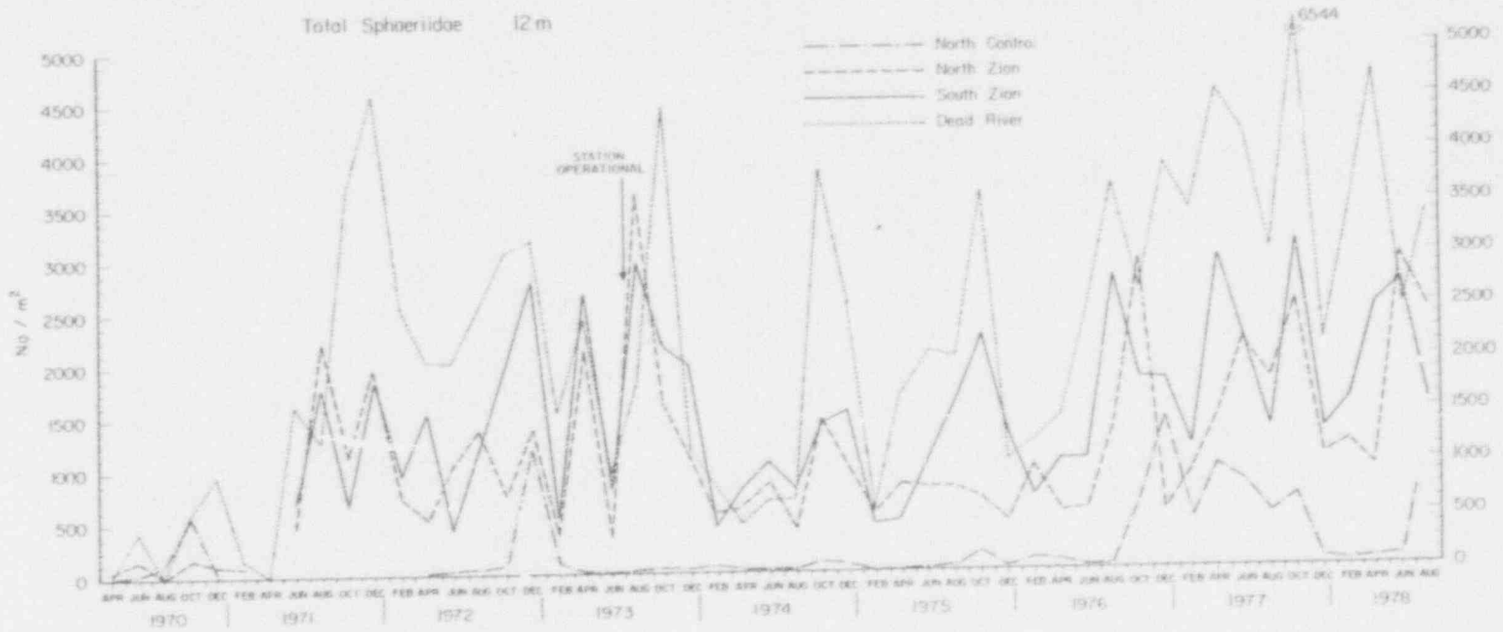


Figure 23. Mean number/m^2 of total Sphaeriidae at the 12 meter locations in southwestern Lake Michigan near Zion, Illinois April 1970-August 1978.

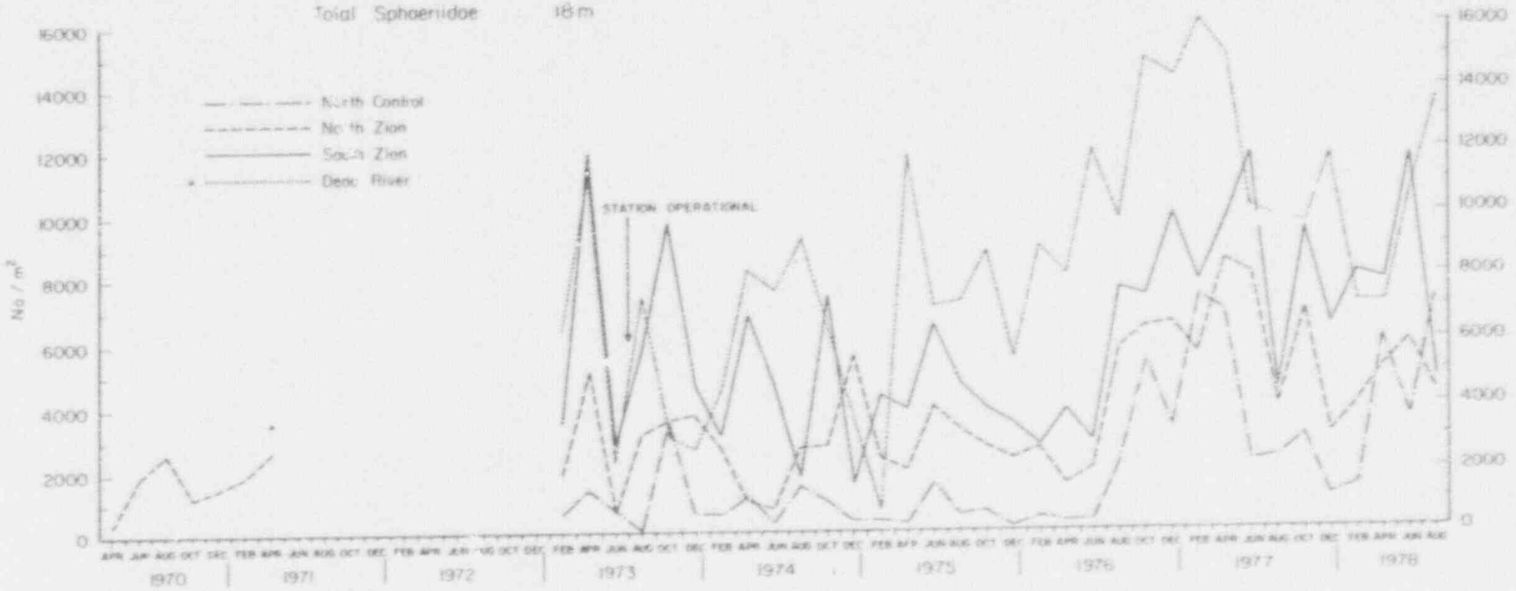


Figure 24. Mean number/m^2 of total Sphaeriidae at the 18 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1970-August 1978.

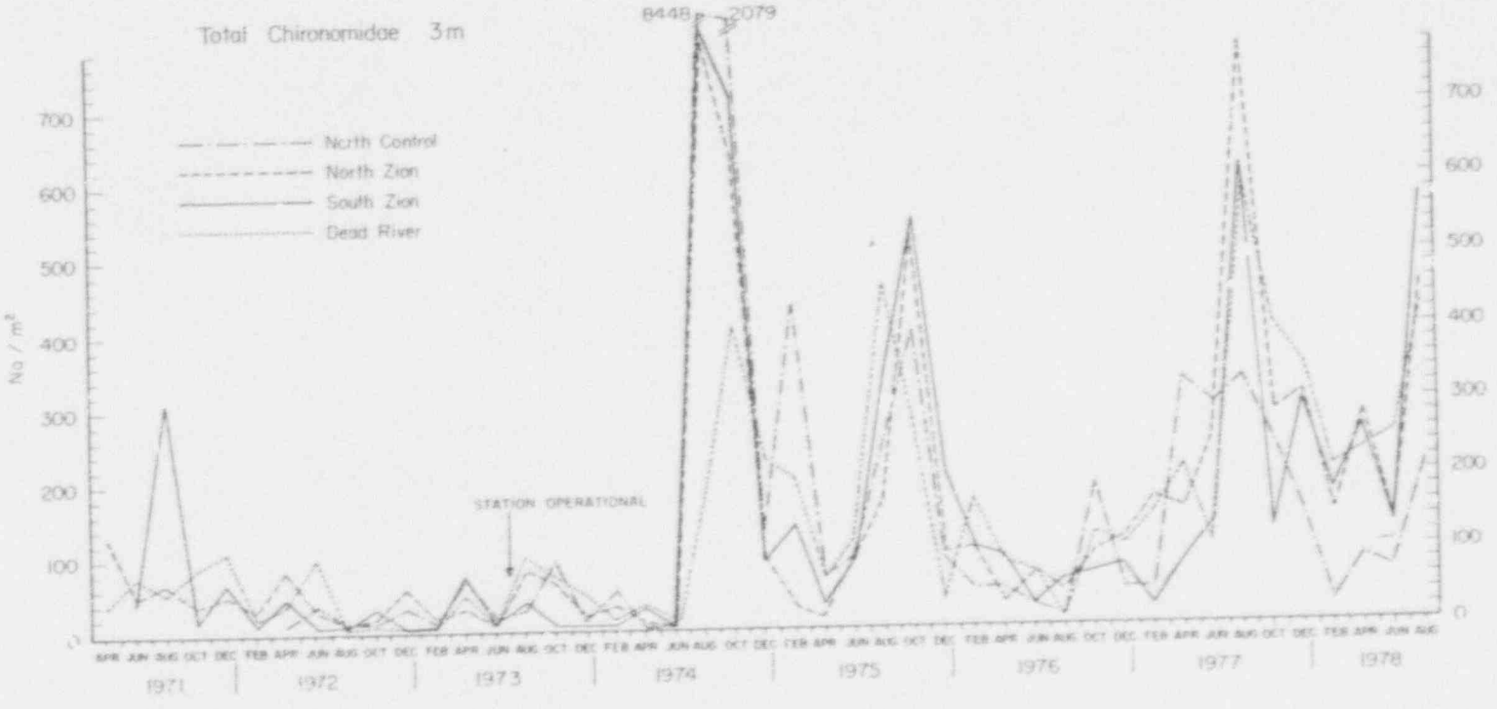


Figure 25. Mean number/m^2 of total Chironomidae at the 3 meter locations in southeastern Lake Michigan near Zion, Illinois, april 1971-August 1978.

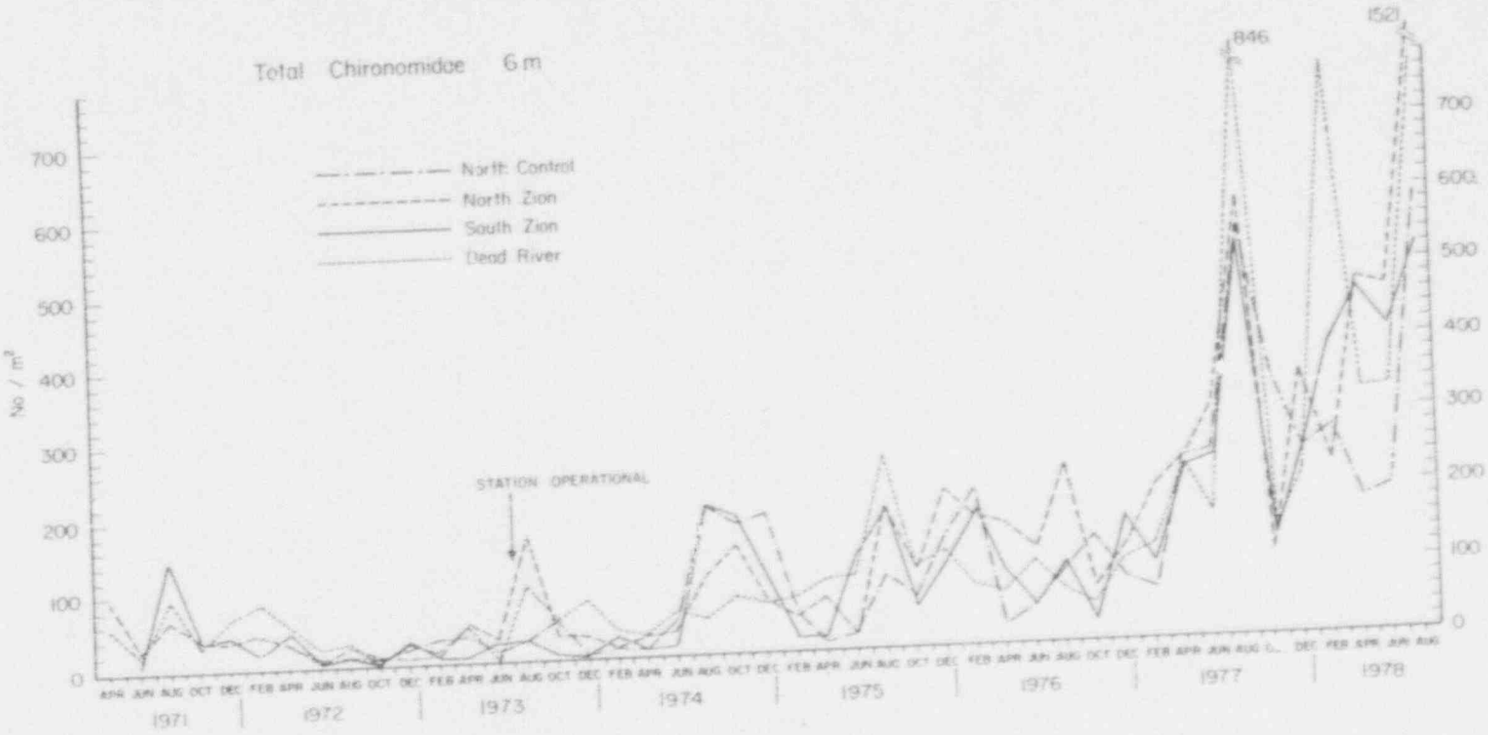


Figure 26. Mean number/m^2 of total Chironomidae at the 6 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1971-August 1978.

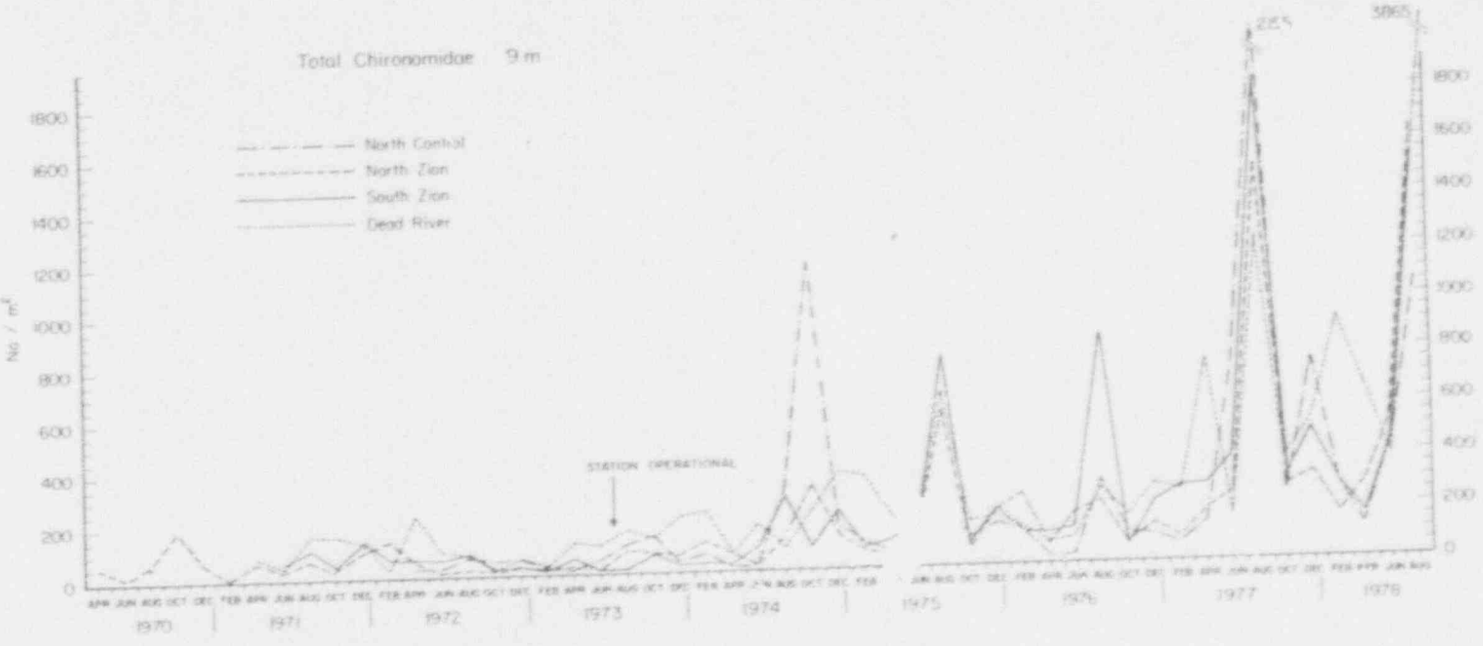


Figure 27. Mean number/m^2 of total Chironomidae at the 9 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1971-August 1978.

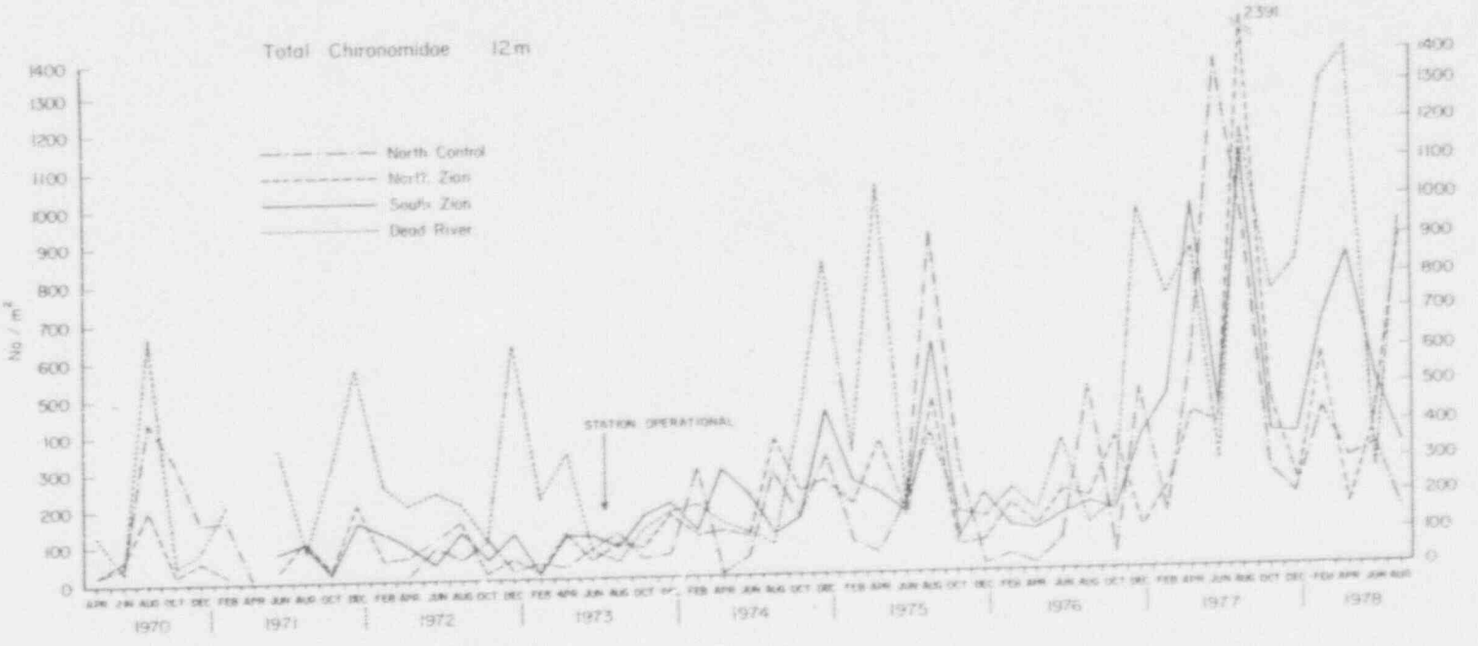


Figure 28. Mean number/m^2 of total Chironomidae at the 12 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1970-August 1978.

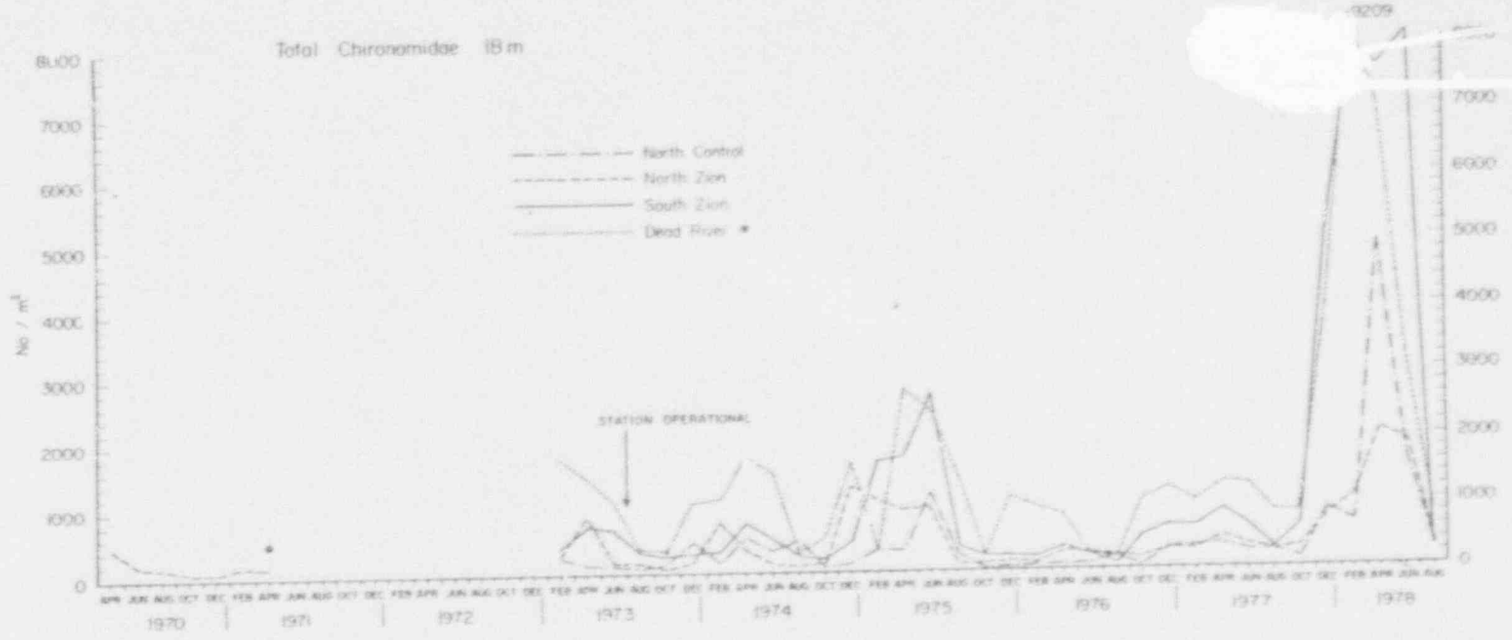


Figure 29. Mean number/m^2 of total Chironomidae at the 18 meter locations in southwestern Lake Michigan near Zion, Illinois, April 1970-August 1978.

HAMPLETON ENVIRONMENTAL SCIENCES

trends were observed, a seasonal trend with peak abundances in late summer and fall and increased densities with increased depth.

Very few statistical differences were observed in abundances of selected individual taxa or groups of oryanisms between the two Zion zones and the two control zones. Also, few differences were noted over time between the Zion locations and the control locations.

There have been increases in abundance of many of the major taxa at the inshore locations through time (Table 3). There have also been changes in percent compostion of the benthic community. Chironomids and ephaerids have increased in percent composition while P. affinis has declined. However, these increases in density and changes in percent composition were apparently not related to Zion Station operation since the increased densities and changed percentages were noted at all zones. These increased densities may in fact indicate an actual increase in production of macroinvertebrates resulting from cultural eutrophication of the nearshore environment or perhaps reflect diminished vertebrate predation.

V. References Cited

Barbour, M. 1974. Benthos study. IN Environmental monitoring in Lake Michigan near Zion and Waukegan Generating Stations, January 1972 through December 1972. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol II: 227-306.

Bousfield, E. L. 1958. Freshwater amphipod crustaceans of glaciated North America. Can. Field. Nat. 72(2):55-113.

Brice, J. R. 1975. Benthos study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1974 through June 1975. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. III: 71-609.

_____. 1976. Benthos study. IN Operational environmental monitoring in Lake Michigan near Zion Station. July 1975 through June 1976. Annual report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. V: 1-660.

Brice, J. R., and K. Stimpson. 1974. Benthos study. IN Environmental monitoring in Lake Michigan near Zion and Waukegan Generating Stations, January 1973 through June 1973. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. (unpublished)

Brillouin, L. 1956. Science and information theory. Academic Press, New York.

Brinkhurst, R. O. and B. G. M. Jamieson. 1971. Aquatic Oligochaeta of the world. Univ. of Toronto Press. Toronto. 860 p.

Burch, J. B. 1972. Freshwater Sphaeriacean clams (Mollusca: Pelecypoda) of North America. Water Pollution Control Research Series (3). EPA. 31 p.

Cima, G. 1977. Occurrence of Mysis relicta and Pontoporeia affinis from ichthyoplankton samples in Lake Michigan near Zion and Waukegan, Illinois. 1976. Report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. 142 p.

Cook, D. G. and M. H. Johnson. 1974. Benthic macroinvertebrates of the St. Lawrence Great Lakes. J. Fish. Res. Board Can. 31:763-782.

Geers, D. F. 1977. Benthos Study. IN Operational Monitoring in Lake Michigan near Zion Station. July 1976 through June 1977. Annual report to Commonwealth Edison Company Chicago, Illinois, by NALCO Environmental Sciences. Vol. V: 330 p.

_____. 1978. Benthos Study. IN Operational Monitoring in Lake Michigan near Zion Station. July 1977 through June 1978. Annual report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. IV: 326 p.

_____. 1979. Benthos Study. IN Operational Monitoring in Lake Michigan near Zion Station. July 1978 through September 1978. Supplemental Report to Commonwealth Edison Company, Chicago, Illinois by Hazleton Environmental Sciences. 337-408.

Hamilton, A. L., O. A. Saether and D. R. Oliver. 1969. A classification of the neartic Chironomidae. Fish. Res. Bd. Canada. Tech. Rept. No. 124. 42 p.

Hiltunen, J. K. 1967. Some oligochaetes from Lake Michigan Trans. Am. Microscop. Soc. 86(4):433-454.

Huh, H., L. Everhart, C. Kondrat, J. Lingle and J. Urry. 1973. Field study program of Lake Michigan in the vicinity of the Waukegan and Zion Generating Stations, April 1971-March 1972. Project X. IN Evaluation of thermal effects in southwestern Lake Michigan 1971-1972. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I: 131 p.

Industrial BIO-TEST Laboratories, Inc. 1972. Evaluation of thermal effects in southwestern Lake Michigan (January 1970-April 1971). Report to Commonwealth Edison Company, Chicago, Illinois. 2 vols.

_____. 1973. Evaluation of thermal effects in southwestern Lake Michigan, 1971-1972. Report to Commonwealth Edison Company, Chicago, Illinois 2 vols.

Klemm, D. J. 1972. Freshwater leeches (Annelida: Hirundinea) of North America. Water Pollution Control Research Series (8). EPA. 53 p.

Mosley, S. C. and L. C. Garcia. 1972. Benthic macrofauna in the Coastal zone of southern Lake Michigan. Proc. 15th Conf. Great Lakes Res., Intern. Assoc. Great Lakes Res., 102-116.

Pritchard-Carpenter Consultants. 1970. Predictions of the distribution of excess temperatures in Lake Michigan resulting from the discharge of condenser cooling water from the Zion Nuclear Power Station. Commonwealth Edison Company, Chicago, Illinois. 68 p.

Segerstrale, S. G. 1977. The taxonomic status and pre-history of the glacial relict Pontoporeia (Crustacea, Amphipoda) living in North American Lakes. Soc. Sci. Fenn., Comment. Bio. 89: 18p.

Sperber, C. 1950. A guide for the determination of European Naididae. Zool. Bidr. Uppsala. 29:45-78.

Stimpson, K. and J. Brice. 1974. Benthos study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through June 1974. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. II: 233-368.

Stimpson, K., J. Brice, M. Barbour and P. Howe. 1975. Distribution and abundance of inshore Oligochaetes in Lake Michigan. Trans. Amer. Microscopic Soc. 94(3):384-394.

Walter, J. H. and J. B. Burch. 1957. Key to genera of freshwater gastropods (snails and limpets) occurring in Michigan. Mus. Zool. Univ. Michigan. Circ. 3. 7 pp.

Chapter 10

FISH EGG AND LARVAE STUDIES

by

Steven D. Garbarino
and
Larry J. LaJeone

SUMMARY REPORT OF ENVIRONMENTAL MONITORING
IN LAKE MICHIGAN NEAR ZION STATION

January 1970 through September 1978

TABLE OF CONTENTS

		Page
	List of Figures	377
	List of Tables	379
I.	Introduction	381
II.	Materials and Methods	
	A. Sampling Locations	383
	B. Sampling Methods	386
	1. Plankton nets	386
	2. Benthic pump	386
	3. Trawl	388
	C. Data Collection and Analysis	389
III.	Results and Discussion	391
IV.	Literature Cited	417

LIST OF FIGURES

No.	Caption	Page
1	Fish egg and larvae sampling locations in southwestern Lake Michigan near Zion, Illinois, 1972-1978	384
2	Distribution by depth of rainbow smelt eggs collected by benthic pump in the Zion-Waukegan sampling area, April-May, 1972-1978	401
3	Distribution by transect of rainbow smelt eggs collected by benthic pump in the Zion-Waukegan sampling area, April-May, 1972-1978	402
4	Mean density of rainbow smelt larvae, by depth and transect, collected by plankton nets in the Zion-Waukegan sampling area, April-July, 1975-1978	404
5	Distribution by depth of juvenile rainbow smelt collected by trawl in the Zion-Waukegan sampling area, August-October, 1972-1978	405
6	Distribution by transect of juvenile rainbow smelt collected by trawl in the Zion-Waukegan sampling area, August-October, 1972-1978	407
7	Distribution by depth of alewife eggs collected by benthic pump in the Zion-Waukegan sampling area, June-August, 1972-1978	409
8	Distribution by transect of alewife eggs collected by benthic pump in the Zion-Waukegan sampling area, June-August, 1972-1978	410
9	Mean density of alewife larvae, by depth and transect, collected by plankton nets in the Zion-Waukegan sampling area, July-September, 1975-1978	411
10	Distribution by depth of juvenile alewives collected by trawl in the Zion-Waukegan sampling area, August-October, 1972-1978	413
11	Distribution by transect of juvenile alewives collected by trawl in the Zion-Waukegan sampling area, August-October, 1972-1978	414

LIST OF TABLES

No.	Title	Page
1	Approximate distance of fish egg and larvae sampling locations from the Zion and Waukegan Station discharges and from a point between and equidistant from the Zion Station discharges.....	385
2	Field sampling programs used in larval fish and egg studies in the Zion-Waukegan sampling area, 1972-1978.....	387
3	Species checklist and total number of eggs, larvae and juvenile fish collected by plankton nets, benthic pump, and trawl in the Zion-Waukegan sampling area, 1972-1978.....	392
4	Total number of fish larvae and eggs collected by benthic pump in the Zion-Waukegan sampling area, 1972-1978.....	394
5	Total number of fish larvae and eggs collected by plankton nets in the Zion-Waukegan sampling area, 1972-1978.....	396
6	Total number of juvenile fish collected by trawl in the Zion-Waukegan sampling area, 1972-1978.....	398

I. Introduction

Studies of larval fish and eggs found in southwestern Lake Michigan in the vicinity of Zion Generating Station were initiated in April 1972 and continued through September 1978 (Cima and Cochran 1973, 1974 a,b,c, 1975 a-b; Cima et al. 1976; Cima 1977, 1978; Cochran 1974a; Cochran and Cima 1974; LaJeone 1978; Otto 1975). The purpose of these studies were to assess the seasonal abundance and distribution of larval fish and eggs in the Zion-Waukegan sampling area. This report is a summary evaluating data from these studies.

The specific objectives addressed in this report were:

1. to evaluate the data to determine if any trends in seasonal abundance and distribution of larval fish and eggs have occurred during the study period.

2. to determine the composition, distribution and relative abundance of juvenile fish that inhabit the sampling area; and

3. to evaluate whether operation of Zion Station has affected these early life stages of fish.

II. Materials and Methods

A. Sampling Locations

Larval fish and eggs were collected from seven transects established in the Zion-Waukegan area of Lake Michigan beginning April 1972 through June 1978 (Figure 1). From July 1978 through September 1978, sampling was reduced to six transects. This consisted of discontinuing sampling at Transect W, which extended into the lake from Waukegan Station to the 40 foot depth contour. After 1 October 1972, sampling was extended at Transect W, to the 60 foot depth contour. In addition, four transects extending to the 50 foot depth contour were established near the Zion Station and were also later extended to the 60 foot depth. Two transects were located one mile from the Station (Z-5 to the north and Z-2 to the south) and two were located 1000 feet from the Station (Z-4 to the north and Z-3 to the south). After June 1978, sampling was discontinued at all 60 foot locations.

Two transects (Z-1 and Z-6) were established 1.9 miles from the Zion Station, one to the south and the other to the north, respectively, and reached the 30 foot depth contour. The entire sampling area around Zion Station formed a semi-circle having a two-mile radius centered at the Station. Approximate distances of sampling locations from points of intake and discharge are shown in Table 1.

Sampling methods included plankton net, bottom trawl, and benthic pump. Sampling frequency varied with method.

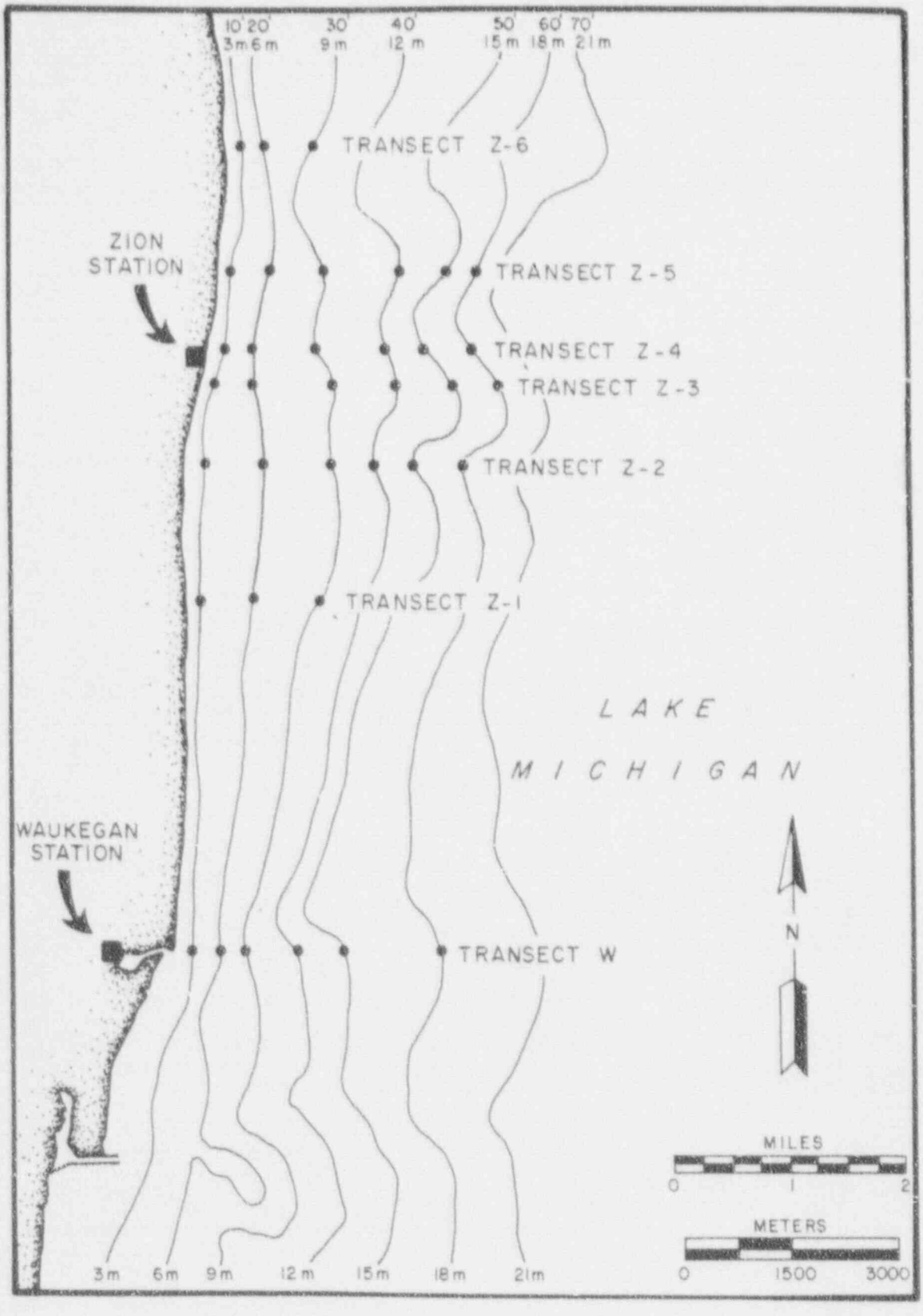


Figure 1. Fish egg and larvae sampling locations in southwestern Lake Michigan near Zion, Illinois, 1972 - 1978.

Table 1. Approximate distance of fish egg and larvae sampling locations from the Zion and Waukegan Station discharges and from a point between and equidistant from the Zion Station discharges.

		Zion Station				Waukegan Station			
		Distance from a point between and equidistant from Discharges		Distance from Intake		Distance from Discharge		Distance from Intake	
Transect	Depth Feet	Feet	Miles	Feet	Miles	Feet	Miles	Feet	Miles
Z-1	10	10000	1.9	10600	2.0	12700	2.4	13200	2.5
	20	10000	1.9	10600	2.0	13200	2.5	13700	2.6
	30	11100	2.1	10000	1.9	13700	2.6	14300	2.7
Z-2	10	5300	1.0	5800	1.1	17400	3.3	18000	3.4
	20	5300	1.0	5300	1.0	18000	3.4	18500	3.5
	30	6900	1.3	5800	1.1	18500	3.5	19000	3.6
	40	8400	1.6	6900	1.3	19500	3.7	20100	3.8
	50	9500	1.8	8400	1.6	20100	3.8	20600	3.9
	60	11100	2.1	11000	1.9	21100	4.0	21600	4.1
Z-3	10	1000	0.2	2600	0.5	21600	4.1	22200	4.2
	20	1600	0.3	1600	0.3	21600	4.1	22200	4.2
	30	4200	0.8	2100	0.4	21600	4.1	22200	4.2
	40	6300	1.2	5300	1.0	21600	4.1	22200	4.2
	50	9000	1.7	7900	1.5	22200	4.2	22700	4.3
	60	10000	1.9	10000	1.9	22700	4.3	23200	4.4
Z-4	10	1000	0.2	2600	0.5	23800	4.5	24300	4.6
	20	1600	0.3	1600	0.3	23800	4.5	24300	4.6
	30	4200	0.8	2100	0.4	23800	4.5	24300	4.6
	40	6300	1.2	5300	1.0	24300	4.6	248 3	4.7
	50	9000	1.7	7900	1.5	24800	4.7	25300	4.8
	60	10600	2.0	9000	1.7	25300	4.8	25900	4.9
Z-5	10	5300	1.0	5800	1.1	28000	5.3	28500	5.4
	20	5300	1.0	5300	1.0	28000	5.3	28500	5.4
	30	6900	1.3	5800	1.1	28000	5.3	28500	5.4
	40	8400	1.6	6900	1.3	28500	5.4	29000	5.5
	50	9500	1.8	8400	1.6	29600	5.6	30100	5.7
	60	11100	2.1	10000	1.9	29600	5.6	30100	5.7
Z-6	10	10000	1.9	10600	2.0	32700	6.2	33300	6.3
	20	10600	2.0	10000	1.9	32700	6.2	33300	6.3
	30	11100	2.1	10600	2.0	33300	6.3	33800	6.4
W	10	22700	4.3	23200	4.4	500	0.1	500	0.1
	20	22700	4.3	22700	4.3	1600	0.3	1600	0.3
	30	22700	4.3	22700	4.3	2600	0.5	2600	0.5
	40	23200	4.4	22700	4.3	4800	0.9	4800	0.9
	50	23200	4.4	22700	4.3	6300	1.2	6300	1 2
	60	24300	4.6	23800	4.5	10600	2.0	10600	2.0

B. Sampling Methods

1. Plankton Nets

Nitex plankton cone nets one-half meter in diameter with number zero mesh aperture, were used to collect larval fish and eggs. All plankton net tows were of three minute durations. Beginning in 1973, a flow meter was mounted in the center of the net to determine the volume of water sampled. From 1973 through 1978 the average sample volume was approximately 55m^3.

During 1972, all locations were sampled at night, twice monthly from April through December (Table 2). Sampling was conducted at the surface at the 10 foot depth and at the surface and mid-depth at successive depth contours. In addition, two vertical tows were made at each location. During 1973 and 1974, all locations were sampled four times a month with two sampling periods during the day and two at night. From 1974 through 1978, two nets were towed at the 10 foot depth, one at the surface and one just off the bottom. At the 20 to 60 foot depth contours, three nets were towed simultaneously at each location, one at the surface, one at mid-depth and one just off the bottom. From 1975 through 1977, all locations were sampled at night, twice monthly from March through October. During 1978, sampling was conducted at night, twice monthly from February through September.

2. Benthic Pump

A Homelite suction pump was used to collect larval fish and eggs on the lake bottom. The pump hose had an intake

Table 2. Field sampling programs used in larval fish and egg studies in the Zion-Waukegan sampling area, 1972 - 1978.

Year	Collection Method	Number of Locations	Number of Replicates	Sampling Depths (ft.)	Sampling Frequency	Sampling Period	Reference
1972	Plankton net	7	1	10 - Surface and vertical	2/month	April-December	Cochran 1975a
	Plankton net	24	1	20-50 - Surface, mid-depth and vertical	2/month	April-October	
	Plankton net	5	1	20-60 - Surface, mid-depth and vertical	2/month	October-December	
	Benthic pump	31	1	10-50 - Bottom	2/month	April-October	
	Benthic pump	5	1	10-60 - Bottom	2/month	October-December	
	Trawl	31	1	10-50 - Bottom	2/month	April-October	
	Trawl	5	1	10-60 - Bottom	2/month	October-December	
1973	Plankton net	7	1	10 - Surface	4/month	January-December	Cima and Cochran 1974a,b
	Plankton net	29	1	20-60 - Surface and mid-depth	4/month	January-December	Cochran and Cima 1974
	Benthic pump	36	1	10-60 - Bottom	2/month	January-December	
	Trawl	36	1	10-60 - Bottom	4/month	January-December	
1974	Plankton net	7	1	10 - Surface and bottom	4/month	March-October	Cima and Cochran 1974c,1975
	Plankton net	29	1	20-60 - Surface, mid-depth and bottom	4/month	March-October	Cochran and Cima 1974
	Benthic pump	36	1	10-60 - Bottom	2/month	March-October	
	Trawl	36	1	10-60 - Bottom	4/month	March-October	
1975	Plankton net	7	1	10 - Surface and bottom	2/month	March-October	Cima et al. 1976
	Plankton net	29	1	20-60 - Surface, mid-depth and bottom	2/month	March-October	
	Benthic pump	36	1	10-60 - Bottom	2/month	January-December	
	Trawl	36	1	10-60 - Bottom	2/month	March-October	
	Trawl	18	1	Mid-depth and surface (N-1, N-2 and N-4)	1/month	August-October	
1976	Plankton net	7	1	10 - Surface and bottom	2/month	March-October	Cima 1977
	Plankton net	29	1	20-60 - Surface, mid-depth and bottom	2/month	March-October	
	Benthic pump	36	1	10-60 - Bottom	2/month	January-December	
	Trawl	36	1	10-60 - Bottom	2/month	March-October	
1977	Plankton net	7	1	10 - Surface and bottom	2/month	March - October	Cima 1978
	Plankton net	29	1	20-60 - Surface, mid-depth and bottom	2/month	March-October	
	Benthic pump	36	1	10-60 - Bottom	2/month	January-December	
	Trawl	36	1	10-60 - Bottom	2/month	March-October	
1978	Plankton net	7	1	10 - Surface and bottom	2/month	February-June	LaJeone 1978
	Plankton net	29	1	20-60 - Surface, mid-depth and bottom	2/month	February-June	
	Plankton net	6	1	10 - Surface and bottom	2/month	July-September	
	Plankton net	20	1	20-50 - Surface, mid-depth and bottom	2/month	July-September	
	Benthic pump	36	1	10-60 - Bottom	2/month	February-June	
	Benthic pump	26	1	10-50 - Bottom	2/month	July-September	
	Trawl	36	1	10-60 - Bottom	2/month	February-June	
	Trawl	26	1	10-50 - Bottom	2/month	July-September	

diameter of three inches and a maximum pumping capacity of 385 GPM. Pumping was conducted at each location for three minutes, twice monthly. Each sample contained approximately 300 gallons.

The organisms and bottom material brought up by the pump were collected in a half-meter diameter plankton net fitted with a collecting bucket. Material collected in the plankton net was transferred to glass jars and perserved in formalin. All pump samples were analyzed in the laboratory.

3. Trawl

A semi-balloon bottom trawl with head and foot ropes of 16 and 19 feet, respectively, and a cod end liner of one-eighth inch mesh was used to collect juvenile (young-of-year) fish. All tows were made along the bottom and were of five minutes duration.

In 1972, all locations were sampled during the day, twice monthly from April through December, but in 1973 and 1974 all locations were sampled four times a month with two sampling periods during the day and two at night (Table 2). From 1975 through 1977, all locations were sampled during the day, twice monthly from March through October. In 1975, surface and mid-depth tows were also conducted during the day at three transects (W, Z-2 and Z-4), once monthly from August through October. In 1978, all locations were sampled during the day, twice monthly from February through September.

C. Data Collection and Analysis

All samples were examined for fish eggs and larvae under a magnifying lens equipped with a flourescent light. Eggs and larvae were counted, measured, and identified to the lowest positive taxon using a stereozoom dissecting scope equipped with an ocular micrometer. Identifications were made using morphological characteristics, size, and known spawning times of indigenous fishes. Larvae were specimens that did not morphologically resemble the adult nor had attained adult fin ray counts. Juveniles were specimens that had completed fins and morphologically resembled the adults. Scientific and common names of all fishes collected in the sampling area are according to Bailey (1970).

A General Oceanics Model 2030 digital flow meter was used to measure water flow through plankton nets. Whenever possible, plankton net catches were reduced to the number of larval fish per cubic meter of water sampled (No./m^3). In 1972, the density of larval fishes was not calculated since no flow meters were used to determine the volume of water sampled. Between 1973 and 1974, the mean densities of larval fish were presented in applicable annual reports only during those months when the larvae were abundant. From 1975 through 1978, however, mean density values were presented for each species during all months collections were made. Therefore, discussion of larval fish distribution within the sampling area is limited to those study years that provide continuity among sampling months.

III. Results and Discussion

A. General Catch Data

A total of 25 taxa of larval and juvenile (young-of-year) fish representing 19 species, 5 genera and 1 unidentifiable taxon, was collected by all sampling methods in the Zion-Waukegan sampling area from 1972 through 1978 (Table 3). In addition, 10 taxa of fish eggs representing 7 species, 2 genera and 1 unidentifiable taxon were also collected. Alewife and rainbow smelt eggs comprised the great majority of fish eggs collected, respectively.

With the exception of 1974, the two most abundant species of larval and juvenile fish collected were the alewife and rainbow smelt. However, in 1974, larval and juvenile slimy sculpin were the second most abundant species collected, with smelt ranking third in abundance. Catches of slimy sculpin, as well as other fish species inhabiting the sampling area, did not represent a consistently high percentage of the total catch and were therefore considered incidental to the larger catches of alewives and smelt.

Each sampling method was selective in the size and life stages of the fish collected. The benthic pump accounted for all 10 taxa of fish eggs, while only 4 taxa were collected by plankton nets (Table 4). Nineteen taxa of larval fish were collected by plankton nets, but only the alewife and rainbow smelt were common (Table 5). Twelve taxa of larval fish were collected by benthic pump. Twelve species of juvenile fish were collected by trawl, but only alewife and rainbow smelt were consistently abundant (Table 6).

Table 3. Species checklist and total number of eggs, larvae and juvenile (young-of-year) fish collected by plankton net, benthic pump and trawl in the Zion-Waukegan sampling area, 1972 - 1978.

		Number of Eggs, Larvae and Juvenile Fish/Year															
		1972				1973				1974				1975			
		Larvae-Juvenile		Eggs		Larvae-Juvenile		Eggs		Larvae-Juvenile		Eggs		Larvae-Juvenile		Eggs	
Scientific Name	Common Name	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Alosa pseudoharengus	Alewife	833	38.8	250146	99.9	6868	85.0	623976	99.9	9284	63.2	501525	99.1	13582	91.7	553679	98.7
Osmerus mordax	Rainbow smelt	1230	57.3	41	T[a]	947	11.7	81	T	1945	13.2	4428	0.9	958	6.5	7261	1.3
Cottus cognatus	Slimy sculpin	61	2.8	0	0.0	194	2.4	0	0.0	3162	21.5	13	T	35	0.2	9	0.0
Cyprinus carpio	Carp	0	0.0	0	0.0	7	0.1	3	T	9	0.1	1	T	155	1.0	22	T
Pungitius pungitius	Ninespine stickleback	1	T	0	0.0	1	T	0	0.0	185	1.3	0	0.0	23	0.2	0	0.0
Perca flavescens	Yellow perch	10	0.5	0	0.0	7	0.1	0	0.0	48	3.3	0	0.0	9	0.1	0	0.0
Myoxocephalus quadricornis	Fourhorn sculpin	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	8	0.1	0	0.0
Notropis sp.		4	0.2	0	0.0	15	0.2	0	0.0	0	0.0	0	0.0	3	T	0	0.0
Lota lota	Burbot	0	0.0	0	0.0	6	0.1	0	0.0	10	0.1	0	0.0	11	0.1	0	0.0
Catostomus commersoni	White sucker	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	11	T	4	T	22	T
Percopsis omiscomaycus	Trout-perch	2	0.1	0	0.0	0	0.0	1	T	10	0.1	3	T	3	T	0	0.0
Cottidae		0	0.0	0	0.0	20	0.2	3	T	0	0.0	0	0.0	0	0.0	0	0.0
Notropis hudsonius	Spottail shiner	0	0.0	0	0.0	8	0.1	0	0.0	4	T	0	0.0	5	T	0	0.0
Rhinichthys cataractae	Longnose dace	0	0.0	0	0.0	0	0.0	0	0.0	15	0.1	0	0.0	6	T	0	0.0
Culaea inconstans	Brook stickleback	0	0.0	0	0.0	0	0.0	0	0.0	8	0.1	0	0.0	0	0.0	0	0.0
Pimephales notatus	Bluntnose minnow	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	5	T	0	0.0
Dorosoma cepedianum	Gizzard shad	0	0.0	0	0.0	3	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Coregonus sp.		0	0.0	0	0.0	0	0.0	1	T	1	T	0	0.0	0	0.0	0	0.0
Lepomis macrochirus	Bluegill	2	0.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Lepomis cyanellus	Green sunfish	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Percina sp.		1	T	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1	T	0	0.0
Notropis atherinoides	Emerald shiner	0	0.0	0	0.0	0	0.0	0	0.0	3	T	0	0.0	0	0.0	0	0.0
Etheostoma sp.		0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Catostomus catostomus	Longnose sucker	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1	T	0	0.0	0	0.0
Unidentified		1	T	49	T	1	T	0	0.0	13	0.1	277	0.1	4	T	12	T
Total No. Species		7		2		9		4		12		7		13		4	
Total Number		2145		250236		8075		624065		14697		506259		14812		560996	

Table 3. (continued)

Scientific Name	Common Name	Number of Eggs, Larvae and Juvenile Fish/Year											
		1976				1977				1978			
		Larvae-Juvenile		Eggs		Larvae-Juvenile		Eggs		Larvae-Juvenile		Eggs	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Alosa pseudoharengus	Alewife	18145	65.0	432950	99.8	2772	49.9	129317	99.9	310	6.0	37951	96.0
Osmerus mordax	Rainbow smelt	9285	33.3	730	0.2	2450	44.2	70	0.1	4642	90.2	1474	3.7
Cottus cognatus	Slimy sculpin	181	0.6	24	T	78	1.4	6	T	27	0.5	101	0.3
Cyprinus carpio	Carp	125	0.4	10	T	29	0.5	0	0.0	4	0.1	0	0.0
Pungitius pungitius	Ninespine stickleback	58	0.2	3	0.0	106	1.9	0	0.0	7	0.1	0	0.0
Perca flavescens	Yellow perch	39	0.1	0	0.0	35	0.6	0	0.0	15	0.3	0	0.0
Myoxocephalus quadricornis	Fourhorn sculpin	6	T	0	0.0	53	1.0	0	0.0	124	2.4	0	0.0
Notropis sp.		31	0.1	0	0.0	0	0.0	0	0.0	1	T	0	0.0
Lota lota	Burbot	6	T	0	0.0	10	0.2	0	0.0	9	0.2	0	0.0
Catostomus commersoni	White sucker	4	T	0	0.0	3	0.1	0	0.0	1	T	0	0.0
Percopsis or Aconcrus	Trout-perch	6	T	0	0.0	0	0.0	0	0.0	3	0.1	0	0.0
Cottidae		0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Notropis hudsonius	Spottail shiner	5	T	0	0.0	1	T	0	0.0	0	0.0	0	0.0
Rhinichthys cataractae	Longnose dace	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Coregonus hoyi	Bloater	1	T	0	0.0	11	0.2	0	0.0	0	0.0	0	0.0
Pimephales notatus	Bluntnose minnow	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Dorosoma cepedianum	Gizzard shad	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Coregonus sp.		1	T	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Lepomis macrochirus	Bluegill	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Lepomis cyanellus	Green sunfish	0	0.0	0	0.0	0	0.0	0	0.0	1	T	0	0.0
Percopsis sp.		0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Notropis atherinoides	Emerald shiner	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Fimephales sp.		1	T	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Catostomus catostomus	Longnose sucker	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Unidentified		0	0.0	20	T	0	0.0	16	T	0	0.0	0	0.0
Total No. Species				4		11		3		11		3	
Total Number		27894		433734		5554		129403		5144		39526	

[a]Trace - less than 0.1%.

Table 4. Total number of fish larvae and eggs collected by benthic pump in the Zion-Waukegan sampling area, 1972 - 1978.

Species	Number of Fish Larvae and Eggs/Year															
	1972				1973				1974				1975			
	Larvae		Eggs		Larvae		Eggs		Larvae		Eggs		Larvae		Eggs	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Alewife	99	95.2	249780	99.9	159	72.6	620274	99.9	152	48.7	477900	99.0	85	75.9	508348	98.6
Rainbow smelt	0	0.0	7	T[a]	0	0.0	79	T	1	0.3	4350	0.9	7	6.3	7218	1.4
Slimy sculpin	0	0.0	0	0.0	46	21.0	0	0	110	35.3	13	T	12	10.7	0	0.0
Carp	0	0.0	0	0.0	0	0.0	3	T	3	1.0	1	T	2	1.8	15	T
Ninespine stickleback	0	0.0	0	0.0	1	0.5	0	0.0	45	14.4	0	0.0	4	3.6	0	0.0
Fourhorn sculpin	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Notropis sp.	4	3.8	0	0.0	2	0.9	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
White sucker	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	11	T	2	1.8	22	T
Trout-perch	0	0.0	0	0.0	0	0.0	1	T	0	0.0	3	T	0	0.0	0	0.0
Cottidae	0	0.0	0	0.0	10	4.6	3	T	0	0.0	0	0.0	0	0.0	0	0.0
Spottail shiner	0	0.0	0	0.0	1	0.5	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Coregonus sp.	0	0.0	0	0.0	0	0.0	1	T	0	0.0	0	0.0	0	0.0	0	0.0
Longnose sucker	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1	T	0	0.0	0	0.0
Unidentified	1	1.0	49	T	0	0.0	0	0.0	1	0.3	277	0.1	0	0.0	12	T
Total No. Species	3		3		6		6		8		9		6		5	
Total Number	104		249836		219		620361		312		482556		112		516120	

HAZLETON ENVIRONMENTAL SCIENCES

Table 4. (continued)

Species	Number of Fish Larvae and Eggs/Year											
	1976				1977				1978			
	Larvae		Eggs		Larvae		Eggs		Larvae		Eggs	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Alewife	3786	96.2	423859	99.8	1	1.3	129630	99.9	0	0.0	37547	96.0
Rainbow smelt	0	0.0	725	0.2	0	0.0	69	0.1	0	0.0	1454	3.7
Slimy sculpin	87	2.2	24	T	33	43.4	6	T	16	76.2	107	0.3
Carp	3	0.1	8	T	1	1.3	0	0.0	2	9.5	0	0.0
Ninespine stickleback	29	0.7	0	0.0	41	53.9	0	0.0	2	9.5	0	0.0
Fourhorn sculpin	0	0.0	0	0.0	0	0.0	0	0.0	1	4.8	0	0.0
Notropis sp.	28	0.7	6	0.0	0	0.0	0	0.0	0	0.0	0	0.0
White sucker	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Trout-perch	1	T	0	0.0	0		0	0.0	0	0.0	0	0.0
Cottidae	0	0.0	0	0.0	0		0	0.0	0	0.0	0	0.0
Spottail shiner	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Coregonus sp.	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Longnose sucker	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Unidentified	0	0.0	18	T	0	0.0	7	T	0	0.0	0	0.0
Total No. Species	7		6		4		3		4		3	
Total Number	3934		424634		76		129712		21		39102	

[a]Trace - less than 0.1%.

HAZLETON ENVIRONMENTAL SCIENCES

Table 5. Total number of fish larvae and eggs collected by plankton nets in the Zion-Waukegan sampling area, 1972 - 1978..

Species	Number of Fish Larvae and Eggs/Year													
	1972				1973				1974				1975			
	Larvae		Eggs		Larvae		Eggs		Larvae		Eggs		Larvae		Eggs	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Alewife	656	93.0	366	91.5	4132	98.3	3702	99.9	4250	79.8	21625	99.6	13149	95.3	45331	99.9
Rainbow smelt	43	6.1	34	8.5	23	0.5	2	0.1	948	17.8	78	0.4	415	3.0	43	0.1
Slimy sculpin	0	0.0	0	0.0	0	0.0	0	0.0	54	1.0	0	0.0	13	0.1	0	0.0
Carp	0	0.0	0	0.0	3	0.2	0	0.0	6	0.1	0	0.0	153	1.1	1	T*
Ninespine stickleback	0	0.0	0	0.0	0	0.0	0	0.0	12	0.2	0	0.0	19	0.1	0	0.0
Yellow perch	5	0.7	0	0.0	3	0.1	0	0.0	35	0.7	0	0.0	8	0.1	0	0.0
Fourhorn sculpin	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	3	T	0	0.0
Notropis sp.	0	0.0	0	0.0	13	0.3	0	0.0	0	0.0	0	0.0	11	0.1	0	0.0
Burbot	0	0.0	0	0.0	6	0.1	0	0.0	10	0.2	0	0.0	2	T	0	0.0
White sucker	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	2	T	0	0.0
Trout-perch	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Cottidae	0	0.0	0	0.0	10	0.2	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Spottail shiner	0	0.0	0	0.0	6	0.1	0	0.0	0	0.0	0	0.0	5	T	0	0.0
Bluntnose minnow	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Gizzard shad	0	0.0	0	0.0	3	0.1	0	0.0	1	T	0	0.0	0	0.0	0	0.0
Coregonus sp.	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1	T	0	0.0
Pomoxis sp.	1	0.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Pimephales sp.	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	4	T	0	0.0
Unidentified	0	0.0	0	0.0	1	T	0	0.0	12	0.2	0	0.0				
Total No. Species	3		2		7		2		7		2		11		3	
Total Number	705		400		4204		3704		5328		21703		13793		45381	

HAZLETON ENVIRONMENTAL SCIENCES

Table 5. (continued)

Species	Number of Fish Larvae and Eggs/Year											
	1976				1977				1978			
	Larvae		Eggs		Larvae		Eggs		Larvae		Eggs	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Alewife	6353	92.0	9091	99.9	1417	45.4	687	99.4	285	38.9	404	95.3
Rainbow smelt	315	4.6	5	0.1	1505	48.2	1	0.1	293	40.0	20	4.7
Slimy sculpin	41	0.6	0	0.0	26	0.8	0	0.0	4	0.5	0	0.0
Carp	122	1.8	2	T	28	0.9	0	0.0	2	0.3	0	0.0
Ninespine stickleback	19	0.3	0	0.0	60	1.9	0	0.0	5	0.7	0	0.0
Yellow perch	33	0.5	0	0.0	21	0.7	0	0.0	6	0.8	0	0.0
Fourhorn sculpin	6	0.1	0	0.0	53	1.7	0	0.0	123	16.8	0	0.0
Notropis sp.	3	T	0	0.0	0	0.0	0	0.0	1	0.1	0	0.0
Burbot	6	0.1	0	0.0	10	0.3	0	0.0	9	1.2	0	0.0
White sucker	4	0.1	0	0.0	3	0.1	0	0.0	1	0.1	0	0.0
Trout-perch	3	T	0	0.0	0	0.0	0	0.0	3	0.4	0	0.0
Cottidae	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Spottail shiner	1	T	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Bluntnose minnow	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Gizzard shad	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Coregonus sp.	1	T	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Percopsis sp.	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Fimephales sp.	1	T	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Unidentified	0	0.0	2	T	0	0.0	3	0.0	0	0.0	0	0.0
Total No. Species	11		3		9		2		20		2	
Total Number	6908		9100		3123		691		732		424	

[a]Trace - less than 0.1%.

HAZL[illegible] ENCES

Table 6. Total number of juvenile (young-of-year) fish collected by trawl in the Zion-Waukegan sampling area, 1972 - 1978.

Species	Number of Juvenile Fish/Year													
	1972		1973		1974		1975		1976		1977		1978	
	Juveniles		Juveniles		Juveniles		Juveniles		Juveniles		Juveniles		Juveniles	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Alewife	78	5.8	2577	70.6	4882	53.9	348	38.4	8006	46.9	1354	57.4	25	0.6
Rainbow smelt	1187	88.8	919	25.2	996	11.0	536	59.1	8970	52.6	953	40.4	4349	99.0
Slimy sculpin	61	4.6	151	4.1	2998	33.1	10	1.1	53	0.3	19	0.8	7	0.2
Ninespine stickleback	1	0.1	0	0.0	128	1.4	0	0.0	10	0.1	5	0.2	0	0.0
Yellow perch	5	0.4	4	0.1	13	0.1	1	0.1	6	T[a]	14	0.6	9	0.2
Trout-perch	2	0.1	0	0.0	10	0.1	1	0.1	2	T	0	0.0	0	0.0
Spottail shiner	0	0.0	1	T	4	T	5	0.6	4	T	1	T	0	0.0
Longnose dace	0	0.0	0	0.0	15	0.2	6	0.7	0	0.0	0	0.0	0	0.0
Bloater	0	0.0	0	0.0	8	0.1	0	0.0	1	T	11	0.5	0	0.0
Bluegill	2	0.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Green sunfish	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1	T
Emerald shiner	0	0.0	0	0.0	3	T	0	0.0	0	0.0	0	0.0	0	0.0
Total Number Species	7		5		10		7		8		7		5	
Total Number	1336		3652		9057		907		17052		2357		4391	

[a]Trace - less than 0.1%.

HAZLETON ENVIRONMENTAL SCIENCES

Discussion of distribution in the sampling area is limited to the rainbow smelt and alewife since individuals of the remaining 22 taxa were not collected in consistently high enough numbers to warrant their discussion.

The effect of Zion Station's operation on the seasonal abundance and distribution of larval fish and eggs is limited in terms of the Station's thermal plume influencing sampling locations. Results from thermal plume studies were related to larval fish and egg sampling locations (Chapter 4-this report) and based on this analysis, surface plumes can potentially affect the inshore 10 to 30 foot depth contours along Transects Z-3 and Z-4. However, the area influenced by the thermal plume is inconsistent, changing with climatic and hydrologic conditions. The same locations, however, are not always affected. Consequently, no consistent pattern of thermal influence among transects was apparent during these studies.

B. Rainbow Smelt

1. Eggs

The annual inshore spawning migration of rainbow smelt in the Zion-Waukegan sampling area, as detected by trawling, has been previously mentioned by Cochran (1974 a and b). Catches of adults were low in January, but increased progressively through May. Initiation of spawning was usually detected in early-April by the presence of eggs collected in benthic pump samples and in plankton net collections. The number of smelt eggs generally increased during each successive sampling period with peak collections

occurring in May. Following the April-May spawning period, smelt eggs were seldom collected, except in June 1978 when 200 eggs were collected primarily at the 40 to 60 foot depth contours (LaJeone 1978).

Depth distribution of smelt eggs, as evidenced by benthic pump collections, revealed no appreciable difference from those collected in April and those collected in May, with the exception of May 1978 (Figure 2). In May 1978, the greatest concentration of smelt eggs occurred at the 30 to 60 foot depth contours; however, prior to 1978, collections were greatest at the 10 to 30 foot depth contours.

Distribution of smelt eggs among transects was, with the exception of April 1977, greatest along Transects Z-2, Z-3, Z-4 and W (Figure 3). In April 1977, smelt eggs were concentrated along Transects Z-5 and Z-6.

Overall, the greatest concentration of smelt eggs occurred at the 10 to 30 foot depth contours along Transects Z-2, Z-3, Z-4 and W, suggesting greater spawning activity in the immediate vicinity of the Zion and Waukegan Generating Stations. Inshore populations of spawning adults may be attracted to thermal plume areas (LaJeone 1978).

Smelt eggs were also collected by plankton nets; however, the nature of the demersal smelt egg, having an adhesive stalk-like membrane, limited the number of eggs present in the water column and subsequently in plankton net samples.

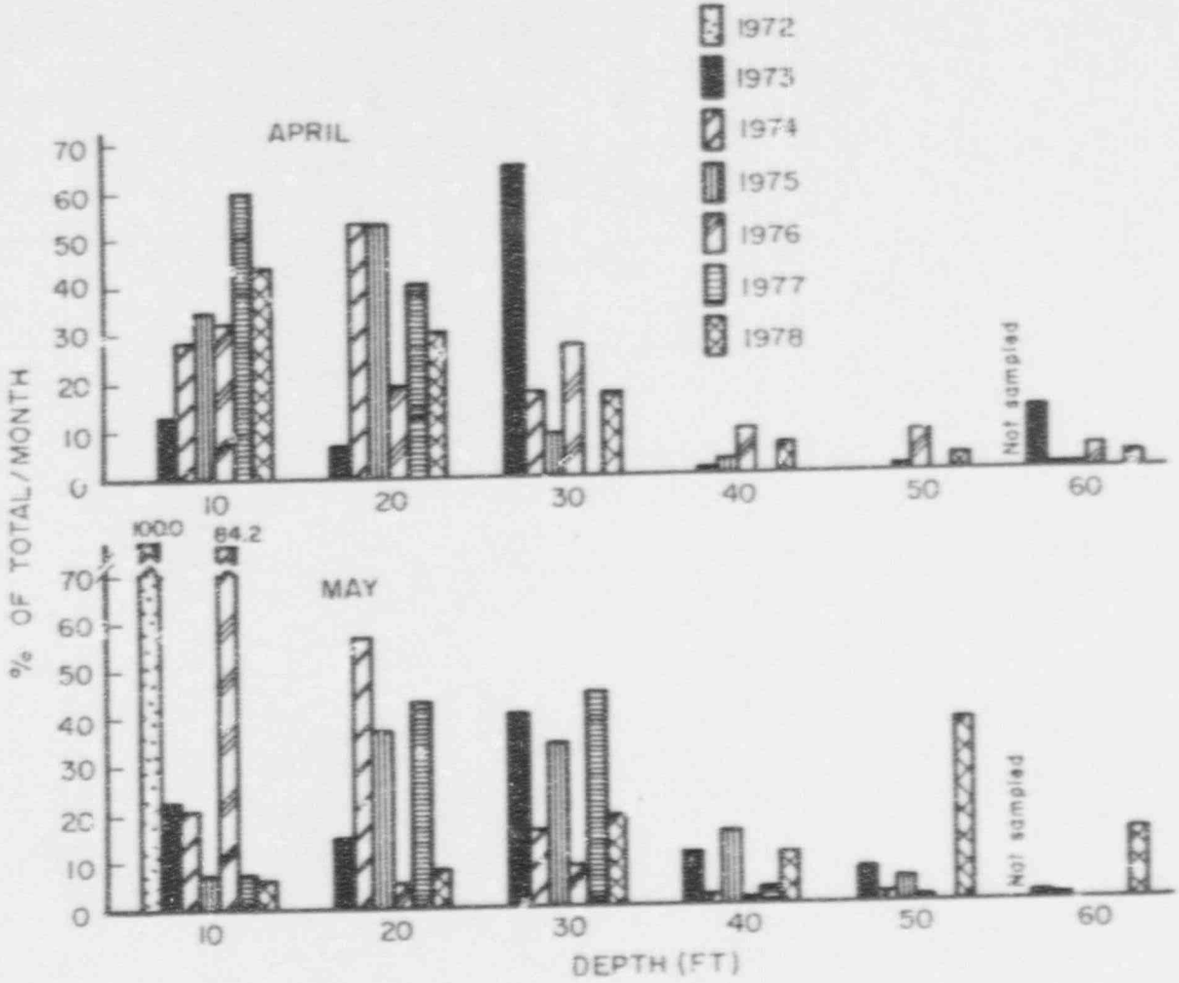


Figure 2. Distribution by depth of rainbow smelt eggs collected by benthic pump in the Zion-Waukegan sampling area, April-May, 1972 - 1978.

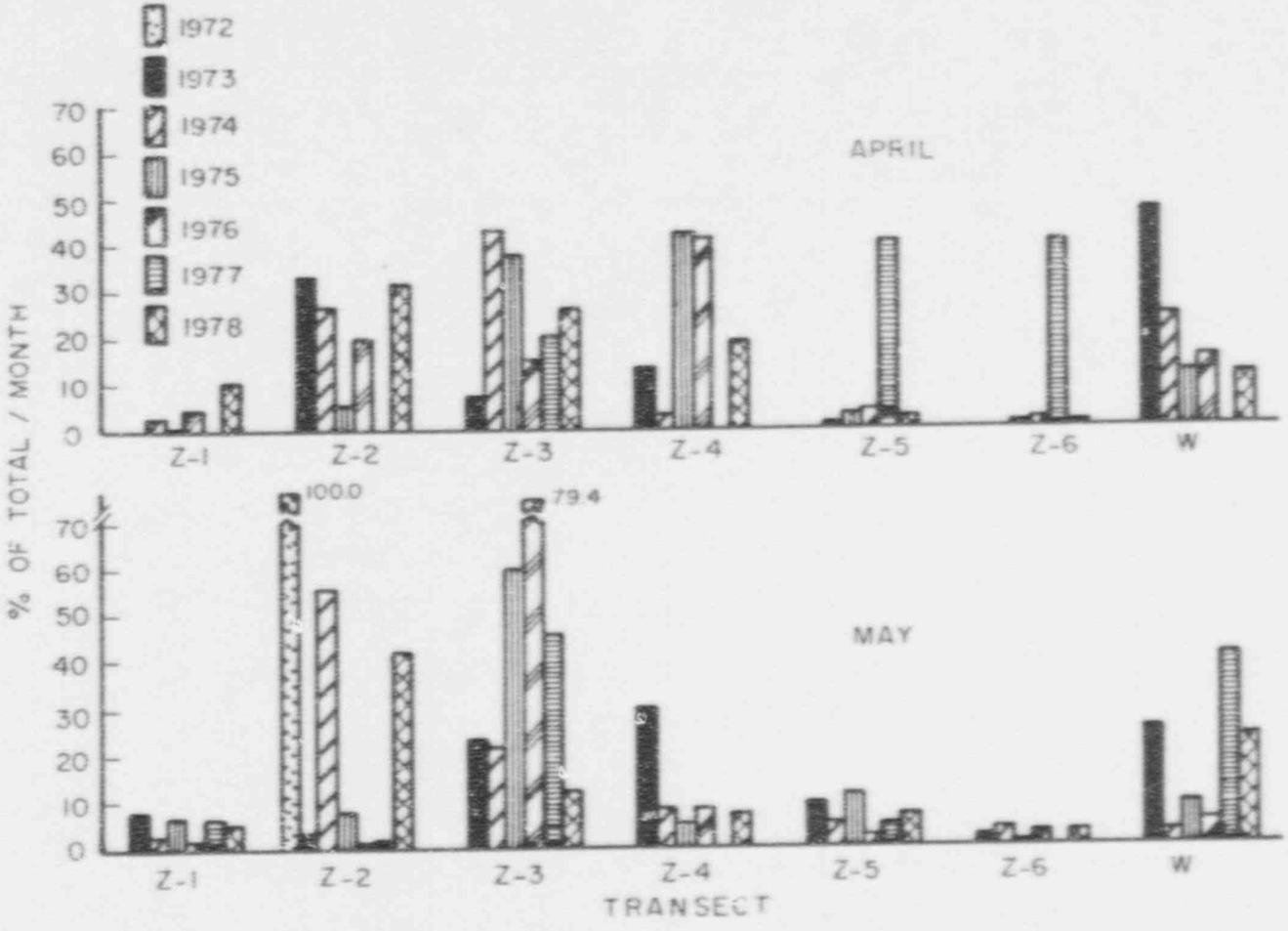


Figure 3. Distribution by transect of rainbow smelt eggs collected by benthic pump in the Zion-Waukegan sampling area, April - May, 1972 - 1978.

2. Larvae

Although rainbow smelt larvae were collected by plankton nets in all study years, discussion of their distribution in the sampling area is limited to those study years which provide density data. From 1975 through 1978, mean densities of larval smelt were highest from April through July. During 1975, 1976, and 1978, the highest mean densities of larval smelt occurred at the 10 to 30 foot depth contours, but in 1977, mean larval densities were highest at the 30 to 60 foot depth contours (Figure 4). No consistent pattern of distribution among transects was discernible. During 1975 and 1976, mean larval densities were highest along Transects Z-6 and Z-1, respectively; however, in 1977, mean larval densities increased progressively from Transects Z-1 through Z-5. In 1978, mean larval densities were extremely low and more uniformly distributed among transects.

3. Juveniles

Smelt utilize the sampling area as a nursery as late as October (Cima 1977). Juvenile smelt were most abundant in bottom trawl collections from August through October. With the exception of 1972 and 1976, juveniles were most abundant at the 10 to 30 foot depth contours, with average catches per trawl tow decreasing with increasing depth (Figure 5). In 1972, average catches of juvenile smelt were greatest at the 10 to 40 foot depth contours, while in 1976, average catches were greatest at 30 and 40 foot depths.

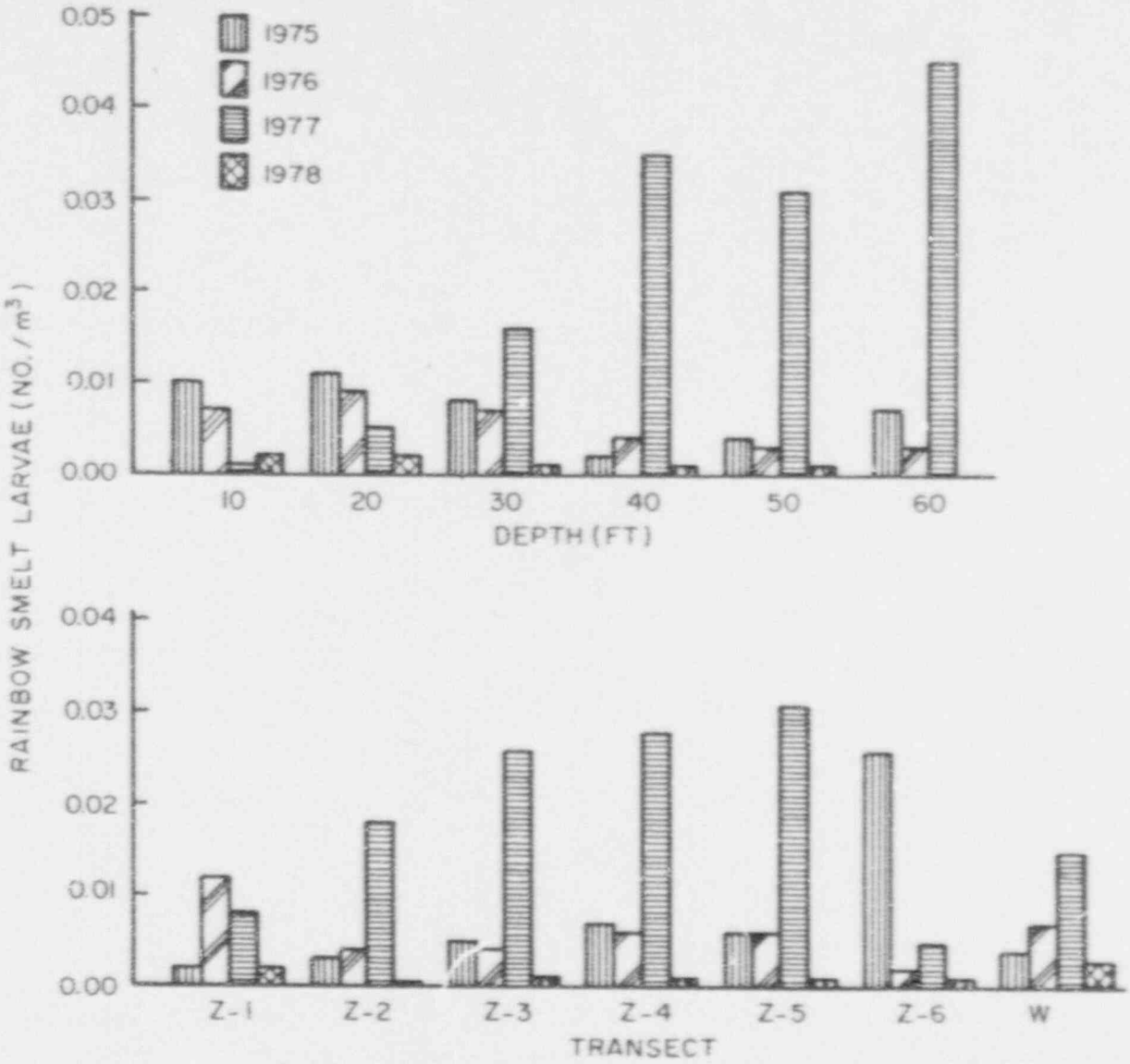


Figure 4. Mean density (No./m^3) of rainbow smelt larvae, by depth and transect, collected by plankton nets in the Zion-Waukegan sampling area, April - July, 1975 - 1978.

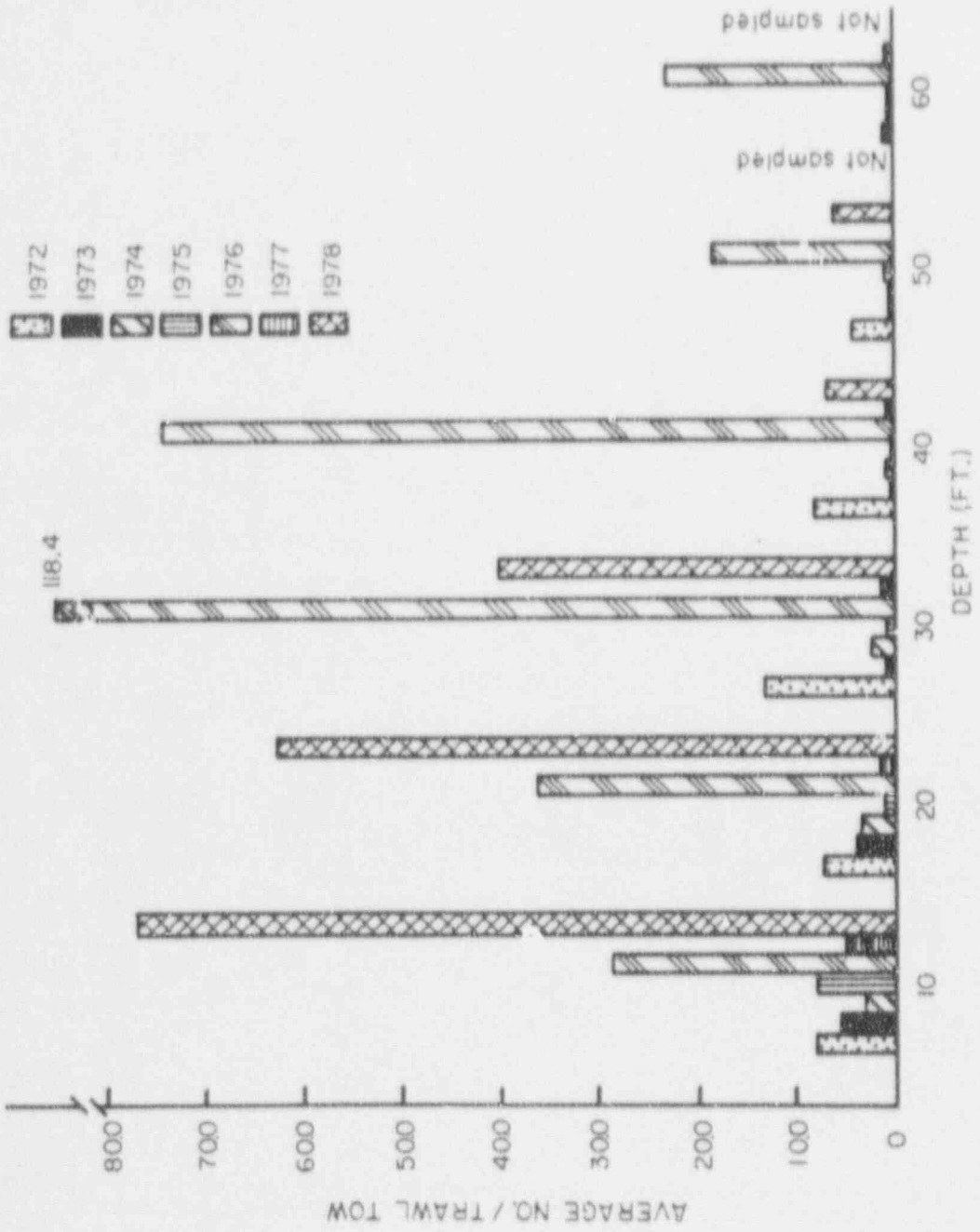


Figure 5. Distribution by depth of juvenile (young-of-year) rainbow smelt collected by trawl in the Zion-Waukegan sampling area, August - October, 1972 - 1978.

In contrast, no consistent pattern of distribution among transects was discernible (Figure 6). During 1976 and 1978, juvenile smelt were collected in the greatest number. Average catches per trawl tow were substantially higher among all transects sampled than in other study years. Average catches in 1972; however, were notably higher than in 1973, 1974, 1975 and 1977 study years. The greatest average catches of juvenile smelt in 1972, 1973, 1974 and 1976 occurred outside the immediate vicinity of the Zion Station's discharge while average catches in 1975, 1977 and 1978, were greatest along Transects Z-3 and Z-4, closest to Zion's discharges.

C. Alewife

1. Eggs

The annual inshore-offshore spawning migrations of the adult alewife in southern Lake Michigan has been described by Wells (1968). Shoreward movement of adults from deeper offshore areas begins in March and increases progressively, with maximum inshore concentrations occurring from June through August, then they disperse from inshore areas and return to deeper waters. In the Zion area, peak trawl catches usually occurred in May (Chapter 11-this report). Spawning activity in the sampling area was detected by the presence of eggs collected in benthic pump samples. The number of eggs collected was directly related to these inshore concentrations of spawning adults.

In all study years, alewife eggs were collected in the greatest numbers from June through August at the 10 to 30 foot

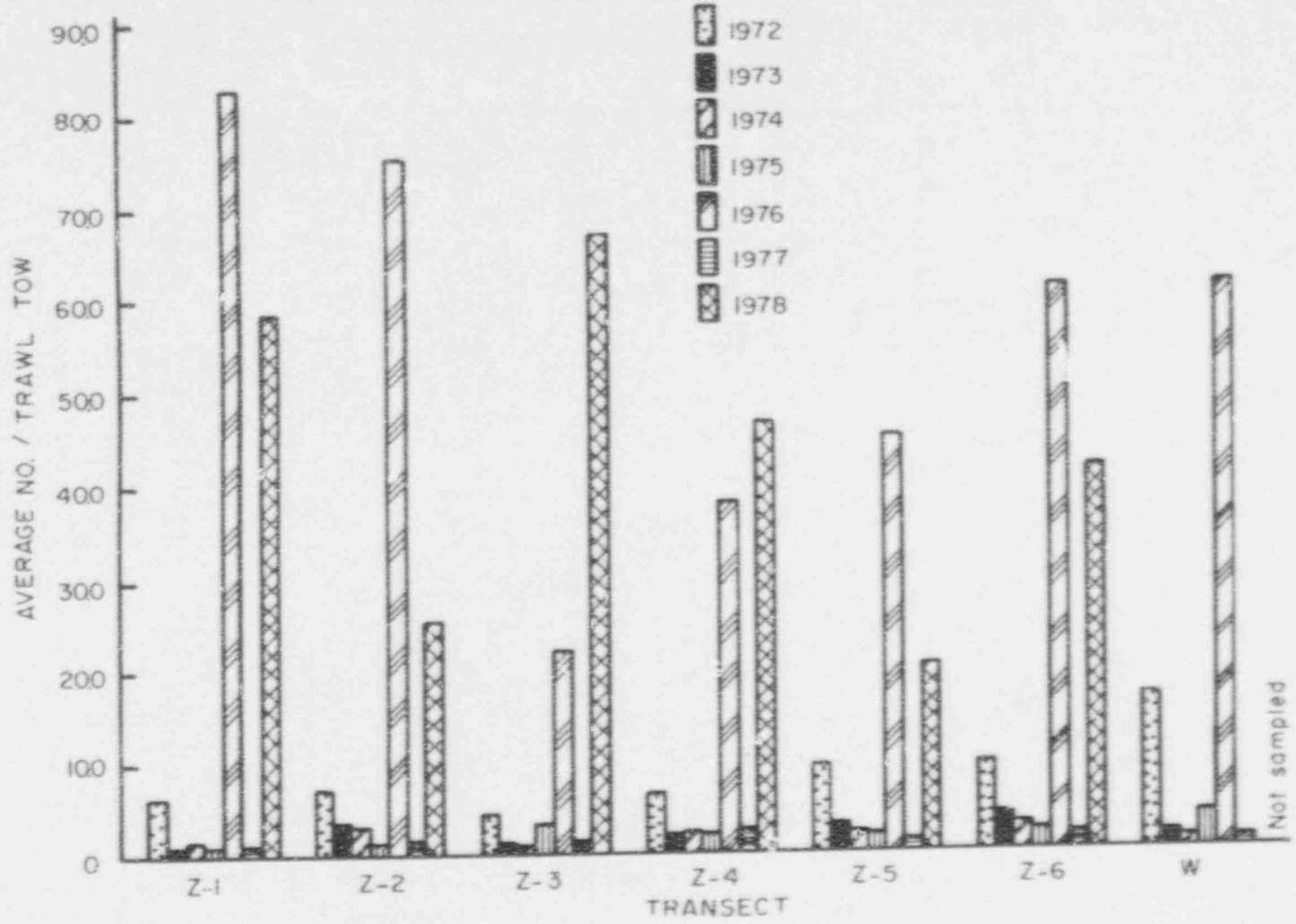


Figure 6. Distribution by transect of juvenile (young-of-year) rainbow smelt collected by trawl in the Zion-Waukegan sampling area, August - October, 1972 - 1978.

depth contours (Figure 7). During the June and July sampling periods, alewife eggs were also collected at offshore 40 to 60 foot depth contours in appreciable amounts. In contrast, no consistent pattern of alewife egg distribution among transects was discernible (Figure 8). Distribution of alewife eggs among transects was inconsistent from June through August, with some months having greater proportions occurring in the immediate vicinity of the Zion Station (Z-3 and Z-4), while in other months outside the area (Z-1 and W).

2. Larvae

Alewife larvae were most abundant in plankton net collections from July through September with the peak density usually occurring in early-July and a lesser peak occurring in August. Larval densities were greatest after peak spawning as indicated by egg collections.

From 1975 through 1978, differences in distribution of larval alewives by depth and transect were apparent in the sampling area. During 1975 and 1976, the highest mean densities of larval alewives occurred at the 10 and 20 foot depth contours along Transects Z-1 and Z-6 (Figure 9). Catches of larval alewives decreased with increasing distance from shore, but increased slightly at the 60 foot depth contour. In addition, mean densities of larval alewives in the vicinity of the Zion Station were uniformly distributed among Transects Z-2 through Z-5. During 1977 and 1978, mean larval densities were low at all depths and transects sampled. In 1977, the highest mean larval densities occurred at

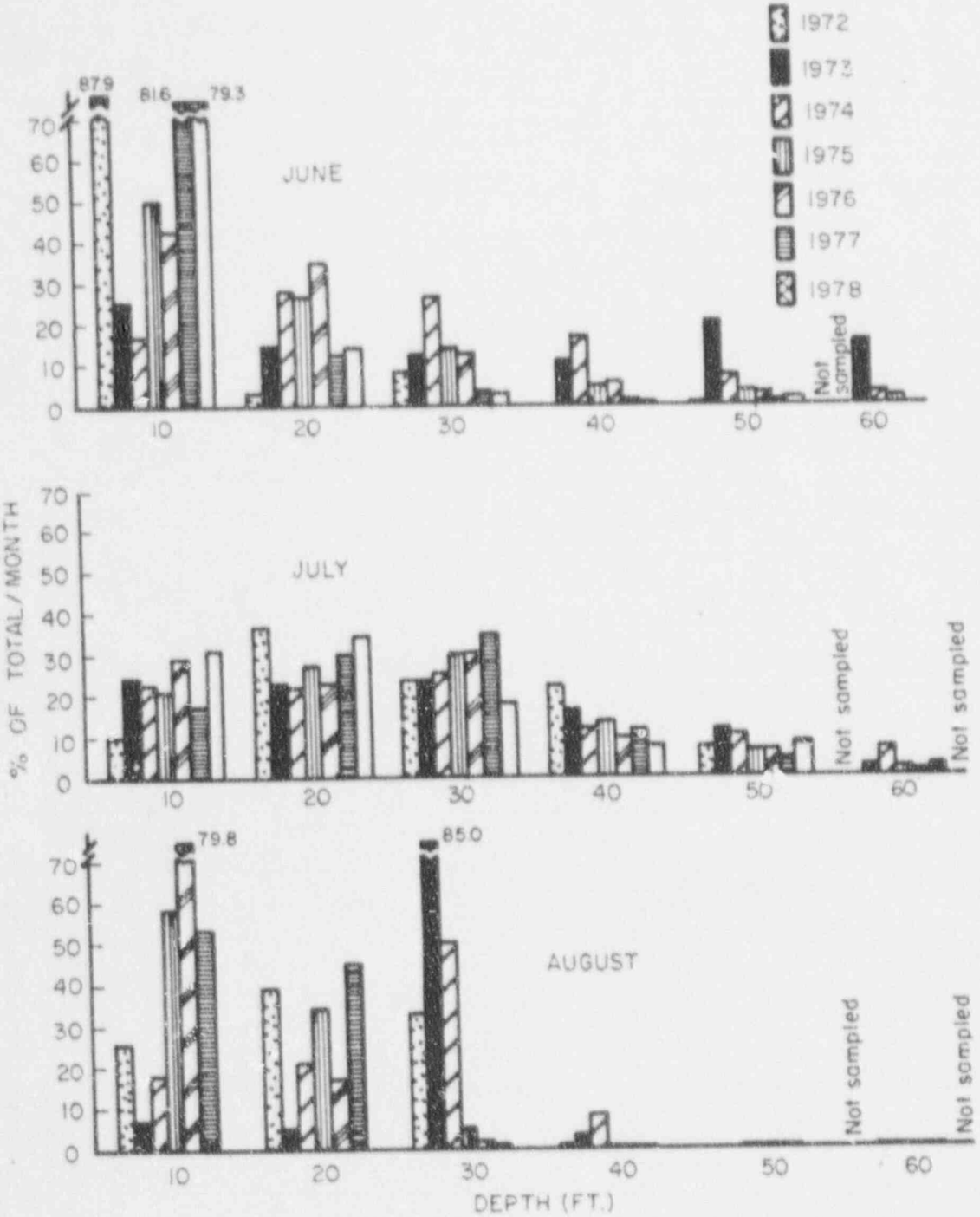


Figure 7. Distribution by depth of alewife eggs collected by benthic pump in the Zion-Waukegan sampling area, June - August, 1972 - 1978.

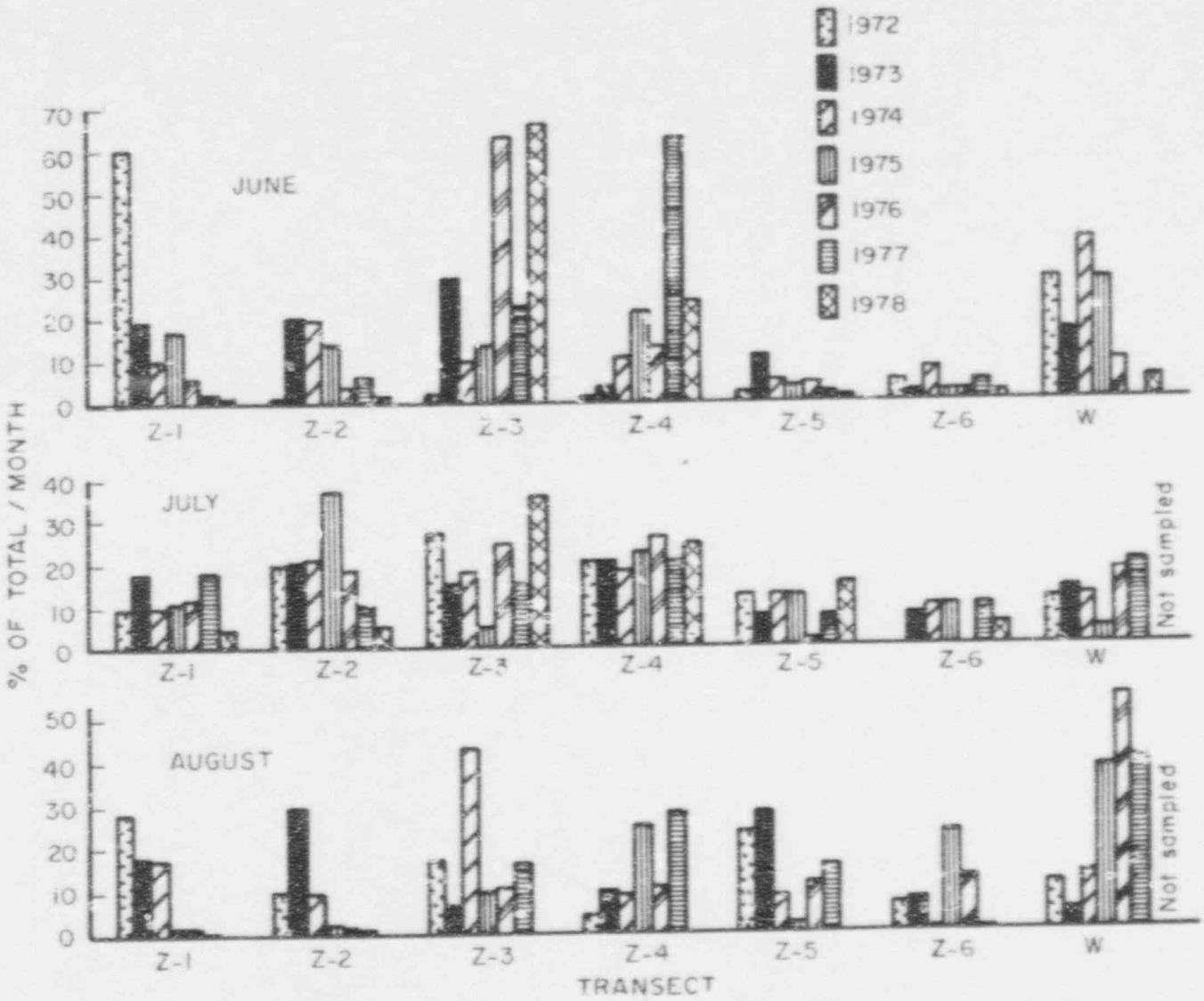


Figure 8. Distribution by transect of alewife eggs collected by benthic pump in the Zion-Waukegan sampling area, June - August, 1972 - 1978.

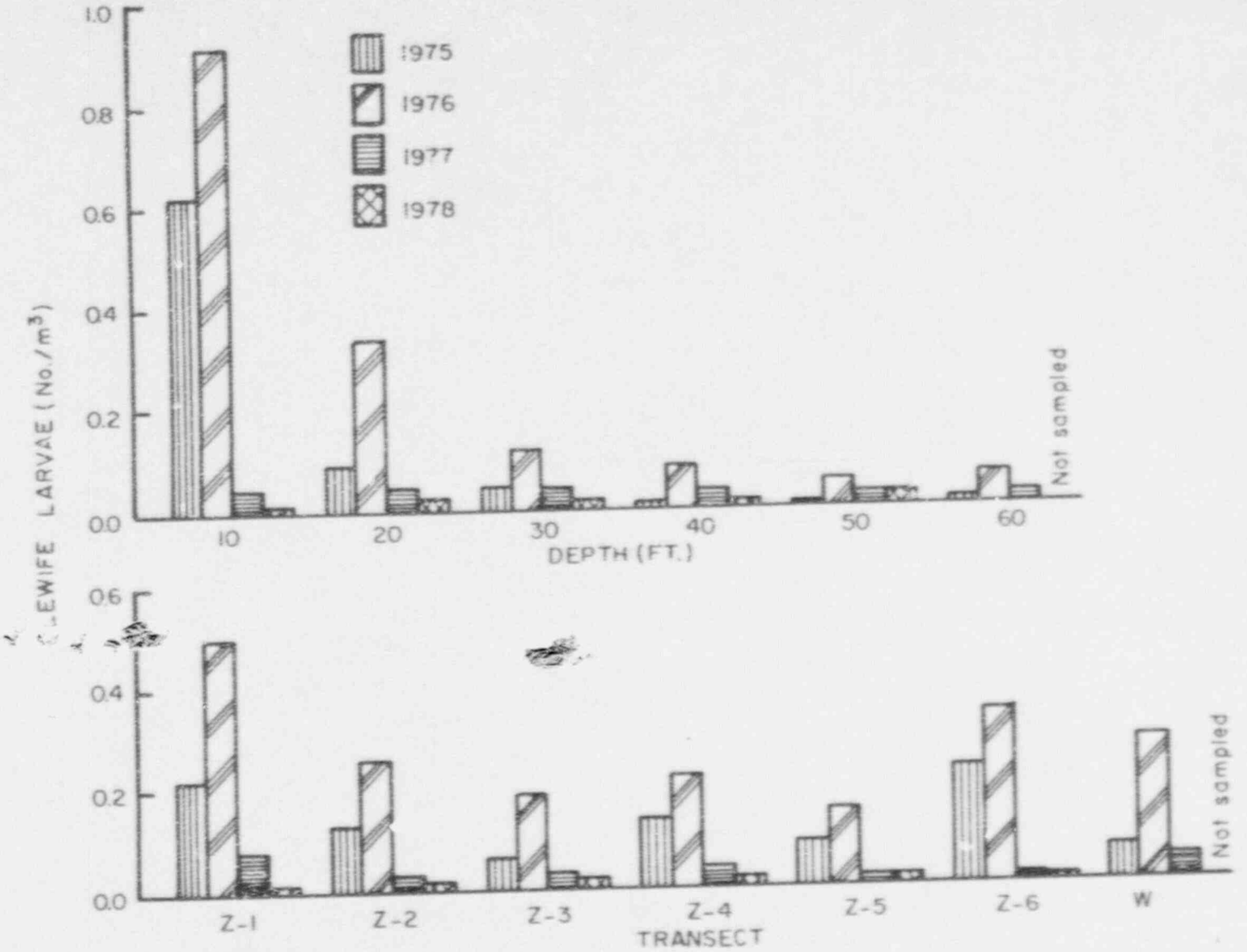


Figure 9. Mean density (No./m^3) of alewife larvae, by depth and transect, collected by plankton nets in the Zion-Waukegan sampling area, July-September, 1975 - 1978.

the 10 to 30 foot depth contours along Transect Z-1. Mean densities among other transects did not differ appreciably from Transect Z-1. In 1978, the highest mean larval densities occurred at 20 and 50 foot depth contours and were uniformly distributed among transects sampled.

3. Juveniles

Juvenile alewives were most abundant in bottom trawl collections from August through October with the greatest numbers occurring in 1976. Average catches per trawl tow were substantially higher at all depths in 1976, than in other study years (Figure 10). The greatest average catches occurred at the 10 and 20 foot depth contours. Average catches in the other study years were also greatest at the 10 and 20 foot depth contours. In contrast, no distributional patterns of juvenile alewives among transects was apparent during these studies (Figure 11).

The greatest concentrations of early life stages of rainbow smelt and alewife generally occurred in inshore areas near Zion Station. The extent with which these life stages were affected by Zion Station operation was difficult to measure due to the affect of climatic and hydrologic conditions on the thermal plume. These conditions affected the plume in such a way that the plume's influence on any one station was extremely variable. Seasonal occurrence of the various early life stages for each species have not changed measurably throughout these monitoring studies. This indicates that spawning and developmental periods have not measurably changed since Zion Station began operation.

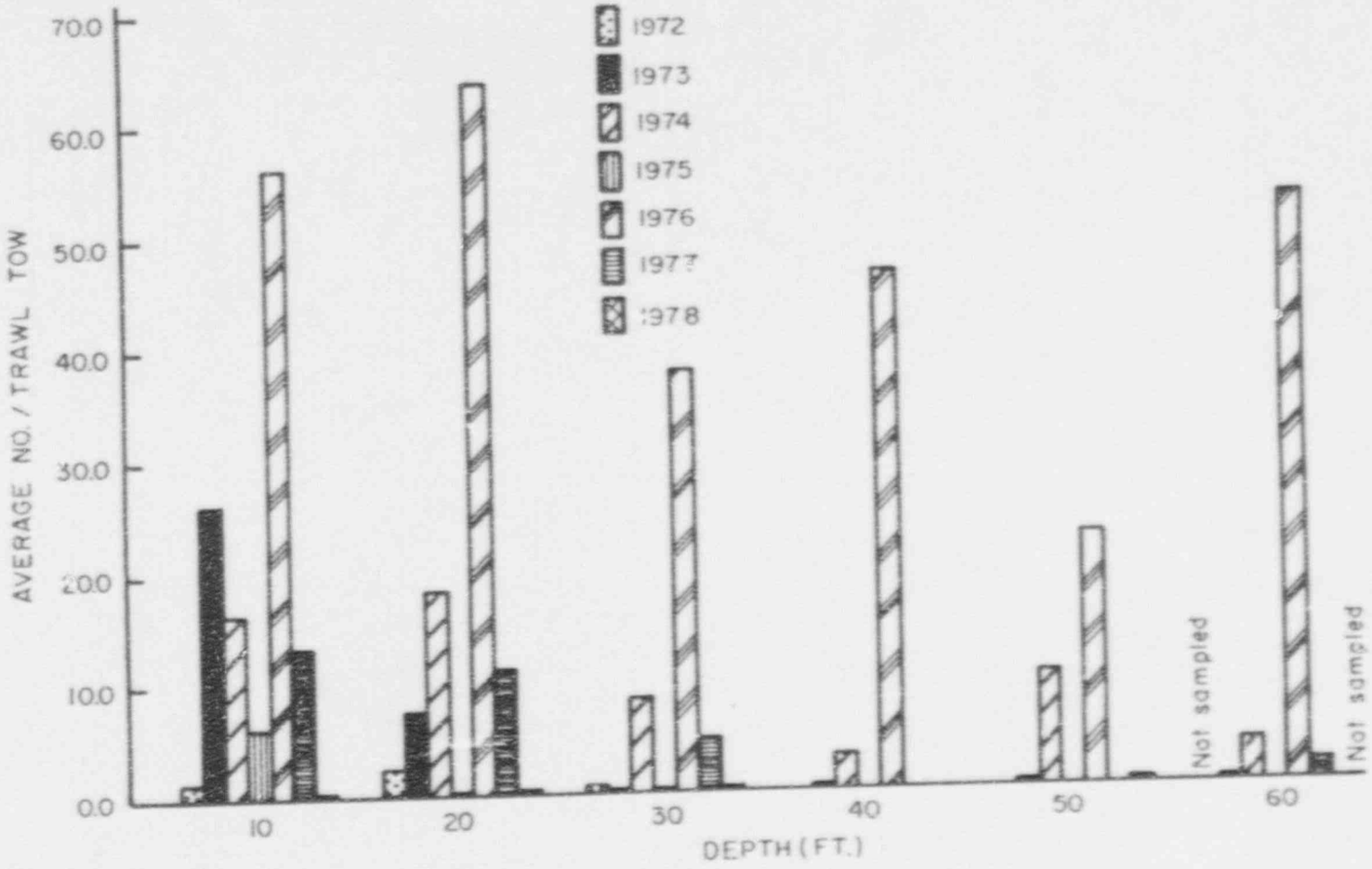


Figure 10. Distribution by depth of juvenile (young-of-year) alewives collected by trawl in the Zion-Waukegan sampling area, August - October, 1972 - 1978.

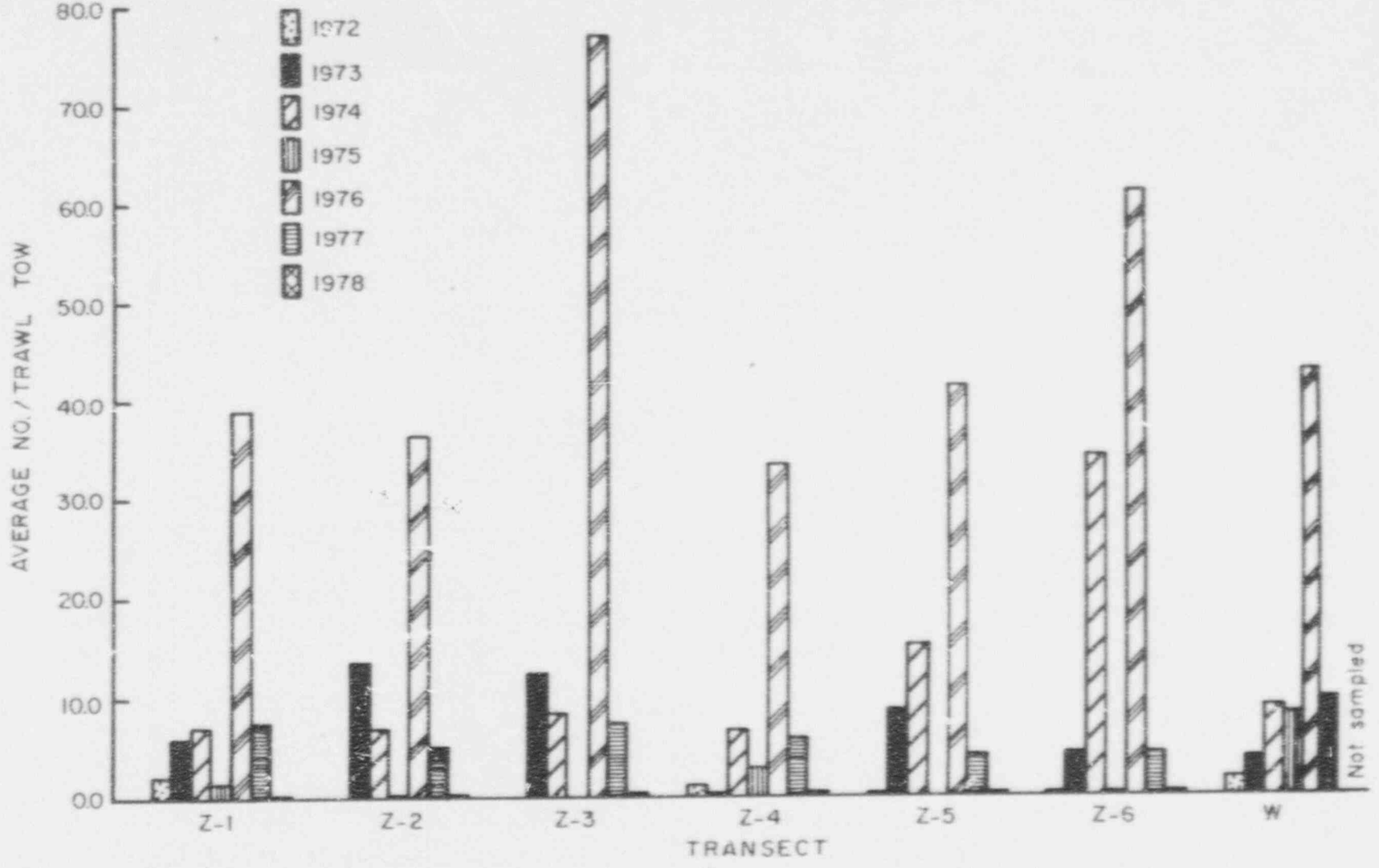


Figure 11. Distribution by transect of juvenile (young-of-year) alewives collected by trawl in the Zion-Waukegan sampling area, August - October, 1972 - 1978.

Considerable fluctuations in the abundance of various early life stages of several species have occurred from one year to the next; however, these variations appear to be related to annual differences in the abundance of spawning adults and spawning activity in the study area rather than to operation of Zion Station.

The only detectable trends in the distribution of fish eggs or larvae observed from these monitoring studies that may be related to operation of Zion Station were greater deposition of smelt eggs and occasionally greater numbers of alewife eggs along transects commonly influenced by the Station's thermal discharge. These increased concentrations of eggs may, in part, be due to attraction of adult smelt and alewife to the plume during their spawning seasons. However, other factors, such as currents or purging of eggs by ripe females impinged on the Station's intake screens, may also account for these increased concentrations.

IV. Literature Cited

Bailey, R.M. (Chairman), 1970. A List of common and scientific names of fishes from the United States and Canada. 3rd ed. Amer. Fish. Soc. Publ, 6. 150 pp.

Cima, G. and M. Cochran. 1973. Fish egg and larvae study in Lake Michigan near Zion and Waukegan Generating Stations January 1973 through June 1973. Report to Commonwealth Edison Company, Chicago, Illinois (Manuscript).

_____. 1974a. Fish egg and larvae study. IN Environmental monitoring in Lake Michigan near Zion and Waukegan Generating Stations, January 1973 through July 1973. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. 44 pp.

_____. 1974b. Fish egg and larvae study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through December 1973. Semi-Annual report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. III:123-170.

_____. 1974c. Fish egg and larvae study. IN Operational environmental monitoring in Lake Michigan near Zion Station, January 1974 through June 1974. Semi-Annual report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. III:107-218.

_____. 1975a. Fish egg and larvae study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July through December 1974. Semi-Annual report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol I:68-73.

_____. 1975b. Fish egg and larvae study. IN Operational environmental monitoring in Lake Michigan near Zion Station, January through June 1975. Semi-Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I:66-71.

_____ and M. Kitchel. 1976. Annual interpretive report on fish eggs and larvae in Lake Michigan near Zion and Waukegan Generating Stations 1975. Report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. 153 pp.

Cima, G. 1977. Annual interpretive report on fish eggs and larvae in Lake Michigan near Zion and Waukegan Generating Stations 1976. Report to Commonwealth Edison Company, Chicago, Illinois. p 1-49.

_____. 1978. Annual interpretive report on fish eggs and larvae in Lake Michigan near Zion and Waukegan Generating Stations 1977. Report to Commonwealth Edison Company, Chicago, Illinois. p 1-82.

Cochran, M. 1974a. Fish Study. IN Environmental monitoring in Lake Michigan near Zion and Waukegan Generating Stations January 1972 through December 1972. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol II:307-501.

_____. 1974b. Adult Fish Study. IN Operational environmental monitoring in Lake Michigan near Zion Station, January 1974 through June 1974. Semi-Annual report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. III:219-408.

_____ and G. Cima. 1974. Larval fish study. IN Operational environmental monitoring in Lake Michigan near Zion Station July 1973 through June 1974. Annual report to Commonwealth Edison Company, Chicago, Illinois, Vol. III; 201-284.

LaJeone, L. 1978. Annual report on the fish egg and larvae sampling program in Lake Michigan near Zion and Waukegan Generating Stations, January through September 1978. Report to Commonwealth Edison Company, Chicago, Illinois, by Hazleton Environmental Sciences. 187 pp.

Otto, R.G. 1975. The effects of once-through cooling on fish eggs and larvae in southwestern Lake Michigan. Report to Commonwealth Edison Company, Chicago, Illinois, p 1-93.

Wells, L. 1968. Seasonal depth distribution of fish in southeastern Lake Michigan. U.S. Fish Wildlife Serv. Fish. Bull 67: 1-15.

Chapter 11

ADULT FISH MONITORING STUDIES

by

Larry J. LaJeone

SUMMARY REPORT OF ENVIRONMENTAL MONITORING
IN LAKE MICHIGAN NEAR ZION STATION

January 1970 through September 1970

TABLE OF CONTENTS

		Page
	List of Figures	423
	List of Tables	425
I.	Introduction	427
II.	Materials and Methods	429
	A. Field Sampling Efforts in Lake Michigan	429
	B. Data Collection	434
	C. Data Analyses	436
III.	Rerults and Discussion	439
	A. General Catch Data	439
	B. Distribution	447
	C. Age and Growth	456
	D. Condition Factors	459
	E. Food Habits	460
	F. Fecundity Estimates	460
	G. Changes in Fishery	462
IV.	Literature Cited	473

LIST OF FIGURES

No.	Caption	Page
1	Adult fish sampling locations used in monitoring studies of Lake Michigan near Zion Generating Station.....	430
2	Average trawl catch-per-effort of alewife collected along the 12 foot depth contour in the Zion sampling area, 1972 through 1978.....	451
3	Average trawl catch-per-effort of alewife collected along the 18 foot depth contour in the Zion sampling area, 1972 through 1978.....	452
4	Average trawl catch-per-effort of rainbow smelt collected along the 12 foot depth contour in the Zion sampling area, 1972 through 1978.....	454
5	Average trawl catch-per-effort of rainbow smelt collected along the 18 foot depth contour in the Zion sampling area, 1972 through 1978.....	455
6	Age group and year class composition of yellow perch catches from the Zion sampling area, 1971 through 1978.....	457
7	Age group composition of lake trout catches from the Zion sampling area, 1975 through 1978..	458

LIST OF TABLES

No.	Title	Page
1	Trawling and gill net locations with distance from shore and approximate distance from Zion Station's discharge point.....	431
2	Field sampling programs used in adult fish studies for Zion Station, 1971 through 1978.....	432
3	Checklist of fish species and total numbers per species collected by trawl, gill net and minnow seive in the Zion sampling area, 1971 through 1978.....	440
4	Total numbers of fish species collected by trawl in the Zion Zone, 1971 through 1978.....	443
5	Total numbers of fish species collected by trawl in the North Zone, 1973 through 1978.....	444
6	Total numbers of fish species collected by gill net in the Zion Zone, 1971 through 1978....	445
7	Total numbers of fish species collected by gill net in the North Zone, 1973 through 1978...	446
8	Total numbers of fish species collected by minnow seine in the Zion Zone, 1971 through 1978.....	448
9	Total numbers of fish species collected by minnow seine in the North Zone, 1973 through 1978.....	449
10	Average catches of principle species collected by trawl in the Zion sampling area, 1971 through 1978.....	463
11	Average catches of principle species collected by gill net in the Zion sampling area, 1971 through 1978.....	464

LIST OF TABLES (continued)

No.	Title	Page
12	Average catch-per-effort of alewife collected by trawl during October in the Zion sampling area and during autumn assessment off Waukegan, Benton Harbor and Saugatuck, 1971 through 1978.....	466
13	Average catch-per-effort of rainbow smelt collected by trawl during October in the Zion sampling area and during autumn assessment off Waukegan, Benton Harbor and Saugatuck, 1971 through 1978.....	468
14	Average catch-per-effort of bloater collected by trawl during October in the Zion sampling area and during autumn assessment off Waukegan, Benton Harbor and Saugatuck, 1971 through 1978.....	470

I. Introduction

Monitoring studies of the adult fish community in Lake Michigan in the vicinity of Zion Generating Station have been conducted since 1970. Preoperational studies began in 1970 and continued through June 1973 (Industrial BIO-TEST Laboratories, Inc. 1971; Cochran 1973, 1974a and b). Zion Station began operation in July 1973 and semi-annual summary reports of fisheries studies have been prepared to the present (Cochran 1974c and d, 1975, 1976a, 1977; Cochran and Ott 1977; LaJeone 1978a and b, 1979). In addition, interpretive reports examined fisheries data compiled during Zion Station's first three years operation (Muerch 1974; Cochran 1975, 1976b).

This report is a summary of fisheries studies conducted in the vicinity of Zion Station from 1971 through 1978. The intent of this report is to examine data compiled during these studies to evaluate whether or not operation of Zion Station has had a measurable effect on the local fishery. Specific objectives of this report are:

1. to compare the composition and abundance of fish species inhabiting the study area over time;

2. to determine if trends in distribution of fish within the sampling area have occurred;

3. to summarize results of age and growth studies, condition factor comparisons, food habit studies and fecundity estimates for various species;

4. and, to determine if changes in the fishery have occurred that are attributable to operation of Zion Station.

II. Materials and Methods

A. Field Sampling Efforts in Lake Michigan

1. Sampling Locations & Frequency

Sampling locations established for adult fish monitoring studies of Zion Station have remained the same since November 1973 and are presented in Figure 1. The distances of locations from the shore and approximate distances of locations from Zion Station's Unit 1 discharge are presented in Table 1. Operational monitoring studies began in July 1973 and, since that time, the only change in sampling locations that has occurred was the addition of gill net sampling at the 12 foot depth in November 1973 (Table 2). Sampling was conducted in two zones during operational monitoring studies. The first zone (Zion Zone) was established just south of Zion Station and extended 2.25 miles (3600 m) into the lake to the 60 foot (18 m) depth contour. The second zone (North Zone), which served as a reference area, was established approximately four miles north of Zion Station and extended into the lake to the 60 foot depth contour a distance of 2.5 miles (4000 m).

Prior to Station start-up in July 1973, sampling was only conducted in the Zion Zone. Sampling locations within the Zion Zone were the same for preoperational studies. Only five locations in the Zion Zone during 1971 were the same or comparable to locations used in subsequent studies. Therefore, only data gathered at those locations are used for comparative purposes. Sampling locations, frequency of collections and collecting gear

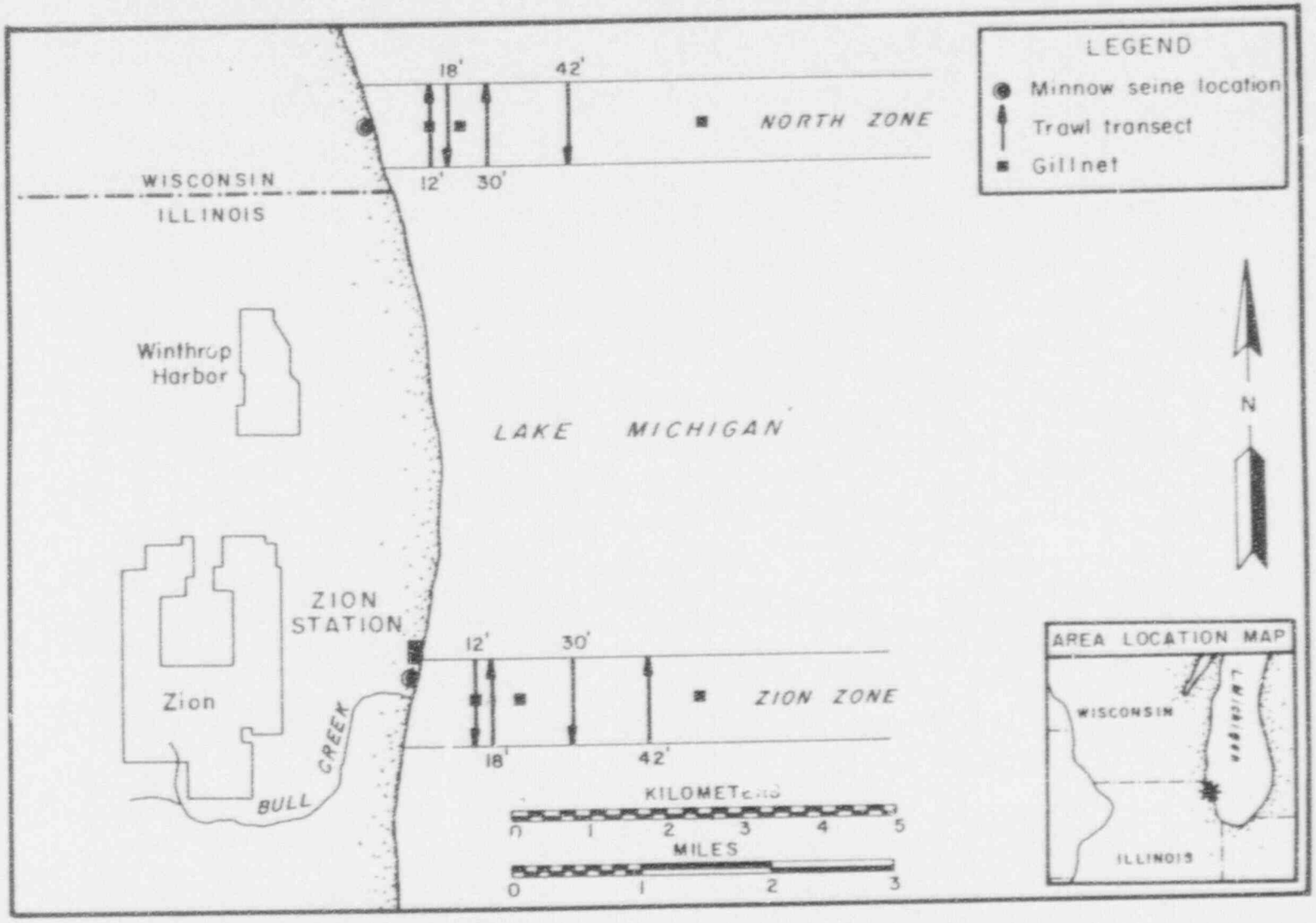


Figure 1. Adult fish sampling locations used in monitoring studies of Lake Michigan near Zion Generating Station.

Table 1. Trawling and gill net locations with distance from shore and approximate distance from Zion Station's discharge point.

North Zone				Zion Zone			
Station	Depth (ft)	Distance From Shore (miles)	Distance From Zion Discharge (miles)	Station	Depth (ft)	Distance From Shore (miles)	Distance From Zion Discharge (miles)
	Trawl Locations				Trawl Locations		
N-1	12	0.40	3.50	Z-1	12	0.40	0.20
N-2	18	0.50	3.50	Z-2	18	0.50	0.35
N-3	30	0.85	3.50	Z-3	30	1.25	0.55
N-4	42	1.40	3.75	Z-4	42	1.80	1.30
	Gill Net Locations				Gill Net Locations		
N-1	12	0.40	3.50	Z-1	12	0.40	0.20
N-5	24	0.65	3.50	Z-5	24	0.60	0.40
N-6	60	2.50	4.00	Z-6	60	2.25	1.75

HAZLETON ENVIRONMENTAL SCIENCES

Table 2. Field sampling programs used in adult fish studies for Zion Station, 1971 through 1978.

Year	Collection Method	Number of Locations[a]	Number of Replicates	Sampling Depths (ft)	Sampling Frequency	Sampling Period	Reference
1971	Trawl	2	1	30,42	2/month	April-December	Cochran 1973
	Gill Net	2	1	18,60	2/month	April-December	
	Seine	1	1	2	Irregular	April-December	
1972	Trawl	4	2	12,18,30,42	2/month	March,June-December[b]	Cochran 1974a
	Gill Net	2	1	24,60	2/month	June-December	
	Seine	1	1	2	2/month	June-December	
1973	Trawl	4	2	12,18,30,42	2/month	January-June	Cochran 1974b,c
	Trawl	6[c]	2	12,18,30,42	2/month	July-December	Muench 1974
	Gill Net	2	1	24,60	2/month	January-June	
	Gill Net	4	1	24,60	2/month	July-October	
	Gill Net	6	1	12,24,60	2/month	November-December	
	Seine	1	1	2	2/month	January-June	
	Seine	2	1	2	2/month	July-December	
1974	Trawl	8[c]	2	12,18,30,42	2/month	January-December	Cochran 1974d,1975
	Gill Net	6	1	12,24,60	2/month	January-December	Muench 1974
	Seine	2	1	2	2/month	January-December	
1975	Trawl	8	2	12,18,30,42	2/month	January-June	Cochran 1975; 1976a,b
	Trawl	8	2	12,18,30,42	1/month	July-December	
	Gill Net	6	1	12,24,60	2/month	January-June	
	Gill Net	6	1	12,24,60	1/month	July-December	
	Seine	2	1	2	2/month	January-June	
	Seine	2	1	2	1/month	July-December	
1976	Trawl	8	2	12,18,30,42	1/month	January-December	Cochran 1976b; 1977
	Gill Net	6	1	12,24,60	1/month	January-December	Cochran and Ott 1977
	Seine	2	1	2	1/month	January-December	
1977	Trawl	8	2	12,18,30,42	1/month	January-December	LaJeone 1978a
	Gill Net	6	1	12,24,60	1/month	January-December	Cochran and Ott 1977
	Seine	2	1	2	1/month	January-December	
1978	Trawl	8	2	12,18,30,42	1/month	January-September	LaJeone 1978b; 1979
	Gill Net	6	1	12,24,60	1/month	January-September	
	Seine	2	1	2	1/month	January-September	

[a]Refers to location comparable to the 1978 program.
[b]Sampled once per month in January and February.
[c]Only seven locations sampled from September-December 1973 and from January-June 1974.

used in the initial monitoring study in 1970 (Industrial BIO-TEST Laboratories, Inc. 1971) did not resemble subsequent studies and, therefore, these data are not included in this comparative summary.

In 1971, sampling was initiated in April and continued through December (Table 2). Limited sampling was conducted from January through March 1972. Beginning with June 1972 all sampling was scheduled on a year-round basis. All sampling was terminated in September 1978.

From April 1971 through June 1975 all sampling was scheduled to be conducted twice per month, weather permitting. Thereafter, the sampling programs were reduced to once per month for the remainder of the monitoring period.

2. Sampling Methods

Collection methods used in Zion fish monitoring studies included bottom trawl, experimental gill nets and minnow seine. All trawling was conducted with a North Atlantic Whiting trawl with head and footropes of 39 and 51 (11.9 m and 15.5 m), respectively, and a cod end of 1/2 inch (1.3 cm) mesh. Trawl tows were made along depth contours at depths specified in Table 2. Except for sampling during 1971, replicate trawl series were made, usually on two successive days when weather permitted. Trawl tows were limited to five minutes at all locations in the North Zone and intermittently at the Zion Zone 12 foot depth due to bottom obstructions. Trawl tows were of 10 minutes duration at the remaining locations in the Zion Zone.

All gill netting was conducted with experimental nets constructed of 300 feet (91 m)of 2 1/2 inch (6.4 cm) mesh, 305 feet (93 m) of 3 1/2 inch (8.9 cm) mesh, and 302 feet (92 m) of 5 1/2 inch (14 cm) mesh extension measure. In 1973, an additional 50 foot (15 m) panel of 1 1/2 inch (3.8 cm) mesh was added to each net. Nets were set along depth contours at locations specified in Table 2. Nets were normally set in the afternoon following the second trawling series, left overnight and retrieved the following morning.

Shoreline minnow seining was conducted after dark at locations in each zone affording easy access and bottom characteristics favorable for sampling (Table 2). The seine most commonly used, from 1973 through 1978, measured 36 feet (11 m) x 6 feet (1.8 m) of 1/4 inch Ace mesh, with a 6 x 6 foot bag of 1/8 inch Ace mesh. Prior to 1973 the seine used measured 25 feet x 6 feet of 1/4 inch Ace mesh. Seining efforts varied, with two to four hauls made at each location. Each haul covered approximately 100 feet of shoreline.

B. Data Collection

All fish collected were identified to species and individual total lengths (mm) and weight (g) recorded, with the exception of large catches of alewife and rainbow smelt which were counted and a total weight per catch recorded. Ten representative individuals of each species were sexed and gonadal condition recorded.

An error in the Tukey's value calculated by the programs used was detected and necessitated statistical reruns

of all data affected. A total of 24 tests on trawl catch comparisons involving primarily alewife and smelt was affected from 1974 through 1977. In many cases there was no change in the statistical significance of the tests. Those tests that changed in significance became more general than originally calculated or changed from significant to not significant. Overall, the results of reanalysis of these data did not notably alter interpretation of distributional differences.

Food habits were determined for lake trout, yellow perch and slimy sculpin. Stomachs were excised and contents were quantified by measuring total volume. Organisms contained in stomachs were identified to the lowest positive taxon and the percent frequency of occurrence was calculated.

Ages were determined for lake trout and yellow perch. Lake trout were aged through fin clip records and yellow perch were aged by scale analysis. In addition, special age and growth studies were conducted on alewife in 1977 and 1978 (LaJeone 1978a and b).

Fecundity estimates were also calculated for several species. Ripe females were collected prior to the spawning season and estimates of fecundity were calculated volumetrically and reported by size group. Fecundity was determined for alewife from 1973 through 1978, smelt from 1973 through 1975 and 1977, slimy sculpin from 1973 through 1975, bloater in 1974 and 1975, yellow perch in 1973 and lake trout in 1974.

C. Data Analyses

Trawl catches were standardized into catch-per-effort and grouped by species and sampling period. When sufficient numbers of a species were obtained, a 4 x 2 factorial analysis of variance (4 depths x 2 zones) was performed, after $\log_e$ transformation, to test for significant differences or interaction between depths and zones. The analysis of variance was followed by Tukey's multiple comparison procedure when a significant F value occurred. All testing was performed at $P \leq 0.05$.

Condition factors (K) were computed on fish caught by trawl and gill nets since 1973. When sufficient numbers were collected, data were grouped by sex, size class and location, and compared monthly using a Mann Whitney U test to test for differences between depths and zones.

Special age and growth studies for alewife involved back-calculation of lengths based on body-scale relationships. Fish were collected from similar locations in each zone and back-calculated lengths were subjected to a weighted linear regression analysis for each zone. A t-test was used to test for homogeniety of the slopes. Greater detail concerning the methods and analyses used in these studies are given in previous reports (LaJeone 1978a and b).

For purposes of this summary report, annual catches for principle species collected by trawl and gill net were standardized into average catches per trawl tow and per gill net. Such calculations were required to depict any changes in the relative

abundance of principle species that have occurred over the eight years of monitoring studies.

III. Results and Discussion

A. General Catch Data

During eight years of monitoring studies for Zion Station, a total of 37 species and 2 hybrids have been collected for a total of 1010198 fish processed (Table 3). Species composition of annual catches ranged from 18 in the 1971 study to 28 in the 1974 study. Changes in species composition that have occurred over the years have been limited to occasional collections of small numbers of individual species that are either not common to Lake Michigan or not common to the Zion sampling area. In all years, alewife

In all years, alewife and rainbow smelt dominated fish collections. Alewife comprised from 40.5% of the annual catch in 1978 to 95.0% of the catch in 1975. Smelt contributed as little as 3.8% of the annual catch in 1975 and as much as 45.9% of the catch in 1978. Collectively, these two species comprised no less than 86.4% of any annual total catch. Additional species commonly contributing to annual collections were bloater, lake trout, coho salmon, slimy sculpin, yellow perch, chinook salmon, trout-perch, spottail shiner, brown trout, rainbow trout, longnose dace, white sucker and ninespine stickleback.

Species common elsewhere in Lake Michigan that are not common in the Zion area include lake whitefish, longnose sucker, carp, lake chub, northern pike, burbot, gizzard shad, black and brown bullheads. Lake herring and emerald shiners are extremely uncommon in the Zion area, as they are now lakewide (Wells and McLain 1973) though both were once locally abundant in Lake Michigan.

Table 3. Checklist of fish species and total numbers per species collected by trawl, gill net and minnow seine in the Zion sampling area, 1971 through 1978.

Species[a]		Number of Fish/Year									
		1971[b]		1972[b]		1973		1974		1975	
Common Name	Scientific Name	No.	%	No.	%	No.	%	No.	%	No.	%
Alewife	Alosa pseudoharengus	25349	72.33	7 22	74.64	218443	32.88	162337	93.87	84723	95.04
Rainbow smelt	Osmerus mordax	8682	24.77	23207	23.50	42022	15.94	7997	4.62	3392	3.81
Bloater	Coregonus hoyi	741	2.11	1169	1.18	1040	0.39	282	0.16	62	0.07
Yellow perch	Perca flavescens	92	0.26	409	0.41	411	0.16	234	0.14	80	0.09
Spottail shiner	Notropis hudsonius	65	0.19	73	0.07	144	0.05	43	0.02	30	0.03
Lake trout	Salvelinus namaycush	26	0.07	112	0.11	144	0.05	224	0.13	168	0.19
Coho salmon	Oncorhynchus kisutch	25	0.07	21	0.02	134	0.05	362	0.21	228	0.26
Slimy sculpin	Cottus cognatus	18	0.05	2	0.00	797	0.30	519	0.30	50	0.06
White sucker	Catostomus commersoni	11	0.03	2	0.00	50	0.02	95	0.05	43	0.05
Longnose dace	Rhinichthys cataractae	9	0.03	5	0.01	19	0.01	55	0.03	47	0.05
Lake whitefish	Coregonus clupeaformis	6	0.02	4	0.00	68	0.03	34	0.02	11	0.01
Emerald shiner	Notropis atherinoides	6	0.02	0	0.00	0	0.00	2	0.00	1	0.00
Brown trout	Salmo trutta	5	0.01	6	0.01	27	0.01	138	0.08	80	0.09
Lake herring	Coregonus artedii	4	0.01	0	0.00	1	0.00	2	0.00	2	0.00
Trout-perch	Percopsis omiscomaycus	3	0.01	12	0.01	65	0.02	5	0.00	1	0.00
Chinook salmon	Oncorhynchus tshawytscha	2	0.01	10	0.01	119	0.05	482	0.28	53	0.06
Brook trout	Salvelinus fontinalis	1	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Longnose sucker	Catostomus catostomus	1	0.00	2	0.00	3	0.00	3	0.00	1	0.00
Carp	Cyprinus carpio	0	0.00	8	0.01	9	0.00	25	0.01	2	0.00
Ninespine stickleback	Pungitius pungitius	0	0.00	2	0.00	34	0.01	13	0.01	11	0.01
Rainbow trout	Salmo gairdneri	0	0.00	1	0.00	8	0.00	49	0.03	151	0.17
Fathead minnow	Pimephales promelas	0	0.00	1	0.00	0	0.00	4	0.00	0	0.00
Mud minnow	Umbra limi	0	0.00	1	0.00	6	0.00	0	0.00	0	0.00
Largemouth bass	Micropterus salmoides	0	0.00	1	0.00	0	0.00	0	0.00	0	0.00
White crappie	Pomoxis annularis	0	0.00	1	0.00	0	0.00	1	0.00	0	0.00
Lake chub	Couesius plumbeus	0	0.00	1	0.00	7	0.00	0	0.00	0	0.00
Northern pike	Esox lucius	0	0.00	0	0.00	1	0.00	0	0.00	0	0.00
Burbot	Lota lota	0	0.00	0	0.00	1	0.00	1	0.00	0	0.00
Gizzard shad	Dorosoma cepedianum	0	0.00	0	0.00	1	0.00	3	0.00	7	0.01
Bluegill	Lepomis macrochirus	0	0.00	0	0.00	0	0.00	21	0.01	0	0.00
Goldfish	Carassius auratus	0	0.00	0	0.00	0	0.00	3	0.00	0	0.00
Golden shiner	Notemigonus crysoleucas	0	0.00	0	0.00	0	0.00	3	0.00	0	0.00
Black bullhead	Ictalurus melas	0	0.00	0	0.00	0	0.00	3	0.00	0	0.00
Brown bullhead	Ictalurus nebulosus	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Warmouth	Lepomis gulosus	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Carp/goldfish	Cyprinus carpio/ Carassius auratus	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Johnny darter	Etheostoma nigrum	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Tiger trout	Salvelinus fontinalis/ Salmo trutta	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Black crappie	Pomoxis nigromaculatus	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Total Species		18		22		24		28		21	
Total Catch		35046		98771		263554		172940		89143	

Table 3. (continued)

Species[a]		Number of Fish/Year					
		1976		1977		1978	
Common Name	Scientific Name	No.	%	No.	%	No.	%
Alewife	Alosa pseudoharengus	145999	91.80	98244	65.63	17015	40.50
Rainbow smelt	Osmerus mordax	3392	2.16	49486	33.06	19265	45.86
Bloater	Coregonus hoyi	277	0.17	145	0.10	4299	10.23
Yellow perch	Perca flavescens	179	0.11	114	0.08	38	0.09
Spottail shiner	Notropis hudsonius	13	0.01	53	0.04	23	0.05
Lake trout	Salvelinus namaycush	294	0.18	615	0.41	395	0.94
Coho salmon	Oncorhynchus kisutch	417	0.26	286	0.19	253	0.60
Slimy sculpin	Cottus cognatus	53	0.03	52	0.03	89	0.21
White sucker	Catostomus commersoni	25	0.02	10	0.01	16	0.04
Longnose dace	Rhinichthys cataractae	6	0.00	57	0.04	88	0.21
Lake whitefish	Coregonus clupeaformis	10	0.01	19	0.01	11	0.03
Emerald shiner	Notropis atherinoides	0	0.00	0	0.00	0	0.00
Brown trout	Salmo trutta	41	0.03	86	0.06	39	0.09
Lake herring	Coregonus artedii	0	0.00	0	0.00	0	0.00
Trout-perch	Percopsis omiscomaycus	79	0.05	248	0.17	285	0.68
Chinook salmon	Oncorhynchus tshawytscha	34	0.02	126	0.08	66	0.16
Brook trout	Salvelinus fontinalis	0	0.00	3	0.00	0	0.00
Longnose sucker	Catostomus catostomus	0	0.00	0	0.00	7	0.02
Carp	Cyprinus carpio	10	0.01	4	0.00	6	0.01
Ninespine stickleback	Pungitius pungitius	9	0.01	74	0.05	85	0.20
Rainbow trout	Salmo gairdneri	45	0.03	54	0.04	18	0.04
Fathead minnow	Pimephales promelas	0	0.00	0	0.00	2	0.00
Mud minnow	Umbra limi	0	0.00	0	0.00	0	0.00
Largemouth bass	Micropterus salmoides	0	0.00	0	0.00	0	0.00
White crappie	Pomoxis annularis	1	0.00	0	0.00	0	0.00
Lake chub	Couesius plumbeus	0	0.00	0	0.00	2	0.00
Northern pike	Esox lucius	0	0.00	1	0.00	0	0.00
Burbot	Lota lota	0	0.00	0	0.00	0	0.00
Gizzard shad	Dorosoma cepedianum	4	0.00	5	0.00	1	0.00
Bluegill	Lepomis macrochirus	1	0.00	0	0.00	0	0.00
Goldfish	Carassius auratus	0	0.00	0	0.00	0	0.00
Golden shiner	Notemigonus crysoleucas	0	0.00	0	0.00	2	0.00
Black bullhead	Ictalurus melas	0	0.00	0	0.00	0	0.00
Brown bullhead	Ictalurus nebulosus	1	0.00	0	0.00	0	0.00
Warmouth	Lepomis gulosus	1	0.00	0	0.00	0	0.00
Carp/goldfish	Cyprinus carpio/ Carassius auratus	0	0.00	2	0.00	0	0.00
Johnny darter	Etheostoma nigrum	0	0.00	2	0.00	1	0.00
Tiger trout	Salvelinus fontinalis/ Salmo trutta	0	0.00	0	0.00	3	0.01
Black crappie	Pomoxis nigromaculatus	0	0.00	0	0.00	1	0.00
Total Species		22		22		25	
Total Catch		159048		149686		42010	

[a]Species names according to Bailey (1970).
[b]Data are from catches only in Zion Zone.

Neither of these species has been collected in Zion monitoring studies since 1975 (Table 3). Species presently listed as threatened in Illinois waters which do occur or have occurred in the Zion sampling area are lake herring, lake whitefish and longnose sucker (Illinois Department of Conservation 1978).

Bottom trawling was the most productive collection method, providing the majority of the total catch in any year. Total catches per year by sampling zone are presented in Tables 4 and 5. Alewife and smelt dominated trawl collections with combined catches comprising no less than 88.8% in the Zion Zone in 1978 and 83.7% in the North Zone in 1978. Other species which commonly contributed to trawl catches were bloater, trout-perch, slimy sculpin, ninespine stickleback and spottail shiner. Species composition was comparable between both zones and consistent trends in species abundance in one zone over the other were not apparent.

Gill nets were the most productive collection device for salmonid species (trout and salmon) and yellow perch. Total catches per year by zone are presented in Tables 6 and 7. Alewife and smelt also comprised the majority of gill net catches; however, alewife were not extremely abundant in gill net catches until 1973 when the 1 1/2 inch mesh panel was added to the existing nets. Additional species commonly taken by gill net were yellow perch, bloater, lake trout, coho and chinook salmon, brown and rainbow trout, and white sucker. As with trawl collections, no consistent differences in species composition or abundance were apparent between zones.

Table 4. Total numbers of fish species collected by trawl in the Zion Zone, 1971 through 1978.

Species	Number of Fish/Year: 1971 No.	1971 %	1972 No.	1972 %	1973 No.	1973 %	1974 No.	1974 %	1975 No.	1975 %	1976 No.	1976 %	1977 No.	1977 %	1978 No.	1978 %
Alewife	24463	72.63	71923	74.80	115367	84.13	58268	94.07	31035	91.29	66354	80.10	41816	55.84	6644	48.82
Rainbow smelt	8652	25.69	23066	23.99	21177	15.44	3518	5.68	1793	5.45	7911	19.62	32819	43.86	5445	40.01
Bloater	520	1.54	1023	1.06	377	0.27	8	0.01	12	0.04	151	0.20	52	0.07	1272	9.35
Slimy sculpin	18	0.05	2	0.00	82	0.06	94	0.16	17	0.05	2	0.00	9	0.01	34	0.25
Lake trout	15	0.04	18	0.02	3	0.00	3	0.00	4	0.01	4	0.01	16	0.02	8	0.06
Spottail shiner	4	0.01	42	0.04	36	0.03	5	0.01	18	0.05	7	0.01	8	0.01	0	0.00
Yellow perch	4	0.01	56	0.05	29	0.02	20	0.03	8	0.02	2	0.00	5	0.01	2	0.01
Lake whitefish	3	0.01	3	0.00	16	0.01	11	0.02	2	0.01	3	0.00	1	0.00	2	0.01
Trout-perch	3	0.01	10	0.01	12	0.01	5	0.01	0	0.00	24	0.03	111	0.15	133	0.98
Lake herring	1	0.00	0	0.00	1	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Carp	0	0.00	7	0.01	1	0.00	0	0.00	1	0.00	6	0.01	0	0.00	0	0.00
Ninespine stickleback	0	0.00	2	0.00	22	0.02	3	0.00	4	0.01	4	0.01	14	0.02	50	0.37
Brown trout	0	0.00	2	0.00	3	0.00	0	0.00	1	0.01	1	0.00	1	0.00	4	0.03
Coho salmon	0	0.00	1	0.00	2	0.00	0	0.00	3	0.01	1	0.00	2	0.00	8	0.06
Rainbow trout	0	0.00	1	0.00	0	0.00	0	0.00	1	0.00	1	0.00	2	0.00	0	0.00
White sucker	0	0.00	1	0.00	0	0.00	0	0.00	1	0.00	1	0.00	1	0.00	1	0.01
Chinook salmon	0	0.00	0	0.00	7	0.01	4	0.01	11	0.03	1	0.00	1	0.00	2	0.01
Lake chub	0	0.00	0	0.00	1	0.00	2	0.00	0	0.00	1	0.00	0	0.00	1	0.01
Gizzard shad	0	0.00	0	0.00	1	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Bluegill	0	0.00	0	0.00	0	0.00	0	0.00	2	0.01	0	0.00	0	0.00	0	0.00
Warmouth	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	0.00	0	0.00	0	0.00
Longnose sucker	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Johnny darter	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	0.00	1	0.01

HAZLETON ENVIRONMENTAL SCIENCES

Table 5. Total numbers of fish species collected by trawl in the North Zone, 1973 through 1978.

Species	Number of Fish/Year											
	1973		1974		1975		1976		1977		1978	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Alewife	89425	81.10	79987	96.44	39181	98.50	63497	95.28	46199	73.78	3[illegible]5	17.36
Rainbow smelt	19670	17.84	2359	2.84	517	1.30	2975	4.46	16084	25.69	13592	66.36
Slimy sculpin	714	0.65	419	0.50	28	0.07	50	0.08	41	0.07	55	0.27
Bloater	188	0.17	4	0.00	8	0.02	48	0.07	40	0.06	3006	14.68
Spottail shiner	98	0.08	34	0.04	11	0.03	1	0.00	25	0.04	20	0.10
Trout-perch	48	0.04	0	0.00	0	0.00	55	0.08	136	0.22	151	0.74
White sucker	34	0.03	29	0.03	10	0.03	0	0.00	0	0.00	1	0.00
Yellow perch	33	0.03	28	0.03	[illegible]	0.02	3	0.00	2	0.00	15	0.07
Lake whitefish	11	0.01	8	0.01	3	0.01	2	0.00	2	0.00	1	0.00
Ninespine stickleback	11	0.01	5	0.01	1	0.00	5	0.01	55	0.09	34	0.17
Lake chub	5	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Brown trout	5	0.00	2	0.00	1	0.00	3	0.00	6	0.01	0	0.00
Carp	5	0.00	6	0.01	0	0.00	0	0.00	3	0.00	2	0.01
Coho salmon	5	0.00	0	0.00	2	0.00	1	0.00	1	0.00	1	0.00
Rainbow trout	2	0.00	0	0.00	0	0.00	1	0.00	0	0.00	0	0.00
Lake trout	2	0.00	0	0.00	2	0.00	1	0.00	14	0.02	5	0.02
Longnose sucker	2	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Chinook salmon	1	0.00	2	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Gizzard shad	0	0.00	2	0.00	4	0.01	0	0.00	1	0.00	0	0.00
Longnose dace	0	0.00	1	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Johnny darter	0	0.00	0	0.00	0	0.00	0	0.00	1	0.00	0	0.00

Table 6. Total numbers of fish species collected by gill net in the Zion Zone, 1971 through 1978.

Species	Number of Fish/Year													
	1971		1972		1973		1974		1975		1976		1977		1978	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Alewife	568	59.17	1286	63.23	6315	84.08	11404	84.61	6898	86.71	8508	89.72	4795	84.76	3792	88.91
Bloater	214	22.29	146	7.18	283	3.77	195	1.45	20	0.25	42	0.44	12	0.21	1	0.02
Yellow perch	88	9.17	337	16.57	257	3.42	105	0.78	51	0.64	129	1.36	65	0.11	9	0.21
Rainbow smelt	28	2.92	138	6.78	495	6.59	1162	8.62	557	7.00	265	2.79	109	1.93	91	2.13
Coho salmon	25	2.60	19	0.93	49	0.65	244	1.81	176	2.21	272	2.88	198	3.50	122	2.86
Lake trout	11	1.14	91	4.47	50	0.66	113	0.84	80	1.00	164	1.73	312	5.52	193	4.53
White sucker	11	1.14	1	0.04	3	0.04	13	0.10	5	0.06	10	0.11	5	0.09	5	0.12
Brown trout	5	0.52	4	0.20	8	0.11	91	0.68	54	0.68	26	0.27	50	0.88	27	0.63
Lake whitefish	3	0.31	1	0.04	26	0.35	3	0.02	2	0.03	3	0.03	13	0.23	6	0.14
Lake herring	3	0.31	0	0.00	0	0.00	0	0.00	2	0.03	0	0.00	0	0.00	0	0.00
Chinook salmon	2	0.21	8	0.39	19	0.25	106	0.79	13	0.16	19	0.20	58	1.03	6	0.14
Longnose sucker	1	0.10	2	0.09	1	0.01	2	0.01	1	0.02	0	0.00	0	0.00	4	0.09
Brook trout	1	0.10	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	0.02	0	0.00
White crappie	0	0.00	1	0.04	0	0.00	0	0.00	0	0.00	1	0.01	0	0.00	0	0.00
Slimy sculpin	0	0.00	0	0.00	1	0.01	1	0.01	0	0.00	0	0.00	1	0.02	0	0.00
Lake chub	0	0.00	0	0.00	1	0.01	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Rainbow trout	0	0.00	0	0.00	1	0.01	30	0.22	96	1.21	39	0.41	32	0.57	5	0.12
Carp	0	0.00	0	0.00	0	0.00	8	0.06	0	0.00	2	0.02	0	0.00	2	0.05
Burbot	0	0.00	0	0.00	0	0.00	1	0.01	0	0.00	0	0.00	0	0.00	0	0.00
Tiger trout	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	2	0.05
Gizzard shad	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	2	0.02	4	0.07	0	0.00
Carp X Goldfish hybrid	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	2	0.04	0	0.00
Black crappie	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	0.02
Brown bullhead	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	0.01	0	0.00	0	0.00

Table 7. Total numbers of fish species collected by gill net in the North Zone, 1973 through 1978.

Species	Number of Fish/Year											
	1973		1974		1975		1976		1977		1978	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Alewife	7064	96.66	12165	91.92	7528	91.14	7450	91.92	5332	85.48	2997	86.69
Rainbow smelt	566	6.94	493	3.73	468	5.67	257	3.17	348	5.58	97	2.81
Bloater	192	2.36	74	0.56	22	0.27	36	0.44	41	0.66	17	0.49
Yellow perch	92	1.13	79	0.60	13	0.16	45	0.56	42	0.67	12	0.35
Lake trout	89	1.09	108	0.82	82	0.99	125	1.54	273	4.38	189	5.47
Coho salmon	77	0.94	118	0.89	47	0.57	143	1.76	82	1.31	110	3.18
Chinook salmon	19	0.23	58	0.44	11	0.13	14	0.17	64	1.03	11	0.32
Lake whitefish	15	0.18	12	0.09	4	0.05	2	0.02	3	0.05	2	0.06
Brown trout	9	0.11	44	0.33	20	0.24	11	0.14	29	0.46	6	0.17
White sucker	5	0.06	49	0.37	16	0.19	14	0.17	4	0.06	9	0.26
Rainbow trout	4	0.04	17	0.12	47	0.57	4	0.05	16	0.26	1	0.03
Carp	1	0.01	9	0.07	1	[illegible]	2	0.02	1	0.02	2	0.06
Gizzard shad	1	.01	1	0.01	0	[illegible]	2	0.02	0	0.00	0	0.00
Trout-perch	1	.01	0	0.00	1	[illegible]	0	0.00	0	0.00	0	0.00
Burbot	1	0.01	0	0.00	0	[illegible]	0	0.00	0	0.00	0	0.00
Goldfish	0	0.00	3	0.02	0	0.00	0	0.00	0	0.00	0	0.00
Lake herring	0	0.00	2	0.02	0	0.00	0	0.00	0	0.00	0	0.00
Longnose sucker	0	0.00	1	0.01	0	0.00	0	0.00	0	0.00	2	0.06
Bluegill	0	0.00	1	0.01	0	0.00	0	0.00	0	0.00	0	0.00
Brook trout	0	0.00	0	0.00	0	0.00	0	0.00	2	0.03	0	0.00
Northern pike	0	0.00	0	0.00	0	0.00	0	0.00	1	0.02	0	0.00
Lake chub	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	0.03
Tiger trout	0	0.0	0	0.00	0	0.00	0	0.00	0	0.00	1	0.03

HAZLETON ENVIRONMENTAL SCIENCES

Minnow seine collections were extremely variable from year to year. Seine catches are dependent on time (dates) of sampling and existing weather conditions during sampling, both of which can greatly affect the results of seining efforts. Annual minnow seine catches by zone are presented in Tables 8 and 9. Alewife and smelt were, again, the most common species collected by seine, though longnose dace was also commonly taken by this method, almost exclusively. Moderate numbers of young coho and chinook salmon recently stocked in the lake were also occasionally collected by seine. Seine collections varied considerably in species composition and relative abundance between zones from year to year, but accounted for a large portion of the incidental species occuring sporadically in the Zion area of Lake Michigan. Many of the uncommon species that accounted for most of the differences in annual species composition changes were represented by small numbers of individuals collected by minnow seine.

B. Distribution

The effect of Zion Station operation on the distribution of fish in the sampling area in limited by the extent of the Station's thermal plume and sampling locations influenced by it. Results from thermal plume studies were related to adult fish sampling locations (Chapter 4, this report). Based on these analyses, surface plumes can potentially affect the 12, 18 and 30 foot depth trawling locations, and the 12 and 24 foot depth gill net locations in the Zion Zone. Sinking plumes, occurring in winter, have the potential to affect the 42 foot depth trawling location in the

Table 8. Total numbers of fish species collected by minnow seine in the Zion Zone, 1971 through 1978.

Species	Number of Fish/Year													
	1971		1972		1973		1974		1975		1976		1977		1978	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Alewife	318	78.91	513	88.30	266	70.93	248	25.54	73	91.48	63	55.26	76	36.71	5	5.15
Spottail shiner	61	15.14	31	5.34	2	0.53	3	0.30	1	0.57	5	4.39	0	0.00	1	1.03
Longnose dace	9	2.23	5	0.86	0	0.00	35	3.60	14	7.95	0	0.00	27	13.04	2	2.06
Bloater	7	1.74	0	0.00	0	0.00	1	0.00	0	0.00	0	0.00	0	0.00	1	1.03
Emerald shiner	6	1.48	0	0.00	0	0.00	1	0.10	1	0.57	0	0.00	0	0.00	0	0.00
Rainbow smelt	2	0.50	3	0.52	42	11.20	429	44.18	50	28.41	45	39.47	95	45.89	38	39.18
Yellow perch	0	0.00	16	2.74	0	0.00	1	0.10	0	0.00	0	0.00	0	0.00	0	0.00
Lake trout	0	0.00	3	0.52	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Chinook salmon	0	0.00	2	0.34	52	73.87	216	22.25	24	13.64	0	0.00	2	0.97	32	32.99
Trout-perch	0	0.00	2	0.34	1	0.27	0	0.00	0	0.00	0	0.00	0	0.00	1	1.03
Carp	0	0.00	1	0.17	2	0.53	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Largemouth bass	0	0.00	1	0.17	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Coho salmon	0	0.00	1	0.17	0	0.00	0	0.00	0	0.00	0	0.00	3	1.45	12	12.37
Mud minnow	0	0.00	1	0.17	1	0.27	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Fathead minnow	0	0.00	1	0.17	6	1.60	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
White sucker	0	0.00	1	0.17	0	0.00	4	0.41	0	0.00	0	0.00	0	0.00	0	0.00
Brown trout	0	0.00	1	0.17	1	0.27	0	0.00	0	0.00	0	0.00	0	0.00	2	2.06
Ninespine stickleback	0	0.00	0	0.00	2	0.53	0	0.00	1	0.57	0	0.00	0	0.00	0	0.00
Northern pike	0	0.00	0	0.00	1	0.27	2	0.20	2	1.13	0	0.00	0	0.00	0	0.00
Bluegill	0	0.00	0	0.00	1	0.27	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Slimy sculpin	0	0.00	0	0.00	0	0.00	20	2.06	0	0.00	0	0.00	0	0.00	0	0.00
Golden shiner	0	0.00	0	0.00	0	0.00	3	0.30	2	1.13	1	0.88	1	0.48	0	0.00
Black bullhead	0	0.00	0	0.00	0	0.00	3	0.30	0	0.00	0	0.00	0	0.00	2	2.06
White crappie	0	0.00	0	0.00	0	0.00	3	0.30	0	0.00	0	0.00	0	0.00	0	0.00
Rainbow trout	0	0.00	0	0.00	0	0.00	1	0.10	0	0.00	0	0.00	0	0.00	0	0.00
Gizzard shad	0	0.00	0	0.00	0	0.00	1	0.10	7	3.98	0	0.00	3	1.45	1	1.03
							0	0.00	1	0.57	0	0.00	0	0.00	0	0.00

HAZLETON ENVIRONMENTAL SCIENCES

Table 9. Total number of fish species collected by minnow seine in the North Zone, 1973 through 1978.

Species	Number of Fish/Year											
	1973		1974		1975		1976		1977		1978	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Rainbow smelt	72	52.94	36	8.37	7	11.48	96	41.92	1	1.22	2	1.3[illegible]
Chinook salmon	27	19.85	98	22.79	5	8.20	0	0.00	1	1.22	15	10.34
Longnose dace	19	13.97	19	4.42	33	54.10	6	2.62	30	36.59	86	59.[illegible]1
Spottail shiner	8	5.80	1	0.23	0	0.00	0	0.00	20	24.39	2	1.[illegible]8
Alewife	6	4.41	265	61.62	8	13.11	127	55.46	26	31.71	22	1[illegible].17
Trout-perch	3	2.21	0	0.00	0	0.00	0	0.00	2	2.44	0	0.00
Rainbow trout	1	0.74	1	0.23	0	0.00	0	0.00	1	1.22	11	7.59
Ninespine stickleback	0	0.00	3	0.69	4	6.56	0	0.00	1	1.22	1	0.69
Slimy sculpin	0	0.00	2	0.47	3	4.92	0	0.00	0	0.00	0	0.00
Carp	0	0.00	2	0.47	0	0.00	0	0.00	0	0.00	0	0.00
Brown trout	0	0.00	1	0.23	0	0.00	0	0.00	0	0.00	0	0.00
Emerald shiner	0	0.00	1	0.23	0	0.00	0	0.00	0	0.00	0	0.00
Yellow perch	0	0.00	0	0.00	1	1.63	0	0.00	0	0.00	0	0.00
White sucker	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	2	1.38
Bloater	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	2	1.38
Fathead minnow	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	0.69
Gizzard shad												

HAZLETON ENVIRONMENTAL SCIENCES

Zion Zone. Water temperature data recorded during adult fish sampling indicate that detectable thermal influence from Zion's thermal discharge is generally limited to sampling locations at the 12 and 18 foot depths in the Zion Zone (LaJeone 1978b).

Long-term comparisons of distributional differences between sampling locations at the 12 and 18 foot depths in each zone are limited to trawl catches of alewife and smelt. These were the only species continually collected in sufficient enough numbers to plot average catch-per-effort (CPE) over time in order to test these data statistically. Temporal distribution of alewife was generally characterized by a springtime peak in May, corresponding to their normal onshore migration (Figures 2 and 3). Catches thereafter generally declined until the fall when another peak occurred in September or October, usually the result of young-of-year alewife becoming available to the trawl. November catches declined again, corresponding to their offshore migration during the winter. Data from December through March were not plotted as catches were either extremely low or nil during this period.

Spatial distribution of alewife between comparable sampling depths was extremely variable, showing no preference for one zone over another (Figures 2 and 3). This variability, occurring between comparable locations at all sampling depths, was greatest between 12 foot depth locations.

Temporal distribution patterns were also evident for rainbow smelt. Smelt catches began to increase in April with a mid-summer peak usually occurring in July or August, except in

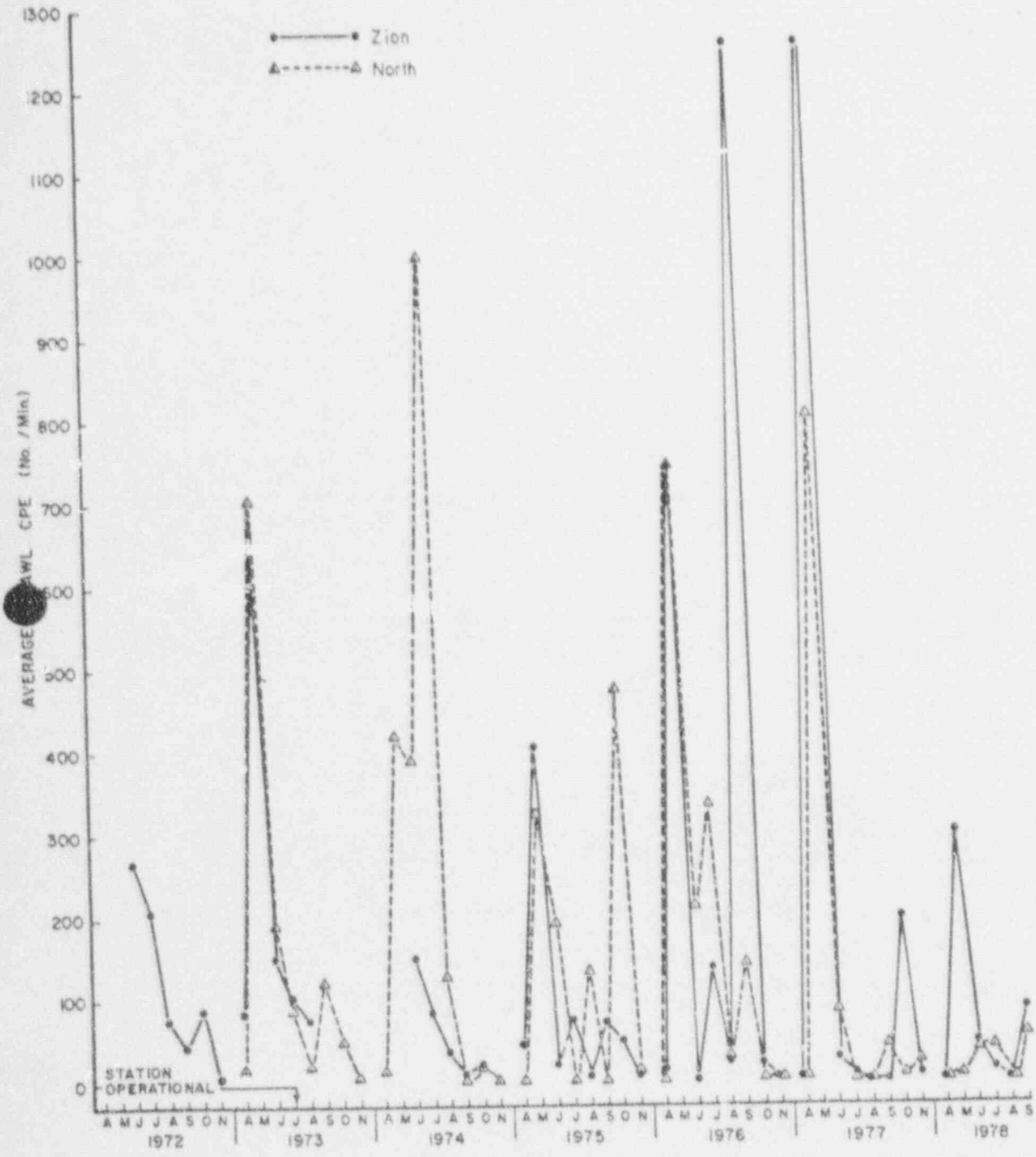


Figure 2. Average trawl catch-per-effort of alewife collected along the 12 foot depth contour in the Zion sampling area, 1972 through 1978.

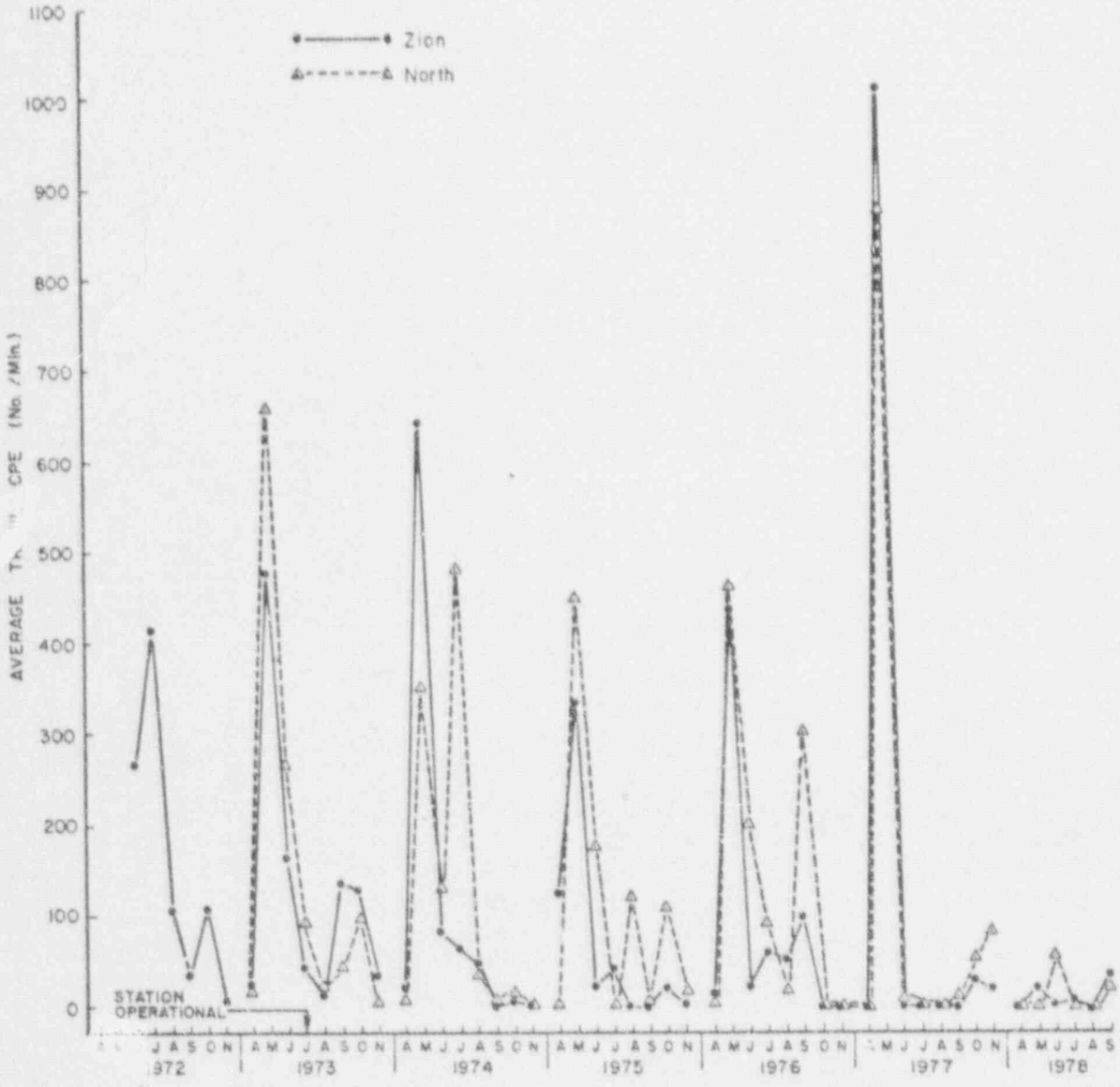


Figure 3. Average trawl catch-per-effort of alewife collected along the 18 foot depth contour in the Zion sampling area, 1972 through 1978.

1974 and 1975, when catches of smelt were extremely low (Figures 4 and 5). Following September, catches generally declined sharply. As with alewife, smelt catches from December through March were very low and were not plotted. Spatial distribution was also quite varialble from year to year, though catches were frequently greater in the North Zone than in the Zion Zone (Figures 4 and 5).

The variability in catches of alewife and smelt shown in Figures 2 through 5 are lessened by averaging of individual trawl CPE's. Individual trawl catches for these and other species have been extremely variable between comparable locations and zones. Catch variability has often been equally as great between replicate samples at the same trawling locations from one day to the next.

Statistically significant differences in distribution of several species within the study area have not been uncommon; however, the variability has been such that no distinct trends or patterns have been apparent.

Based on these analyses, operation of Zion Station does not appear to effect the normal seasonal movements of fish, nor does it strongly influence the distribution of fish inhabiting the study area. There are occasional indications in the data of alewife and smelt being attracted to the plume area during the early stages of their onshore seasonal migration, and attraction of salmon to the plume area during the early stages of their northward migrations. However, once these seasonal migrations have progressed past their early stages, evidence of attraction to the plume area has been difficult to detect.

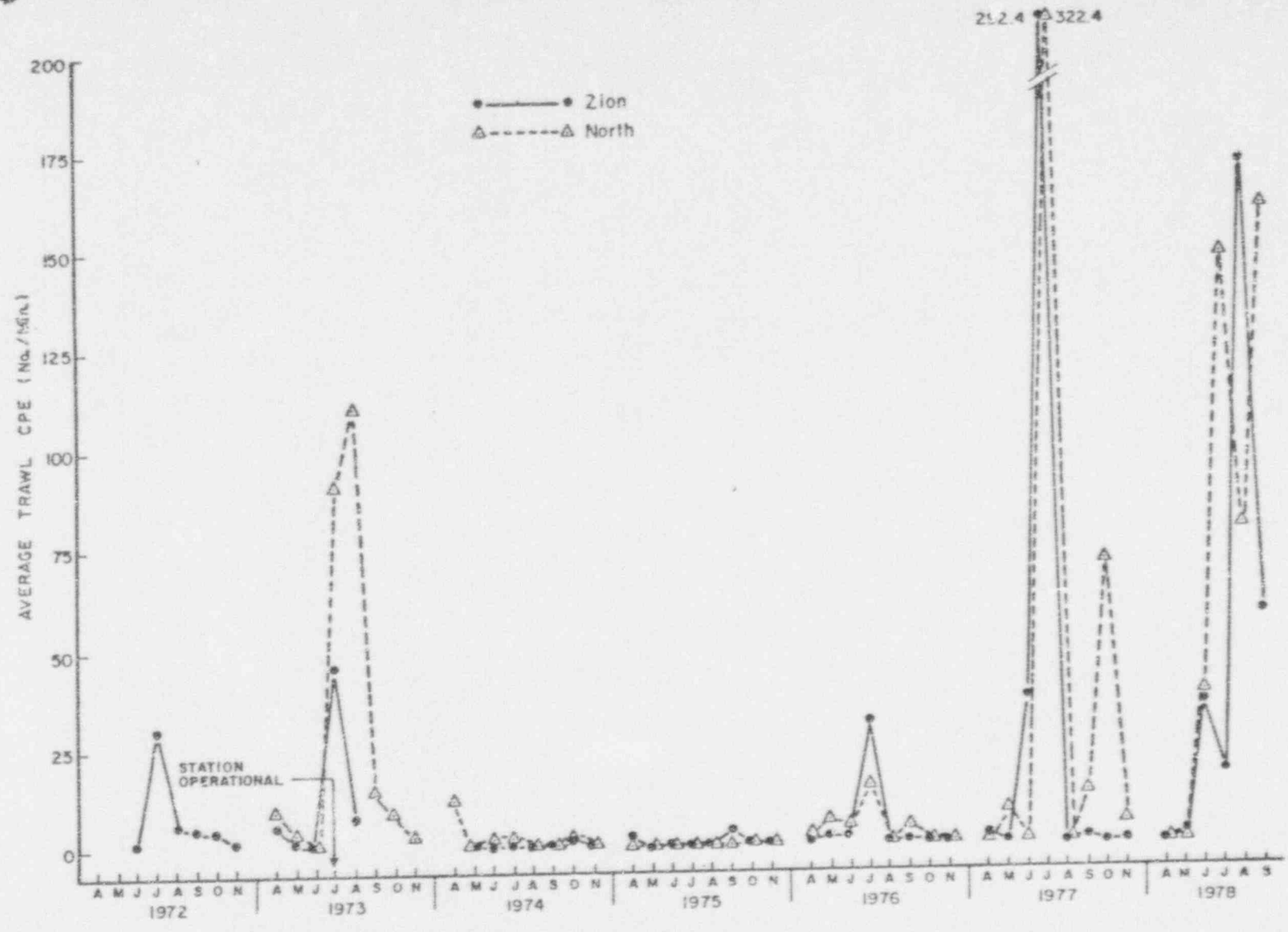


Figure 4. Average trawl catch-per-effort of rainbow smelt collected along the 12 foot depth contour in the Zion sampling area, 1972 through 1978.

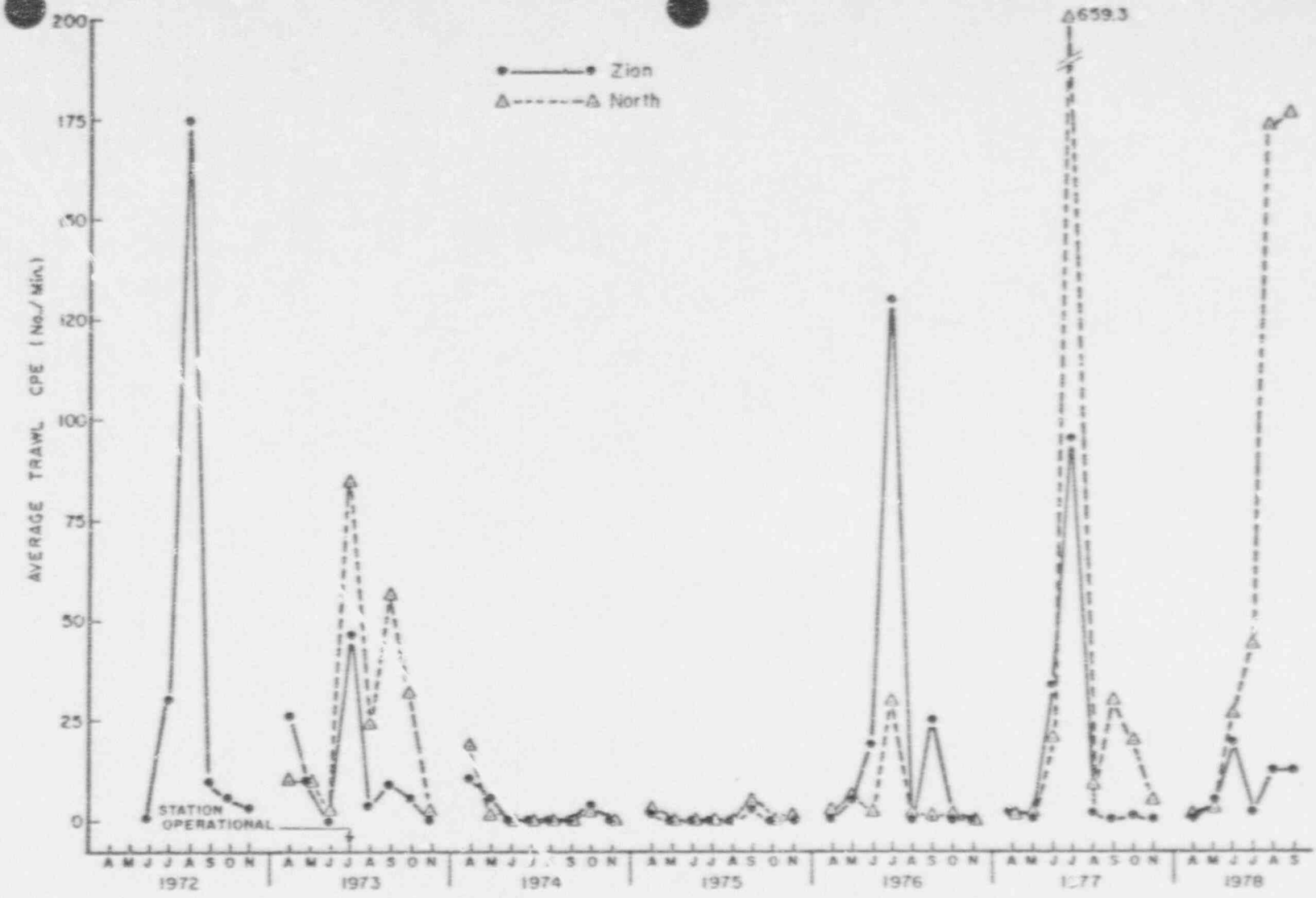


Figure 5. Average trawl catch-per-effort of rainbow smelt collected along the 18 foot depth contour in the Zion sampling area, 1972 through 1978.

C. Age and Growth

Throughout all years of monitoring studies, data were collected on the age structure of yellow perch and lake trout inhabiting the sampling area. Yellow perch were aged by scale impressions while lake trout were aged through fin clip records.

Yellow perch catches were comprised primarily of two to five year old fish, with age groups III and IV constituting the majority of the catch (Figure 6). Very few yearling or young-of-year yellow perch were collected thoughout the study period and larval fish monitoring studies (Chapter 10, this report) have found little evidence that perch utilize the study area as a spawning or nursery area. Yellow perch were collected in greatest numbers in 1972, with moderate catches occurring in 1971 and 1973 (Figure 6). These catches consisted primarily of fish produced from 1967 through 1970 year classes. The 1969 year class was a particularly strong one, produced in southeastern Lake Michigan (Wells 1978a). These data suggest that yellow perch abundance in the Zion area is partially dependent on year class strength and movement of fish, produced elsewhere, into the area.

Age composition of lake trout catches have remained relatively stable over the years. Virtually all lake trout collected have been fin clipped (stocked) indicating little or no contribution from natural reproduction. The majority of the gill net catch of lake trout during the last four years has consisted of three to six year old fish (Figure 7). Seven to ten year old fish have contributed very little to the catch. Similar results have

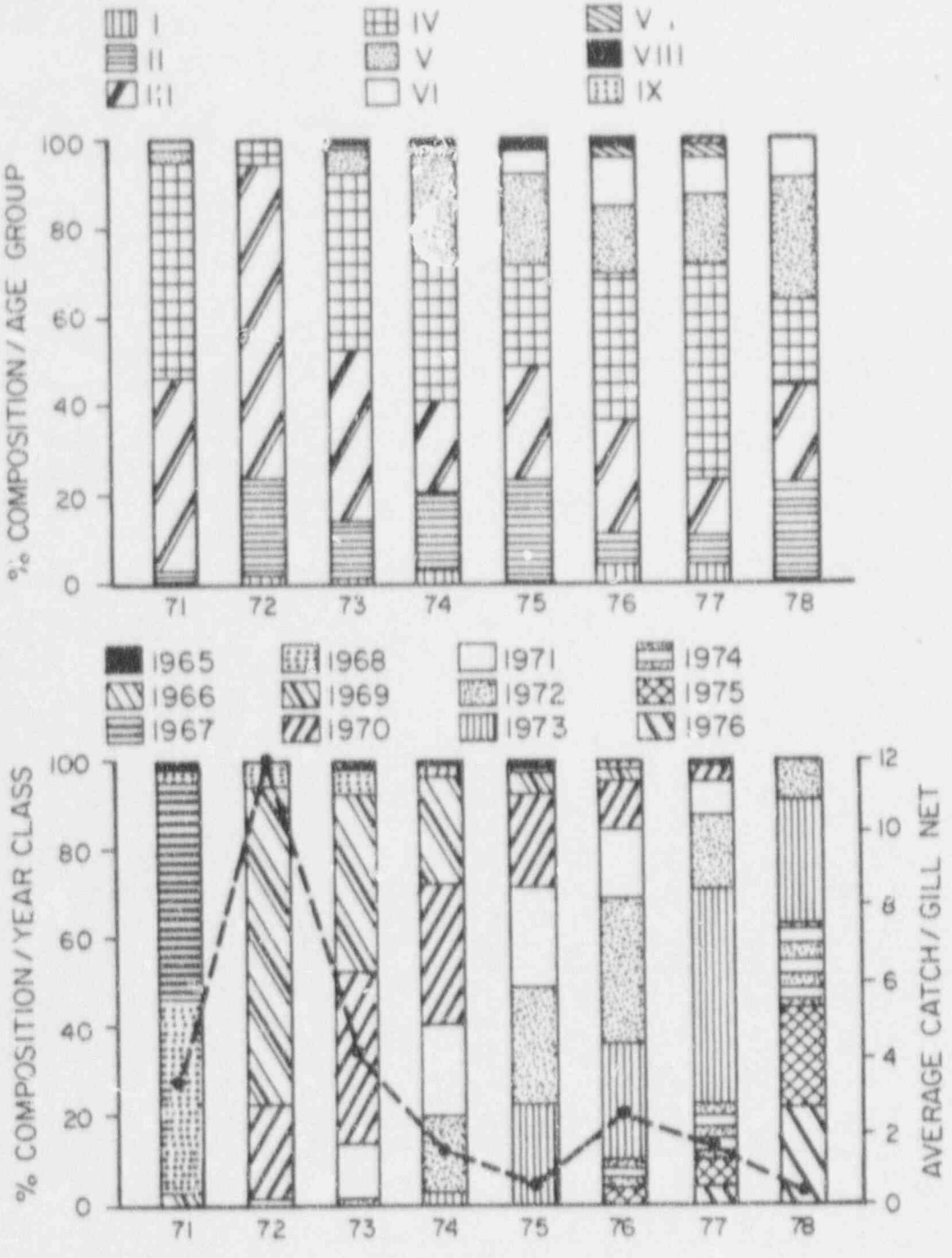


Figure 6. Age group and year class composition of yellow perch catches from the Zion sampling area, 1971 through 1978.

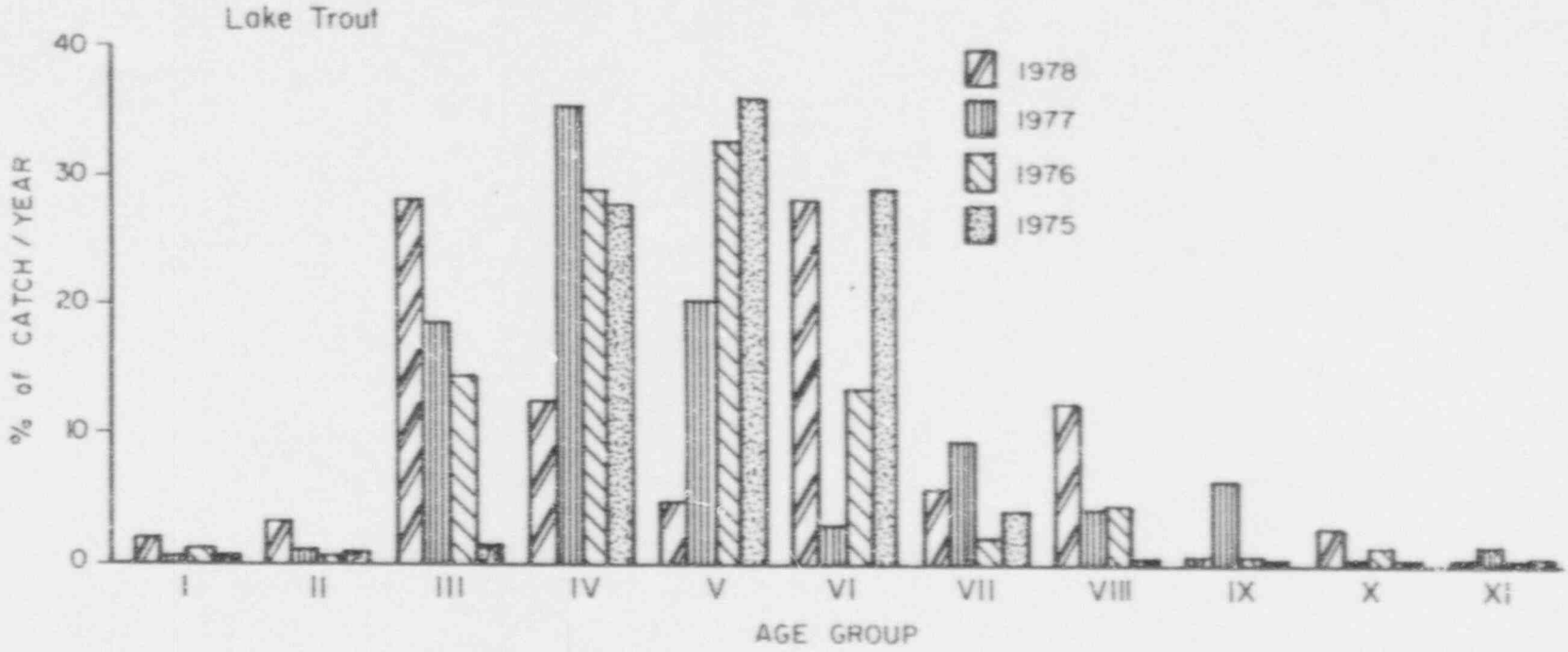


Figure 7. Age group composition of lake trout catches from the Zion sampling area, 1975 through 1978.

HAZLETON ENVIRONMENTAL SCIENCES

recently been experienced by the Illinois Department of Conservation (B.I. Muench, personal communication). Studies conducted in northwestern Lake Michigan (LaJeone 1975, 1976, 1977) have yielded relatively large numbers of seven to ten year old lake trout. Fin clip records showed that many of these fish were originally stocked in Illinois waters, suggesting that older trout are migrating from Illinois waters to the northern basin of the lake.

Alewife age and growth studies were conducted in 1977 and 1978 to determine if growth was similar between the Zion Zone and the North Zone (LaJeone 1978a and b). Equal numbers of fish were randomly collected from each zone during each year. The majority of alewives collected in 1977 were three and four years old fish while the 1978 catch consisted primarily of four and five years olds. In spite of the random selection process, 83% of the 1977 collection were females; however, in 1978 females comprised only 39% of the collection. During both studies, slopes for weighted linear regression analysis of back-calculated lenghth data were not significantly different between zones. The alewife population within the entire sampling area exhibited the same growth rates.

D. Condition Factors

Condition factor data have been compared between zones since 1973. Data were grouped by size class, date, location and sex, and compared using a Mann-Whitney U test. Data presented have been primarily for alewife and smelt though data were also presented for other species when sufficient numbers were collected. From 1973 through 1978, a total of 2808 individual tests was reported

to have been performed. Of these, only 92 tests were significantly different. Those significant differences in condition that did occur were primarily limited to small size groups of alewife and smelt, for which accurate field measurements of weight were difficult. It was concluded that no biologically important differences in the body condition of fish have occurred within the study area since Zion Station began operation.

E. Food Habits

Food habit studies of lake trout, yellow perch and slimy sculpin have been conducted since monitoring began. Lake trout have been primarily piscivorous, consuming mostly alewife and smelt, though slimy sculpin occasionally contributed to their diet. Yellow perch consumed a wide variety of fish and aquatic macroinvertebrates, and appeared to be somewhat selective, in that they did not necessarily prey heavily on young smelt or alewife when these species were abundant. Slimy sculpin prey heavily on Pontoporeia affinis, though other macroinvertbrates are also consumed. No detectable changes in the feeding habits of these species have occurred throughout the eight year monitoring period.

F. Fecundity Estimates

Fecundity estimates for several species have been done over the years. Results of these estimates from 1973 through 1975 have been reported by Cima et al (1976). Subsequent fecundity data for 1976 through 1978 were reported by Cochran (1977a), Cochran and Ott (1977) and LaJeone (1978b). The number of species for which fecundity was determined varied from year to

year due to scopes of work for various annual studies and the availability of ripe females. Fecundity was estimated for alewife from 1973 through 1978, rainbow smelt from 1973 through 1975 and in 1977, slimy sculpin from 1973 through 1975, bloater in 1974 and 1975, lake trout in 1974 and yellow perch in 1973.

Data on egg numbers were compared by converting to number of eggs per gram of body weight. These fecundity values remained comparable for bloater and slimy sculpin. Comparisons of alewife and smelt fecundity from 1973 through 1975 were reported by Gerking (1976). During this time period, smelt fecundity values increased while alewife fecundity values declined. Gerking suggested that fecundity increases of smelt were possibly a compensatory response to a declining adult population which should result in a leveling off of the population rather than a continued decline. Fecundity estimates for smelt in 1977 were quite low, possibly due to the fact that females had already begun spawning by the time fecundity samples were collected.

Alewife fecundity, which had declined between 1973 and 1975, increased in 1976 and declined again in 1977 and 1978. These fluctuations were not interpreted by Gerking (1976) in relation to changes in the adult population. If fecundity varies with adult population levels, as suggested, it follows that fluctuations in the alewife population may also have occurred. Numerous ecological factors may effect fish populations and ultimately the fecundity of a species; however, unless the influence of other factors are known, estimation of the effects of Zion Station operation on the fecundity of a species cannot be accurately determined.

G. Changes in Fishery

Though changes in the distribution and seasonal occurrence of principle fish species have not occurred, some measurable changes in the abundance of several species have been observed. Annual catches have been standardized (average catch/ trawl tow and average catch/gill net) to permit comparison between years, since sampling efforts have varied considerably. Average catches for eight species commonly collected by trawl are presented in Table 10 and average catches for ten species commonly captured by gill net are presented in Table 11.

Average trawl catches of alewife have varied considerably (Table 10). Catches were high from 1971 through 1973, declined in 1974 and 1975, and reached their lowest level in 1978. Large average catches of alewife in 1976 and 1977 were primarily the result of a few unusually large trawl catches of juvenile alewife during the fall of 1976 and spring of 1977. Abundance of adult alewife in 1976 and 1977 appeared comparable to the 1974 and 1975 collections. Unusually low average catches of alewife in 1978 were undoubtedly influenced by colder than normal inshore water temperatures and to the fact that sampling was completed in September, prior to the time when juvenile alewife contribute substantially to the trawl catch. Gill net catches of alewife did not show the annual fluctuations detected from trawl data (Table 11). The meshes used in these gill nets captured only adult alewife and catch efficiency was undoubtedly impeded when small meshes were already filled with fish. Indication of this stems from

Table 10. Average catches of principle species collected by trawl in the Zion sampling area, 1971 through 1978.

Species	Average Catch/Trawl Tow/Zone/Year															
	1971		1972		1973		1974		1975		1976		1977		1978	
	Zion	North	Zion	North	Zion	North	Zion	North	Zion	North	Zion	North	Zion	North	Zion	North
Alewife	679.5	a	459.5	a	640.9	465.8	351.+	434.7	221.7	279.9	737.3	721.6	454.5	502.2	94.9	52.3
Rainbow smelt	240.3	a	160.2	a	117.7	101.4	21.2	12.8	12.8	3.2	87.9	33.8	357.1	174.8	77.8	199.9
Bloater	14.4	a	7.1	a	2.1	1.0	b	b	0.2	0.1	1.7	0.5	0.6	0.4	19.2	44.7
Slimy sculpin	0.5	a	b	a	0.5	0.7	0.6	2.3	0.3	0.2	b	0.6	0.1	0.4	0.5	0.9
Trout-perch	0.1	a	0.1	a	0.1	0.3	b	0.0	0.0	0.0	0.3	0.6	1.2	1.5	1.9	2.2
Ninespine stickleback	0.0	a	b	a	0.1	0.1	b	b	b	b	b	0.1	0.2	0.6	0.7	0.5
Spottail shiner	0.1	a	0.3	a	0.2	0.5	b	0.2	0.3	0.1	0.1	b	0.1	0.3	0.0	0.3
Yellow perch	0.1	a	0.4	a	0.2	0.2	0.1	0.2	0.1	0.1	b	b	0.1	b	b	0.2

[a] No sampling scheduled.
[b] Less than 0.05.

HAZLETON ENVIRONMENTAL SCIENCES

Table 11. Average catches of principle species collected by gill net in the Zion sampling area, 1971 through 1978.

Species	Average Catch/Gill Net/Zone/Year															
	1971		1972		1973		1974		1975		1976		1977		1978	
	Zion	North	Zion	North	Zion	North	Zion	North	Zion	North	Zion	North	Zion	North	Zion	North
Alewife	21.0	a	45.9	a	150.4	168.2	190.1	202.8	135.3	147.6	250.2	225.8	154.7	166.6	180.6	142.7
Rainbow smelt	1.0	a	4.9	a	11.8	13.5	19.4	8.2	10.9	9.2	7.8	7.8	3.5	10.9	4.3	4.6
Bloater	7.9	a	5.2	a	6.7	4.6	3.3	1.2	0.4	0.4	1.2	1.1	0.4	1.3	b	0.8
Yellow perch	3.3	a	12.0	a	6.1	2.2	1.8	1.3	1.0	0.3	3.8	1.4	2.1	1.3	0.4	0.6
Lake trout	0.4	a	3.3	a	1.2	2.1	1.9	1.8	1.6	1.6	4.8	3.8	10.1	8.5	9.2	9.0
Coho salmon	0.9	a	0.7	a	1.2	1.8	4.1	2.0	3.5	0.9	8.0	4.3	6.4	2.6	5.8	5.2
Chinook salmon	0.1	a	0.3	a	0.5	0.5	1.8	1.0	0.3	0.2	0.6	0.4	1.9	2.0	0.3	0.5
Brown trout	0.2	a	0.1	a	0.2	0.2	1.5	0.7	1.1	0.4	0.8	0.3	1.6	0.9	1.3	0.3
Rainbow trout	0.0	a	0.0	a	b	0.1	0.5	0.3	1.4	0.9	1.1	0.1	1.0	0.5	0.2	b
White sucker	0.4	a	b	a	0.1	0.1	0.2	0.8	0.1	0.1	0.3	0.4	0.2	0.1	0.2	0.4

[a]No sampling scheduled.
[b]Less than 0.05.

comparison of average gill net catches from 1973 through 1978. Except in 1976, average gill net catches were generally comparable despite the variability in average annual trawl catches. Low average gill net catches of alewife in 1971 and 1972 occurred because the 50 ft panel of 1 1/2 inch mesh was not fished until 1973.

Lakewide declines in alewife abundance, which appear to have stabilized now, have been reported in recent years (Wells 1978b). Notable declines were reported in 1976 and 1977. October 1978 cruise reports from the U.S. Fish and Wildlife Service (1978) indicate that alewife catches were up again this year. The difference in results between Zion trawl data and the U.S. Fish and Wildlife Service data is felt to be due to a greater sampling effort within a smaller area at Zion. This afforded a greater opportunity at capturing large numbers of alewife when they occur in inshore waters. Comparisons of alewife trawl catch-per-effort data in the Zion sampling area during October were made with U.S. Fish and Wildlife Service fall assessment trawl data from comparable depths at various index transects within the southern basin of Lake Michigan (Table 12). These data illustrate the high degree of variability in catch rates along each transect, from one year to the next and from one transect to the next. No one transect appeared to be continually more productive than any other, and catch rates in the Zion sampling area were typical of those recorded by the U.S. Fish and Wildlife Service. It is generally agreed that alewife are less abundant in Lake Michigan in recent years

Table 12. Average catch-per-effort of alewife collected by trawl during October in the Zion sampling area and during autumn assessment off Waukegan, Benton Harbor and Saugatuck, 1971 through 1978.

	Average Trawl CPE (No./min.)/Transect/Year														
	Zion Zone			North Zone			Waukegan[a]			Benton Harbor[a]			Saugatuck[a]		
	Depth (ft)			Depth			Depth			Depth			Depth		
Year	18	30	42	18	30	42	18	30	42	18	30	42	18	30	42
1971	b	87.5	60.6	b	b	b	104.2	6.8	0.1	469.2	170.2	11.5	150.2	9.9	7.7
1972	108.1	56.7	91.2	b	b	b	10.0	10.2	22.2	25.2	25.1	14.9	35.0	50.5	6.0
1973	129.4	85.3	36.1	97.0	71.8	100.9	9.2	1.6	32.9	365.4	24.5	8.0	14.0	500.7	27.2
1974	4.2	14.8	185.1	18.3	8.9	10.3	45.4	17.7	315.8	1.4	95.3	27.6	203.6	5.2	76.9
1975	23.1	0.1	105.9	112.8	55.2	21.9	72.2	0.2	17.4	65.4	39.0	56.5	71.0	116.3	28.9
1976	2.2	2.2	321.6	3.5	13.9	4.0	0.4	14.3	20.6	5.4	15.6	6.9	42.4	89.0	21.9
1977	31.6	302.5	268.9	56.7	806.5	559.5	75.8	1.1	b	107.8	1.4	b	6.0	613.7	b
1978	b	b	b	b	b	b	b	220.9	b	b	401.6	57.7	b	248.7	256.6

[a]Data provided by U.S. Fish and Wildlife Service.
[b]No sampling scheduled.

HAZLETON ENVIRONMENTAL SCIENCES

than they were in the early 1970's.

The influence of the alewife on the abundance of other species has been discussed (Smith 1970; Wells 1978a; Wells and McLain 1973). Competition for space and food, as well as predation on larvae, have been suggested as possible explanations for declines in smelt, bloater and yellow perch populations. If alewife abundance has declined in recent years, as suspected, this may partially explain increases in the abundance of ther principle species in the Zion sampling area.

Average trawl catches of rainbow smelt were high in 1971 but declined to extremely low levels in 1974 and 1975 (Table 10). Catches began to increase in 1976 and moderately large catches were also taken in 1977 and 1978. Similar increases in smelt abundance, particularly along the western shore of Lake Michigan have also been reported in recent cruise summaries of the U.S. Fish and Wildlife Service (1978). As in the case of alewife, comparisons of smelt catch-per-effort with U.S. Fish and Wildlife Service assessment data exhibited high variability and show that Zion area trawl catches were comparable to Federal assessment catches (Table 13). Trawl catches of smelt in the Zion area since 1976 have been comprised predomenantly of juvenile and young adult fish probably produced since 1975.

Both trawl and gill net catches of bloater declined to very low levels; however, average trawl catches of bloaters comprised almost exclusively of juveniles, increased dramatically in 1978 (Tables 10 and 11). From July through September 1978 more bloaters

Table 13. Average catch-per-effort of rainbow smelt collected by trawl during October in the Zion sampling area and during autumn assessment off Waukegan, Benton Harbor and Saugatuck, 1971 through 1978.

	Average Trawl CPE (No./min.)/Transect/Year														
	Zion Zone			North Zone			Waukegan[a]			Benton Harbor[a]			Saugatuck[a]		
	Depth (ft)			Depth			Depth			Depth			Depth		
Year	18	30	42	18	30	42	18	30	42	18	30	42	18	30	42
1971	b	14.2	0.3	b	b	b	1.6	0.1	0.6	2.0	8.3	0.3	0.6	6.7	7.4
1972	6.4	8.6	16.3	b	b	b	3.4	2.3	12.3	1.0	1.0	0.1	0.2	0.7	1.2
1973	5.9	19.3	72.1	32.1	29.3	93.3	6.2	1.4	15.6	4.4	1.1	2.7	0.6	3.2	17.4
1974	3.3	0.9	4.1	2.9	2.4	2.2	1.2	0.8	12.7	5.2	0.9	7.0	0.0	0.4	0.3
1975	0.0	0.0	0.0	0.0	0.0	0.1	3.8	3.2	0.9	4.8	12.9	4.8	0.0	1.0	1.0
1976	0.1	0.0	2.2	1.0	0.4	3.4	8.8	28.2	27.3	2.6	2.9	1.6	10.4	76.3	65.8
1977	1.0	3.6	9.5	20.4	26.2	2.6	1.0	3.9	b	0.8	4.8	b	0.0	0.1	b
1978	b	b	b	b	b	b	b	14.1	b	b	2.6	0.5	b	3.6	6.9

[a]Data provided by U.S. Fish and Wildlife Service.
[b]No sampling scheduled.

HAZLETON ENVIRONMENTAL SCIENCES

were collected than in all previous years of monitoring combined (LaJeone 1979). Sharp increases in trawl catches of juvenile bloaters have also occurred lakewide in 1978 (U.S. fish and Wildlife Service 1978). Again, October catch figures for bloater from the Zion sampling area were comparable to those obtained by the U.S. Fish and Wildlife Service (Table 14).

Trawl catches of less common species, namely troutperch and ninespine stickleback, have also increased in recent years (Table 10). Slimy sculpin were taken in moderate numbers by trawl only in 1973 and 1974 in the North Zone. These catches correspond to the first 1 1/2 years of sampling in that zone and the decline of slimy sculpins in that zone may be related to our collection efforts. Too few spottail shiners or yellow perch were collected by trawl to detect if there were any change in their abundance.

Gill net catches of yellow perch have been generally low, though good average catches were taken in the Zion Zone in 1972 and 1973 (Table 11). As previously mentioned, these catches were comprised primarily of fish from the strong 1969 year class. The 1969 year class was produced during a time when alewife abundance in Lake Michigan was low, following the 1967 die-off. Relatively poor catches of perch have also occurred in recent years off Lake Bluff, an index transect of the U.S. Fish and Wildlife Service (Wells 1978a).

Average gill net catches of salmonids have generally increased over the years, particularly for lake trout and coho salmon (Table 11). These increases are attributed to increased

Table 14. Average catch-per-effort of bloater collected by trawl during October in Zion sampling area and during autumn assessment off Waukegan, Benton Harbor and Saugatuck, 1971 thrcugh 1978.

	Average Trawl CPE (No./min.)/Transect/Year														
	Zion Zone			North Zone			Waukegan[a]			Benton Harbor[a]			Saugatuck[a]		
	Depth (ft)			Depth			Depth			Depth			Depth		
Year	18	30	42	18	30	42	18	30	42	18	30	42	18	30	42
1971	b	3.2	1.1	b	b	b	4.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1972	4.2	3.0	3.9	b	b	b	0.0	0.1	0.6	0.0	0.0	0.0	0.0	0.0	0.0
1973	0.5	0.4	3.8	0.5	0.3	2.6	0.0	0.1	0.5	0.2	0.0	0.8	0.2	0.7	0.3
1974	0.0	0.0	0.1	0.1	0.0	0.1	0.0	0.2	0.9	0.4	0.4	0.2	0.0	0.3	0.2
1975	0.0	0.0	0.1	0.0	0.0	0.0	1.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.1
1976	0.0	0.1	0.1	0.0	0.1	0.2	0.0	0.0	0.3	0.0	0.0	0.3	0.0	0.0	0.0
1977	0.1	0.0	0.2	0.7	1.6	0.3	0.0	0.8	b	0.2	0.2	b	0.0	0.0	b
1978	b	b	b	b	b	b	b	1.5	b	b	0.0	0.4	b	3.5	18.2

[a]Data provided by U.S. Fish and Wildlife Service.
[b]No sampling scheduled.

HAZLETON ENVIRONMENTAL SCIENCES

stocking efforts since natural reproduction contributes little, if at all, to the salmonid fishery. No increase in the abundance of adult trout or salmon, during their respective spawning seasons, has been detected within the Zion sampling area.

White suckers were collected in low numbers during each year of monitoring; however, there has been no appreciable change in their abundance.

Changes in the abundance of several principle species have been detected form the monitoring studies for Zion Station, but supportive catch data from the U.S. Fish and Wildlife Service indicate that these changes have not been restricted to that area of Lake Michigan in the vicinity of the Station. Fluctuations in the alewife population of Lake Michigan may have contributed to changes in abundance of several species. The high population of alewives that developed in the 1960's has been associated with declines in smelt, bloater and yellow perch populations. A relatively large population of alewives in the early 1970's might, expectedly, have resulted in the delines in smelt and bloater abundance observed in these studies. Subsequent declines in the alewife population, for any number of reasons, may have resulted in population increases for smelt, bloater, trout-perch and ninespine stickleback. However, strict commercial fishing controls on bloater harvests may be another factor in the increased abundance of this species.

V. Literature Cited

Bailey, R.M. 1970. A list of common and scientific names of fish from the United States and Canada. 3rd ed. Amer. Fish. Soc. Spec. Publ. 6. 150 pp.

Cima, G., M. Cochran and M. Kitchel. 1976. Annual interpretive report on fish eggs and larvae in Lake Michigan near Zion and Waukegan generating stations 1975. Report to Commonwealth Edison Company, Chicago, Illinois. p 1-153.

Cochran, M. 1973. Fish populations and life histories in southwestern Lake Michigan, April 1971-December 1971. Project IX. IN Evaluation of thermal effects in south-western Lake Michigan, 1971-1972. Report to Commonwe lth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I: 78 pp.

_____. 1974a. Fish study. IN Environmental monitoring in Lake Michigan near Zion and Waukegan Generating Station, January 1972 through December 1972. Report to Common-wealth Edison Company.

_____. 1974b. Adult fish study. IN Environmental monitoring in Lake Michigan near Zion and Waukegan Generating Stations, January 1973 through July 1973. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. 212 pp.

_____. 1974c. Adult fish study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through December 1973. Semi-Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. III: 171-336.

_____. 1974d. Adult fish study. IN Operational environmental monitoring in Lake Michigan near Zion Station, January 1974 through June 1974. Semi-Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. III: 219-408.

_____. 1975. Adult fish study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1974 through June 1975. Report to Commonwealth Edison Company. Chicago, Illinois by NALCO Environmental Sciences.

_____. 1976a. Adult fish study. IN Operational environ-mental monitoring in Lake Michigan near Zion Station, July 1975 through December 1975. Semi-Annual report to Common-wealth Edison Company, Chicago,Illinois by NALCO Environ-mental Sciences.

Cochran, M. 1976b. Adult fish study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1975 through June 1976. Annual report to Commonwealth Edison company, Chicago, Illinois by NALCO Environmental Sciences, Vol. VI: 83-298.

_____. 1977. Adult fish study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1976 through December 1976. Semi-Annual report to Commonwealth Edison Company, Chicago, Illinois by NALCO Environmental Sciences, Vol. II: 405-490.

_____ and T. Ott. 1977. Adult fish study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1976 through June 1977. Annual report to Commonwealth Edison Company, Chicago, Illinois by NALCO Environmental Sciences. Vol. III: 207-416.

Gerking, S.D. 1976. Report on fecundity in the Waukegan-Zion sampling area of Lake Michigan for Commonwealth Edison Company. IN: Compilation of reports relating to entrainment and impingement studies at Zion Generating Station, 1976. Report to Commonwealth Edison Company, Chicago, Illinois by NALCO Environmental Sciences. Vol. II: 7 p.

Illinois Department of Conservation. 1978. Article CXXXVIII-Illinois list of endangered and threatened vertebrate species issued in accordance with provisions of section 337 of the Illinois endangered species protection act. Springfield, Illinois. 3 p. mimeo.

Industrial BIO-TEST Laboratories, Inc. 1971. Fish populations and life histories. Project IX (IBT No. W9493). IN Evaluation of thermal effects in southwestern Lake Michigan. Waukegan and Zion Generating Stations. April 1971-December 1971. Prepared for Commonwealth Edison Company, Chicago, Illinois.

LaJeone, L.J. 1975. Fish population and life history. Chapter 9. IN; Operational environmental monitoring program of Lake Michigan near Kewaunee Nuclear Power Plant-Chemical and Biological Studies, January-December 1974. Fourth Annual Report prepared for Wisconsin Public Service Corp., Green Bay, Wisconsin, by Industiral BIO-TEST Laboratories Inc., Northbrook, Illinois. 61 p.

_____. 1976. Fish population and life history. Chapter 9. IN: Operational environmental monitoring program of Lake Michigan near Kewaunee Nuclear Power Plant-Chemical and Biological Studies, January-December 1975. Fifth Annual Report prepared for Wisconsin Public Service Corp., Green Bay, Wisconsin, by NALCO Environmental Sciences, Northbrook, Illinois. 71 p.

LaJeone, L.J. 1977. Fish population and life history. Chapter 9. IN: Operational environmental monitoring program of Lake Michigan near Kewaunee Nuclear Power Plant, January-December 1976. Sixth Annual Report to Wisconsin Public Service Corp., Northbrook, Illinois. 70 p.

_____. 1978a. Adult fish study. IN Operational environmenatal monitoring in Lake Michigan near Zion station, July 1977 through December 1977. Semi-Annual report to Commonwealth Edison Company, Chicago, Illinois by NALCO Environmental Sciences.

_____. 1978b. Adult fish study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1977 through June 1978. Annual report to Commonwealth Edison Company, Chicago, Illinois by NALCO Environmental Sciences. Vol. II: 171-405.

_____. 1979. Adult fish study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July through September 1978. Supplemental report to Commonwealth Edison Company, Chicago, Illinois by Hazleton Environmental Sciences Corporation. 73-174.

Wench, B.I. 1974. Adult fish study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through June 1974. Annual report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. III: 141-200.

Smith, S.H. 1970. Species interactions of the alewife in the great lakes. Trans. Amer. Fish. Soc. 99(4): 754-765.

Wells, L . 1978a. Changes in yellow perch (Perca flavescens) populations of Lake Michigan, 1954-1975. J. Fish. Res. Board Can. 34: 1821-1829.

_____. 1978b. Status of alewife and yellow perch in Lake Michigan. Presented at Great Lakes Fishery Commission, Lake Michigan Committee Meeting, Milwaukee, Wisconsin. 3 p. mimeo.

_____ and A.L. McLain. 1973. Lake Michigan: mans effects on native fish stocks and other biota. Great Lakes Fishery commission, Tech. Rept. No. 20: 55 p.

U.S. Fish and Wildlife Service. 1978. Cruise report Nos. IV, VII, IX and X of the R/V Cisco in Lake Michigan, 1978. Great Lakes Fishery Commission, Ann Arbor, Michigan.

Chapter 12

FISH IMPINGEMENT AND ENTRAINMENT STUDIES

by

John O. Rice
Steven D. Garbarino
and
Larry J. LaJeone

SUMMARY REPORT OF ENVIRONMENTAL MONITORING
IN LAKE MICHIGAN NEAR ZION STATION

January 1970 through September 1978

TABLE OF CONTENTS

		Page
	List of Figures	481
	List of Tables	483
I.	Introduction	485
II.	Materials and Methods	487
	A. Impingement	487
	B. Entrainment	491
	C. Forebay Stocking	494
III.	Results and Discussion	495
	A. Impingement	495
	B. Entrainment	508
	C. Forebay Stocking Returns	517
IV.	Literature Cited	519

LIST OF FIGURES

No.	Caption	Page
1	Schematic of cooling water circulation at Zion Station showing intake/discharge sampling locations	488
2	Schematic of Zion Station traveling screen operations from forebay to trash containers	489
3	Estimated number of alewife and rainbow smelt impinged at Zion Station, September 1973 through December 1975 and March through July 1977	500
4	Number of alewife and rainbow smelt impinged on the Zion Station traveling screens at various intake flow rates, 1973 through 1974	502
5	Number of alewife and rainbow smelt impinged on the Zion Station traveling screens and mean daily flow through the plant, 1975	503
6	Summary of fish impingement counts at Zion Station from March through July, 1977	504
7	Seasonal distribution (% of total number) of alewife and rainbow smelt impinged at Zion Station, collected at 18' by trawl and 20' by gill net, and mean observed flow through Zion Station, 1975	506
8	Seasonal occurrence and spawning times of adult fish collected in the Zion-Waukegan sampling area	509
9	Mean number of rainbow smelt eggs collected in the Zion Station forebay and discharge; at Stations Z-3 and Z-4, 20' with plankton nets; and Stations Z-1, Z-3 and Z-4 by pump, 1975	512

LIST OF TABLES

No.	Title	Page
1	Summary of the impingement sampling program used at Zion Station, September 1973 through December 1975 and March 1977 through July 1977	490
2	Summary of the ichtyoplandton entrainment sampling program used at Zion Station, March 1974 through November 1975	492
3	Estimated numbers and weights of fish impinged on the Zion Station traveling screens, September 1973 through December 1975 and March 1977 through July 1977	496
4	Estimated numbers of fish impinged per year on the Zion Station traveling screens, 1973 through 1975 through 1977	498
5	Estimated numbers and weights of fish impinged at Zion Station, January through December and total Lake Michigan commercial production , sport landings, and plantings, 1974	507

I. Introduction

Shorty after Zion Generating Station began commercial operation in July 1973, monitoring studies for fish entrainment and impingement were conducted. Fish impingement studies were conducted continuously from September 1973 through December 1975 (Cochran and Kitchel 1976; Industrial BIO-TEST Laboratories, Inc. 1975; Kitchel 1973, 1974, 1975; Kitchel and Otto 1974; NALCO Environmental Sciences 1976; Rice 1975), and from March through July 1977 (Cochran and Ott 1977). Ichthyoplankton (fish eggs and larvae) entrainment studies were conducted continuously from March 1974 through November 1975 (Cima et al 1976; Cochran and Cima 1974; Industrial BIO-TEST Laboratories, Inc. 1975; Otto 1975; Rice 1975).

This report is a summary of fish impingement and entrainment studies conducted at Zion Station since operation began. The specific objectives of this report are:

1. to evaluate data on the daily and seasonal variation in composition, number and size of various fish species impinged on the intake screens;

2. to evaluate data on the daily and seasonal variations in composition, number and size of ichthyoplankton entrained in Zion Station's cooling water; and

3. to assess whether or not operation of Zion Station has measurably affected the fish community inhabiting the sampling area.

II. Materials and Methods

A. Impingement

A detailed description of cooling water uptake and circulation through the Station to offshore discharge structures has been previously described by Cochran and Kitchel (1976). The traveling screens at Zion Station are positioned between the trash racks and circulating water pumps in the forebay (Figure 1). These 3/8" square mesh screens extend from the forebay bottom to approximately 30 feet above the water level. The screens travel vertically and can be activated either automatically, through pressure differential, or manually for cleaning. High velocity water jets remove material from the screens, forcing it into a sluiceway which empties to a large collection basket which is then removed from its concrete vault, emptied and cleaned of impinged fish (Figure 2).

The traveling screens were monitored daily from September 1973 through December 1974; every fourth day from January through December 1975; and twice weekly from March through July 1977 (Table 1). The screens were run through at least one complete cycle prior to emptying the collection basket, to insure that all fish retained during that 24-hour period were removed. All fish collected were then identified to species, weighted and measured. When more than thirty individuals of a given species were collected, a random subsample was removed and a total weight on the remainder determined. Fish in the subsample were then weighed and measured separately. An estimated total number was then calculated, according to the formula.

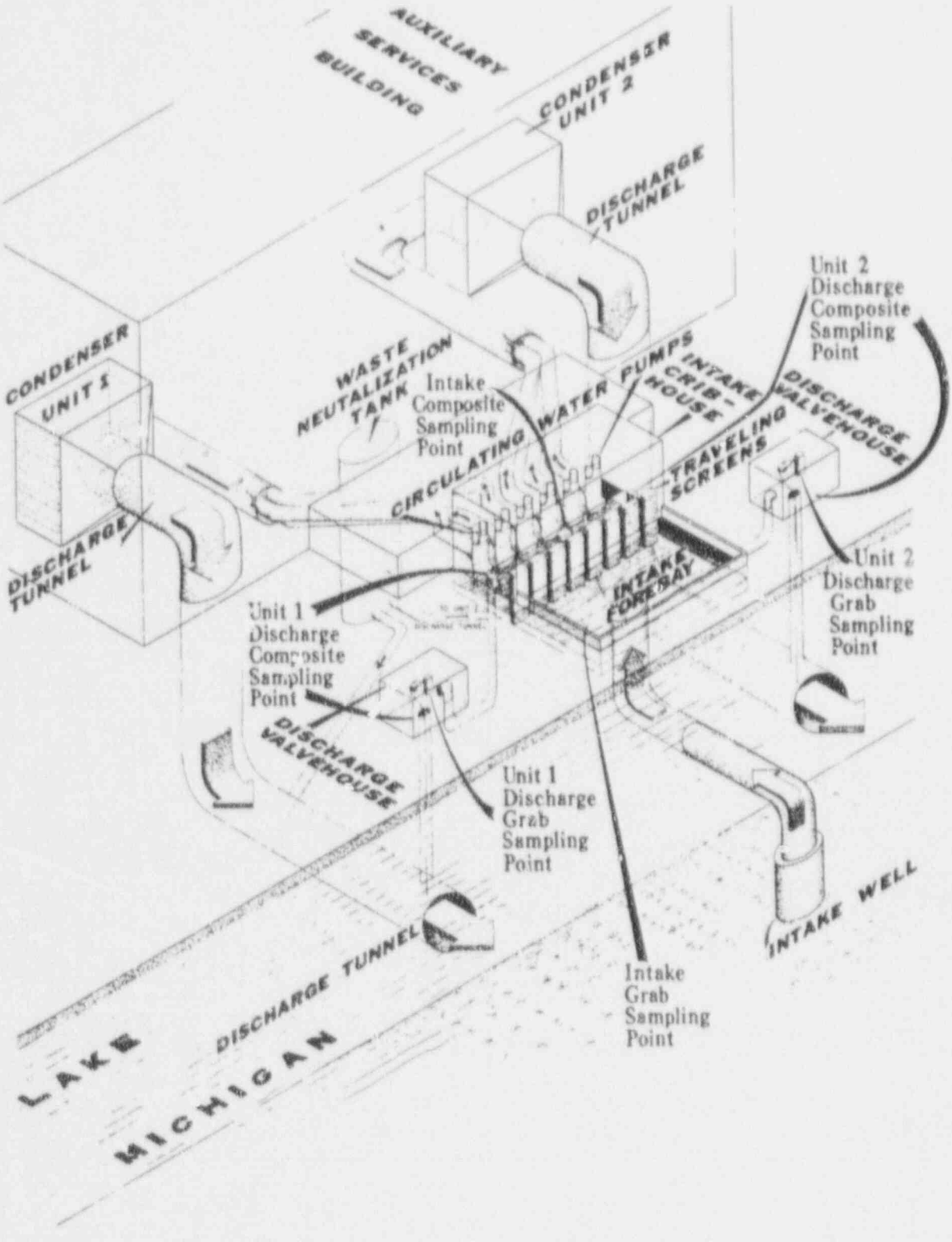


Figure 1. Schematic of cooling water circulation at Zion Station showing intake/discharge sampling locations.

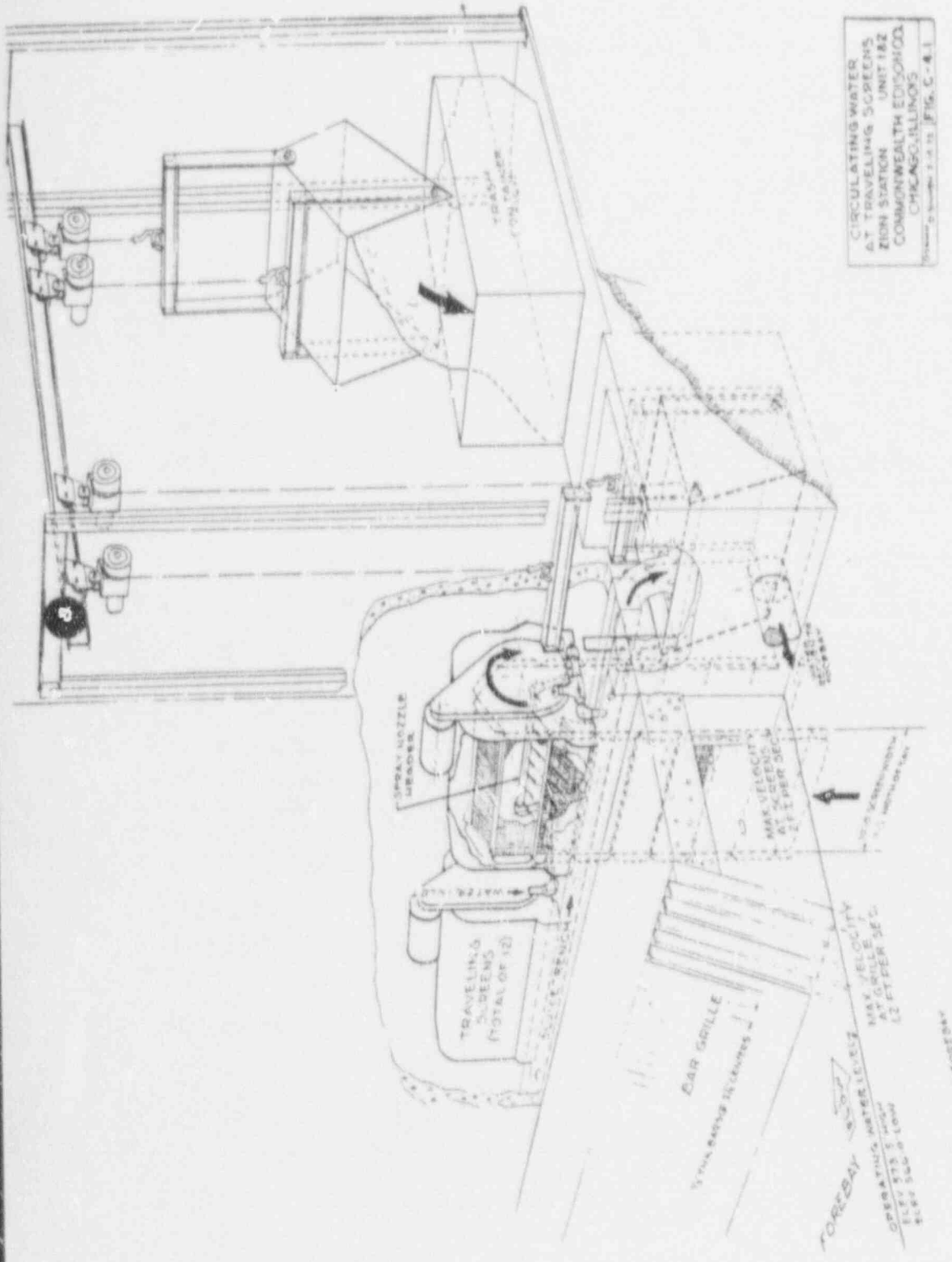


Figure 2. Schematic of Zion Station traveling screen operations from forebay to trash containers.

Table 1. Summary of the impingement sampling program used at Zion Station, September 1973 through December 1975 and March 1977 through July 1977.

Time Period	Sampling Frequency	References
Sep. 1973 - Jun. 1974	Daily	Kitchel, 1973 Kitchel, 1974 Kitchel and Otto, 1974
Jul. 1974 - Dec. 1974	Daily	Rice, 1975 Kitchel, 1975
Jan. 1975 - Jun. 1975	Every Fourth Day	Industrial BIO-TEST, 1975 Kitchel, 1975 Cochran and Kitchel, 1976
Jul. 1975 - Dec. 1975	Every Fourth Day	NALCO ES, 1976 Cochran and Kitchel, 1976
Mar. 1977 - Jul. 1977	Once Weekly	Cochran and Ott, 1977

$$\text{Estimated total number} = \frac{\text{total weight of species}}{\text{subsample weight of species}} \times 30$$

Fish were measured to the nearest 1/10 inch for standard length (the distance from the tip of the snout to the end of the caudal peduncle) and weighed to the nearest 1/8 ounce.

Total number or weight of fish impinged on the screens during a given month was estimated by the formula:

$$\text{estimated monthly total number or weight} = \frac{\text{number of days in month}}{\text{number of sample days}} \times \text{total number or weight actually recorded}$$

Plant operating conditions for the 24-hour period were acquired after completion of the fish count, from log books maintained at the Station control rooms. Data recorded included mean intake flow (GPM), mean intake temperature, mean discharge temperature and mean ΔT (temperature differential).

B. Entrainment

The intake forebay and Unit 1 and 2 discharges were sampled for entrained ichthyoplankton (Table 2). Plankton nets were used for forebay sampling and centrifugal pumps for discharge sampling.

Beginning March 1974 through June 1974, two Nitex plankton conn nets 0.5 m in diameter with #0 mesh aperature, were placed in the Station forebay while at least two circulating pumps per unit or three pumps for both units combined were operating. These nets were allowed to drift in the current for 7-1/2 minutes.

Table 2. Summary of the ichthyoplankton entrainment sampling program used at Zion Station, March 1974 through November 1975.

Time Period	Location	Frequency	Method	Number of Replicates	Duration of Sampling	Interval of Sample Collection	References
Mar. 1974-Jun. 1974	Forebay	Weekly	Plankton net	2	7-1/2 min.	Each 8 hr.	Cochran and Cima, 1974
Jul. 1974-Dec. 1974	Forebay	Weekly	Plankton net	4	7-1/2 min.	Each 8 hr.	Rice, 1975 Otto, 1975
Jan. 1975-Mar. 1975	Forebay	Monthly	Plankton net	4	7-1/2 min.	Each 8 hr.	IBT, 1975 Otto, 1975
Apr. 1975-Jun. 1975	Forebay	Weekly	Plankton net	4	7-1/2 min.	Each 6 hr.	IBT, 1975
	Discharges	Weekly	Pump	1	Continuous	Each 6 hr.	Otto, 1975
Jun. 1975-Aug. 1975	Forebay	Weekly	Plankton net	4	7-1/2 min.	Each 6 hr.	Cima, Cochran and
	Discharges	Weekly	Pump	1	Continuous	Each 6 hr.	Kitchel, 1976
Sep. 1975	Forebay	Twice monthly	Plankton net	4	7-1/2 min.	Each 6 hr.	Cima, Cochran and
	Discharges	Twice monthly	Pump	1	Continuous	Each 6 hr.	Kitchel, 1976
Oct.-Nov. 1975	Forebay	Monthly	Plankton net	4	7-1/2 min.	Each 6 hr.	Cima, Cochran and
	Discharges	Monthly	Pump	1	Continuous	Each 6 hr.	Kitchel, 1976

HAZLETON ENVIRONMENTAL SCIENCES

A General Oceanics Model 2030 digital flow meter was used to measure flow through plankton nets. The volume of each sample was approximately 50 m^3. Samples were collected every 8 hours for a 24-hour period. After June 1974, samples were collected in duplicate (a total of four replicates) every 6 or 8 hours for a 24-hour period. The 6 hour period was somewhat flexible as the desired data was to represent two day and two night collections.

For discharge ampling, two 220 V centrifugal pumps, each rated at approximately 100 GPM, were used to sample Unit 1 and 2 discharges beginning in April 1975. Samples were collected through 3 inch inside diameter PVC lined pipes that extend down to the center of the discharge tunnel for each unit. The sample volume was measured using a Rockwell digital flow-meter calibrated in gallons. Discharge samples were filtered through Nitex plankton nets, with #0 mesh aperture, suspended in a barrel with overflow returning to the discharges via large manholes located in the discharge structures. Samples were collected over a 24-hour period. The nets were cleaned and samples were removed at 6 hour intervals beginning at 1200 hours.

All samples collected by plankton nets and pumping were examined for fish eggs and larvae under a magnifying lens equiped with a flourescent light. Eggs and larvae were counted, measured and identified to the lowest positive taxon using a stereozoom dissecting scope equiped with an ocular micrometer. Identifications were made using morphological characteristics, size, and known spawning times of indigenous fishes. Larvae were specimens

that did not morphologically resemble the adult nor had attained adult fin ray counts. Juveniles were specimens that had completed fins and morphologically resembled the adults. Plankton net collections were reduced to the number of fish eggs or larvae per cubic meter of water sampled (No./m^3). Scientific and common names of all fishes collected are according to Bailey (1970).

C. Forebay Stocking

Ninety rainbow trout were stocked in the Station forebay on 31 October 1975 (Cochran 1976). These fish ranged in size from 245-355 mm. Prior to stocking, these fish were anesthesized in a tub containing 10 ppm quinaldine solution, measured for total length and tagged with a numbered monel jaw tag. After tagging, the fish were transferred to another tub and allowed to revive. Then the fish were placed in the forebay. All fish swam vigorously towards the bottom and no mortality was observed during the first 24 hours after stocking. Impingement collections were then monitored for these tagged trout to provide data on fish residence time within the Station's forebay.

III. Results and Discussion

A. Impingement

1. Seasonal Abundance and Occurrence

An estimated 25.7 million fish, representing 36 species were impinged during the 33 months of impingement sampling (Table 3). Total numbers and weights of fish impinged were dominated by alewife, which comprised 98.9% of the total number and weight, respectively. Estimated weights of fish impinged was determined only from September 1973 through December 1975. No weights were estimated from March through July 1977. Rainbow smelt composed an additional 1% of the total number and weight impinged, respectively. All other species combined totaled less than 0.1% of the total number and weight of fish impinged.

In terms of average numbers of fish impinged per time period, only alewife and rainbow smelt were impinged at a rate higher than one fish per hour over the 33 months sampled (Table 3). Only seven species were impinged at an average rate greater than one fish per day. Important sport or commercial species, other than rainbow smelt, were uniformly impinged in very low numbers.

The number of species impinged was generally highest during the winter when cold water species were inshore and during the spring when inshore spawning activity was heaviest. The number of species impinged declined during the summer and fall. Seasonal occurrence of fish species in impingement results did not correlate exactly with seasonal occurrence of the same species in lake sampling near the Station intake (Cochran and Kitchel 1976). This

Table 3. Estimated numbers and weights of fish impinged on the Zion Station traveling screens, September 1973 through December 1975 and March 1977 through July 1977.

Scientific Name	Common Name	Estimated Total Number Impinged (September 1973 through December 1975 and March 1977 through July 1977)	Percent of Total	Estimated Total Weight (pounds) Impinged (September 1973 through December 1975)	Percent of Total	Average Impingement Rate Per Time Period
Alosa pseudoharqenus	Alewife	25388063	98.9	1666372.5	98.9	
Osmerus mordax	Rainbow smelt	260704	1.0	16254.9	1.0	
Pungitius pungitius	Ninespine stickleback	14147	<0.1	5.1	<0.1	<one fish/hour
Cottus cognatus	Slimy sculpin	6187	<0.1	102.5	<0.1	" "
Notropis hudsonius	Spottail shiner	2251	<0.1	30.5	<0.1	"
Perca flavescens	Yellow perch	1537	<0.1	209.1	<0.1	"
Percopsis omiscomaycus	Trout-perch	1141	<0.1	19.1	<0.1	"
Oncorhynchus kisutch	Coho salmon	639	<0.1	533.8	<0.1	<one fish/da
Catostomus commersoni	White sucker	417	<0.1	654.6	<0.1	" "
Ictalurus melas	Black bullhead	341	<0.1	22.0	<0.1	" "
Salmo gairdneri	Rainbow trout	186	<0.1	61.8	<0.1	" "
Salmo trutta	Brown trout	179	<0.1	99.0	<0.1	" "
Coregonus clupeaformis	Lake whitefish	144	<0.1	194.5	<0.1	" "
Cyprinus carpio	Carp	123	<0.1	752.2	<0.1	<one fish/wee
Dorosoma cepedianum	Gizzard shad	120	<0.1	11.8	<0.1	" "
Oncorhynchus tshawytscha	Chinook salmon	84	<0.1	30.5	<0.1	" "
Umbra limi	Central mudminnow	81	<0.1	1.6	<0.1	" "
Salvelinus namaycush	Lake trout	48	<0.1	17.9	<0.1	" "
Ictalurus nebulosus	Brown bullhead	39	<0.1	a	0.0	" "
Coregonus hoyi	Bloater	31	<0.1	3.9	<0.1	<one fish/month
Lota lota	Burbot	27	<0.1	47.0	<0.1	" "
Rhinichthys cataractae	Longnose dace	13	<0.1	0.4	<0.1	" "
Lepomis cyanellus	Green sunfish	12	<0.1	0.3	<0.1	" "
Notemigonus crysoleucas	Golden shiner	11	<0.1	0.6	<0.1	" "
Lepomis macrochirus	Bluegill	8	<0.1	0.3	<0.1	" "
Notropis atherinoides	Emerald shiner	8	<0.1	0.1	<0.1	" "
Carassius auratus	Goldfish	7	<0.1	0.9	<0.1	" "
Ictalurus natalis	Yellow bullhead	7	<0.1	a	<0.1	" "
Pomoxis annularis	White crappie	5	<0.1	0.1	<0.1	" "
Esox lucius	Northern pike	5	<0.1	0.2	<0.1	" "
Etheostoma nigrum	Johnny darter	3	<0.1	a	0.0	" "
Salvelinus fontinalis	Brook trout	3	<0.1	a	0.0	" "
Ambloplites rupestris	Rock bass	3	<0.1	a	0.0	" "
Catostomus catostomus	Longnose sucker	3	<0.1	a	0.0	" "
Pimephales promelas	Fathead minnow	2	<0.1	0.1	<0.1	" "
Culaea inconstans	Brook stickleback	2	<0.1	0.1	<0.1	" "
Total Number of Species	36					
Total Number		25676581				
Total Weight (pounds)				1685427.4		

[a]Species impinged from March through July 1977; no weight data available.

result was presumably due to differences in sampling effort (field sampling was short-term and the Station operated continuously) and also due to delayed impingement. Fish can live for an extended period of time and show good growth in the Station forebay (see forebay stocking). It was possible for a fish to be entrained in the intake flow but not become impinged until several months later. The actual time of impingement may therefore have been masked by several months of forebay residence, and may have occurred at a time when field sampling indicated the species was not present in the study area.

The number of alewife and rainbow smelt impinged annually varied greatly because of fractional-year sampling during 1973 and 1977 and differences in Station operation during 1975 (Table 4). The total estimated impingement of alewife during 1975 was disproportionately high. The net, which surrounds the intake structure and serves as a fish barrier, was undergoing structural modification and was not installed until 22 May 1975, well after the inshore migration of alewife. Eighteen of the 19 million alewife, which accounted for over 70% of the total number impinged during the four years of study, were impinged during the month of May 1975 when the net was not in place (Cochran and Kitchel 1976). With the intake net in place, alewife impingement should be limited to from 1 to 5 million fish per year, similar to 1974 and 1977. Yearly impingement of rainbow smelt ranged from 10 to 184 thousand

Table 4. Estimated numbers of fish impinged per year on the Zion Station traveling screens, 1973 through 1975 and 1977.

Species	Estimated Total Number Impinged/Year			
	1973[a]	1974	1975	1976[b]
Alewife	94799	1429798	19135638	4727828
Rainbow smelt	10115	183705	39293	27591
Ninespine stickleback	56	672	58	13361
Slimy sculpin	412	3502	558	1715
Spottail shiner	362	563	116	1210
Yellow perch	81	560	530	366
Trout-perch	117	528	8	488
Coho salmon	0	177	106	356
White sucker	0	120	262	36
Black bullhead	1	75	262	3
Rainbow trout	2	63	23	98
Brown trout	0	25	136	18
Lake whitefish	0	85	42	17
Carp	0	40	83	0
Gizzard shad	3	21	96	0
Chinook salmon	1	1	31	51
Central mudminnow	9	42	27	3
Lake trout	0	14	9	25
Brown bullhead	0	0	0	39
Bloater	0	28	0	3
Burbot	0	1	23	3
Longnose dace	0	1	12	0
Green sunfish	6	6	0	0
Golden shiner	1	3	4	3
Bluegill	0	8	0	0
Emerald shiner	0	0	8	0
Goldfish	0	7	0	0
Yellow bullhead	0	0	0	7
White crappie	0	2	0	3
Northern pike	0	1	4	0
Johnny darter	0	0	0	3
Brook trout	0	0	0	3
Rock bass	0	0	0	3
Longnose sucker	0	0	0	3
Fathead minnow	0	2	0	0
Brook stickleback	0	2	0	0
Total Number Species	14	29	23	26
Total Number	105965	1620053	19177329	4773235

[a] September 1973 through December 1973
[b] March 1977 through July 1977

fish.

Seasonal impingement rates of alewife and rainbow smelt differed with their inshore abundance (Figure 3). Alewives were impinged in the greatest numbers from April through June, with the major peak occurring in May of each year. In contrast, the number of alewives impinged during the winter was generally low with a minor peak occurring in October or November. Rainbow smelt were impinged in large numbers, twice yearly, with one peak occurring in March and April and another peak occurring in the fall (September 1973 and 1974) or early winter (December 1975).

Length-frequency distributions indicated that the majority of alewives impinged, were 5 to 7 inch (standard length) adults (Cochran and Kitchel 1976). Juveniles appeared as smaller size classes during June and July and dominated winter impingement collections. The secondary peaks in alewife impingement that occurred in October 1973, November 1974, and October 1975 were largely juvenile fish (Figure 3).

Length-frequency distributions of rainbow smelt impinged during the first peak (March and April) each year indicated these fish were 5 to 7 inch (standard length) adults (Cochran and Kitchel 1976). Adult rainbow smelt were also present in impingement collections throughout the rest of the year. Juvenile smelt were collected throughout the fall and winter, and were most apparent in length-frequency distributions from July through September of each year. The peak numbers of rainbow smelt impinged during September 1973 and 1974 were predominantly young-of-year;

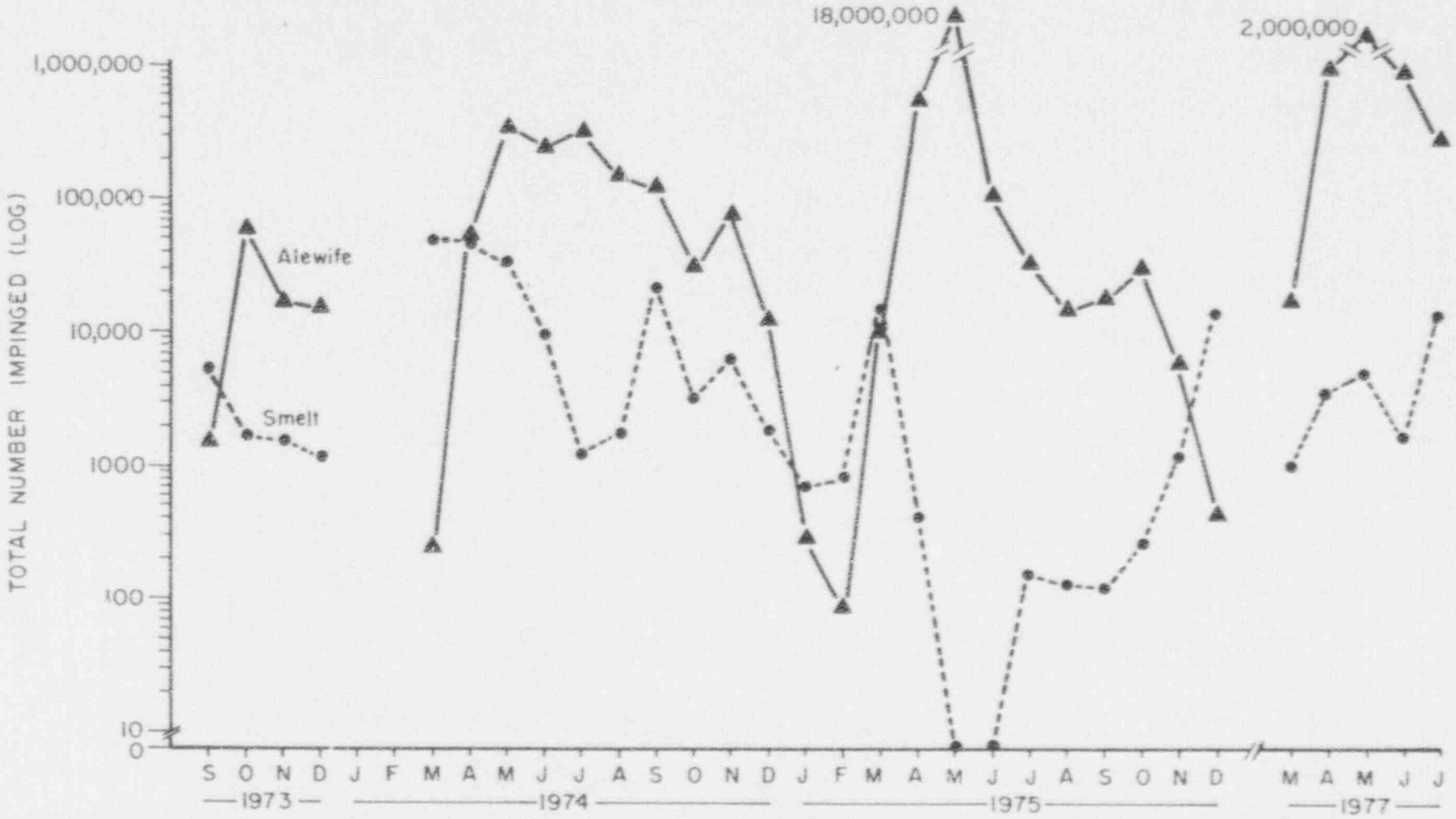


Figure 3. Estimated number of alewife and rainbow smelt impinged at Zion Station, September 1973 through December 1975 and March through July 1977.

HAZLETON ENVIRONMENTAL SCIENCES

500

however, the peak, during December 1975, was composed primarily of adults.

2. Comparison with Station Operation Data

Comparisons of numbers of fish impinged with station intake flow rates were made by Kitchel and Otto (1974), Cochran and Kitchel (1976), and Cochran and Ott (1977). The number of alewife, rainbow smelt, and other species collected were compared with Zion Station intake flow during impingement sampling (Figures 4 through 6). In each case, it was concluded that there was no direct or consistent relationship between numbers of fish impinged and Station cooling water flow rates.

3. Comparison with Field Data

Comparisons of impingement collections with data from concurrent lake sampling near the intake were made by Kitchel and Otto (1974), Kitchel (1975), and Cochran and Kitchel (1976). Kitchel and Otto (1974) concluded that the overall species composition in the lake collections and in impingement samples was similar and that impingement results represented the predominance of adult alewife in the lake during May, and of young-of-year alewife during October. Adult rainbow smelt predominated impingement collections during May while lake collections contained equal numbers of adults and yearlings. Kitchel (1975) concluded that seasonal inshore and offshore migrations, as shown by numbers of alewives and rainbow smelt impinged, corresponded with migrations in the lake near the Station as reported by others.

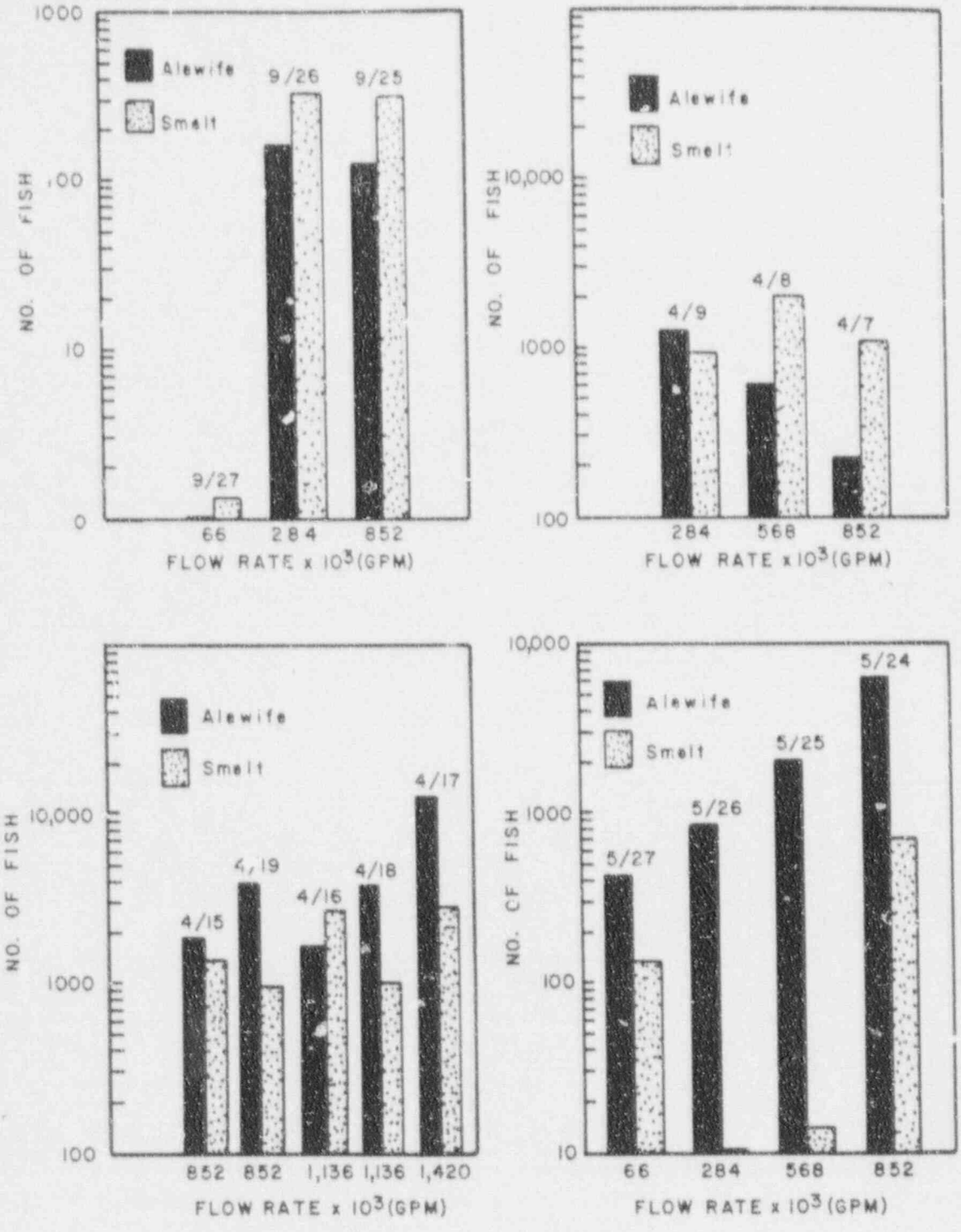


Figure 4. Number of alewife and rainbow smelt impinged on the Zion Station traveling screens at various intake flow rates, 1973 through 1974. Sampling dates are indicated above the corresponding bars (from Kitchel and Otto 1974).

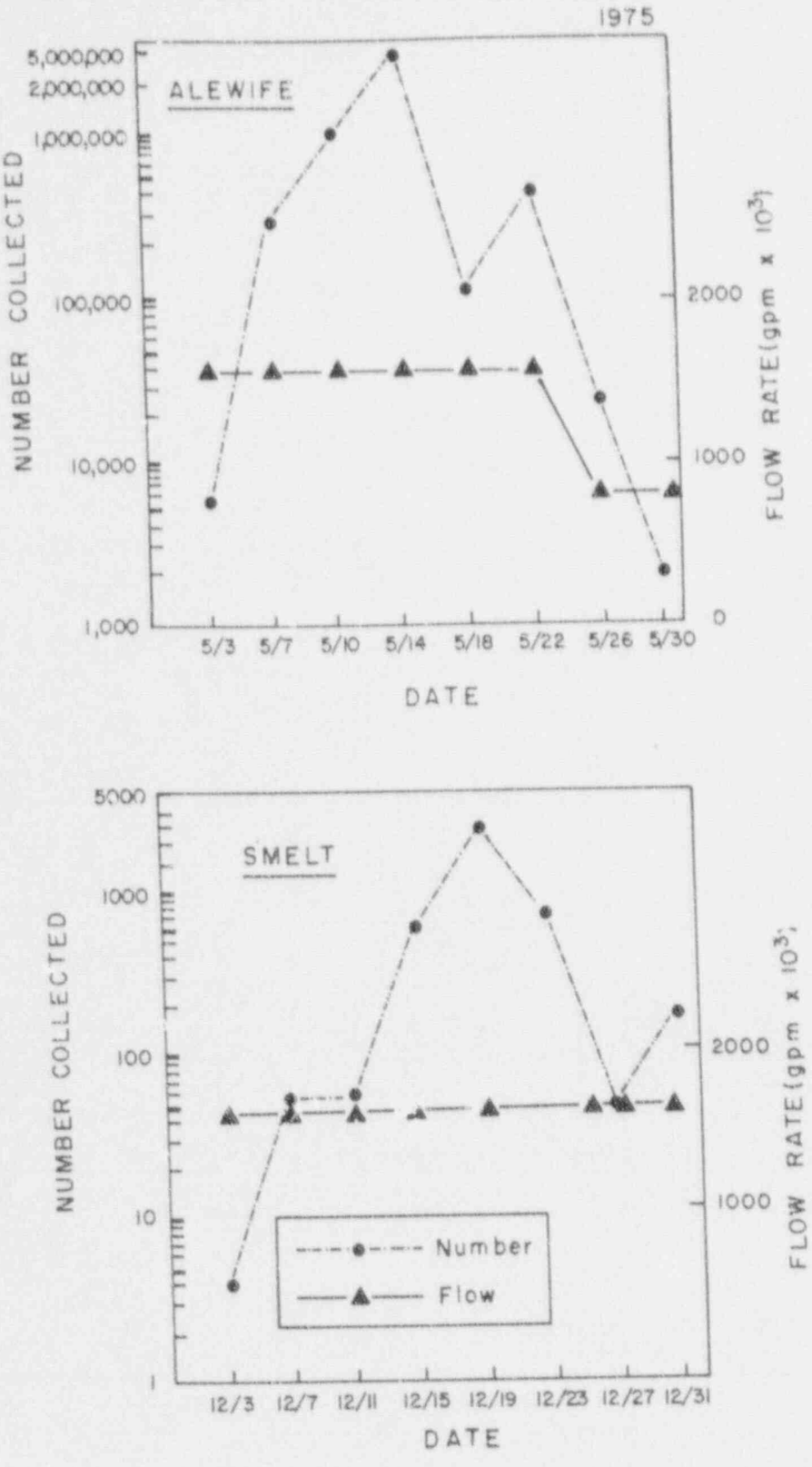


Figure 5. Number of alewife and rainbow smelt impinged on the Zion Station traveling screens and mean daily flow through the plant, 1975.

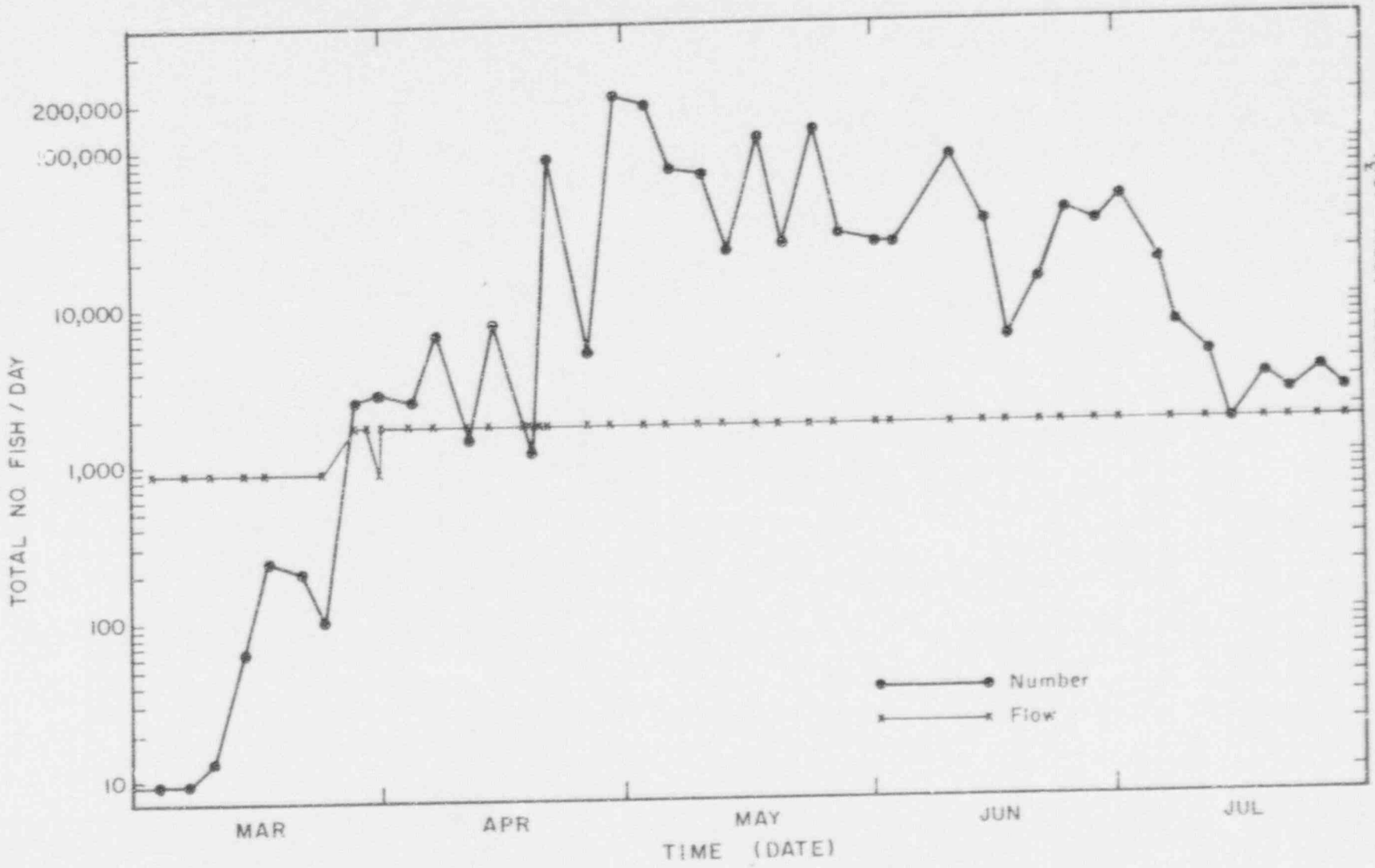


Figure 6. Summary of fish impingement counts at Zion Station from March through July, 1977.

Cochran and Kitchel (1976) compared seasonal occurrence, seasonal abundance, and length-frequency distributions of impinged fish and fish captured in field collections near the Station. Seasonal occurrence and percent composition was similar between impinged fish and field catches. Peaks in numbers of fish impinged and abundance in field collections occurred during the same periods (Figure 7). Length-frequency distributions of impinged and field collected fish were compared using a Kolmogorov-Smirnov type test. Significant differences were found in 63 of 69 tests. The differences were attributable to the schooling behavior of fish, selectivity of the trawl, and intensity of sampling effort. In general, impingement samples contained a better representation of all size classes which was in contrast to the trawl catches. The trawl tended to capture fish of more uniform size.

4. Comparison with Biomass, Commercial Production, Sport Landings, and Plantings

Cochran and Kitchel (1976) compared estimated total numbers and weights of fish impinged during 1975 with estimates of lakewide biomass, commercial production, sport landings, and stockings of the same species. Annual impingement for 1975 equalled from 0.01 to 3.4% of the commercial production; 1.3% for rainbow smelt and 3.4% for alewife. Annual impingement for the same year equalled 0.01 to 0.06% of sport landings, and less than 0.02% of the fish stocked (Table 5). Annual impingement of alewife during 1975 equalled 0.05 to 0.7% of two lakewide biomass estimates; impingement of rainbow smelt equalled 0.01% of lakewide biomass

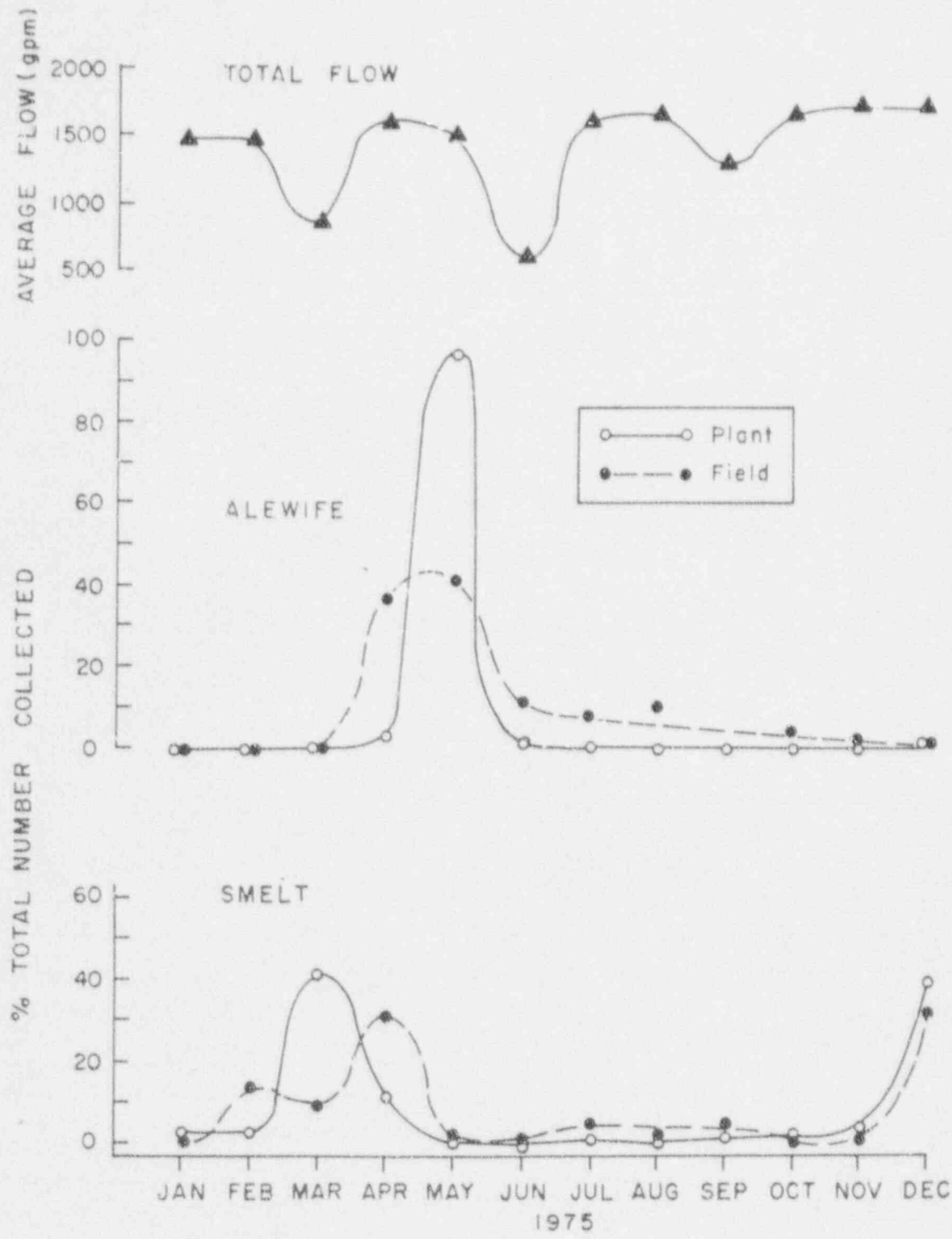


Figure 7. Seasonal distribution (% of total number) of alewife and rainbow smelt impinged at Zion Station, collected at 18' by trawl and 20' by gill net, and mean observed flow through Zion Station, 1975.

Table 5. Estimated numbers and weights of fish impinged at Zion Station, January through December and total Lake Michigan commercial production, sport landings, and plantings, 1974.

	Estimated Impinged at Zion		Commercial Production (Pounds) All States, 1974	Sport Landings (Number) All States, 1974	Plantings (Number) All States, 1974
	Number	Pounds			
Alewife	19135638	1565621	1555725	a	a
Rainbow smelt	39293	4381	336500	a	a
Slimy sculpin	558	17	a	a	a
Yellow perch	530	125	834900	1601[b]	a
White sucker	262	478	311700	a	a
Black bullhead	262	16	33300	46000	a
Brown trout	136	67	a	a	840000
Spottail shiner	116	3	a	a	a
Coho salmon	106	239	a	171000	3233000
Gizzard shad	96	8	a	a	a
Carp	83	577	3243800	a	a
Ninespine stickleback	58	0.5	a	a	a
Whitefish	42	79	1174200	a	a
Chinook salmon	31	28	a	73000	3533000
Central mudminnow	27	0.5	a	a	a
Rainbow trout	23	9	a	86000	1542000
Burbot	23	45	205800	a	a
Longnose dace	12	0.5	a	a	a
Lake trout	9	4	23300	84000	2308000
Trout-perch	8	0.5	a	a	a
Emerald shiner	8	0.5	a	a	a
Golden shiner	4	0.5	a	a	a
Northern pike	4	0.5	22700	a	a

[a] No data.
[b] Wisconsin census only, 1974, pounds.

HAZLETON ENVIRONMENTAL SCIENCES

estimates; and slimy sculpin impingement equalled 4.3×10^{-4} percent of lakewide biomass estimates. Impingement estimates from several power facilities on Lake Michigan were compared with lakewide biomass estimates of alewife and rainbow smelt, and it was reported that combined weight of impinged alewife at all facilities comprised only 0.064% of the 1972 biomass estimate and that combined weight of impinged rainbow smelt comprised 0.067% and 0.064% of the 1973 and 1974 biomass estimates, respectively (CDM/Limnetics 1977).

B. Entrainment

Results of entrainment sampling at Zion Station and fish egg and larvae sampling in Lake Michigan near the Station were reported by Otto (1975) and Cima et al. (1975). Results and discussion presented here are based on these studies.

1. Species Occurrence, Abundance and Spawning Activity of Adult Fish in the Sampling Area

A total of 36 species of fish was collected during the 1972, 1973 and 1974 study years. The alewife and rainbow smelt were the two most abundant species collected comprising 83.7% and 14.4% of the total catch, respectively. The remaining 34 species comprised less than 2% of the total.

The species which are of primary interest in this report are those which inhabit the study area during their spawning period. A comparison of the available literature on spawning times with adult catch data for the study area would indicate that this is true for 34 of the 36 species collected (Figure 8). Based

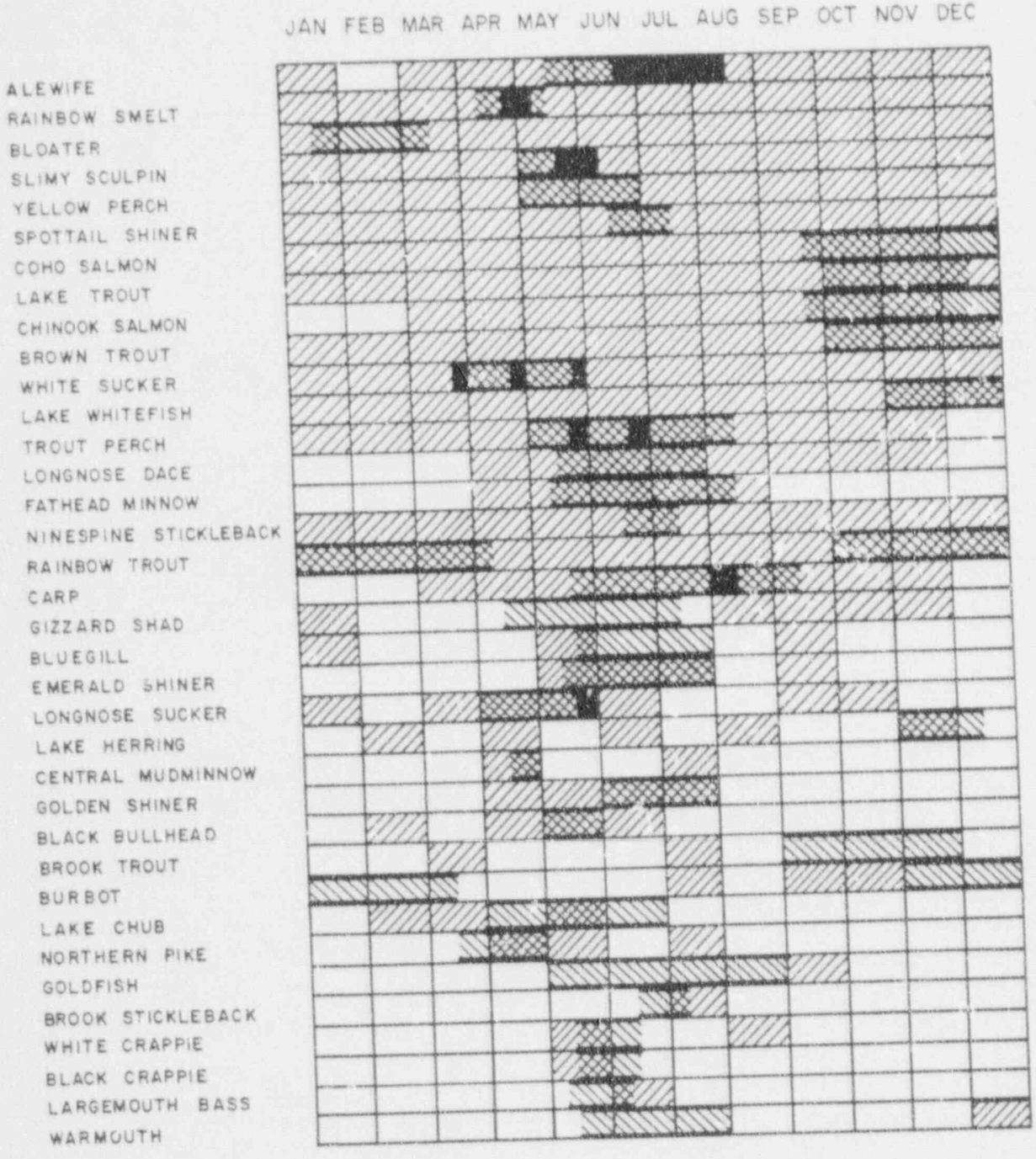


Figure 8. Seasonal occurrence (▨) and spawning times (▩) of adult fish collected in the Zion-Waukegan sampling area. Periods in which eggs were collected are also indicated (■).

on the occurrence of eggs, only 7 of these 34 species appear to actually utilize the study area for spawning (Otto 1975). Most of the remaining species either do not normally spawn in the lake such as salmon and trout, suckers and pike; species which have spawning habitat requirements not available in the study area such as centrachid species; or are in such low numbers that spawning would not be detected following the sampling program used. It is of particular importance to note that there is no spawning in the study area by salmon or trout.

The species of principal concern are, therefore, limited to the alewife, rainbow smelt, slimy sculpin, trout-perch, carp and suckers. The carp typically spawns in protected embayments, whereas, suckers spawn in streams. Spawning of suckers in the study area is probably restricted to the Dead River while carp have been observed spawning in the intake and discharge canals at Waukegan Station. The occurrence of eggs for these two species was extremely low, suggesting a minimal amount of spawning activity in the study area. Slimy sculpin and trout-perch eggs were also collected at random locations and in sufficiently small numbers to indicate that spawning activity in the study area is either very localized (missed by the sampling program) or occurs at such a low level as to be of minimal importance relative to the potential effects of Zion Station. Emphasis is, therefore, directed to the effects of Zion Station on the rainbow smelt and alewife.

2. Rainbow Smelt

a. Spawning in the Study Area

The seasonal occurrence of eggs, larvae, and

juvenile rainbow smelt in the vicinity of Zion Station during 1973 and 1974 has been described by Otto (1975). Briefly, rainbow smelt eggs were collected in the highest percentages during April and May, larvae during June, and juveniles from July through September. Field data for 1975 were similar (Cima et al. 1976).

Longshore and depth distributions of eggs and larvae were analyzed to reveal the greatest concentrations of each early life stage and relative susceptibility of entrainment at the Zion intake structure. No consistent longshore distributional trends were found. Depth-density distributions indicated that rainbow smelt eggs were more concentrated inshore, at the 20 and 30 foot depths, whereas, larvae and juveniles were more concentrated at depths of 20 to 30 feet (Otto 1975; Cima et al. 1976). Early life stages of rainbow smelt were, therefore, susceptible to entrainment through Zion Station.

b. Entrainment at Zion Station

During the spring of 1974 and 1975, a large number of rainbow smelt eggs was collected with plankton nets in the Zion Station forebay (Otto 1975, and Cima et al. 1976). However, the source of the entrained eggs was uncertain. Correlation of forebay egg densities with field egg densities was low and correlation of forebay egg densities with numbers of adults impinged was high (Figure 9). Peak egg densities occurred in the forebay during a period when none were found with plankton nets in the lake. The peak egg densities in the forebay however, coincide with the peak period of adult impingement. Therefore, it appears that the

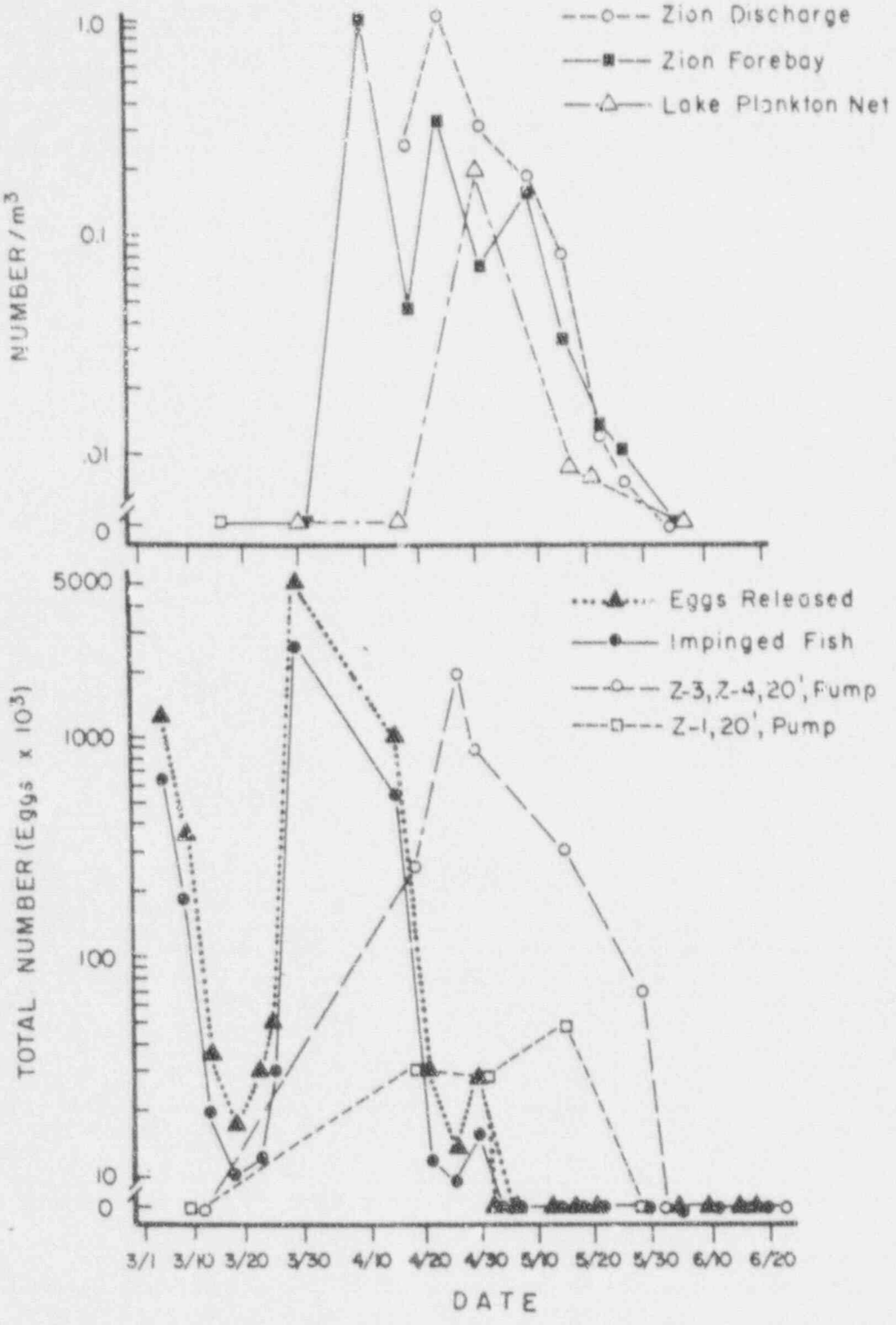


Figure 9. Mean number of rainbow smelt eggs collected in the Zion Station forebay and discharge; at Stations Z-3 and Z-4, 20' with plankton nets; at Stations Z-1, Z-3 and Z-4 by pump during 1975. Also shown, the number of smelt impinged at Zion Station. Eggs released = number of fish x 63% females x 29,000 per female (Otto 1975). (from Cima et al. 1976).

first peak of smelt eggs collected in the forebay were released by adult females entrapped in the intake.

Estimates of numbers of rainbow smelt larvae entrained per day ranged from 40,000 to 200,000 during peak abundance in 1974 (Otto 1975) and from 5,800 to 34,800 per day during 1975 (Cima et al. 1976). Few juvenile smelt were taken in entrainment sampling which precluded estimates of total numbers entrained.

Intensive sampling of the Station forebay and discharges was conducted during 1975 in order to evaluate diel and intake/discharge differences (Cima et al. 1976). Rainbow smelt eggs collected in the Station forebay and discharges followed similar trends in density with discharge abundances slightly higher. There was no apparent difference between day and night egg densities. Numbers of rainbow smelt larvae collected were not sufficient to permit comparisons, other than the observation that densities were similar. Juveniles were not compared.

c. Comparison with Field Data

The seasonal occurence of larvae in entrainment samples was similar to field occurrence and peak entrainment occurred during the same period as peak field abundance. Estimated losses of early life stages of rainbow smelt due to entrainment were compared with estimated production in the study area. Because of the probable origin of rainbow smelt eggs from the forebay, indicated by the lack of synchronization with egg densities in the lake, egg losses due to entrainment were compared with lost potential egg production due to impingement of ripe adult females.

Nearly three times as many potential eggs were lost because of impingement than of entrainment during 1974 (Otto 1975) and nearly five times as many were lost because of impingement in 1975 (Cima et al. 1976).

Total numbers of rainbow smelt larvae entrained were compared with standing crops in the vicinity of Zion Station. Results for 1974 indicated that the average standing stock in the study area during May and June was 1.86×10^7 larvae (Otto 1975). Standing stock estimates were made from April through October 1975 (Cima et al. 1976). The highest estimate, 2.1×10^7 larvae, was for 28 May 1975. Because entrainment estimates and field collections were made on the same days during 1975, percentages of standing stocks entrained on each date could be calculated. The mean percentage of larvae in the study area which were entrained through the Station on 15, 16, and 21 May 1975 (dates when larvae were entrained which coincided with field sampling) was 0.77% (Cima et al. 1976). No comparisons were made for juveniles. Otto (1975) concluded that operation of Zion Station has had no long term deleterious effects on the local rainbow smelt population.

3. Alewife

a. Spawning in the Study Area

The seasonal occurrence of juvenile alewife in the vicinity of Zion Station during 1973 and 1974 was described by Otto (1975). Highest percentages of alewife eggs were found from late June through early-July, highest percentages of larvae in mid-July and mid-August, and young-of-year in October. Similar temp-

oral abundance distributions occurred in 1975 (Cima et al. 1976).

Longshore and depth distribution of eggs and larvae were analyzed to reveal the greatest concentrations of each life stage and relative susceptibility to entrainment at the Zion intake structure. No consistent longshore distributional trends were found. Depth-density distributions indicated that alewife eggs were most concentrated at depths of 20 feet or greater during 1974 (Otto 1975) while data for 1975 showed a decrease in density from 20 to 60 feet (Cima et al. 1976). Eggs were most concentrated at the 20 foot depth contour during each year.

Alewife larvae were most concentrated nearshore and densities consistently decreased with distance from shore during both years (Otto 1975; Cima et al. 1976). Juveniles were probably concentrated at a depth of 10 to 20 feet during the early summer of 1974 (Otto 1975). Data for 1975 suggested greatest concentration at the 10 foot depth (Cima et al. 1976).

b. Entrainment at Zion Station

It was estimated that during periods of greatest alewife egg densities the potential to entrain from 10 million (Otto 1975) to 125 million (Cima et al. 1976) alewife eggs per day exists. As with rainbow smelt, the probable source of alewife eggs in the Station forebay was attributed to entrapped adults, rather than lake-spawned eggs. Total numbers of alewife larvae entrained during 1974 was based on mean larval densities in the forebay from 11 July through 5 August, and equalled 3.6×10^7 larvae (Otto 1975). Entrainment estimates for 1975 totaled 1.16 x

10^7 larvae for the period of 25 June through 17 September (Cima et al. 1976). No entrainment estimates for young-of-year were made because few were collected at the Station.

Intake/discharge and day/night comparisons of 1975 data were made for alewife as were for smelt (Cima et al. 1976). Intake/discharge egg densities were not significantly different and day/night comparisons yielded no consistent pattern. Larval alewife data showed slightly lower densities collected in the discharge than in the intake. The difference was attributed to comparative sampling gear efficiency. There were no consistent diel trends in larval alewife catches. No comparisons of young-of-year were made.

c. Comparison with Field Data

The seasonal occurrence and peak forebay densities of alewife were similar to field occurrence and peak densities. Loss of eggs resulting from impingement was compared with loss of eggs dues to entrainment and concluded that entrainment losses were insignificant (Otto 1975). Cima et al. (1976) estimated total egg production in the study area to be 1.26×10^{11} from adult standing crop estimate and 2.8×10^{11} eggs from bottom egg densities. Estimated total entrainment then equalled the eggs of 1.58% of the standing crop of females in the study area or 0.005% of the eggs in the study area. Based on the average number of eggs per square meter of lake bottom, entrainment during 1975 equalled the removal of eggs from about 0.4% of the study area. Total larval entrainment was compared with anticipated hatch of the egg

standing crop estimate and found entrainment to equal 0.025% of the larvae expected to hatch (Otto 1975).

Larval entrainment was compared with larval standing crops in the study area (Cima et al. 1976). Estimates of total numbers of larvae in the study area on two dates in July 1975 were 6.8×10^7 and 2.1×10^7. Larval entrainment on 14 July 1975 equalled about 2% of larval standing crops in the study area. Total entrainment for the entire period equalled about 13% of the largest single day standing crop in the study area (Cima et al. 1976) A comparisen of length-frequency distributions of entrained and lake alewife larvae yielded significantly smaller larvae entrained. It appeared that newly hatched larvae were more susceptible to entrainment (Cima et al 1976). No comparisons of young-of-year were made.

The above studies indicate that the operation of Zion Station has no long term deleterious effect on the alewife population in Lake Michigan. Additionally, there has been no measureable effect on the alewife populations due to entrainment losses.

C. Forebay Stocking Returns

In order to determine whether or not fish could survive for any length of time in Zion Station's intake forebay before becoming impinged on the intake screens, ninety tagged rainbow trout were released in the forebay on 31 October 1975 (Cochran 1976). Impingement was monitored every fourth day and a total of 10 tagged trout was recovered as of 25 May 1976. Though some

tagged trout were undoubtedly missed due to the frequency of impingement monitoring, the results of this study indicated that fish can survive for long periods and even overwinter in the Station forebay before becoming impinged on the intake screens. Limited data on the size of trout recovered after residing in the forebay further indicated good growth while in the forebay. Results of this study suggest that fish could be entrained by Zion Station's intake and not become impinged on the intake screens for a considerable period of time.

V. Literature Cited

Bailey, R. M. 1970. A list of common and scientific names of fish from the United States and Canada. 3rd ed. Amer. Fish. Soc. Spec. Publ. 6. 150 pp.

Cima, G., M. Cochran and M. Kitchel. 1976. Annual interpretive report on fish eggs and larvae in Lake Michigan near Zion and Waukegan Generating Stations 1975. Report to Commonwealth Edison Company, Chicago, Illinois. p 1-153.

CDM/Limnetics. 1977. The lake-wide effects of impingement and entrainment on the Lake Michigan fish populations. Report prepared for Commonwealth Edison Company, Northern Indiana Public Service Company, Indiana and Michigan Power Company, and Consumers Power Company. 257 pp.

Cochran, M. 1976. Adult fish study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1975 through June 1976. Annual report to Commonwealth Edison Company, Chicago, Illinois by NALCO Environmental Sciences. Vol. VI: 83-298.

_____ and G. Cima. 1974. Larval fish study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through June 1974. Annual report to Commonwealth Edison Company, Chicago, Illinois. Vol. III: 201-284.

_____ and M. Kitchel. 1976. Fish impingement at Zion Station, January through December 1975. IN Compilation of reports relating to entrainment and impingement studies at Zion Generating Station. Report to Commonwealth Edison Company, Chicago, Illinois by NALCO Environmental Sciences. Vol. I: 84 pp.

_____ and T. Ott. 1977. Adult fish study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1976 through June 1977. Annual report to Commonwealth Edison Company, Chicago, Illinois by NALCO Environmental Sciences. Vol. III: 207-416.

Industrial BIO-TEST Laboratories, Inc. 1975. Operational environmental monitoring in Lake Michigan near Zion Station, January 1975 through June 1975. Semi-Annual report to Commonwealth Edison Company, Chicago, Illinois.

Kitchel, M. A. 1973. Screen monitoring at Zion Station. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through December 1973. Semi-Annual report to Commonwealth Edison Company, Chicago, Illinois by Industrial BIO-TEST Laboratories, Inc. Vol. III: 367-410.

Kitchel, M.A. 1974. Screen monitoring at Zion Station. IN Operational environmental monitoring in Lake Michigan near Zion Station, January through June 1974. Semi-Annual report to Commonwealth Edison Company, Chicago, Illinois by Industrial BIO-TEST Laboratories, Inc. Vol. III: 409-472.

_____ 1975. Screen monitoring at Zion Station. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1974 through June 1975. Annual report to Commonwealth Edison Company, Chicago, Illinois by NALCO Environmental Sciences. Vol. IV: pp. 237-260.

_____ and R. G. Otto. 1974. Screen monitoring study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through June 1974. Annual report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. III: pp. 345-374.

NALCO Environmental Sciences. 1976. Operational environmental monitoring in Lake Michigan near Zion Station, July 1975 through December 1975. Semi-Annual report to Commonwealth Edison Company, Chicago, Illinois.

Otto, R. 1975. The effects of once-through cooling on fish eggs and larvae in southwestern Lake Michigan. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1974 through June 1975. Report to Commonwealth Edison Company, Chicago, Illinois by NALCO Environmental Sciences. Vol. IV: pp. 57-236.

Rice, J. (ed). 1975. Operational environmental monitoring in Lake Michigan near Zion Station, July 1974 through December 1974. Semi-Annual report to Commonwealth Edison Company, Chicago, Illinois by Industrial BIO-TEST Laboratories, Inc.

APPENDIX A

Illustrations of Sampling Locations,
Analytical Methods,
and Sampling Schedule for 1972,
Water Quality Studies,
Zion Station, February 1970 through September 1978

LIST OF FIGURES

No.	Captions	Page
A-1	Water chemistry sampling locations, July 1974 through September 1978	A-7
A-2	Water chemistry sampling locations, May 1971 through March 1972 and April 1972 through June 1974	A-8
A-3	Water chemistry sampling locations, 6 miles offshore, April 1970 through April 1971	A-9
A-4	Water chemistry sampling locations, 32,000 ft offshore, February through March 1970	A-10
A-5	Water chemistry sampling locations near the Zion and Waukegan Generating Stations, January 1970-April 1971	A-11

LIST OF TABLES

No.	Title	Page
A-1	Analytical methods for the chemical constituents measured in water samples collected in Lake Michigan near Zion, Illinois, July 1975 through September 1978	A-13
A-2	Analytical methods for the chemical constituents measured in water samples collected in Lake Michigan near Zion, Illinois, July 1974 through June 1975	A-15
A-3	Analytical methods for the chemical constituents measured in water samples collected in Lake Michigan near Zion and Waukegan, Illinois, January 1973 through June 1974	A-16
A-4	Analytical methods for the chemical constituents measured in water samples collected in Lake Michigan near Zion and Waukegan, Illinois, April through December 1972	A-17
A-5	Analytical methods for the chemical constitutents measured in water samples collected in Lake Michigan near Zion and Waukegan, Illinois, April 1971 through March 1972	A-23
A-6	Analytical methods for the chemical constituents measured in water samples collected in Lake Michigan near Zion and Waukegan, Illinois, February 1970 through March 1971	A-24
A-7	Analytical methods for the chemical constituents measured in water samples collected in Lake Michigan, inshore and offshore near Zion and Waukegan, Illinois, January 1970 through April 1971	A-26
A-8	Sampling frequency for water quality parameters in southwestern Lake Michigan near Zion and Waukegan, Illinois, 1972	A-29

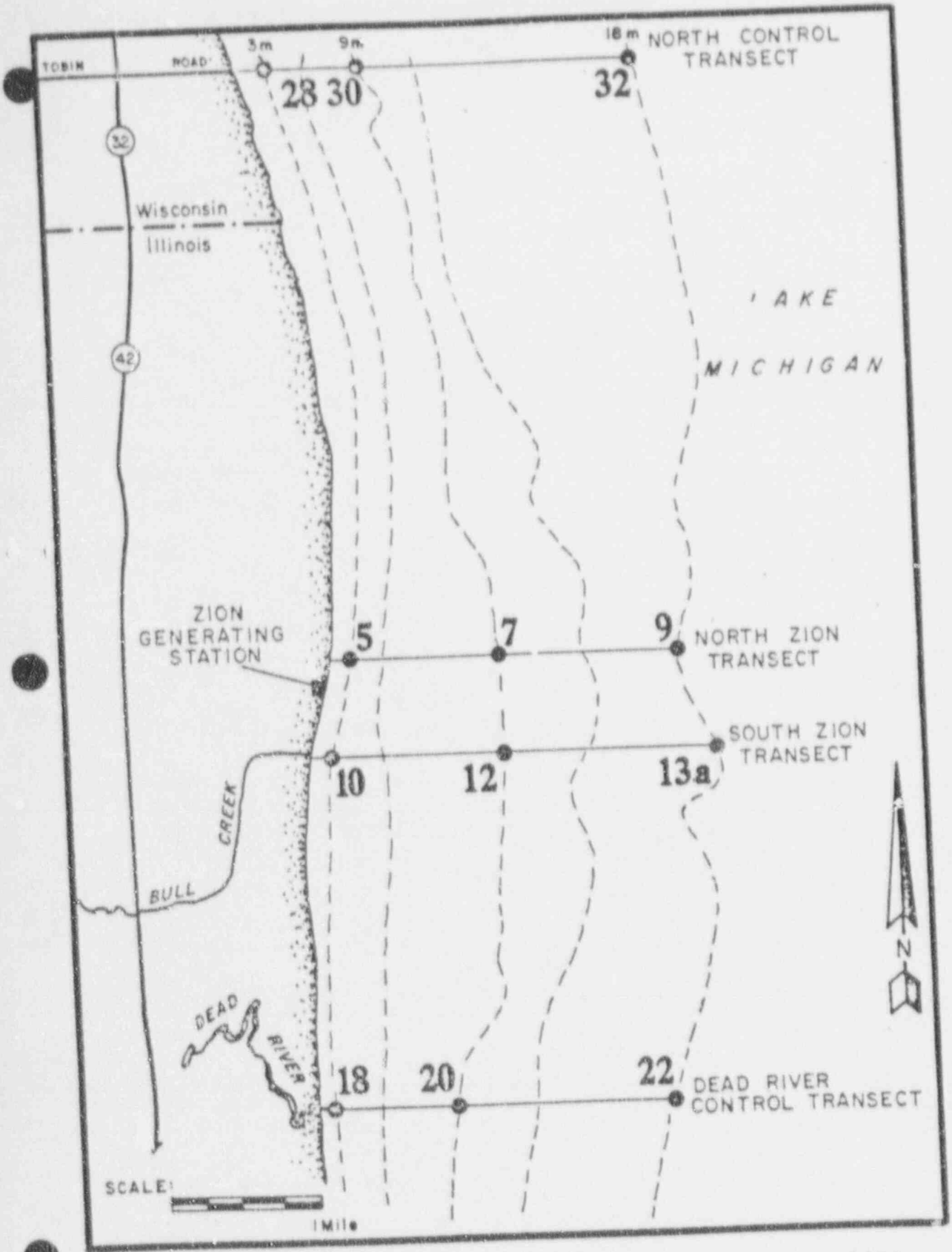


Figure A-1. Water chemistry sampling locations, July 1974 through September 1978.

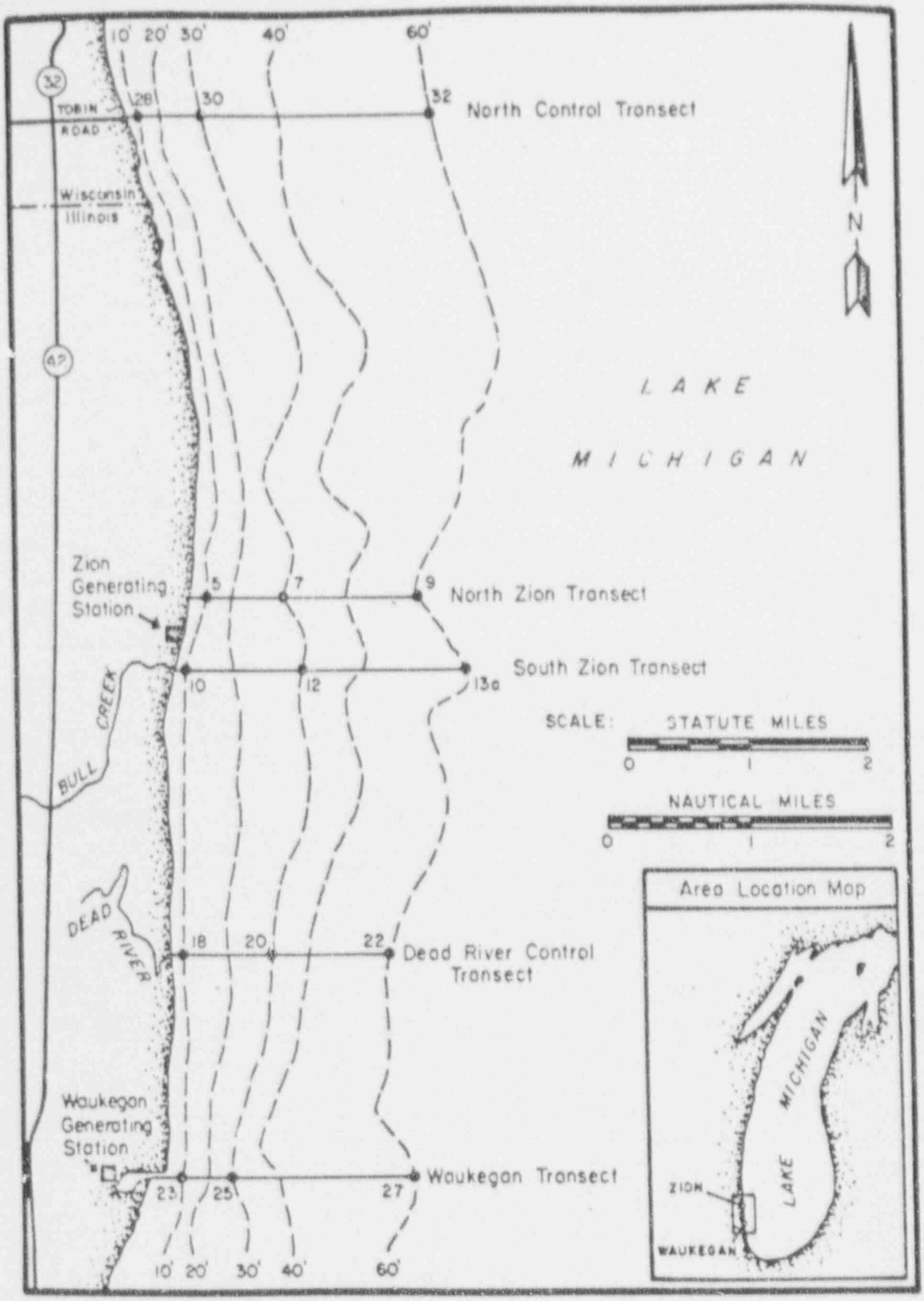


Figure A-2. Water chemistry sampling locations, May 1971 through March 1972 (selected) and April 1972 through June 1974.

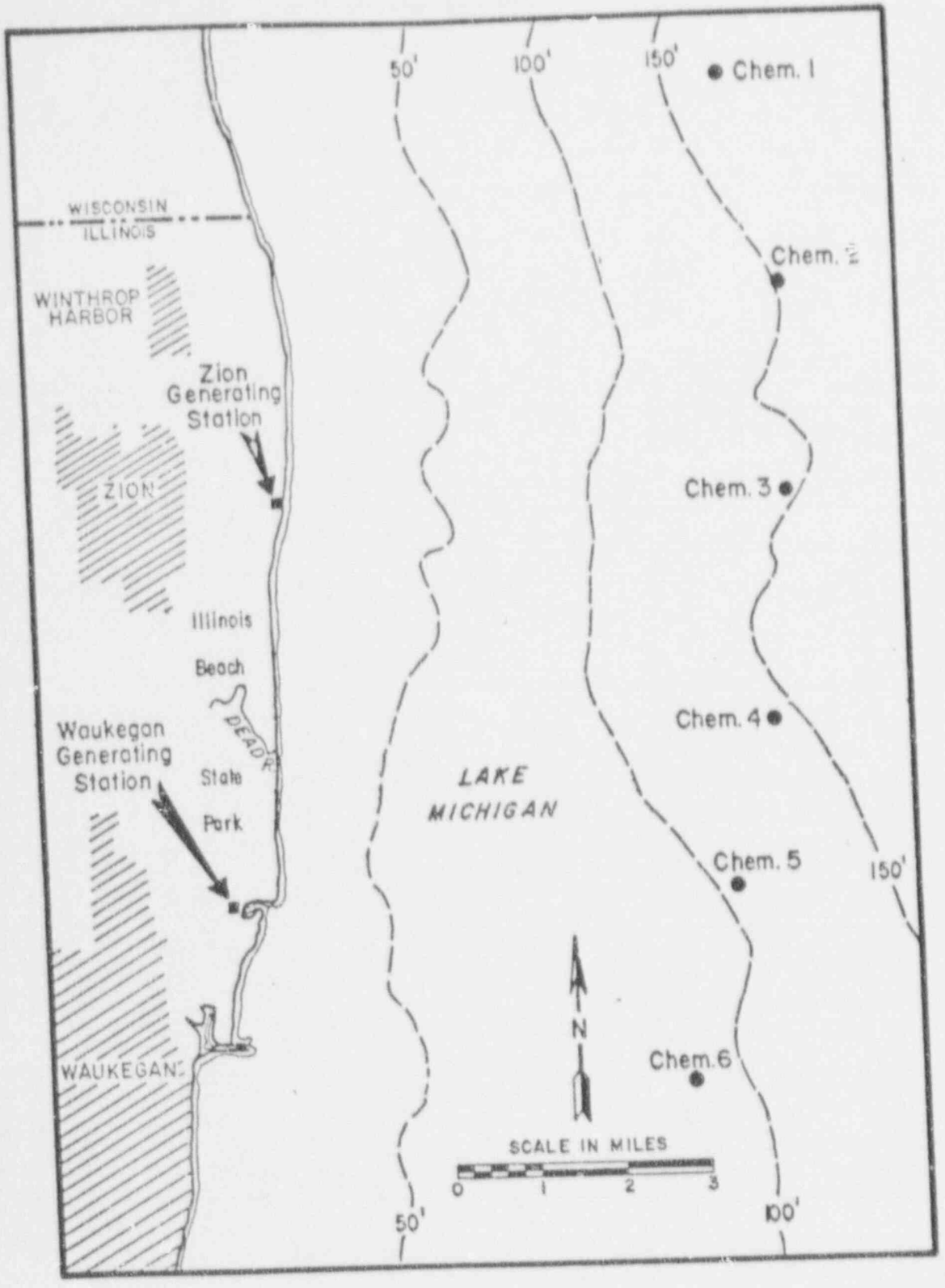


Figure A-3. Water chemistry sampling locations, 6 miles offshore, April 1970 through April 1971.

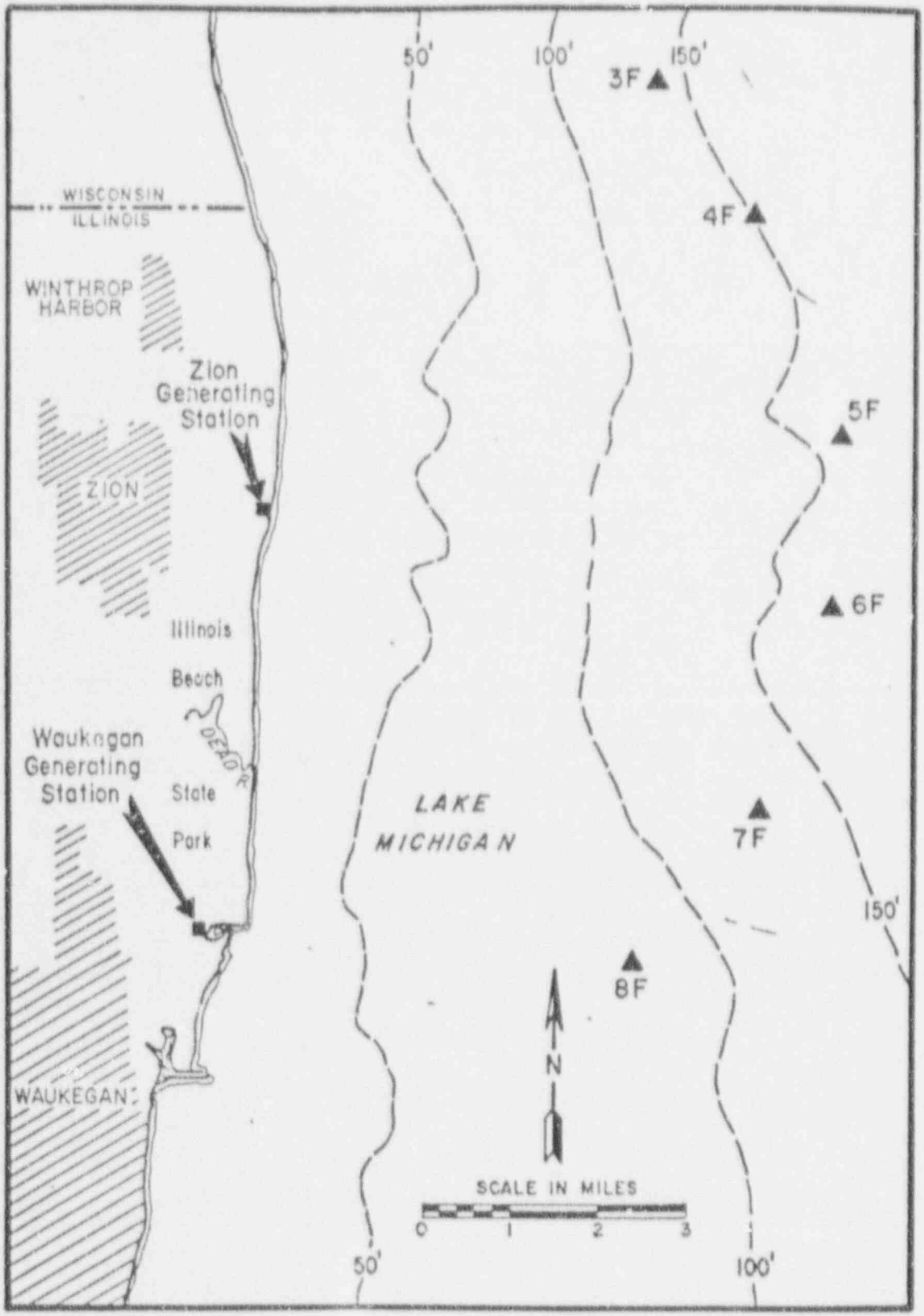


Figure A-4. Water chemistry sampling locations, 32,000 ft offshore, February through March 1970.

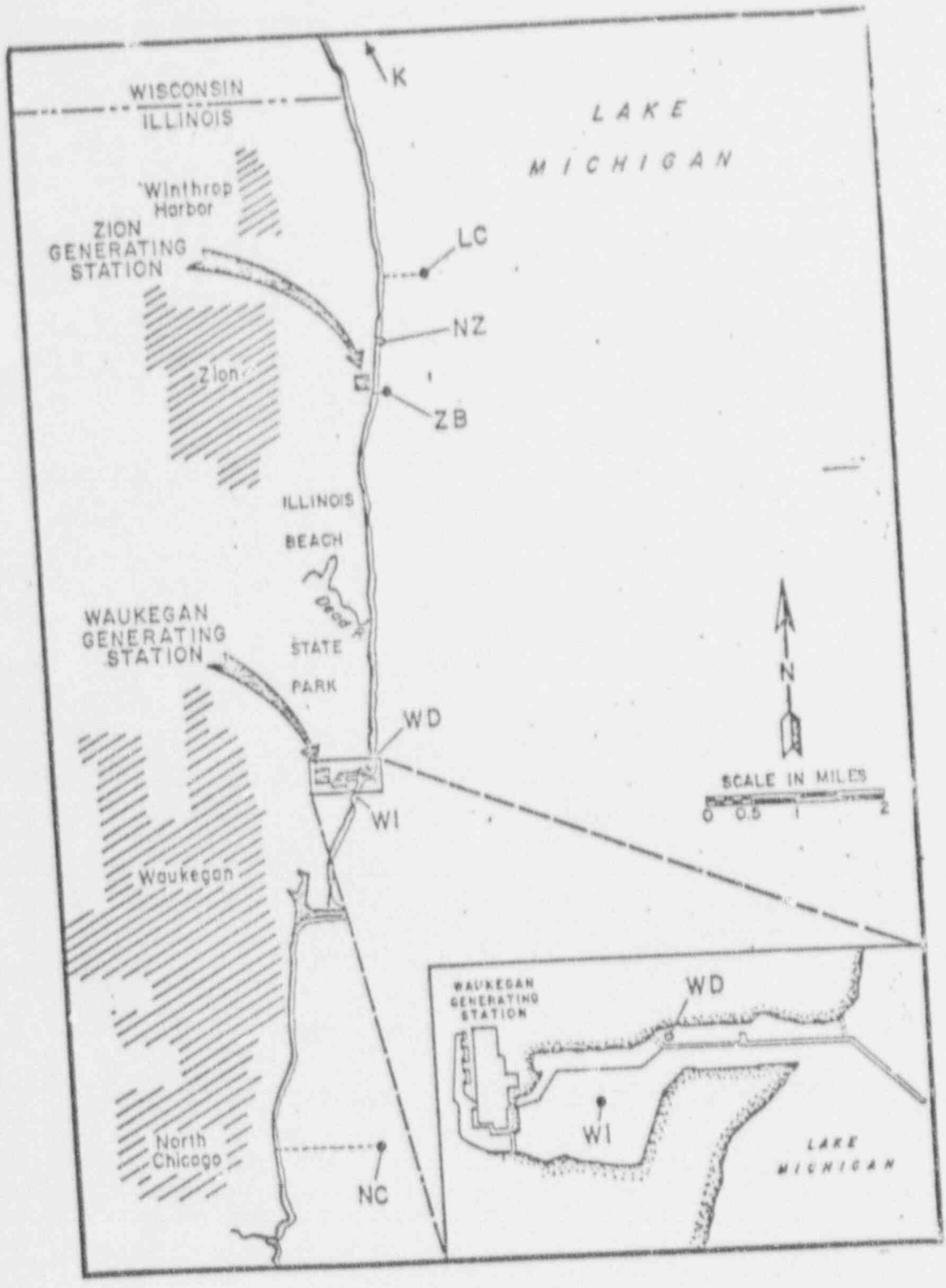


Figure A-5. Water chemistry sampling locations near the Zion and Waukegan Generating Stations, January 1970-April 1971.

Table A-1. Analytical methods for the chemical constituents measured in water samples collected in Lake Michigan near Zion, Illinois, July 1975 through September 1978.

Constituent	Method	Preservation Technique	Reference	Detection Limit
Alkalinity, total	Potentiometric, titrimetric	Refrigeration	Method 403, A.P.H.A. et al. 1976	1 mg/l-$CaCO_3$
	Autoanalyzer	Refrigeration, filtration, 0.45 µm membrane filter	U.S.E.P.A. 1974	2 mg/l-$CaCO_3$
Ammonia	Gas diffusion electrode	$HgCl_2$, refrigeration	Thomas and Booth 1973; Howe and Holley 1969	0.01 mg/l-N
	Phenate method	$HgCl_2$, refrigeration	Method 418C A.P.H.A. et al. 1976; Howe and Holley 1969	0.01 mg/l-N
	Autoanalyzer Phenate method	$HgCl_2$, refrigeration	Method 604 A.P.H.A. et al. 1976; Howe and Holley 1969	0.01 mg/l-N
Nitrate	Brucine method	$HgCl_2$, refrigeration	Method 419D A.P.H.A. et al. 1976; Howe and Holley 1969	0.01 mg/l-N
	Autoanalyzer cadmium reduction	$HgCl_2$, refrigeration	Method 605 A.P.H.A. et al. 1976; Howe and Holley 1969	0.01 mg/l-N
Orthophosphate, soluble	Ascorbic acid	Filtration, 0.45 µm membrane filter, refrigeration	Method II.J, Strickland and Parsons 1972; Ryden et al. 1972	1 µg/l-P
Oxygen, dissolved	Hydrolab Surveyor, or oxygen analyzer, membrane electrode	Measured *in situ*	Methods 422F and 422B A.P.H.A. et al. 1976; Hydrolab Corp. 1973	0.1 mg/l
	Azide modified Winkler titration	Measured in the field	Method 422B A.P.H.A. et al. 1976	0.1 mg/l
Oxygen saturation	Calculated	Calculated	Method 422B A.P.H.A. et al. 1976	1%
pH	Hydrolab Surveyor, potentiometric	Measured *in situ*	Method 424 A.P.H.A. 1976, Hydrolab Corp. 1973	0.1 pH
	Potentiometric	Measured in the field	Method 424 A.P.H.A. et al. 1976	0.1 pH

Table A-1. (continued)

Constituent	Method	Preservation Technique	Reference	Detection Limit
Phosphorus, total	Digestion then ascorbic acid method	None required	Method 425C A.P.H.A. et al. 1976; then method 11.1 Strickland and Parsons 1972	1ug/l-P
Residue, filtrable (total dissolved solids)	Filtration, gravimetry at 103-105C	None required	Method 208C A.P.H.A. et al. 1976	2 mg/l
Residue, nonfiltrable (total suspended solids)	Filtration then gravimetry at 103-105C or by difference	None required	Method 208D A.P.H.A. et al. 1976	1 mg/l
Silica, soluble	Heteropoly blue method	filtration, 0.45 µm membrane filter	Method 426C A.P.H.A. et al. 1976	0.01 mg/l-SiO_2
	Autoanalyzer Heteropoly blue method	Filtration, 0.45 µm membrane filter	Method 105-71 W Technicon Industrial Systems 1974	0.01 mg/l-SiO_2
Temperature	Hydrolab Surveyor, or Whitney Thermometer	Measured *in situ*	Method 16? A.P.H.A. et al. 1976; Hydrolab Corp. 1973	0.1 C
Turbidity	Hach Turbidimeter, nephelometric	None required	Method 214A A.P.H.A. et al. 1976	0.1 N.T.U.

Table A-2. Analytical methods for the chemical constituents measured in water samples collected in Lake Michigan near Zion, Illinois, July 1974 through June 1975.

Parameter	Method	Preservation Technique	Reference	Detection Limit
Alkalinity, total	Method 102	Refrigeration	A.P.H.A. et al. 1971	1 mg/l-$CaCO_3$
Ammonia [a]	Gas diffusion electrode	$HgCl_2$ refrigeration	Thomas and Booth 1973; Howe and Holley 1969	0.01 mg/l-N
	Method 132C	$HgCl_2$ refrigeration	A.P.H.A. et al. 1971; Howe and Holley 1969	0.01 mg/l-N
Nitrate	Method 213C	$HgCl_2$ refrigeration	A.P.H.A. et al. 1971; Howe and Holley 1969	0.01 mg/l-N
	Cadmium reduction	$HgCl_2$ refrigeration	U.S.E.P.A. 1974	0.01 mg/l-N
Orthophosphate, soluble	Method 11.1.	Filtration, refrigeration	Strickland and Parsons 1972; Ryden et al. 1972	1 µg/l-P
Oxygen, dissolved	Hydrolab Surveyor, methods 218F and 218B	Measured *in situ*	Hydrolab Corp. 1973; A.P.H.A. et al. 1971	0.1 mg/l
Oxygen, saturation	Calculated method 218B		A.P.H.A. et al. 1971	Expressed as percent
pH	Method 144A	Measured in the field	A.P.H.A. et al. 1971	0.1 pH
Phosphorus, total	Method 223C, then method 11.1.	None required	A.P.H.A. et al. 1971; Strickland and Parsons 1972	1 µg/l-P
Residue, filtrable (total dissolved solids)	148B	None required	A.P.H.A. et al. 1971	1 mg/l
Residue, nonfiltrable (total suspended solids)	Method 148C	None required	A.P.H.A. et al. 1971	1 mg/l
Silica, soluble	Method 151C	Filtration refrigeration	A.P.H.A. et al 1971	.01 mg/l-SiO_2
Temperature	Hydrolab Surveyor, method 162	Measured *in situ*	Hydrolab Corp. 1973; A.P.H.A. et al. 1971	0.1 C
Turbidity [b]	Hach Turbidimeter method 163A	None required	A.P.H.A. et al. 1971	0.1 N.T.U.

[a] The gas diffusion electrode method was used in July and September 1974, and in January 1975.

[b] Until May 1975 the detection limit and units were 1 J.T.U. Beginning in May, they were changed to 0.1 N.T.U.

Table A-3. Analytical methods for the chemical constituents measured in water samples collected in Lake Michigan near Zion and Waukegan, Illinois, Janaury 1973 through June 1974.

Parameter	Method	Preservative	Reference	Detection Limit
Alkalinity, total	Method 102	None required	A.P.H.A. et al. 1971	1 mg/l-$CaCO_3$
Ammonia	Gas diffusion electrode	$HgCl_2$[a]	Thomas and Booth 1973	0.01 mg/l-N
Chlorine, total	Method 114B	Measured in the field	A.P.H.A. et al. 1971	0.01 mg/l
Nitrate	Method 213C	$HgCl_2$[a]	A.P.H.A. et al. 1971	0.01 mg/l-N
Orthophosphate, soluble	Method II.1.	Filtration[b]	Strickland and Parsons 1972	1 µg/l-P
Oxygen, dissolved	Oxygen Meter, method 218B	Measured in situ	A.P.H.A. et al. 1971	0.1 mg/l
Oxygen, saturation	Calculated, method 218B	-	A.P.H.A. et al. 1971	Expressed as percent
pH	Method 114A	Measured in the field	A.P.H.A. et al. 1971	0.1 pH
Phosphorus, total	Method 223C, then method II.1.	None required	A.P.H.A. et al. 1971; Strickland and Parsons 1972	1 µg/l-P
Residue, filtrable (total dissolved solids)	Method 148B	None required	A.P.H.A. et al. 1971	1 mg/l
Residue, non-filtrable (total suspended solids)	Method 148C	None required	A.P.H.A. et al. 1971	1 mg/l
Silica, soluble	Method 151C	Filtration	A.P.H.A. et al. 1971	0.01 mg/l-SiO_2
Turbidity	Hach Model 2100A Turbidimeter	None required	A.P.H.A. et al. 1971	1 J.T.U.

[a] 40 mg $HgCl_2$ added to one liter of sample, refrigerated. Howe, L. H. III, and C. W. Holley. 1969. Comparisons of mercury (II) chloride and sulfuric acid as preservatives for nitrogen forms in water samples. Environ. Sci. Technol. 3: 478-481.

[b] Ryden, J. C., J. K. Syers, and R. F. Harris. 1972. Sorption of inorganic phosphate by laboratory ware. Implications in environmental phosphorus techniques. Analyst. 97: 903-908.

Table A-4. Analytical methods for the chemical constituents measured in water samples collected in Lake Michigan near Zion and Waukegan, Illinois, April through December 1972.

Parameter	Method and Reference	Preservation Techniques	Detection Limit
Alkalinity, total	Method 102[a]		1 mg/l-$CaCO_3$
Aluminum	AAS/DA[b]	HNO_3[c]	0.1 mg/l
Ammonia	Nessler method 132B[a];	$HgCl_2$[e]	0.03 mg/l-N
	beginning Feb. 1972, phenate method 132C[a];	$HgCl_2$[e]	0.01 mg/l-N
	beginning Sept. 1972, gas diffusion electrode[d]	$HgCl_2$[e]	0.01 mg/l-N
Arsenic	AAS/AsH_3[f]	HNO_3[c]	1 µg/l
Bacteria, standard plate count	Techniques for microbiological analysis[g]	Sterile[h]	0 organisms/ 100 ml
Bacteria, total coliform	Method 408A[a]	Sterile[h]	0 organisms/ 100 ml
Bacteria, fecal coliform	Method 408B[a]	Sterile[h]	0 organisms/ 100 ml
Bacteria, fecal streptococci	Method 409B[a]	Sterile[h]	0 organisms/ 100 ml
Barium	AAS/DA[b]	HNO_3[c]	0.1 mg/l
Beryllium	AAS/DA[b]	HNO_3[c]	5 µg/l
Biochemical oxygen demand (5-day)	Method 219[a]	BOD water sealed bottle, refrigerated	0.5 mg/l
Boron	Dianthrimide method[i]		0.01 mg/l with 10 ml sample size
Cadmium	AAS/Chelation[j]	HNO_3[c]	0.1 µg/l
Calcium	AAS/DA[b]	HNO_3[c]	2 µg/l

Table A-4. (continued)

Parameter	Method and Reference	Preservation Techniques	Detection Limit
Cesium	Flame emission	HNO_3	0.1 mg/l
Chemical oxygen demand	Low level method[k]	Glass container, refrigerated	0.1 mg/l
Chloride	Mercuric nitrate method 112B[a]		0.05 mg/l
Chlorine, total	Amperometric method 114B[a]	Measured at sampling location	0.01 mg/l
Chromium, hexavalent	AAS/Chelation[j]	HNO_3[c]	1 µg/l
Chromium, trivalent	Total Cr by digestion/ AAS/Chelation[j], subtract Cr (VI)	HNO_3[c]	1 µg/l
Cobalt	AAS/Chelation[j]	HNO_3[c]	1 µg/l
Color, true	Colorimetric method 118[a]		1 unit
Conductance, specific	Method 154[a]		1 µmhos/cm
Copper	AAS/Chelation[j]	HNO_3[c]	0.1 µg/l
Cyanide	Method on pg. 41[k]	NaOH to pH 11, refrigerated	-
Fluoride	Specific ion electrode[d]		0.01 mg/l
Hardness, total	Sum of Ca and Mg, AAS/DA[b]		1 mg/l-$CaCO_3$
Hexane soluble materials	Soxhlet extraction[k]	HCl to pH < 3, refrigerated	0.1 mg/l
Iron	AAS Chelation[j]	HNO_3[c]	1 µg/l

Table A-4. (continued)

Parameter	Method and Reference	Preservation Techniques	Detection Limit
Iron, total	AAS/DA[b]	HNO_3[c]	0.01 mg/l
Lead	AAS/Chelation[j]	HNO_3[c]	1 µg/l
Lithium	AAS/DA[b]	HNO_3[c]	2 µg/l
Magnesium	AAS/DA[b]	HNO_3[c]	1 µg/l
Manganese	AAS/Chelation[l]	HNO_3[c]	1 µg/l
Mercury	Flameless AAS[m]	HNO_3[c]	0.05 µg/l
Methylene blue-active substances	Method 159[a]	Glass container, refrigerated	0.025 mg/l
Molybdenum	AAS/DA[b]	HNO_3[c]	0.05 mg/l
Nickel	AAS/Chelation[j]	HNO_3[c]	1 µg/l
Nitrate	Brucine method 213C[a]	$HgCl_2$[e]	0.01 mg/l-N
Nitrite	Method 134[a]; beginning Nov. 1972, sulfanilamide method[n]	$HgCl_2$[e]	0.2 µg/l-N
Odor, threshold	Method 136[a]	Glass container, refrigerated	-
Organic carbon, total	Beckman Carbonaceous Analyzer Model 915	HCl to pH 2	1 mg/l
Organic nitrogen, total	Method 135[a] and phenate method 132C[a]	$HgCl_2$[e]	0.01 mg/l
Organic nitrogen, soluble	Millipore HA 0.45 µ filtration, method 135[a]	$HgCl_2$[e]	0.01 mg/l
Orthophosphate, soluble	Stannous chloride method 223E[a]; beginning Aug. 1972, ascorbic acid method[n]	Filtration[o]	1 µg/l-P
		Filtration[o]	1 µg/l-P

Table A-4. (continued)

Parameter	Method and Reference	Preservation Techniques	Detection Limit
Oxygen, dissolved	Dissolved Oxygen Meter standardized by method 218B[a]	Measured at sampling location	0.1 mg/l
Oxygen, saturation	Calculated from D.O. and temperature data using Table 218(1)[a]		Expressed as percent
pH	Glass electrode method 144A[a]	Measured at sampling location	0.1 pH
Phenols	Methods 222B & C[a]	$CuSO_4$, H_3PO_4 to pH 4.0, refrigerated	1 µg/l
Phosphorus, total	Method 223C[a] then stannous chloride method 223E[a]; beginning Aug. 1972, method 223C[a] then ascorbic acid method[n]		[illegible] µg/l-P 1 µg/l-P
Potassium	AAS/DA[b]	HNO_3[c]	5 µg/l
Residue, filtrable	Method 148B[a]		1 mg/l
Residue, non-filtrable	Method 148C[a]		1 mg/l
Residue, total	Method 148A[a]		1 mg/l
Residue, total volatile	Method 148D[a]		1 mg/l
Residue, filtrable volatile	Method 148D[a]		1 mg/l
Residue, non-filtrable volatile	Method 148D[a]		1 mg/l
Selenium	AAS/SeH_3[f]	HNO_3[c]	1 µg/l

Table A-4. (continued)

Parameter	Method and Reference	Preservation Techniques	Detection Limit
Silica, soluble	Method 151C[a]	Filtrati[illegible]	0.01 mg/l
Silver	AAS/Chelation[j]	HNO_3[c]	[illegible] µg/l
Sodium	AAS/DA[b]	HNO_3[c]	[illegible] µg/l
Solids, total dissolved	Method 148B[a]		1 mg/l
Solids, total suspended	Method 148C[a]		1 mg/l
Solids, total	Method 148A[a]		1 mg/l
Solids, total volatile	Method 148D[a]		1 mg/l
Solids, dissolved volatile	Method 148D[a]		1 mg/l
Solids, suspended volatile	Method 148D[a]		1 mg/l
Strontium	AAS/DA[b]	HNO_3[c]	0.1 mg/l
Sulfate	Turbidimetric method 156C[a]	Filtration prior to analysis	5 mg/l
Sulfide	Specific ion electrode[d]	Zinc acetate and NaOH	4 µg/l
Tin	AAS/DA[b]	HNO_3[c]	0.1
Turbidity	Hach Model 2100A Turbidimeter		1 J.T.U.
Vanadium	AAS/DA[b]	HNO_3[c]	0.1 mg/l
Zinc	AAS/Chelation[j]	HNO_3[c]	1 µg/l

Table A-4. (continued)

---

[a] A.P.H.A., A.W.W.A. and W.P.C.F. 1971. Standard Methods for the Examination of Water and Wastewater. 13th ed. Am. Public Health Assn. Washington, D. C. 874 pp.

[b] Atomic Absorption Spectrophotometry/Direct Aspiration.

[c] 5 ml concentrated HNO_3 added to two liters of sample.

[d] Orion Research, Inc. 1970. Instruction Manual. Cambridge, Massachusetts.

[e] 40 mg $HgCl_2$ added to one liter of sample, refrigerated. Howe, L. H. III, and E. W. Hulley. 1969. Comparisons of Mercury (II) Chloride and Sulfuric Acid as Preservatives for Nitrogen Forms in Water Samples. Environ. Sci. Technol. 3:471-48[illegible].

[f] Perkin-Elmer Corporation. 1972. Instructions for High Sensitivity Arsenic-Selenium Sampling System #303-0849. Norwalk, Connecticut.

[g] Millipore Corporation. 1967. Techniques for Microbiological Analysis. ADM-40. Bedford, Massachusetts.

[h] Sterile conditions, refrigerated beginning in June with 1 ml/l 10% $Na_2S_2O_3$ added.

[i] Levinson, A. A. 1971. An Improved Dianthrimide Technique for the Determination of Boron in River Waters. Water Res. 5:41-42.

[j] Fishman, M. J. and M. R. Midgett. 1968. Extraction Techniques for the Determination of Cobalt, Nickel and Lead in Freshwater by Atomic Absorption. p. 230-236. In: R. F. Gould (ed.), Trace Inorganics in Water. Amer. Chem. Soc., Washington, D. C.

[k] Environmental Protection Agency. 1971. Methods for Chemical Analysis of Water and Wastes. Water Quality Office, Analytical Control Laboratory, Cincinnati, Ohio. 312 pp.

[l] Fishman, M. J. and M. R. Midgett. 1968. Modified pH and Extraction Technique. p. 230-236. In: R. F. Gould (ed.), Trace Inorganics in Water. Amer. Chem. Soc., Washington, D. C.

[m] Hatch, W. R. and W. L. Ott. 1968. Determination of Sub-microgram Quantities of Mercury by Atomic Absorption Spectrophotometry. Analytical Chemistry. 40:2085-2087.

[n] Strickland, J. D. H. and T. R. Parsons. 1968. A Practical Handbook of Seawater Analysis. Bull. Fish. Res. Bd. Canada. 167. 311 pp.

[o] Immediate filtration (Millipore HA 0.45 μ), refrigerated.

Table A-5. Analytical methods for the chemical constituents measured in water samples collected in Lake Michigan near Zion and Waukegan, Illinois, April 1971 through March 1972.

Parameter	Method and Reference	Preservation Techniques	Detection Limit
Ammonia	Nesslerization Method 132B[1], Beginning in Feb., 1972: Phenate Method 132C[1]	$HgCl_2$ solution, refrigerated	0.03 mg/l-N 0.01 mg/l-N
Bacteria, Total Coliform	Membrane Filtration 408A[1]	Sterile conditions, refrigerated.	0 organisms/100 ml
Biochemical Oxygen Demand (5-day)	Method 219[1]	BOD water sealed bottles, refrigerated.	0.1 mg/l
Color, True	Colorimetric Method 118[1]		1 unit
Copper	Atomic Absorption Spectrophotometry/ Chelation/Direct Aspiration[2]	5 ml Conc. HNO_3 added to 2 liters of sample.	0.1 µg/l
Iron, Total	Atomic Absorption Spectrophotometry/ Chelation/Direct Aspiration[2]	5 ml Conc. HNO_3 added to 2 liters of sample.	0.001 mg/l
Magnesium	Atomic Absorption Spectrophotometry/ Direct Aspiration[2]	5 ml Conc. HNO_3 added to 2 liters of sample.	0.1 mg/l
Manganese	Atomic Absorption Spectrophotometry/ Chelation/Direct Aspiration[3]	5 ml Conc. HNO_3 added to 2 liters of sample.	0.5 µg/l
Mercury	Flameless Atomic Absorption Spectrophotometry[4]	5 ml Conc. HNO_3 added to 2 liters of sample.	0.05 µg/l
Nitrate	Brucine Method 213C[1]	$HgCl_2$ solution, refrigerated.	0.01 mg/l-N
Nitrite	Sulfanilic Acid Method 134[1]	$HgCl_2$ solution, refrigerated.	0.2 µg/l-N
Organic Nitrogen, Total	Method 135[1]	$HgCl_2$ solution, refrigerated.	0.002 mg/l
Orthophosphate, Soluble	$SnCl_2$ Method 223E[1]	Immediate membrane filtration, refrigerated.	0.002 mg/l-PO_4
Phosphorus, Total	Digestion Method 223C[1] then $SnCl_2$ Method 223E[1]		0.002 mg/l-PO_4
Potassium	Atomic Absorption Spectrophotometry/ Direct Aspiration	5 ml Conc. HNO_3 added to 2 liters of sample.	0.01 mg/l
Silica	Heteropoly Blue Method 151C[1]		0.01 mg/l
Solids, Total Volatile	Method 224D[1]		1 mg/l
Turbidity	Hach Turbidimeter 2100A		1 J.T.U.

1/ A.P.H.A., A.W.W.A. and W.P.C.F. (1971).
2/ Fishman, M. J., and Midgett, M. R. (1968).
3/ Fishman, M. J. 1970. Personal communication. U. S. Geological Survey, Denver, Colorado.
4/ Dow Chemical Company (1970).

Table A-6. Analytical methods for the chemical constituents measured in water samples collected in Lake Michigan near Zion and Waukegan, Illinois, February 1970 through March 1971.

Parameter	Method and Reference	Preservation Techniques	Detection Limit
Alkalinity, Total	Titrimetric Method pg. 48[1] using pH meter to detect end-points.	Measured upon sample collection.	1 mg/l
Ammonia	Preliminary distillation, pg. 187[1] followed by Nesslerization Method, pg. 193[1].	$HgCl_2$ solution, refrigerated.	0.03 mg/l-N
Arsenic	Colorimetric Method, pg. 66[1].		0.5 mg/l
Bacteria, Total Coliform	Multiple-tube fermentation technique, pg. 594[1]. Beginning in August 1970 membrane filter technique, pg. 611[1].		0 organisms/100 ml
Bacteria, Fecal Coliform	Multiple-tube fermentation technique, pg. 594[1]. Beginning in August 1970 membrane filter technique, pg. 610[1].		0 organisms/100 ml
Bacteria, Fecal Streptococci	Multiple-tube technique, page 620[1]. Beginning in August 1970 membrane filter technique, pg. 619[1].		0 organisms/100 ml
Biochemical Oxygen Demand (5-day)	BOD Method, pg. 218[1].	BOD water sealed bottles, refrigerated.	0.1 mg/l
Boron	Colorimetric Method, pg. 53[1].		0.01 mg/l
Chemical Oxygen Demand	Titrimetric Method, pg. 510[1]		0.1 mg/l
Chloride	Mercuric Nitrate Method, pg. 87[1]		0.5 mg/l
Chromium	Atomic Absorption Spectrophotometry/ Chelation/Direct Aspiration[2].	5 ml Conc. HNO_3 added to 2 liters of sample.	1 µg/l
Color, Apparent	Colorimetric Method, modified, pg. 127[1].		1 unit
Color, True	Colorimetric Method, modified, preceded by centrifugation, pg. 127[1].		1 unit
Conductance, Specific	Conductance Bridge at 25° C, pg. 280[1].		1 µmho/cm
Cyanide	Distillation and colorimetric Method pg. 445[1].	NaOH to pH 11.0, refrigerated.	0.005 mg/l
Fluoride	Alizarin Photometric Method, pg. 142[1].		0.01 mg/l
Hardness, Total	Titrimetric Method, pg. 147[1].		1 mg/l as $CaCO_3$

Table A-6. (continued)

Parameter	Method and Reference	Preservation Techniques	Detection Limit
Hexane Soluble Materials	Soxhlet Extraction Method, pg. 384[1].	HCl to pH 1	0.1 mg/l
Methylene Blue-Active Substances	Methylene Blue Method, pg. 267[1]	Glass container, refrigerated.	0.025 mg/l
Nitrate	Brucine Method, pg. 196[1]. Beginning in January 1971 Jenkins modified Brucine Method[3].	$HgCl_2$ solution, refrigerated.	0.01 mg/l-N
Nitrite	Sulfanilic Acid Method, pg. 205[1].	$HgCl_2$ solution, refrigerated.	0.0002 mg/l-N
Odor, Threshold	Method on pg. 304[1].	Glass bottles, refrigerated.	
Organic Carbon, Total	Carbon Analyzer.	HCl to pH	1 mg/l
Orthophosphate, Soluble	Stannous Chloride Method, pg. 234[1]	Immediate membrane filtration.	0.002 mg/l - PO_4
Oxygen, Dissolved	Modified Winkler Titration, pg. 406[1]. Beginning in November 1970 Model 300 Weston and Stack Dissolved Oxygen Meter.	Measured at sampling location.	0.1 mg/l
Oxygen, Saturation	Calculated from D.O. and water temperature data using Table 25, pg. 409[1].		
pH	Glass Electrode Method, pg. 226[1], Sargent-Welch PBX pH Meter.	Measured at sampling location.	0.1 pH
Phenols	Distillation and $CHCl_3$ Extraction Method, pg. 517[1].	$CuSO_4$, Conc. H_3PO_4 to pH 4.0, refrigerated.	0.001 mg/l
Phosphorus, Total	Digestion with sulfuric acid, pg. 236[1] followed by the Aminonaphtholsulfonic Acid Method, pg. 231[1].		0.03 mg/l - PO_4
Phosphorus, Total	Beginning in January 1971 Sulfuric acid-persulfate digestion followed by the Stannous Chloride Method, pg. 234[1].		0.002 mg/l - PO_4
Potassium	Atomic Absorption Spectrophotometry/ Direct Aspiration.	5 ml Conc. HNO_3 added to 2 liters of sample.	0.01 mg/l
Silica	Heteropoly Blue Method, pg. 264[1].		0.01 mg/l
Sodium	Atomic Absorption Spectrophotometry/ Direct Aspiration.	5 ml Conc. HNO_3 added to 2 liters of sample.	0.01 mg/l
Solids, Total Dissolved	Filtrable Residue Method, pg. 245[1].		1 mg/l
Solids, Total Suspended	Nonfiltrable Residue Method, pg. 246[1]		1 mg/l
Sulfate	Turbidimetric Method, pg. 291[1].	Filtration prior to analysis.	0.1 mg/l
Temperature	NBS Certified Thermometer. Beginning in November 1970 Whitney Model TC-5A Thermistor/Thermometer.	Measured at sampling location.	0.1 C
Turbidity	Hach Turbidimeter Model 2100.		1 J.T.U.

1/ A.P.H.A., A.W.W.A. and W.P.C.F. 1965. Standard Methods for the Examination of Water and Wastewater. 12th ed. Am. Public Health Assn., Inc. New York, N.Y. 769 pp.

2/ Fishman, M. J. and M. R. Midgett. 1968. In Gould, R. F. ed., Trace Inorganics in Water, Am. Chem. Soc., Washington, D. C. 396 pp.

3/ Jenkins, D. and L. L. Medaker. 1964. A brucine method for the determination of nitrate in ocean, estuarine and fresh waters. Anal. Chem. 36: 610.

Table A-7. Analytical methods for the chemical constituents measured in water samples collected in Lake Michigan, inshore and offshore near Zion and Waukegan, Illinois, January 1970 through April 1971.

Parameter	Method and Reference	Preservation Techniques	Detection Limit
Alkalinity, Total	Titrimetric Method pg. 48[1] using pH meter to detect end-points.	Measured upon sample collection.	1 mg/l
Ammonia	Preliminary distillation, pg. 187[1] followed by Nesslerization Method, pg. 193[1].	$HgCl_2$ solution, refrigerated.	0.03 mg/l-N
Arsenic	Colorimetric Method. pg. 56[1].		0.5 mg/l
Bacteria, Total Coliform	Multiple-tube fermentation technique, pg. 594[1]. Beginning in August 1970 membrane filter technique, pg. 610[1].		0 organisms/100 ml
Bacteria, Fecal Coliform	Multiple-tube fermentation technique, pg. 594[1]. Beginning in August 1970 membrane filter technique, pg. 610[1].		0 organisms/100 ml
Bacteria, Fecal Streptococci	Multiple-tube technique, page 620[1]. Beginning in August 1970 membrane filter technique, pg. 619[1].		0 organisms/100 ml
Biochemical Oxygen Demand (5-Day)	BOD Method, pg. 218[1].	BOD water sealed bottles, refrigerated.	0.1 mg/l
Boron	Colorimetric Method, pg. 63[1].		0.01 mg/l
Cadmium	Atomic Absorption Spectrophotometry/ Chelation/Direct Aspiration[2].	5 ml Conc. HNO_3 added to 2 liters of sample.	1 µg/l
Calcium	Atomic Absorption Spectrophotometry/ Direct Aspiration.	5 ml Conc. HNO_3 added to 2 liters of sample.	0.1 mg/l
Chemical Oxygen Demand	Titrimetric Method, pg. 510[1].		0.1 mg/l
Chloride	Mercuric Nitrate Method, pg. 87[1]		0.5 mg/l
Chromium	Atomic Absorption Spectrophotometry/ Chelation/Direct Aspiration[2].	5 ml Conc. HNO_3 added to 2 liters of sample.	1 µg/l
Color, Apparent	Colorimetric Method, modified, pg. 127[1].		1 unit
Color, True	Colorimetric Method, modified, preceded by centrifugation, pg. 127[1].		1 unit
Conductance, Specific	Conductance Bridge at 25° C, pg. 280[1].		1 µmho/cm
Copper	Atomic Absorption Spectrophotometry Chelation/Direct Aspiration[2].	5 ml Conc. HNO_3 added to 2 liters of sample	0.1 µg/l

Table A-7. (continued)

Parameter	Method and Reference	Preservation Techniques	Detection Limit
Cyanide	Distillation and colorimetric Method, pg. 445[1].	NaOH to pH 11.0, refrigerated.	0.005 mg/l
Fluoride	Alizarin Photometric Method, pg. 142[1].		0.01 mg/l
Hardness, Total	Titrimetric Method, pg. 147[1].		1 mg/l as $CaCO_3$
Hexane Soluble Materials	Soxhlet Extraction Method, pg. 384[1].	HCl to pH 1	0.1 mg/l
Iron	Atomic Absorption Spectrophotometry/ Chelation/Direct Aspiration[2].	5 ml Conc. HNO_3 added to 2 liters of sample.	1 µg/l
Lead	Atomic Absorption Spectrophotometry/ Chelation/Direct Aspiration[2].	5 ml Conc. HNO_3 added to 2 liters of sample.	1 µg/l
Magnesium	Atomic Absorption Spectrophotometry/ Direct Aspiration.	5 ml Conc. HNO_3 added to 2 liters of sample	0.1 mg/l
Manganese	Atomic Absorption Spectrophotometry/ Chelation/Direct Aspiration[2].	5 ml Conc. HNO_3 added to 2 liters of sample.	1 µg/l
Mercury	Flameless Atomic Absorption Spectrophotometry[4].	5 ml Conc. HNO_3 added to 2 liters of sample.	0.05 µg/l
Methylene Blue-Active Substances	Methylene Blue Method, pg. 297[1].	Glass container, refrigerated.	0.025 mg/l
Nickel	Atomic Absorption Spectrophotometry/ Chelation/Direct Aspiration[2].	5 ml Conc. HNO_3 added to 2 liters of sample.	1 µg/l
Nitrate	Brucine Method, pg. 199[1]. Beginning in January 1971 Jenkins modified Brucine Method[5].	$HgCl_2$ solution, refrigerated.	0.01 mg/l-N
Nitrite	Sulfanilic Acid Method, pg. 205[1].	$HgCl_2$ solution, refrigerated.	0.0002 mg/l-N
Odor, Threshold	Method on pg. 304[1].	Glass bottles, refrigerated.	
Organic Carbon, Total	Carbon Analyzer	HCl to pH 2	1 mg/l
Orthophosphate, Soluble	Stanous Chloride Method, page 234[1].	Immediate membrane filtration.	0.002 mg/l - PO_4
Oxygen, Dissolved	Modified Winkler Titration, pg. 406[1]. Beginning in November 1970 Model 300 Weston and Stack Dissolved Oxygen Meter.	Measured at sampling location.	0.1 mg/l

Table A-7. (continued)

Parameter	Method and Reference	Preservation Techniques	Detection Limit
Oxygen, Saturation	Calculated from D. O. and water temperature data using Table 25, pg. 409[1].		
pH	Glass Electrode Method, pg. 226[1], Sargent-Welch PBX pH Meter.	Measured at sampling location.	0.1 pH
Phenols	Distillation and $CHCl_3$ Extraction Method, pg. 517[1].	$CuSO_4$, Conc. H_3PO_4 to pH 4.0, refrigerated.	0.001 mg/l
Phosphorus, Total	Digestion with sulfuric acid, pg. 236[1] followed by the Aminonaphtholsulfonic Acid Method, pg. 231[1].		0.03 mg/l - PO_4
Phosphorus, Total	Beginning in January 1971 Sulfuric acid - persulfate digestion followed by the Stannous Chloride Method, pg. 234[1].		0.002 mg/l - PO_4
Potassium	Atomic Absorption Spectrophotometry/ Direct Aspiration.	5 ml Conc. HNO_3 added to 2 liters of sample.	0.01 mg/l
Silica	Heteropoly Blue Method, pg. 264[1].		0.01 mg/l
Sodium	Atomic Absorption Spectrophotometry/ Direct Aspiration.	5 ml Conc. HNO_3 added to 2 liters of sample.	0.01 mg/l
Solids, Total Dissolved	Filtrable Residue Method, pg. 245[1].		1 mg/l
Solids, Total Suspended	Nonfiltrable Residue Method, pg. 246[1].		1 mg/l
Sulfate	Turbidimetric Method, pg. 291[1].	Filtration prior to analysis.	0.1 mg/l
Temperature	NBS Certified Thermometer. Beginning in November 1970 Whitney Model TC-5A Thermistor/Thermometer.	Measured at sampling location.	0.1 C
Turbidity	Hach Turbidimeter Model 2100.		1 J.T.U.
Zinc	Atomic Absorption Spectrophotometry/ Chelation/Direct Aspiration[2].	5 ml Conc. HNO_3 added to 2 liters of sample.	1 µg/l

1/ A.P.H.A., A.W.W.A. and W.P.C.F. 1965. Standard Methods for the Examination of Water and Wastewater. 12th ed. Am. Public Health Assn., Inc. New York, N. Y. 769 pp.

2/ Fishman, M. J. and M. R. Midgett. 1968. In Gould, R. F. ed., Trace Inorganics in Water, Am. Chem. Soc., Washington, D. C. 396 pp.

3/ Personal communication, M. J. Fishman, U. S. Geological Survey, Denver, Colorado, October 1970.

4/ Anon. 1970. Determination of mercury by atomic absorption spectrophotometric method. Dow Chemical Company # CAS-AM-70. 13, Midland, Michigan.

5/ Jenkins, D. and L. L. Medsker. 1964. A brucine method for the determination of nitrate in ocean, estuarine and fresh waters. Anal. Chem. 36:610.

Table A-8. Sampling frequency for water quality parameters in southwestern Lake Michigan near Zion and Waukegan, Illinois, 1972.

Water quality parameter	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Alkalinity, total	T[a]B[b]	TB	TB	TB	TB	TT[c]	TT	TT	TT	TT	TT	TT
Aluminum						TT	TT	TT	TT	TT	TT	TT
Ammonia[d]	TTB	TTB	TTB	TTB	TB	TT	TT	TT	TT	TT	TT	TT
Arsenic							TT					TT
Bacteria, total coliform[d]	TT	TT	TT	TT	T	TT	TT	TT	TT	TT	TT	TT
Bacteria, fecal coliform	T	T	T	T	T	TT	TT	TT	TT	TT	TT	TT
Bacteria, fecal streptococci	T	T	T	T	T	TT	TT	TT	TT	TT	TT	TT
Bacteria, standard plate count							TT					TT
Barium							TT					TT
Beryllium							TT					TT
Biochemical oxygen demand[d]	TT	TT	TT	TT	TT	TT	TT	TT	TT	TT	TT	TT
Boron						TT	TT	TT	TT	TT	TT	TT
Cadmium						TT	TT	TT	TT	TT	TT	TT
Calcium						TT	TT	TT	TT	TT	TT	TT
Cesium							TT					TT
Chemical oxygen demand						TT	TT	TT	TT	TT	TT	TT
Chloride						TT	TT	TT	TT	TT	TT	TT
Chlorine, total						TT	TT	TT	TT	TT	TT	TT
Chromium, hexavalent						TT	TT	TT	TT	TT	TT	TT
Chromium, trivalent						TT	TT	TT	TT	TT	TT	TT
Cobalt							TT					TT
Color, true						TT	TT	TT	TT	TT	TT	TT
Conductance, specific	TB	TB	TB	TB		TT	TT	TT	TT	TT	TT	TT
Copper						TT	TT	TT	TT	TT	TT	TT
Cyanide							TT					TT
Fluoride						TT	TT	TT	TT	TT	TT	TT

Table A-8. (continued)

Water quality parameter	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Hardness, total						TT	TT	TT	TT	TT	TT	TT
Hexane soluble materials							TT					TT
Iron						TT	TT	TT	TT	TT	TT	TT
Lead						TT	TT	TT	TT	TT	TT	TT
Lithium							TT					TT
Magnesium						TT	TT	TT	TT	TT	TT	TT
Manganese						TT	TT	TT	TT	TT	TT	TT
Mercury						TT	TT	TT	TT	TT	TT	TT
Methylene blue-active substances						TT	TT	TT	TT	TT	TT	TT
Molybdenum							TT					TT
Nickel						TT	TT	TT	TT	TT	TT	TT
Nitrate[d]	TTB	TTB	TTB	TTB	TB	TT	TT	TT	TT	TT	TT	TT
Nitrite[d]	TTB	TTB	TTB	TTB	TB		TT					TT
Odor, threshold						TT	TT	TT	TT	TT	TT	TT
Organic carbon, total[d]	TTB	TTB	TTB	TTB	TB	TT	TT	TT	TT	TT	TT	TT
Organic nitrogen, total						TT	TT	TT	TT	TT	TT	TT
Organic, nitrogen soluble						TT	TT	TT	TT	TT	TT	TT
Orthophosphate, soluble[d]	TTB	TTB	TTB	TTB	TB	TT	TT	TT	TT	TT	TT	TT
Oxygen, dissolved[e]	TTBB	TTBB	TTBB	TTBB	TB	TT	TT	TT	TT	TT	TT	TT
pH[e]	TTBB	TTBB	TTBB	TTBB	TB	TT	TT	TT	TT	TT	TT	TT
Phenols							TT					TT
Phosphorus, total[d]	TTB	TTB	TTB	TTB	TB	TT	TT	TT	TT	TT	TT	TT
Potassium						TT	TT	TT	TT	TT	TT	TT
Selenium							TT					TT
Silica[d]	TTB	TTB	TTB	TTB	TB	TT	TT	TT	TT	TT	TT	TT
Silver							TT					TT
Sodium						TT	TT	TT	TT	TT	TT	TT
Solids, total						TT	TT	TT	TT	TT	TT	TT

Table A-8. (continued)

Water quality parameter	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Solids, total dissolved						TT	TT	TT	TT	TT	TT	TT
Solids, suspended volatile							TT					TT
Solids, total volatile							TT					TT
Solids, total suspended							TT					TT
Sulfate						TT	TT	TT	TT	TT	TT	TT
Strontium							TT					TT
Sulfide, total							TT					TT
Temperature[d]	TTB	TTB	TTB	TTB	TB	TT	TT	TT	TT	TT	TT	TT
Tin							TT					TT
Turbidity[d]	TTB	TTB	TTB	TTB	TB	TT	TT	TT	TT	TT	TT	TT
Vanadium							TT					TT
Zinc						TT	TT	TT	TT	TT	TT	TT

[a] T indicates a single sample was collected 1 meter below the surface.
[b] B indicates a single sample was collected 1 meter above the bottom.
[c] TT indicates duplicate samples collected simultaneously 1 meter below the surface.
[d] Only a single top sample was collected at sampling locations 10, 12, 13a from January through April.
[e] For this parameter, only a single top sample and a single bottom sample was collected at sampling locations 10, 12, 13a from January through April.

APPENDIX B

PHYTOPLANKTON SPECIES LIST

LIST OF TABLES

No.	Title	Page
B-1	List of phytoplankton taxa encountered in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978.....	A-37

Table B-1 List of phytoplankton taxa encountered in southwestern Lake Michigan near Zion, Illinois, January 1972 through September 1978.

BACILLARIOPHYTA: Centrales

Attheya T. West
- zachariasi J. Brun

Coscinodiscus Ehrenberg
- rothii var. subsalsa (Juhlin-Dannfeld) Hustedt
- unidentified sp.

Cyclotella Kuetzing
- antiqua W. Smith
- atomus Hustedt
- bodanica Eulenstein
- caspia Grunow
- comta (Ehrenberg) Kuetzing
- glomerata Bachmann
- kutzingiana Thawaites
- kutzingiana var. planetophora Fricke
- kutzingiana var. radiosa Fricke
- meneghiniana Kuetzing
- meneghiniana var. plana Fricke
- michiganiana Skvortzow
- ocellata Pantocsek
- pseudostelligera Hustedt
- stelligera (Cleve and Grunow) Van Heurck
- temperei Peragallo and Heribaud
- wolterecki Hustedt
- unidentified sp.

Melosira Agardh
- agassizii Ostenfeld
- agassizzi var. malayensis Hustedt
- ambigua (Grunow) O. Mueller
- distans (Egrenberg) Kuetzing
- granulata (Ehrenberg) Ralfs
- granulata var. angustissima O. Mueller
- islandica O. Mueller
- italica (Ehrenberg) Kuetzing
- varians Agardh
- unidentified sp.

Microsiphona Weber
- potamos Weber

Rhizosolenia Ehrenberg
- eriensis H. L. Smith
- longiseta Zacharias

Stephanodiscus Ehrenberg
- alpinus Hustedt ex. Huber-Pestalozzi
- astraea (Ehrenberg) Grunow in: Cleve and Grunow
- binderanus (Kuetzing) Krieger

Table -1 (continued).

hantzschii Grunow
invisitatus Hohn and Hellerman
minutus Grunow ex. Cleve and Moller
niagarae Ehrenberg
tenuis Hustedt ex. Huber-Pestalozzi
transilvanicus Pantocsek
unidentified sp.
unidentified sp. 2
Thalassiosira Cleve
unidentified sp.

BACILLARIOPHYTA: Pennales

Achnanthes Bory
clevei Grunow
clevei var. rostrata Hustedt
conspicua A. Mayer
exigua Grunow
haukiana Grunow
hungarica (Grunow)
lanceolata (Brebisson) Grunow
lanceolata var. dubia Grunow
lanceolata var. elliptica Cleve
lanceolata var. omissa Reimer
lewisiana Patrick
linearis (W. Smith) Grunow
microcephala Kuetzing
minutissima Kuetzing
peragalli var. parvula (Patrick) Reimer
pinnata Hustedt
unidentified sp.
Amphipleura Kuetzing
pellucida (Kuetzing) Kuetzing
Amphora Ehrenberg
coffeaeformis Agardh
coffeaeformis var. acutiuscula (Kuetzing) Hustedt
delicatissima Krasske
ovalis (Kuetzing) Kuetzing
ovalis var. constricta Skortzow
ovalis var. libyca (Ehrenberg) Cleve
ovalis var. pediculus (Kuetzing) Van Heurck
perpusilla Grunow
veneta Kuetzing
unidentified sp.
Asterionella Hassall
formosa Hassal
formosa var. gracillima (Hantzsch) Grunow

Table B-1 (continued).

Caloneis Cleve
- bacillum (Grunow) Cleve
- bacillum var. fontinalis Hustedt
- hyalina Hustedt
- ventricosa var. minuta (Grunow) Patrick
- ventricosa var. subundulata (Grunow) Patrick
- ventricosa var. truncatula (Grunow) Meister
- unidentified sp.

Capartogramma
- crucicula ex. Cleve) Ross

Cocconeis Ehr
- diminuta sek
- disculus (..numann) Cleve in: Cleve and Jentzsch
- pediculus Ehrenberg
- placentula Ehrenberg
- placentula var. euglypta (Ehrenberg) Cleve
- placentula var. lineata (Ehrenberg) Van Heurck
- thumensis A. Mayer
- unidentified sp.

Cymatopleura W. Smith
- elliptica (Brebisson and Godey) W. Smith
- solea (Brebisson and Godey) W. Smith
- solea var. apiculata (W. Smith) Ralfs

Cymbella Agardh
- amphicephala Naegeli ex. Kuetzing
- microcephala Grunow in: Van Heurck
- minuta Hilse ex. Rabenhorst
- minuta var. silesiaca (Bleisch ex. Rabenhorst) Reimer
- naviculaformis Auerswald
- parvula Krasske
- prostrata (Berkely) Cleve
- prostrata var. auerswaldii (Rabenhorst) Reimer
- sinuata Gregory
- tumida (Brebisson) Van Heurck
- turgida Gregory
- ventricosa Kuetzing
- unidentified sp.

Denticula Ehrenberg
- tenuis Kuetzing
- tenuis var. crassula (Naegeli) Hustedt
- unidentified sp.

Diatoma Bory
- elongatum var. minor Grunow
- hiemale var. mesodon (Ehrenberg) Grunow
- tenue Agardh
- tenue var. elongatum Lyngbye
- vulgare Bory
- vulgare var. breve Grunow
- vulgare var. linearis Van Heurck
- unidentified sp.

Table B-1 (continued).

Diploneis Ehrenberg
elliptica (Kuetzing) Cleve
oblongella (Naegeli ex. Kuetzing) Ross
oculata (Brebisson) Cleve
pseudovalis Hustedt
puella (Schumann) Cleve
smithii (Brebisson ex. W. Smith) Cleve
unidentified sp.
Grammoneis Ehrenberg
ornata (J. W. Bailey) Reimer
Rhopalodia Brebisson
zebra (Ehrenberg) Kuetzing
unidentified sp.
Eunotia Ehrenberg
curvata (Kuetzing) Lagerstedt
soleirolii (Kuetzing) Rabenhorst
unidentified sp.
Fragilaria Lyngbye
atomus Hustedt
brevistriata Grunow
capucina Desmazieres
capucina var. mesolepta Rabenhorst
construens (Ehrenberg) Grunow
construens var. binodis (Ehrenberg) Grunow
construens var. venter (Ehrenberg) Grunow
crotonensis Kitton
intermedia Grunow
leptostauron (Ehrenberg) Hustedt
leptostauron var. dubia (Grunow) Hustedt
pinnata Ehrenberg
pinnata var. intercedens (Grunow) Hustedt
pinnata var. lancettula (Schumann) Hustedt
vaucheriae (Kuetzing) Peterson
vaucheriae var. distans (Grunow) P. Boye
unidentified sp.
Frustulia Rabenhorst nom. cons. non Agardh
vulgaris (Thwaites) De Toni
Gomphonema Agardh
abbreviatum (Agardh) Kuetzing
angustatum (Kuetzing) Rabenhorst
angustatum var. sarcophagus (Gregory) Grunow
lanceolatum Ehrenberg
longiceps Ehrenberg
olivaceum (Lyngbye) Kuetzing
olivaceum var. calcarea Cleve
olivaceum var. minutissima Hustedt
parvulum Kuetzing
unidentified sp.

Table B-1 (continued).

Gyrosigma Hassall
nodiferum (Grunow) Reimer
obtusatum (Sullivan and Wormley) Boyer
scalproides (Rabenhorst) Cleve
spencerii (Quekett) Griffet and Henfrey
spencerii var. nodifera Grunow
unidentified sp.
Hantzschia Grunow
amphioxys (Ehrenberg) Grunow
Meridion (Greville) Agardh
circulare Agardh
circulare var. constrictum (Ralfs) Van Heurck
Navicula Bory
aikenensis Patrick
anglica Ralfs
bacillum Ehrenberg
bicapitellata Hustedt
bicontracta Oestrup
capitata Ehrenberg
capitata var. hungarica (Grunow) Ross
cari Ehrenberg
citrus Krasske
confervacea (Kuetzing) Grunow in: Van Heurck
confervacea var. peregrina (W. Smith) Grunow in: Van Heurck
costulata Grunow in: Cleve and Grunow
cryptocephala Kuetzing
cryptocephala var. intermedia (Grunow) Cleve
cryptocephala var. veneta (Kuetzing) Rabenhorst
cuspidata (Kuetzing) Kuetzing
declinata (Skortzow) Hustedt
decussis Oestrup
elginensis (Gregory) Ralfs
exigua Gregory ex. Grunow in: Van Heurck
exigua var. capitata Patrick
frugalis Hustedt
gastrum (Ehrenberg) Kuetzing
graciloides A. Mayer
gregaria Donkin
halophila (Grunow) Cleve
hambergii Hustedt
heufleri Grunow
integra (W. Smith) Ralfs
lanceolata (Agardh) Kuetzing
laterostrata Hustedt
longirostris Hustedt
menisculus Schumann
menisculus var. upsaliensis (Grunow) Grunow

Table B-1 (continued).

minima Grunow
minnewaukonensis Elm.
minuscula Grunow
mobiliensis Boyer
muralis Grunow in: Van Heurck
mutica Kuetzing
notha Wallace
peregrina (Ehrenberg) Kuetzing
placentula (Ehrenberg) Kuetzing
placentula f. rostrata A. Mayer
platystoma Ehrenberg
protracta Grunow
pupula Kuetzing
pupula var. elliptica Hustedt
pupula var. rectangularis (Gregory) Grunow
in: Cleve and Grunow
pupula var. rostrata Hustedt
pygmaea Kuetzing
radiosa Kuetzing
radiosa var. tenella (Brebisson) ex. Kuetzing Grunow
reinhardtii (Grunow) in: Cleve and Grunow
rhynchocephala Kuetzing
rhynchocephala var. amphiceros (Kuetzing) Grunow
in: Cleve and Grunow
salinarum Grunow in: Cleve and Grunow
salinarum var. intermedia (Grunow) Cleve
secura Patrick
scutelloides W. Smith ex. Gregory
seminulum Grunow
subhamulata var. undulata Hustedt
symmetrica Patrick
tripunctata (O. F.-Mueller) Bory
tripunctata var. schizonemoides (Van Heurck) Patrick
tuscula Ehrenberg
tuscula fo. minor (Ehrenberg) Grunow
vanheurckii Patrick
vaucheriae Petersen
viridula Kuetzing emend. Van Heurck
viridula var. avenacea (Brebisson ex. Grunow) Van Heurck
vitabunda Hustedt
unidentified sp.
unidentified sp. 1

Neidium Pfitzer
dubium (Ehrenberg) Cleve
dubium fo. constrictum Hustedt
ladogense Cleve
unidentified sp.

Table B-1 (continued)

Nitzschia Hassall
- accomodata Hustedt
- acicularis (Kuetzing) W. Smith
- actinastroides Lemmermann
- acuta Hantzsch
- agnewii Cholnoky
- amphibia Grunow
- angustata (W. Smith) Grunow
- apiculata (Gregory) Grunow
- bacata Hustedt
- capitellata Hustedt
- diserta Hustedt
- dissipata (Kuetzing) Grunow
- dissipata var. media (Hantzsch) Grunow
- filiformis (W. Smith) Schutt in: Engler and Prantl
- fonticola Grunow in: Van Heurck
- fonticola var. capitata A. Cleve
- frustulum (Kuetzing) Grunow
- frustulum var. perpusilla (Rabenhorst) Grunow
- gracilis Hantzsch
- holsatica Hustedt
- hungarica Grunow
- kutzingiana Hilse
- lauenburgiana Hustedt
- linearis W. Smith
- longissima var. closterium (W. Smith) Van Heurck
- longissima var. reversa Grunow
- palea (Kuetzing) W. Smith
- paleacea Grunow
- pseudofonticola Hustedt
- recta Hantzsch
- sigma (Kuetzing) W. Smith
- sigmoidea (Nitzsch) W. Smith
- spiculum Hustedt
- subacicularis Hustedt
- subcapitellata Hustedt
- sublinearis Hustedt
- subtilis Kuetzing
- tryblionelia Hantzsch
- tryblionella var. levidensis (W. Smith) Grunow
- tryblionella var. victoriae Grunow
- vermicularis (Kuetzing) Grunow
- unidentified sp.

Opephora Petit
- martyi Heribaud

Pinnularia Ehrenberg
- borealis Ehrenberg
- unidentified sp.

Table B-1 (continued).

Pleurosigma W. Smith
unidentified sp.
Rhoicosphenia Grunow
curvata (Kuetzing) Grunow
Rhopalodia O. Mueller
unidentified sp.
Stauroneis Ehrenberg
acuta W. Smith
lapponica Cleve
smithii Grunow
smithii var. incisa Pantocsek
unidentified sp.
Surirella Turpin
angusta Kuetzing
linearis W. Smith
linearis var. constricta (Ehrenberg) Grunow
ovalis Brebisson
ovata Kuetzing
unidentified sp.
Synedra Ehrenberg
acus Kuetzing
amphicephala Kuetzing
delicatissima W. Smith
delicatissima var. angustissima Grunow
demerarae Grunow
famelica Kuetzing
fasiculata (Agardh) Kuetzing
fasiculata var. truncata (Greville) Patrick comb. nov.
filiformis Grunow
minuscula Grunow
parasitica (W. Smith) Hustedt
parasitica var. subconstricta (Grunow) Hustedt
pulchella Ralfs ex. Kuetzing
radians Kuetzing
rumpens Kuetzing
stela Hohn and Hellerman
ulna (Nitzsch) Ehrenberg
ulna var. chaseana Thomas
ulna var. danica (Kuetzing) Van Heurck
ulna var. longissima (W. Smith) Brun
ulna var. subaequalis (Grunow) Van Heurck
unidentified sp.
Tabellaria Ehrenberg
fenestrata var. geniculata A. Cleve
flocculosa (Roth) Kuetzing
Tropidoneis Cleve
unidentified sp.

Table B-1 (continued).

CHLOROPHYTA

Actinastrum Lagerheim
hantzschii var. fluviatile Schroeder
Ankistrodesmus Corda
convolutus Corda
falcatus (Corda) Ralfs
falcatus var. mirabilis (West and West) G. S. West
fractus (West and West) Brunnthaler
spiralis (Turner) Lemmermann
Arthrodesmus Ehrenberg
incus var. extensus Anderss
unidentified sp.
Botryococcus Kuetzing
braunii Kuetzing
Characium A. Braun
hookeri (Reinsch) Hansgirg
unidentified sp.
Chlamydomonas Ehrenberg
unidentified sp.
Chlorogonium Ehrenberg
elongatum Dangeard
Closteriopsis Lemmermann
longissima Lemmermann
longissima var. tropica West and West
Closterium Nitzsch
unidentified sp.
Coccomonas Stein
unidentified sp.
Coelastrum Naegeli
cambricum Archer
microporum Naegeli
reticulatum (Dangeard) Senn
sphaericum Naegeli
unidentified sp.
Cosmarium Corda
depressum (Naegeli) Lundell
unidentified sp.
Crucigenia Morren
apiculata (Lemmermann) Schmidle
irregularis Wille
quadrata Morren
rectangularis (A. Braun) Gay
tetrapedia (Kirchner) West and West
Cylindrocapsa Reinsch
geminella Wolle

Table B-1 (continued).

Dictyosphaerium Naegeli
ehrenbergianum Naegeli
pulchellum Wood
Dimorphococcus A. Braun
lunatus A. Braun
Elakatothrix Wille
gelatinosa Wille
viridis (Snow) Printz
Franceia Lemmermann
ovalis (France) Lemmermann
tuberculata G. M. Smith
Geminella Turpin
minor (Naegeli) Heering
mutabilis (Brebisson) Wille
ordinata (West and West) Heering
unidentified sp.
Gloeoactinium G. M. Smith
limneticum G. M. Smith
Gloeocystis Naegeli
ampla (Kuetzing) Lagerheim
gigas (Kuetzing) Lagerheim
planctonica (West and West) Lemmermann
vesiculosa Naegeli
unidentified sp.
Golenkinia Chodat
radiata (Chodat) Wille
Gonium O. F. Mueller emend. Prescott in: Prescott, Silva and Wade
pectorale O. F. Mueller
Kirchneriella Schmidle
contorta (Schmidle) Bohlin
lunaris (Kirchner) Moebius
lunaris var. dianae Bohlin
lunaris var. irregularis G. M. Smith
obesa (W. West) Schmidle
Lagerheimia (DeToni) Chodat
ciliata (Lagerheim) Chodat
citriformis (Snow) G. M. Smith
longiseta (Lemmermann) Printz
quadriseta (Lemmermann) G. M. Smith
subsalsa Lemmermann
wratislawiensis (Schroeder) Ley
Micractinium Fresenius
eriense Tiffany and Ahlstrom
pusillum Fresenius
quadrisetum (Lemmermann) G. M. Smith
Mougeotia (Agardh) Wittrock
americana Transeau

Table B-1 (continued).

gracilima (Hassall) Wittrock
unidentified sp.
Nephrocytium Naegeli
agardhianum Naegeli
limneticum G. M. Smith
obesum West and West
Oocystis Naegeli
borgei Snow
crassa Wittrock
gloeocystiformis Borge
lacustris Chodat
parva West and West
pusilla Hansgirg
solitaria Wittrock
submarina Lagerheim
unidentified sp.
Pandorina Bory
morum (O. F. Mueller) Bory
Pediastrum Meyen
boryanum (Turpin) Meneghini
duplex Meyen
duplex var. clathratum (A. Braun) Lagerheim
duplex var. cohaerens Bohlin
duplex var. rotundatum Lucks
simplex (Meyen) Lemmermann
simplex var. duodenarium (Bailey) Rabenhorst
tetras (Ehrenberg) Ralfs
Planktosphaeria G. M. Smith
gelatinosa G. M. Smith
Platymonas G. S. West
unidentified sp
Plectonema Thuret
notatum Schmidle
Polyblepharides Dangeard
unidentified sp.
Quadrigula Printz
chodatii (Tanner-Fullman) G. M. Smith
closterioides (Bohlin) Printz
lacustris (Chodat) G. M. Smith
Radiofilum Schmidle
irregulare (Wille) Brunnthaler
Scenedesmus Meyen
abundans (Kirchner) Chodat
acuminatus (Lagerheim) Chodat
anomalus (G. M. SMith) Ahlstrom and Tiffany
arcuatus Lemmermann
arcuatus var. playtdisca G. M. Smith

Table B-1 (continued).

armatus (Chodat) G. M. Smith
bernardii G. M. Smith
bijuga (Turpin) Lagerheim
bijuga var. alternans (Reinsch) Hansgirg
bijuga var. flexuosus (Lemmermann) Collins
brasilensis Bohlin
carinatus (Lemmermann) Chodat
denticulatus Lagerheim
dimorphus (Turpin) Kuetzing
incrassatulus Bohlin
intermedius Chodat
longispina Chodat
longus Meyen
longus var. naegelii (Brebisson) G. M. Smith
obliquus (Turpin) Kuetzing
opoliensis P. Richter
quadricauda (Turpin) Brebisson
quadricauda var. quadrispina (Chodat) G. M. Smith
quadricauda var. westii G. M. Smith

Schizochlamys Braun in: Kuetzing
compacta Prescott
gelatinosa A. Braun

Schroederia Lemmermann
ancora G. M. Smith
setigera (Schroeder) Lemmermann

Selenastrum Reinsch
gracile Reinsch
minutum (Naegeli) Collins

Sphaerocystis Chodat
schroeteri Chodat

Spondylosium Brebisson
planum (Wolle) W. and G. S. West
unidentified sp.

Staurastrum Meyen
curvatum W. West
natator var. carssum W. and G. S. Smith
paradoxum Meyen
unidentified sp.

Stichococcus Naegeli
unidentified sp.

Stigeoclonium Kuetzing
unidentified sp.

Tetraedron Kuetzing
caudatum (Corda) Hansgirg
minimum (A. Braun) Hansgirg
muticum (A. Braun) Hansgirg
pentaedricum West and West

Table B-1 (continued)

regulare Kuetzing
regulare var. incus Teiling
trigonum (Naegeli) Hansgirg
unidentified sp.
Tetrapora Link
gelatinosa (Vacher) Desvau
lacustris Lemmermann
lamellosa Prescott
Tetrastrum Chodat
elegans Playfair
staurogeniaeforme (Schroeder) Lemmermann
Treubaria Bernard
setigerum (Archer) G. M. Smith
triappendiculata Bernard
Trochiscia Kuetzing
reticularis (Reinsch) Hansgirg
Ulothrix Kuetzing
unidentified sp.

CHRYSOPHYTA

omonas Lackey
unidentified sp.
Biocoeca (J. Clark) Stein
lacustris J. Clark
Chrysosphaerella Lauterborn
longispina Lauterborn
Cladomonas Stein
fruticulosa Stein
unidentified sp.
Codonosiga Senn
botrytis (Ehrenberg) S.Kent
unidentified sp.
Collodictyon arter
unidentified sp.
Diceras Reverdin
ohridana Fott
phaseolus Fott
Dichotomococcus Korshikov
elongatus Fott
lunatus Fott
Dinobryon Ehrenberg
bavaricum Imhof
cylindricum Imhof ex. Ahlstrom
divergens Imhog
pediforme (Lemmermann) Steinecke
sertularia Ehrenberg
sociale Ehrenberg

Table B-1 (continued)

unidentified sp.
Harpochytrium Lagerheim
unidentified sp.
Hyalobryon Lauterborn
leickii Gessner
Musicola (Lemmermann) Pascher
Mallomonas Perty
acaroides Pertz
caudata Iwanoff
producta (Zacharias) Iwanoff
pseudocoronata Prescott
tonsurate Teiling
unidentified sp.
Monosiga S. Kent
unidentified sp.
Ochromonas Wyssotzki
unidentified sp.
Ophiocytium Naegeli
capitatum Wolle
capitatum var. longispinum (Moebius) Lemmermann
Peroniella Gobi
hyalothecae Gobi
planctonica G. M. Smith
Rhizochrysis Pascher
limnetica G. M. Smith
Salpingoeca J. Clark
frequentissima (Zacharias) Lemmermann
Sphaeroeca Lauterborn
volvox Lauterborn
Stichogloea Chodat
doederleinii (Schmidle) Wille
Stipitococcus West and West
apiculatus Prescott
urceolatus West and West
unidentified sp.
Synura Ehrenberg
uvella Ehrenberg
unidentified sp.
Uroglenopsis Lemmermann
americana (Calkins) Lemmermann

CRYPTOPHYTA

Chilomonas Ehrenberg
unidentified sp.
Chroomonas Hansgirg
unidentified sp.

Table B-1 (continued)

Cryptomonas Ehrenberg
erosa Ehrenberg
marssonii Skuja
ovata Ehrenberg
Rhodomonas Karsten
minuta var. nannoplanctica Skuja
unidentified sp.

CYANOPHYTA

Anabaena Bory
circinalis Rabenhorst
flos-aquae (Lyngbye) Brebisson
spiroides Kepahn
unidentified sp.
Aphanizomenon Morren
flos-aquae (Lemmermann) Ralfs
Aphanocapsa Naegeli
delicatissima West and West
elachista W. and G. Smith
unidentified sp.
Aphanothece Naegeli
castagnei Brebisson
clathrata G. S. West
microscopica Naegeli
nidulans P. Richter
Chroococcus Naegeli
dispersus (Keissler) Lemmermann
limneticus Lemmermann
pallidus Naegeli
prescottii Drouet and Daily
turgidus (Kuetzing) Naegeli
Coelosphaerium Naegeli
kuetzingianum Naegeli
naegelinaum Unger
Glaucocystis Itzigsohn
unidentified sp.
Gloeocapsa Kuetzing
aeruginosa (Carmichael) Kuetzing
Gomphosphaeria Kuetzing
lacustris Ghodat
lacustris var. compacta Lemmermann
Lyngbya Agardh
contorta Lemmermann
unidentified sp.

Table B-1 (continued)

Merismopedia Meyen
- convoluta Brebisson
- elegans A. Braun
- glauca (Ehrenberg) Naegeli
- punctata Meyen

Microcystis Kuetzing
- aeruginosa Kuetzing emend. Elenkin
- incerta Lemmermann

Oscillatoria Vaucher
- amoena (Kuetzing) Gomont
- geminata Meneghini
- limnetica Lemmermann
- tenuis Agardh
- unidentified sp.

Phormidium Kuetzing
- mucicola Naumann and Huber-Pestalozzi in: Huber-Pestalozzi and Naumann

Stichosiphon Geitler
- unidentified sp.

EUGLENOPHYTA

Euglena Ehrenberg
- acus Ehrenberg
- acus var. rigida Huebner
- polymorpha Dangeard
- proxima Dangeard
- unidentified sp.

Lepocinclis Perty
- acuta Prescott
- ovum (Ehrenberg) Lemmermann

Phacus Dujardin
- caudatus Huebner
- curvicauda Swirenko
- orbicularis Huebner

Trachelomonas Ehrenberg
- crebea (Kellicott) Deflandre
- hispida (Perty) Stein
- tambowika Swirenko
- varians (Lemmermann) Deflandre
- unidentified sp.

PYRRHOPHYTA

Ceratium Schrank
- cornutum (Ehrenberg) Claparede and Lachmann
- hirundinella (O. F. Mueller) Dujardin

Table B-1 (continued)

Glenodinium (Ehrenberg) Stein
quadridens (Stein) Schiller
unidentified sp.
Peridinium Ehrenberg
unidentified sp.

APPENDIX C

BIBLIOGRAPHY OF ZION RELATED PUBLICATIONS

tstaetter, C. 1974. Periphyton study. IN Operation environmental monitoring in Lake Michigan near Zion Station, July 1973 through June 1974. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. II: 1-74.

_____. 1975. Periphyton study. IN Operational environmental monitoring in Lake Michigan near Zion Station. July 1974 through June 1975. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. III: 1-70.

_____. and M. Flores. 1974. Periphyton study. IN Operational environmental monitoring in Lake Michigan near Zion Station, January 1974 through June 1974. Semi-Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I: 167-230.

_____. and M. Phillips. 1976. Periphyton study. IN Operational environmental monitoring in Lake Michigan near Zion Station. July 1975 through June 1976. Annual report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. VI: 1-82.

Arneson, P.D. 1975. Statistical comparisons of phytoplankton populations at experimental and control locations in relation to Zion Station operation, southwestern Lake Michigan, Zion, Illinois. IN Compilation of special reports on the effects of Zion Station operation on the biota in southwestern Lake Michigan. Special Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc.

Barber, B.E. and D.G. Redmond. 1975. Phytoplankton study. IN Operational environmental monitoring in Lake Michigan near Zion Station. July 1974 through June 1975. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. II: 1-352.

_____. 1976. Phytoplankton study. IN Operation environmental monitoring in Lake Michigan near Zion Station. July 1975 through June 1976. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. III: 1-696.

_____. 1977. Phytoplankton Study. IN Operational monitoring in Lake Michigan near Zion Station. July 1976 through June 1977. Annual report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. III: 1-375.

Barbour, M. 1974. Benthos study. IN Environmental monitoring in Lake Michigan near Zion and Waukegan Generating Stations, January 1972 through December 1972. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. II: 227-306.

Bartholomew, P. S., and D. G. Redmond. 1977. Phytoplankton Entrainment Study. IN Operational monitoring in Lake Michigan near Zion Station. July 1976 through June 1977. Annual report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. IV: 1-477.

Beer, L. and W. Pipes. 1968. A practical approach: environmental effects of condenser water discharge in southwest Lake Michigan. Commonwealth Edison Company, Chicago, Illinois. 106 p.

Blewitt, D. 1973. Temperature and dissolved oxygen monitoring at Waukegan Generating Station, February 1971-December 1971. Project I. IN Evaluation of thermal effects in southwestern Lake Michigan, 1971-1972. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I: 47 p.

_____, and J. Hawley. 1974. Water quality monitoring at Waukegan Generating Station. IN Environmental monitoring in Lake Michigan near Zion and Waukegan Generating Stations, January 1972 through December 1972. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I: 1-54.

Bremer, K. 1974. Phytoplankton productivity study. IN Environmental monitoring in Lake Michigan near Zion and Waukegan Generating Stations, January 1972 through December 1972. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. II: 149-166.

Briars, R.P. 1974. Water quality monitoring in Lake Michigan in the vicinity of the Zion and Waukegan Generating Stations, January 1972 through December 1972. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I: 197-343.

_____. 1974. Field chemistry study. IN Environmental monitoring in Lake Michigan near Zion and Waukegan Generating Stations, January 1973 through June 1973. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc.

_____. 1974. Field chemistry study. IN Operational environmental monitoring in Lake Michigan near Zion Station, January 1974 through June 1974. Semi-Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I: 1-78.

_____. 1974. Field chemistry study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through June 1974. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. III: 1-74.

_____, and M. Barbour. 1974. Field chemistry study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through December 1973. Semi-Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I: 1-82.

Brice, J.R. 1975. Preoperational operational comparison of the benthic community at Zion Station. IN Compilation of special reports on the effects of Zion Station operation on the biota in southwestern Lake Michigan. Special Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc.

_____. 1975. Benthos study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1974 through June 1975. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. III: 71-609.

_____. 1976. Benthos study. IN Operational environmental monitoring in Lake Michigan near Zion Station. July 1975 through June 1976. Annual report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol V: 1-660.

_____, and K. Stimpson. 1974. Benthos study. IN Environmental monitoring in Lake Michigan near Zion and Waukegan Generating Stations, January 1973 through June 1973. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc.

_____. 1974. Benthos study. IN Operational environmental monitoring in Lake Michigan near Zion Station, January 1974 through June 1974. Semi-Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. III: 1-106.

_____, and M. Barbour. 1974. Benthos study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through December 1973. Semi-Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. III: 1-122.

Cima, G. 1977. Annual interpretive report on fish eggs and larvae in Lake Michigan near Zion and Waukegan Generating Stations. 1976. Report to commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. 281 p.

Cima, G. and M. Cochran. 1974. Fish egg and larvae study. IN Environmental monitoring in Lake Michigan near Zion and Waukegan Generating Stations, January 1973 through July 1973. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc.

_____. 1974. Fish egg and larvae study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through December 1973. Semi-Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. III: 123-170.

_____. 1974. Fish egg and larvae study. IN Operational environmental monitoring in Lake Michigan near Zion Station, January 1973 through June 1974. Semi-Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories Inc. Vol. III. 107-218.

_____. 1977. Occurrence of Mysis relicta and Pontoporeia affinis from ichthyoplankton samples in Lake Michigan near Zion and Waukegan, Illinois. 1976. Report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. 142 p.

_____. and M. Kitchel. 1976. Annual interpretive report on fish eggs and larvae in Lake Michigan near Zion and Waukegan Generating Stations. 1975. Report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. 325 p.

Cochran, M. 1973. Fish populations and life histories in southwestern Lake Michigan, April 1971-December 1971. Project IX. IN Evaluation of thermal effects in southwestern Lake Michigan, 1971-1972. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I: 78 p.

_____. 1974. Fish study. IN Environmental monitoring in Lake Michigan near Zion and Waukegan Generating Stations, January 1972 through December 1972. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. II: 307-501.

_____. 1974. Adult fish study. IN Environmental monitoring in Lake Michigan near Zion and Waukegan Generating Stations, January 1973 through July 1973. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc.

_____. 1974. Adult fish study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through December 1973. Semi-Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. III: 171-366.

lfino, J. 1973. Intake-Discharge experiments at Waukegan Generating Station, May 1971-April 1972. Project XI, Water Quality Section. IN Evaluation of thermal effects in southwestern Lake Michigan, 1971-1972. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. II: 358 p.

DeLibero, F., D. McCaughran and F. Oshsner. 1976. Power functions in testing for change in the biotic community and water chemistry of Lake Michigan in the area of Zion Station. Report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. 244 p.

Delinck, H. and M. Lamble. 1972. Phytoplankton study, August 1970-April 1971. Project III. IN Evaluation of thermal effe ts in southwestern Lake Michigan (January 1970-April 1971). Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I: 42 p.

_____, and J. Cerwinski. 1972. Field Studies on periphyton, April 1970-March 1971. Project V. IN Evaluation of thermal effects in southwestern Lake Michigan (January 1970-April 1971). Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I: 61 p.

orak, D. 1975. Zooplankton study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1974 through June 1975. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. II: 353-491.

_____. 1976. Zooplankton study. IN Operational environmental monitoring in Lake Michigan near Zion Station. July 1975 through June 1976. Annual report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. IV: 1-416.

_____. 1977. Zooplankton Study. IN Operational monitoring in Lake Michigan near Zion Station. July 1976 through June 1977. Annual report to Commonwealth Edison Company, Chicago, Illinois by NALCO Environmental Sciences. Vol. III: 377-573.

_____, G. Hunt and M. McGrath. 1974. Zooplankton study. IN Operational environmental monitoring in Lake Michigan near Zion Station, January 1974 through June 1974. Semi-Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. II: 117-287.

Ellis, D.B. 1975. Field chemistry study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1974 through 1975. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. I: 271-396.

_____ 1974. Adult fish study. IN Operational environmental monitoring in Lake Michigan near Zion Station, January 1974 through June 1974. Semi-Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. III: 219-408.

_____ 1975. Adult fish study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1974 through June 1975. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. IV: 1-56.

_____. 1976. Adult fish study. IN Operational environmental monitoring in Lake Michigan near Zion Station. July 1975 through June 1976. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. VI: 83-298.

_____, and G. Cima. 1974. Larval fish study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through June 1974. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. III: 201-284.

_____. and M. Kitchel. 1975. Fish impingement at Zion Station, January through December 1975. IN Compilation of reports relating to entrainment and impingement studies at Zion Generating Station. Report to Commonwealth Edison Company Chicago, Illinois, by NALCO Environmental Sciences. Vol. I. 192 p.

Cochran, M., and T. Ott. 1977. Adult Fish Study. IN Operational monitoring in Lake Michigan near Zion Station. July 1976 through June 1977. Annual report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. II: 207-416

Condit, T. 1976. Current measurement study. IN Operational environmental monitoring in Lake Michigan near Zion Station. July 1975 through June 1976. Annual report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol I: 1-410.

Condit, T. 1977. Current measurement study. IN Operational environmental monitoring in Lake Michigan near Zion Station. July 1976 through June 1977. Annual report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. I: 1-373.

Dacone, J. 1974. Intake-Discharge monitoring at Waukegan Generating Station. IN Environmental monitoring in Lake Michigan near Zion and Waukegan Generating Stations, January 1972 through December 1972. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I: 15-148.

_____. 1976. Field chemistry study. IN Operational environmental monitoring in Lake Michigan near Zion Station. July 1975 through June 1976. Annual report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. II: 1-178.

_____. 1977. Field chemistry study. IN Operational environmental monitoring in Lake Michigan near Zion Station. July 1976 through June 1977. Annual report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. II: 1-170.

_____. 1977. Intake-discharge Chemistry Summary Report. July 1973 through June 1977. Report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. 301 p.

Everhart, L., K. Bremer, M. Cochran, J. Cerwinski, J. Gulo and A. Restaino. 1973. Intake-Discharge experiments at Waukegan Generating Station, May 1971-April 1972. Project XI, Biological Section. IN Evaluation of thermal effects in southwestern Lake Michigan 1971-1972. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I: 71 p.

ores, M. 1974. Periphyton study. IN Environmental monitoring in Lake Michigan near Zion and Waukegan Generating Stations, January 1973 through June 1973. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc.

_____, and M. Barbour. 1974. Periphyton study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through December 1973. Semi-Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I: 153-232.

Geers, D. F. 1977. Benthos Study. IN Operational Monitoring in Lake Michigan near Zion Station. July 1976 through June 1977. Annual report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. V: 330 p.

Gulo, J. and M. Lamble. 1972. Inshore water quality evaluation, May 1970-Mar[illegible] 1971. Project II, Part B - Phytoplankton. IN Evaluation of thermal effects in southwestern Lake Michigan (January 1970-April 1971). Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I: 49 p.

zleton Environmental Sciences Corporation. 1978. Annual interpretive report on fish egg and larval in Lake Michigan near Zion and Waukegan Generating Station, January through December 1978.

_____. 1978. Operational environmental monitoring in Lake Michigan near Zion Station, July through September 1978. Supplemental report to Commonwealth Edison Company, Chicago, Illinois. 408 pp.

Heath, M. and J. Hawley. 1974. Intake-Discharge chemistry study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through June 1974. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. III: 75-140.

Huebner, L. 1971. Final report in the tritium concentration of Lake Michigan water near the Zion Station, Zion, Illinois, for the period January-December 1970. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. 35 p.

_____. 1972. Preoperational radiological monitoring program for Zion Station. Semi-Annual Report, January 1, 1972 through June 30, 1972. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. 105 p.

_____. 1972. Preoperational radiological monitoring program for Zion Station. Semi-Annual Report July 1, 1971 through December 31, 1971. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. 105 p.

_____. 1973. Preoperational monitoring program for Zion Station. Semi-Annual Report July 1, 1972 through December 31, 1972. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. 109 p.

Huh, H., L. Everhart, C. Kondrat, J. Lingle and J. Urry. 1973. Field study program of Lake Michigan in the vicinity of the Waukegan and Zion Generating Stations, April 1971-March 1972. Project X. IN Evaluation of thermal effects in southwestern Lake Michigan 1971-1972. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I: 131 p.

Hunt, G. 1974. Zooplankton study. IN Environmental monitoring in Lake Michigan near Zion and Waukegan Generating Stations, January 1972 through December 1972. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. II: 167-226.

_____. 1974. Zooplankton study. IN Environmental monitoring in Lake Michigan near Zion and Waukegan Generating Stations, January 1973 through June 1973. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc.

_____, and M. Barbour. 1974. Zooplankton study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through December 1973. Semi-Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. II: 91-308.

Industrial BIO-TEST Laboratories, Inc. 1970. Preoperational environmental monitoring (thermal) of Lake Michigan near Zion Station, July 1969-December 1969. Report to Commonwealth Edison Company, Chicago, Illinois. 158 p.

_____. 1972. Evaluation of thermal effects in southwestern Lake Michigan (January 1970-April 1971). Report to Commonwealth Edison Company, Chicago, Illinois. 2 vols.

_____. 1973. Evaluation of thermal effects in southwestern Lake Michigan, 1971-1972. Report to Commonwealth Edison Company, Chicago, Illinois. 2 vols.

_____. 1973. The spring thermal bar in the Waukegan-Zion area of Lake Michigan. Data Summary. Report to Commonwealth Edison Company, Chicago, Illinois.

_____. 1974. Environmental monitoring in Lake Michigan near Zion and Waukegan Generating Stations, January 1972 through December 1972. Report to Commonwealth Edison Company, Chicago, Illinois. 2 vols.

_____. 1974. Environmental monitoring in Lake Michigan near Zion and Waukegan Generating Stations, January 1973 through June 1973. Report to Commonwealth Edison Company, Chicago, Illinois. (not printed).

_____. 1974. Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through December 1973. Semi-Annual Report to Commonwealth Edison Company, Chicago, Illinois. 3 vols.

_____. 1974. Operational environmental monitoring in Lake Michigan near Zion Station, January 1974 through June 1974. Semi-Annual Report to Commonwealth Edison Company, Chicago, Illinois. 3 vols.

_____. 1974. Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through June 1974. Annual Report to Commonwealth Edison Company, Chicago, Illinois. 3 vols.

_____. 1975. Operational environmental monitoring in Lake Michigan near Zion Sation, July 1974 through December 1974. Semi-Annual Report to Commonwealth Edison Company, Chicago, Illinois. 2 vols.

_____. 1975. Operational environmental monitoring in Lake Michigan near Zion Station, January 1975 through June 1975. Semi-Annual Report to Commonwealth Edison Company, Chicago, Illinois. 2 vols.

Johnson, D. and B. Muench. 1972. Field sampling program, March 1970-October 1970. Project VII, Part C - Fish Study. IN Evaluation of thermal effects in southwestern Lake Michigan (January 1970-April 1971). Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. II: 21 p.

Katnik, K., M. Heath and D. Redmond. 1974. Intake-Discharge chemistry study. IN Operational environmental monitoring in Semi-Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I: 76-166.

Katnik, K. and D. Redmond. 1974. Intake-Discharge chemistry study. IN Environmental monitoring in Lake Michigan near Zion and Waukegan Generating Stations, January 1973 through June 1973. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc.

_____. 1974. Intake-Discharge chemistry study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through December 1973. Semi-Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I: 83-152.

Kitchel, M. 1974. Screen monitoring at Zion Station. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through December 1973. Semi-Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. III: 367-410.

_____. 1974. Screen monitoring at Zion Station. IN Operational environmental monitoring in Lake Michigan near Zion Station, January 1974 through June 1974. Semi-Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. III: 409-472.

_____. 1975. 316(b) studies at Zion Station, January-June 1975. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc.

_____. 1975. 316(b) studies at Zion Station, July-September 1975. Report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences.

_____. 1975. Screen monitoring study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1974 through June 1975. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. IV: 237-260.

_____, and R. Otto. 1974. Screen monitoring study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through June 1974. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. III: 345-374.

Krueger, J. 1974. Thermal tolerance limit determinations for Lake Michigan zooplankton, July 1972-March 1973. Project XVII-B. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. 71 p.

_____. 1974. Operation environmental monitoring in Lake Michigan near Zion Station, July 1973, through June 1974. Annual Report to Commonwealth Edison Company, Chicago, Illinois. 3 vols.

_____. 1974. Operational environmental monitoring in Lake Michigan near Zion Station, January 1974 through June 1974. Semi-Annual Report to Commonwealth Edison Company, Chicago, Illinois. 3 vols.

_____. 1975. Special report on the abundance and entrainment of Pontoporeia affinis at Zion Station. IN Compilation of special reports on the effects of Zion Station operation on the biota in southwestern Lake Michigan. Special Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc.

_____. 1975. Thermal tolerance determinations for Lake Michigan zooplankton. IN Evaluation of thermal effects in southwestern Lake Michigan. Special Studies 1972-1973. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. pp. 39-128.

Lamble, M. 1972. Zooplankton study, August 1970-March 1971. Project VIII. IN Evaluation of thermal effects in southwestern Lake Michigan (January 1970-April 1971). Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. II: 60 p.

Larker, T.D. 1975. Intake-Discharge chemistry study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1974 through June 1975. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. I: 1-270.

_____. 1976. Intake-discharge chemistry study. In Operational environmental monitoring in Lake Michigan near Zion Station. July 1975 through June 1976. Annual report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. II: 179305.

Mayhew, E. 1974. Phytoplankton study. IN Environmental monitoring in Lake Michigan near Zion and Waukegan Generating Stations, January 1972 through December 1972. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. II: 1-148.

_____. 1974. Phytoplankton study. IN Environmental monitoring in Lake Michigan near Zion and Waukegan Generating Stations, January 1973 through June 1973. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc.

_____. 1974. Phytoplankton study. IN Operational environmental monitoring in Lake Michigan near Zion Station, January 1974 through June 1974. Semi-Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I: 231-437.

_____, and B. Barber. 1974. Phytoplankton study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through June 1974. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I. 1-318.

_____, and M. Barbour. 1974. Phytoplankton study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through December 1973. Semi-Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I: 233-507.

McCaughran, D.A. and F.M. Ochsner. 1975. Determination of subsampling distribution of plankton counts. IN Evaluation of thermal effects in southwestern Lake Michigan. Special Studies 1972-1973. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. pp. 207-306.

_____. 1975. Power functions in testing for change in the biotic community and water chemistry of Lake Michigan in the area of Zion Station. IN Evaluation of thermal effects in southwestern Lake Michigan. Special Studies 1972-1973. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. pp. 1-38.

McGrath, M. and D. Dvorak. 1974. Zooplankton study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through June 1974. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. II: 75:232.

Minsley, B. 1974. Water quality monitoring at the Lake County Water Treatment Plant. IN Environmental monitoring in Lake Michigan near Zion and Waukegan Generating Stations, January 1972 through December 1972. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I: 149-196.

Muench, B. 1974. Adult fish story. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through June 1974. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. III: 141-200.

NALCO Environmental Sciences. 1975. Operational environmental monitoring in Lake Michigan near Zion Station, July 1974 through June 1975. Annual Report to Commonwealth Edison Company, Chicago, Illinois. 4 vols.

_____. 1976. Compilation of reports relating to entrainment and impingement studies at Zion Generating Station. Report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. 2 Vol.

_____. 1976. The effects of entrainment on Pontoporeia affinis in the vicinity of Zion and Waukegan Generating Stations. IN Compilation of reports relating to entrainment and impingement studies at Zion Generating Station. Report to Commonwealth Edison Company, Chicago Illinois, by NALCO Environmental Sciences. Vol II. 123 p.

_____. 1976. Gas saturation studies at Zion Generating Station. Report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. 14 p.

_____. 1976. Operational environmental monitoring in Lake Michigan near Zion Station. July 1975 through December 1975. Semi-Annual Report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. 2 Vols.

_____. 1977. Operational environmental monitoring in Lake Michigan near Zion Station. July 1976 through December 1976. Semi-Annual Report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. 2 Vols.

_____. 1978. Operational environmental monitoring in Lake Michigan near Zion Station, July 1977 through December 1977. Semi-annual report to Commonwealth Edison Company, Chicago, Illinois. 2 vols.

_____. 1978. Operational environmental monitoring in Lake Michigan near Zion Station, July 1977 through June 1978. Annual report to Commonwealth Edison Company, Chicago, Illinois. 4 vols.

_____. 1978. Annual interpretive report on the fish egg and larval sampling program in Lake Michigan near Zion and Waukegan Generating Stations, January through December 1977.

O'Neill, J. 1972. Field sampling program. Project VII, Part E - Buoyant Plume Study, April 1970-June 1971. IN Evaluation of thermal effects in southwestern Lake Michigan (January 1970-April 1971). Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. II. 30 p.

_____, and D. Davidson. 1973. Meteorological and hydrological environmental monitoring in Lake Michigan near Zion Station. July 1974 through June 1975. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. I: 1-270.

_____, and W. Pipes. 1974. A study of the spring thermal bar in southwestern Lake Michigan. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. 29 p.

_____. 1975. A study of the spring thermal bar in southwestern Lake Michigan. IN Evaluation of thermal effects in southwestern Lake Michigan. Special Studies 1972-1973. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. pp. 1-38.

Ochsner, F. and D. McCaughran. Lake Michigan field study statistical report. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc.

Otto, R. 1973. Effects of gas supersaturation on fishes in southwestern Lake Michigan, January 1972-April 1972. Project XV. IN Evaluation of thermal effects in southwestern Lake Michigan, 1971-1972. Report to Commonwealth Edison Company Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. II: 48 p.

_____. 1974. Temperature effects on fish. Laboratory Studies, June 1972-June 1973. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. 69 p.

_____. 1975. The effects of once-through cooling on fish eggs and larvae in southwestern Lake Michigan. IN Compilation of special reports on the effects of Zion Station operation on the biota in southwestern Lake Michigan. Special Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc.

_____, M. Kitchel and J. Rice. 1973. Effects of temperature on fish, interim period June 1972-December 1972. Interim Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. 198 p.

_____. 1975. Temperature effects on fish. IN Evaluation of thermal affects in southwestern Lake Michigan. Special Studies 1972-1973. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. pp. 129-206.

Phillips, M. 1977. Periphyton Study. IN Operational environmental monitoring in Lake Michigan near Zion Station. July 1976 through June 1977. Annual report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. II: 171-206.

Piala, J. and M. Lamble. 1972. Field sampling program, May 1970-March 1971. Project VII, Part A - Phytoplankton. IN Evaluation of thermal effects in southwestern Lake Michigan (January 1970-April 1971). Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. II: 52 p.

Pipes, W.O., D. Pritchard and L. Beer. 1973. Condenser water discharge plumes from Waukegan Generating Station under winter conditions. Commonwealth Edison Company, Chicago, Illinois. 43 p.

Redmond, D. 1974. Phytoplankton entrainment study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through December 1973. Semi-Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. II: 49-90.

_____. 1974. Phytoplankton entrainment study. IN Operational environmental monitoring in Lake Michigan near Zion Station, January 1974 through June 1974. Semi-Annual Report to Commonwealth Edison Company. Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. 57-116.

_____. 1974. Primary productivity study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through June 1974. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I: 319-338.

_____. 1974. Primary productivity study. IN Operational environmental monitoring in Lake Michigan near Zion Station, January 1974 through June 1974. Semi-Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. II: 1-56.

_____, and M. Barbour. 1974. Primary productivity study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through December 1973. Semi-Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. II: 1-48.

_____, and K. Bremer. 1974. Primary productivity study. IN. Environmental monitoring in Lake Michigan near Zion and Waukegan Generating Stations, January 1973 through June 1973. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc.

Restaino A. and T. Morse. 1977. Zooplankton Entrainment Study. IN Operational Monitoring in Lake Michigan near Zion Station. July 1976 through June 1977. Annual report to Commonwealth Edison Company, Chicago, Illinois, by NALCO Environmental Sciences. Vol. IV: 479-652.

Restaino, A. and D. Redmond. 1974. Zooplankton entrainment study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through December 1973. Semi-Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. II: 309-350.

_____. 1974. Zooplankton entrainment study. IN Operational environmental monitoring in Lake Michigan near Zion Station, January 1974 through June 1974. Semi-Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. II: 289-425.

_____, and R. Otto. 1974. Entrainment study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through June 1974. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. III: 285-344.

_____, D.G. Redmond and R. G. Otto. 1975. Entrainment study at Zion Station. IN Compilation of special reports on the effects of Zion Station operation on the biota in southwestern Lake Michigan. Special Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc.

Rice, J. 1972. Physiological effects on fish, April 1970-February 1971. Project IV. IN Evaluation of thermal effects in southwestern Lake Michigan (January 1970-April 1971). Report to Commonwealth Ediston Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I: 28 p.

Rich, W. and D. Blewitt. 1972. Temperature and dissolved oxygen monitoring at Waukegan Station, January 19, 1970-February 28, 1971. IN Evaluation of thermal effects in southwestern Lake Michigan (January 1970-April 1971). Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I: 81 p.

Sheehan, W., E. Skepnek and W. Bauszek. 1972. Inshore water quality evaluation, February 1970-April 1971. Project II, Part A - Chemistry. IN Evaluation of thermal effects in southwestern Lake Michigan (January 1970-April 1971). Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I: 122 p.

_____, and J. Delfino. 1972. Field sampling program, January 1970-April 1971. Project VII, Part D - Offshore Water Quality, IN Evaluation of thermal effects in southwestern Lake Michigan (January 1970-April 1971). Report to Commonwealth Edison Company Vol. II: 160 p.

Stimpson, K. and J. Brice. 1974. Benthos study. IN Operational environmental monitoring in Lake Michigan near Zion Station, July 1973 through June 1974. Annual Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. II: 233-368.

Williams, W.C. 1975. Current measurement study. IN Operational monitoring at Waukegan and Zion Generating Stations, July 1971-June 1972. Project VI. IN Evaluation of thermal effects in southwestern Lake Michigan, 1971-1972. Report to Commonwealth Edison Company, Chicago, Illinois, by Industrial BIO-TEST Laboratories, Inc. Vol. I: 86 p.