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An Ecological Evaluation of the Fate of Radioisotopes from the Fermi II Nuclear Power Plant in Western Lake Erie: Trace Elements in Water, Seston, Zooplankton and Fish, and Background Gamma Levels in Fish near the Western Shore of Lake Erie

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Dale L. Brege

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Niles R. Kevern
Major professor

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AN ECOLOGICAL EVALUATION OF THE FATE OF RADIOISOTOPES FROM THE FERMI II NUCLEAR POWER PLANT IN WESTERN LAKE ERIE:

TRACE ELEMENTS IN WATER, SESTON, ZOOPLANKTON, AND FISH, AND BACKGROUND GAMMA LEVELS IN FISH NEAR THE WESTERN SHORE OF LAKE ERIE

by

Dale A. Brege

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science

to

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ABSTRACT

Water, seston, zooplankton, and fish samples were collected for the year 1974 in the vicinity of the proposed Fermi II nuclear power plant on the western shore of Lake Erie. Water, seston, zooplankton, and fish samples were studied for the stable elements Co, Cs, Fe, K, Mn, Sr, and Zn; fish samples were also studied for background radioactivity. All data collected for this study were part of a preoperational study of the consequences of waste discharge from the proposed Fermi II power plant.

All trace elements in water samples showed trends of higher concentrations during the spring months. This corresponded to a time period when runoff from the Maumee and Raisin Rivers was more influential on the total water mass of the basin. Iron and zinc concentrations were highest in the spring months when wave-height observations and suspended solids were high while manganese, potassium, and strontium values were highest during the winter months when there was ice cover.

Trace-element concentrations in the seston were generally highest during months of strong wave action. Iron and zinc showed direct correlations with wave-heights while manganese, strontium, and potassium showed no relationship with wave-height.

The zooplankton data expressed as ug of element per liter of lake water samples showed a trend of increasing concentrations with warming water temperature because there were more zooplankton present during the summer months; however, when the zooplankton data (expressed

on a wet-weight basis) are analyzed, manganese and potassium concentrations remained fairly constant while iron and zinc showed trends of higher concentrations during the summer months.

Seasonal variations in yellow perch and goldfish were not noted, nor was there any difference between fish of the same species taken from the Monroe plant as compared to the Fermi plant.

Significant variations were noted between the two species of fish. Yellow perch had higher concentrations of cesium while the goldfish contained higher concentrations of iron, zinc, and strontium.

Size-class variations were noted only for goldfish. Larger goldfish had higher concentrations of iron and zinc than the smaller goldfish.

For the background levels of radioisotopes, only ^{40}K and ^{137}Cs were found. Concentrations of ^{137}Cs appeared slightly higher for northern pike as compared to yellow perch and carp while ^{40}K varied only slightly among the three species of fish analyzed.

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Seasonal variations in yellow perch and goldfish were not noted, nor was there any difference between fish of the same species taken from the Monroe plant as compared to the Fermi plant.

ACKNOWLEDGEMENTS

I would like to express sincere appreciation to my major professor, Dr. Niles R. Kevern, for his interest, supervision, and review of the manuscript. Special appreciation is also extended to Drs. Eugene Roelofs, Kenneth Reckhow, Frank D'Itri, and Richard Cole for serving as members of my committee.

My thanks is also given to the many graduate students, family, and friends who helped me with my work and who made university life enjoyable.

This study was supported by the Detroit Edison Company.

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Dedicated to DANNY

A finer brother could never be

Missed until eternity

Peace be with you

Always

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INTRODUCTION

Within a time span of only a few years, the energy consumption of the United States has risen tremendously. Most of this energy has been in the form of fossil fuel, but there has also been an ever increasing reliance upon foreign nations for supplying the necessary crude oil for gasoline and other oil products. Not only has this dependence upon foreign oil been extremely costly both in dollars and in U.S. sovereignity, but the energy crisis of the past few years has clearly demonstrated that forms of energy additional to fossil fuels are needed to maintain an acceptable American standard of living.

One form of energy that is currently under consideration is nuclear energy which offers an almost inexhaustible potential as a power supply. However, before this huge potential of nuclear energy can be utilized, the safety of its use must be considered. Through accidental spills, activation of cooling waters, and controlled releases of dilute waste water, radioactive liquids could get into our aquatic systems. Thus, the biogeochemical pathways of radioactive elements should be carefully studied.

One method developed for predicting the pathways of radioactive isotopes is that of the specific activity hypothesis (National Academy of Sciences, 1960; Nelson, et al., 1972). This hypothesis is based upon the assumption that radioactive isotopes follow the same pathways as their counterpart stable isotopes. At equilibrium the radioactive isotope to total isotope ratio should be the same for all

components of that system, provided that availability of the isotope is equal to all components. In other words, based upon the specific activity hypothesis, once the distribution of the stable isotope has been determined, predictions can be made about the eventual fate of radioactive isotopes released into that environment.

Several factors, however, could hinder the equilibration process, such as mass differences between the radioactive isotope and the stable isotope, fluctuating characteristics of the system receiving the discharge, physical decay of the radioisotope, and biological uptake and elimination rates. Any one of these factors or combinations of them could mean that a true equilibrium may never be reached.

The Fermi II study is a preoperational study designed to determine the stable element distribution and to use the specific activity hypothesis for predictions about the radioactive isotopes that may later be introduced into the western basin of Lake Erie. The elements being studied (iron, manganese, zinc, strontium, cesium, and cobalt) are those having the potential for creating hazardous conditions near a nuclear plant.

Previous studies of stable and radioactive isotopes have been conducted on the Fermi II area. Shaffer (1975) conducted research on water and sediments while Gottschalk (1975) worked with the trophic levels of fish.

This study, conducted for the calendar year 1974, is intended to provide seasonal data for the stable element distribution in water, seston, zooplankton, and two species of fish primarily in the vicinity of the Fermi II power plant. A secondary objective of this study is to determine the background levels of radioisotopes in selected fishes.

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METHODS AND MATERIALS

Site Description

The Fermi II power plant, under construction at the time of this study, is located along the western shore of Lake Erie approximately twelve kilometers north of Monroe, Michigan. The whole western basin of Lake Erie, which comprises about 3000-km^2, is shallow, with an average depth of eight meters and a maximum depth of only 15 meters. The western basin of Lake Erie receives more than 90% of the total water discharged into the entire lake even though it makes up only about 5% of the total lake volume. The estimated minimum possible flushing time for the western basin is approximately two months (Beeton, 1961) while that for the entire lake is approximately three years (Beeton, 1971).

The main tributary rivers that flow into the western basin of Lake Erie include the Detroit River, the Maumee River, and the Raisin River. The Detroit River, which contributes over 90% of the annual incoming water, is laden with industrial and sewage wastewater from the metropolitan Detroit area. Detroit River water makes up a high of 95% of the water in the western basin in the fall and a low of 74% during the spring months. The Maumee River, which enters near Toledo, Ohio, and the Raisin River, which enters near Monroe, Michigan, both contribute large quantities of clay, silt, and agricultural runoff to the basin. From 1970 to 1975, the Maumee River contributed 14 to 18% of the lake water in the spring, 11% in the summer, and 5% in the fall,

while the Raisin River contributed 12% in the spring and 5% in the fall (Ecker and Cole, 1976).

Along with enriched tributary flows and the shallowness of the basin, windy conditions keep the basin from frequent stratification. Temperature and dissolved oxygen conditions usually are quite consistent throughout the water column. In addition, lake bottom sediments often are resuspended and the lake is usually kept quite turbid (Britt et al., 1973).

Water currents in the western basin of Lake Erie are directly influenced by tributary flows and wind conditions. The Detroit River, connecting Lake Erie with Lake St. Clair and the Upper Great Lakes, enters at the northern-most part of the basin. From there, the main water mass flows southward. Hartley et al. (1966) stated that the major currents in the basin moved south to southeast and were maintained by the predominantly southwest summer winds. Evidently, these winds gradually interrupt the southward flow of the Detroit River and push the main water mass eastward through the Pelee Passage and into the central basin. A lesser current, indicated by the ILEWPB (1969), flows northward along the Michigan shoreline.

Strong wind conditions frequently produce wind tides in the western basin. Sustained winds either from the east or the west push large amounts of water to the opposite side of the basin. Water levels often rise as much as two meters with the wave action causing considerable shoreline erosion and resuspension of bottom sediments.

The area considered in this study focused on an area near the Fermi I power plant. This area is quite shallow, with a maximum depth of only four meters at an offshore distance of one kilometer. As a result, it receives considerable pounding from high waves and seiches.

while the Raisin River contributed 12% in the spring and 5% in the fall (Ecker and Cole, 1976).

Along with enriched tributary flows and the shallowness of the basin, windy conditions keep the basin from frequent stratification. Temperature and dissolved oxygen conditions usually are quite consistent throughout the water column. In addition, lake bottom sediments

Figures 1 and 2 show the location of the study area and the location of the sampling stations.

Station 1 was located at the lakeward end of the Fermi I breakwall where it was about three meters deep. Water conditions at this station reflected those conditions characteristic of the surrounding lake. The physical and chemical data collected for station 1 for 1974 have been summarized in Table 1.

Station 2, located at the mouth of Swan Creek, was 1.5 meters deep. Water from the creek usually was turbid and nutrient-loaded because the drainage area of the creek was primarily agricultural. Station 2 was also an area where substantial mixing could occur between creek water and lake water if strong easterly winds were prevalent. Table 2 summarizes the physical and chemical data collected in 1974 at the Swan Creek station.

The screening rooms of both Fermi and the Monroe power plants served as the sites for fish collections. Fermi I was to be located adjacent to Fermi II while the Monroe plant is located approximately twelve kilometers southward in the city of Monroe, Michigan.

Field Collections

Temperature, dissolved oxygen, alkalinity, wave-heights, chlorides, and suspended, volatile, and total solids were taken each sampling period. Water temperatures were taken with a mercury hand-thermometer; dissolved oxygen measurements were made by azide-modified Winkler titrations; alkalinity was measured by H_2SO_4 titrations; and wave-height measurements were taken from a staff gauge. Chlorides, measured by the mercuric-nitrate method, and all solids data were determined in the laboratory.

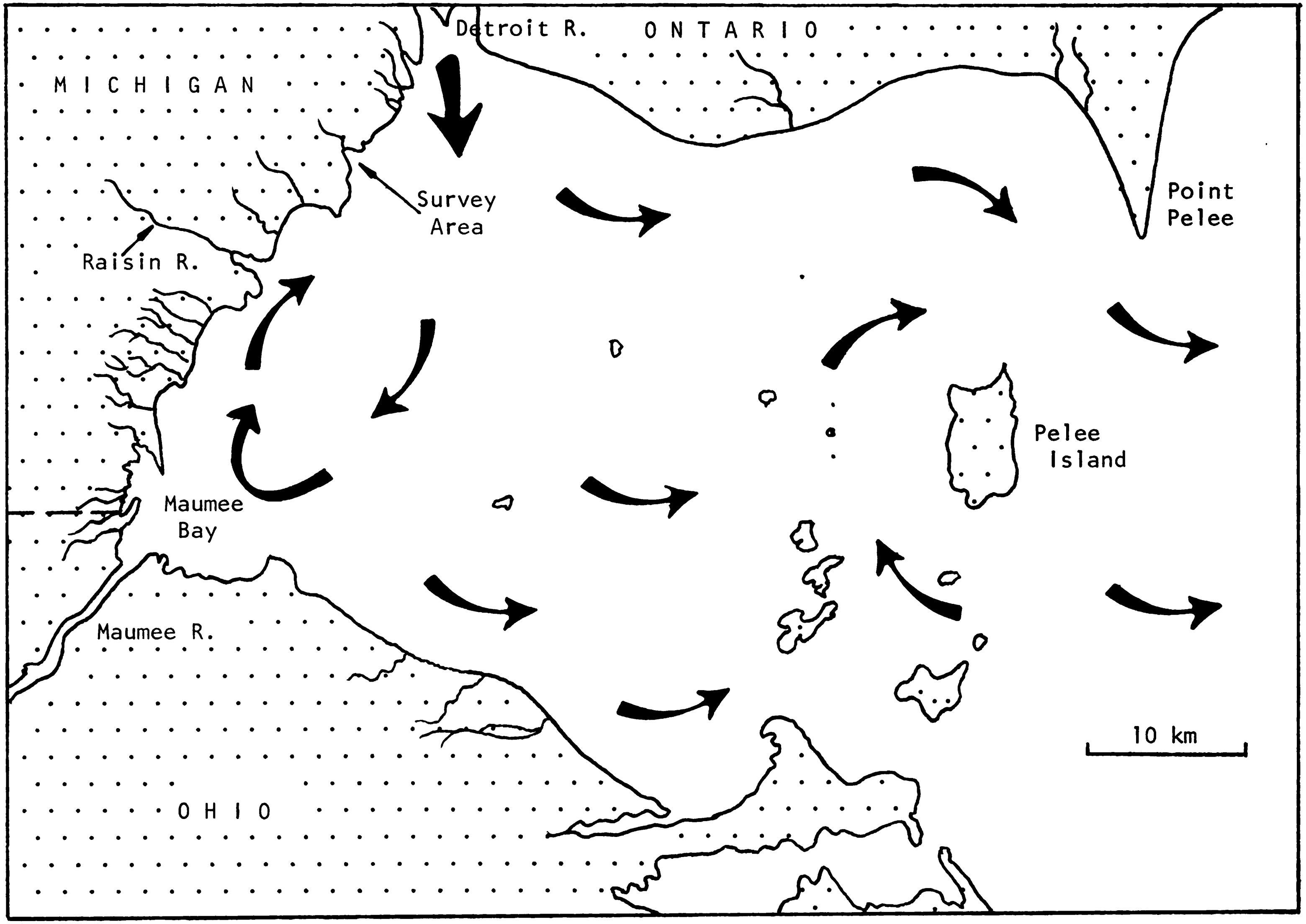

Figure 1. A map of the western basin of Lake Erie indicating the location of the survey area and a typical summer water current pattern (see text for detailed explanation of currents).

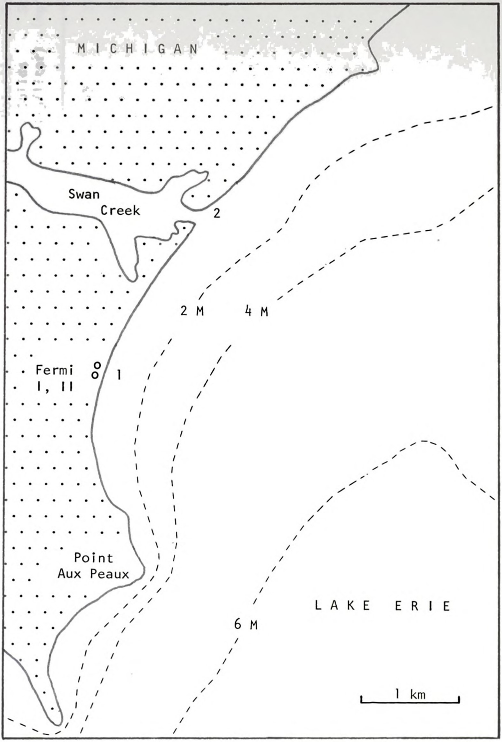

Figure 2. A map of the survey area showing the location of the sampling stations.

Table 1. Water chemistry data taken for station 1 for the year 1974.

Date	Water temp. (°C)	Wave-height observations (meters)	Total Alkalinity* (mg/liter $CaCO_3$)	Dissolved Oxygen (mg/liter)	Chlorides (mg/liter)	Suspended Solids (mg/liter)	Volatile Solids (mg/liter)	Total Solids (mg/liter)
2/15/74	2	ice cover	100	12.5	26.9	14	69	190
3/25/74	4	0.5	102	12.5	21.4	69	55	287
4/16/74	8	0.5	96	10.9	19.8	48	82	235
5/21/74	17	0.5	101	11.5	25.2	48	97	246
6/17/74	19	0.1	94	8.8	17.8	22	72	212
7/16/74	24	0.0	86	7.6	22.3	29	58	207
8/20/74	24	0.2	77	9.3	10.9	15	48	161
9/16/74	19	0.4	86	8.9	17.4	52	62	201
10/15/74	12	0.1	90	11.1	17.7	16	41	205
11/20/74	7	0.3	95	11.4	16.9	33	53	198
12/18/74	1	0.4	97	12.0	41.4	39	86	336

* All values for alkalinity are total alkalinity; no phth alkalinity was observed.

Table 2. Water chemistry data taken for station 2 for the year 1974.

Date	Water temp. (°C)	Wave-height observations (meters)	Total Alkalinity* (mg/liter $CaCO_3$)	Dissolved Oxygen (mg/liter)	Chlorides (mg/liter)	Suspended Solids (mg/liter)	Volatile Solids (mg/liter)	Total Solids (mg/liter)
3/25/74	3	0.5	107	12.7	24.2	60	54	293
4/16/74	9	0.7	112	10.6	21.4	87	109	326
5/21/74	20	0.5	125	9.8	30.1	49	118	312
6/17/74	18	0.3	98	8.5	19.7	52	76	247
7/16/74	24	0.0	88	7.9	17.0	23	59	162
8/20/74	23	0.4	85	9.5	17.8	29	61	171
9/16/74	19	0.2	87	10.8	17.3	32	70	185
10/15/74	11	0.1	92	10.9	16.8	23	44	217
11/20/74	7	0.4	96	11.4	17.4	33	60	202
12/18/74	1	0.4	102	12.1	28.5	42	81	217

* All values for alkalinity are total alkalinity; no phth alkalinity was observed.

Quadruplicate samples of water, seston, zooplankton, and fish were collected near the middle of each month. Water samples were taken using a Van Dorn water sampler and were stored in one-liter polyethylene bottles. Trace-metal water samples were immediately filtered through a micropore filter (0.45-u pore size) and then preserved with 10-ml of HNO_3. Water samples used for nutrient analyses were preserved with 10-ml of $HgCl_2$ while chloride samples were left unpreserved. Water samples used for seston analyses were collected using a Van Dorn water sampler and stored in polyethylene bottles containing 10-ml of HNO_3.

Zooplankton samples were collected by pumping lake water through a Wisconsin plankton net (75-u). A smaller mesh net was not suitable for use because the large amount of detritus in the lake water clogged the net too quickly. The zooplankton were separated from the rest of the seston by aspirating the swimming zooplankton from the settled debris. Zooplankton samples were stored in counting vials containing 70% ethanol. Microscope slides for counting were made using one drop of the zooplankton sample as described in the IBP Handbook, Number 12 (1971).

Monthly fish collections of yellow perch (Perca flavescens) and goldfish (Carassius auratus) were taken from the Monroe power plant by using drop nets in the screen room. When available, other pertinent fish species were also collected. Fish collections were similarly taken from the Fermi I power plant every three months.

Laboratory Procedures

Water samples were filtered through a micropore filter (0.45-u pore size) and a 30-ml subsample was taken for direct analysis for potassium. Analyses of the other elements, iron, manganese, zinc, cesium, cobalt, and strontium, required a concentration procedure in which a 400-gram

subsample was freeze-dried and redissolved in 20-ml of 1N-HNO_3. Table 3 summarizes the procedure used for the preparation of water samples. Trace-metal analyses were conducted either by flame emission or atomic bsorption with the specific conditions for each element given in Table 4.

Seston samples were concentrated by freeze-drying a 400-gram subsample and then redissolving as much residue as possible with 1-ml of concentrated HNO_3 and three successive rinses of 5-ml of distilled water. The samples were rinsed into counting vials, digested in a boiling water bath modified from Adrian (1971), and analyzed for trace-elements by atomic absorption or flame emission. Table 5 outlines the procedure for the preparation of seston samples.

Zooplankton samples were placed in the refrigerator overnight to allow the debris in the sample to settle to the bottom of the vial. Separation of the swimming zooplankton from the rest of the seston was accomplished by aspirating off the upper portion of the sample. The samples were rinsed into counting vials, digested in a boiling water bath described by Adrian (1971), and analyzed by atomic absorption or flame emission. Table 6 outlines the procedure for the preparation of zooplankton samples.

When possible, three fish per replicate were used for the fish samples. Gut contents were removed, fish were thoroughly homogenized in a grinder and a blender, and then the mixture was digested in an HNO_3 distillation process. Table 7 outlines the procedure for the preparation of fish samples for analysis of trace-elements.

Fish samples were also analyzed for radioisotopes. A 200-gram subsample of the frozen homogenized fish mixture was freeze-dried for 24-hours and ashed in a muffle furnace. The fish ash was transferred to a counting vial and placed in a Nuclear Chicago gamma well counter coupled subsample was freeze-dried and redissolved in 10ml of 1N-HNO$_3$. Table 3 summarizes the procedure used for the preparation of water samples. Trace-metal analyses were conducted either by flame emission or atomic absorption with the specific conditions for each element given in Table 4.

Seston samples were concentrated by freeze-drying a 500-gram subsample and then redissolving as much residue as possible with 1-ml of concentrated [illegible] distilled water.

[illegible]

Table 3. Preparation of water samples for the analysis of trace-elements.

1. As a precautionary rinsing step, pass 100-ml of a 1-liter water subsample through a 0.45-u micropore filter and discard the filtrate.

2. Filter the remainder of the sample and store the filtrate in a 1-liter acid-washed polyethylene bottle. Add 10-ml of concentrated HNO_3 as a preservative.

3. Take a 30-ml subsample and analyze directly for potassium.

4. Weigh a 400-gram subsample into a freeze-dryer bottle and freeze-dry the sample.

5. Add 20-ml of 1N HNO_3 to the flask and swirl until all particles are in solution.

6. Take a 5-ml subsample from step 5, add 0.5-ml of 12.5% lanthanum chloride solution, and analyze for strontium.

7. Analyze the remaining portion of the acid solution from step 5 for iron, manganese, zinc, cesium, and cobalt.

Table 3. Preparation of water samples for the analysis of trace-elements.

---

1. As a preparation [illegible] rinse [illegible] 100-ml of a 1-liter water sample [illegible] 0.45 [illegible] filter and discard the filtrate.

2. [illegible] the filtrate in a 1-liter [illegible]

Table 4. Operating conditions for atomic absorption and flame emission **analysis.**

Element	Resonance A^{o}	Sensitivity mg/liter	Absorption or Emission	Comments
Co	2407	0.2	Absorption	-
Cs	8521	0.03	Emission	Add K to suppress ionization.
Fe	2483	0.1	Absorption	-
Mn	2795	0.06	Absorption	-
Sr	4607	0.15	Emission	Add 1% lanthanum chloride to prevent PO_4, Al, and Si interferences.
Zn	2139	0.03	Absorption	-

* Table based on Elwell and Gidley (1967), with the data supplied by Jarrell-Ash, Division of Fischer Scientific Company.

Table 5. Preparation of seston samples for the analysis of trace elements.

---

1. Shake seston sample preserved with HNO_3 vigorously until sample is thoroughly mixed.

2. Weigh a 400-g subsample into a freeze-drying flask and freeze-dry the sample.

3. Add 1-ml of concentrated HNO_3 and 5-ml of distilled water to the flask, swirl the acid mixture getting as much residue as possible into solution, and pour the acid mixture into a counting vial.

4. Add an additional 5-ml of distilled water to the flask, swirl, and pour the solution into the vial.

5. As an additional rinsing precaution, repeat step 4.

6. Place uncapped vials into a boiling water bath and allow solution to evaporate to approximately 2 - 3 ml.

7. Cap the vials and heat in water bath for 6 - 8 hours.

8. Add distilled water to vials so that each vial contains 16-ml of liquid.

9. Recap vials and heat in water bath 3 - 4 hours. Solution is now ready for analysis.

---

* Digestion method modified from Adrian (1971).

Table 6. Preparation of zooplankton samples for trace-element analysis.

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1. Place polystyrene vials containing the zooplankton sample in the refrigerator overnight.
2. Separate the zooplankton from the total seston by aspirating the swimming zooplankton from the settled debris.
3. Store the zooplankton in counting vials containing 70% ethanol.
4. Place the uncapped vials in a boiling water bath and allow the samples to evaporate to 2 - 3 ml.
5. Add 1-ml of concentrated HNO_3 to each vial, recap, and heat in the water bath for 6 - 8 hours.
6. Add distilled water to the vials so that each vial contains 16-ml of liquid.
7. Recap vials and heat in the water bath for 3 - 4 hours. Solution is now ready for analysis.

---

* Digestion method modified from Adrian (1971).

Table 7. Preparation of fish samples for the analysis of trace elements.

---

1. Grind fish in a meat grinder and then homogenize the ground fish in a blender.

2. Place 10-g of the homogenized fish mixture into a boiling flask.

3. Add 50-ml of concentrated HNO_3 and allow to stand for 1-hour.

4. Reflux the acid mixture for 4-hours or until nitrous oxide fumes are no longer visible.

5. Distill excess liquid off until only 5-ml of acid are left.

6. Add 80-ml of distilled water.

7. Reflux for 4 - 6 hours.

8. Dilute to 100-ml with distilled water.

9. Take a 9-ml subsample from step 8, add 1-ml of 12.5% lanthanum chloride, and analyze for strontium.

10. Analyze the remaining solution from step 8 for iron, manganese, cesium, cobalt, and zinc.

Table 8. Preparation of fish samples for radioisotope analysis.

---

1. Freeze-dry 200-g, wet-weight, of frozen homogenized fish for at least 24-hours.
2. Transfer sample to a crucible and place in a muffle furnace for 4-hours at 100°C.
3. Increase temperature 50°C every 4-hours.
4. Upon reaching a temperature of 450°C, keep samples in muffle furnace for 6 - 8 hours.
5. Allow fish ash to cool to roon temperature and record the ash weight.
6. Transfer fish ash to counting vial for radioisotope analysis.

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to a 512-channel analyzer and counted for 480 minutes. The procedure for the preparation of fish samples for radioisotope analysis is given in Table 8.

Data Analysis

One-way analysis of variance tests were performed on the data to determine spatial, temporal, and size-class differences. Whenever means were found to be significantly different, a further statistical test, Tukey's multiple range comparison, was used (Glass and Stanley, 1970).

Data used for the analysis of temporal differences were pooled to correspond to the four seasons of the year. These data were then analyzed for seasonal significance rather than monthly differences.

RESULTS AND DISCUSSION

Water

Concentrations of metals found in filtered Lake Erie water samples ranged from less than 2.5 to 32.6 ug/liter for manganese, 5.6 to 29.9 ug/liter for zinc, 110 to 460 ug/liter for strontium, 17.0 to 672.5 ug/liter for iron, and 1000 to 2300 ug/liter for potassium (Table A-1). These data are consistent with those of Shaffer (1975) who conducted similar studies on the western basin of Lake Erie.

Cesium was not detectable under the methods employed by this study. Cobalt, although detectable, was not measurable; however, samples analyzed by a private research laboratory indicated that cobalt was present at about 1.5 ug/liter (Table A-2). The cobalt data compare favorably with Durum et al. (1970) who found 2 - 4 ug/liter of cobalt in water from the central basin of Lake Erie.

Statistically significant differences between stations ($p = .05$) were noted during times when Swan Creek had high discharge rates. On the April sampling date Swan Creek had significantly higher values for the elements iron, zinc, manganese, and strontium (Figures 3, 4, 5, and 6, respectively). These differences generally were not noted in the summer or fall months when the creek discharge was lower and when winds and seiches caused considerable mixing of lake water with the Swan Creek water. Potassium (Figure 7) exhibited significantly higher levels for the months of May, November, and December at the Swan Creek station.

Trace-elements in the Fermi area exhibited considerable temporal

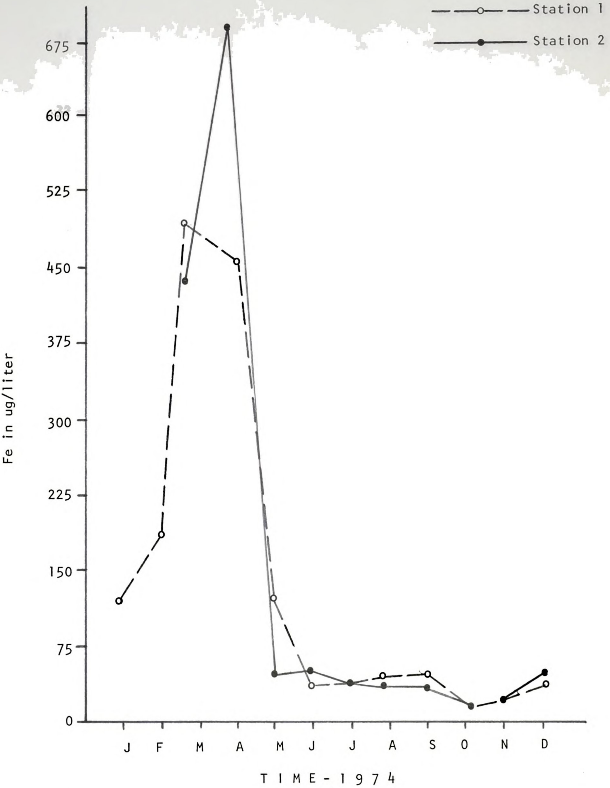

Figure 3. Temporal variation of iron from stations 1 and 2 of the survey area.

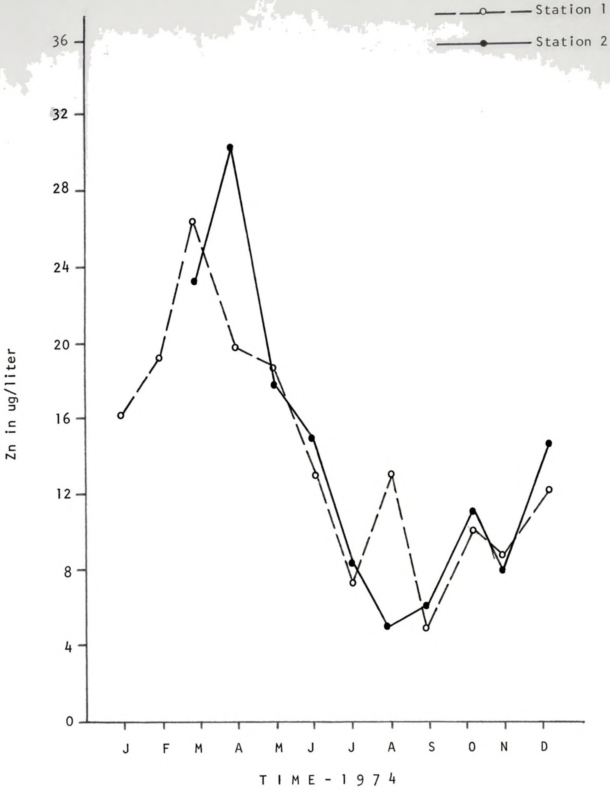

Figure 4. Temporal variation of zinc from stations 1 and 2 of the survey area.

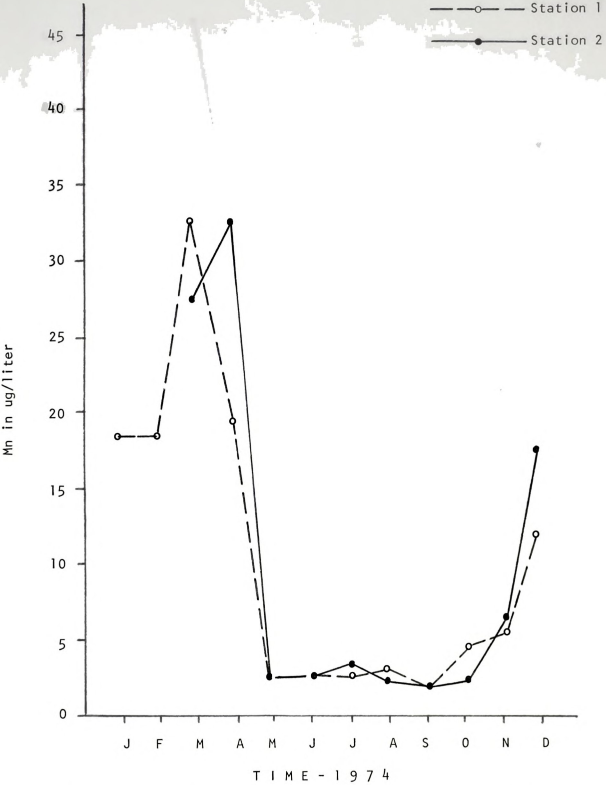

Figure 5. Temporal variation of manganese from stations 1 and 2 of the survey area.

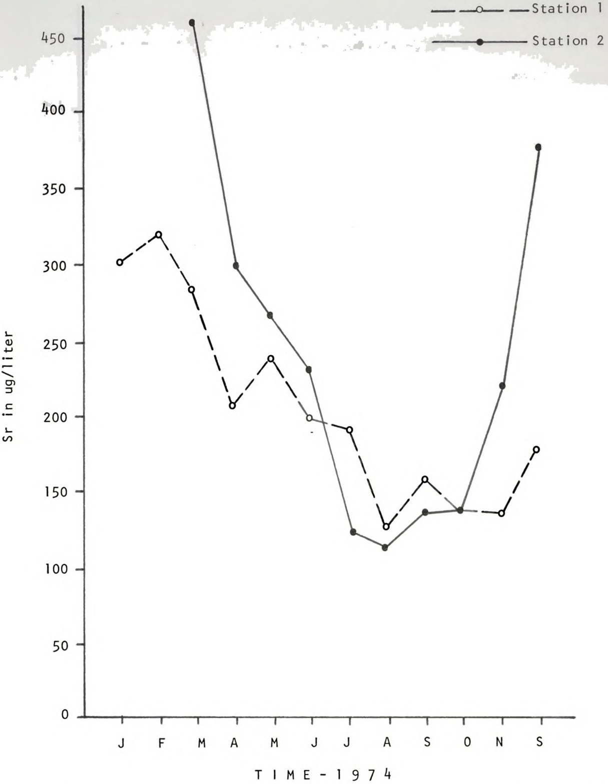

Figure 6. Temporal variation of strontium from stations 1 and 2 of the survey area.

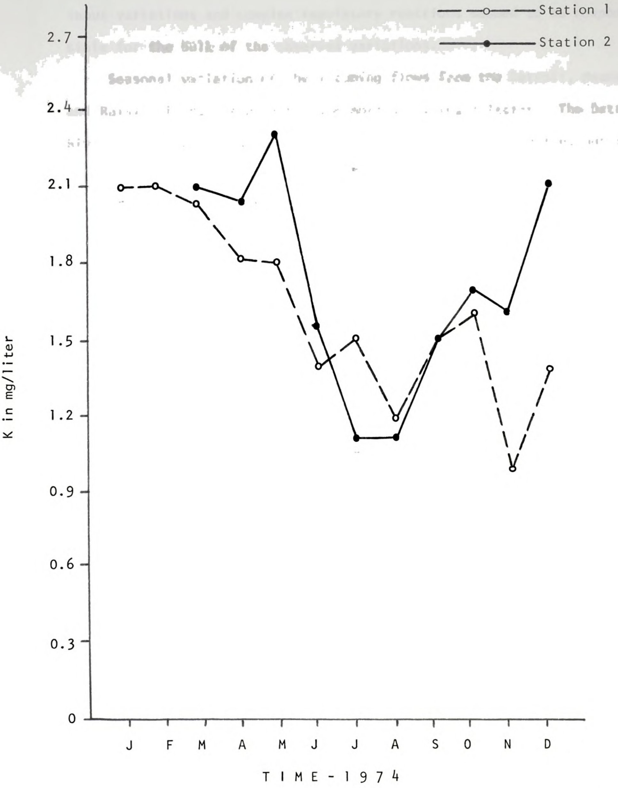

Figure 7. Temporal variation of potassium from stations 1 and 2 of the survey area.

differences. All of the elements under consideration showed a definite trend toward lower concentrations during the summer months. Flow input variations and complex regulatory reactions seemed to be responsible for the bulk of the observed variations.

Seasonal variation of the incoming flows from the Detroit, Maumee, and Raisin Rivers was probably the more significant factor. The Detroit River contributed about 95% of the annual input into the basin, but the amount and relative proportion varied with the season. The percentage of the lake water contributed by the Detroit River ranged from 74% in the spring to 95% in the fall. The Maumee River contributed only 2.5% annually, but it contributed 14 to 18% of the total input in the spring, 11% in the summer, and 5% in the fall. The Raisin River contributed only 0.5% annually, but it contributed almost 12% of the spring total and 5% of the fall total (Ecker and Cole, 1976). Together, these three tributaries comprise 99% of the flow in the western basin of Lake Erie.

The variation of trace-metal levels found in the water from the Fermi area seemed to be related to the variability of the tributary inputs. High levels of iron, zinc, manganese, and strontium in the water during the spring season corresponded to periods of high spring runoff from the Maumee and Raisin Rivers. Both of these rivers receive industrial and municipal effluents in addition to draining large agricultural watersheds. High runoff periods from these two rivers could account for higher concentrations of trace-elements in the study area. Ecker and Cole (1976) calculated that the Maumee River was particularly influential in the spring, but less influential during times of low water input.

Complex chemical regulatory reactions could also explain a part of the seasonal variation noted. The highest concentrations of iron and differences. All of the elements under consideration showed a definite trend toward lower concentrations during the summer months. Flow input variations and complex regulatory reactions seemed to be responsible for the bulk of the observed variations.

Seasonal variation of the incoming flows from the Detroit, Maumee, zinc were observed during the spring months when wave-height observations and suspended solids were highest while manganese, potassium, and strontium values were highest during the winter months when there was ice cover and little suspended solids. Apparently, zinc and iron are highly associated with the bottom sediments and more of these two elements are put into solution when the bottom sediments are suspended and highly exposed to the water column due to the turbulent conditions.

It also follows that strontium, potassium, and manganese are less concentrated in the sediments since in this study, they did not exhibit a similar tendency with suspended solids and high wave conditions. This supposition is partially supported by Brungs (1967) who showed that strontium has little association with suspended materials and Childs (1970) who stated that potassium, like other alkali metals, generally exists as a simple ion in solution.

Contradictory evidence (Shaffer, 1975), however, indicates that manganese and strontium are associated with the sediments. Shaffer found that the trace-elements cobalt, strontium, iron, manganese, and zinc show a direct relationship with the amount of clay and organic content found in finer sediments. Shaffer also found that strontium showed seasonal variations with higher summer concentrations in the sediments than in the fall. Jennne (1968) stated that iron and manganese form oxide coatings on the sediments and that other transition metals are greatly affected through sorption and coprecipitation with these oxide coatings. Manganese, however, redissolves from the sediments under less extreme redox conditions and higher dissolved oxygen concentrations than those necessary for the redissolving of iron.

Manganese and iron are two transition elements that are often found dissolved in concentrations that are above their theoretical solubility

factors controlled primarily by ph/Eh and water temperatures. Some of the attempts to explain this phenomenon include the formation of organic complexes (Childs, 1971), colloidal oxides (Friend, 1963), and the association of trace metals with other suspended materials.

Seston

Mean monthly concentrations and standard deviations of each element were calculated for the seston (Table A-3). Concentrations of metals found in the seston ranged from 362 to 1655 ug/liter for iron, 20 to 54 ug/liter for manganese, 2.7 to 26.0 ug/liter for zinc, and 900 to 2500 ug/liter for potassium (Figures 8, 9, 10, and 11, respectively). Again cobalt was not measurable under the methods employed in the study; however, results from a private research laboratory indicate a level of approximately 4 ug/liter (Table A-2).

Inconsistent, but significant variations between stations were noted most commonly during the fall and winter months. On the December sampling date when the wave-height observed at both stations was a rather high 0.4 meters, there were significant variations for iron, manganese, and potassium. However, since these variations were noted when the wave-height and suspended solids were basically equal between the two stations these differences could be attributed to the type and nature of the bottom sediments.

Most of the temporal variation observed seemed to be directly related to the wave conditions. Generally, larger values for iron and zinc were recorded when higher wave conditions were prevalent. A correlation coefficient of 0.74 was calculated for the relationship of iron and the wave-height while the zinc correlation coefficient was 0.37. This indicates that iron had a direct relationship while zinc showed only a moderate correlation. In contrast, manganese and potassium values

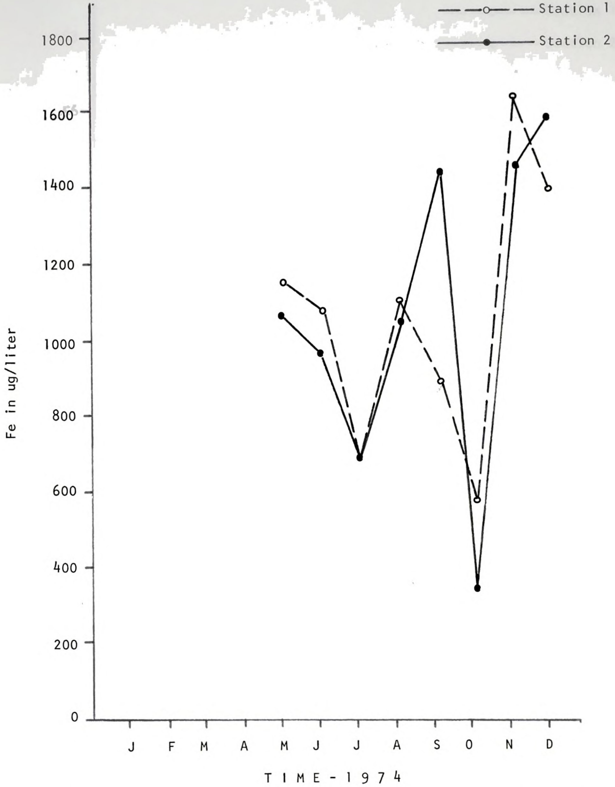

Figure 8. Temporal variation of iron in the seston taken from stations 1 and 2 of the survey area.

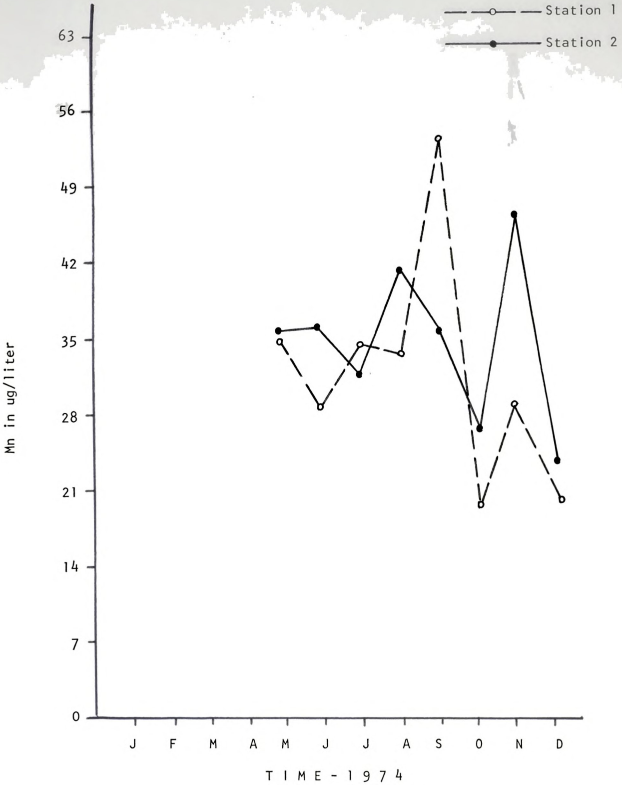

Figure 9. Temporal variation of manganese in the seston taken from stations 1 and 2 of the survey area.

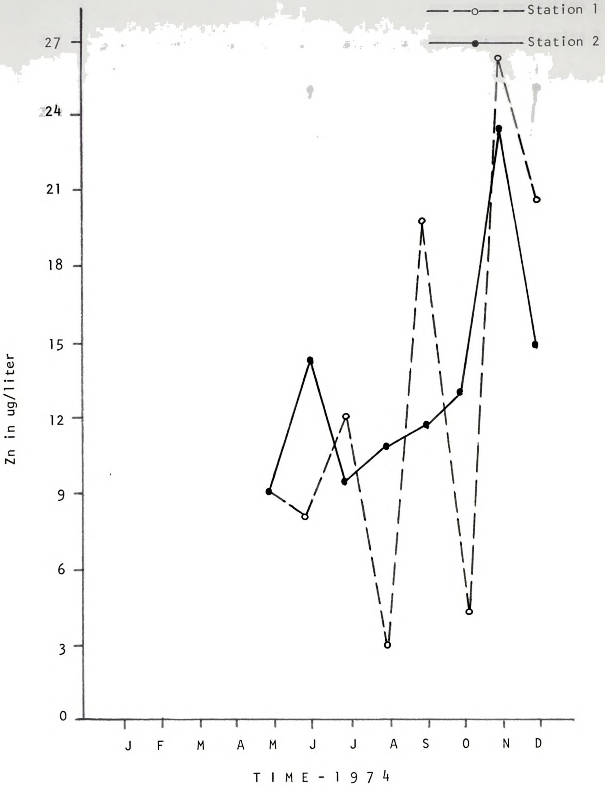

Figure 10. Temporal variation of zinc in the seston taken from stations 1 and 2 of the survey area.

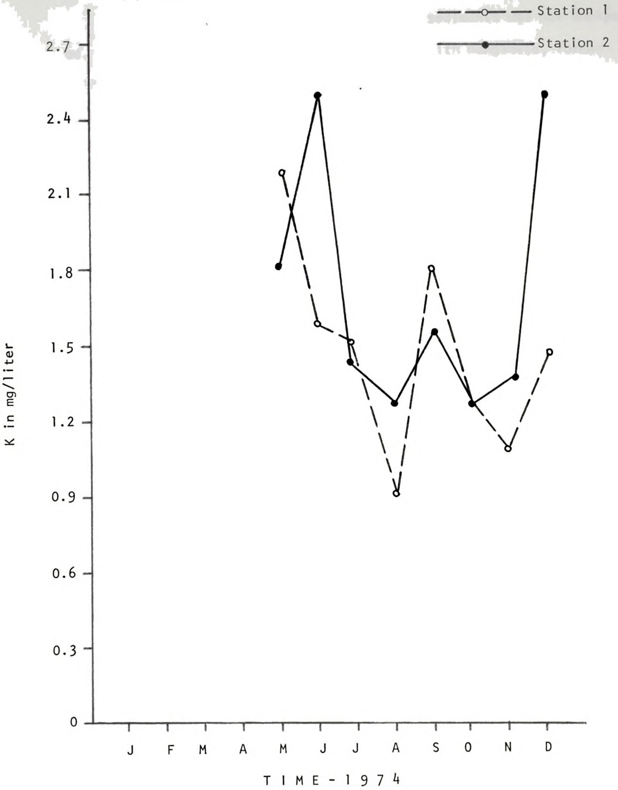

Figure 11. Temporal variation of potassium in the seston taken from stations 1 and 2 of the survey area.

fluctuated freely and did not seem to exhibit much of a relationship with wave-height conditions.

The strong association of iron with the sediments was not unexpected. Jenne (1968) suggested that iron, along with manganese, formed oxide coatings on suspended particulate matter which settled during periods of low wave conditions. Lee (1970) stated that iron precipitates as an iron hydroxide flock under redox conditions normally found in natural waters. Lee further stated that iron will not redissolve except during periods of very low dissolved oxygen, but since the water in the Fermi area does not often stratify, large amounts of iron redissolving from the sediment would not seem likely.

Zooplankton

Mean monthly concentrations and standard deviations of each element were calculated for the zooplankton data (Tables A-4 and A-5). Concentrations of metals found in the zooplankton ranged from 1.2 to 7.3 mg/gram for zinc, 3.8 to 18.1 mg/gram for iron, less than 0.3 to 1.0 mg/gram for manganese, and 22.9 to 86.4 mg/gram for potassium (Figures 12, 13, 14, and 15, respectively). Neither cobalt nor strontium were present in sufficient quantities to obtain reliable results.

Zooplankton concentrations (expressed on a wet-weight basis) of manganese and potassium remained fairly constant throughout the sampling period while iron and zinc showed increasing trends during the spring and early summer months. This period of increasing concentrations in zooplankton corresponded to declining water concentrations in these two elements during the summer months. Apparantly, the warming water and increased photoperiod resulted in higher primary productivity and the zooplankton obtaining higher concentrations of these elements through

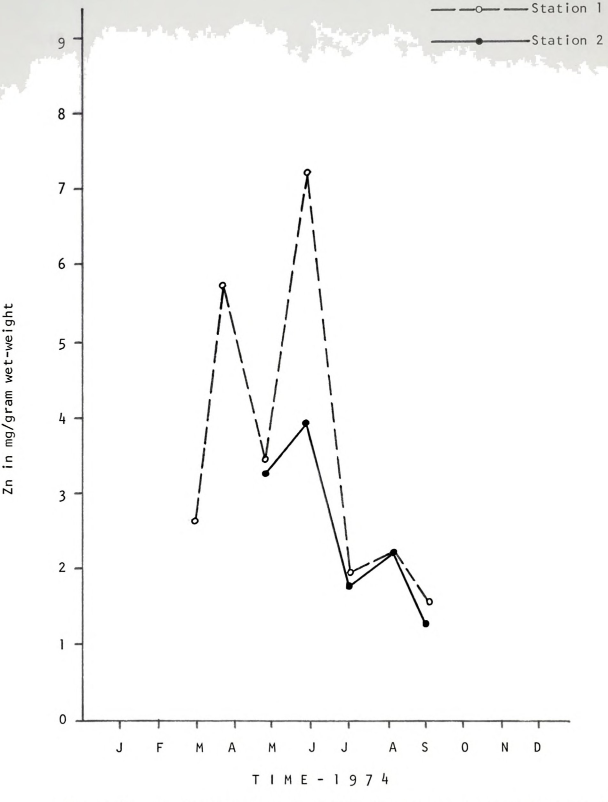

Figure 12. Temporal variation of zinc in the zooplankton from stations 1 and 2 of the survey area.

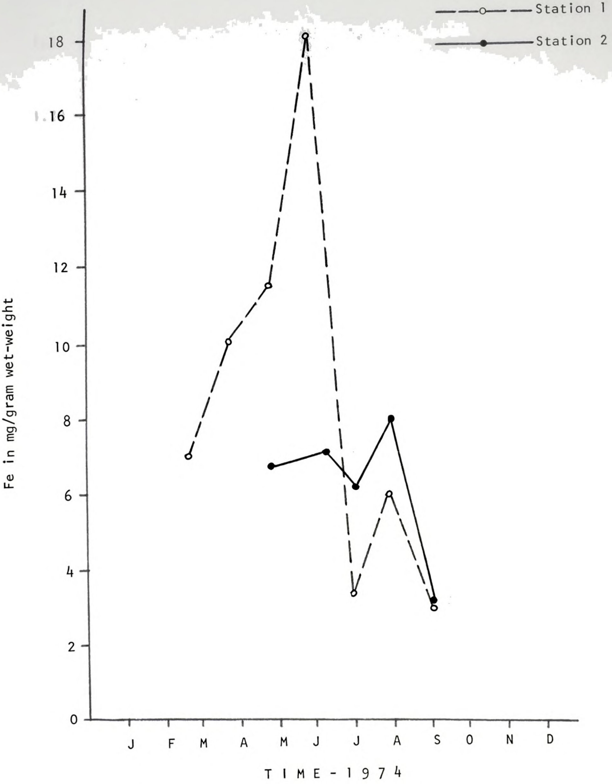

Figure 13. Temporal variation of iron in the zooplankton from stations 1 and 2 of the survey area.

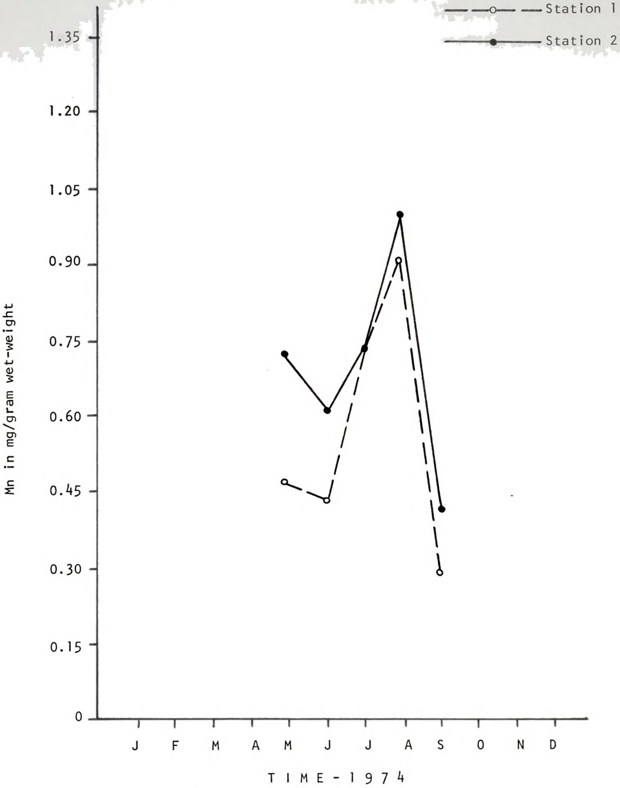

Figure 14. Temporal variation of manganese in the zooplankton from stations 1 and 2 of the survey area.

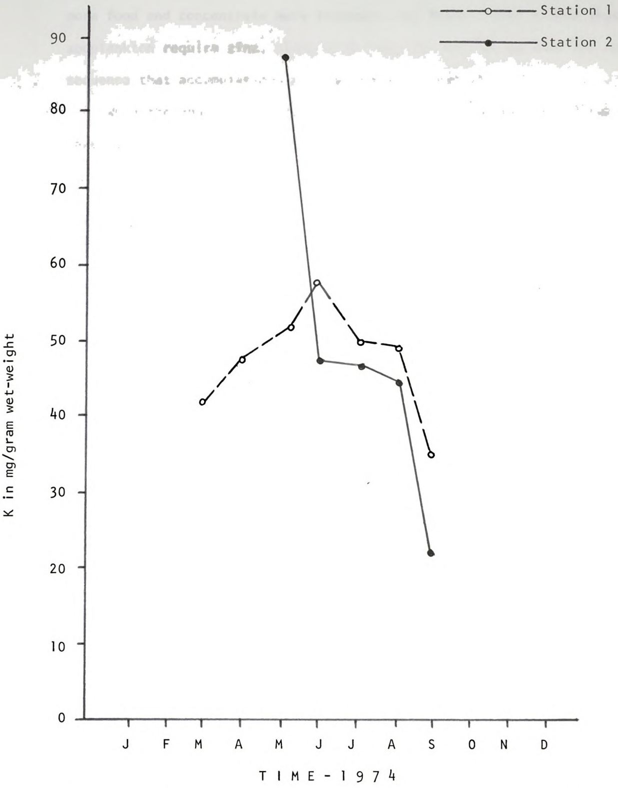

Figure 15. Temporal variation of potassium in the zooplankton taken from stations 1 and 2 of the survey area.

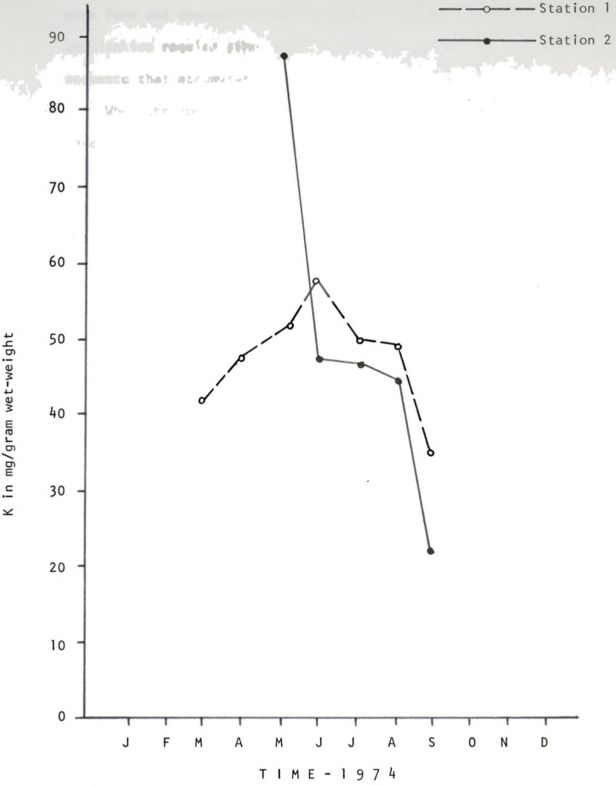

Figure 15. Temporal variation of potassium in the zooplankton taken from stations 1 and 2 of the survey area.

the food chain. Brooks and Dodson (1965) stated that larger, adult zooplankton are more effieient predators with the result that they consume more food and concentrate more isotopes, and Bowen (1966) stated that zooplankton require zinc, along with iron, for metabolism with the consequence that accumulations of iron and zinc develop.

When the zooplankton data (expressed as ug of element per liter of lake water sampled, Table A-5), there was definite trend of increasing concentrations for all elements during the warmer months with the highest concentrations found in June. This might be expected simply because the zooplankton were more abundant during the summer months. Figures 16 and 17 show that the highest numbers of all classes of zooplankton combined were usually during the months of June, July, and September. Zooplankton numbers dropped during late fall to non-detectable levels in November and December.

Fish

Mean monthly concentrations and standard deviations were calculated for both species of fish (Tables A-7 and A-8). Concentrations of metals found in yellow perch ranged from 18.5 to 34.0 ug/gram of iron, 2.87 to 3.50 ug/gram of manganese, 26.2 to 45.0 ug/gram of zinc, 3.8 to 7.0 ug/gram of strontium, and 0.0055 to 0.0098 ug/gram of cesium (Figures 18, 19, 20, 21, and 22, respectively).

In yellow perch (Table A-7), no significant differences (p = .05) were found between the Monroe station and the Fermi station. Baker and Scholl (1971) showed that yellow perch are widely distributed and move freely in Lake Erie. It is not surprising, therefore, that spatial differences in element concentrations were not present since the fish movements probably integrated the effects of conditions found throughout the

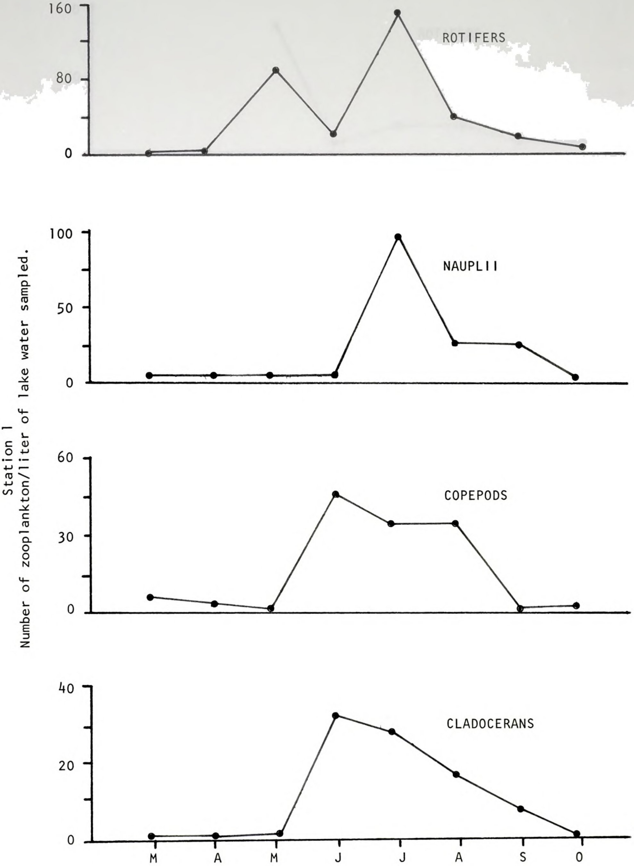

Figure 16. Temporal variation of zooplankton from station 1 for 1974.

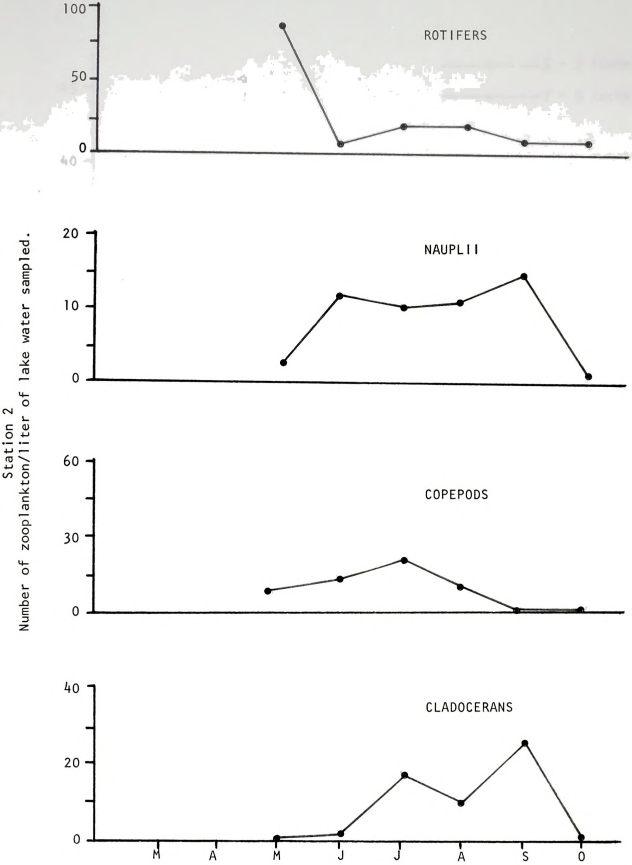

Figure 17. Temporal variation of zooplankton from station 2 for 1974.

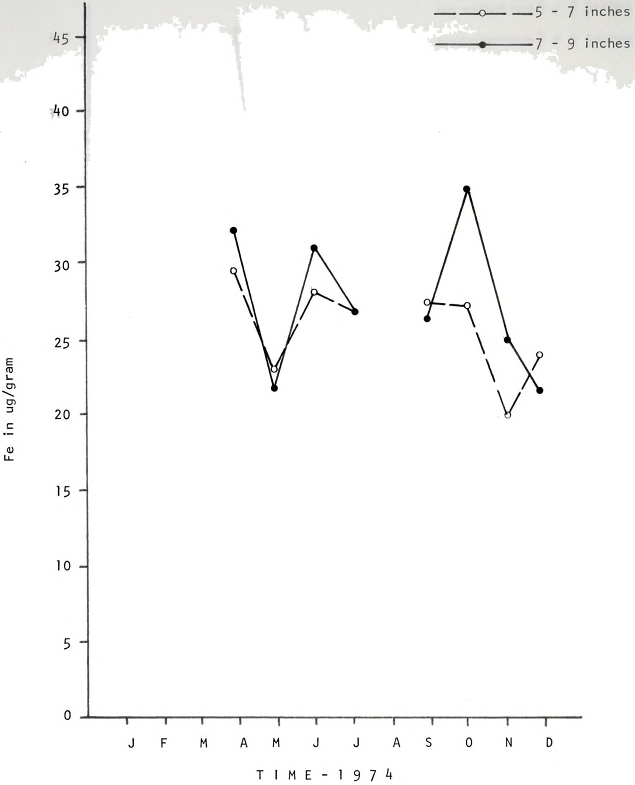

Figure 18. Temporal variation of iron found in yellow perch taken from the Monroe station.

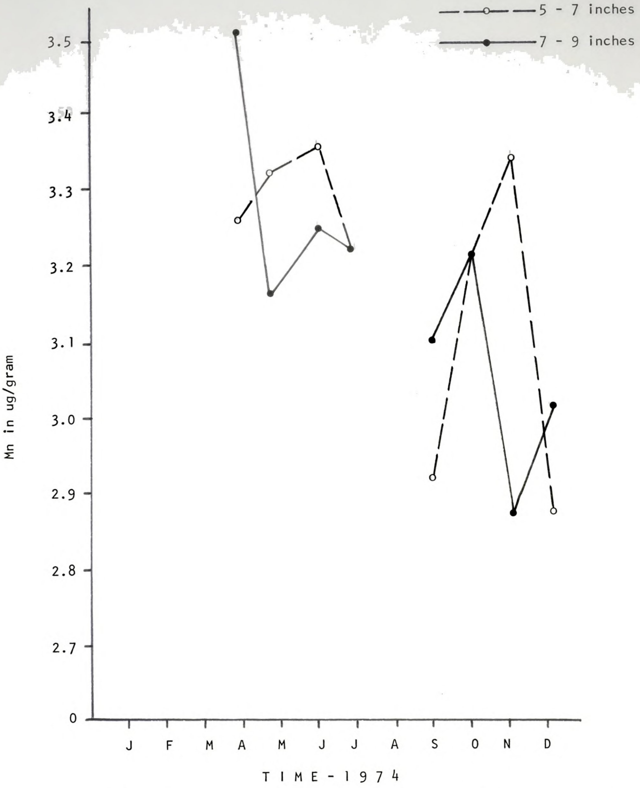

Figure 19. Temporal variation of manganese found in yellow perch taken from the Monroe station.

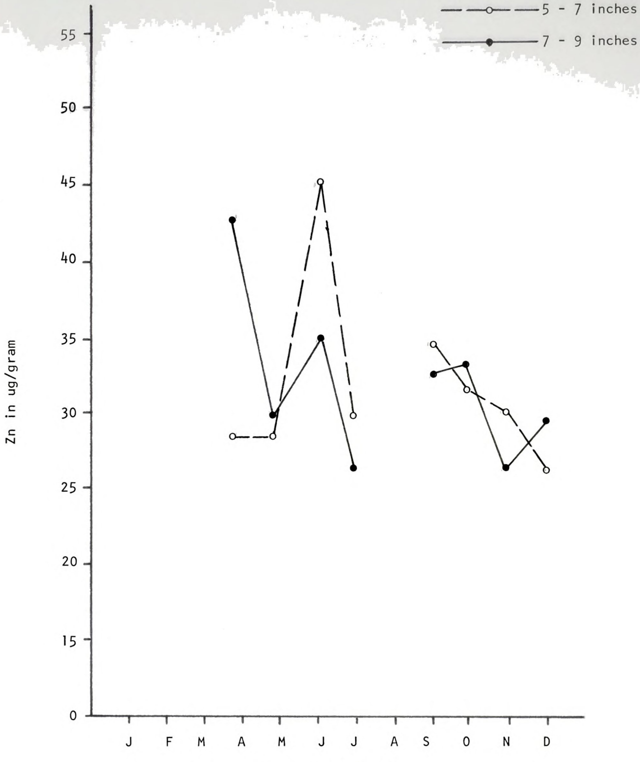

Figure 20. Temporal variation of zinc found in yellow perch taken from the Monroe station.

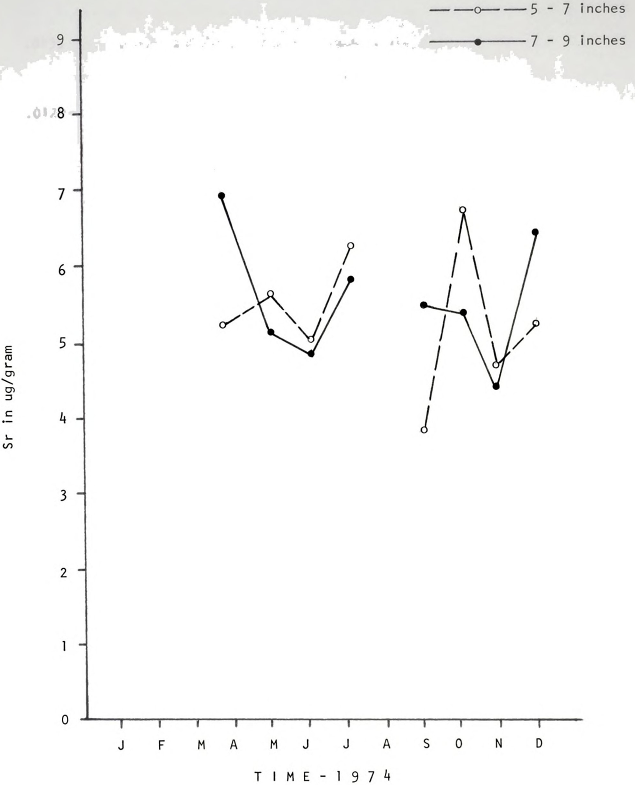

Figure 21. Temporal variation of strontium found in yellow perch taken from the Monroe station.

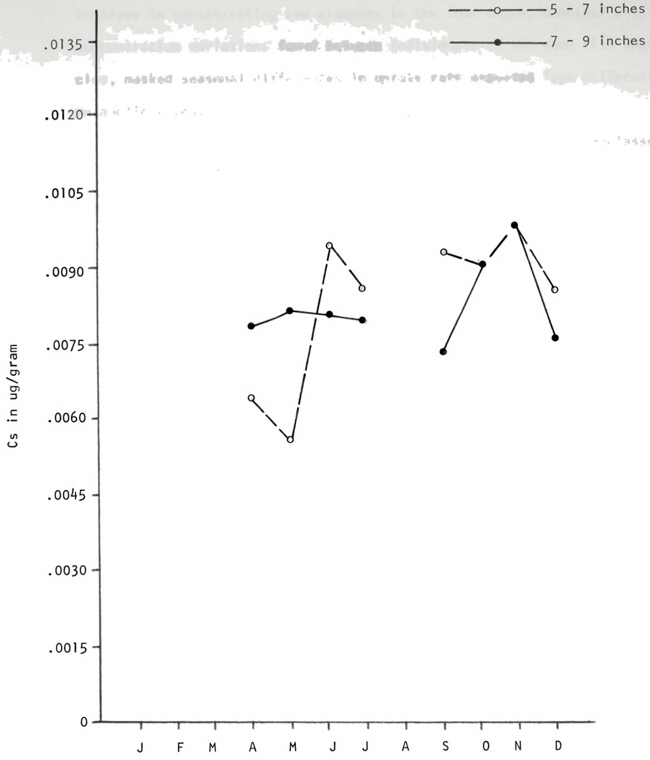

Figure 22. Temporal variation of cesium in yellow perch taken from the Monroe station.

surrounding area. Neither were significant differences (p = .05) found among seasonal concentrations in yellow perch. Possibly, the lag time involved in concentrating the elements in the food chain, combined with concentration variations found between individuals of the same fish species, masked seasonal differences in uptake rate expected from different metabolic rates.

Analysis of the yellow perch data for the two different size-classes also revealed no significant differences (p = .05). The yearly grand averages for the different size classes are given in Table A-9.

Concentrations of metals found in goldfish ranged from 29.5 to 50.0 ug/gram of iron, 1.80 to 2.60 ug/gram of manganese, 71.5 to 94.0 ug/gram of zinc, 0.0048 to 0.0087 ug/gram of cesium, and 10.8 to 14.8 ug/gram of strontium (Figures 23, 24, 25, 26, and 27, respectively). Examination of Figures 23 - 27 for goldfish shows that there were no significant differences (p = .05) among the seasons of the year or between the Monroe and Fermi stations. However, between fish size-classes, significant differences were noted for the element iron. The yearly average of iron for Monroe goldfish 8 - 10 inches long was 33.4 ug/gram while for the 12 - 15 inch goldfish, it was 51.3 ug/gram. Although goldfish were at times opportunistic in their feeding habits, stomach samples generally classified them as bottom feeders. Since iron has already been shown to be highly associated with the sediments, the goldfish possibly continue to incorporate iron into their tissue through their feeding habits as they mature.

Other evidence of size class differences comes from Kleinert and Degurse (1972). They stated that larger walleyes and northern pike have higher concentrations of mercury than smaller individuals of the same species.

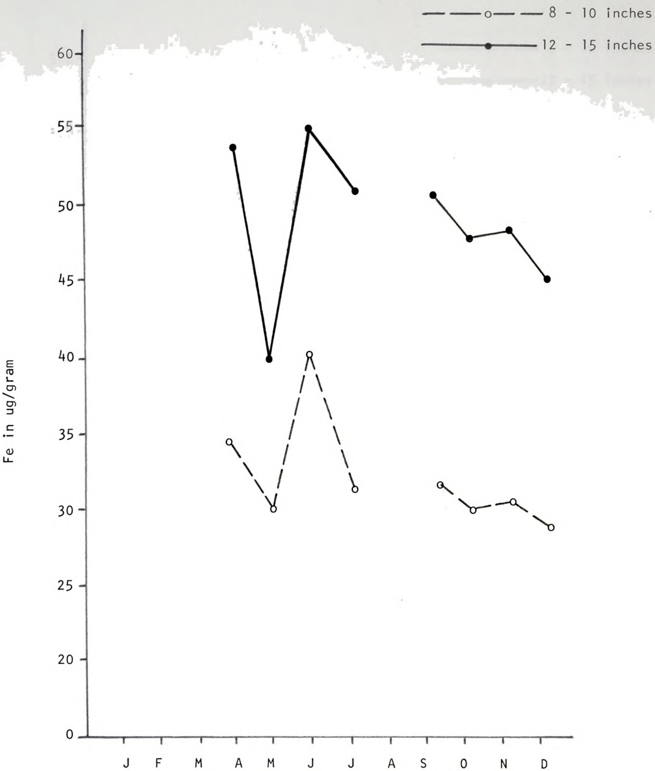

Figure 23. Temporal variation of iron found in goldfish taken from the Monroe station.

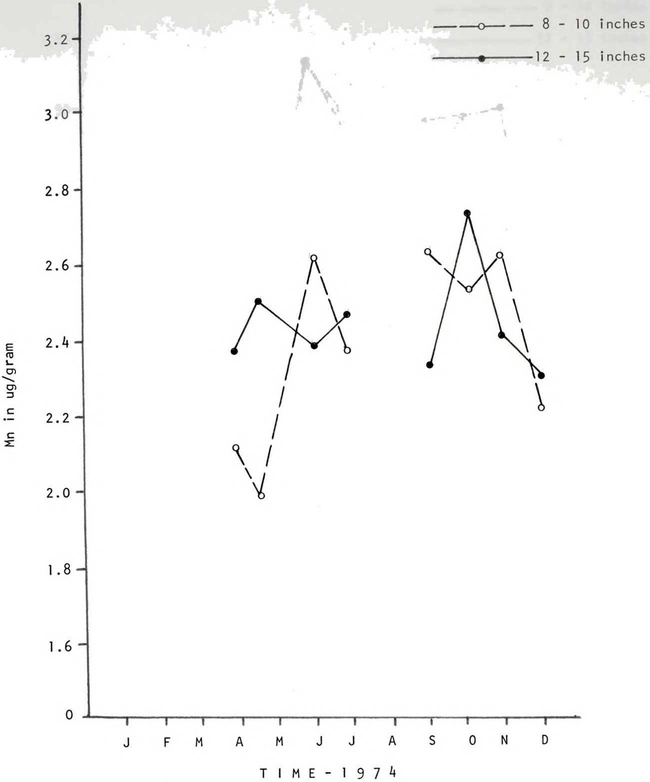

Figure 24. Temporal variation of manganese found in goldfish taken from the Monroe station.

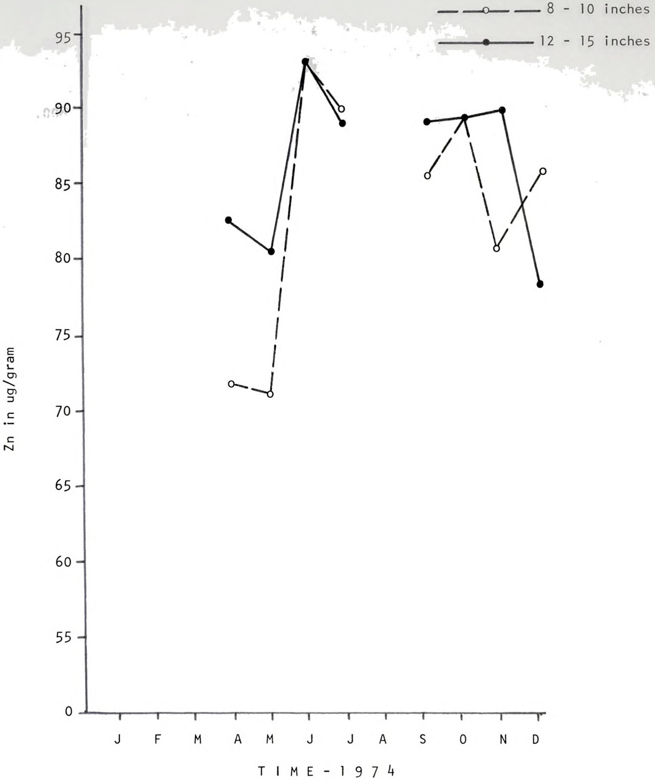

Figure 25. Temporal variation of zinc found in goldfish taken from the Monroe station.

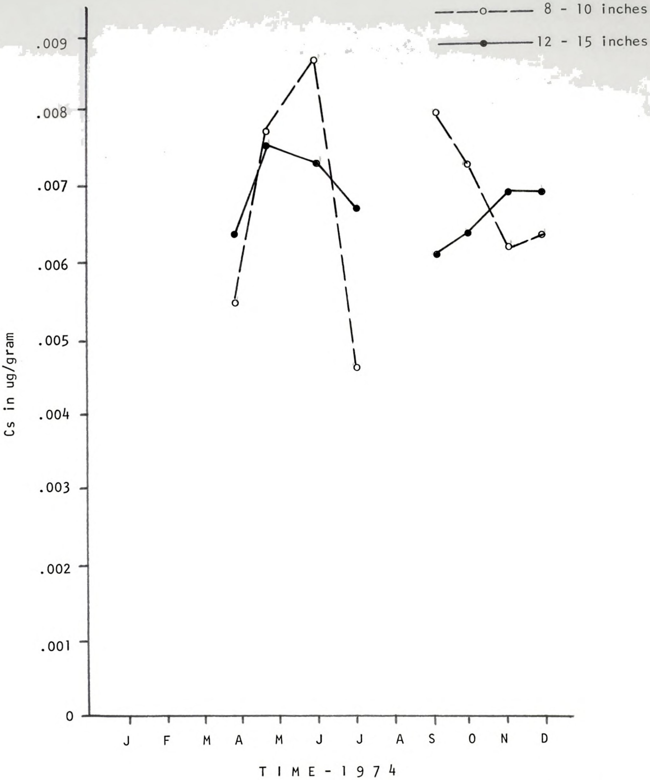

Figure 26. Temporal variation of cesium found in goldfish taken from the Monroe station.


δ = 10 Inches
Inches
600.
800.

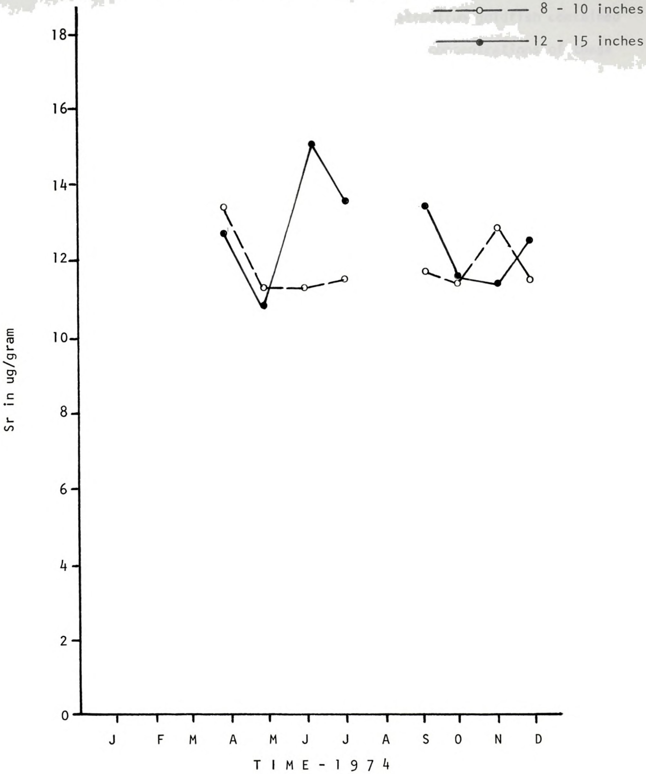

Figure 27. Temporal variation of strontium found in goldfish taken from the Monroe station.

Comparisons of yellow perch data (Figures 18 - 22) and goldfish data (Figures 23 - 27) revealed significant differences (p = .05) between the larger size-classes. For iron, zinc, and strontium goldfish contained higher concentrations than the perch. Higher concentrations of these metals in bottom feeding fish is not surprising since iron and zinc are highly associated with the sediments, and strontium, during periods of high pH, precipitates much like calcium carbonate in marl formation.

Mathis and Cummings (1971), working on the Middle Illinois River, Eyman (1972), studying a hypereutrophic lake in Southern Michigan, and Gottschalk (1975), working on the western basin of Lake Erie, indicated similar trends of higher concentrations of iron, zinc, manganese, and strontium with bottom feeding fish. Hesse and Evans (1972) reported that mercury is concentrated more by predatory fish species while chromium, zinc, manganese, copper, and nickel were higher in bottom feeding fish.

Fish - Radioisotopes

Radioisotope concentrations were determined for three species of fish (Table A-10). Only the two radioisotopes ^{40}K and ^{137}Cs were detected. ^{40}K is a naturally occuring radioisotope accounting for over 90% of all natural radiation (Rice and Duke, 1969), while the radioisotope ^{137}Cs is a man-made fission product with a long half-life.

^{40}K values, approximately 0.1 pCi/gram, varied slightly among the three species of fish analyzed. ^{137}Cs values ranged from 0.02 - 0.38 pCi/gram and were slightly higher for northern pike than yellow perch or carp. These results compare favorably with those of Gottschalk (1975) who found that 23% of the total gamma activity in fish was due ^{40}K. Gottschalk also found mean annual concentrations for ^{137}Cs of 0.019, 0.021, and 0.038 pCi/gram for planktivores, bottom feeders, and piscivores, respectively.

CONCLUSIONS

Through accidental spills and the release of radioactive cooling water, effluent from the Fermi II power plant may contain radioisotopes. The counterparts of these radioisotopes are the stable isotopes which have been shown to be accumulated by the components of an aquatic ecosystem.

Accidental spills and allowable releases in the Fermi area, however, might not create long term problems. With a minimum possible flushing time of two months for the western basin, material deposited in the Fermi area might not remain concentrated there very long. Wind-generated turbulence likely would resuspend the sediments and carry them via southeasterly currents to be dispersed in the deeper waters of the western basin or beyond the basin boundaries entirely.

Some complications could develop in the offshore waters of Swan Creek. Although substantial mixing of lake water probably occurs rapidly with Swan Creek water, Hartley et al. (1966) shows that currents in the Fermi area are eddy currents and ILEWPB (1969) shows that suspended particles are deposited just to the south of the Swan Creek mouth. Since transition metal isotopes are often associated with suspended particulate matter, this could create an area of highly enriched radioactive sediments.

A glance at Tables 9 and 10 for all of the biological components suggests that water and the seston/sediments play the most important roles in determining trace-element distribution. A comparison of the huge amounts of water and sediments in the Fermi area seems to make it

Table 9. Yearly grand averages for data taken from the Fermi II survey area.[1]

Element	Water (ug/liter)	Seston (ug/liter)	Sediments[2] (ug/gram)	Zooplankton (ug/liter)	Fish[3] (ug/gram)
Fe	134.3	1073.0	21423.0	0.449	33.4
Zn	14.1	12.9	144.0	0.038	57.7
Mn	10.3	34.0	401.0	0.018	2.76
Co	1.4[4]	4.0[4]	13.0	0.00013[4]	0.30[4]
Sr	222.0	244.0[4]	49.5	0.12[4]	8.9
Cs	-	-	-	-	7.3
K	1650.0	1600.0	-	0.59	-

1. Unless otherwise indicated, values have been derived from this study.
2. All sediment data derived from Shaffer (1975).
3. Based on all fish of all size categories taken for this study.
4. Data taken from CLOW, Table A-2 of the Appendix.

Table 10. Approximate amounts of each element found in the different aquatic components of the Fermi II survey area as based on the yearly grand averages of Table 9 on page 53.

Element	Water[1] (Kg)	Seston[1] (Kg)	Sediments[2] (Kg)	Zooplankton[1] (Kg)	Fish[3,4] (Kg)
Fe	402.9	3219.0	4174.0	1.35	2.51
Zn	42.3	38.7	28.0	0.11	4.32
Mn	30.9	102.0	78.1	0.05	0.21
Co	4.2	12.0	2.5	0.0004	0.02
Sr	666.0	731.9	9.6	0.36	0.67
Cs	-	-	-	-	0.55
K	4950.0	4800.0	-	1.78	-

1. Values based on a survey area 1.5-km wide and a distance of 1-km offshore with an average depth of 2-m.
2. Sediment calculations based on upper 10-cm of the sediments of the survey area.
3. Values based on all fish for the survey area.
4. Fish production estimates from Churchill (1976) and LeCren (1972).

quite apparent that the total amount of trace elements found in the zooplankton is almost insignificant. For example the water to zooplankton and sediment to zooplankton ratios for the element iron are almost 300:1 and 3100:1, respectively. Also, zooplankton live for a relatively short time period, and unless eaten by fish, the death and decomposition of the zooplankton will release, either to the water or to the sediments, the small amounts of trace elements they did contain.

Although the amount of trace-elements found in fish is also relatively small, it definitely should not be considered unimportant. Evidence is present in the literature stating that fish found in metal discharge areas do have higher concentrations of those elements (Hesse and Evans, 1972; Tong et al., 1972). Fish are a product directly consumed by man, and bioaccumulations in fish, especially radioisotopes of iron and zinc in bottom feeding fish, could present a real potential hazard. Also, it is known that fish are attracted to the warmer water of power plant discharges during the colder months; this could increase their exposure time and present further potential for accumulations of radioisotopes.

Until the limits of the specific activity hypothesis are known, short term predictions based on this hypothesis should be used conservatively. Wrongly predicting the fate of radioisotopes entering an aquatic system could have long term detrimental effects. Seelye (1974) suggested that whenever potentially hazardous conditions to man are being assessed that a safety multiplication factor be used in which the allowable wastes be further reduced by a factor of 10. The ramifications of such a safety factor seem worthwhile.

LITERATURE CITED

Adrian, W. J. 1971. A new wet digestion method for biological material utilizing pressure. Atomic Absorption Newsletters 10(4):96.

American Public Health Association. 1971. Standard methods for the examination of water and wastewater. 13th ed. A.P.H.A., New York. 873 pp.

Baker, C. T. and R. L. Scholl. 1971. Lake Erie fish populations trawling survey. Dingell-Johnson Project F-35-R-9. 30 pp.

Beeton, A. M. 1961. Environmental changes in Lake Erie. Trans. Amer. Fish. Soc. 90:153-159.

Beeton, A. M. 1971. Chemical characteristics of the Laurentian Great Lakes, In: Proceedings of the conference on changes in the chemistry of Lakes Erie and Ontario. Bull. Buffalo Soc. Nat. Sci. 25(2):1-21.

Bowen, H. J. M. 1966. Trace elements in biochemistry. Academic Press, London. 241 pp.

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

Britt, N. W., J. T. Addis, and R. Engel. 1973. Limnological Studies of the Island Area of Western Lake Erie. The Ohio Biological Bulletin, Vol. 4, No. 3. Ohio State University. 89 pp.

Brungs, W. A., Jr. 1967. Distribution of cobalt 60, zinc 65, strontium 85, and cesium 137 in a freshwater pond. U. S. Dept. H.E.W., Public Health Service, National Center for Radiological Health, Rockville, Maryland. 52 pp.

Childs, C. W. 1971. Chemical equilibrium models for lake water which contains nitrilotriacetate and for "normal" lake water. Proceedings 14th Conference on Great Lakes Research. International Association for Great Lakes Research, Ann Arbor, Michigan. pp. 198-210.

Churchill, W. S. 1976. Population and biomass estimates of fishes in Lake Wingra. Wisconsin Dept. Nat. Res., Technical Bulletin No. 93. 8 pp.

Durum, W. H., J. D. Hem, and S. G. Heidel. 1970. Reconnaissance of selected minor elements in surface waters of the United States, U. S. Geol. Survey, Circ. No. 643, Washington, D. C.

Ecker, T. J. and R. A. Cole. 1976. Chloride and nitrogen concentrations along the west shore of Lake Erie. Tech. Rep. No. 32.8. Institute of Water Research, Michigan State University, E. Lansing, Mich. 132 pp.

Elwell, W. T. and J. A. Gidley. 1967. Atomic-absorption spectrophotometry. Pergamon Press, London. 139 pp.

Eyman, L. D. 1972. Cesium-137 and stable cesium in a hypereutrophic lake. Ph.D. Thesis, Dept. of Fish. and Wild., Michigan State University, E. Lansing, Michigan. 55 pp.

Friend, A. G. 1963. The aqueous behavior of Strontium-85, Cesium-137, Zinc-65, and Cobalt-60 as determined by lab-type studies, pp. 43-60. In: B. A. Kornegay et al., (eds.). Transport of Radionuclides in Freshwater Systems. U. S. AEC Report No. TID 7664.

Glass, G. V. and J. C. Stanley. 1970. Statistical Methods in Education and Psychology. Prentice-Hall Inc., Engelwood Cliffs, New Jersey. 596 pp.

Gottschalk, F. W. 1975. Trace elements and background gamma levels in fish near the western shore of Lake Erie. M.S. Thesis, Dept. of Fish. and Wild., Michigan State University, E. Lansing, Michigan. 75 pp.

Hartley, R. P., C. E. Herdendorf, and M. Keller. 1966. Synoptic survey of water properties in the western basin of Lake Erie. Ohio Geol. Survey. Report No. 58. 19 pp.

Hesse, J. L. and E. D. Evans. 1972. Heavy metals in surface waters, sediments, and fish in Michigan. Mich. Water Res. Comm., Dept. Nat. Res. 58 pp.

IBP Handbook No. 12. 1971. A manual on methods for measuring primary production in aquatic environments. R. A. Vollenweider ed. Blackwell Scientific Publications, Oxford and Edinburgh. 225 pp.

ILEWPB (International Lake Erie Water Pollution Board). 1969. Pollution of Lake Erie, Lake Ontario, and the international section of the St. Lawrence River, Vol. 2: Lake Erie. 316 pp.

Jenne, E. A. 1968. Controls on Mn, Fe, Co, Ni, Cu, and Zn concentrations in soils and water: The significance role of hydrous Mn and Fe oxides, pp. 337-387. In: Gould, R. F. (ed.). Trace Inorganics in Water. American Chemical Society, Advances in Chemistry Series No. 73.

Kleinert, S. J. and P. E. Degurse. 1972. Mercury levels in Wisconsin fish and wildlife. Wisconsin Dept. Nat. Res., Technical Bulletin No. 52. 22 pp.

LeCren, E. D. 1972. Fish production in freshwaters. Symp. Zool. Soc., London, Vol. 29:115-133.

Lee, G. F. 1970. Factors affecting the transfer of materials between water and sediments. University of Wisconsin Water Resources Center, Eutrophication Information Program, Literature Review No. 1. 50 pp.

Mathis, B. J. and T. F. Cummings. 1971. Distribution of selected metals in bottom sediments, water, clams, tubificid annelids, and fishes of the Middle Illinois River. University of Illinois, Water Research Center, WRC Research Report No. 41.

National Academy of Sciences, National Research Council. 1960. The biological effects of atomic radiation. Summary Report No. A/AC. Vol. 82:G1-358.

Nelson, D. J., S. V. Kaye and R. S. Booth. 1972. Radionuclides in river systems, pp. 367-387. In: R. T. Oglesby, C. A. Carlson, and J. A. McCann (eds.), River Ecology and Man. Academic Press, New York.

Rice, T. R. and T. W. Duke. 1969. Radiobiological Laboratory Bureau of Commercial Fisheries. U. S. Fish and Wildlife Service. Washington, D. C.

Seelye, J. G. 1974. Predictive capabilities of the specific activity hypothesis for Cs and Zn in freshwater systems. Ph.D. Thesis, Dept. of Fish. and Wild., Michigan State University, East Lansing, Michigan. 98 pp.

Shaffer, P. W. 1975. Trace elements and background gamma levels in water and sediments near the western shore of Lake Erie. M.S. Thesis Dept. of Fish. and Wild., Michigan State University, East Lansing, Michigan. 125 pp.

Tong, S. C., W. H. Gutenmann, D. J. Lisk, G. E. Burdick and E. H. Harris. 1972. Trace metals in New York State fish. N. Y. Fish and Game Journal 19(2):123-131.

APPENDIX A

DATA TABLES

Table A-1. Mean concentrations ($\overline{x} \pm 1$ S.D.) of stable isotopes in filtered water samples. All values are expressed as ug/liter.

Date	Station	Fe	Mn	Zn	K	Sr
1/20/74	1	123.1	18.8	16.2	2100	300
		12.0	0.7	1.6	100	50
2/15/74	1	179.6	18.8	19.1	2100	320
		8.2	0.7	1.7	100	15
3/25/74	1	505.0	32.1	26.1	2000	270
		31.9	2.2	1.4	100	17
	2	420.0	27.9	23.1	2100	460
		14.7	0.7	1.6	100	42
4/16/74	1	458.8	19.2	19.8	1800	210
		6.3	0.5	1.7	100	38
	2	672.5	32.6	29.9	2000	300
		15.5	0.8	1.3	100	27
5/21/74	1	108.0	2.5	18.4	1800	240
		16.2	0.2	5.1	100	28
	2	49.2	2.5	17.9	2300	270
		7.6	0.2	1.1	500	21
6/17/74	1	30.2	<2.5	12.9	1400	230
		2.9	-	1.7	0	30
	2	46.0	<2.5	15.0	1600	200
		7.6	-	1.2	100	19
7/16/74	1	35.0	3.0	7.3	1500	190
		2.9	0.5	0.6	100	26
	2	26.2	3.2	8.3	1100	130
		3.3	0.7	1.5	100	16
8/20/74	1	35.0	2.8	13.3	1200	130
		2.9	0.5	1.2	100	16
	2	26.8	<2.5	5.3	1100	110
		6.7	-	1.0	100	16
9/17/74	1	32.8	<2.5	5.6	1500	160
		5.6	-	0.8	100	22
	2	31.2	<2.5	6.6	1500	140
		2.8	-	2.0	100	18

Table A-1 (Cont.):

Date	Station	Fe	Mn	Zn	K	Sr
10/16/74	1	18.2	4.3	10.1	1600	140
		1.5	0.3	0.8	100	14
	2	17.0	2.5	11.0	1700	140
		2.4	0.5	1.5	100	14
11/16/74	1	22.5	6.0	8.5	1000	140
		4.4	0.7	1.5	100	12
	2	25.2	7.0	8.0	1600	220
		3.0	0.5	1.2	100	14
12/20/74	1	44.0	12.0	12.5	1400	180
		2.4	0.5	1.6	0	19
	2	46.8	18.8	14.6	2100	380
		2.4	0.7	3.1	100	46

Table A-2. Cobalt and strontium data as analyzed by Hydro Research Laboratories, Division of CLOW, Pontiac, Michigan.

Parameter	Date	Location	Element	Amount
Goldfish (8 - 10 in.)	4/26/74	Monroe	Co Sr	0.22 ug/gram 7.0 ug/gram
Yellow perch (5 - 7 in.)	1/20/74	Fermi	Co Sr	0.38 ug/gram 2.9 ug/gram
Carp (21 in.)	1/20/74	Fermi	Co Sr	0.31 ug/gram 4.8 ug/gram
Zooplankton	9/16/74	Station 1	Co Sr	0.00002 mg/liter 0.00190 mg/liter
Seston	8/20/74	Station 1	Co Sr	0.004 mg/liter 0.237 mg/liter
Seston	5/21/74	Station 2	Co Sr	0.004 mg/liter 0.252 mg/liter
Water	8/20/74	Station 1	Co Sr	0.0012 mg/liter 0.2435 mg/liter
Water	12/20/74	Station 1	Co Sr	0.0016 mg/liter 0.2000 mg/liter

Table A-3. Mean concentrations ($\bar{x}$ ± 1 S.D.) of stable isotopes in the seston. All values are expressed in ug/liter.

Date	Station	Wave Height	Fe	Mn	Zn	K
5/21/74	1	0.5 m	1072	35.0	9.0	2200
			53	4.0	2.1	200
	2	0.5 m	1141	36.0	9.0	1800
			13	5.0	3.2	600
6/17/74	1	0.1 m	950	30.0	8.1	1600
			40	1.0	2.7	100
	2	0.3 m	1074	37.0	14.0	2500
			70	5.0	3.2	300
7/16/74	1	0.0 m	705	35.0	11.7	1500
			50	2.1	3.1	200
	2	0.0 m	684	33.0	9.0	1400
			70	2.1	3.4	300
8/20/74	1	0.2 m	1055	34.0	2.7	900
			60	5.0	1.2	300
	2	0.4 m	1093	42.0	10.7	1300
			60	2.0	1.4	100
9/17/74	1	0.4 m	1447	54.0	19.4	1800
			31	1.0	4.1	100
	2	0.2 m	918	37.0	11.4	1600
			30	1.0	3.6	200
10/16/74	1	0.1 m	362	20.0	3.9	1300
			10	5.0	1.2	100
	2	0.1 m	583	27.0	13.0	1300
			40	1.1	1.8	200
11/16/74	1	0.3 m	1447	30.0	26.0	1100
			60	2.1	1.8	200
	2	0.4 m	1655	47.0	23.0	1400
			80	4.0	2.3	300
12/20/74	1	0.4 m	1596	21.0	20.5	1500
			30	1.1	1.6	200
	2	0.4 m	1400	25.0	14.4	2200
			20	1.2	3.7	100

Table A-4. Mean concentrations ($\bar{x}$ ± 1 S.D.) of stable isotopes in zooplankton. All values expressed as mg of element per gram wet-weight of zooplankton.

Date	Station	Fe	Mn	Zn	K
3/25/74	1	7.1	<0.3	2.6	41.9
		1.7	-	0.4	3.4
4/16/74	1	10.0	<0.3	5.6	45.1
		2.0	-	2.0	1.0
5/21/74	1	11.4	0.5	3.4	52.4
		2.0	0.1	0.6	5.4
	2	6.6	0.7	3.3	86.4
		0.9	0.1	0.4	12.8
6/18/74	1	18.1	0.4	7.3	57.2
		2.2	0.1	1.7	6.5
	2	7.2	0.6	3.9	46.8
		1.0	0.2	0.5	7.1
7/16/74	1	3.7	0.7	1.8	50.6
		1.4	0.1	0.2	3.8
	2	6.0	0.7	1.7	47.1
		0.3	0.2	0.2	2.9
8/20/74	1	6.2	0.9	2.2	49.3
		1.4	0.1	0.4	4.8
	2	7.8	1.0	2.2	45.5
		0.7	0.1	0.4	4.6
9/17/74	1	3.3	0.3	1.4	34.4
		0.3	0.0	0.4	8.0
	2	3.3	0.4	1.2	22.9
		0.4	0.1	0.4	1.6

Table A-5. Mean concentrations ($\overline{x} \pm 1$ S.D.) of stable isotopes in zooplankton. All values expressed as ug of element per liter of lake water sampled.

Date	Station	Fe	Mn	Zn	K
3/25/74	1	0.104	< 0.004	0.038	0.614
		0.025	-	0.005	0.050
4/16/74	1	0.053	< 0.004	0.030	0.024
		0.010	-	0.014	0.004
5/21/74	1	0.218	0.010	0.064	0.998
		0.038	0.003	0.011	0.103
	2	0.126	0.013	0.064	0.008
		0.018	0.003	0.008	0.244
6/18/74	1	5.915	0.087	0.238	1.872
		0.716	0.004	0.053	0.211
	2	1.745	0.033	0.095	1.135
		0.233	0.004	0.013	0.172
7/16/74	1	0.136	0.027	0.064	1.838
		0.050	0.003	0.006	0.138
	2	0.217	0.027	0.060	1.712
		0.010	0.007	0.006	0.104
8/20/74	1	0.416	0.032	0.082	1.850
		0.060	0.003	0.016	0.240
	2	1.080	0.038	0.080	2.050
		0.142	0.005	0.020	0.388
9/17/74	1	0.064	0.065	0.027	0.662
		0.006	0.001	0.010	0.155
	2	0.062	0.062	0.022	0.441
		0.008	0.008	0.007	0.030

Table A-6. Zooplankton data expressed as No./liter.

Date	Station	Cladocerans	Copepods	Nauplii	Rotifers
3/25/74	1	0.0	5.9	1.5	4.4
4/16/74	1	0.0	1.6	1.6	3.2
5/21/74	1	0.0	3.1	6.3	94.3
	2	0.0	9.4	3.1	84.9
6/18/74	1	33.3	48.5	6.1	18.2
	2	3.0	15.2	12.1	6.1
7/16/74	1	28.3	38.6	92.7	151.9
	2	18.0	20.6	10.3	18.0
8/20/74	1	15.9	38.3	28.7	41.4
	2	9.6	12.8	9.6	19.1
9/17/74	1	8.6	1.0	17.3	29.8
	2	26.9	1.0	14.4	7.7
10/15/74	1	1.8	1.0	1.0	3.7
	2	1.8	1.0	0.0	4.6

Table A-7. Mean concentrations ($\overline{x} \pm 1$ S.D.) of stable isotopes in yellow perch. All values are expressed in ug/gram.

Date	Station	Size (in.)	Fe	Mn	Zn	Cs	Sr
1/20/74	Fermi	5 - 7	25.0	3.30	33.1	.006	4.0
			6.4	0.24	9.3	.001	1.0
	Fermi	7 - 9	21.5	3.15	29.7	.006	5.5
			5.3	0.17	3.3	.001	1.3
4/19/74	Fermi	5 - 7	27.2	3.25	34.0	.006	6.3
			4.1	0.14	3.2	.001	1.3
	Fermi	7 - 9	33.5	3.22	38.3	.006	6.3
			5.0	0.28	5.1	.001	1.0
4/26/74	Monroe	5 - 7	28.8	3.25	28.5	.006	5.3
			7.1	0.17	2.1	.001	1.0
	Monroe	7 - 9	32.3	3.50	42.8	.008	7.0
			7.1	0.37	6.6	.001	1.4
5/21/74	Fermi	5 - 7	25.8	3.32	32.0	.008	6.8
			5.0	0.17	2.0	.002	2.2
	Fermi	7 - 9	25.3	3.15	30.0	.009	6.0
			3.3	0.40	2.0	.001	1.4
5/21/74	Monroe	5 - 7	21.8	3.32	30.0	.006	5.7
			5.9	0.14	0.8	.001	1.1
	Monroe	7 - 9	22.3	3.05	29.0	.008	5.3
			5.9	0.57	2.5	.002	1.0
6/18/74	Monroe	5 - 7	30.2	3.35	45.0	.010	5.0
			8.5	0.14	6.1	.001	0.8
	Monroe	7 - 9	27.3	3.25	35.2	.008	4.8
			5.5	0.20	6.4	.001	1.0
7/16/74	Monroe	5 - 7	26.3	3.22	30.0	.009	6.3
			6.5	0.26	3.6	.001	1.9
	Monroe	7 - 9	26.3	3.20	26.2	.008	5.8
			6.2	0.17	1.3	.001	1.7
9/16/74	Monroe	5 - 7	25.5	2.92	34.8	.009	3.8
			6.4	0.43	11.8	.001	0.5
	Monroe	7 - 9	26.3	3.10	32.0	.007	5.5
			6.2	0.22	2.9	.001	1.3
10/15/74	Fermi	5 - 7	25.8	3.22	31.5	.009	6.0
			6.0	0.20	4.4	.001	1.4
	Fermi	7 - 9	23.0	3.35	29.2	.009	4.8
			6.8	0.35	1.0	.001	1.7

Table A-7 (Cont.).

Date	Station	Size (in.)	Fe	Mn	Zn	Cs	Sr
10/16/74	Monroe	5 - 7	34.0	3.22	31.5	.009	6.8
			5.8	0.28	9.5	.001	1.0
	Monroe	7 - 9	26.5	3.20	32.8	.009	5.5
			5.8	0.22	4.4	.001	1.3
11/16/74	Monroe	5 - 7	24.0	3.35	30.0	.010	4.8
			5.8	0.37	2.0	.000	0.5
	Monroe	7 - 9	18.5	2.87	26.3	.010	4.5
			3.4	0.50	1.3	.000	1.3
12/20/74	Monroe	5 - 7	21.0	2.87	26.2	.009	5.3
			7.1	0.33	2.8	.001	0.5
	Monroe	7 - 9	23.0	3.02	29.8	.008	6.5
			6.5	0.36	1.7	.001	1.7

Table A-8. Mean concentrations ($\overline{x} \pm 1$ S.D.) of stable isotopes in goldfish. All values are expressed in ug/gram.

Date	Station	Size (in.)	Fe	Mn	Zn	Cs	Sr
1/20/74	Fermi	8 - 10	30.5	1.80	75.3	.006	12.3
			12.3	0.33	15.8	.001	0.6
	Fermi	12 - 15	37.5	2.17	80.8	.006	13.0
			3.4	0.31	9.6	.001	2.9
3/15/74	Fermi	8 - 10	35.5	2.15	91.5	.006	11.3
			5.1	0.24	3.0	.001	1.5
	Fermi	12 - 15	53.0	2.10	84.0	.006	11.7
			2.2	0.17	8.1	.001	1.3
4/19/74	Fermi	8 - 10	33.3	1.90	65.8	.007	11.7
			6.5	0.17	7.9	.001	1.7
	Fermi	12 - 15	53.0	2.32	81.4	.007	12.7
			3.2	0.26	8.7	.001	1.5
4/26/74	Monroe	8 - 10	34.5	2.10	71.5	.006	13.5
			6.0	0.39	3.3	.001	2.6
	Monroe	12 - 15	54.1	2.37	83.0	.006	12.8
			3.3	0.22	7.6	.001	2.4
5/21/74	Fermi	8 - 10	29.5	1.95	71.5	.008	11.3
			2.4	0.24	3.2	.001	1.7
	Fermi	12 - 15	40.0	2.50	80.3	.008	10.8
			10.5	0.36	5.6	.001	1.7
6/18/74	Monroe	8 - 10	40.0	2.60	93.8	.009	11.3
			3.1	0.56	13.8	.000	1.7
	Monroe	12 - 15	55.0	2.37	94.0	.007	14.8
			3.0	0.22	5.4	.001	3.4
7/15/74	Monroe	8 - 10	31.8	2.35	89.5	.005	11.7
			5.6	0.24	5.5	.001	0.6
	Monroe	12 - 15	52.5	2.45	89.0	.007	13.3
			4.5	0.26	3.9	.001	2.1
9/16/74	Monroe	8 - 10	33.8	2.65	85.3	.008	12.0
			6.1	0.60	8.7	.001	1.7
	Monroe	12 - 15	51.8	2.32	88.5	.006	13.3
			4.2	0.58	4.2	.001	3.1
10/15/74	Fermi	8 - 10	31.0	2.47	89.5	.007	11.3
			3.8	0.41	5.1	.001	2.1
	Fermi	12 - 15	47.8	2.72	90.3	.006	11.5
			3.3	0.61	2.2	.001	2.1

Table A-8 (Cont.):

Date	Station	Size (in.)	Fe	Mn	Zn	Cs	Sr
11/20/74	Monroe	8 - 10	30.8	2.62	80.6	.006	12.8
			3.4	0.42	4.6	.001	3.0
	Monroe	12 - 15	48.3	2.40	89.0	.007	11.5
			2.6	0.24	4.0	.001	2.1
12/20/74	Monroe	8 - 10	29.5	2.22	86.3	.007	11.5
			3.9	0.26	8.6	.001	1.3
	Monroe	12 - 15	45.8	2.30	78.0	.007	12.8
			4.6	0.22	7.3	.001	1.7

Table A-9. Yearly grand averages of stable element concentrations for yellow perch and goldfish. All values are expressed in ug/gram.

Station	Size (in.)	Fe	Mn	Zn	Cs	Sr
		Yellow perch				
Fermi	5 - 7	25.9	3.29	32.6	.007	5.8
		5.4	0.19	4.7	.001	1.5
Fermi	7 - 9	25.8	3.22	31.8	.008	5.7
		5.1	0.30	2.9	.001	1.4
Monroe	5 - 7	26.4	3.19	32.0	.008	5.4
		6.6	0.26	4.8	.001	0.9
Monroe	7 - 9	25.3	3.15	31.7	.008	5.6
		7.0	0.32	3.4	.001	1.3
		Goldfish				
Fermi	8 - 10	32.0	2.05	78.7	.007	11.6
		6.0	0.28	7.0	.001	1.5
Fermi	12 - 15	46.3	2.36	83.4	.006	11.9
		4.5	0.34	6.8	.001	1.9
Monroe	8 - 10	33.9	2.42	84.5	.007	12.1
		4.7	0.41	7.4	.001	1.8
Monroe	12 - 15	51.3	2.37	86.9	.007	13.1
		3.7	0.29	5.4	.001	2.5

Table A-10. Radioisotope concentrations of ^{40}K and ^{137}Cs in whole fish ash. All values are expressed in pCi/gram.

Fish Species	Size (in.)	Station	Date	^{137}Cs Activity	^{40}K Activity
Nor. pike	15	Monroe	5/21/74	.038	.10
Nor. pike	15	Monroe	5/21/74	.034	.11
Carp	18	Fermi	1/20/74	.020	.10
Carp	17	Fermi	5/21/74	.027	.10
Carp	21	Monroe	5/21/74	.024	.11
Yel. perch	7	Fermi	5/21/74	.030	.11
Yel. perch	8	Monroe	11/11/74	.027	.11
Yel. perch	9	Fermi	1/20/74	.024	.10

Table A-11. Supplementary water chemistry data on phosphorous, nitrogen, and carbon for the year 1974. P values are given as mg/liter P; N values as mg/liter N; C values as mg/liter C.

Date	Station	Total phosphorous	Soluble phosphorous	Kjeldahl nitrogen	NH_3	NO_3^-	Organic nitrogen	Total nitrogen	Organic carbon	Total carbon
2/15/74	1	0.08	0.03	0.68	0.28	0.79	0.40	1.47	3	26
3/25/74	1	0.16	0.04	0.90	0.14	1.11	0.76	2.01	8	33
	2	0.12	0.03	0.75	0.15	1.07	0.60	1.83	6	30
4/16/74	1	0.10	0.04	1.02	0.20	2.14	0.82	3.16	3	27
	2	0.15	0.04	1.24	0.22	1.66	1.02	2.90	4	32
5/21/74	1	0.13	0.06	0.78	0.15	0.41	0.63	1.19	7	29
	2	0.13	0.04	0.91	0.04	0.42	0.86	1.33	9	35
6/17/74	1	0.09	0.05	0.84	0.10	0.74	0.73	1.57	6	29
	2	0.07	0.06	0.91	0.07	0.73	0.84	1.64	7	32
7/16/74	1	0.17	0.05	1.10	0.01	0.06	1.09	1.17	9	28
	2	0.12	0.04	0.81	0.14	0.30	0.67	1.12	6	22
8/20/74	1	0.08	0.03	0.73	0.06	0.18	0.67	0.91	7	21
	2	0.11	0.04	0.82	0.06	0.10	0.75	0.92	9	24
9/16/74	1	0.13	0.06	1.04	0.12	0.08	0.92	1.12	8	23
	2	0.10	0.05	0.91	0.11	0.06	0.80	0.97	8	23
10/15/74	1	0.06	0.03	-	0.02	0.04	-	-	6	25
	2	0.08	0.03	-	0.02	0.06	-	-	7	26
11/20/74	1	0.08	0.03	0.61	0.08	0.17	0.53	0.78	5	26
	2	0.08	0.02	0.71	0.12	0.26	0.59	0.97	6	26
12/18/74	1	0.11	0.04	0.78	0.25	0.60	0.53	1.39	-	-
	2	0.10	0.04	0.77	0.31	0.39	0.46	1.16	-	-

Table A-12. Multiple range analysis of mean stable isotope concentrations in filtered water samples taken from station 1.

Fe (ug/liter)

Month	10	11	6	9	7	8	12	5	1	2	4	3
Mean	18.2	22.5	30.2	32.8	35.0	35.0	44.0	108.0	123.1	179.6	458.8	505.0

Mn (ug/liter)

Month	5	6	9	8	7	10	11	12	1	2	4	3
Mean	2.5	2.5	2.5	2.8	3.0	4.3	6.0	12.0	18.8	18.8	19.2	32.1

Zn (ug/liter)

Month	9	7	11	10	12	6	8	1	5	2	4	3
Mean	5.6	7.3	8.5	10.1	12.5	12.9	13.3	16.2	18.4	19.1	19.8	26.1

K (ug/liter)

Month	11	8	6	12	7	9	10	4	5	3	1	2
Mean	1100	1200	1400	1400	1500	1500	1600	1800	1800	2000	2100	2100

Sr (ug/liter)

Month	8	10	11	9	12	7	4	6	5	3	1	2
Mean	130	140	140	160	180	190	210	230	240	270	300	320

Table A-13. Multiple range analysis of mean stable isotope concentrations in filtered water samples taken from station 2.

Fe (ug/liter)

Month	10	11	7	8	9	6	12	5	3	4
Mean	17.0	25.2	26.2	26.8	31.2	46.0	46.8	49.2	420.0	672.5

Mn (ug/liter)

Month	5	6	8	9	10	7	11	12	3	4
Mean	2.5	2.5	2.5	2.5	2.5	3.2	7.0	18.8	27.9	32.6

Zn (ug/liter)

Month	8	9	11	7	10	12	6	5	3	4
Mean	5.3	6.6	8.0	8.3	11.0	14.6	15.0	17.9	23.1	29.9

K (ug/liter)

Month	7	8	9	6	11	10	4	3	12	5
Mean	1100	1100	1500	1600	1600	1700	2000	2100	2100	2300

Sr (ug/liter)

Month	8	7	9	10	6	11	5	4	12	4
Mean	110	130	140	140	200	220	270	300	380	460

Table A-14. Multiple range analysis of mean stable isotope concentrations in seston samples taken from station 1 of the study area.

Fe (ug/liter)

Month	10	7	6	8	5	9	11	12
Mean	362	705	950	1055	1072	1447	1447	1596

Mn (ug/liter)

Month	10	12	6	11	8	5	7	9
Mean	20.0	21.0	30.0	30.0	34.0	35.0	35.0	54.0

Zn (ug/liter)

Month	8	10	6	5	7	9	12	11
Mean	2.7	3.9	8.1	9.0	11.7	19.4	20.5	26.0

K (ug/liter)

Month	8	11	10	7	12	6	9	5
Mean	900	1100	1300	1500	1500	1600	1800	2200

Table A-15. Multiple range analysis of mean stable isotope concentrations in seston samples taken from station 2 of the study area.

Fe (ug/liter)

Month	10	7	9	6	8	5	12	11
Mean	583	684	918	1074	1093	1141	1400	1655

Mn (ug/liter)

Month	12	10	7	5	6	9	8	11
Mean	25.0	27.0	33.0	36.0	37.0	37.0	42.0	47.0

Zn (ug/liter)

Month	5	7	8	9	10	6	12	11
Mean	9.0	9.0	10.7	11.4	13.0	14.0	14.4	23.0

K (ug/liter)

Month	8	10	7	11	9	5	12	6
Mean	1300	1300	1400	1400	1600	1800	2200	2500

Table A-16. Multiple range analysis of mean stable isotope concentrations in zooplankton samples taken from station 1 of the study area.

Fe (mg/gram)

Month	9	7	8	3	4	5	6
Mean	3.3	3.7	6.2	7.1	10.0	11.4	18.1

Mn (mg/gram)

Month	3	4	9	6	5	7	8
Mean	0.3	0.3	0.3	0.4	0.5	0.7	0.9

Zn (mg/gram)

Month	9	7	8	3	5	4	6
Mean	1.4	1.8	2.2	2.6	3.4	5.6	7.3

K (mg/gram)

Month	9	3	4	8	7	5	6
Mean	34.4	41.9	45.1	49.3	50.6	52.4	57.2

Table A-17. Multiple range analysis of mean stable isotope concentrations in zooplankton samples taken from station 2 of the survey area.

Fe (mg/gram)

Month	9	7	5	6	8
Mean	3.3	6.0	6.6	7.2	7.8

Mn (mg/gram)

Month	9	6	5	7	8
Mean	0.4	0.6	0.7	0.7	1.0

Zn (mg/gram)

Month	9	7	8	5	6
Mean	1.2	1.7	2.2	3.3	3.9

K (mg/gram)

Month	9	8	6	7	5
Mean	22.9	45.5	46.8	47.1	86.4

Table A-18. Multiple range analysis of mean stable isotope concentrations in yellow perch, 7 - 9 inches long, from the Monroe station.

Fe (ug/gram)

Month	11	5	12	7	8	10	6	4
Mean	18.5	22.3	23.0	26.3	26.3	26.5	27.3	32.3

Mn (ug/gram)

Month	11	12	5	9	7	10	6	4
Mean	2.87	3.02	3.05	3.10	3.20	3.20	3.25	3.50

Zn (ug/gram)

Month	7	11	5	12	9	10	6	4
Mean	26.2	26.3	29.0	29.8	32.0	32.8	35.2	42.8

Cs (ug/gram)

Month	9	12	4	7	5	6	10	11
Mean	.0072	.0075	.0080	.0080	.0082	.0082	.0090	.0098

Sr (ug/gram)

Month	11	6	5	9	10	7	12	4
Mean	4.5	4.8	5.3	5.5	5.5	5.8	6.5	7.0

Table A-19. Multiple range analysis of mean stable isotope concentrations in goldfish, 12 - 15 inches long, from the Monroe station.

Fe (ug/gram)

Month	12	11	9	7	4	6
Mean	45.8	48.3	51.8	52.5	54.1	55.0

Mn (ug/gram)

Month	12	9	4	6	11	7
Mean	2.30	2.32	2.37	2.37	2.40	2.45

Zn (ug/gram)

Month	12	4	6	7	11	6
Mean	78.0	83.0	88.5	89.0	89.0	94.0

Cs (ug/gram)

Month	9	4	12	7	11	6
Mean	.0062	.0063	.0065	.0068	.0070	.0074

Sr (ug/gram)

Month	11	4	12	7	9	6
Mean	11.5	12.8	12.8	13.3	13.3	14.8