TRACE ELEMENTS AND BACKGROUND GAMMA LEVELS IN FISH NEAR THE WESTERN SHORE OF LAKE ERIE

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ABSTRACT

TRACE ELEMENTS AND BACKGROUND GAMMA LEVELS IN FISH
NEAR THE WESTERN SHORE OF LAKE ERIE

By

Fred William Gottschalk

Fish collected from Lake Erie in the vicinity of the proposed discharge from Fermi II, a nuclear powered electric generating station, were analyzed for concentrations of stable trace elements and radioisotopes. Stable elements studied were Cs, Co, Fe, Mn, Sr, and Zn. Radioisotope analyses were conducted for ^{134}Cs, ^{137}Cs, ^{57}Co, ^{54}Mn, and ^{65}Zn. Samples were collected from April 1973 to December 1973. Data collected in this study constitute part of the preoperational study of the radioecological impact of the discharge from Fermi II on the aquatic environment.

Samples were collected by experimental gill nets and trawling at five stations located in the study area. Analysis of variance and Student, Neuman, Keuls Multiple Range Tests were used to analyze differences in stable and radioisotope concentrations between stations and between feeding habits.

Spatial distribution of stable elements appeared to follow the Swan Creek plume to some extent. Bottom feeding fish had significantly higher concentrations of stable iron, manganese, strontium and zinc than piscivores.

The only man-made radioisotope present in high enough concentrations to detect was ^{137}Cs, but it did not significantly ($\alpha = .05$) vary spatially, trophically, or temporally.

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INTRODUCTION

The increasing number of nuclear, electric-generating plants poses a potential hazard to aquatic environments receiving the cooling waters from these installations. Bioaccumulation by aquatic organisms has been demonstrated for some of the radioisotopes associated with nuclear power plants. Fish in the vicinity of the receiving waters may accumulate sufficient amounts of the radioisotopes to present a health hazard to humans who consume them.

The Detroit Edison Company is constructing a nuclear powered electric-generating plant, Fermi II, on the western shore of Lake Erie, approximately seven miles north of Monroe, Michigan. Fission products from the nuclear reaction or radioisotopes induced by the neutron activation of stable isotopes in the vicinity of the nuclear reaction may be contained in the plant's effluent.

The present study was undertaken to provide information on the aquatic distribution of stable cesium, cobalt, iron, manganese, strontium, and zinc, which are the counterparts of radioisotopes, in the vicinity of Fermi II. The distribution of stable isotopes was assessed to predict the fate of radioisotopes that may be released based on the specific activity hypothesis offered by the National Academy of Sciences (1960).

A second objective was to establish data on the distribution and levels of man-made radioisotopes in the aquatic environment near the plant site. With this background information, it should be possible to determine the amount of radioactivity that the plant is contributing to the aquatic environment.

The specific purpose of this study was to determine preoperational and spatial variation in concentrations of stable elements and radioisotopes in fish captured from the study area. Fish were separated into three groups, according to their major feeding habits, to determine if stable or radioisotope concentrations varied with the gross trophic differences.

DESCRIPTION OF THE STUDY AREA

The study area (Figures 1 and 2) is located between Point aux Peaux and Point Mouillee in the near shore area of Lake Erie's western basin. Also included in the area is Swan Creek, a small stream that enters the lake about 4 km north of Point aux Peaux. Fermi II is being constructed approximately midway between Point aux Peaux and the mouth of Swan Creek. The plant effluent will enter the lake somewhere between the plant and the mouth of Swan Creek.

The western basin of Lake Erie is shallow. It has a mean depth of 7.4 m, a maximum depth of 20.4 m, representing less than 13% of the total lake's surface area, and including 5% of the lake's volume. Minimum possible flushing time for the western basin is about 60 days. The bottom of the basin is made up of 58% soft gray mud, 17% sand, 12% sand and mud, 7% gravel, 3% bedrock, and 3% clay (Verber, 1957). Sand and gravel are common near shore and mud predominates in the deeper water (Hartman, 1973).

Langlois (1954) considered the western basin to be the most valuable spawning and nursery grounds for most species found in the lake. The relatively warm waters in this area coupled with the extensive shoal areas provide ideal fishing grounds for many species of fish.

Maximum depth in the study area is 6 m. Bottom sediments in this area range from coarse sand to mud. High turbidities in the area are associated with the wind generated turbulence and high plankton

Figure 1. Map of the study area in relation to western Lake Erie.

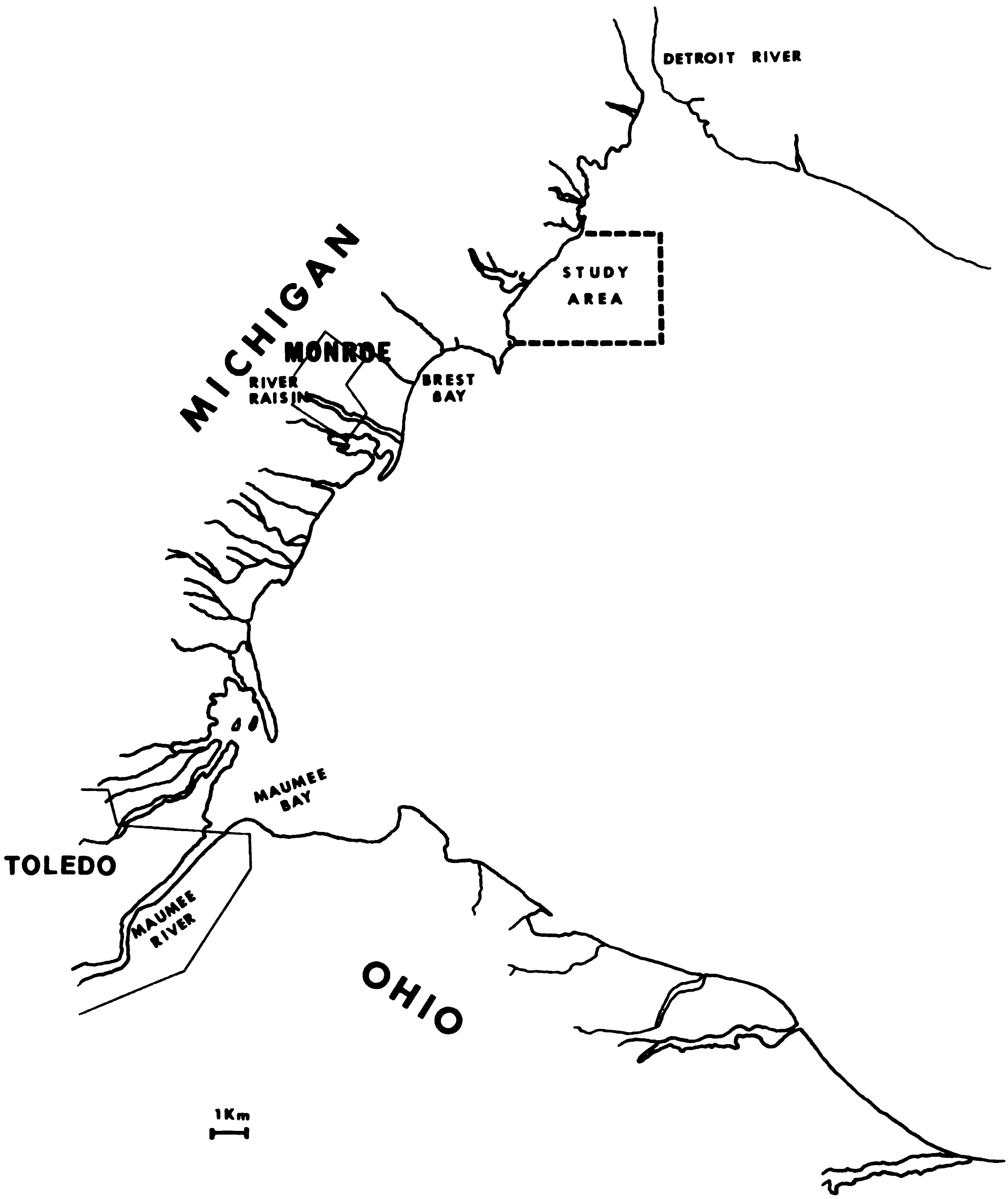
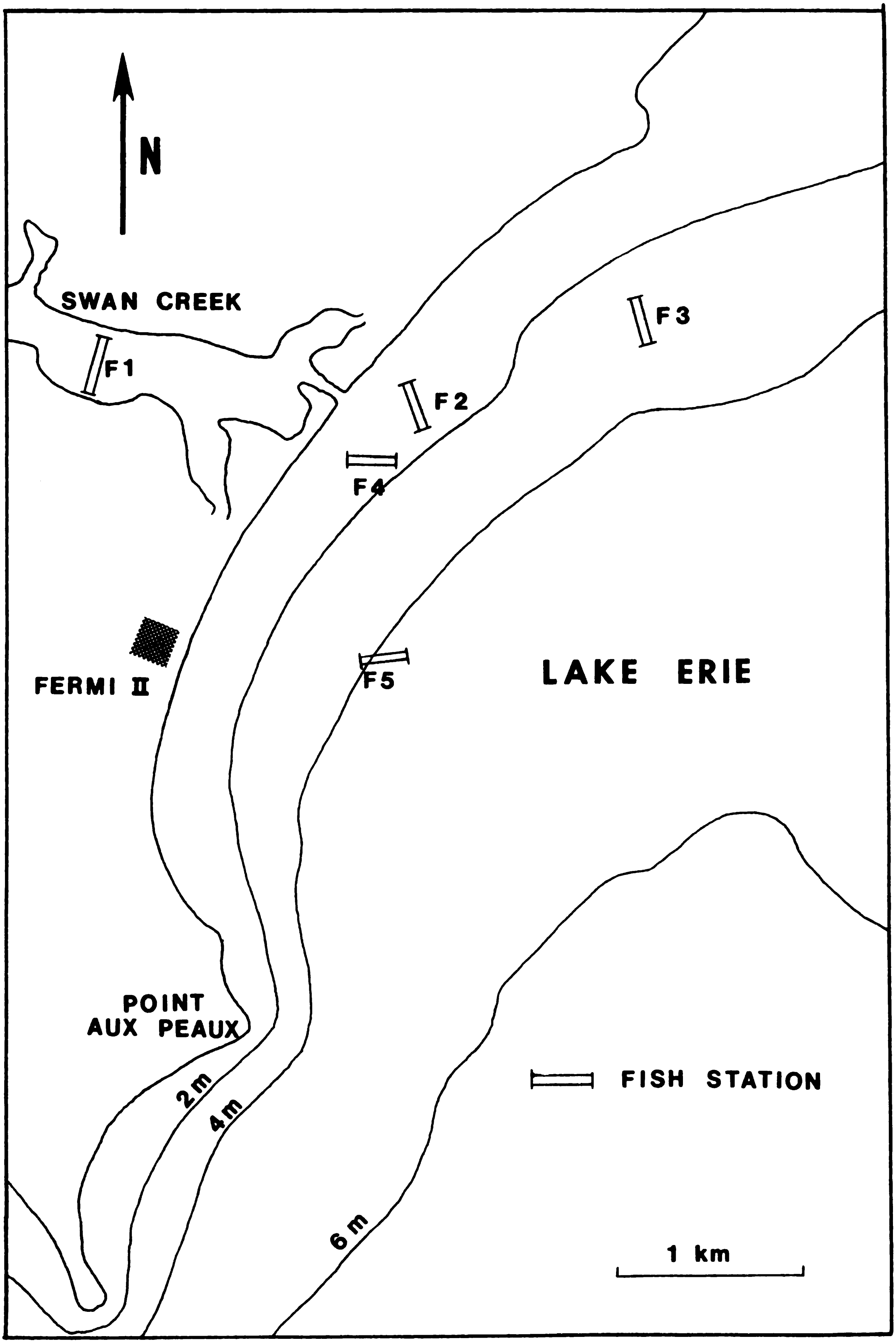

DETROIT RIVER
STUDY AREA
MICHIGAN
MONROE
RIVER RAISIN
BREST BAY
MAUMEE BAY
TOLEDO
MAUMEE RIVER
OHIO
1Km

Figure 2. Map of the study area including positions of the sampling stations. (Stations F1, F2, and F3 are fixed. Stations F4 and F5 are along a moveable transect).


N
SWAN CREEK
F1
F2
F3
F4
F5
FERMI II
LAKE ERIE
POINT
AUX PEAUX
2 m
4 m
6 m
FISH STATION
1 km

densities (Beeton, 1961). Secchi-disc readings were low throughout the sampling period; never more than 1.5 meters. Temporary stratification of the western basin occurs during summer (Britt, 1955), but because of the shallowness of the basin, it is usually well mixed. Dissolved oxygen is usually near 80% saturation in the bottom waters of the basin.

Major currents in the basin move south to southwest (Hartley et al., 1966). These currents are caused primarily by the Detroit River which enters the lake about 4 km north of the study area. About 99% of the flow into the western basin comes from the Detroit and Maumee Rivers. As the flow from these rivers meet in the southwest part of the basin, a large eddy is formed. This eddy causes the western shore water to be influenced most by industrial and municipal wastes entering primarily via the large rivers (FWPCA, 1968). Water chemistry of the study area is presented in Table 1.

The impact of Swan Creek on the lake is measureable only near the mouth of the creek. Conductivity studies made during the sampling period revealed that the water from Swan Creek had thoroughly mixed with the lake water within 1 km of the creek's mouth.

Station F1 (Figure 2) was located in Swan Creek about 1 km from the creek's mouth. The depth at this location ranged from 1.5 to 2.0 m. Sediment was composed mostly of silt.

Station F2 was located in the lake about 0.5 km north of the mouth of Swan Creek and 0.25 km from shore. Average water depth at this station was about 2 m, although, for short periods the depth was increased by 1 m due to seiches. In 1973, seiches were most frequent during the spring. The sediment was composed mostly of sand.

Table 1. Mean annual water quality parameters (mg/liter) among the lake stations.

	Suspended Solids	Organic Carbon	Total Chloride	Total Nitrogen	Total Phosphorus
Mean	19.1	4.8	17.0	1.2	0.08
Range	12.4-32.5	4.3-5.7	12.6-20.8	0.8-1.4	0.06-0.11

Station F3 was located about 2 km north of the mouth of Swan Creek and 0.75 km from shore. Average water depth at this station was about 2 m. Sediments were composed of fine sand and scattered boulders.

Station F4 was located about 0.5 km south of the mouth of Swan Creek and about 0.25 km from shore. Water depth was about 2 m. Sediment composition varied from silt to sand depending on weather conditions prior to sampling.

Station F5 was located about 1.5 km south of the mouth of Swan Creek and 1.25 km offshore. Water depth was about 4 m. Fine sand and silt composed the sediments in this area.

METHODS AND MATERIALS

Field Procedures

Fish samples were collected from five locations (Figure 2) at six-week intervals when conditions permitted. Sampling stations were located in Swan Creek and along two transects that radiated from the mouth of Swan Creek. One transect was fixed along the axis of the prevailing plume of Swan Creek after entering the lake. The other transect was moveable, with its position determined by the plume direction of Swan Creek on the day of sampling. When the plume was in the direction of the prevailing current, the moveable transect was established perpendicular to the fixed transect. This sampling scheme was designed to allow use of the discharge from Swan Creek to simulate the plant's discharge.

Fish were collected using a 5-m otter trawl with 2.5-cm stretched mesh netting in the wings and 6-mm stretch mesh netting in the cod end. On days when trawling failed to produce enough biomass for analysis, or a boat capable of pulling the trawl was unavailable, experimental gill nets were set overnight. The gill nets had 1.3, 2.5, 3.8, and 6.3-cm square mesh netting and an overall length of 30.5 m.

When fish samples were brought back to shore they were sorted into three trophic categories (bottom feeders, planktivores or piscivores), determined by random stomach samples and from the literature. After being sorted into feeding types, the fish were placed in plastic bags and frozen for transport to the laboratory.

Laboratory Procedures

In the laboratory the fish were kept frozen until analyzed. Contents of the gut were included in the analysis of fish collected on 4 April 1973 and 7 June 1973. Fish collected during the remainder of the year had the gut contents washed out prior to analysis.

Samples collected on 4 April 1973 and 7 June 1973 were cut into strips on a bandsaw, then ground 3 separate times to obtain a homogeneous mixture. Fish collected after 7 June 1973, after initially being sorted into broad trophic categories, were divided into three groups as similar as possible in numbers, species compositions, and size of the individual fish. In this manner, variations among groups of individual fish became identifiable. Triplicate sets of 10-g subsamples were taken from the ground tissue for analysis of stable Cs, Co, Fe, Mn, and Zn as outlined in Table 2. Strontium was analyzed as summarized in Table 3. Analyses of stable Co, Fe, Mn, and Zn were accomplished using a Jarrell-Ash 82-800 series atomic absorption spectrophotometer. Stable isotopes of Cs and Sr were determined by flame emission spectroscopy on the same instrument (Table 4).

Radioisotope analysis was accomplished by freeze-drying triplicate subsamples (200 g) of the ground fish. This was done to prevent loss due to splattering when these samples were ashed in a muffle furnace at 450°C The ash was transferred to a glass counting vial for gamma analysis. A summary of the method is given in Table 5.

Table 2. Summary of method for nitric acid digestion of fish samples to determine concentrations of Cs, Co, Fe, Mn, and Zn.

1. Grind whole fish in meat grinder to obtain a homogeneous mixture.
2. Place 10 g, wet weight, of ground fish into boiling-flask.
3. Add 50 ml concentrated HNO_3 to a boiling-flask.
4. Allow oxidation to proceed 1 hour with no heat applied.
5. Reflux the solution approximately 4 hours, until nitrous oxide fumes are no longer visible.
6. Distill off excess acid and water until about 5 ml of acid are left in boiling-flask.
7. Add 80 ml distilled water.
8. Reflux with stopcock open for 4-6 hours.
9. Allow to cool and remove from flask by rinsing into 100 ml volumetric flask with distilled water.
10. Dilute solution to 100 ml with distilled water.

Table 3. Summary of method used to prepare fish samples for Sr analysis.

1. Transfer 9 ml of final solution produced from the technique described in Table 2 to 1-oz. nalgene bottle.
2. Add 1 ml 12.5% lanthanum chloride solution to each sample.
3. Analyze samples by flame emission spectroscopy.

Table 4. Operating conditions for analysis by atomic absorption and flame emission.[1]

Element	Resonance Line A°	Sensitivity mg/liter	Absorption or Emission
Cs	8521	0.03	Emission
Co	2407	0.2	Absorption
Fe	2483	0.1	Absorption
Mn	2795	0.06	Absorption
Sr	4607	0.15	Emission
Zn	2139	0.03	Absorption

[1]Table based on Elwell and Gidley (1967), and data supplied by Jarrell-Ash Division, Fischer Scientific Company.

Table 5. Summary of method used to prepare fish samples for radioisotope analysis.

1. Place 200 g, wet weight, of frozen ground fish in 1.5 cm^3 pieces into a freeze-dryer flask and freeze-dry sample 24 hours.
2. Transfer freeze-dried sample to crucible and place in muffle furnace at 103°C for 4 hours.
3. Increase temperature 50°C every 4 hours.
4. Allow sample to remain in muffle furnace at 450°C for 6-8 hours.
5. Weigh ash after it has cooled to room temperature.
6. Transfer ash to vial for radioisotope analysis.

The dry ashing method used in this study has been used by Nelson (1969) for preparation of biological samples for cesium analysis. A study was made to determine how much volatilization occurred during ashing at 450°C. Radioisotopes were placed on chunks (about 1.5 cm^3) of fish and the chunks were analyzed in a gamma counter. The chunks were then freeze-dried and ashed at 450°C for 12 hours and analyzed again in the gamma counter to determine how much, if any, of the radioisotope was lost. The results obtained (Table 6) are in agreement with those of Blincoe (1962), Martin and Blanchard (1969) and Meranger and Somers (1968).

Samples used for radioisotope analysis were counted for 500 minutes with a Nuclear Chicago, 512 multichannel spectrophotometer coupled to a 3 inch, well type NaI(Tl) crystal detector and equipped with an automatic sample changer. The data were punched on paper tapes and activities were determined using a modified least squares analysis computer program originally devised by Brooks et al. (1970).

Statistical tests performed on the data included analysis of variance to evaluate differences both spatially and temporally. When a mean was found to be significantly different, a multiple range test (Student, Neuman, Keuls) was performed to determine which means were significantly different. All values were tested at the 0.05 level. Variation of the mean is denoted by one standard error.

Table 6. Percent of radioisotope recovered from fish chunks after ashing at 450°C.

Isotope	No. of Samples	Percent Recovery After Ashing at 450°C	Standard Error
^{134}Cs	5	90.09	0.0191
^{57}Co	4	99.75	0.0025
^{54}Mn	4	90.35	0.0118
^{65}Zn	3	100.00	0.0000

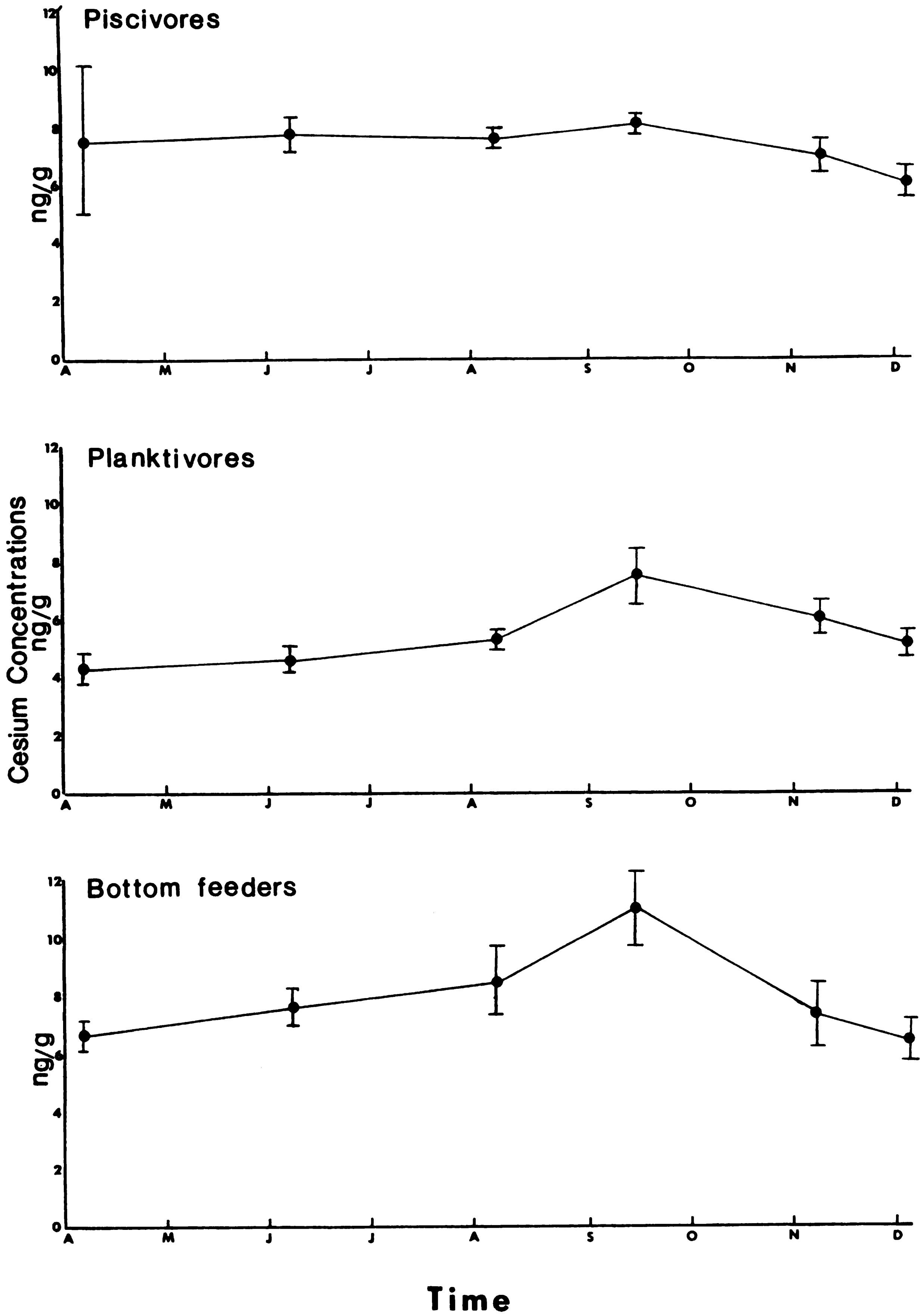
RESULTS

Stable Analysis

A total of 170 composite samples of fish were analyzed for stable Cs, Co, Fe, Mn, Sr and Zn. There were discernible differences in the concentrations of some of the elements in fish with different feeding habits, in fish collected from different stations, and in fish collected on different dates. Figure 3 graphically illustrates the concentrations of Cs in the three feeding groups collected from the lake stations (F2-F5). Figures 4-6 illustrates the concentrations of Co, Fe, Mn, Sr and Zn in bottom feeders, planktivores, and piscivores collected from these stations.

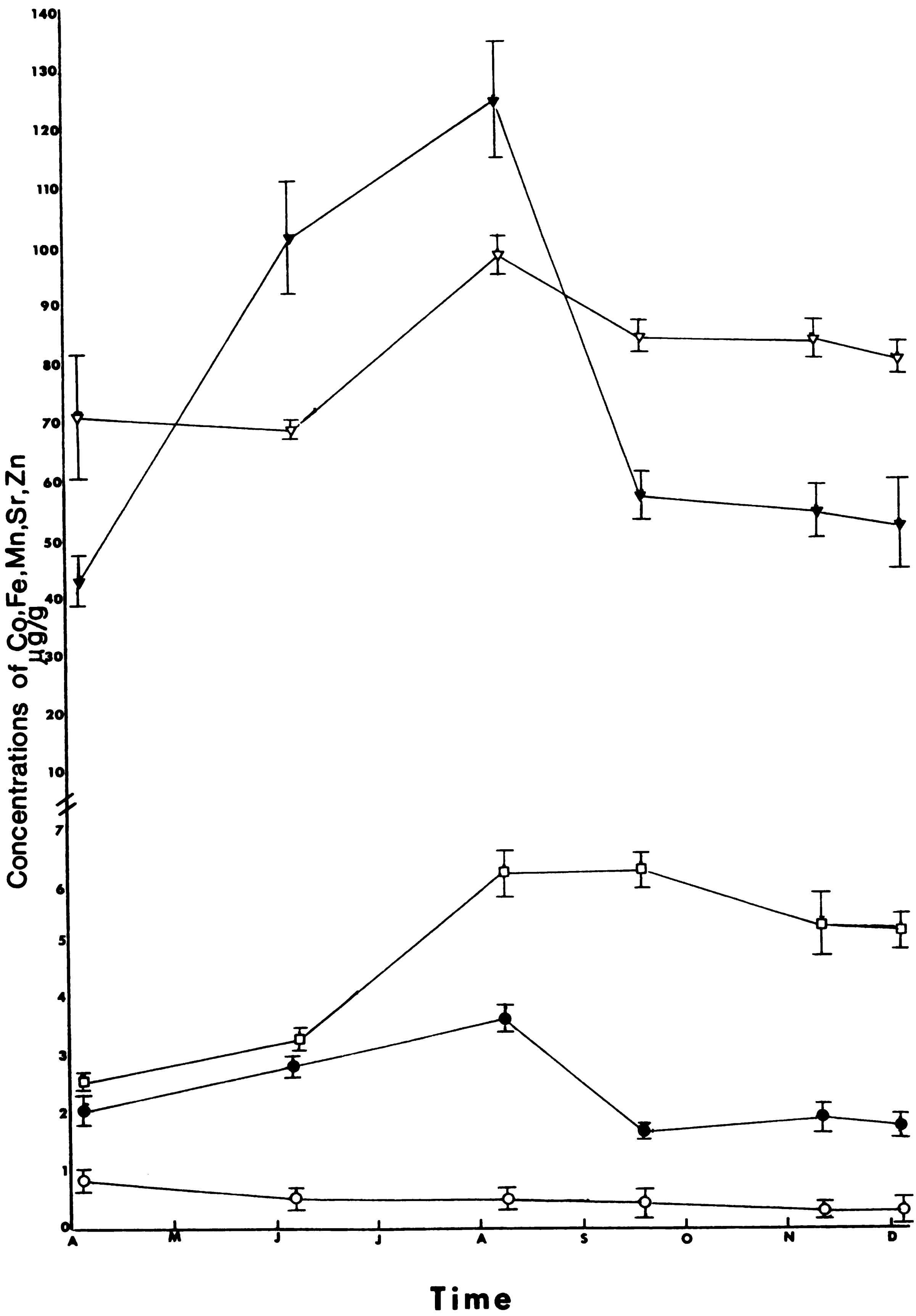
A one-way analysis of variance was used to test: (1) The difference in concentrations of stable elements in fish collected from five sampling locations on each date and over the entire sampling period; (2) The difference in concentrations of stable elements throughout the sampling period; and (3) Concentrations in whole fish of the three different trophic habits. Results were tested at the 0.05 level. Table 7 gives the results of a multiple range test performed on the annual mean concentrations of the stable isotopes in the three trophic levels of fish. The results of multiple range tests performed on the stable element data obtained on each date of collection is included in the appendix.

Figure 3. Cesium concentrations (mean ± 1 standard error) in piscivores, planktivores and bottom feeders collected from the lake stations (F2-F5).



Piscivores
Planktivores
Bottom feeders
Cesium Concentrations
ng/g
0
2
4
6
8
10
12
A
M
J
J
A
S
O
N
D
Time

Figure 4. Concentrations (mean ± 1 standard error) of Co ○, Fe ▼, Mn □, Sr ● and Zn ▽ in bottom feeders collected from the lake stations (F2-F5).



140
130
120
110
100
90
80
70
60
50
40
30
20
10
7
6
5
4
3
2
1
0
Concentrations of Co,Fe,Mn,Sr,Zn
μg/g
A
M
J
J
A
S
O
N
D
Time

Figure 5. Concentrations (mean $\underline{+}1$ standard error) of Co , Fe ▼, Mn □, Sr ● and Zn ▽ in planktivores collected from the lake stations (F2-F5).

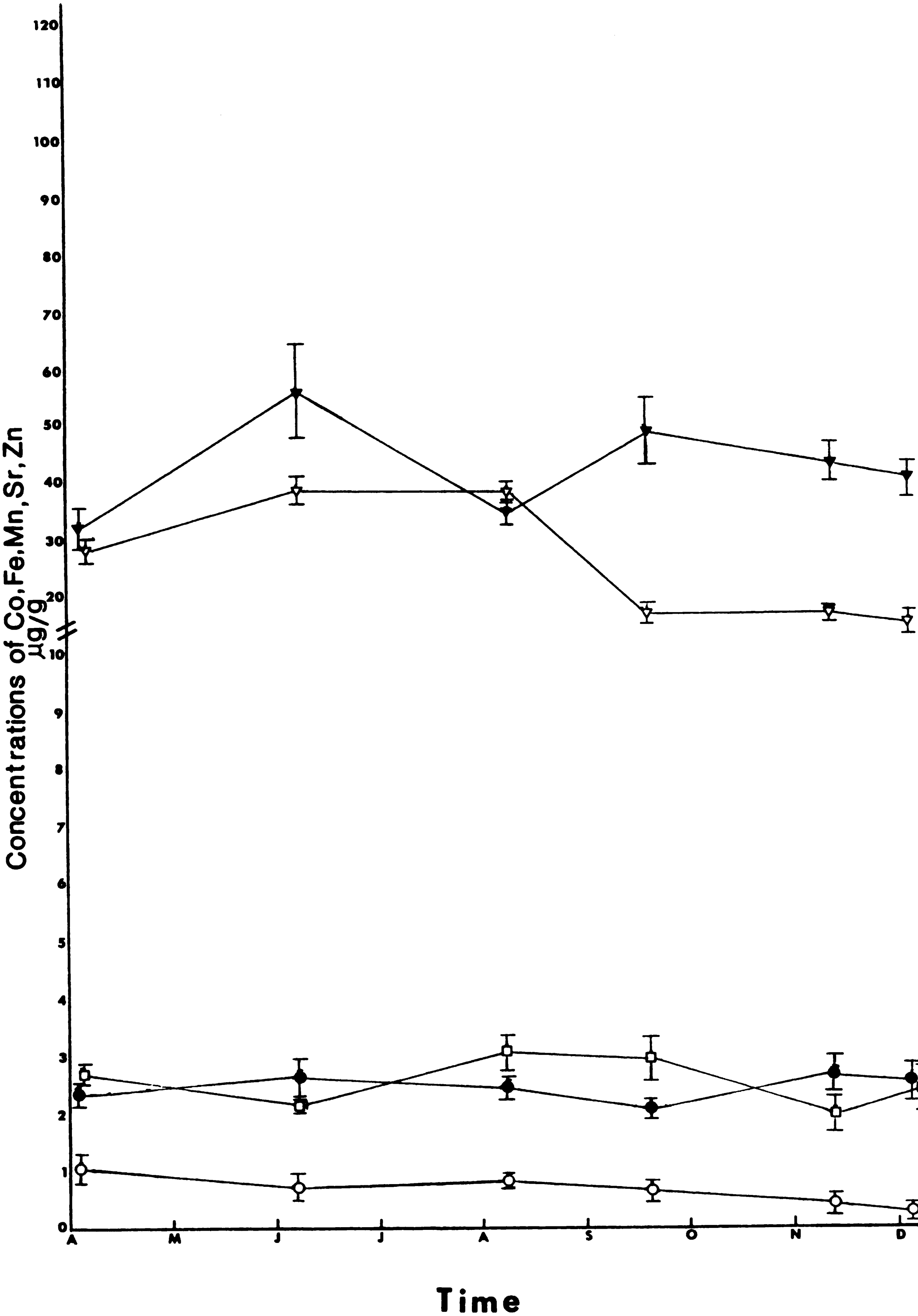
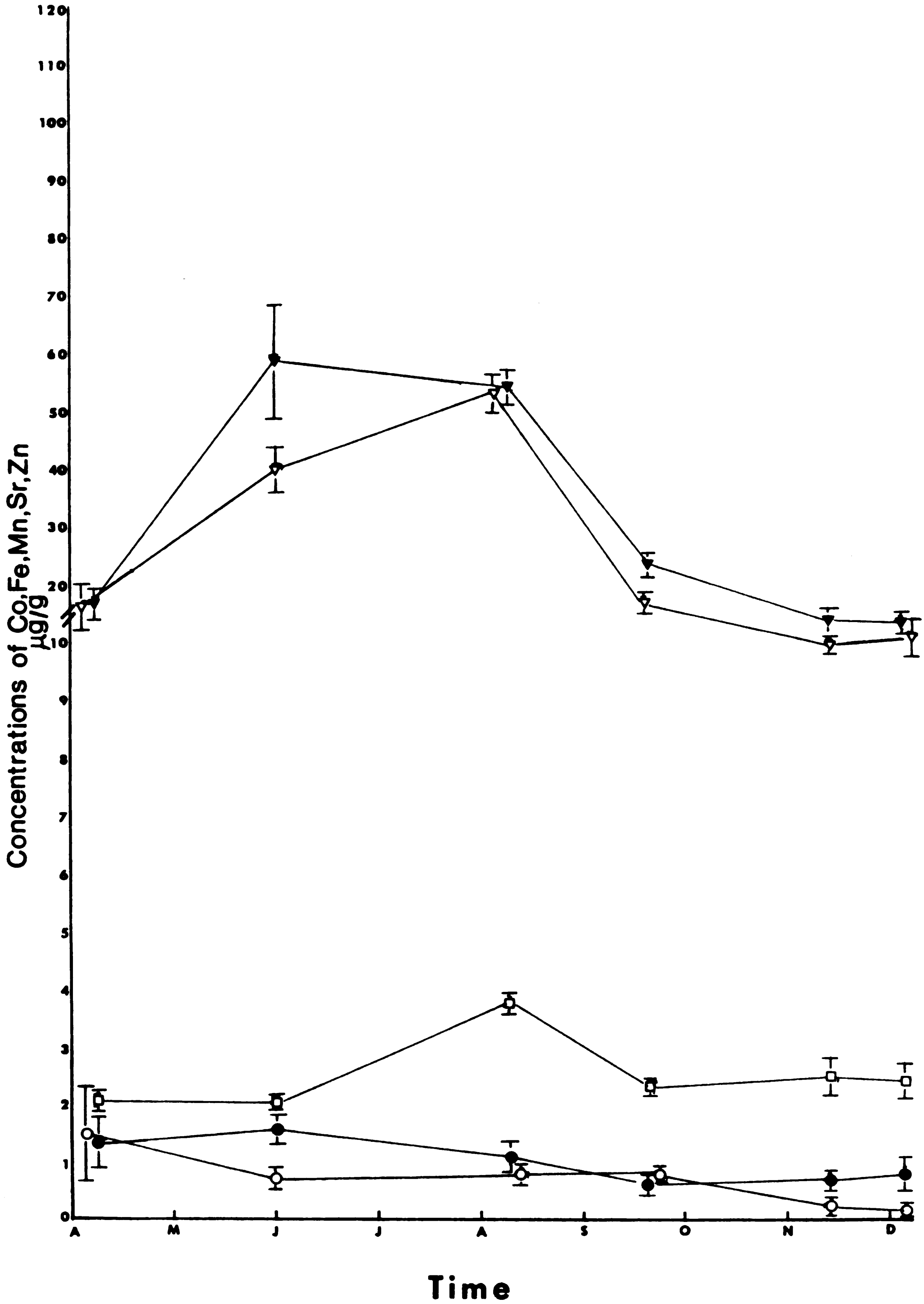

Concentrations of Co, Fe, Mn, Sr, Zn
μg/g
120
110
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
0
A
M
J
J
A
S
O
N
D
Time

Figure 6. Concentrations (mean ± 1 standard error) of Co ○, Fe ▼, Mn □, Sr ● and Zn ∇ in piscivores collected from the lake stations (F2-F5).



120
110
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
0
Concentrations of Co,Fe,Mn,Sr,Zn μg/g
A
M
J
J
A
S
O
N
D
Time

Table 7. Multiple range analysis of mean annual concentrations of stable isotopes in three trophic levels of fish.

Cs			
Feeding Type	Planktivores	Piscivores	Bottom Feeders
Concentration[1]	5.6	7.6	8.2
Co			
Feeding Type	Bottom Feeders	Planktivores	Piscivores
Concentration	0.52	0.68	0.73
Fe			
Feeding Type	Piscivores	Planktivores	Bottom Feeders
Concentration	32.67	42.58	72.67
Mn			
Feeding Type	Piscivores	Bottom Feeders	Planktivores
Concentration	1.06	2.34	2.48
Sr			
Feeding Type	Planktivores	Piscivores	Bottom Feeders
Concentration	2.56	2.57	4.84
Zn			
Feeding Type	Planktivores	Piscivores	Bottom Feeders
Concentration	26.00	26.92	81.83

[1]Cs in ng/g; Co, Fe, Mn, Sr, Zn in ug/g.

Cesium

Mean annual cesium concentrations were not significantly different among the three trophic levels. Bottom feeders appeared to have slightly greater concentrations of stable cesium (8.2 ng/g) than planktivores (5.6 ng/g) or piscivores (7.1 ng/g).

No spatial pattern could be detected for cesium concentrations of the three feeding types. Although the bottom feeders collected from Swan Creek in November and December appeared to have the greatest cesium concentrations, the difference was not significant ($\alpha = 0.05$).

Seasonal fluctuations in levels of cesium in fish were not statistically significant, but an apparent trend could be seen in bottom feeders and planktivores. Cesium levels tended to increase in these two feeding groups from 3 April until a peak was reached on 14 September after which time a gradual decrease was observed in November and December. Cesium concentrations in piscivores remained relatively constant throughout the study, decreasing only slightly in November and December (Figure 3).

Cobalt

Cobalt concentrations did not differ significantly between the three trophic habits. There did appear to be some trophic differences, with cobalt present in lowest amounts in bottom feeders and greatest amounts in piscivores. The mean annual concentration of cobalt in bottom feeders, planktivores and piscivores collected from the lake stations were 0.52, 0.68, and 0.73 ug/g, respectively.

Bottom feeding fish collected in Swan Creek (Station F1) had greater concentrations of cobalt than those collected from the lake stations on five of the six sampling dates. Although concentrations were usually greater in Swan Creek, the difference was not always significant.

Bottom feeders collected from Stations F2 and F4 contained slightly greater amounts of cobalt than fish with similar feeding habits collected from Stations F3 and F5, but the annual differences were not statistically significant. Planktivorous fish captured at Stations F1 and F2 had greater cobalt concentrations than those collected from Stations F3-F5. No pattern could be detected for cobalt concentrations in piscivorous fish in relation to the location where they were collected.

The annual trend of cobalt concentrations in bottom feeders was one of continuously decreasing amounts throughout the sampling period. Samples collected on 3 April averaged 0.98 ug/g cobalt, which was significantly greater than samples collected during the remainder of the study. Amounts of cobalt in planktivores and piscivores collected on 3 April were also greater than at any other time during the study. Concentrations declined by 7 June and increased somewhat on 7 August, after which time they decreased through the remainder of the year in planktivores and piscivores.

Iron

Iron concentrations were consistently greater ($p < .05$) in bottom feeding fish than in planktivores and piscivores (Table 7). The annual mean concentration of iron in bottom feeders was 1.7 and 2.2 times higher than in planktivores and piscivores, respectively.

The concentration of iron, spatially distributed within the study area, appears to be greatest in fish collected from Swan Creek, although the difference was not always significant. Fish in all three feeding categories had greatest concentrations of iron at Station F1.

Bottom feeders and planktivores collected from Stations F4 and F5 generally exhibited lower iron concentrations than those fish collected from Stations F2 and F3. Piscivorous fish collected at Station F4 appeared to have higher concentrations of iron than piscivorous fish collected from the other lake stations, although these differences in iron concentrations were not statistically significant.

Seasonal fluctuations in the levels of iron detected in the fish followed the same general pattern in each of the three feeding types (Figures 4-6). Concentrations in fish collected on 3 April were significantly below concentrations recorded for fish collected on 7 June for each of the three categories of fish. On 7 August concentrations of iron in bottom feeders and piscivores still were significantly above concentrations that were recorded for 3 April. The concentrations of iron in these two feeding types were not significantly different from levels reported for 7 June although levels had increased in bottom feeders by 22.5 ug/g and decreased in piscivores by 0.16 ug/g. Amounts of iron in planktivores had decreased significantly between 7 June and 7 August by 19.3 ug/g. On 14 September iron concentrations had declined significantly in bottom feeders and piscivores, after which time no significant changes were recorded during the remainder of the sampling period which terminated on 8 December 1973. Planktivores collected on 14 September showed intermediate concentrations of iron between the high recorded on 7 June and the decreased amount reported on 7 August. Samples collected on 7 November and 8 December showed a gradual decrease of iron in planktivores.

Manganese

The annual averages of manganese in bottom feeders and planktivores were not significantly different, but both were significantly greater than in piscivores (Table 7). Manganese concentrations were about 2.25 times greater in bottom feeders and planktivores than in piscivores.

Manganese also seems to be higher in fish collected from Swan Creek than from the lake stations, although an analysis of variance did not show any significant differences between any of the stations. All fish tended to have highest concentrations when collected from station F1, moderate concentrations at stations F2 and F3, low to moderate concentrations at station F4, and bottom feeders and piscivores had high concentrations at station F5 where planktivores had low concentrations.

Bottom feeding fish had annual fluctuations of manganese concentrations that generally followed the same pattern as iron. Concentrations appeared to increase steadily from 3 April, when a mean concentration of 2.07 ug/g was detected, through 6 August when a high of 3.65 ug/g was recorded. On 14 September a significant decrease of 1.97 ug/g manganese had occurred in bottom feeders after which time no significant change in manganese concentrations was observed throughout the study period. In planktivores and piscivores, levels increased slightly in June in both feeding types, and again in November in planktivores.

Strontium

Mean concentrations of strontium were greatest in bottom feeders, being significantly above levels found in planktivores and piscivores which were not significantly different from one another. The mean annual concentration of strontium was 1.9 times higher in bottom feeders than the other feeding types.

Spatial distribution of strontium appears to have concentrations greatest in fish collected in Swan Creek for planktivores and piscivores, with bottom feeders having similar concentrations throughout the study area. There was no difference in concentrations of strontium in planktivores collected from the four lake stations. Moderate concentrations were found in piscivores collected at stations F4 and F5, while those collected at stations F2 and F3 had low concentrations in relation to the other stations.

The lowest concentrations of strontium in bottom feeders were recorded on 3 April when a value of 2.75 ug/g was recorded. By June, strontium concentrations had increased slightly. On 8 August strontium concentrations had increased significantly to a mean level of 6.42 ug/g and remained relatively unchanged until 7 November when the mean concentration had decreased by about 1 ug/g from its summer high. Concentrations in December showed a slight decrease from November. Strontium concentrations in planktivores and piscivores did not change significantly during the sampling period. Amounts of strontium had increased slightly in planktivores and piscivores by the middle of the summer but had declined again by September in piscivores and by November in planktivores.

Zinc

Average amounts of zinc in bottom feeders on each sampling date varied between 68.96 ug/g and 100.93 ug/g fresh weight, and all were higher than the amounts in the other feeding types. The annual average of zinc was significantly greater in bottom feeders than in planktivores and piscivores.

Statistical analysis showed no significant differences in spatial zinc concentration in all three feeding types. Planktivores collected from the lake stations had zinc concentrations that were less than those found in planktivores collected from station F1 (Swan Creek). No trend could be seen for spatial zinc concentrations in bottom feeders or piscivores.

Zinc concentrations in the three feeding types followed the same pattern observed for iron and manganese. Significant increases were detected in planktivores and piscivores from 3 April through 7 June. During this time zinc levels had decreased slightly in bottom feeders. On 6 August, significant increases were detected in all feeding types compared to 3 April concentrations. Samples collected on 14 September showed significant decreases in zinc in each feeding type. November and December samples showed little change in zinc concentrations from the September collection.

Distribution of Stable Elements in Fish

An analysis was performed to determine the distribution of trace elements in various components of fish. Carp were chosen for this analysis because they consistently appeared in samples and because they are used for food when caught by commercial and sport fishermen.

An analysis was accomplished by cutting the frozen fish in half longitudinally on a band saw with a stainless steel blade. One half of the fish was processed in the same manner as whole fish samples were, as described in Tables 2 and 3. The other half of the fish was divided into four components: (1) flesh; (2) viscera; (3) skin and scales; and (4) slime. Table 8 gives the results of this analysis. Cesium was below limits of detectability for all components measured. Cobalt could only be detected in the whole fish. Highest concentrations of strontium were found associated with the skin and scales. Most of the zinc appeared to be associated with viscera, the skin, and scales.

The results of this study are in agreement with those of Ting (1971) who worked with the distribution of Fe, Mn, Sr and Zn in fish.

Mean stomach volume was determined for age IV carp, which was the most frequently captured age class along the western shore of Lake Erie at Monroe (Parkhurst, 1971). This was done in an attempt to establish the maximum influence of gut contents on analysis of whole fish without removing the gut contents (3 April and 7 June). The mean stomach volume for age IV carp was 20.25 ml. If the gut of an age IV carp was full of sediment when analyzed, the maximum amount of trace elements associated with the gut contents would be: Co, 488 ug; Fe, 676 ug; Mn, 1098 ug; Sr, 3090 ug; and Zn, 6159 ug (Anonymous, 1973).

Table 8. Distribution of stable elements in carp (ug/g).

Body Parts	Cs	Co	Fe	Mn	Sr	Zn
1 Whole Fish[1]	< 0.03	< 0.2	33.50	< 0.06	4.89	126.12
2 Whole Fish	< 0.03	0.46	66.00	1.25	5.49	114.98
1 Flesh	< 0.03	0.39	11.13	< 0.06	< 0.15	46.28
2 Flesh	< 0.03	0.48	24.07	< 0.06	1.75	32.69
1 Visceral	< 0.03	< 0.2	39.02	2.08	< 0.15	126.26
2 Visceral	< 0.03	< 0.2	173.07	5.24	< 0.15	117.08
1 Skin and Scales	< 0.03	< 0.2	20.33	1.85	10.72	119.96
2 Skin and Scales	< 0.03	< 0.2	35.93	2.44	9.25	78.77
1 Slime	< 0.03	< 0.2	420.44	14.89	3.71	61.51
2 Slime	< 0.03	< 0.2	387.05	17.63	5.59	33.92

[1] Gut contents removed.

Average weight of an age IV carp from the Monroe area was 1108 g (Parkhurst, 1971). It is possible that bottom feeders collected during the first two sampling dates may have had sufficient amounts of trace elements in their guts to influence the stable analysis.

Radioisotope Analysis

Radioecological monitoring of fish during the study period showed most radioisotopes of concern (^{134}Cs, ^{57}Co, ^{54}Mn and ^{65}Zn) to be below the limits of detectability. Only ^{137}Cs was present in high enough amounts to determine baseline concentrations in fish from the study area. The naturally occurring radioisotope of potassium, ^{40}K, was also measurable in fish. Over 23% of the total gamma activity in fish was due to the presence of ^{40}K. A list of ^{137}Cs activities found in the three trophic levels of fish at each station throughout the study period is included in the appendix.

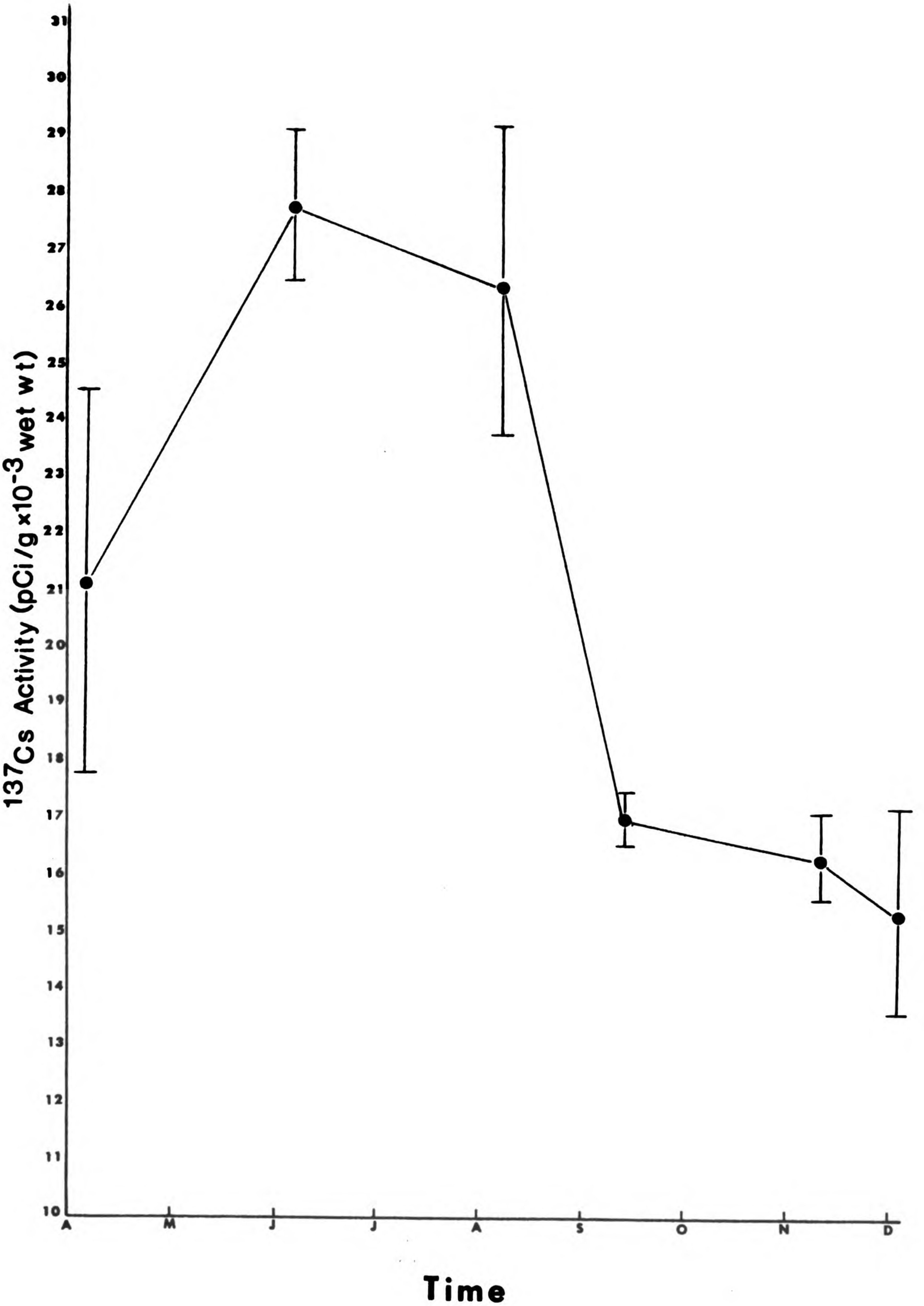
The results of an analysis of variance (Table 9) revealed no significant difference, at the 0.05 confidence level, among trophic habits. The annual mean concentration of ^{137}Cs was 0.019, 0.021 and 0.038 pCi/g for planktivores, bottom feeders and piscivores, respectively.

No significant differences were detected in spatial distribution or seasonal variation (Figures 7, 8 and 9) of ^{137}Cs in any of the feeding groups studied.

Table 9. Analysis of variance to test differences in ^{137}Cs concentrations due to feeding habits.

Source	d.f.	S.S.	M.S.	F	F 0.95
Between feeding types	2	0.0013	0.0007	2.333 ns	3.68
Within feeding types	15	0.0042	0.0003		

Figure 7. Concentrations (mean ± 1 standard error) of ^{137}Cs in bottom feeders collected from the lake stations (F2-F5).



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137Cs Activity (pCi/g x10-3 wet wt)
A
M
J
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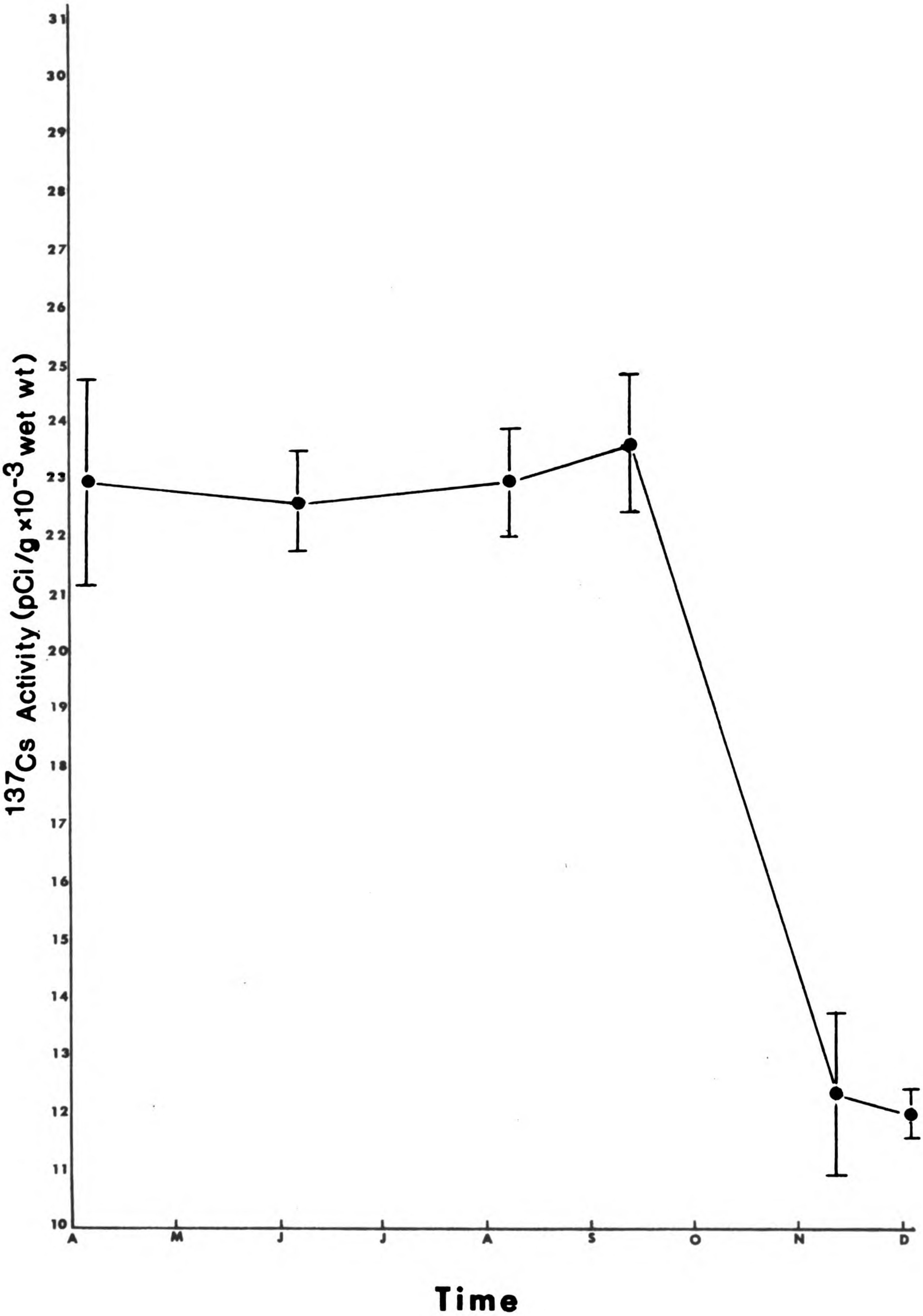
D
Time

Figure 8. Concentrations (mean $\pm$ 1 standard error) of ^{137}Cs in planktivores collected from the lake stations (F2-F5).



^{137}Cs Activity (pCi/g ×10^{-3} wet wt)
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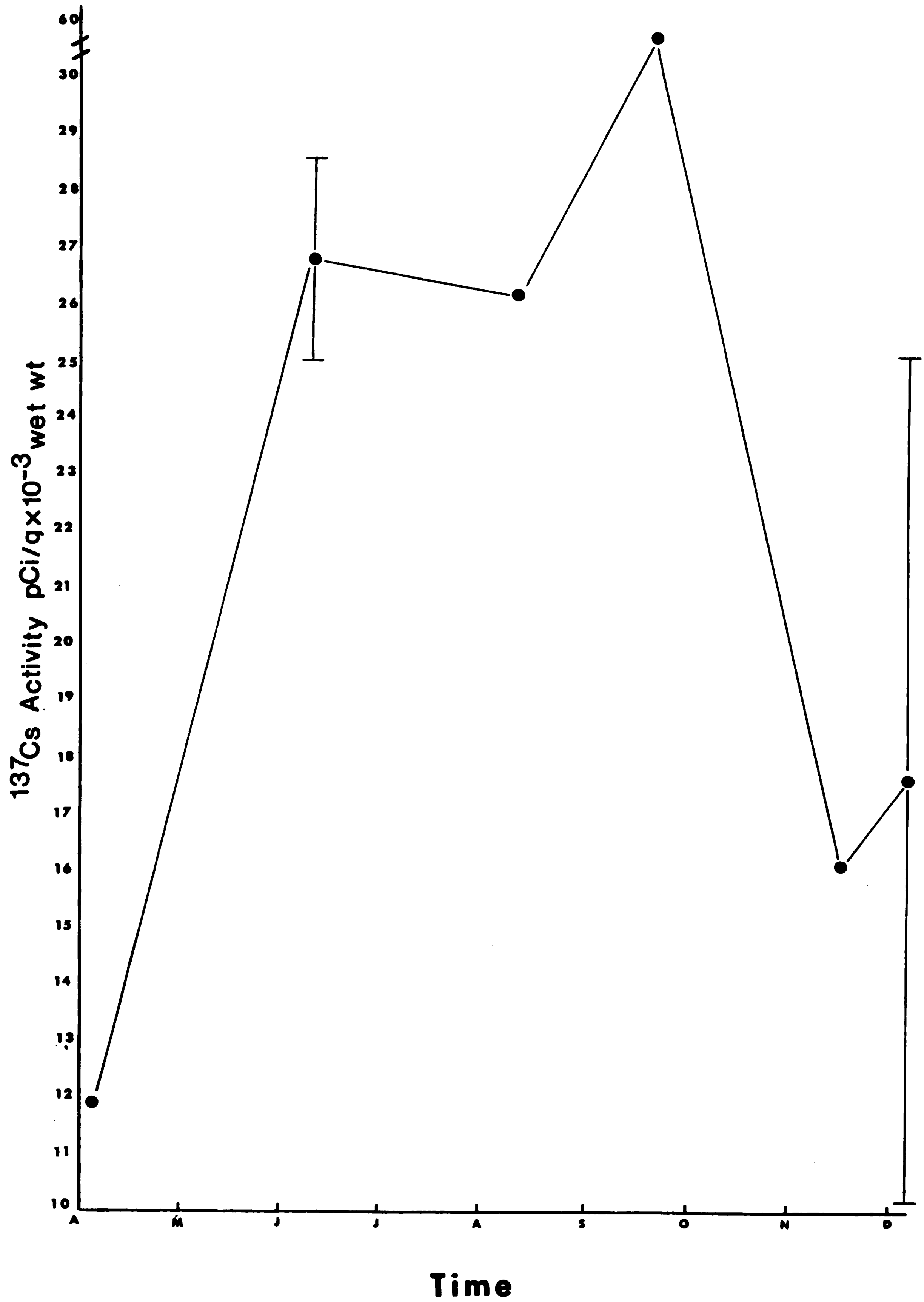
Figure 9. Concentrations (mean ± 1 standard error) of ^{137}Cs in piscivores collected from the lake stations (F2-F5).



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^{137}Cs Activity pCi/g x 10^{-3} wet wt
A
M
J
J
A
S
O
N
D
Time

DISCUSSION

In general, concentrations of the trace elements in fish captured within the study area are typical of fresh water fish reported from other studies conducted around the world and exhibit no extreme characteristics.

Trace element concentrations in fish have been reported by Bowen (1966), Chapman et al. (1968), Copeland et al. (1973), Lucas et al. (1970), Mathis and Cummings (1971) and the Michigan Department of Natural Resources (1972). Table 10 compares the results of this study with those from other locations in the Great Lakes and other fresh water environments.

Mean concentrations of cobalt, iron and zinc were slightly higher than values reported by Copeland et al. (1973) for Lake Michigan fish; however, iron and zinc values found in this study were within the range reported by Copeland et al. (1973). Cobalt levels reported in this study are slightly greater than levels reported in the literature. The mean for fish of all feeding habits was 0.64 ug/g in this study, whereas the Michigan Department of Natural Resources found a mean of 0.14 ug/g for cobalt in fish throughout the state. Copeland et al. (1973) found a mean of 0.11 ug/g and a range of 0.02 - 0.44 ug/g in Lake Michigan fish. The higher concentrations of Co found in this study may be real and result from cobalt entering the study area from the Detroit River. Cobalt is used for making alloys, as a pigment in glass and china, and as a binder in the tungsten carbide tool industry

Table 10. Trace element concentrations in fresh water fish (ug/g wet weight).

	Present Study (1973)	Bowen (1966)	Chapman et al (1968)	Copeland et al (1973)		Lucas et al (1970)	Mathis and Cummings (1971) (carnivorous)	Mathis and Cummings (1971) (noncarnivorous)	Michigan DNR (1972)
Cs	0.007	--	0.02	0.026	(.007-.07)	--	--	--	--
Co	0.64	0.05	0.05	0.11	(.02-.44)	0.028	0.10	0.10	0.14
Fe	49.31	3.0	30.0	40.6	(9.2-125)	--	2.50	7.36	--
Mn	1.96	0.08	0.25	4.0	(1.4-7.0)	--	--	--	0.55
Sr	3.32	--	4.0	7.7	(2.4-23.3)	--	--	--	--
Zn	44.92	8.0	10.0	34.0	(21-55)	--	3.49	5.02	16.0

(Sax, 1968). The apparent difference in cobalt levels may be the result of different analytical methods (atomic absorption and neutron activation), yielding the wide range of values reported by various investigators.

Fish collected in Swan Creek usually had higher concentrations of trace elements than fish collected from the lake stations. The distribution of the elements spatially within the study area appears to be divided into two distinct areas: (1) Swan Creek and (2) the lake stations. Swan Creek usually exhibits higher concentrations of trace elements in the water and sediments than the lake stations (Anonymous, 1973). This is probably caused by surface runoff from the surrounding agricultural land. Although fish movements have not been determined in the study area, it appears from the data collected during this study that most of the fish collected at Swan Creek have spent considerable time there, enough to accumulate greater amounts of trace elements than fish collected in the lake. Some of the fish species collected in Swan Creek were not captured at any other station (Table A-1), so it was assumed that these species were either permanent residents of the creek or spent considerably more time in the creek than in the lake during the sample period.

Spatial distribution in the lake appeared to follow the Swan Creek plume to some extent. Station F2 fish often had higher concentrations than fish from other lake stations, although the difference in concentrations was seldom statistically significant. It is expected that fish in the lake are mobile and integrate the conditions found within the study area.

As stated earlier, iron and manganese were found to be concentrated nearly 1000 times more in slime than in whole fish. These two elements showed a greater tendency to be present in large amounts in fish captured in Swan Creek than in those collected from the lake. Because these metals are present in relatively high concentrations in the slime, they may reflect spatial distribution more quickly than the other elements studied. These elements apparently have to be ingested to result in significant bioaccumulation. Since most fish do not feed constantly, concentrations of Cs, Co, Sr, or Zn may not reflect as accurately as Fe and Mn where a fish has been spatially. This would seem to apply especially to fish with great amounts of slime (carp, pike and goldfish).

A problem frequently encountered during the study was the inability to detect differences in trace metal concentrations between feeding types. The differences probably would have been more readily detected had not all the species with similar feeding habits been pooled together, and had a much larger sample of fish been obtained on each collecting date so that each species was well represented for statistical analysis. Some of the species collected were always found to have the same feeding habits. Random stomach analyses of shiners showed that all sizes captured were consistently feeding on plankton. Yellow perch were less consistent in their feeding habits. Young perch, age 0 - III, generally fed on plankton but older perch were found with both plankton and crayfish in their stomachs. Since only 3 perch stomachs were found to contain crayfish, all perch were considered planktivores. This may have resulted in some perch that were primarily bottom feeders being grouped with the planktivores. Price (1963) concluded that Lake Erie yellow perch feed on any form of animal life available.

Fresh water drum were another species that did not exhibit one specific feeding habit. Random stomach samples indicated that drum feed primarily on bottom materials, but often these fish were observed chasing minnows. This species has been reported to feed on crayfish, scuds, worms, and minnows in Iowa waters (Harlan and Speaker, 1956). Price (1963) found that drum in Lake Erie exhibit a general diet with respect to the food organisms available to them. Worms, leeches, zooplankton and fish were frequently found to be included in the drum's diet.

It should be noted that there does not appear to be a stepwise increase in concentrations of trace elements as one moves up the food chain. Fish which primarily fed on organisms that live on the mud or mud-water interface had significantly higher concentrations of iron, manganese, strontium and zinc than piscivores. This same trend was observed by Mathis and Cummings (1971) for fish of the Middle Illinois River and Eyman (1972) in a hyper-eutrophic lake in southern Michigan.

A correlation analysis was performed to determine if either size or species composition could be related to trace element concentrations. The results of this analysis yielded R values that were rejected at the 0.05 confidence level. It was concluded that neither of these factors alone significantly influenced stable trace element concentrations.

Since species were pooled with others of generally similar feeding habits, the error terms obtained are relatively large in some instances and may mask some differences that exist among species within feeding categories.

It is likely that specific differences do exist which cannot be identified through analyses based on pooled samples. Specific differences could have been identified only through intensive sampling of each species which was likely to be important in the study area at all times or during certain seasons. Since it could not be easily predicted prior to sampling which of the species would be important and because statistically adequate sampling of all the species present was not feasible at this early stage of the study, a pooled sample approach based on feeding categories became the elected option. From this study the important species were catalogued so that select species can now be identified for more intensive study. The fact that a significant difference ($\alpha = 0.05$) appeared among the three feeding categories, using pooled samples in which great intraspecific and interspecific variability is incorporated, supports the rejection of the hypothesis that no difference exists among trophic categories. In future studies the trophic category most likely to indicate dangerous accumulations of radioisotopes in fish, the bottom feeders, can be selected for more intensive study.

SUMMARY

1. Concentrations of the trace elements in fish captured within the study area generally are similar to values reported for fresh water fish of the world and exhibit no unusual variation.
2. Trophic differences were detected for concentrations of Fe, Mn, Sr and Zn. All of which were most concentrated in bottom feeders.
3. Significant seasonal fluctuations in concentration occurred in fish populations for each element studied except Cs.
   a) Co was present in highest concentrations in April, then decreased throughout the remainder of the study.
   b) Fe concentrations were highest in June and August.
   c) Mn and Zn concentrations increased through August and decreased significantly by September.
   d) Bottom feeders comprised the only feeding type that exhibited seasonal differences in Sr concentrations, which reached maximum levels in August and September.
4. Fish collected from Swan Creek usually had higher concentrations of trace elements than fish collected from the lake stations.
5. The only radioisotope present in high enough concentrations to determine baseline concentrations in fish was ^{137}Cs.
6. At the intensity of sampling there was no measurable difference in ^{137}Cs concentrations seasonally, spatially or trophically.

CONCLUSIONS

The effluent from Fermi II may contain radioisotopes produced either by fission or neutron activation. Bioaccumulation of the stable isotopes, which are the counterparts of these radioisotopes, has been reported by Chapman et al. (1968). The increase in radioisotope concentrations in fish, due to the plant's discharge into Lake Erie, will probably be insignificant, even in the case of an accidental short-term high-radioisotope level release. Most of the radioisotopes entering aquatic environments become associated with the sediments within a short time (Brungs, 1967).

Considering the relative amounts of water, sediments and fish in the study area, it is apparent that the amount of fish is insignificant in comparison to the amounts of water and sediments.

A problem may arise if fish are attracted to the warm water discharge in the colder months, thus increasing their exposure to any radioisotopes. Because large numbers of yellow perch spawn in the study area, they may be particularly attracted to the discharge.

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APPENDIX A

Table A-1. Assigned trophic habits of fish species collected from the study area. (A = bottom feeder; B = planktivore; C = piscivore).

Date	Species	Feeding	Scientific Name (Stations frequented)
3 April 1973	Carp	A	Cyprinus carpio (F-1, F-2, F-3, F-4, F-5)
	Freshwater Drum	A	Aplodinotus grunniens (F-1)
	Gizzard Shad	A,B	Dorosoma cepedianum (F-4)
	Goldfish	A	Carassius auratus (F-1)
	White Sucker	A	Catostomus commersoni (F-5)
	Common Shiner	B	Notropis cornutus (F-2, F-3, F-4, F-5)
	Smelt	B	Osmerus mordax (F-2)
	Yellow Perch	B	Perca flavescens (F-1, F-2, F-3, F-4, F-5)
	Walleye	C	Stizostedion vitreum (F-2)
6 June 1973	Carp	A	Cyprinus carpio (F-2, F-3, F-5)
	Freshwater Drum	A	Aplodinotus grunniens (F-1, F-3, F-4)
	Goldfish	A	Carassius auratus (F-1, F-2, F-3, F-4, F-5)
	Alewife	B	Alosa pseudoharengus (F-2, F-5)
	Common Shiner	B	Notropis cornutus (F-3)

Table A-1 (Cont'd):

Date	Species	Feeding	Scientific Name (Stations frequented)
	Spottail Shiner	B	Notropis hudsonius (F-3)
	Yellow Perch	B	Perca flavescens (F-1, F-5)
	Black Crappie	C	Pomoxis nigromaculatus (F-3)
	Walleye	C	Stizostedion vitreum (F-5)
	White Bass	C	Morone chrysops (F-3, F-4)
7 August 1973	Carp	A	Cyprimus carpio (F-1, F-2, F-3, F-4, F-5)
	Goldfish	A	Carassius auratus (F-1, F-2)
	Freshwater Drum	A	Aplodinotus grunniens (F-1)
	Bluegill	B	Lepomus macrochirus (F-1)
	Gizzard Shad	A,B	Dorosoma cepedianum (F-1)
	Yellow Bullhead	C	Ictalurus natalis (F-1)
	White Bass	C	Morone chrysops (F-2)
	Walleye	C	Stizostedion vitreum (F-2)
	Common Shiner	B	Notropis cornutus (F-2, F-4)

Table A-1 (Cont'd):

Date	Species	Feeding	Scientific Name (Stations frequented)
	Spottail Shiner	B	*Notropis hudsonius* (F-4)
	Trout Perch	B	*Percopsis omiscamaycus* (F-3, F-5)
	Log Perch	B	*Percina caprodes* (F-3, F-4)
	Alewife	B	*Alosa pseudoharengus* (F-4)
	Johnny Darter	B	*Etheostoma nigrum* (F-5)
14 September 1973	Carp	A	*Cyprinus carpio* (F-1, F-2)
	Gizzard Shad	A,B	*Dorosoma cepedianum* (F-1, F-2, F-3, F-4)
	Yellow Bullhead	C	*Ictalurus natalis* (F-1)
	Quillback Carpsucker	A	*Carpiodes cyprinus* (F-1)
	Longnose Gar	C	*Lepisosteus osseus* (F-2)
	Alewife	B	*Alosa pseudoharengus* (F-2)
	Yellow Perch	B	*Perca flavescens* (F-3, F-4)
	Common Shiner	B	*Notropis cornutus* (F-3, F-4)
	Emerald Shiner	B	*Notropis atherinoides* (F-4)

Table A-1 (Cont'd):

Date	Species	Feeding	Scientific Name (Stations frequented)
	Smelt	B	*Osmerus mordax* (F-3, F-5)
7 November 1973	Carp	A	*Cyprinus carpio* (F-1, F-2, F-4)
	Northern Pike	C	*Esox lucius* (F-1)
	Yellow Perch	B	*Perca flavescens* (F-1, F-2, F-3, F-4, F-5)
	Alewife	B	*Alosa pseudoharengus* (F-1)
	Gizzard Shad	A,B	*Dorsoma cepedianum* (F-1, F-3)
	Goldfish	A	*Carassius auratus* (F-2)
	Common Shiner	B	*Notropis cornutus* (F-2, F-3, F-5)
	Spottail Shiner	B	*Notropis hudsonius* (F-2, F-3)
	Walleye	C	*Stizostedion vitreum* (F-3, F-4)
	White Bass	C	*Morone chrysops* (F-4)
	Yellow Bullhead	C	*Ictalurus natalis* (F-1)
	Freshwater Drum	B	*Aplodinotus grunniens* (F-5)
	Black Bullhead	A	*Ictalurus melas* (F-1)

Table A-1 (Cont'd):

Date	Species	Feeding	Scientific Name (Stations frequented)
8 December 1973	Northern Pike	C	*Esox lucius* (F-1)
	Yellow Bullhead	C	*Ictalurus natalis* (F-1)
	Black Bullhead	A	*Ictalurus melas* (F-1)
	Gizzard Shad	B	*Dorosoma cepedianum* (F-1, F-4)
	Carp	A	*Cyprinus carpio* (F-2, F-3)
	Goldfish	A	*Carassius auratus* (F-2, F-5)
	Yellow Perch	B	*Perca flavescens* (F-2, F-3, F-4, F-5)
	Common Shiner	B	*Notropis cornutus* (F-2)
	Alewife	B	*Alosa pseudoharengus* (F-2, F-4, F-5)
	Walleye	C	*Stizostedion vitreum* (F-3)
	Trout Perch	B	*Percopsis omiscomaycus* (F-3)
	Smelt	B	*Osmerus mordax* (F-5)

Table A-2. Mean concentrations ($\bar{x} \pm 1$ S.E.) of stable isotopes in whole fish samples taken from the study area on 3 April 1973.

Feeding Habit	Station	Mn ug/g	Co ug/g	Fe ug/g	Zn ug/g	Sr ug/g	Cs ng/g
Bottom Feeders	1	1.78± 0.10	1.85± 0.18	39.60± 4.03	88.45± 4.49	2.87± 0.71	7.4± 1.3
	2	1.35± 0.23	1.25± 0.18	40.93± 3.75	95.55± 5.03	2.99± 0.85	5.3± 1.8
	3	1.43± 0.42	1.11± 0.08	39.31± 13.28	96.29± 5.66	2.71± 0.26	7.7± 2.3
	4	1.92± 0.11	0.90± 0.13	72.60± 10.45	88.72± 15.46	3.14± 0.18	7.0± 3.3
	5	3.56± 0.45	0.56± 0.25	22.39± 2.06	37.85± 3.26	2.15± 0.63	5.9± 1.4
Planktivores	2	2.92± 0.45	1.30± 0.29	44.77± 9.67	24.31± 1.50	2.13± 0.14	4.2± 1.6
	3	2.04± 0.09	0.75± 0.07	36.89± 4.76	30.91± 3.04	2.10± 0.42	5.3± 1.9
	4	1.85± 0.46	0.90± 0.29	19.84± 2.66	36.42± 2.17	2.44± 0.10	4.8± 2.2
	5	2.55± 0.51	1.41± 0.26	27.57± 1.83	23.07± 4.49	2.19± 0.14	3.2± 1.0
Piscivores	2	1.45± 0.65	1.55± 0.84	19.08± 3.65	18.64± 5.23	2.15± 0.11	7.8± 2.6

Table A-3. Mean concentrations ($\bar{x}$ ±1 S.E.) of stable isotopes in whole fish samples taken from the study area on 7 June 1973.

Feeding Habit	Station	Mn ug/g	Co ug/g	Fe ug/g	Zn ug/g	Sr ug/g	Cs ng/g
Bottom Feeders	1	3.42± 0.10	0.97± 0.10	118.05± 3.10	52.08± 0.94	2.73± 0.28	8.0± 3.2
	2	2.87± 0.64	0.50± 0.08	114.48± 6.17	71.02± .31	2.98± 0.31	7.2± 3.9
	3	3.18± 0.07	0.29± 0.07	99.10± 3.86	67.55± 1.00	3.97± 0.81	9.7± 1.6
	4	2.40± 0.44	1.04± 0.07	66.68± 4.32	66.55± 5.28	3.01± 0.38	6.2± 3.2
	5	2.98± 0.23	0.50± 0.06	138.37± 10.47	70.71± 1.28	3.41± 0.16	8.4± 1.8
Planktivores	2	3.13± 0.55	0.93± 0.30	64.16± 3.90	42.24± 4.18	2.15± 0.20	4.7± 1.5
	4	2.85± 0.27	0.97± 0.07	53.20± 5.65	36.66± 2.64	2.15± 0.30	4.4± 0.8
	5	1.76± 0.18	0.30± 0.03	45.90± 2.14	39.13± 2.11	2.14± 0.29	5.4± 1.9
Piscivores	2	1.35± 0.48	0.50± 0.07	42.79± 3.11	37.24± 4.43	2.00± 0.20	6.8± 2.0
	4	1.31± 0.23	0.64± 0.27	43.90± 3.70	32.46± 3.43	2.16± 0.21	8.9± 4.7
	5	2.26± 0.21	1.21± 0.16	87.27± 9.42	54.32± 1.68	2.18± 0.28	8.3± 2.3

Table A-4. Mean concentrations ($\bar{x}$ $\pm$1 S.E.) of stable isotopes in whole fish samples taken from the study area on 7 August 1973.

Feeding Habit	Station	Mn ug/g	Co ug/g	Fe ug/g	Zn ug/g	Sr ug/g	Cs ng/g
Bottom Feeders	1	2.79± 0.55	1.01± 0.07	100.07± 5.99	68.02± 6.06	7.40± 0.10	9.3± 2.1
	2	3.66± 0.13	0.56± 0.10	108.97± 1.58	100.93± 6.13	5.96± 0.19	8.0± 4.7
	3	3.65± 0.04	0.33± 0.04	127.03± 3.14	100.31± 2.40	6.25± 0.19	9.9± 4.3
	4	2.76± 0.25	0.67± 0.14	97.00± 3.75	100.01± 2.40	5.20± 0.28	7.3± 2.0
	5	4.53± 0.35	0.53± 0.09	175.61± 19.48	100.19± 10.46	8.25± 1.70	9.7± 3.6
Planktivores	1	5.98± 0.99	0.78± 0.21	151.40± 9.62	44.83± .60	5.85± 0.33	5.1± .0
	2	2.47± 0.52	0.99± 0.16	35.11± 3.92	43.44± 3.48	3.98± 0.67	4.9± 1.1
	3	2.62± 0.07	0.70± 0.10	34.77± 1.21	39.38± .47	3.33± 0.02	5.7± 1.5
	4	2.94± 0.19	0.85± 0.04	34.33± 3.33	39.61± 3.43	3.74± 0.18	5.3± 2.6
	5	1.64± 0.13	0.89± 0.16	36.52± 6.03	33.93± 2.05	1.66± 0.12	6.1± 1.9
Piscivores	2	1.14± 0.20	0.83± 0.02	57.83± 2.49	56.67± 2.83	3.71± 0.08	7.8± 1.7

Table A-5. Mean concentrations ($\bar{x} \pm 1$ S.E.) of stable isotopes in whole fish samples taken from the study area on 14 September 1973.

Feeding Habit	Station	Mn ug/g	Co ug/g	Fe ug/g	Zn ug/g	Sr ug/g	Cs ng/g
Bottom Feeders	1	3.62± 0.34	0.69± 0.01	137.83± 6.29	76.37± 5.15	7.65± 0.51	9.1± 4.0
	2	1.62± 0.13	0.47± 0.13	46.33± 2.96	94.04± 1.32	6.80± 0.39	9.7± 3.7
	3	1.42± 0.11	0.36± 0.07	64.50± 16.21	82.36± 7.13	6.39± 0.82	11.4± 3.1
	4	2.08± 0.18	0.41± 0.03	52.10± 0.47	80.31± 3.52	6.74± 0.82	15.4± 4.4
	5	1.58± 0.07	0.47± 0.08	66.00± 0.50	82.51± 1.85	5.49± 0.17	11.9± 5.3
Planktivores	2	1.92± 0.18	0.70± 0.18	42.80± 2.93	16.22± 1.30	2.68± 0.41	6.3± 3.4
	3	2.04± 0.48	0.72± 0.08	54.00± 20.52	18.39± 3.16	1.79± 0.22	7.7± 1.3
	4	2.02± 0.03	0.63± 0.13	50.77± 0.66	16.01± 0.42	4.56± 0.15	9.2± 4.8
Piscivores	2	0.64± 0.12	0.75± 0.03	25.75± 1.25	19.14± 2.14	2.37± 0.06	8.4± 3.0

Table A-6. Mean concentrations ($\bar{x}$ $\pm$1 S.E.) of stable isotopes in whole fish samples taken from the study area on 7 November 1973.

Feeding Habit	Station	Mn ug/g	Co ug/g	Fe ug/g	Zn ug/g	Sr ug/g	Cs ng/g
Bottom Feeders	1	1.16$\pm$ 0.42	0.63$\pm$ 0.08	64.51$\pm$ 9.32	84.03$\pm$ 7.11	5.28$\pm$ 0.16	9.5$\pm$ 1.3
	2	1.39$\pm$ 0.21	0.31$\pm$ 0.04	50.17$\pm$ 4.03	79.37$\pm$ 2.87	6.20$\pm$ 1.18	5.7$\pm$ 1.1
	4	3.27$\pm$ 0.45	0.36$\pm$ 0.07	47.33$\pm$ 6.02	90.10$\pm$ 6.01	4.57$\pm$ 0.23	7.3$\pm$ 2.2
Planktivores	2	1.98$\pm$ 0.13	0.50$\pm$ 0.10	37.13$\pm$ 4.72	17.06$\pm$ 0.26	1.20$\pm$ 0.12	4.9$\pm$ 0.8
	3	4.08$\pm$ 0.17	0.40$\pm$ 0.03	48.01$\pm$ 2.27	17.27$\pm$ 0.19	1.26$\pm$ 0.06	7.1$\pm$ 2.6
	4	2.59$\pm$ 0.32	0.47$\pm$ 0.05	52.46$\pm$ 7.85	17.84$\pm$ 1.60	3.30$\pm$ 0.40	7.5$\pm$ 3.0
	5	2.22$\pm$ 0.50	0.32$\pm$ 0.04	36.13$\pm$ 1.71	16.45$\pm$ 1.17	2.44$\pm$ 0.28	5.4$\pm$ 1.6
Piscivores	1	4.75$\pm$ 0.72	0.37$\pm$ 0.11	22.29$\pm$ 0.49	33.43$\pm$ 3.15	6.26$\pm$ 0.49	6.1$\pm$ 2.3
	3	0.88$\pm$ 0.19	0.29$\pm$ 0.08	14.87$\pm$ 0.99	13.03$\pm$ 0.65	2.25$\pm$ 0.47	7.7$\pm$ 3.4
	4	0.56$\pm$ 0.06	0.22$\pm$ 0.08	17.83$\pm$ 2.47	10.77$\pm$ 0.09	2.87$\pm$ 0.22	7.5$\pm$ 2.8

Table A-7. Mean concentrations ($\bar{x}$ ±1 S.E.) of stable isotopes in whole fish samples taken from the study area on 8 December 1973.

Feeding Habit	Station	Mn ug/g	Co ug/g	Fe ug/g	Zn ug/g	Sr ug/g	Cs ng/g
Bottom Feeders	1	2.49 ± 0.30	0.55 ± 0.09	62.48 ± 7.14	84.32 ± 4.83	5.98 ± 1.01	8.3 ± 2.7
	2	1.97 ± 0.13	0.40 ± 0.10	53.24 ± 9.01	88.91 ± 4.00	5.44 ± 0.30	7.0 ± 4.4
	3	1.66 ± 0.19	0.21 ± 0.03	46.33 ± 8.90	76.93 ± 4.52	5.08 ± 0.46	5.3 ± 1.3
	5	1.71 ± 0.32	0.35 ± 0.05	45.29 ± 6.35	77.01 ± 4.77	4.81 ± 0.22	5.8 ± 1.0
Planktivores	1	2.18 ± 0.09	0.33 ± 0.01	38.42 ± 7.11	24.11 ± 1.38	3.72 ± 0.22	5.4 ± 1.0
	2	3.82 ± 0.11	0.34 ± 0.08	45.90 ± 3.51	15.23 ± 1.02	2.99 ± 0.40	5.9 ± 1.2
	3	2.69 ± 0.70	0.30 ± 0.01	43.14 ± 5.76	15.46 ± 0.98	2.54 ± 0.31	4.7 ± 0.9
	4	2.49 ± 0.21	0.24 ± 0.09	49.91 ± 8.43	15.88 ± 0.24	2.17 ± 0.07	4.1 ± 1.5
	5	1.81 ± 0.42	0.20 ± 0.08	31.62 ± 4.78	13.69 ± 0.81	2.08 ± 0.24	6.3 ± 4.0
Piscivores	1	4.04 ± 0.18	0.36 ± 0.02	22.03 ± 0.39	28.41 ± 2.06	5.31 ± 0.51	6.6 ± 2.7
	2	1.03 ± 0.29	0.18 ± 0.04	15.40 ± 0.78	17.02 ± 0.98	2.46 ± 0.13	5.1 ± 1.7
	4	0.75 ± 0.17	0.22 ± 0.01	17.61 ± 1.22	10.94 ± 0.40	2.72 ± 0.15	6.4 ± 2.5

Table A-8. Multiple range analysis of mean stable isotope concentrations in bottom feeding fish from the study area 3 April 1973.[1]

Co					
Station	V	IV	III	II	I
Mean	0.56	0.90	1.11	1.25	1.85
Cs					
Station	II	V	IV	I	III
Mean	5.3	5.9	7.0	7.4	7.7
Fe					
Station	V	III	I	II	IV
Mean	22.39	39.31	39.60	40.39	72.60
Mn					
Station	II	III	I	V	IV
Mean	1.35	1.43	1.78	1.92	3.56
Sr					
Station	V	III	I	II	IV
Mean	2.15	2.71	2.87	2.98	3.14
Zn					
Station	V	I	IV	II	III
Mean	37.85	88.45	88.72	95.55	96.29

[1] Co, Fe, Mn, Sr, Zn in ug/g; Cs in ng/g.

Table A-9. Multiple range analysis of mean stable isotope concentrations in bottom feeding fish from the study area 7 June 1973.[1]

Co					
Station	III	II	V	I	IV
Mean	0.29	0.50	0.50	0.97	1.04
Cs					
Station	IV	II	I	V	III
Mean	6.2	7.2	8.0	8.4	9.7
Fe					
Station	IV	III	II	I	V
Mean	66.68	99.10	114.48	118.05	138.37
Mn					
Station	IV	II	V	III	I
Mean	2.40	2.87	2.98	3.18	3.42
Sr					
Station	I	II	IV	V	III
Mean	2.73	2.98	3.01	3.41	3.97
Zn					
Station	I	IV	III	V	II
Mean	52.08	66.55	67.55	70.71	71.02

[1]Co, Fe, Mn, Sr, Zn in ug/g; Cs in ng/g.

Table A-10. Multiple range analysis of mean stable isotope concentrations in bottom feeding fish from the study area 7 August 1973.[1]

Co					
Station	III	V	II	IV	I
Mean	0.33	0.53	0.56	0.67	1.01
Cs					
Station	IV	II	I	V	III
Mean	7.3	8.0	9.3	9.7	9.9
Fe					
Station	IV	I	II	III	V
Mean	97.00	100.07	108.97	127.03	175.61
Mn					
Station	IV	I	III	II	V
Mean	2.76	2.79	3.65	3.66	4.53
Sr					
Station	IV	II	III	I	V
Mean	5.20	5.96	6.25	7.40	8.25
Zn					
Station	I	IV	V	III	II
Mean	68.02	100.01	100.19	100.31	100.93

[1] Co, Fe, Mn, Sr, Zn in ug/g; Cs in ng/g.

Table A-11. Multiple range analysis of mean stable isotope concentrations in bottom feeding fish from the study area 14 September 1973.[1]

Co					
Station	III	IV	II	V	I
Mean	0.36	0.41	0.47	0.47	0.69
Cs					
Station	I	II	III	V	IV
Mean	9.1	9.7	11.4	11.9	15.4
Fe					
Station	II	IV	III	V	I
Mean	46.33	52.10	64.50	66.00	137.83
Mn					
Station	III	V	II	IV	I
Mean	1.42	1.58	1.62	2.08	3.62
Sr					
Station	V	III	IV	II	I
Mean	5.49	6.39	6.74	6.80	7.65
Zn					
Station	I	IV	III	V	II
Mean	76.37	80.31	82.36	82.51	94.04

[1] Co, Fe, Mn, Sr, Zn in ug/g; Cs in ng/g.

Table A-12. Multiple range analysis of mean stable isotope concentrations in bottom feeding fish from the study area 7 November 1973.[1]

Co			
Station	III	V	I
Mean	0.31	0.36	0.63
Cs			
Station	II	IV	I
Mean	5.7	7.3	9.5
Fe			
Station	IV	II	I
Mean	47.33	50.17	64.51
Mn			
Station	IV	II	I
Mean	1.16	1.39	3.27
Sr			
Station	IV	I	II
Mean	4.57	5.28	6.20
Zn			
Station	II	I	IV
Mean	79.37	84.03	90.10

[1] Co, Fe, Mn, Sr, Zn in ug/g; Cs in ng/g.

Table A-13. Multiple range analysis of mean stable isotope concentrations in bottom feeding fish from the study area 8 December 1973.[1]

Co				
Station	III	V	II	I
Mean	0.21	0.35	0.40	0.55
Cs				
Station	III	V	II	I
Mean	5.3	5.8	7.0	8.3
Fe				
Station	V	III	II	I
Mean	45.29	46.33	53.24	62.48
Mn				
Station	III	V	II	I
Mean	1.66	1.77	1.97	2.49
Sr				
Station	V	III	II	I
Mean	4.81	5.08	5.44	5.98
Zn				
Station	III	V	I	II
Mean	76.93	77.01	84.32	88.91

[1] Co, Fe, Mn, Sr, Zn in ug/g; Cs in ng/g.

Table A-14. Multiple range analysis of mean stable isotope concentrations in planktivorous fish from the study area 3 April 1973.[1]

Co				
Station	III	IV	II	V
Mean	0.75	0.90	1.30	1.41
Cs				
Station	V	II	IV	III
Mean	3.2	4.2	4.8	5.3
Fe				
Station	IV	V	III	II
Mean	19.84	27.57	36.89	44.77
Mn				
Station	IV	III	V	II
Mean	1.85	2.04	2.55	2.92
Sr				
Station	III	II	V	IV
Mean	2.09	2.13	2.19	2.44
Zn				
Station	V	II	III	IV
Mean	23.07	24.31	30.91	36.42

[1]Co, Fe, Mn, Sr, Zn in ug/g; Cs in ng/g.

Table A-15. Multiple range analysis of mean stable isotope concentrations in planktivorous fish from the study area 6 June 1973.[1]

Co			
Station	V	IV	II
Mean	0.30	0.93	0.97
Cs			
Station	IV	II	V
Mean	4.4	4.7	5.4
Fe			
Station	V	IV	II
Mean	45.90	53.20	64.16
Mn			
Station	V	IV	II
Mean	1.76	2.85	3.13
Sr			
Station	V	IV	II
Mean	2.14	2.15	2.15
Zn			
Station	IV	V	II
Mean	36.66	39.13	42.24

[1] Co, Fe, Mn, Sr, Zn in ug/g; Cs in ng/g.

Table A-16. Multiple range analysis of mean stable isotope concentrations in planktivorous fish from the study area 7 August 1973.[1]

Co					
Station	III	I	IV	V	II
Mean	0.70	0.78	0.85	0.89	0.99
Cs					
Station	II	I	IV	III	V
Mean	4.9	5.1	5.3	5.7	6.1
Fe					
Station	IV	III	II	V	I
Mean	34.33	34.7	35.1	36.5	151.4
Mn					
Station	V	II	III	IV	I
Mean	1.64	2.47	2.62	2.94	5.98
Sr					
Station	V	III	IV	II	I
Mean	1.66	3.33	3.84	3.98	5.85
Zn					
Station	V	III	IV	II	I
Mean	33.93	39.38	39.61	43.44	44.83

[1] Co, Fe, Mn, Sr, Zn in ug/g; Cs in ng/g.

Table A-17. Multiple range analysis of mean stable isotope concentrations in planktivorous fish from the study area 14 September 1973.[1]

Co			
Station	IV	II	III
Mean	0.63	0.70	0.72
Cs			
Station	II	III	IV
Mean	6.3	7.7	9.2
Fe			
Station	II	IV	III
Mean	42.80	50.77	54.00
Mn			
Station	II	IV	III
Mean	1.92	2.02	2.04
Sr			
Station	III	II	IV
Mean	1.79	2.68	4.56
Zn			
Station	IV	II	III
Mean	16.01	16.22	18.39

[1] Co, Fe, Mn, Sr, Zn in ug/g; Cs in ng/g.

Table A-18. Multiple range analysis of mean stable isotope concentrations in planktivorous fish from the study area 11 November 1973.[1]

Co				
Station	V	III	IV	II
Mean	0.32	0.40	0.47	0.50
Cs				
Station	II	V	III	IV
Mean	4.9	5.4	7.1	7.5
Fe				
Station	V	II	III	IV
Mean	36.13	37.13	48.01	52.46
Mn				
Station	II	V	IV	III
Mean	1.98	2.22	2.59	4.08
Sr				
Station	II	III	V	IV
Mean	1.203	1.261	2.437	3.302
Zn				
Station	V	III	II	IV
Mean	16.45	16.91	17.06	17.84

[1] Co, Fe, Mn, Sr, Zn in ug/g; Cs in ng/g.

Table A-19. Multiple range analysis of mean stable isotope concentrations in planktivorous fish from the study area 8 December 1973.[1]

Co					
Station	V	IV	III	I	II
Mean	.20	.24	.30	.33	.34
Cs					
Station	IV	III	I	II	V
Mean	4.1	4.7	5.4	5.9	6.3
Fe					
Station	V	I	III	II	IV
Mean	31.62	38.42	43.14	45.90	49.91
Mn					
Station	V	I	IV	III	II
Mean	1.81	2.18	2.49	2.69	3.82
Sr					
Station	V	IV	III	II	I
Mean	2.08	2.17	2.54	2.99	3.72
Zn					
Station	V	II	III	IV	I
Mean	13.69	15.23	15.46	15.88	24.11

[1] Co, Fe, Mn, Sr, Zn in ug/g; Cs in ng/g.

Table A-20. Multiple range analysis of mean stable isotope concentrations in piscivorous fish from the study area 7 June 1973.[1]

Co			
Station	II	IV	V
Mean	0.50	0.64	1.21
Cs			
Station	II	V	IV
Mean	6.8	8.3	8.9
Fe			
Station	II	IV	V
Mean	42.79	43.90	87.27
Mn			
Station	IV	II	V
Mean	1.31	1.35	2.26
Sr			
Station	II	IV	V
Mean	2.00	2.16	2.18
Zn			
Station	IV	II	V
Mean	32.46	37.24	54.32

[1] Co, Fe, Mn, Sr, Zn in ug/g; Cs in ng/g.

Table A-21. Multiple range analysis of mean stable isotope concentrations[1] in piscivorous fish from the study area 7 November 1973.

Co			
Station	IV	III	I
Mean	0.22	0.29	0.37
Cs			
Station	I	IV	III
Mean	6.1	7.5	7.7
Fe			
Station	III	IV	I
Mean	14.87	17.83	22.29
Mn			
Station	IV	III	I
Mean	0.56	0.88	4.75
Sr			
Station	III	IV	I
Mean	2.25	2.87	6.26
Zn			
Station	IV	III	I
Mean	10.77	13.03	33.43

[1] Co, Fe, Mn, Sr, Zn in ug/g; Cs in ng/g.

Table A-22. Multiple range analysis of mean stable isotope concentrations in piscivorous fish from the study area 8 December 1973.[1]

Co			
Station	II	IV	I
Mean	0.18	0.22	0.36
Cs			
Station	II	IV	I
Mean	5.1	6.4	6.7
Fe			
Station	II	IV	I
Mean	15.40	17.61	22.03
Mn			
Station	IV	II	I
Mean	0.75	1.03	4.04
Sr			
Station	II	IV	I
Mean	2.46	2.72	5.31
Zn			
Station	IV	II	I
Mean	10.94	17.02	28.41

[1] Co, Fe, Mn, Sr, Zn in ug/g; Cs in ng/g.

Table A-23. Multiple range analysis of mean stable isotope concentrations in bottom feeding fish from 3 April 1973 through 8 December 1973.[1]

Co						
Date[2]	E	F	D	C	B	A
Concentration[3]	0.31	0.32	0.43	0.52	0.58	0.98
Cs						
Date	F	A	E	B	C	A
Concentration	6.6	6.7	7.5	7.9	8.8	11.5
Fe						
Date	A	F	E	D	B	C
Concentration	43.81	48.29	54.11	57.23	104.66	127.15
Mn						
Date	D	F	E	A	B	C
Concentration	1.68	1.80	1.92	2.07	2.86	3.65
Sr						
Date	A	B	F	E	D	C
Concentration	2.75	3.34	5.18	5.38	6.29	6.42
Zn						
Date	B	A	F	E	D	C
Concentration	68.96	79.60	80.95	84.64	84.81	100.36

[1] Lake stations only.

[2] A = 3 April; B = 7 June; C = 7 August; D = 14 September; E = 7 November; F = 8 December.

[3] Co, Fe, Mn, Sr, Zn in ug/g; Cs in ng/g.

Table A-24. Multiple range analysis of mean stable isotope concentrations in planktivorous fish from 3 April 1973 through 8 December 1973.[1]

Co						
Date[2]	F	E	D	B	C	A
Concentration[3]	0.27	0.42	0.68	0.73	0.86	1.09
Cs						
Date	A	B	F	C	E	D
Concentration	4.4	4.8	5.3	5.4	6.2	7.7
Fe						
Date	A	C	F	E	D	B
Concentration	32.27	35.16	42.64	43.28	49.19	54.42
Mn						
Date	D	A	C	B	F	E
Concentration	1.99	2.34	2.42	2.58	2.70	2.72
Sr						
Date	E	B	A	F	D	C
Concentration	2.05	2.16	2.26	2.45	3.01	3.18
Zn						
Date	F	D	E	A	C	B
Concentration	15.06	16.87	17.06	28.68	39.09	39.34

[1] Lake stations only.

[2] A = 3 April; B = 7 June; C = 7 August; D = 14 September; E = 7 November; F = 8 December.

[3] Co, Fe, Mn, Sr, Zn in ug/g; Cs in ng/g.

Table A-25. Multiple range analysis of mean stable isotope concentrations in piscivorous fish from 3 April 1973 through 8 December 1973.[1]

Co						
Date[2]	F	E	D	B	C	A
Concentration[3]	0.20	0.26	0.75	0.78	0.83	1.55
Cs						
Date	F	E	A	C	B	D
Concentration	5.8	7.6	7.8	7.8	8.0	8.4
Fe						
Date	E	F	A	D	C	B
Concentration	16.35	16.51	19.08	25.75	57.83	57.99
Mn						
Date	D	E	F	C	A	B
Concentration	0.64	0.72	0.89	1.14	1.45	1.64
Sr						
Date	A	B	D	E	F	C
Concentration	2.15	2.18	2.37	2.55	2.59	3.71
Zn						
Date	E	F	A	D	B	C
Concentration	11.90	13.98	18.64	19.14	41.34	56.67

[1] Lake stations only.

[2] A = 3 April; B = 7 June; C = 7 August; D = 14 September; E = 7 November; F = 8 December.

[3] Co, Fe, Mn, Sr, Zn in ug/g; Cs in ng/g.

Table A-26. Concentration (pCi/g) of ^{137}Cs ($\bar{x} \pm 1$ S.E.) in whole fish.

Feeding Type	Station	3 April	7 June	7 August	14 September	7 November	8 December
Bottom Feeders	1	0.021 ± 0.003	0.025 ± 0.001	0.030 ± 0.007	0.015 ± 0.002	BDL[1]	0.017 ± 0.007
	2	0.024 ± 0.001	0.031 ± 0.004	0.029 ± 0.003	0.018 ± 0.006	0.016 ± 0.003	BDL
	3	0.026 ± 0.004	0.028 ± 0.007	0.025 ± 0.002	0.016 ± 0.002	NC[2]	0.015 ± 0.011
	4	0.011 ± 0.001	0.024 ± 0.001	0.032 ± 0.004	0.017 ± 0.004	0.017 ± 0.002	NC
	5	0.024 ± 0.006	0.028 ± 0.006	0.020 ± 0.010	0.017 ± 0.003	NC	BDL
Planktivores	1	NC	NC	0.030 ± 0.002	NC	NC	0.013 ± 0.006
	2	0.024 ± 0.003	0.021 ± 0.004	0.025 ± 0.003	0.026 ± 0.015	0.016 ± 0.002	0.013 ± 0.003
	3	0.027 ± 0.003	NC	0.023 ± 0.008	0.024 ± 0.008	0.011 ± 0.001	BDL
	4	0.021 ± 0.002	0.022 ± 0.004	0.024 ± 0.004	0.022 ± 0.005	0.010 ± 0.004	0.011 ± 0.005
	5	0.019 ± 0.008	0.024 ± 0.006	0.020 ± 0.002	NC	0.012 ± 0.001	0.012 ± 0.001

Table A-26 (Cont'd):

Feeding Type	Station	3 April	7 June	7 August	14 September	7 November	8 December
Piscivores	1	NC	NC	NC	NC	0.061 $\pm$ 0.005	0.018 $\pm$ 0.005
	2	0.012 $\pm$ 0.007	0.030 $\pm$ 0.008	0.026 $\pm$ 0.002	0.086 $\pm$ 0.002	NC	NC
	3	NC	NC	NC	NC	0.065 $\pm$ 0.009	NC
	4	NC	0.025 $\pm$ 0.008	NC	NC	0.050 $\pm$ 0.002	NC
	5	NC	0.026 $\pm$ 0.001	NC	NC	NC	NC

[1]BDL = Below limits of detectability.

[2]NC = None captured.