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DYNAMICS OF MANGANESE, CADMIUM AND LEAD IN EXPERIMENTAL POWER PLANT PONDS

by

B. J. Mathis
T. F. Cummings
Mary Gower
Michael Taylor
Christine King

Departments of Biology and Chemistry
Bradley University
Peoria, Illinois 61625

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UNIVERSITY OF ILLINOIS
WATER RESOURCES CENTER
2535 Hydrosystems Laboratory
Urbana, Illinois 61801

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ABSTRACT

Dynamics of Manganese, Cadmium and Lead in Experimental Power Plant Ponds

This study was designed to determine the effect of heated power plant cooling water on the compartmentalization of manganese, lead and cadmium in experimental ponds. Caged channel catfish and green sunfish were kept in an experimental pond and a control pond. Periodically, whole fishes, gill, heart, kidney, liver and musculature were analyzed for the three metals. Concentrations of the three metals in fishes were not affected by the temperature differential maintained during the study. There was no correlation in concentrations of cadmium and lead with age (weight and length) of fishes but manganese concentrations declined slightly with age. The water component of the system contained the lowest concentration of the metals with sediments acting as a characteristic sink. Concentrations of the three metals in water and sediments of the ponds were unaffected by heat inasmuch as concentration differences between ponds were not significant at the .05 level. Aquatic organisms such as snails, fingernail clams, leeches, tubificid annelids and dragonfly nymphs exhibited concentrations of cadmium higher than sediments while snails and duckweed more closely reflected concentrations of manganese in sediments. Tubificid worms and leeches more closely reflected lead concentrations in sediments while fingernail clams and snails exhibited higher concentrations.

Mathis, B. J., T. F. Cummings, Mary Gower, Michael Taylor and Christing King
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Water Pollution*/ Heavy Metals*/ Biota*/ Illinois River*/ Manganese/ Cadmium/ Lead/ Atomic Absorption Spectrophotometry/ Benthos*/ Aquatic Environment*/ Limnology/ Food Chain*/ Lentic Environment

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OBJECTIVES

The objectives of this investigation were to (1) determine the effect of heated power plant water on the uptake and retention of manganese, cadmium and lead in selected aquatic invertebrates, channel catfish, green sunfish, and aquatic macrophytes and (2) to study the distribution of manganese, cadmium and lead in sediments and water of experimental power plant ponds.

The objectives were to be accomplished by (1) placing fingerling channel catfish and green sunfish in holding pens in two ponds, one an experimental pond and one a control pond. Whole fish and selected organs of channel catfish and green sunfish were to be analyzed intensively during the study. The experimental pond was to receive heated power plant water and be maintained 4-6^{o}C above ambient temperature during the study and (2) collecting sediments, water, Odonata nymphs, tubificid annelids, snails, leeches, fingernail clams and duckweed and analyzing for the metals.

A typical distribution profile for manganese, cadmium and lead for power plant cooling ponds was to be developed.

INTRODUCTION

Over the past few decades, a number of heavy metals have been released into the environment where most have been concentrated in sediments of aquatic environments, especially large navigable rivers. The significance of heavy metals and thermal enrichment in aquatic environments has been recognized by various regulatory agencies for some time. Tied in closely with this situation is the concomitant growth of electrical generating plants requiring large volumes of water for cooling purposes. As a result, aquatic organisms can be exposed to higher than normal ambient temperatures. A secondary problem related to this is the potential for synergistic effects of heavy metals and heated water.

In recent years, a number of investigations have been made on the distribution of heavy metals in aquatic systems (Mathis and Cummings, 1973; Mathis and Kevern, 1975; Enk and Mathis, 1977; Collinson and Shimp, 1972; Bulthuis, Craig and McNabb, 1974). Most investigations have been concerned with the dynamics of heavy metals at ambient temperatures and, in general, it has been shown that certain metals are accumulated in tissues of aquatic organisms. A number of investigations have also been made on the effects of heated effluents on aquatic life in the past few years (Schubel, 1974; Bennet, 1972; Gibbons and Bennet, 1973).

Most studies have dealt with one problem or the other with few studies concerned with both temperature and heavy metals. A significant number of studies, however, have been performed under controlled laboratory conditions. Rehwoldt et al. (1972) showed that cadmium toxicity for fishes at 15°C and 28°C was not significantly different. Jude (1973) reported that green sunfish exposed to 0.05 ppm cadmium accumulated in 20 days as much cadmium as fish exposed to 2 ppm cadmium and that effects of temperature on cadmium uptake were not significant. On the other hand, a study by van Breedveld (1971) showed that tissue fat in oysters exhibited increased cadmium and manganese concentrations with increasing temperatures. Lead, on the other hand, declined initially with increased temperature but then increased.

Studies on the distribution of heavy metals in aquatic ecosystems have shown that sediments act as a sink for heavy metals (Mathis and Cummings, 1973; Mathis and Kevern, 1975; Enk and Mathis, 1977; Collinson and Shimp; 1972). Aquatic organisms such as annelids and clams inhabitating bottom sediments have been shown to exhibit higher lead and cadmium concentrations than fishes while lowest concentrations are found in water (Mathis and Cummings, 1973). Both lead and cadmium exhibit similar concentration profiles in normal aquatic systems, but little is known about the profile for manganese. Lentsch et al. (1971) found that the manganese content of several species of rooted aquatic plants was proportional to the dissolved manganese concentrations in water while several species of fishes maintained relatively constant manganese levels regardless of concentrations in water. Harvey (1971a) demonstrated that midge larvae are poor concentrators of manganese. In another study, Harvey (1971b) showed that temperature had no effect on the sorption of the radioisotope manganese-54 by freshwater algae. Manganese is probably not as limnologically important as cadmium and lead inasmuch as it is essential as a trace element for all living organisms (Bowen, 1966). Kotliarevski, however, as quoted by Medved et al. (1964) reported the production of abnormalities in conditioned responses of dogs following exposure to manganese dust at levels too low to produce any normal signs of poisoning.

Aquatic organisms are expected to experience an increase in metabolic rate due to increased temperatures. Bennet (1971) has shown that largemouth bass captured in heated environments had significantly higher body temperatures than those from control areas. As a result, fishes exposed to higher temperatures would be expected to exhibit higher maintenance requirements. On the other hand, an investigation of the effects of heated power plant cooling water on five species of fish eggs by Schubel (1974) concluded that entrainment times of 2.5 to 60 minutes and temperature changes of 6-10°C did not significantly affect hatching success.

The present study was designed to examine the dynamics of cadmium, lead and manganese in an aquatic ecosystem under actual field conditions to determine if typical compartmentalization of these metals is retained under conditions of thermal enrichment.

DESCRIPTION OF STUDY AREA

Two shallow ponds (approximately 75' X 75' X 5') located on the Central Illinois Light Company's E. D. Edwards coal fired electrical generating station were utilized in this study. The ponds were identical with one serving as an experimental pond and the other serving as a control pond. Both ponds received Illinois River water from the plant. Unheated river water was allowed to flow continuously through the control pond, while once through cooling water was pumped from a discharge tunnel into the experimental pond where it was allowed to flow back into the river. Pond levels were maintained at a constant depth by means of upright overflow pipes. The temperature differential was maintained at 4-6°C for 133 out of 139 days from June 16, 1975, through November 1, 1975, and for 55 days from April 22, 1976, through June 15, 1976.

METHODS AND MATERIALS

Field Procedures

Approximately 125 channel catfish, Ictalurus punctatus, averaging 16.3 cm in length and 35.0 g in weight, were placed in ¼ inch mesh net pens in each pond (one experimental and one control) during May of 1975 along with 100 green sunfish, Lepomis cyanellus, averaging 8.3 cm and 15.0 g. Heavy ice cover on both ponds during January of 1976 killed the catfish in both ponds. In March of 1976, the pens were restocked with 300 channel catfish averaging 13.9 cm in length and 19.4 g in weight. At the end of the study, the green sunfish averaged 13.4 cm in length and 49.0 g in weight. Channel catfish placed in the nets during May, 1975, averaged 25.2 cm and 172 g when the last sample was taken in November of 1975. Channel catfish used in the restocking averaged 17.0 cm and 43.4 g at the end of the study. Fishes were fed on commercial grade fish food consisting of floating and sinking trout chow and catfish chow. Mean manganese concentration in the fish food was 109 ppm, mean cadmium concentration was 0.23 ppm and mean lead concentration was 5.7 ppm.

At periodic intervals, six to twelve individuals of each species were removed from each pond and sacrificed in order to remove gill, heart, liver, kidney, and muscle tissue. Tissue samples were placed in acid washed beakers and kept frozen until digestion. Six whole fish were also weighed and frozen for whole body analysis at this time. Digestion of whole catfish was discontinued after June of 1975, however, because they had become too large. After restocking in March of 1976, whole catfish were again digested and analyzed.

Aquatic macroinvertebrates such as snails, Physa sp., and Odonata nymphs, Enallagma sp., Leucorrhinia sp. and Erythmis sp., were collected by hand from algal mats growing in the ponds. Benthic macroinvertebrates such as the leech, Glossiphonia heteroclita, the fingernail clam, Musculium transversum, and the tubificid annelid, Limnodrilus hoffmeistri, were separated from Ekman dredge samples by means of soil sieves.

Aquatic macroinvertebrates were brought back to the laboratory and kept alive in pond water. Before weighing, they were allowed to dry for five minutes and then sponged. Duckweed, Lemma minor, was removed from the water, sponged and weighed. Samples were kept frozen prior to digestion.

Laboratory Procedures

Flame atomic absorption spectrophotometry was utilized to determine metal concentrations in all samples according to procedures utilized by Mathis and Cummings (1973). Fishes, fish tissues and invertebrates were digested in concentrated nitric acid while bottom sediments were extracted with nitric acid. The amount of acid used was recorded and metal impurities were subtracted from final readings.

Water samples were filtered in order to remove such impurities as clay particles and plankton. Manganese was determined by aspirating the water samples directly into the spectrophotometer but lead and cadmium had to be concentrated by extraction with ammonium pyrrolidinecarbodithioate into methyl isobutyl ketone (MIBK). In order to perform lead and cadmium determinations, a water saturated MIBK blank was continuously aspirated into the spectrophotometer in order to obtain a constant base line on the recorder. All samples were analyzed on a Perkin-Elmer model 290-B atomic absorption spectrophotometer and metal concentrations were determined as follows:

$$\begin{array}{c}\text{ppm of metal}\\ \text{in solution}\end{array} \times \frac{\text{Final Volume of extract (10 mls)}}{\text{grams of sample}} = \begin{array}{c}\text{ppm of metal}\\ \text{in sample}\end{array}$$

RESULTS AND DISCUSSION

Manganese

Manganese, as opposed to cadmium and lead, is a biologically essential metal in all organisms (Bowen, 1966) inasmuch as it activates numerous enzymes. It is used extensively for manufacturing steel alloys, dry-cell batteries, glass, ceramics, paints, varnishes, inks, dyes and matches (McKee and Wolf, 1963). Manganese is not highly toxic to aquatic organisms. Clemens and Sneed (1959) reported that fingerling channel catfish were able to tolerate 40 ppm of manganese (from manganese disodium versenate) for four days. McKee and Wolf (1963) suggested that 1.0 ppm of manganese is not deleterious to fish and aquatic life.

In the present study, highest concentrations of manganese were found in snails and sediments (Fig. 1). On the basis of this study it appears that snails may be capable of accumulating manganese to levels found in sediments. Sediments, as with cadmium and lead, acted as a sink for manganese.

Differences between the ponds in the concentrations of manganese in water and sediments were not significant at the .05 level (Table 1). The metal was more highly concentrated in heart tissue of both species of fishes with lowest concentrations found in muscle tissue (Tables 2, 3 and 4). Concentrations in whole fish declined slightly as weight and length increased (See Appendix). Cross et al. (1973) reported that manganese either decreases or remains constant in whole fish as a function of age. Concentrations of manganese in fish organs remained essentially constant or declined slightly with age also (See Appendix). There were, however, no significant differences in metal concentrations in fishes between the ponds at the .05 level (Tables 5 and 6). In a study of temperature effects on absorption of ^{54}Mn by a blue

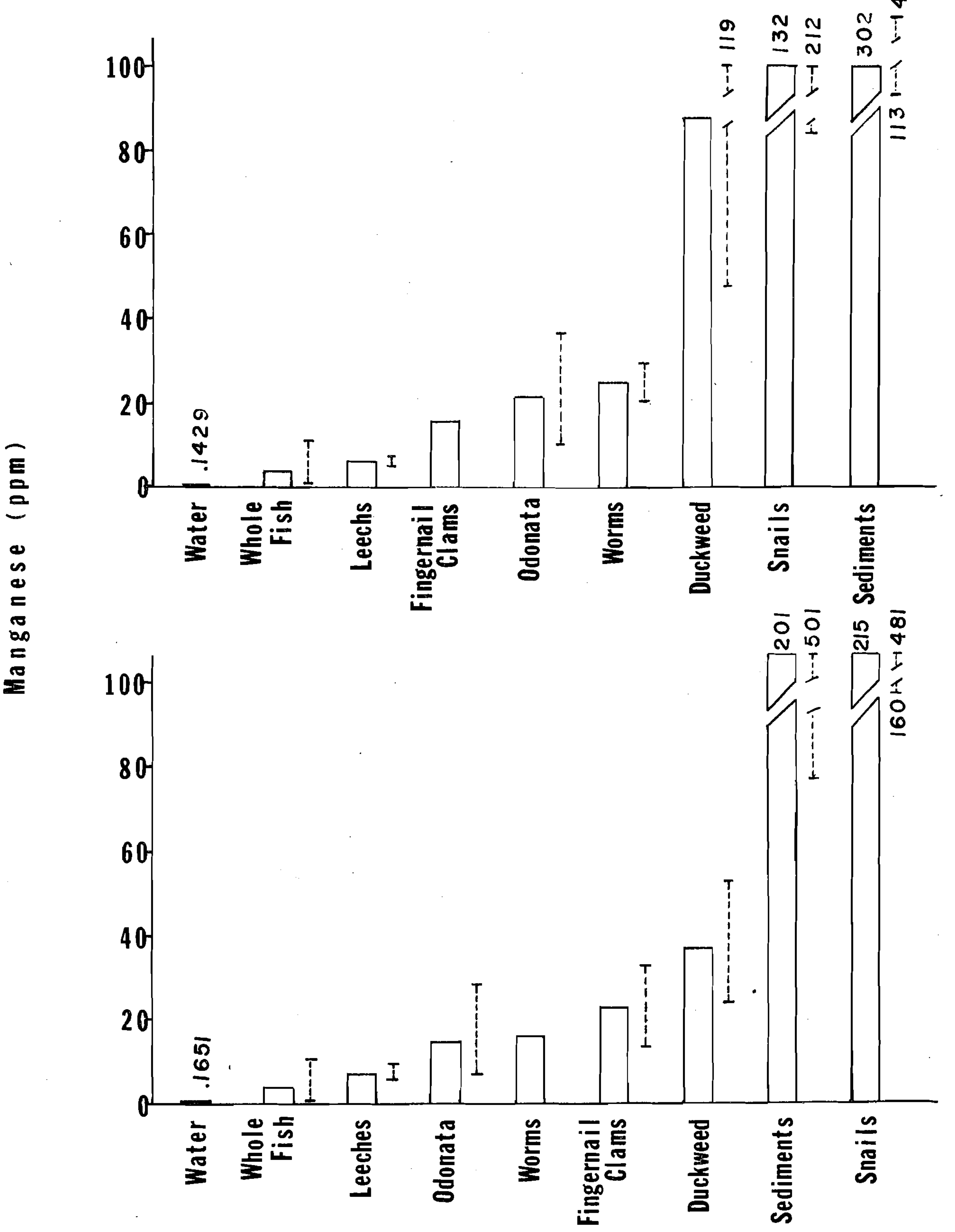

Figure 1. Distribution of manganese in experimental power plant ponds. Upper graph = control pond; lower graph = experimental pond; ⊢----⊣ = range.

TABLE 1

SUMMARY TABLE FOR MULTIPLE ANOVAS - METALS IN WATER AND SEDIMENTS FROM CONTROL AND EXPERIMENTAL PONDS

	Metal					
Observation	Manganese		Cadmium		Lead	
	Degrees of Freedom	F	Degrees of Freedom	F	Degrees of Freedom	F
Water	1,29	0.83	1,18	0.36	1,14	0.35
Sediments	1,16	2.83	1,16	0.10	1,16	0.0015

None of the F ratios were significant at the 0.05 level.

TABLE 2

DISTRIBUTION OF MANGANESE, CADMIUM AND LEAD IN CAGED CHANNEL CATFISH - FALL, 1975

Organ		Control Pond			Experimental Pond		
		Mn (ppm)	Cd (ppm)	Pb (ppm)	Mn (ppm)	Cd (ppm)	Pb (ppm)
Whole Fish	Mean	2.6	0.19	0.60	2.8	0.20	0.84
	Range	0.4 - 5.0	0.05 - 0.46	0.03 - 1.73	0.5 - 5.7	0.09 - 0.46	0.03 - 1.82
	N	11	11	10	11	11	10
	C.I.	1.7 - 3.6	0.11 - 0.26	0.21 - 0.98	1.7 - 3.9	0.14 - 0.27	0.36 - 1.32
Gill	Mean	3.9	0.78	2.53	3.9	0.75	2.50
	Range	2.1 - 8.4	0.30 - 3.21	0.23 - 5.15	2.0 - 8.5	0.29 - 2.63	0.23 - 4.70
	N	30	31	31	30	31	31
	C.I.	3.3 - 4.4	0.53 - 1.10	2.00 - 3.05	3.3 - 4.5	0.54 - 0.95	2.00 - 2.88
Heart	Mean	6.8	16.5	24.9	6.3	11.3	18.5
	Range	1.5 - 37.2	1.5 - 87.1	6.4 - 86.2	0.7 - 26.6	1.9 - 75.4	2.1 - 74.1
	N	28	27	27	31	29	31
	C.I.	4.0 - 9.6	8.1 - 24.8	16.9 - 32.8	3.8 - 8.8	5.6 - 16.9	13.4 - 23.6
Kidney	Mean	1.5	1.6	2.7	1.5	1.7	3.2
	Range	0.5 - 6.5	0.4 - 5.4	0.2 - 9.9	0.2 - 2.6	0.5 - 4.8	0.2 - 9.9
	N	31	30	30	32	32	30
	C.I.	1.1 - 1.9	1.1 - 2.1	1.8 - 3.6	1.3 - 1.7	1.3 - 2.1	2.3 - 4.1
Liver	Mean	1.7	0.98	1.13	1.4	0.69	1.23
	Range	0.8 - 6.9	0.13 - 6.42	0.22 - 2.78	0.6 - 6.9	0.003 - 4.1	0.34 - 5.03
	N	31	31	29	32	32	31
	C.I.	1.2 - 2.2	0.48 - 1.48	0.89 - 1.37	1.0 - 1.9	0.37 - 1.00	0.87 - 1.57
Muscle Tissue	Mean	0.63	0.41	0.66	0.35	0.24	0.53
	Range	0.05 - 4.76	0.04 - 1.85	0.04 - 4.78	0.17 - 0.78	0.005 - 1.23	0.04 - 2.28
	N	31	31	31	30	29	29
	C.I.	0.25 - 1.00	0.23 - 0.59	0.31 - 1.00	0.29 - 0.41	0.13 - 0.35	0.34 - 0.70

* C.I. = Confidence Interval (Mean ± t.95 x standard error of the mean).

TABLE 3

DISTRIBUTION OF MANGANESE, CADMIUM AND LEAD IN CAGED CHANNEL CATFISH - SPRING, 1976

Organ		Control Pond			Experimental Pond		
		Mn (ppm)	Cd (ppm)	Pb (ppm)	Mn (ppm)	Cd (ppm)	Pb (ppm)
Whole Fish	Mean	4.5	0.18	1.0	3.7	0.17	1.0
	Range	0.3 - 10.5	0.05 - 0.33	0.07 - 2.5	0.5 - 10.5	0.06 - 0.33	0.05 - 3.2
	N	31	31	31	32	32	32
	C.I.	3.5 - 5.5	0.15 - 0.21	0.7 - 1.3	2.8 - 4.5	0.15 - 0.21	0.7 - 1.2
Gill	Mean	4.5	0.63	2.5	4.7	0.72	2.4
	Range	2.4 - 12.5	0.09 - 1.29	0.9 - 5.7	2.6 - 12.5	0.18 - 1.78	1.2 - 5.7
	N	28	29	29	28	29	29
	C.I.	3.6 - 5.5	0.50 - 0.77	2.2 - 2.9	3.8 - 5.6	0.56 - 0.88	2.0 - 2.7
Heart	Mean	7.2	10.6	27.0	6.5	12.9	22.7
	Range	1.4 - 19.4	1.6 - 40.7	3.5 - 71.4	0.2 - 42.0	0.16 - 62.0	6.1 - 60.8
	N	28	27	29	29	27	30
	C.I.	5.0 - 9.4	7.3 - 14.0	20.1 - 33.9	3.6 - 9.5	8.1 - 17.7	17.1 - 28.1
Kidney	Mean	1.98	1.78	2.89	2.15	1.64	1.85
	Range	0.56 - 5.57	0.34 - 7.33	0.61 - 8.58	0.88 - 5.89	0.46 - 7.33	1.11 - 8.58
	N	30	28	30	30	28	30
	C.I.	1.51 - 2.46	1.16 - 2.39	2.11 - 3.67	1.65 - 2.63	1.13 - 2.15	2.60 - 3.96
Liver	Mean	1.31	0.77	1.17	1.40	0.81	1.44
	Range	0.47 - 2.08	0.10 - 5.90	0.36 - 4.01	0.61 - 3.20	0.15 - 5.90	0.55 - 4.00
	N	30	29	29	30	29	30
	C.I.	1.18 - 1.44	0.38 - 1.16	0.89 - 1.45	1.21 - 1.58	0.43 - 1.20	1.19 - 1.70
Muscle Tissue	Mean	0.40	0.14	0.50	0.41	0.14	0.46
	Range	0.18 - 1.08	0.02 - 0.30	0.22 - 1.38	0.20 - 1.08	0.03 - 0.30	0.08 - 1.64
	N	30	30	30	27	27	27
	C.I.	0.33 - 0.48	0.11 - 0.16	0.38 - 0.59	0.32 - 0.49	0.11 - 0.16	0.33 - 0.60

* C.I. = Confidence Interval (Mean ± t.95 x standard error of the mean).

TABLE 4

DISTRIBUTION OF MANGANESE, CADMIUM AND LEAD IN CAGED GREEN SUNFISH

		Control Pond			Experimental Pond		
Organ		Mn (ppm)	Cd (ppm)	Pb (ppm)	Mn (ppm)	Cd (ppm)	Pb (ppm)
	Mean	3.9	0.39	2.2	4.7	0.45	2.4
Whole	Range	0.7 - 8.2	0.03 - 0.90	0.2 - 6.3	0.7 - 10.2	0.05 - 1.24	0.2 - 4.5
Fish	N	47	48	48	51	50	51
	C.I.	3.4 - 4.5	0.33 - 0.45	1.8 - 2.7	4.1 - 5.2	0.37 - 0.53	2.0 - 2.8
	Mean	7.8	1.5	4.6	7.4	1.6	5.4
Gill	Range	0.7 - 27.8	1.0 - 7.3	0.6 - 12.4	4.4 - 15.8	1.0 - 7.3	0.8 - 20.8
	N	33	33	33	37	37	36
	C.I.	5.8 - 9.8	0.9 - 2.1	3.4 - 5.4	6.5 - 8.4	1.1 - 2.1	4.1 - 6.7
	Mean	21	55	104	28	37	121
Heart	Range	3 - 214	2 - 560	7 - 1241	2 - 460	2 - 322	6 - 692
	N	37	38	38	37	38	38
	C.I.	7 - 34	13 - 97	35 - 174	3 - 53	17 - 55	64 - 178
	Mean	1.5	0.99	2.1	1.2	1.03	1.8
Liver	Range	0.2 - 7.5	0.15 - 4.41	0.2 - 7.8	0.2 - 7.4	0.31 - 4.88	0.4 - 5.7
	N	38	38	38	37	38	36
	C.I.	1.1 - 1.9	0.67 - 1.31	1.5 - 2.7	0.8 - 1.6	0.74 - 1.33	1.4 - 2.2
	Mean	0.64	0.31	0.94	0.72	0.47	0.90
Muscle	Range	0.19 - 2.85	0.006 - 2.15	0.03 - 3.90	0.07 - 2.85	0.09 - 3.39	0.03 - 3.40
Tissue	N	37	36	37	34	33	34
	C.I.	0.44 - 0.84	0.17 - 0.44	0.67 - 1.28	0.47 - 0.96	0.23 - 0.71	0.62 - 1.18

* C.I. = Confidence Interval (Mean ± t.95 x standard error of the mean).

TABLE 5

SUMMARY TABLE FOR MULTIPLE ANOVAS - MANGANESE IN CHANNEL CATFISH FROM CONTROL AND EXPERIMENTAL PONDS

	Fall, 1975		Spring, 1976	
Organ	Degrees of Freedom	F	Degrees of Freedom	F
Whole Fish	1,20	0.07	1,61	1.86
Gill	1,58	0.00005	1,54	0.07
Heart	1,57	0.10	1,55	0.15
Kidney	1,61	0.03	1,58	0.22
Liver	1,61	0.70	1,58	0.64
Musculature	1,59	2.1	1,55	0.0027

None of the F ratios were significant at the 0.05 level.

TABLE 6

SUMMARY TABLE FOR MULTIPLE ANOVAS - MANGANESE IN GREEN SUNFISH FROM CONTROL AND EXPERIMENTAL PONDS

Organ	Degrees of Freedom	F
Whole Fish	1,96	0.34
Gill	1,68	0.13
Heart	1,72	0.28
Liver	1,73	1.31
Musculature	1,69	0.25

None of the F ratios were significant at the 0.05 level.

green alga, Harvey (1967) concluded that nonlethal variations in water temperature had no effect on manganese uptake.

Cadmium

Cadmium was detected at all levels in both ponds (Fig. 2). It was more highly concentrated in aquatic invertebrates than in sediments. In the present study, Odonata nymphs (dragonflies and damselflies), fingernail clams, snails and worms had higher concentrations of cadmium than other components of the system. In an earlier study of a stream ecosystem, Enk and Mathis (1977) determined that Odonata nymphs had higher cadmium concentrations than other aquatic insects. The relatively high levels of cadmium observed in both snails and clams is indicative of the ability of molluscs to accumulate the metal to higher than background levels, an observation reported by Eustace (1974) and Eisler, Zargoogian and Hennekey (1972).

As reported in earlier investigations, sediments act as a sink for cadmium (Mathis and Cummings, 1973; Mathis and Kevern, 1975; and Enk and Mathis, 1977). In the present study, there was roughly 450 times as much cadmium in sediments as in water and the differences in concentrations in both ponds were insignificant at the .05 level (Table 1).

An analysis of cadmium in caged channel catfish and green sunfish indicated that concentrations are quite variable in whole fish as well as selected organs but that heart tissue had higher concentration (Tables 2,3 and 4). There was no significant correlation between length, weight and cadmium concentration in either species, an observation earlier reported by Eustace (1974), Lovett et al. (1972) and Havre, Underdal and Christiansen (1973).

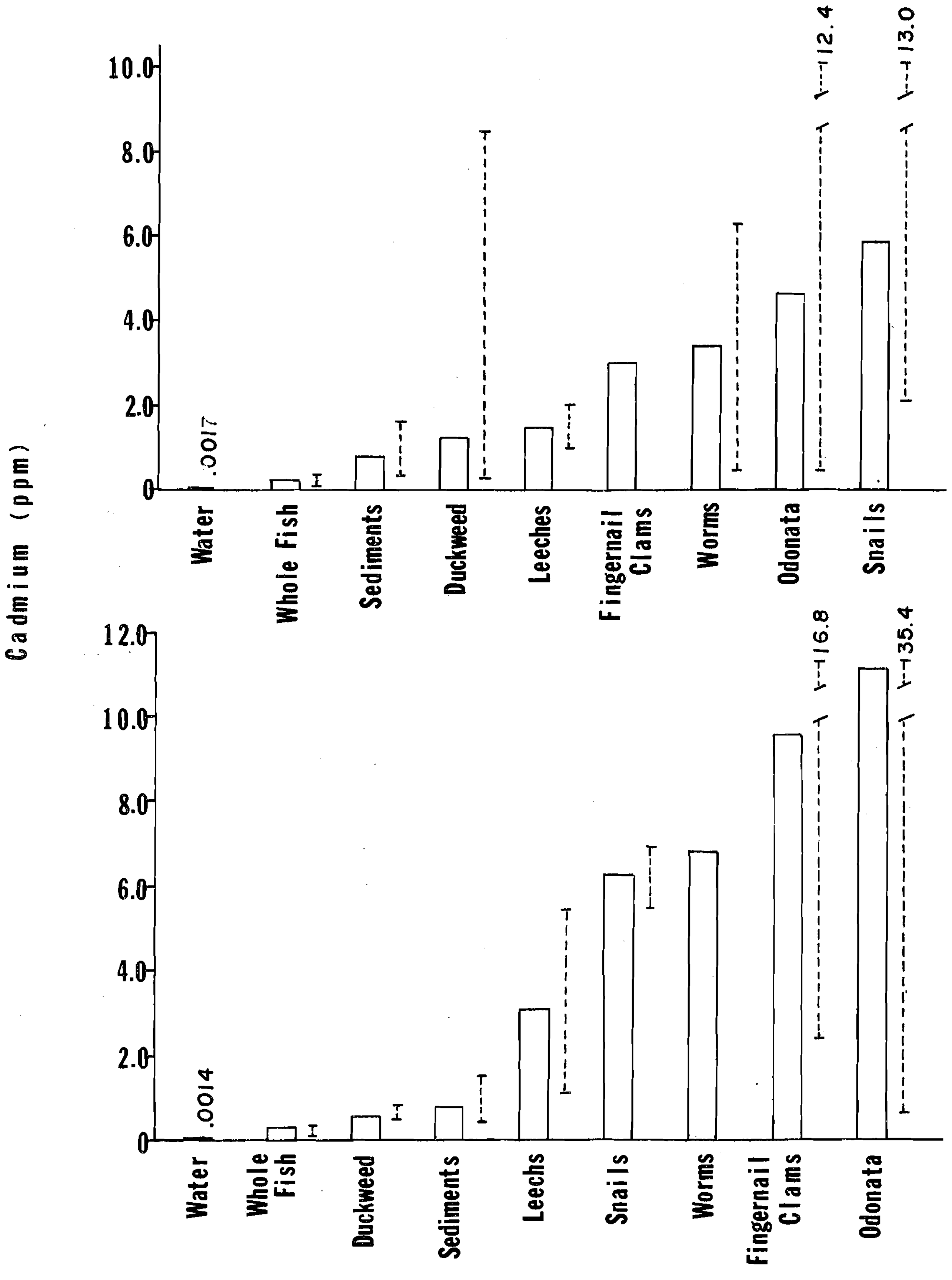

Figure 2. Distribution of cadmium in experimental power plant ponds. Upper graph = control pond; lower graph = experimental pond; ⊢- - - -⊣ = range.

Any effect of temperature on the uptake of cadmium by both green sunfish and catfish was not discernible in this study. Analysis of variance showed any differences in concentrations between ponds to be insignificant at the .05 level (Tables 7 and 8). Jude (1973) reported that the effects of temperature on cadmium uptake in green sunfish was of little importance.

Lead

Lead was present in greatest concentration in snails and clams of both ponds (Fig. 3). Snails are classified as detritus feeders and grazers and it has been shown by other investigations (Enk and Mathis 1977; Leland and McNurney, 1974) that they typically contain concentrations of lead higher than concentrations in sediments. Bottom dwelling fingernail clams also exhibited concentrations of lead higher than in sediments. In an earlier study, Mathis and Cummings (1973) reported that lead concentrations in three species of freshwater mussels were somewhat less than concentrations in sediments. In the present study, however, the whole organism (valves included) was digested for analysis while soft tisuue only was utilized in the 1973 study. Mussels have been suggested as indicators of lead contamination. The common mussel *Mytilus edulis*, directly reflects the actual lead concentration in the environment (Schulz-Baldes, 1973).

As was the case with manganese and cadmium, differences in lead concentrations in water and sediments between ponds were insignificant at the .05 level (Table 1). Bottom sediments also acted as a sink for the metal since lead in sediments was concentrated some 4,000 times that in water.

TABLE 7

SUMMARY TABLE FOR MULTIPLE ANOVAS - CADMIUM IN CHANNEL CATFISH FROM CONTROL AND EXPERIMENTAL PONDS

	Fall, 1975		Spring, 1976	
Organ	Degrees of Freedom	F	Degrees of Freedom	F
Whole Fish	1,20	0.09	1,61	0.02
Gill	1,60	0.04	1,56	0.65
Heart	1,54	1.11	1,52	0.60
Kidney	1,60	0.22	1,54	0.13
Liver	1,61	0.96	1,56	0.023
Muscle Tissue	1,58	2.60	1,55	0.004

None of the F ratios were significant at the 0.05 level.

TABLE 8

SUMMARY TABLE FOR MULTIPLE ANOVAS - CADMIUM IN GREEN SUNFISH FROM CONTROL AND EXPERIMENTAL PONDS

Organ	Degrees of Freedom	F
Whole Fish	1,96	1.24
Gill	1,68	0.0052
Heart	1,74	0.68
Liver	1,74	0.04
Muscle Tissue	1,67	1.50

None of the F ratios were significant at the 0.05 level.

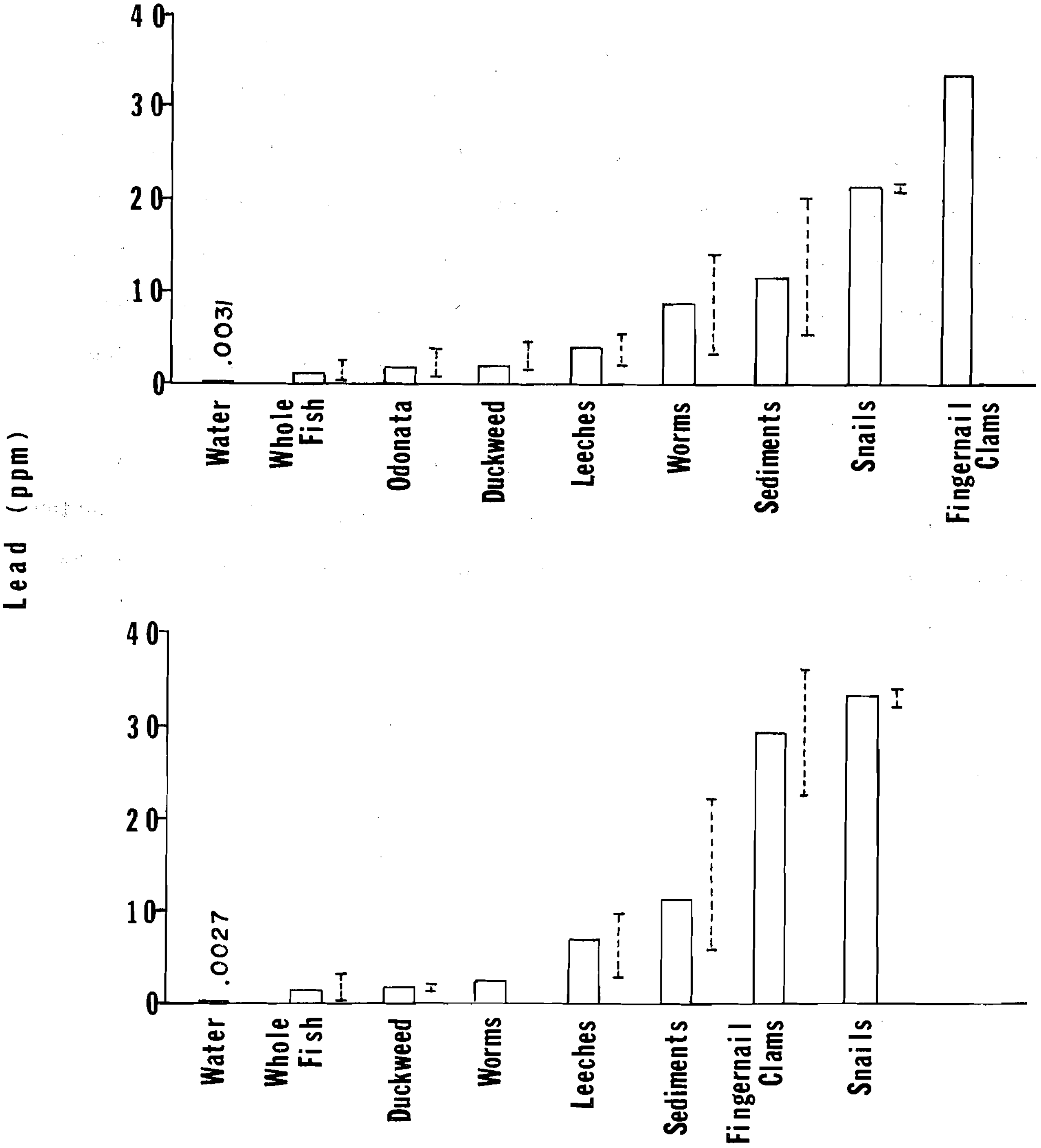

Figure 3. Distribution of lead in experimental power plant ponds. Upper graph = control pond; lower graph = experimental pond; ⊢----⊣ = range.

In this study, analysis of variance showed no significant differences in lead concentrations of fishes between the two ponds at the .05 level (Tables 9 and 10). As with cadmium, there was no correlation between age (weight and length) and lead concentration (See Appendix). Heart tissue in both species had highest mean concentrations of lead (Tables 2, 3 and 4) and concentrations in individual fishes varied considerably. In a study of brook trout Holcombe et al. (1976) reported that gill, liver and kidney tissue accumulated the greatest amount of lead.

All three metals examined in this study appear to be unaffected by thermal enrichment of 4-6°C above ambient. The model of compartmentalization determined for the control pond was, with minor variations, mirrored by the experimental pond.

TABLE 9

SUMMARY TABLE FOR MULTIPLE ANOVAS - LEAD IN CHANNEL CATFISH FROM CONTROL AND EXPERIMENTAL PONDS

	Fall, 1975		Spring, 1976	
Organ	Degrees of Freedom	F	Degrees of Freedom	F
Whole Fish	1,18	0.73	1,61	0.07
Gill	1,60	0.06	1,56	0.63
Heart	1,56	1.93	1,57	1.00
Kidney	1,58	0.61	1,58	0.54
Liver	1,58	0.21	1,57	2.08
Musculature	1,58	0.41	1,55	0.07

None of the F ratios were significant at the 0.05 level.

TABLE 10

SUMMARY TABLE FOR MULTIPLE ANOVAS - LEAD IN GREEN SUNFISH FROM CONTROL AND EXPERIMENTAL PONDS

Organ	Degrees of Freedom	F
Whole Fish	1,97	0.47
Gill	1,67	1.12
Heart	1,74	0.14
Liver	1,72	0.76
Musculature	1,69	0.04

None of the F ratios were significant at the 0.05 level.

SUMMARY

The dynamics of manganese, cadmium and lead in experimental power plant ponds were studied by means of atomic absorption spectrophotometry. Two ponds were utilized in the study with one pond serving as a control pond and the other as an experimental pond. Two populations of channel catfish and one population of green sunfish were exposed to a temperature differential of 4-6°C during the study. Significant differences in concentrations of the three metals in fishes, sediments and water from the ponds were not discernible at the .05 level.

Snails and duckweed had concentrations of manganese similar to concentrations in sediments. Cadmium, on the other hand, was more highly concentrated in tubificid worms, fingernail clams, snails, leeches and Odonata nymphs than in sediments. Fingernail clams and snails exhibited higher lead concentrations than sediments while tubificid worms and leeches had concentrations similar to sediments.

Whole fish had lower concentrations of all three metals than any of the components that were analyzed except for water. Manganese in whole fish was concentrated 20 times over water while cadmium was 170 times greater than water and lead was 460 times more than water.

There was no correlation between age (weight and length) and concentrations of cadmium and lead in either whole fishes or tissues. Manganese in whole fish, on the other hand, declined slightly as weight and length increased.

Compartmentalization of the three metals appears to be unaffected by thermal enrichment.

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POTENTIAL APPLICATION TO WATER RESOURCES PROBLEMS

The results of this research should prove useful to the Environmental Protection Agency, to utility companies and to fish culturists who may be planning to utilize thermal enrichment to prolong growing seasons.

APPENDIX

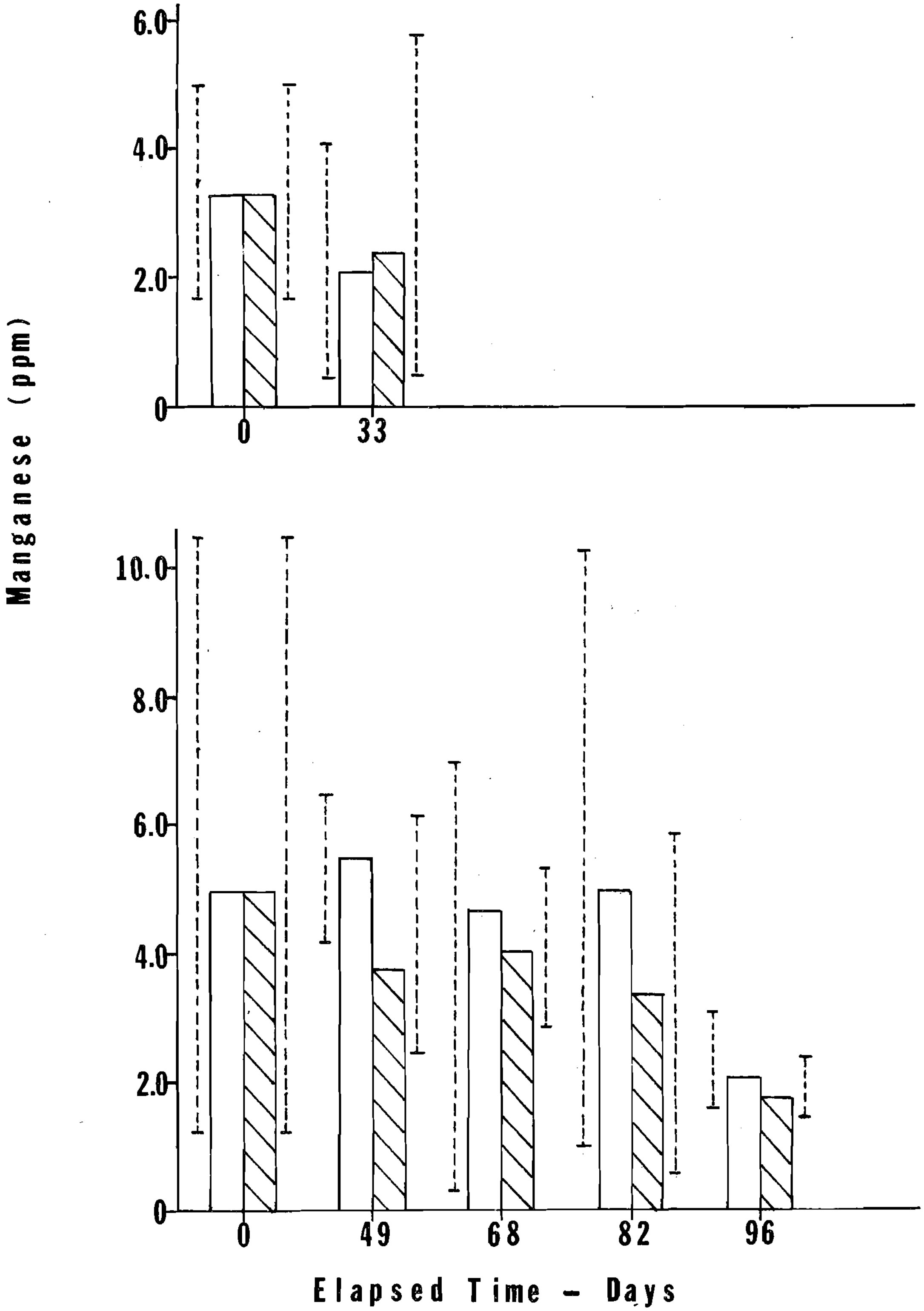

Figure 4. Manganese in whole channel catfish. Upper graph = Fall, 1975; lower graph = Spring, 1976. ☐ = control pond; ▨ = experimental pond; ├----┤ = range.

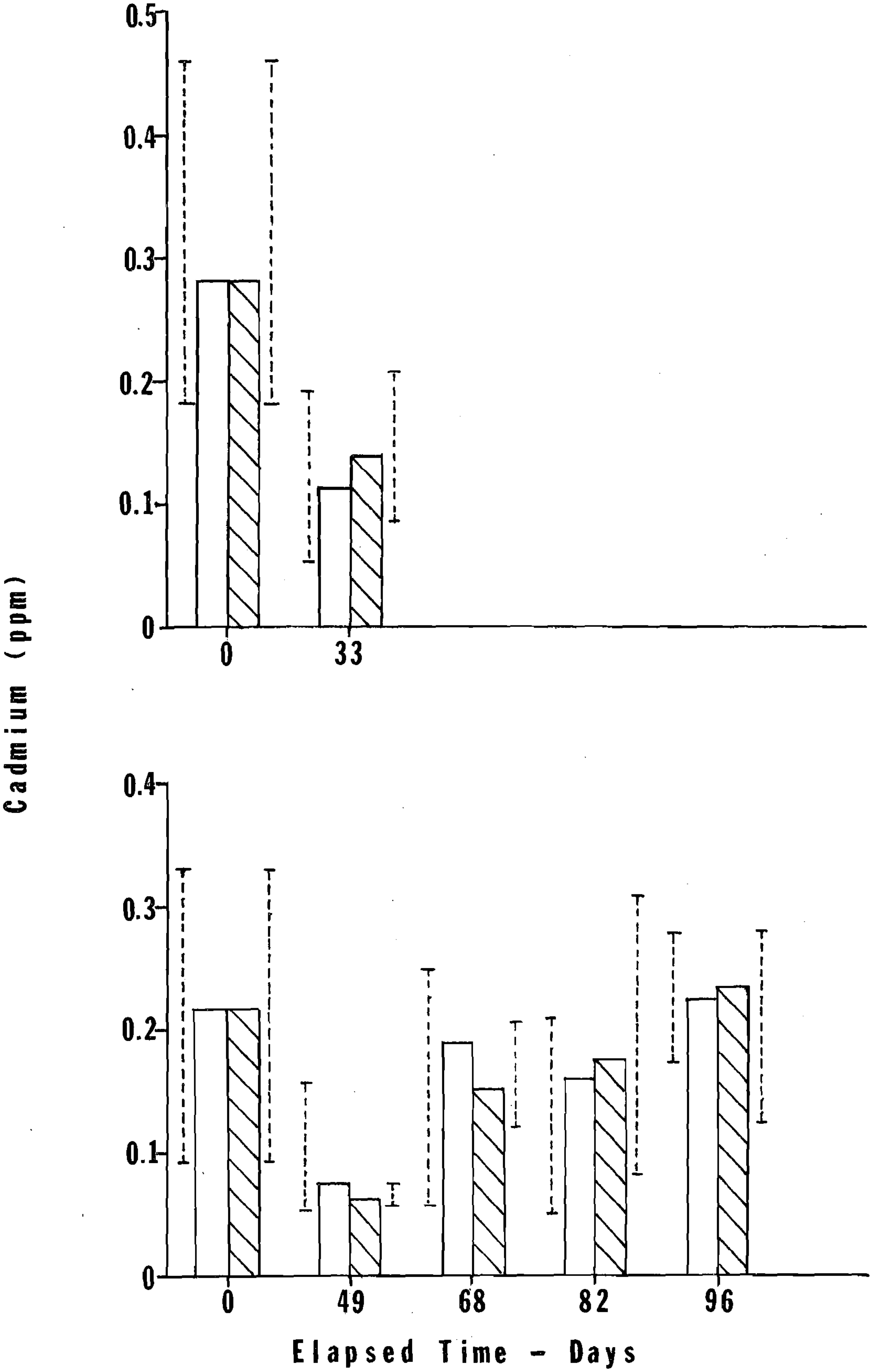

Figure 5. Cadmium in whole channel catfish. Upper graph = Fall, 1975; lower graph = Spring, 1976. ☐ = control pond; ▨ = experimental pond; ⊢- - -⊣ = range.

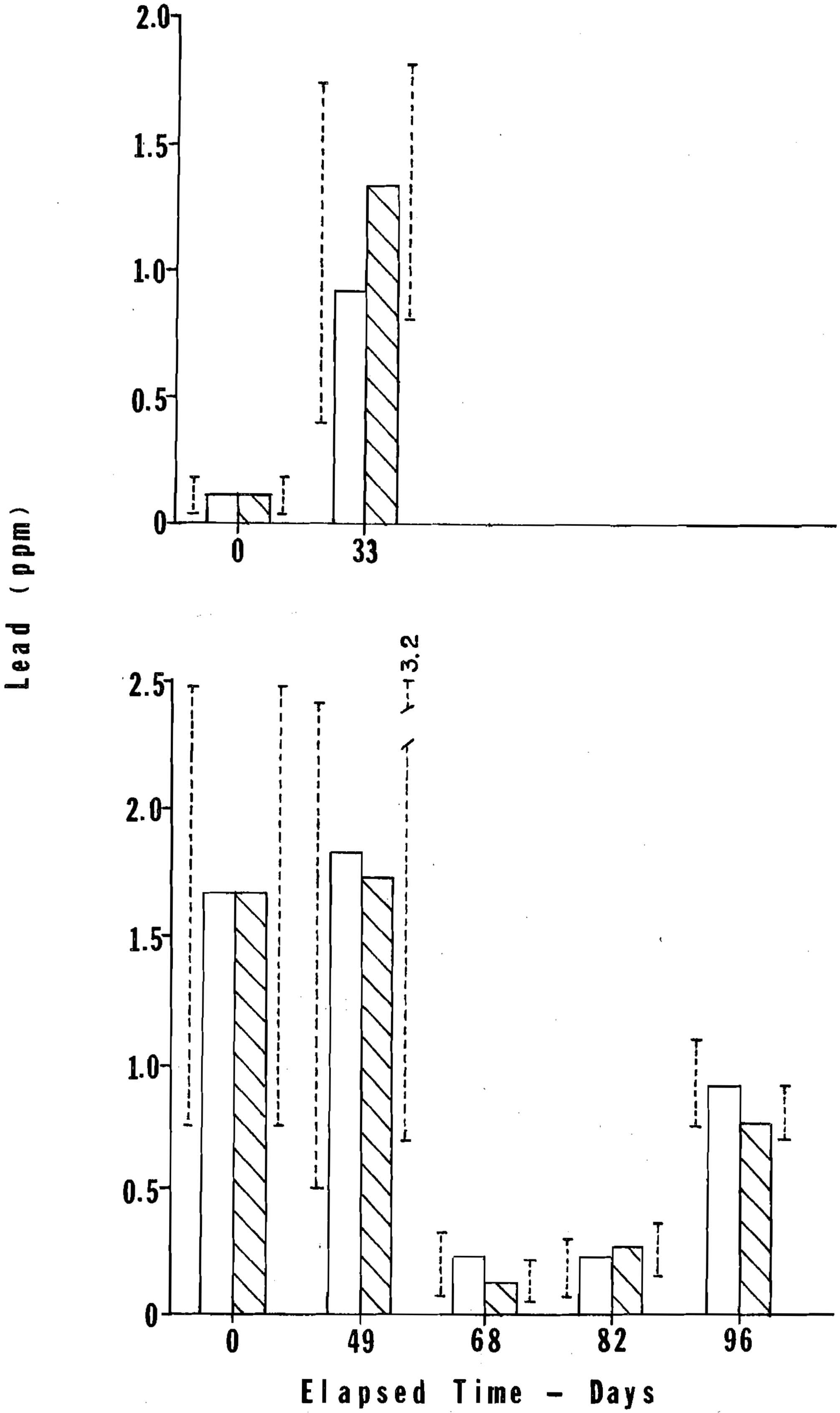

Figure 6. Lead in whole channel catfish. Upper graph = Fall, 1975; lower graph = Spring, 1976. ☐ = control pond; ▨ = experimental pond; ⊢---⊣ = range.

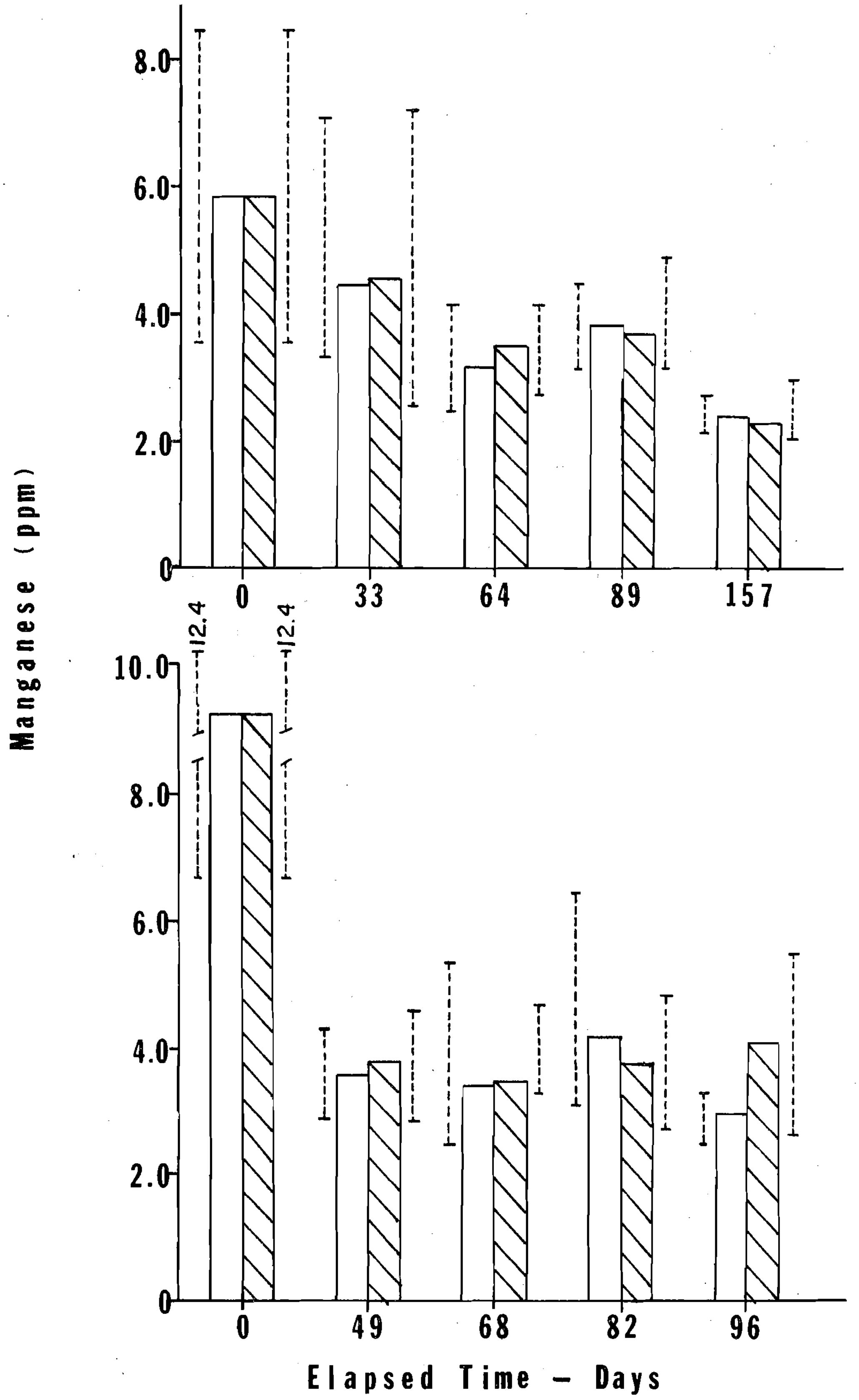

Figure 7. Manganese in gill tissue of channel catfish. Upper graph = Fall, 1975; lower graph = Spring, 1976. □ = control pond; ▨ = experimental pond; ⊢---⊣ = range.

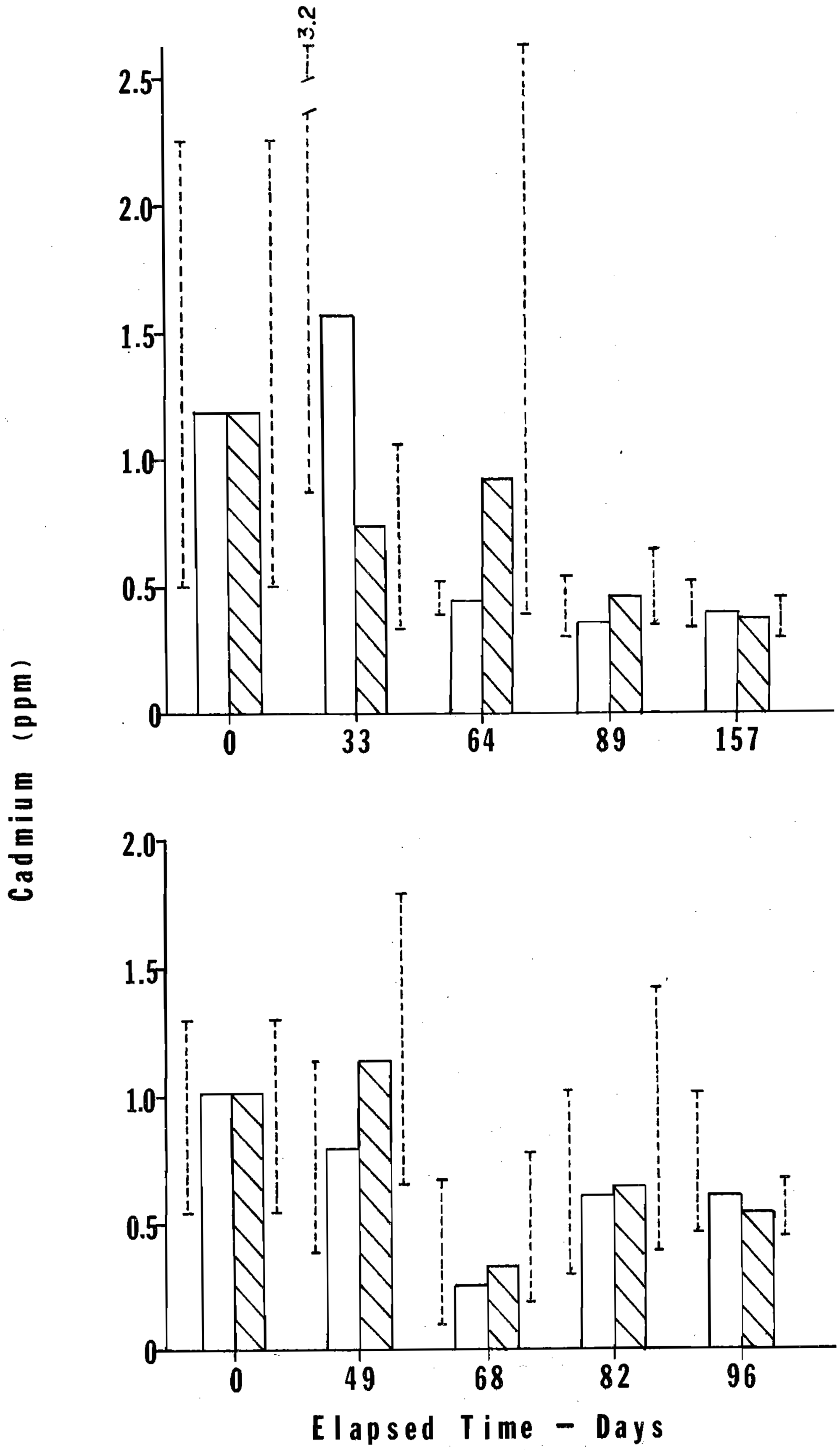

Figure 8. Cadmium in gill tissue of channel catfish. Upper graph = Fall, 1975; lower graph = Spring, 1976. ☐ = control pond; ▨ = experimental pond; ⊢----⊣ = range.

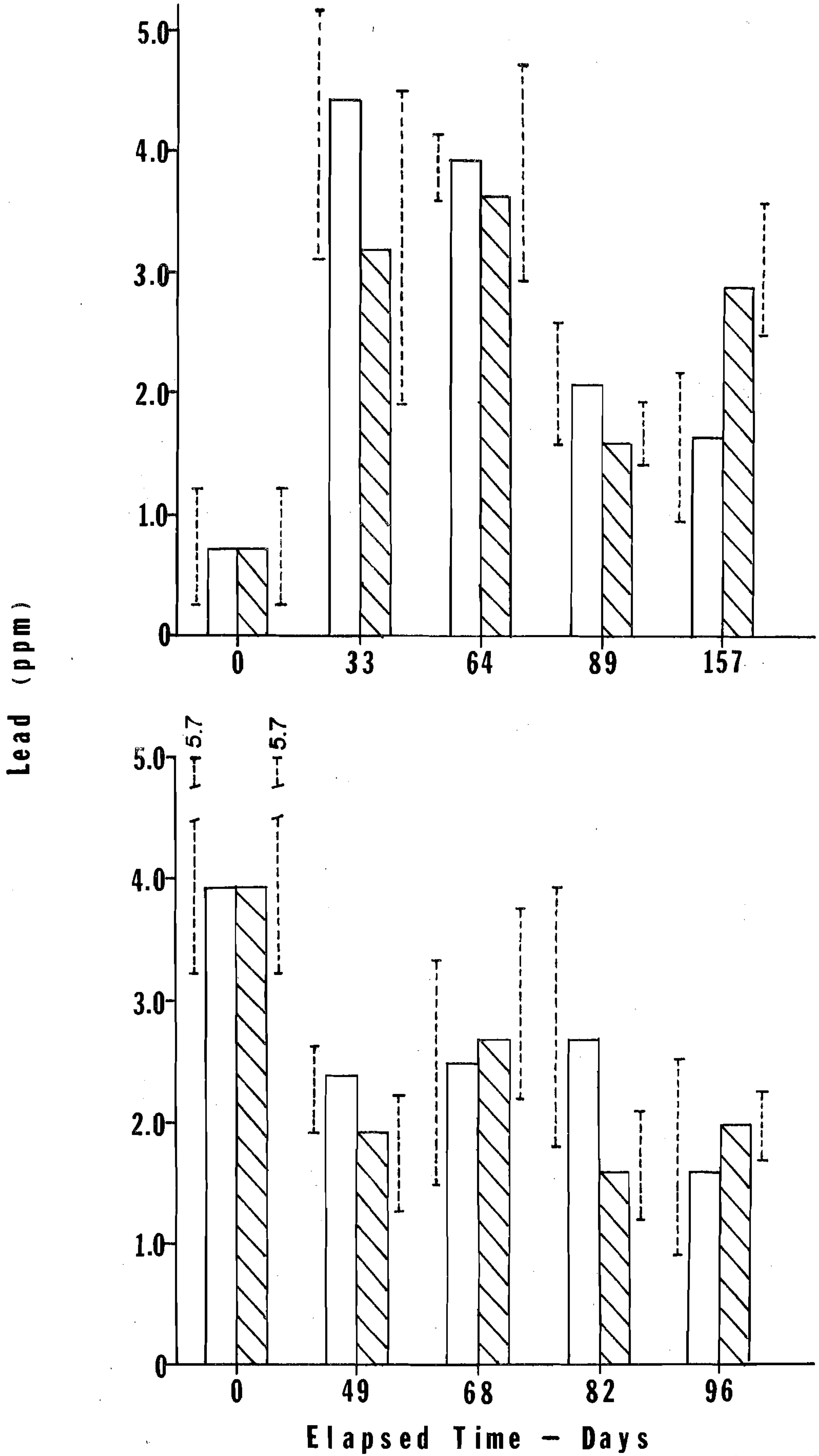

Figure 9. Lead in gill tissue of channel catfish. Upper graph = Fall, 1975; lower graph = Spring, 1976. □ = control pond; ▨ = experimental pond; ⊢----⊣ = range.

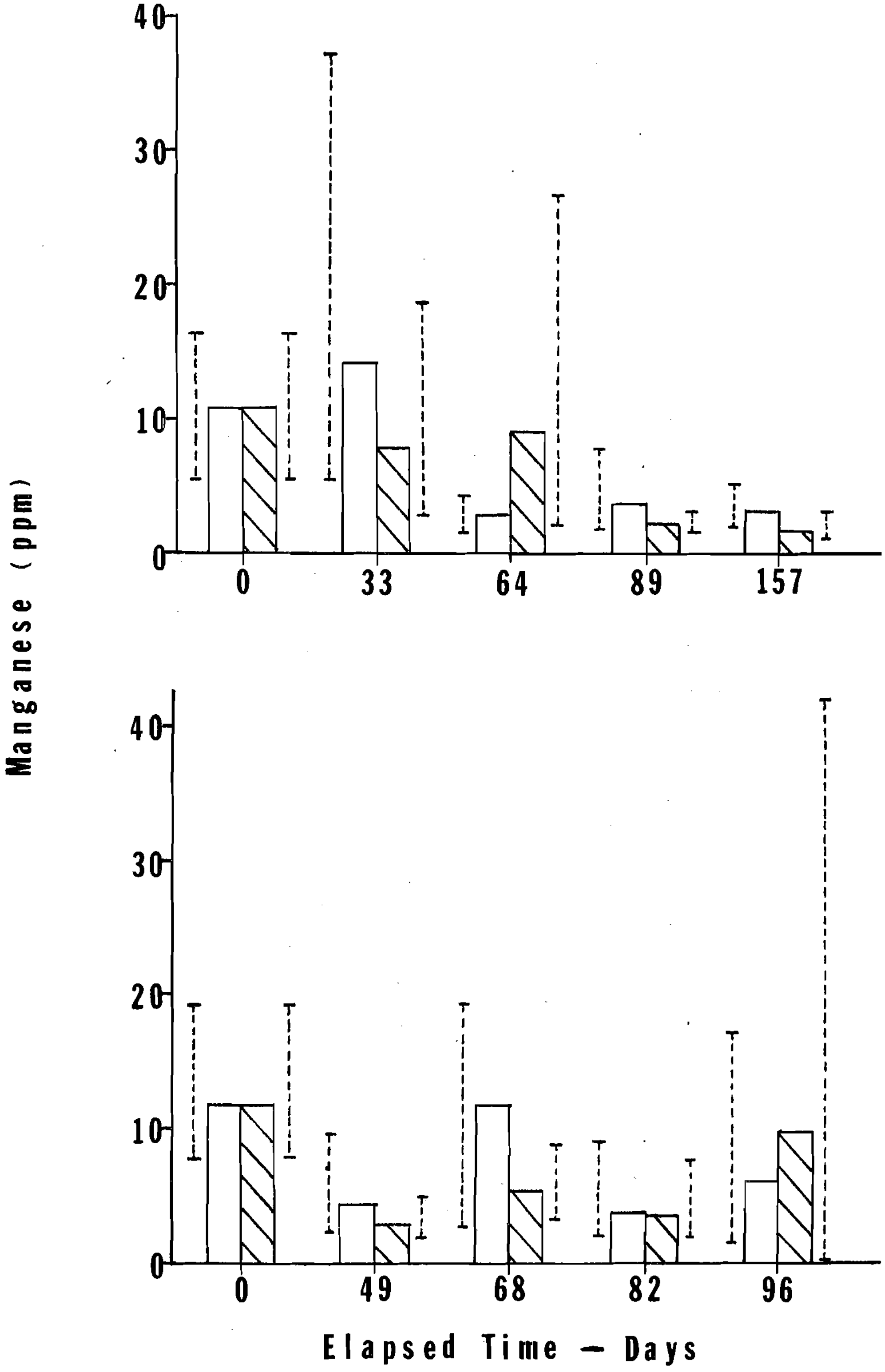

Figure 10. Manganese in heart tissue of channel catfish. Upper graph = Fall, 1975; lower graph = Spring, 1976. □ = control pond; ▨ = experimental pond; ⊢---⊣ = range.

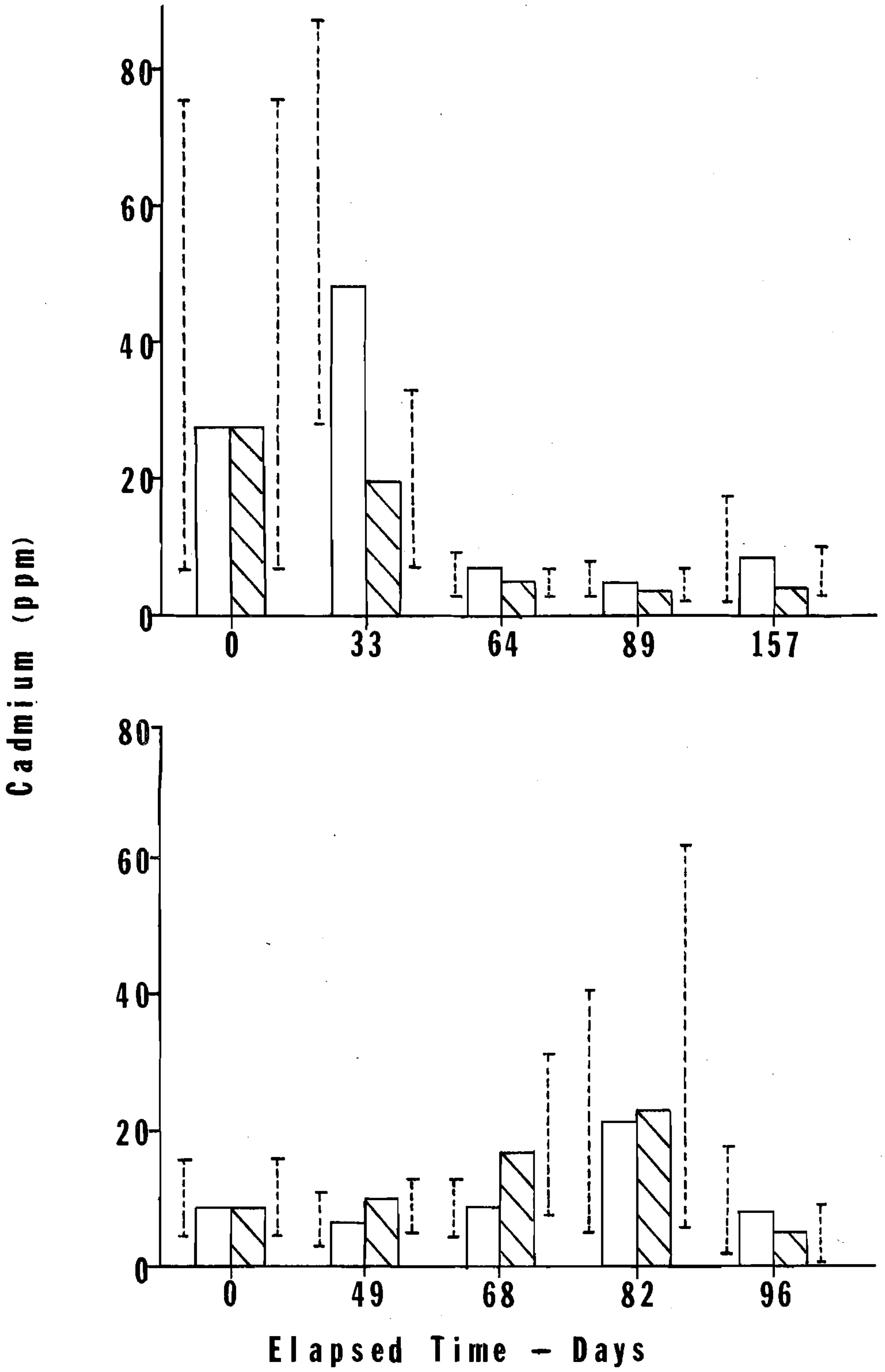

Figure 11. Cadmium in heart tissue of channel catfish. Upper graph = Fall, 1975; lower graph = Spring, 1976. ☐ = control pond; ▨ = experimental pond; ├----┤ = range.

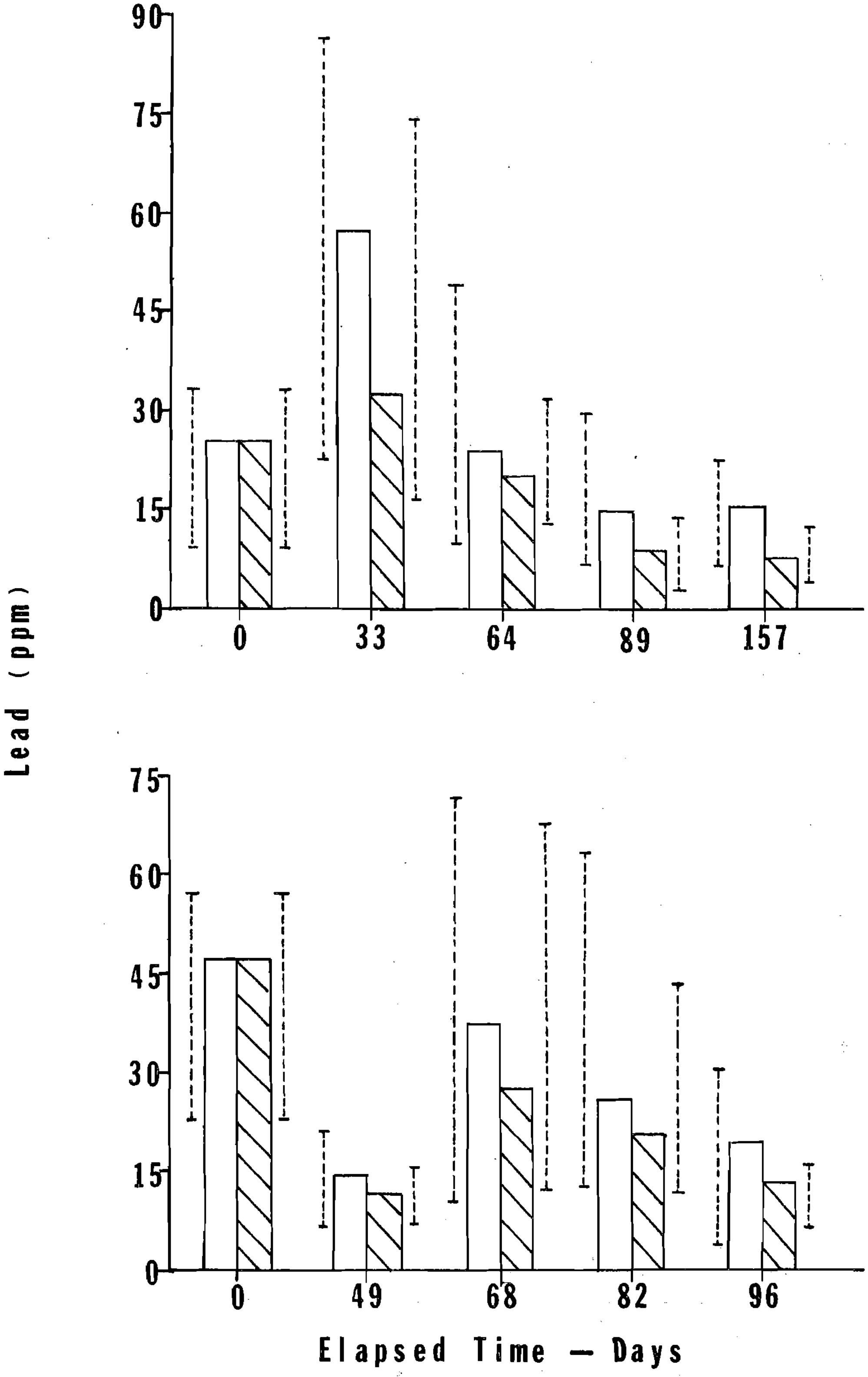

Figure 12. Lead in heart tissue of channel catfish. Upper graph = Fall, 1975; lower graph = Spring, 1976. ☐ = control pond; ▨ = experimental pond; ⊢---⊣ = range.

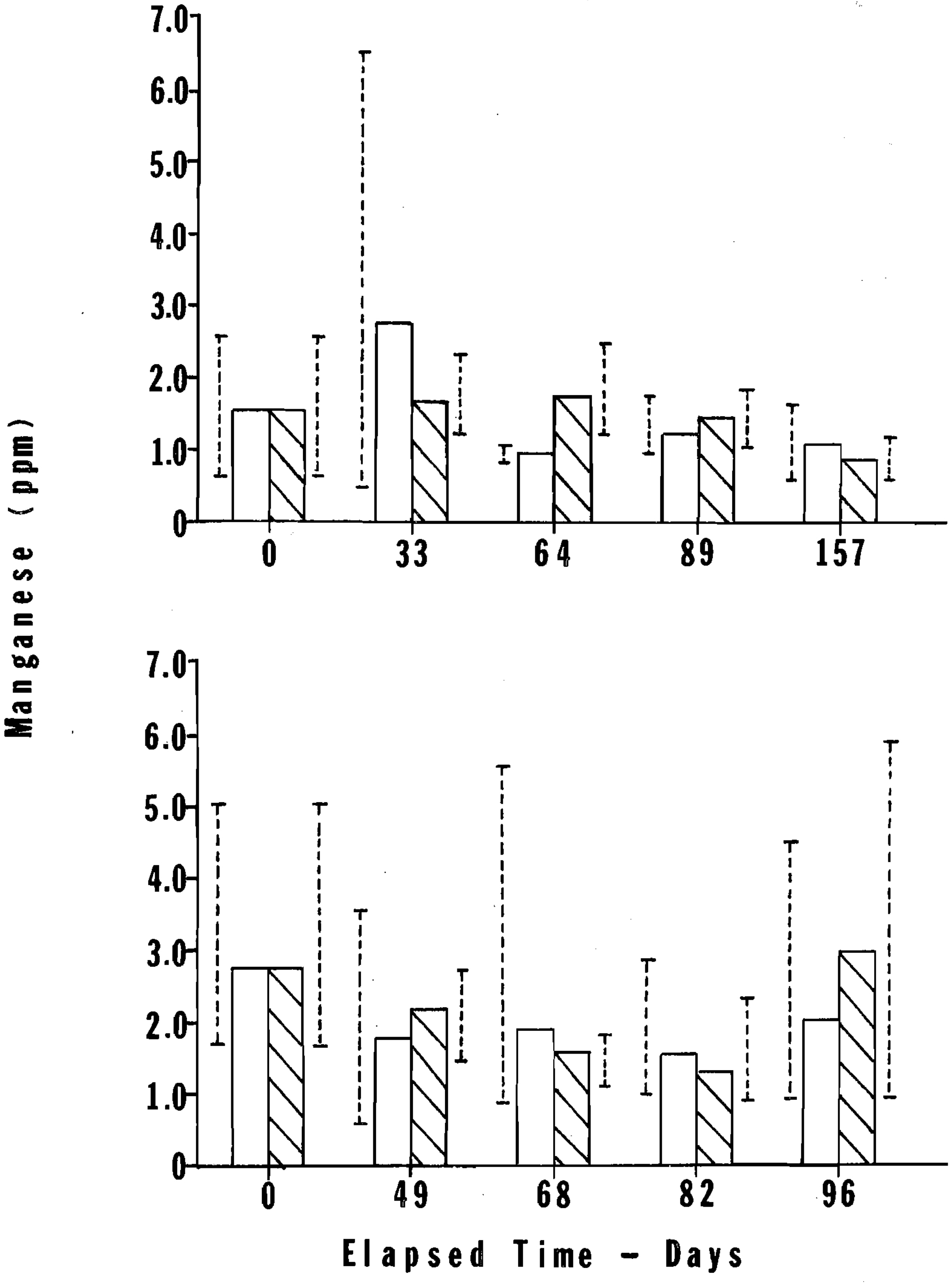

Figure 13. Manganese in kidney tissue of channel catfish. Upper graph = Fall, 1975; lower graph = Spring, 1976. ☐ = control pond; ▨ = experimental pond; ⊢-----⊣ = range.

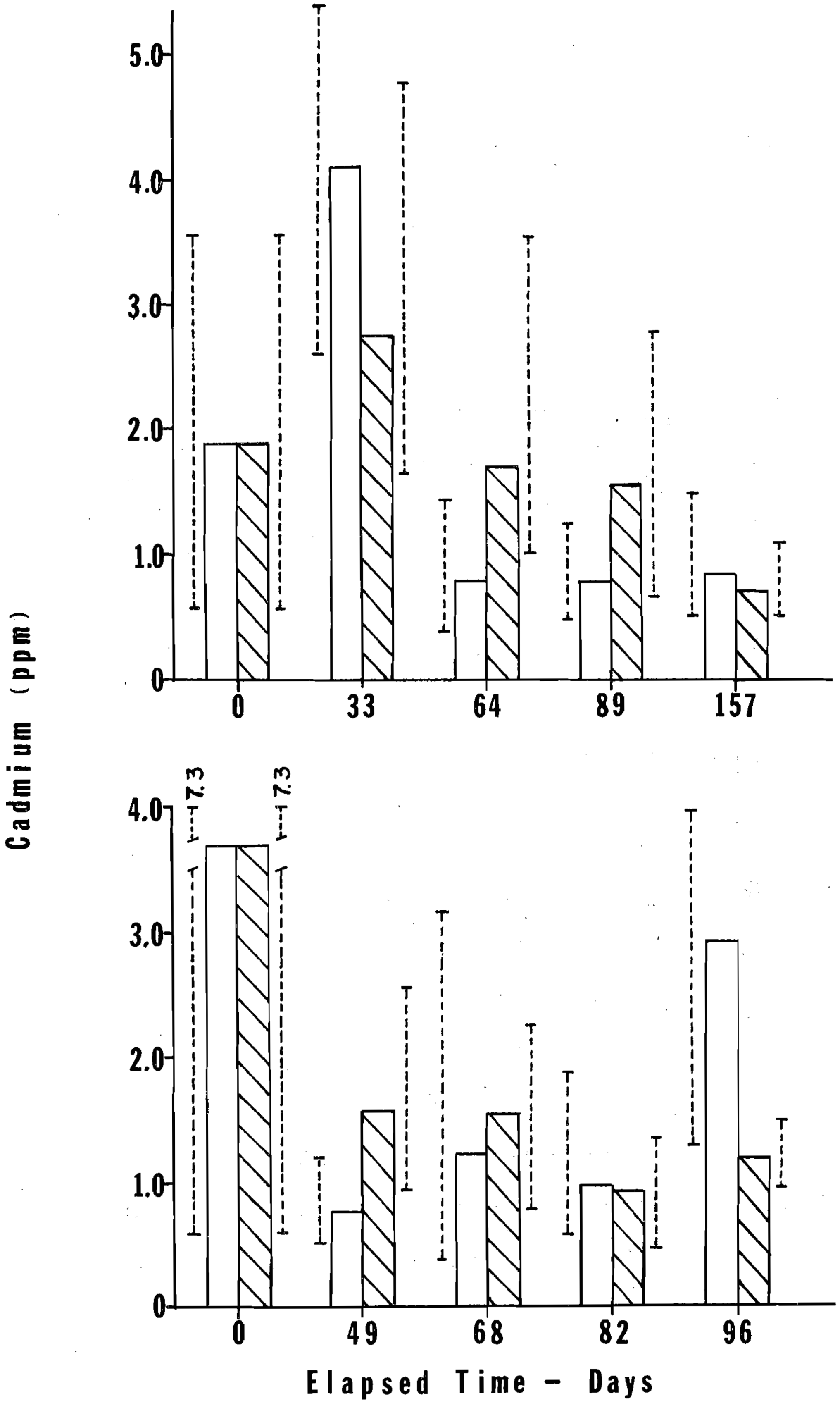

Figure 14. Cadmium in kidney tissue of channel catfish. Upper graph = Fall, 1975; lower graph = Spring, 1976. ☐ = control pond; ▨ = experimental pond; ├----┤ = range.

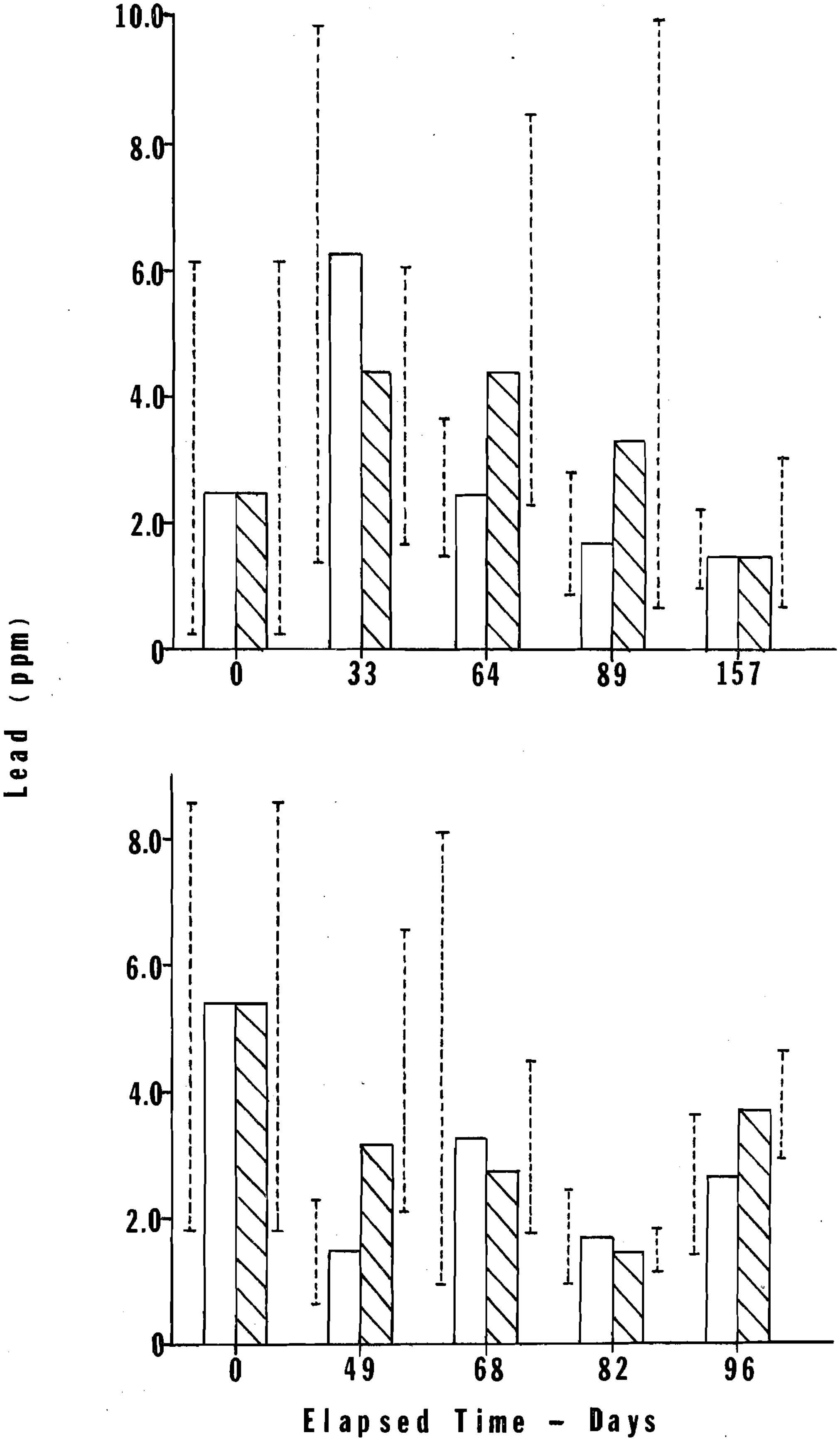

Figure 15. Lead in kidney tissue of channel catfish. Upper graph = Fall, 1975; lower graph = Spring, 1976. ☐ = control pond; ▨ = experimental pond; ┌----┐ = range.

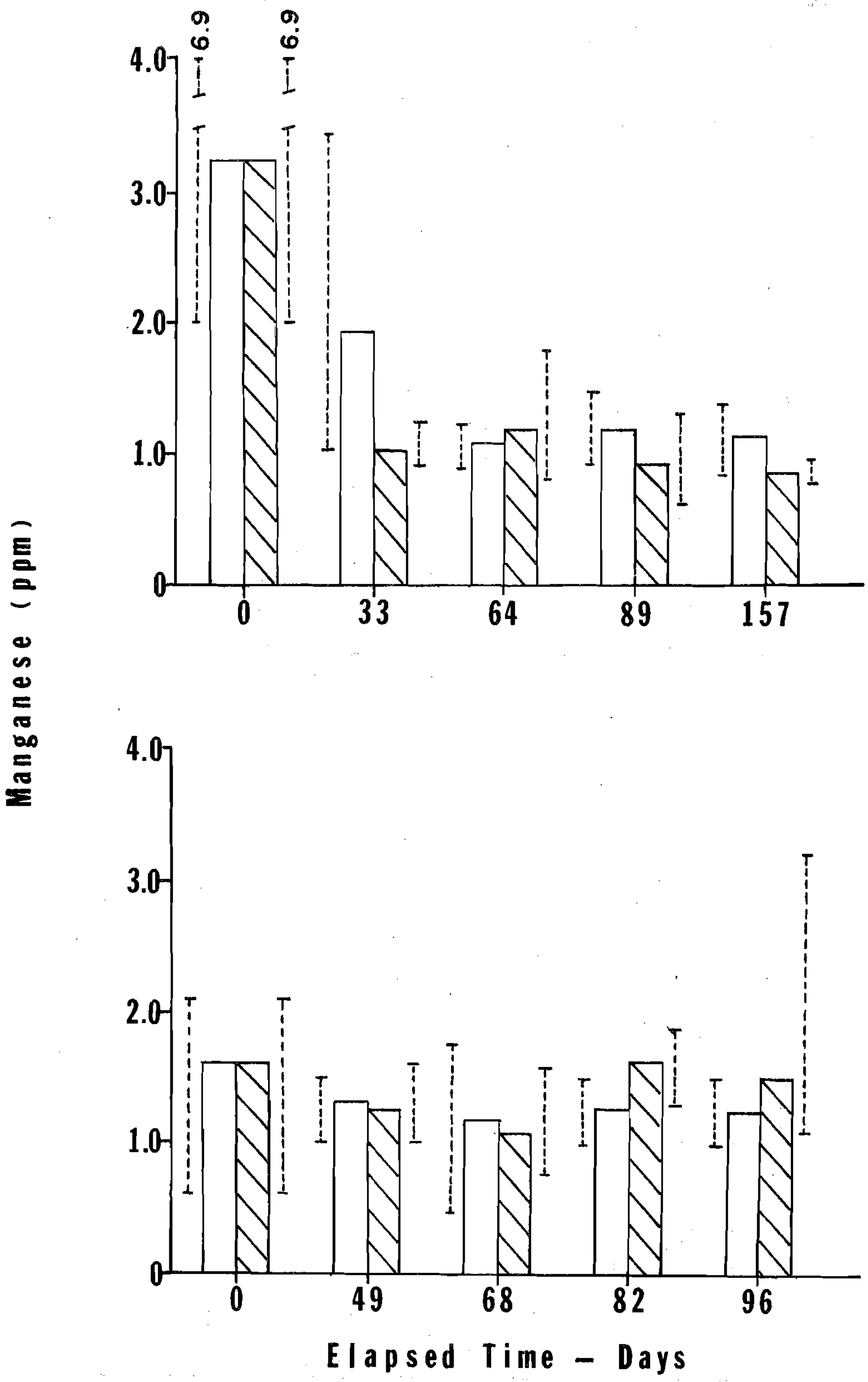

Figure 16. Manganese in liver tissue of channel catfish. Upper graph = Fall, 1975; lower graph = Spring, 1976. ☐ = control pond; ▨ = experimental pond; ⊢---⊣ = range.

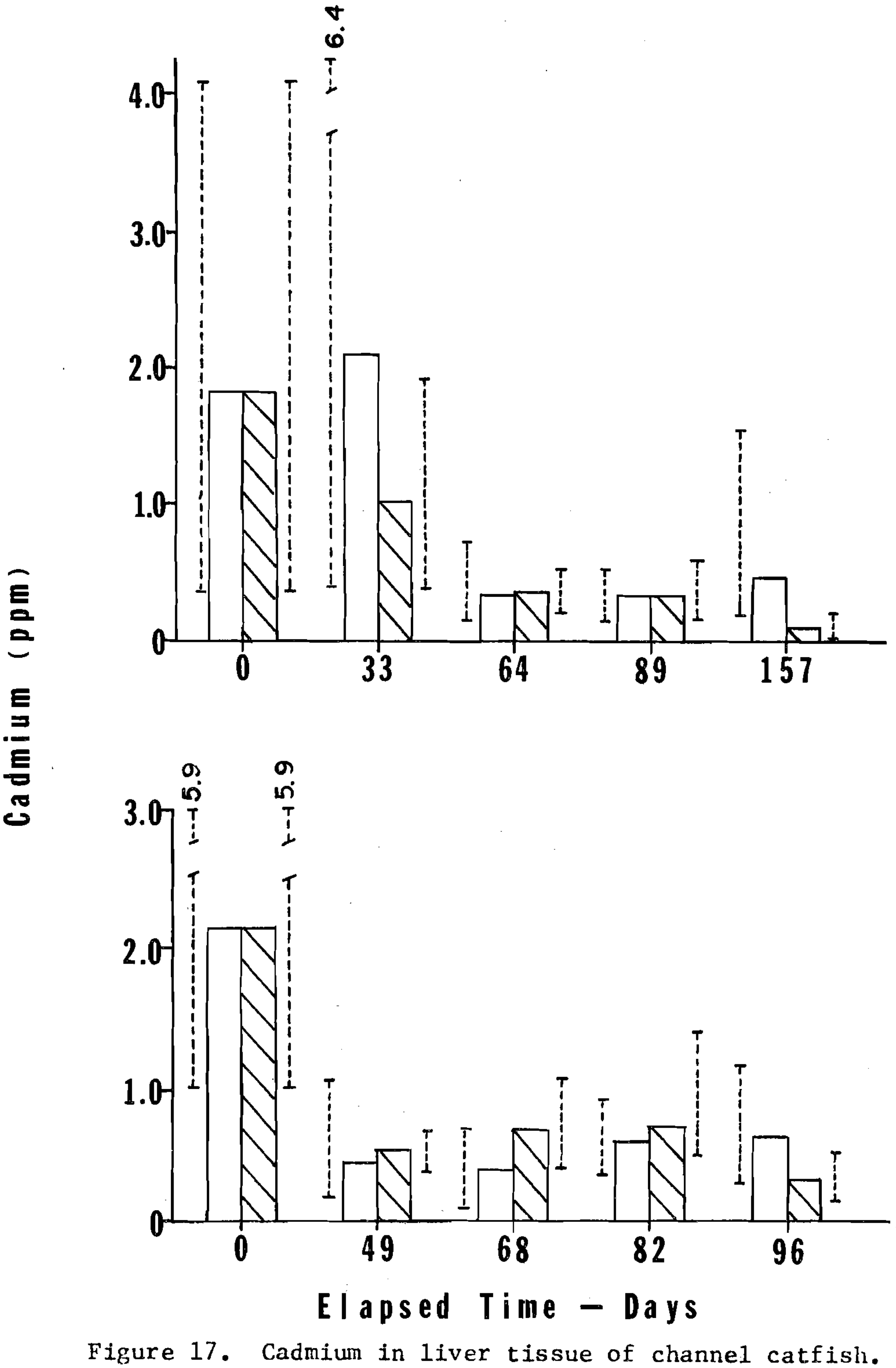

Figure 17. Cadmium in liver tissue of channel catfish. Upper graph = Fall, 1975; lower graph = Spring, 1976. ☐ = control pond; ▨ = experimental pond; ⊢----⊣ = range.

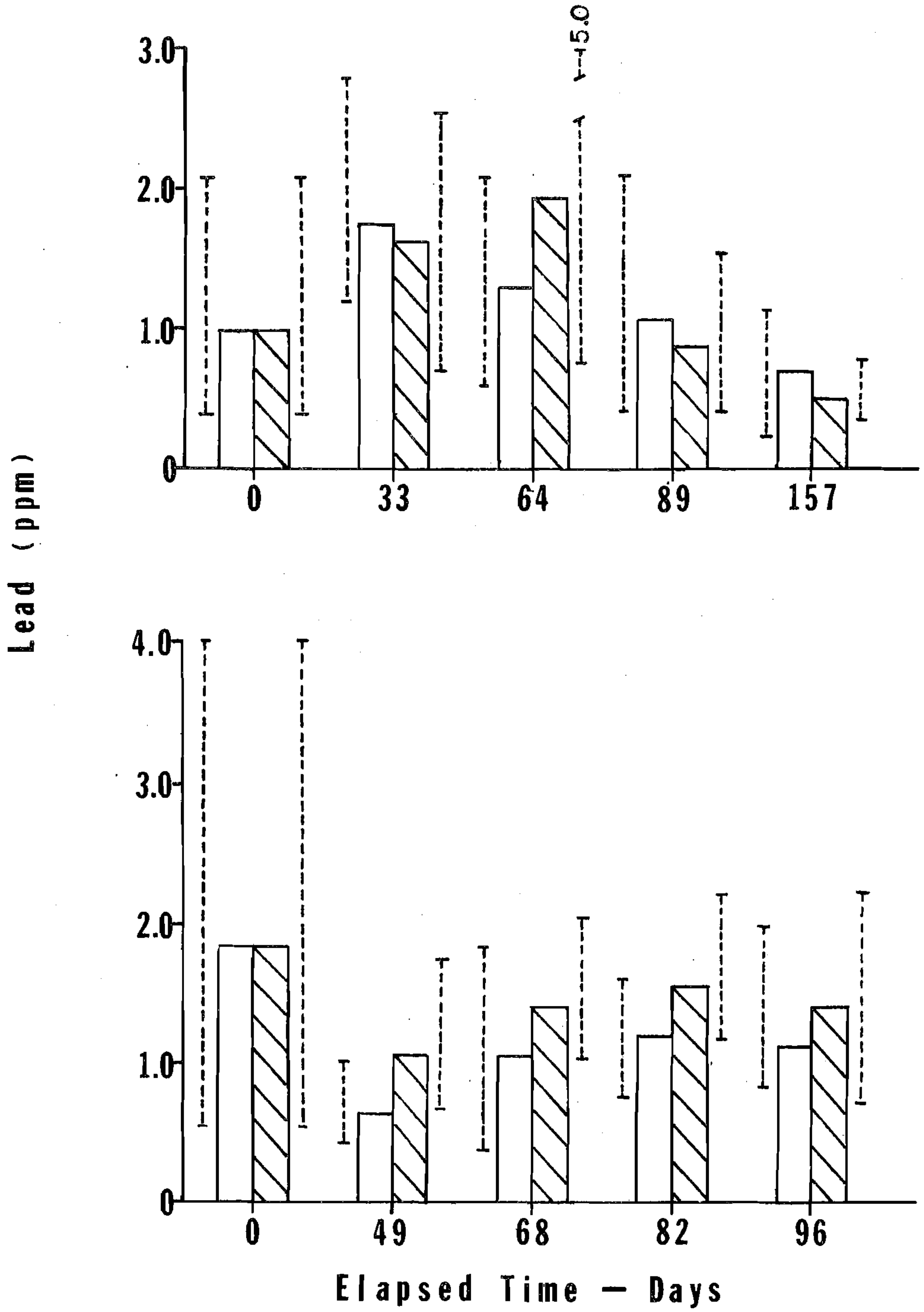

Figure 18. Lead in liver tissue of channel catfish. Upper graph = Fall, 1975; lower graph = Spring, 1976. ☐ = control pond; ▨ = experimental pond; ⊢---⊣ = range.

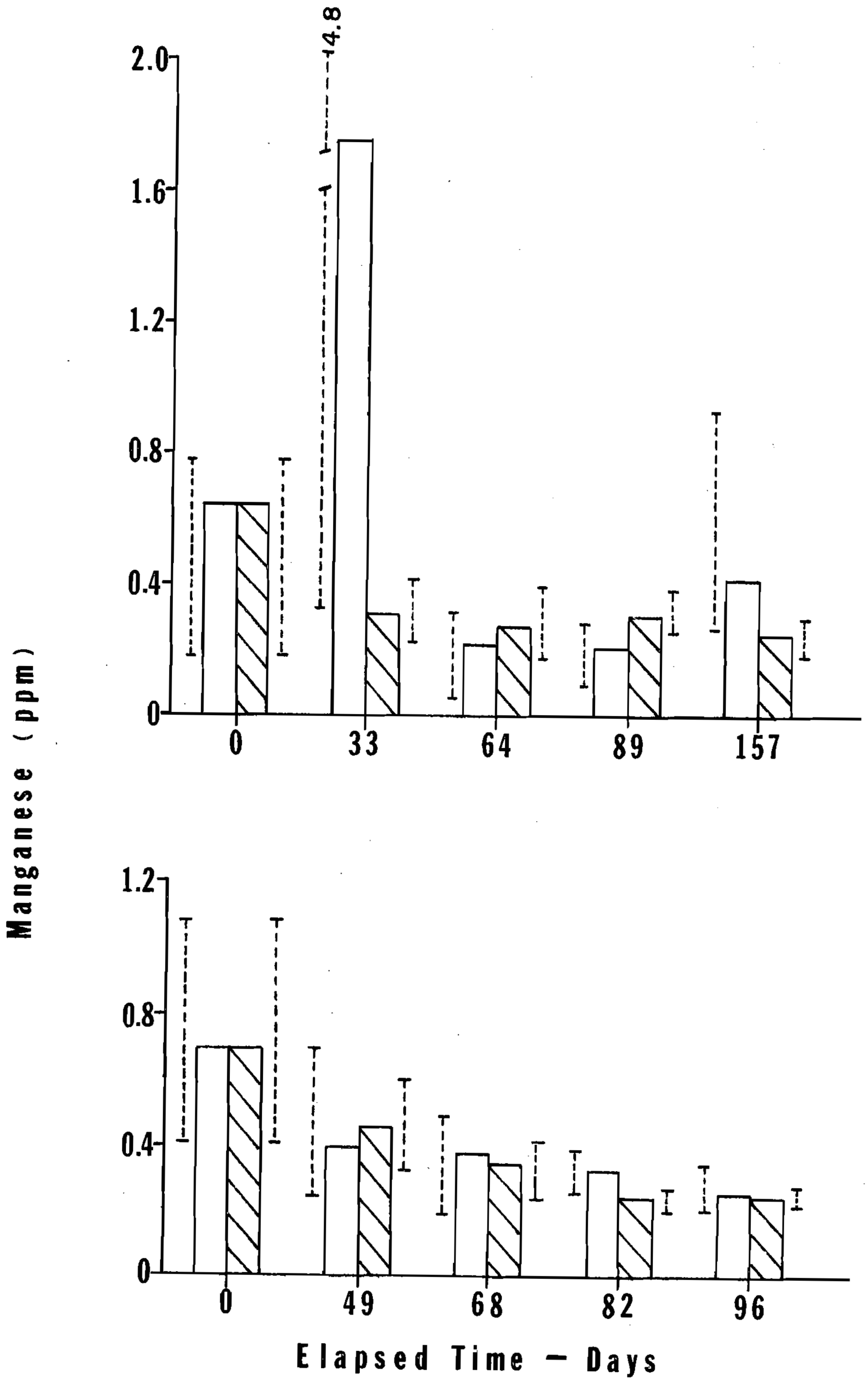

Figure 19. Manganese in muscle tissue of channel catfish. Upper graph = Fall, 1975; lower graph = Spring, 1976. ☐ = control pond; ▨ = experimental pond; ⊢---⊣ = range.

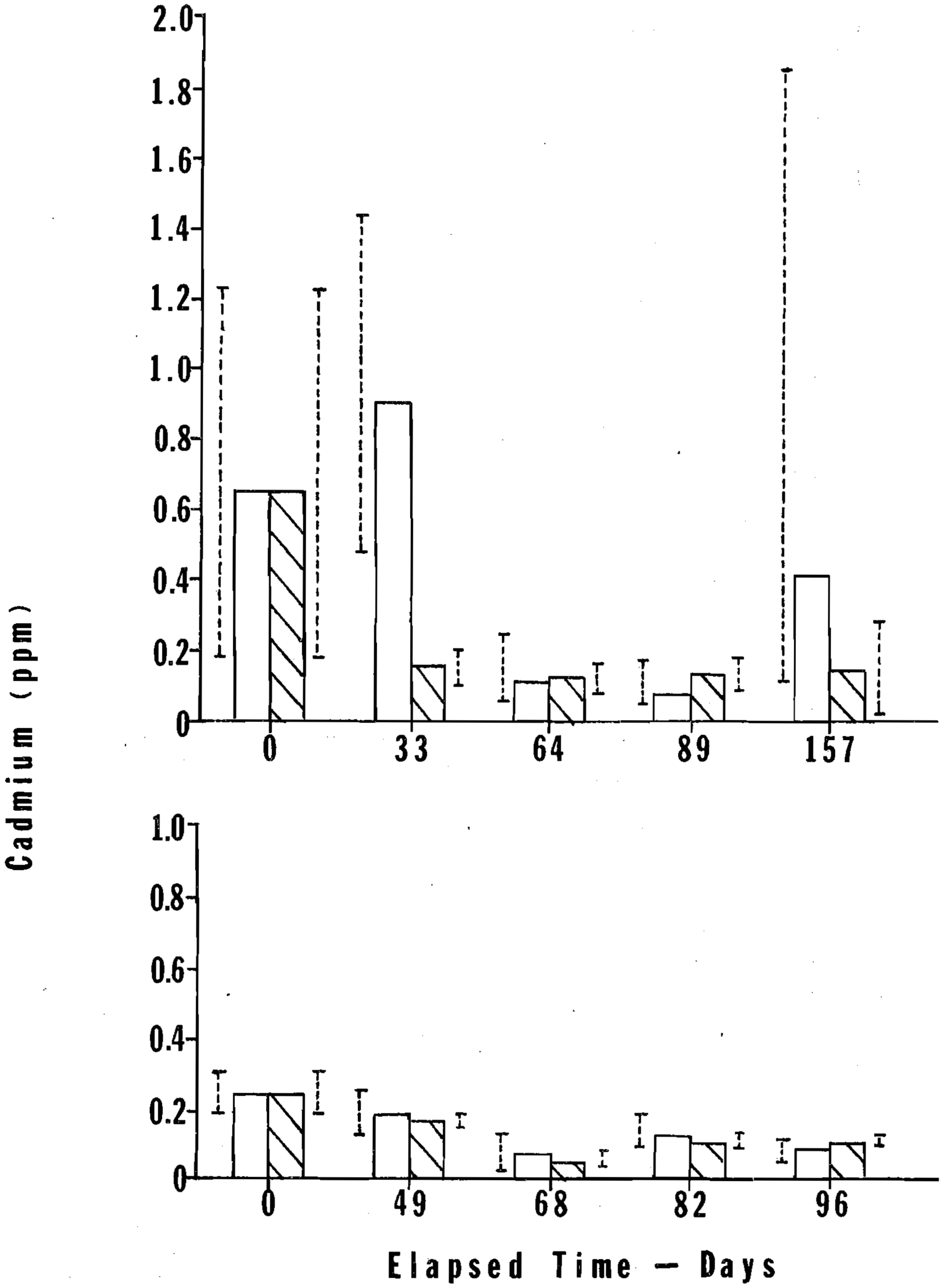

Figure 20. Cadmium in muscle tissue of channel catfish. Upper graph = Fall, 1975; lower graph = Spring, 1976. ☐ = control pond; ▨ = experimental pond; ⊢---⊣ = range.

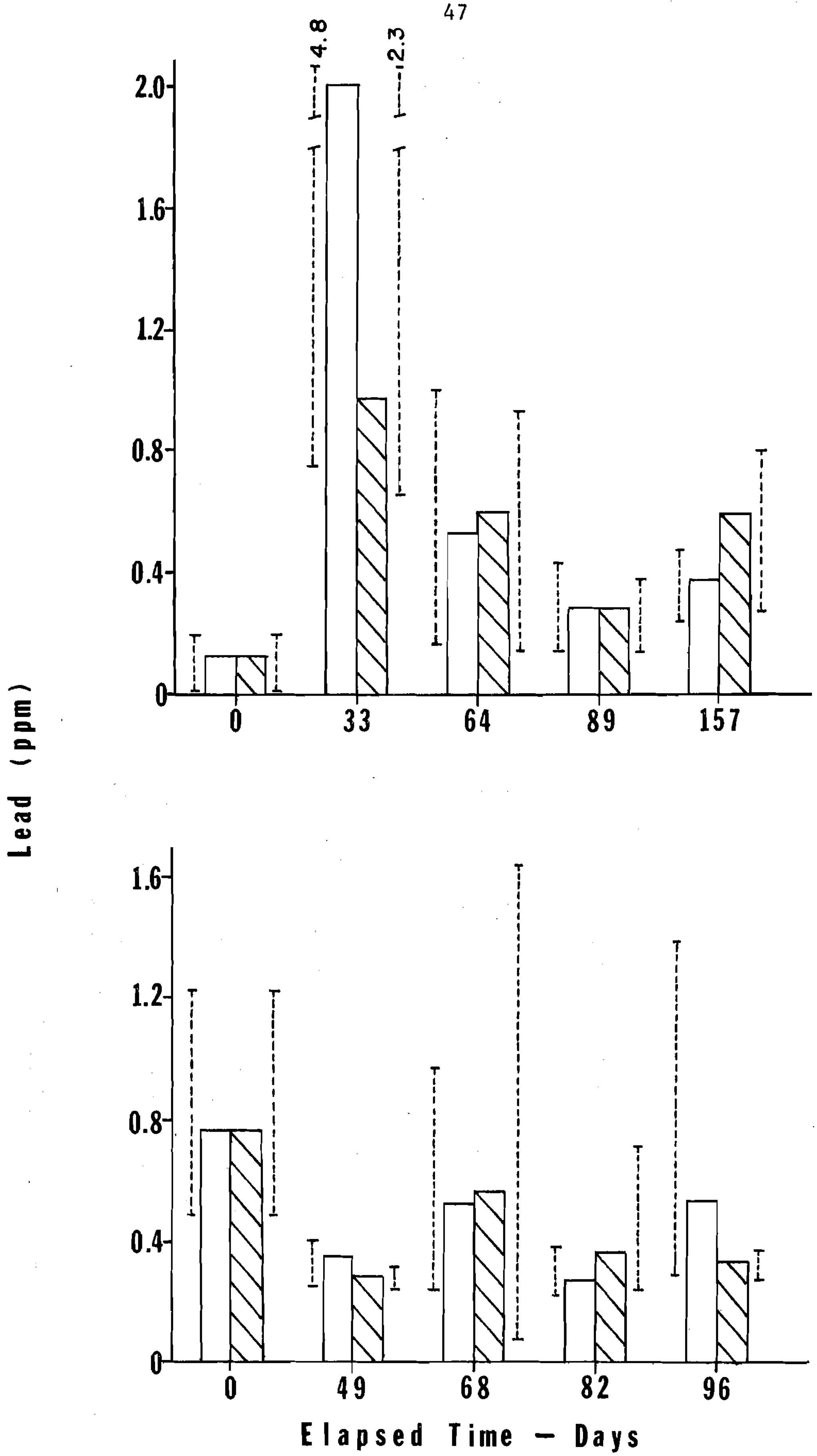

Figure 21. Lead in muscle tissue of channel catfish. Upper graph = Fall, 1975; lower graph = Spring, 1976. □ = control pond; ▨ = experimental pond; ⊢----⊣ = range.

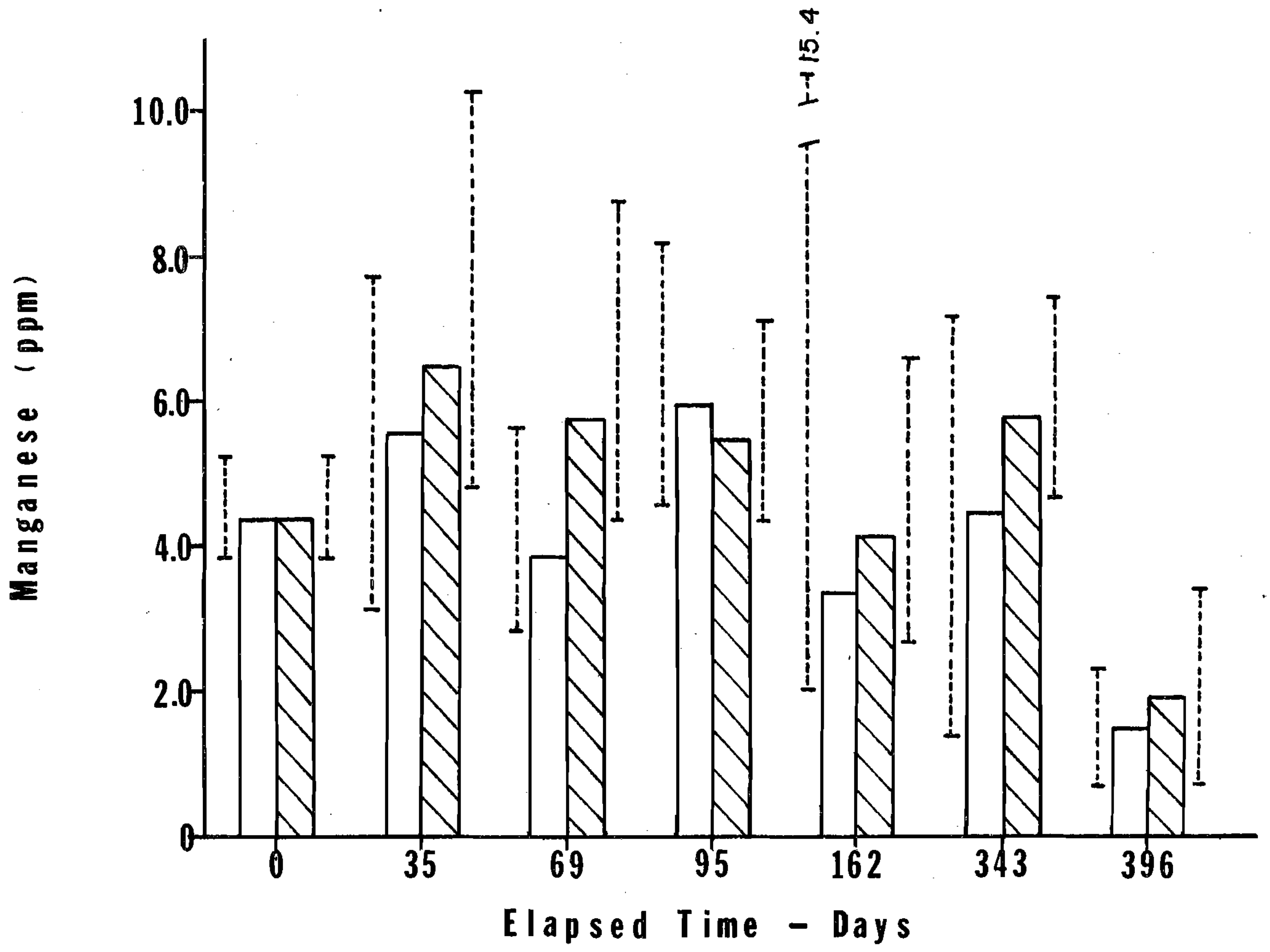

Figure 22. Manganese in whole green sunfish. □ = control pond; ▨ = experimental pond; ⊢---⊣ = range.

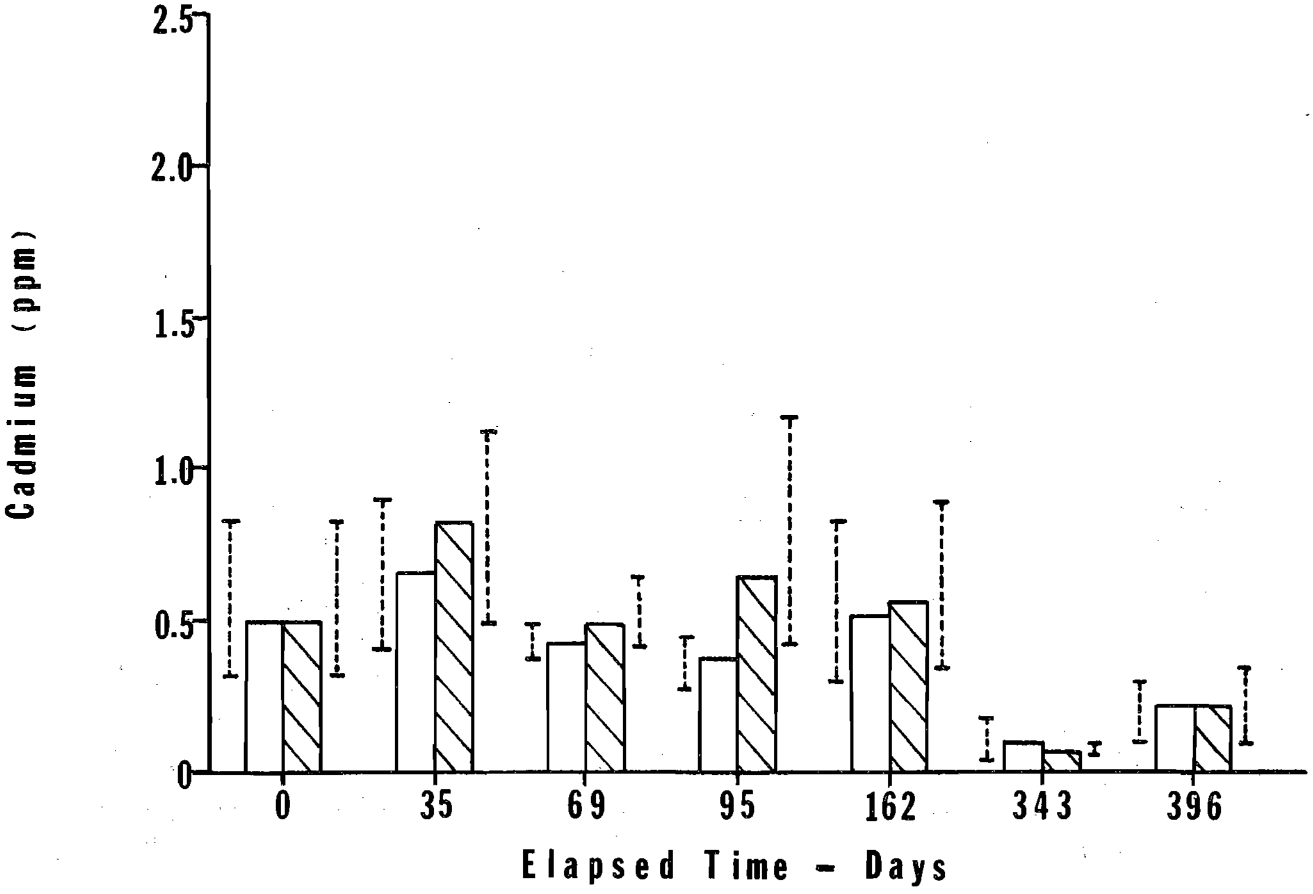

Figure 23. Cadmium in whole green sunfish. ☐ = control pond; ▨ = experimental pond; ⊢----⊣ = range.

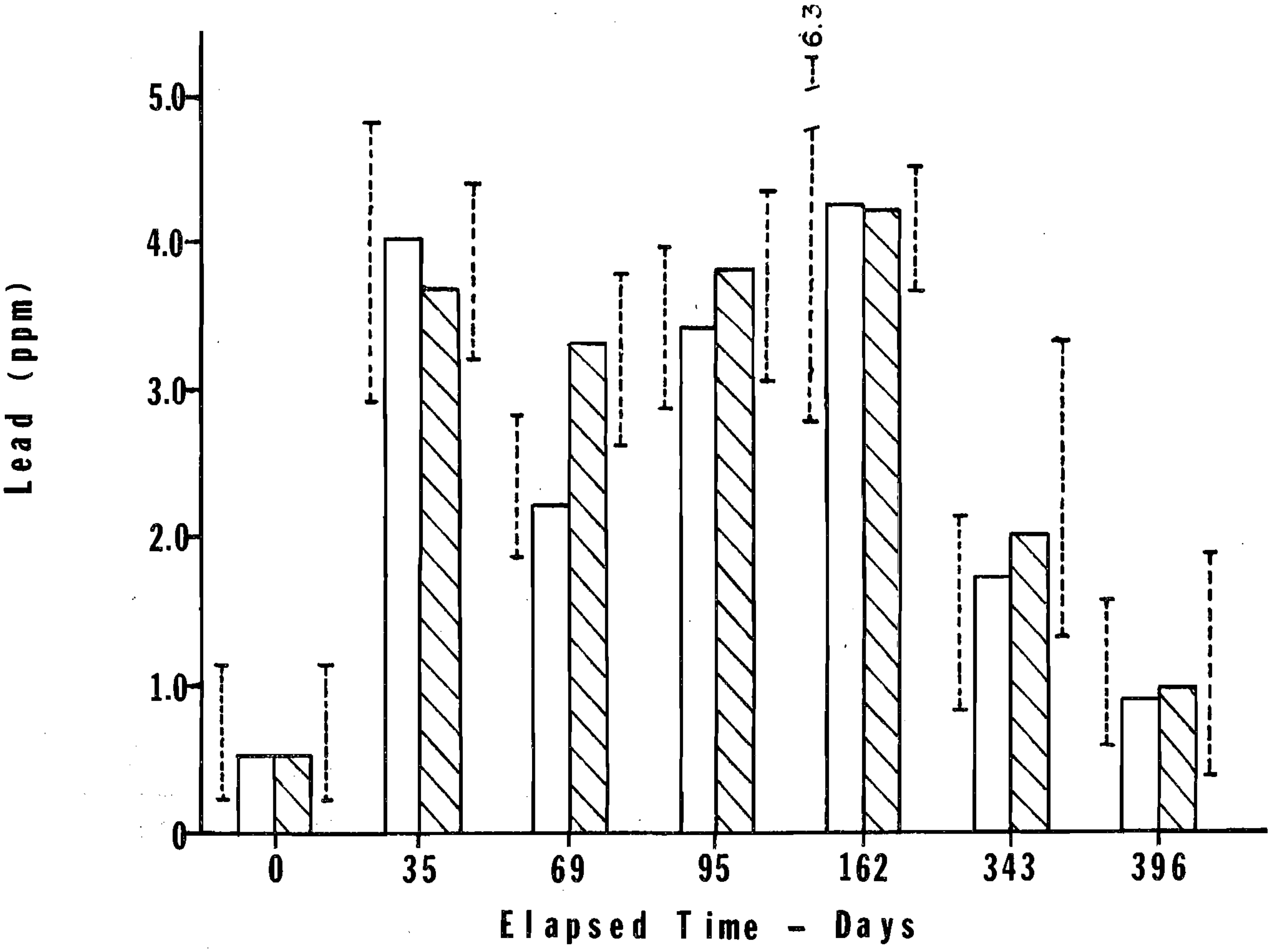

Figure 24. Lead in whole green sunfish. ☐= control pond; ▨= experimental pond; ├----┤= range.

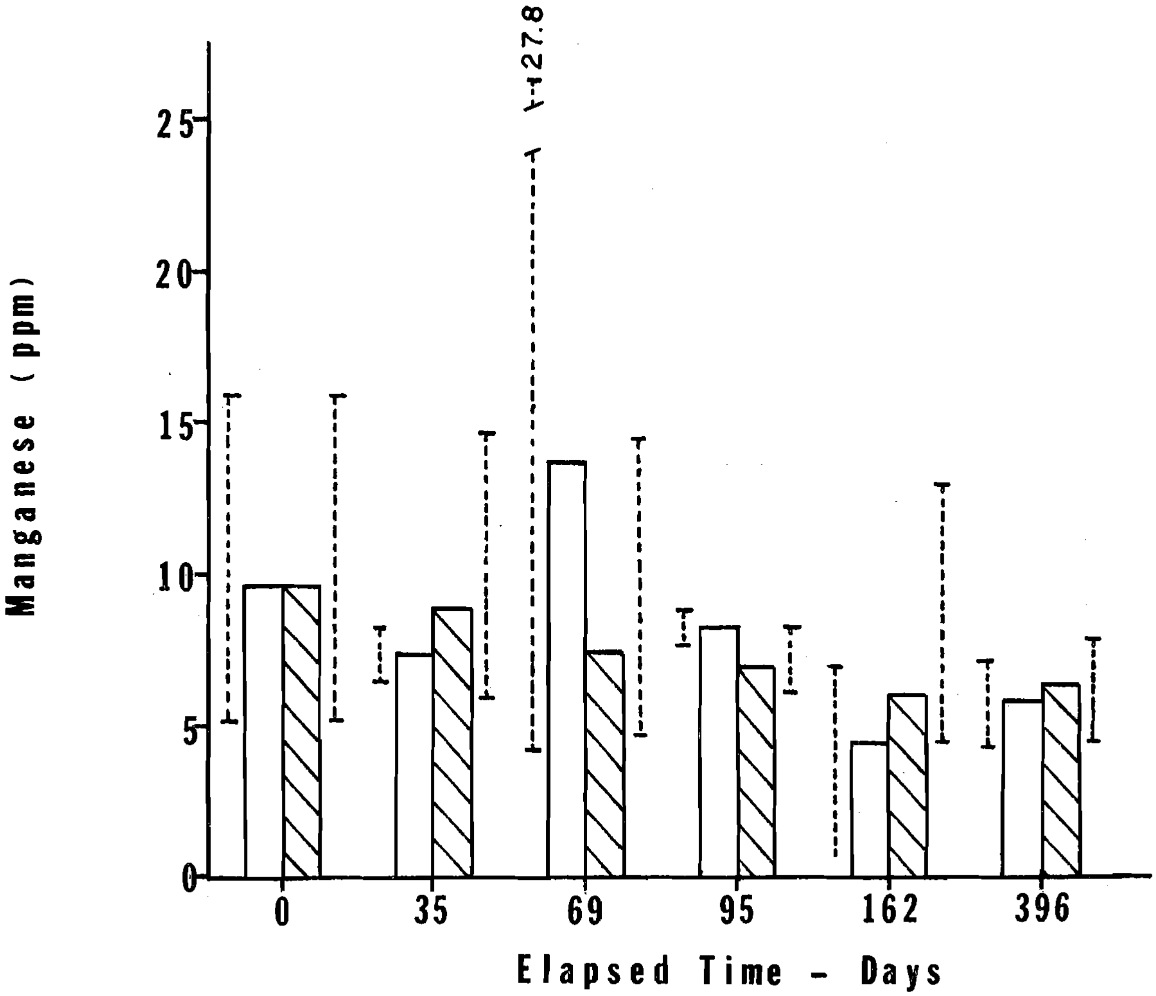

Figure 25. Manganese in gill tissue of green sunfish. □ = control pond; ▨ = experimental pond; ⊢---⊣ = range.

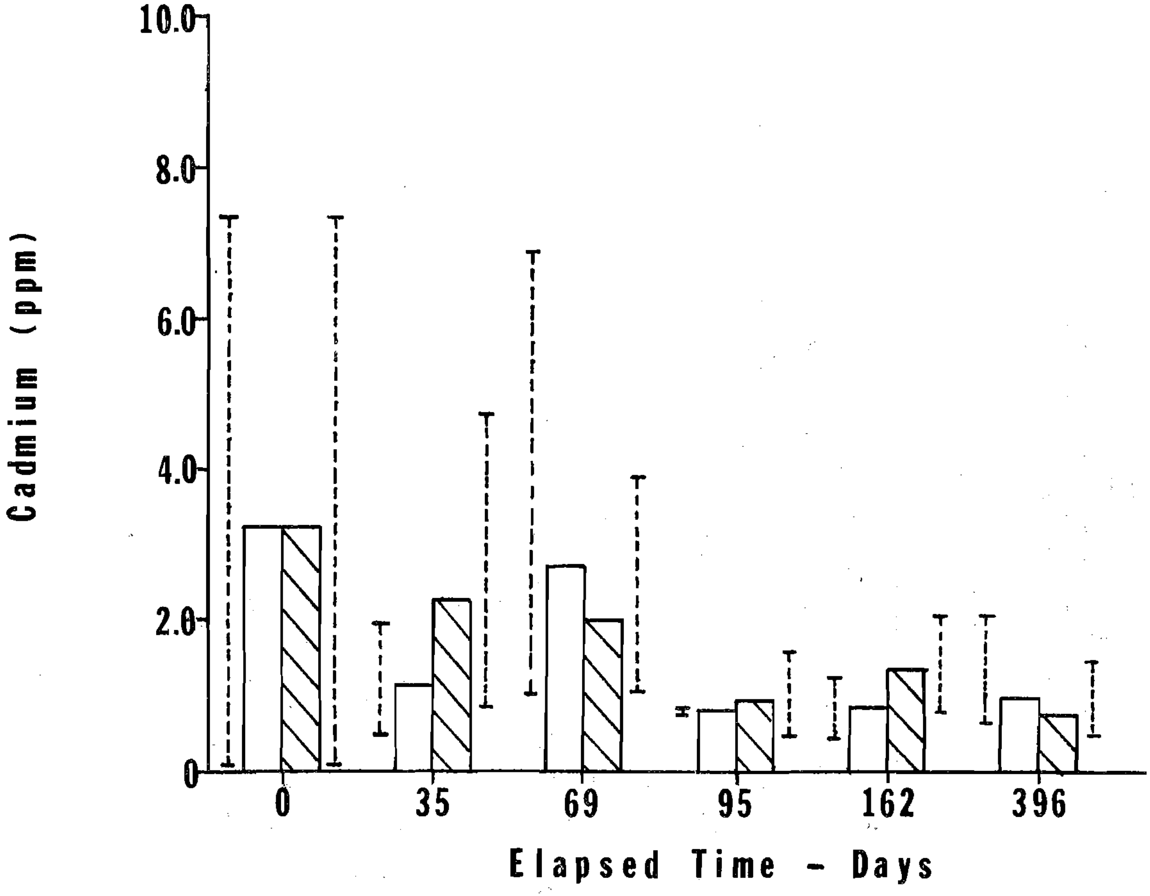

Figure 26. Cadmium in gill tissue of green sunfish. ☐ = control pond; ▨ = experimental pond; ⊢----⊣ = range.

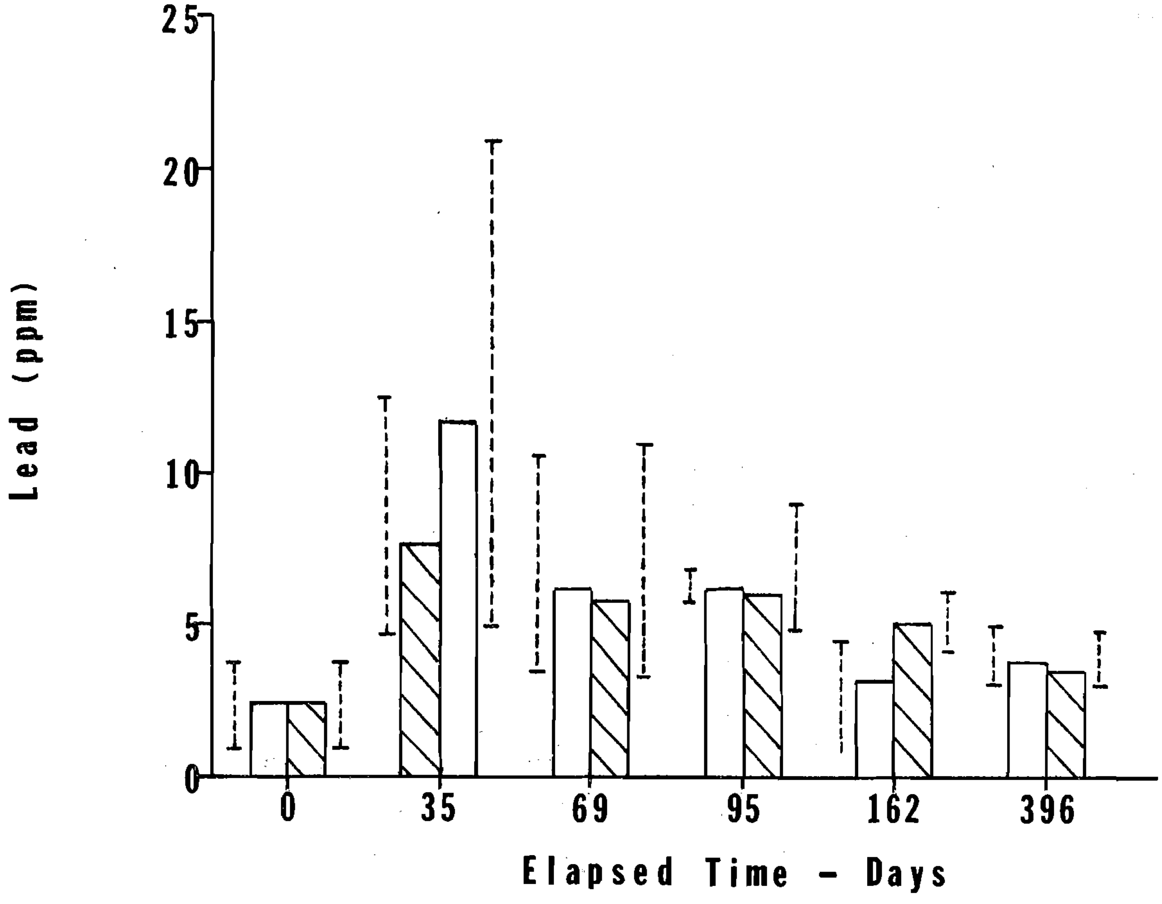

Figure 27. Lead in gill tissue of green sunfish. ☐ = control pond; ▨ = experimental pond; ⊢---⊣ = range.

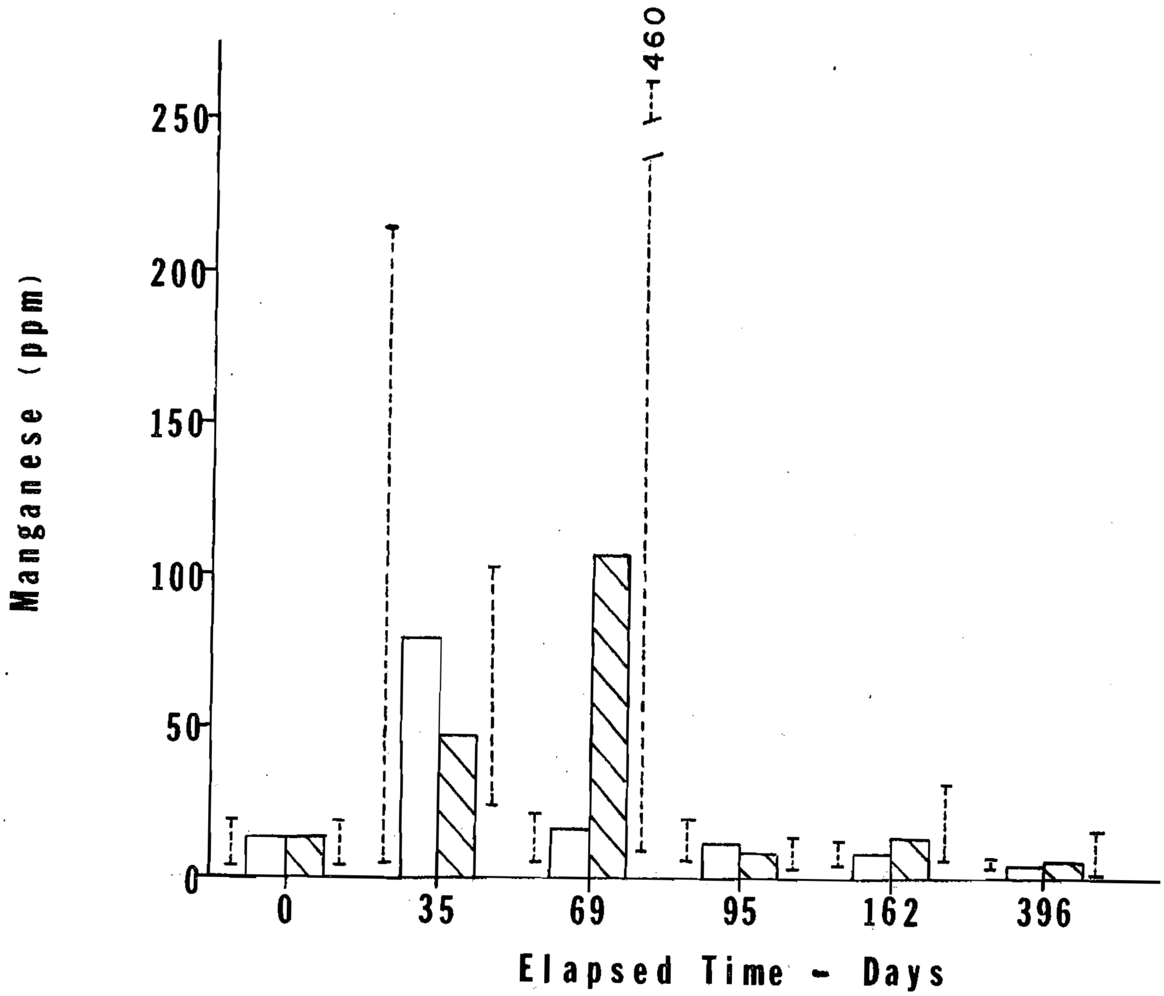

Figure 28. Manganese in heart tissue of green sunfish. ▭ = control pond; ▨ = experimental pond; ⊢---⊣ = range.

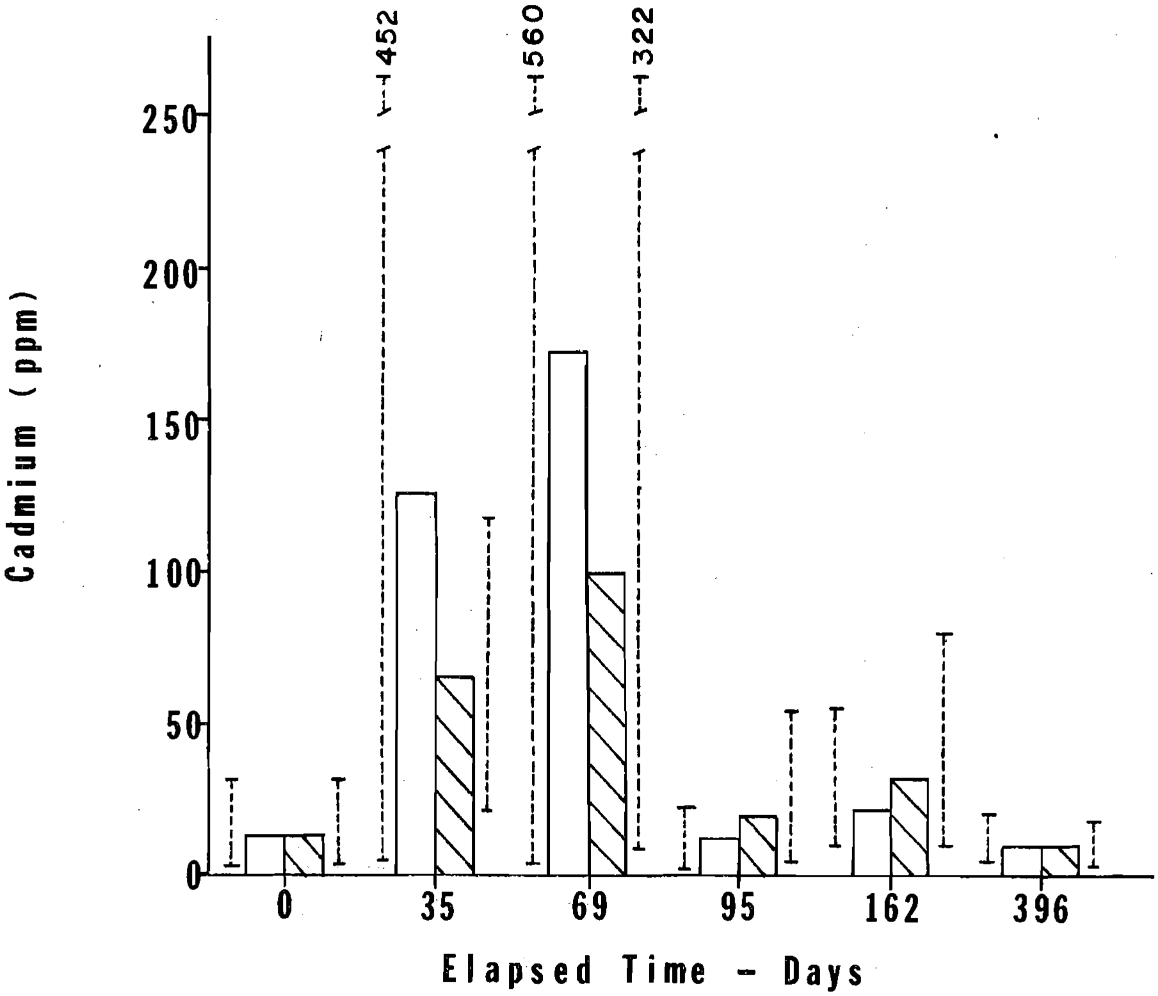

Figure 29. Cadmium in heart tissue of green sunfish. ☐ = control pond; ▨ = experimental pond; ⊢----⊣ = range.

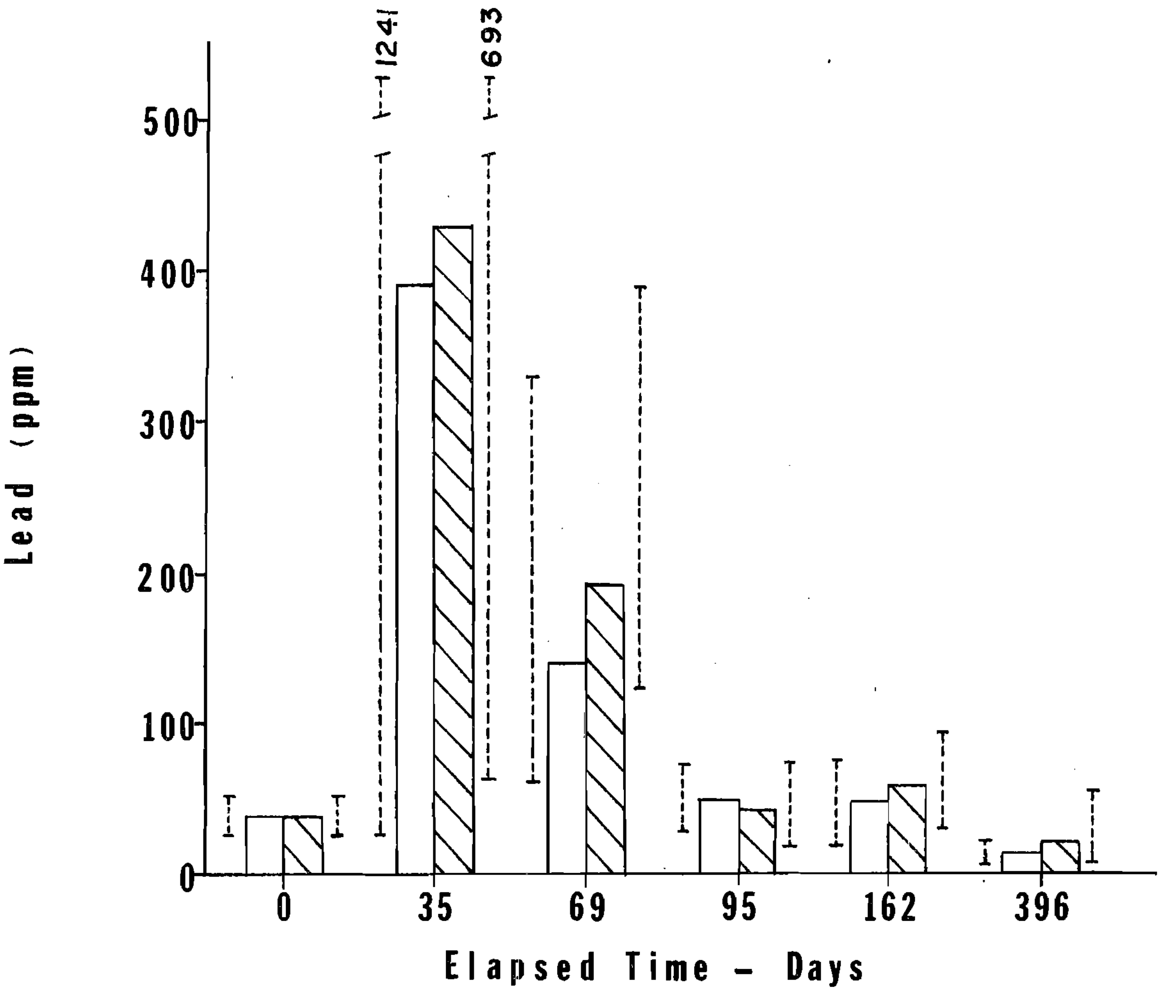

Figure 30. Lead in heart tissue of green sunfish. ☐ = control pond; ▨ = experimental pond; ⊢----⊣ = range.

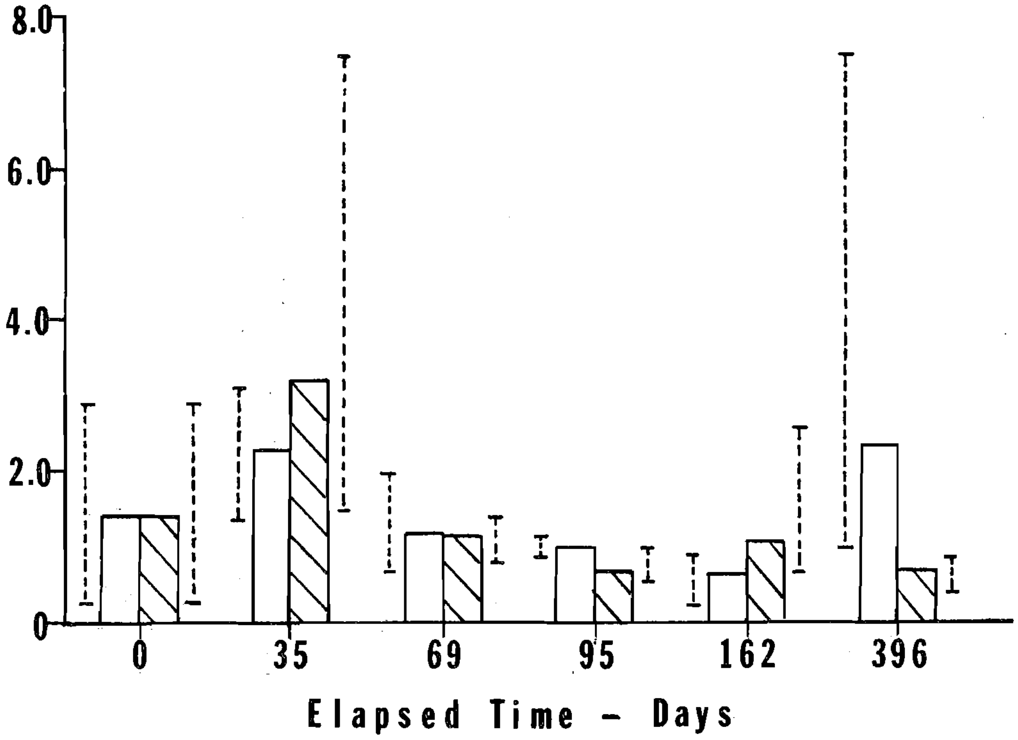

Figure 31. Manganese in liver tissue of green sunfish. ☐ = control pond; ▨ = experimental pond; ⊢---⊣ = range.

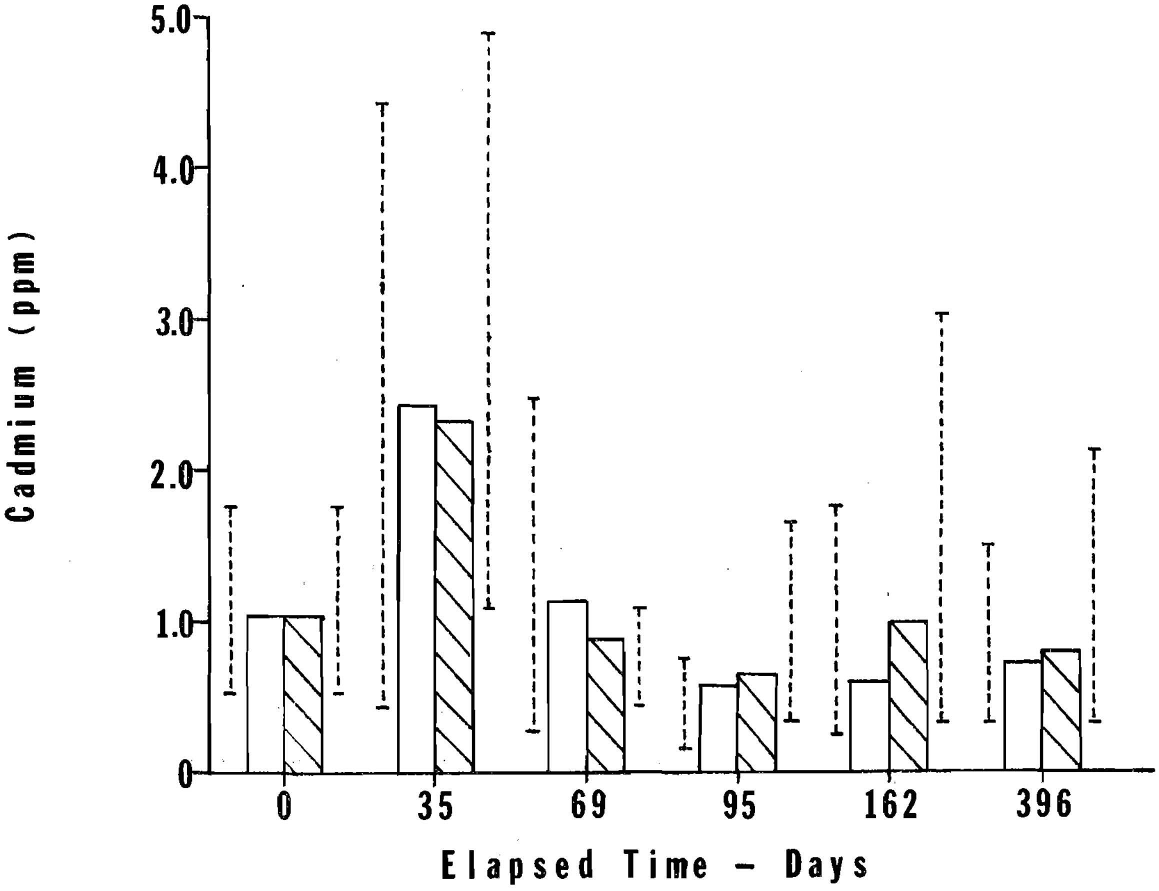

Figure 32. Cadmium in liver tissue of green sunfish. ▭ = control pond; ▨ = experimental pond; ⊢----⊣ = range.

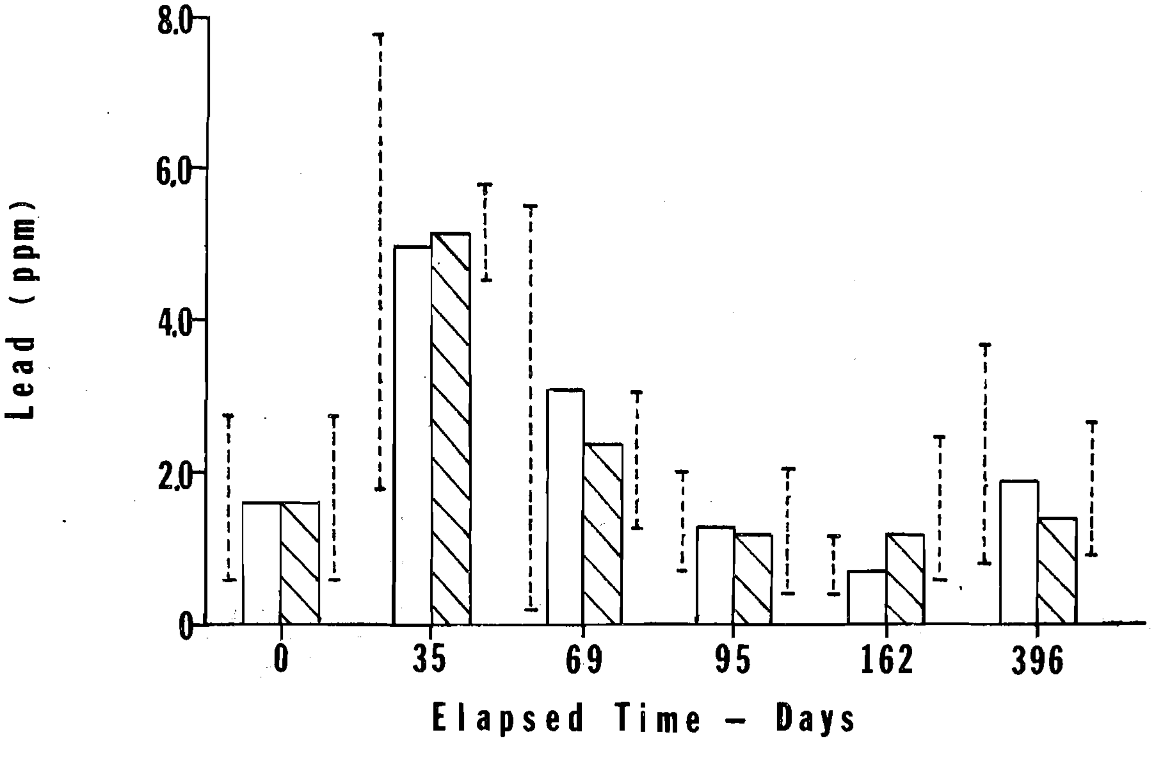

Figure 33. Lead in liver tissue of green sunfish. ☐ = control pond; ▨ = experimental pond; ⊢----⊣ = range.

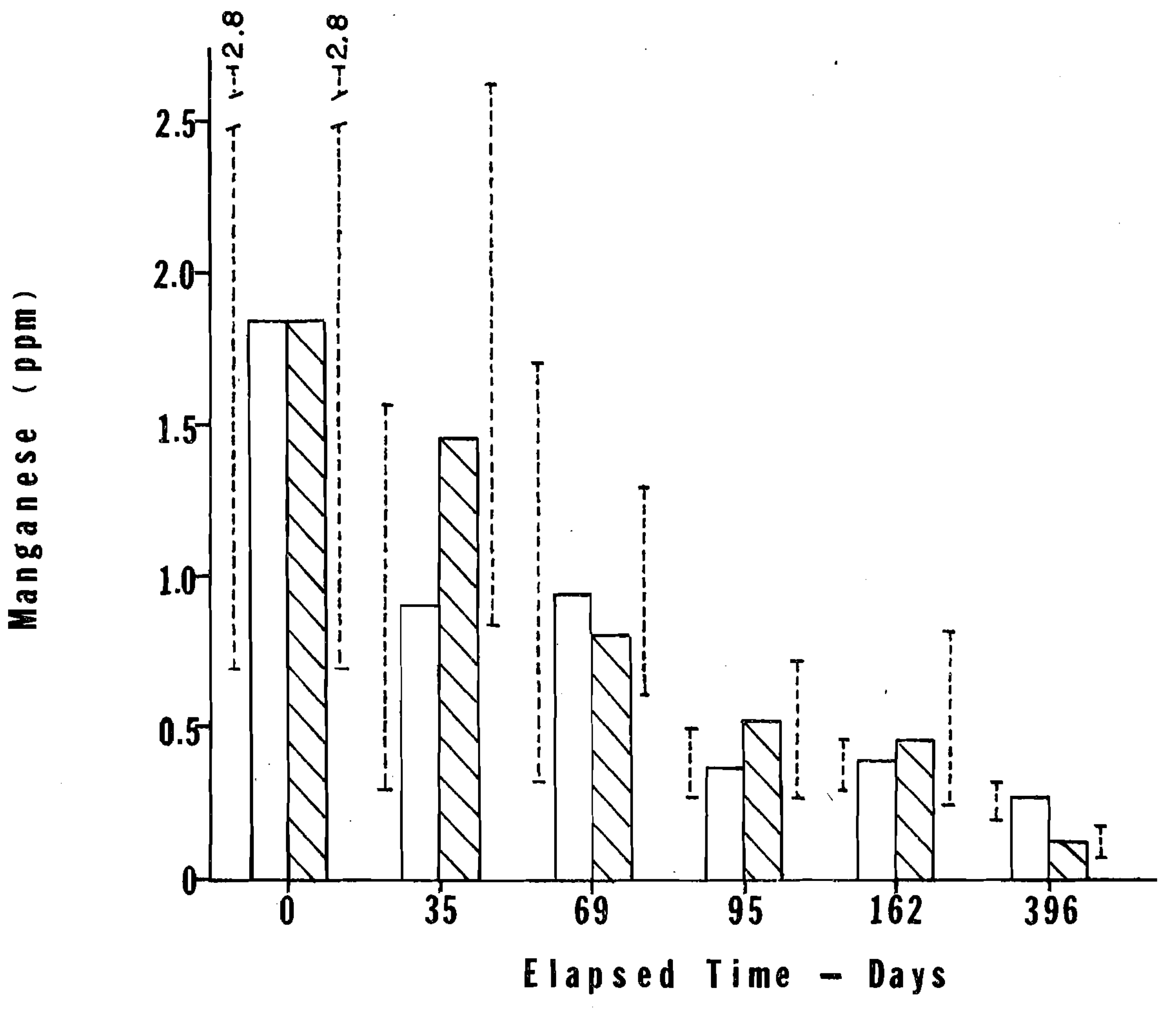

Figure 34. Manganese in muscle tissue of green sunfish. ▭ = control pond; ▨ = experimental pond; ⊢----⊣ = range.

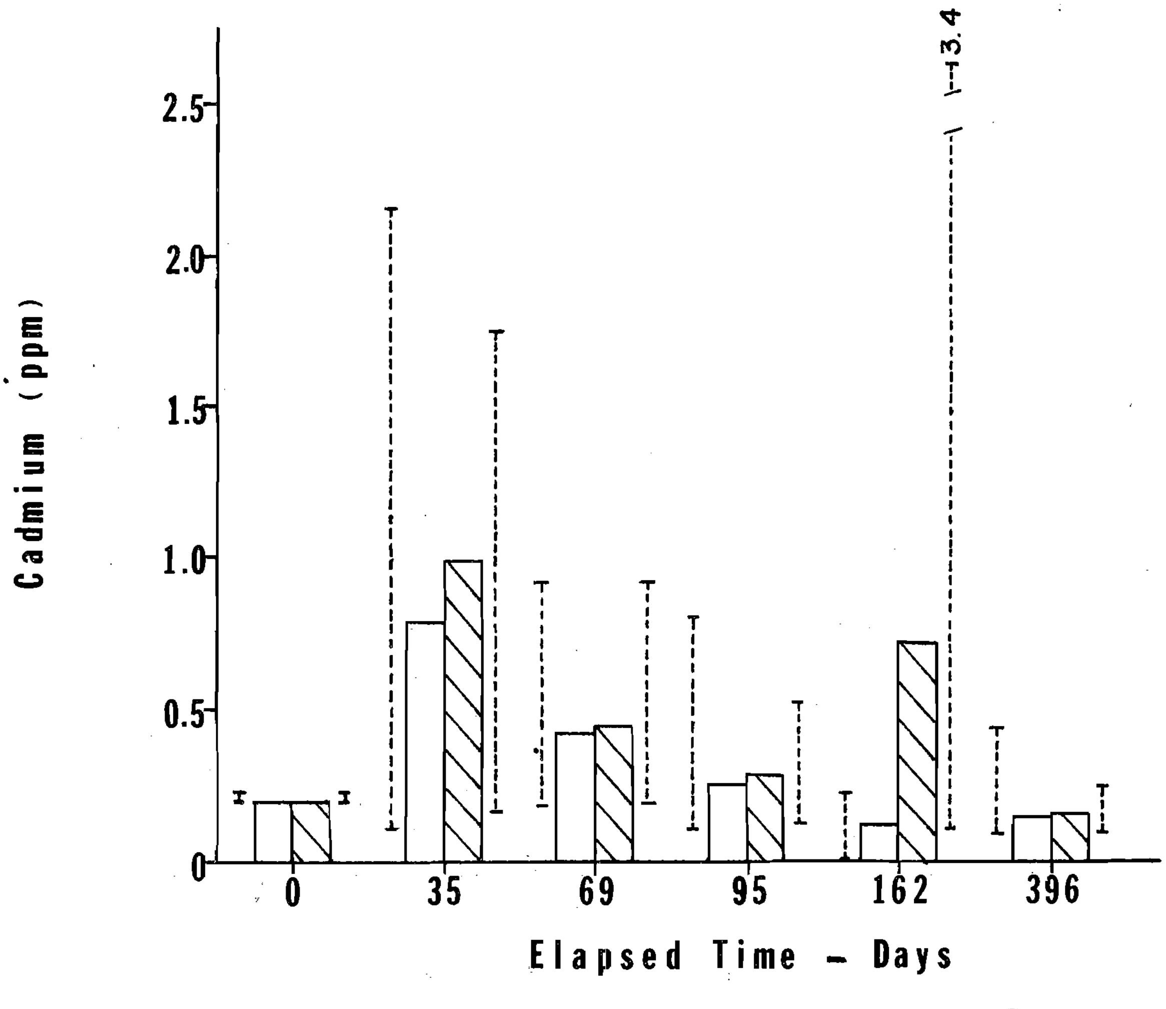

Figure 35. Cadmium in muscle tissue of green sunfish. ☐ = control pond; ▨ = experimental pond; ├---┤= range.

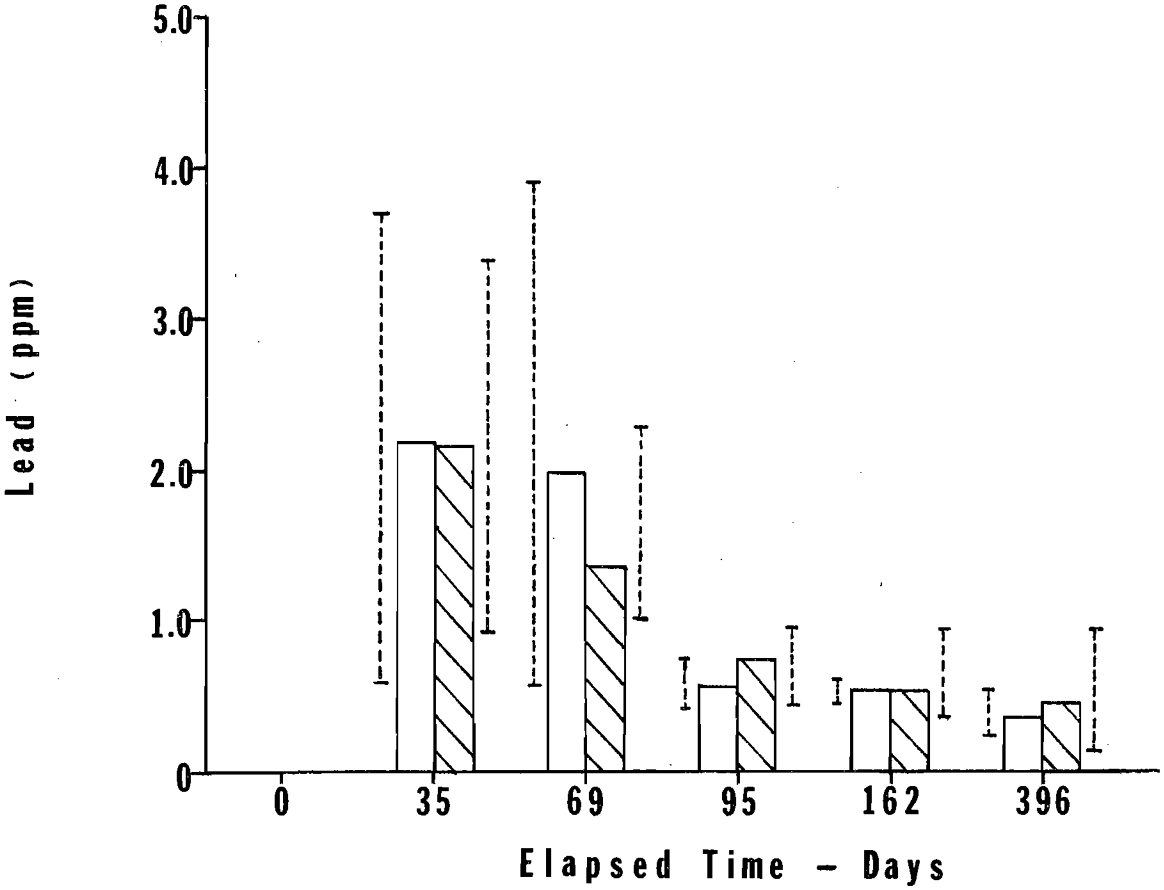

Figure 36. Lead in muscle tissue of green sunfish. ☐ = control pond; ▨ = experimental pond; ⊢---⊣ = range.