

CONCENTRATIONS OF CADMIUM, MANGANESE, AND ZINC  
IN LIVER TISSUE OF COMMON CARP (CYPRINUS CARPIO)  
FROM LAKE PEPIN, NAVIGATION POOL NO. 4,  
UPPER MISSISSIPPI RIVER

A Thesis

Submitted to the Faculty

of

University of Wisconsin - La Crosse

La Crosse, Wisconsin 54601

by

William J. Kowalski

In Partial Fulfillment of the

Requirements for the Degree

of

Master of Science in Biology

July 1983

WT  
83  
AC  
02

UNIVERSITY OF WISCONSIN - LA CROSSE

La Crosse, Wisconsin 54601

COLLEGE OF ARTS, LETTERS, AND SCIENCES

Candidate: William J. Kowalski

We recommend acceptance of this thesis to the College of Arts, Letters, and Sciences in partial fulfillment of this candidate's requirements for the degree Master of Science in Biology. The candidate has completed his oral defense of the thesis.

Thesis approved:

Donald E. Dodal  
Thesis Committee Chairperson

7 July 1983  
Date

Paul J. Taylor  
Thesis Committee Member

July 7, 1983  
Date

Thomas O. Clapp  
Thesis Committee Member

July 7, 1983  
Date

James H. Mines  
Thesis Committee Member

July 20, 1983  
Date

[Signature]  
Dean, College of Arts, Letters, and Sciences

7/29/83  
Date

Howard C. Rose  
Dean, Office of Graduate Studies

July 29, 1983  
Date

## ABSTRACT

Concentrations of Cd, Mn, and Zn were determined for liver tissue of common carp (Cyprinus carpio) from Lake Pepin in Navigation Pool No. 4 of the Upper Mississippi River. Effects of length, weight, condition factor, sex, and season on metal concentrations were evaluated.

Fish were collected from the north end of the lake on three dates over approximately a one year period from the summer of 1980 through the summer of 1981.

Cadmium concentrations ranged from 0.062 to 1.72  $\mu\text{g/g}$  (dry weight) with mean values of 0.467 to 0.591  $\mu\text{g/g}$  for the three sample dates. Manganese concentrations ranged from 0.40 to 94.8  $\mu\text{g/g}$  with means of 1.57 to 8.79  $\mu\text{g/g}$ . Zinc levels ranged from 248 to 2892  $\mu\text{g/g}$  with mean concentrations of 644 to 866  $\mu\text{g/g}$ . Concentrations of Cd and Mn were similar to those reported in common carp and other fish species from other waters, while Zn concentrations were higher than those in other fish species from other waters.

Statistical analyses indicated no consistent effects of total length, wet weight, Fulton's condition factor, sex, or season on Cd, Mn, or Zn concentrations (sexes pooled). There may have been a relation between Cd concentrations in male fish and total length and wet weight and between Mn concentrations in female fish and Fulton's condition factor.

## ACKNOWLEDGMENTS

This study was completed with the help of many people. First, I would like to thank my major advisor, Dr. R. Rada, for his guidance, understanding, and encouragement through all aspects of the study. Special thanks is extended to Dr. J. Wiener whose expertise was indispensable throughout the study. Thanks are also owed to Dr. T. Claflin and Dr. P. Taylor for reviewing the manuscript.

I would like to extend sincere appreciation to Rick Jacobson, Tom Kammer, Jim Rogala, and Dwight Will for assisting in the collection of the fish. Thanks also go to Pat Bailey whose suggestions saved many hours in the laboratory.

This study was funded by the River Studies Center, University of Wisconsin - La Crosse

## TABLE OF CONTENTS

	<u>PAGE</u>
LIST OF TABLES . . . . .	v
LIST OF FIGURES . . . . .	vi
INTRODUCTION . . . . .	1
DESCRIPTION OF STUDY AREA . . . . .	2
LITERATURE REVIEW . . . . .	6
Chemical and Physical Characteristics of Water . . . . .	6
Sediment-Water Interactions . . . . .	7
Microbial Activity . . . . .	8
Organism Biology . . . . .	9
Life History of Common Carp . . . . .	13
MATERIALS AND METHODS . . . . .	14
RESULTS AND DISCUSSION . . . . .	18
Quality Assurance . . . . .	18
Metal Concentrations in Common Carp . . . . .	21
Comparisons of Metals in Common Carp from Lake Pepin to Those of Other Waters . . . . .	21
Effects of Total Length, Wet Weight, and Fulton's Condition Factor . . . . .	25
Effects of Season and Sex . . . . .	28
SUMMARY AND CONCLUSIONS . . . . .	30
LITERATURE CITED . . . . .	31
APPENDIX . . . . .	36

## LIST OF TABLES

<u>TABLE</u>	<u>PAGE</u>
1. Water chemistry data from the Upper Mississippi River at Red Wing, Minnesota (Source: Minnesota Pollution Control Agency 1978) . . . . .	4
2. Instrument parameters for Instrumentation Laboratory Model 257 atomic absorption spectrophotometer, Model 655 furnace atomizer, and Model 254 auto-sampler . . . . .	16
3. Regression coefficients (slopes) for simple linear regressions and metal concentrations from standard additions (SA) and standard curves (SC) for liver tissue of common carp from Lake Pepin and NBS bovine liver . . . . .	19
4. Results of quality assurance procedures for metal analyses of liver tissue of common carp from Lake Pepin . . . . .	20
5. Description of common carp collected from Lake Pepin. Ranges of total length, wet weight, and Fulton's condition factor (K) are given in parentheses below each mean . . . . .	22
6. Mean concentrations ( $\mu\text{g/g}$ dry weight) of Cd, Mn, and Zn in liver tissue of common carp from Lake Pepin. Metal concentration ranges are in parentheses . . . . .	23
7. Pearson correlation coefficients ( $r$ ) for metal concentrations in liver tissue of common carp from Lake Pepin . . . . .	26
8. Results of one-way and two-way ANCOVA (p values) performed on metal concentrations in liver tissue of common carp from Lake Pepin. Sex and season were factors and length was the covariate . . . . .	27
 <u>APPENDIX TABLE</u>	
A. Sex, total length, wet weight, Fulton's condition factor, and metal concentration in liver tissue of individual common carp from Lake Pepin . . . . .	36

LIST OF FIGURES

<u>FIGURE</u>	<u>PAGE</u>
1. The Upper Mississippi River from the Twin Cities to La Crosse, Wisconsin. An enlarged map of the study area in Lake Pepin is shown in the box at lower left . . . . .	3

## INTRODUCTION

The Upper Mississippi River receives considerable quantities of trace metals, which include Cd, Cr, Ni, Pb, and Zn, in the Minneapolis-St. Paul (Twin Cities) metropolitan area (Sprafka 1981). Impoundments and lakes downstream of the Twin Cities may serve as sinks for these metals. Common carp (Cyprinus carpio) from one such lake, Lake Pepin, were analyzed to assess the accumulation of Cd, Mn, and Zn in liver tissue. The primary objectives of this study were to:

1. compare Cd, Mn, and Zn concentrations in common carp from Lake Pepin to those of other waters;
2. assess relations between concentrations of these metals in fish tissue and length, weight, and condition factor of the fish;
3. determine whether Cd, Mn, and Zn concentrations varied seasonally;
4. determine whether Cd, Mn, and Zn concentrations varied with sex;
5. provide baseline information for future monitoring.

DESCRIPTION OF STUDY AREA

Lake Pepin is located in Navigation Pool No. 4 of the Upper Mississippi River between River Miles 765 and 786 (Fig. 1). It is bordered by Pierce and Pepin counties in Wisconsin and Goodhue and Wabasha counties in Minnesota. Lake Pepin is located about 110 km downstream of the Twin Cities metropolitan area. It varies in width from 1.6 to 4.0 km and has a surface area of 101.2 km<sup>2</sup>; maximum and mean depths are 17.1 and 5.0 m. Lake Pepin is a hard (total hardness, 185 mg/l as CaCO<sub>3</sub>), alkaline (alkalinity, 161 mg/l as CaCO<sub>3</sub>) (Minnesota Pollution Control Agency 1978), and eutrophic body of water (U. S. Environmental Protection Agency 1975). Water quality characteristics for the Mississippi River just upstream from Lake Pepin are listed in Table 1. Lake Pepin has a large capacity-to-inflow ratio and therefore has a relatively high trapping efficiency for suspended sediments. The sedimentation rate is approximately 2 cm/yr in the upper portion of the lake with lower rates in the downstream reaches of the lake (McHenry et al. 1983). The sediments in the lake are predominantly clays with some near shore areas consisting largely of sands and silts (Bailey and Rada 1983). Sediments have mean Cd and Zn concentrations of 4.2 and 128 µg/g dry weight, respectively; these metals were enriched when concentrations in surficial sediments of Lake Pepin were compared to surficial sediments in Pools 5 and 9 (Bailey and Rada 1983).

Common carp were collected primarily along the north shore of the lake near Bay City, Wisconsin, where much of the shoreline is exposed to wave action, which at times results in high turbidity (30-52 NTU). The substrate is predominantly silt and clay. The average depth in

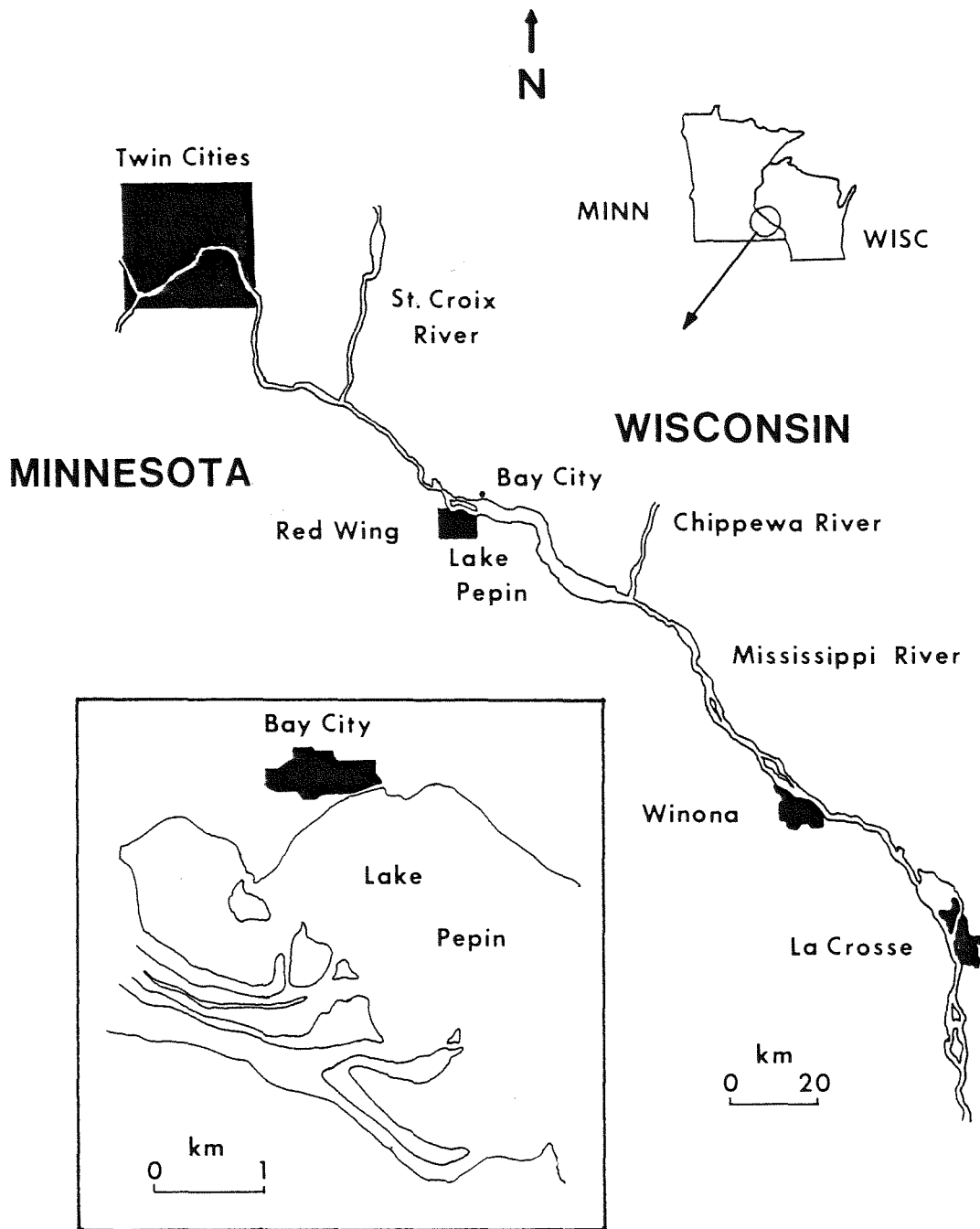


Figure 1. The Upper Mississippi River from the Twin Cities to La Crosse, Wisconsin. An enlarged map of the study area in Lake Pepin is shown in the box at lower left.

Table 1. Water chemistry data from the Upper Mississippi River at Red Wing, Minnesota (Source: Minnesota Pollution Control Agency 1978).

Parameter	Mean
Conductivity	429 $\mu$ hos/cm
Total residue	271 mg/l
Total nonfiltrable residue	16.8 mg/l
Turbidity	17.6 FTU <sup>a</sup>
pH	8.2
Total hardness	185 mg/l as CaCO <sub>3</sub>
Total alkalinity	161 mg/l as CaCO <sub>3</sub>
Total Cd	~10 $\mu$ g/l
Total Mn	170 $\mu$ g/l
Total Zn	14 $\mu$ g/l

<sup>a</sup>FTU = Formazin Turbidity Units.

this area is approximately 1 m.

## LITERATURE REVIEW

The availability of trace metals to aquatic organisms can be influenced by four general factors: (1) chemical and physical characteristics of water; (2) sediment-water interactions; (3) microbial activity; and (4) organism biology. Each of these factors are discussed in the following text.

### Chemical and Physical Characteristics of Water

The biological availability of trace metals in the aquatic environment is very complex, because dissolved organic and inorganic components of water affect availability of trace metals to biota (Giesy et al. 1978). The affinity of organic substances is greater for trace metal ions than for alkaline earth or alkali ions (Forstner and Wittmann 1979). Jenne and Luoma (1977) stated that organic complexes usually decrease the bioavailability of trace element forms in solution. Giesy et al. (1978), however, found that the aqueous cadmium-binding capacity was lower in some acidic Maine surface waters with elevated organic carbon concentrations than in waters with lower organic carbon concentrations, suggesting that Cd might be more available for uptake by biota in those high organic carbon waters.

Water hardness is one of the most important factors influencing trace metal toxicity and availability to aquatic organisms. Metal toxicity generally decreases with increased hardness (Farmer et al. 1979), due to formation of insoluble carbonates or from adsorption on calcium carbonate (Forstner and Wittmann 1979). Carroll et al. (1979)

showed reduction of Cd toxicity to brook trout (Salvelinus fontinalis) by Ca ions, whereas the carbonate system provided little inhibition to Cd toxicity. Calamari et al. (1980) and Sinley et al. (1974) demonstrated that Zn toxicity in rainbow trout (Salmo gairdneri) decreased as water hardness increased. Matthiessen and Brafield (1977) noted that  $^{65}\text{Zn}$  uptake by common carp was reduced at high waterborne Ca concentrations.

The toxicity of certain trace metals may increase as water temperature increases, due to greater respiratory activity at higher water temperatures (Lloyd 1965). Hodson (1975) demonstrated that  $^{65}\text{Zn}$  uptake by Atlantic salmon (Salmo salar) was faster at 19°C than at 11 or 3°C, and that the lethal concentration of Zn was lower at 19°C than at 11 or 3°C. Edgren and Notter (1980) demonstrated that  $^{115}\text{Cd}$  uptake by fingerling perch (Perca fluviatilis) was faster at 15°C than at 5°C. Lloyd (1960) showed that survival of rainbow trout exposed to lethal Zn levels was twice as long at 12°C than at 22°C. Cairns et al. (1971) reported similar results with bluegills (Lepomis macrochirus). Cadmium was more toxic to mummichogs (Fundulus heteroclitus) at 20°C than at 5°C (Eisler 1971).

Trace metal availability and toxicity are also influenced by pH. Toxicity typically increases with decreased pH (Forstner and Wittmann 1979).

### Sediment-Water Interactions

Sediments act as a sink for most trace metals (Mathis and Cummings 1973, Mathis and Kevern 1975, Enk and Mathis 1977, Forstner

and Wittmann 1979, and Mathis et al. 1979). Metal concentrations in sediments typically increase with decreasing particle size (Forstner and Wittmann 1979). Bailey and Rada (1983) demonstrated a strong positive relationship between Cd and Zn concentrations in bed sediments of Lake Pepin and the percentage of sediments less than 4  $\mu\text{m}$  in particle size. The primary sites of adsorption for trace elements are Fe and Mn oxides and organic substances (Jenne and Luoma 1977). Other complexes for trace metal deposition include carbonates, phosphates, sulfides, oxidic Al and silicon, and basic sulfate and chloride salts.

The movement of trace metals between solute and solid phases is achieved through several sorption and desorption processes, including surface exchange, diffusion exchange, precipitation, coprecipitation, and complexation (Jenne and Luoma 1977).

### Microbial Activity

The importance of microbial activity in Hg mobilization is well known (Jensen and Jernelov 1969, Langley 1973, and Spangler et al. 1973). Iverson and Brinckman (1978) cited evidence of microbial transformation of As, Cd, Pb, Hg, Se, and Sn. Forstner and Wittmann (1979) suggested that there are three principal mechanisms resulting in trace metal mobilization by microbial activity: the degradation of organic matter to lower molecular weight compounds that are better able to complex metal ions, environmental changes (e.g., redox potential and pH) induced by metabolic activities, and the enzyme-catalyzed reactions of the transformation of inorganic compounds into metal complexes by organic substances.

## Organism Biology

Four general biological factors affect the toxicity and accumulation of trace metals by aquatic organisms: (1) life history of organisms; (2) species differences; (3) seasonal differences of trace metal concentrations in organisms; and (4) trace metal contents of ingested food (Forstner and Wittmann 1979). Benoit et al. (1976) and Holcombe et al. (1979) determined the effects of Cd and Zn exposure on three generations of brook trout. Benoit et al. (1976) found that prespawning brook trout showed no abnormal behavior when exposed to Cd concentrations of 3.4  $\mu\text{g}/\text{l}$ . During the spawning period, however, male trout became hyperactive and eventually died. The hatch and survival of second generation trout through the juvenile stage were not affected by the Cd levels tested. The weights of second generation juvenile trout were inversely related to increasing Cd concentrations. As with first generation trout, second generation trout assumed normal behavior until spawning, when the males exposed to 3.4  $\mu\text{g}/\text{l}$  became hyperactive and died. The hatch and survival of third generation brook trout were similar to that of the second generation. Both second and third generation juvenile trout exposed to 3.4  $\mu\text{g}/\text{l}$  weighed less than trout exposed to Cd concentrations  $\leq 1.7 \mu\text{g}/\text{l}$ .

Holcombe et al. (1979) showed that Zn concentrations as high as 1360  $\mu\text{g}/\text{l}$  did not affect the growth, survival, and spawning of yearling first generation brook trout. Hatching success was reduced at Zn concentrations of 1360  $\mu\text{g}/\text{l}$  but was not affected at lower concentrations in second generation trout. Growth of second generation trout increased at concentrations of 266 and 534  $\mu\text{g}/\text{l}$ , but spawning was not affected at

any of the Zn concentrations tested. Hatching success of third generation trout was not affected at the Zn levels tested (534 µg/l was the highest concentration used). Third generation larval and juvenile trout survival did not appear to be affected. The fragility of third generation trout eggs increased with increasing Zn concentrations. Egg fragility was not evaluated in first and second generation trout.

Accumulation of trace metals varies substantially among fish species. Murphy et al. (1978a) found that Cd and Zn concentrations in axial muscle tissue were significantly higher in bluegills than in largemouth bass (Micropterus salmoides). Murphy et al. (1978b) observed higher whole body concentrations of Cd and Zn in warmouth (Lepomis gulosus) and bluegills than in largemouth bass and black crappie (Pomoxis nigromaculatus) from the western basin of the metal-contaminated Palestine Lake. Mathis et al. (1979) showed that green sunfish (Lepomis cyanellus) had greater whole body concentrations of Cd, Mn, and Pb than channel catfish (Ictalurus punctatus) in both control and experimental ponds. These results indicate that fish species with greater omnivorous feeding habits (bluegill, warmouth, and green sunfish) seem to accumulate more of these trace metals than the more carnivorous fish species (largemouth bass, black crappie, and channel catfish). Other researchers have refuted these findings. Wiener and Giesy (1979) indicated that none of the seven species of fish analyzed from a South Carolina pond had consistently higher or lower Cu, Mn, and Zn levels. However, mean whole body concentrations of Mn and Pb were higher in bluegills than in largemouth bass and chain pickerel (Esox niger). Mean concentrations of Cu, Mn, and Zn in axial muscle and liver tissues were extremely variable and did not show the same trends as the whole

body concentrations. Enk and Mathis (1977) observed similar mean concentrations of Cd and Pb among river carpsucker (Carpoides carpio), fantail darter (Etheostoma flabellare), and smallmouth bass (Micropterus dolomieu).

Seasonal fluctuations of trace metal contamination in fish have been reported. Van Den Broek (1979) noted that Cd, Pb, and Zn levels in muscle and liver tissue of eel (Anguilla anguilla), whiting (Merlangius merlangus), flounder (Platichthys flesus), and plaice (Pleuronectes platessa) tended to be the lowest in summer. It was concluded that the lower metal levels in some fish species may have been due to summer migration of fish from the open ocean into the estuary where the fish were collected. Fletcher and King (1978) found highest Zn concentrations in liver tissue of winter flounder (Pseudopleuronectes americanus) in August with levels declining from August to November in males and from October to May in females. Hardisty et al. (1974a) indicated that whole body concentrations of Cd, Pb, and Zn in 1+ age and older flounder increased between October and February, but remained fairly constant or decreased slightly between February and June. Stomach content analyses indicated that a seasonal change in diet may have contributed to the results.

Another factor affecting trace metal accumulation and toxicity in aquatic organisms is trace metal content in ingested food (Forstner and Wittmann 1979). There is some controversy as to whether uptake from water or food is the primary mechanism of trace metal accumulation. Williams and Giesy (1978) observed that water was the more important source of Cd in the mosquitofish (Gambusia affinis) in soft water. Patrick and Loutit (1978) demonstrated that contaminated tubificid

worms fed to tropical fish (Hyphessobrycon serpae) was a major source of metals in these fish. Renfro et al. (1975) compared uptake of radioactive Zn via water alone and food and water pathways in Gobius sp. during a three-month period. It was determined that Gobius exposed to contaminated food and water accumulated 2.5 times more whole body radioactivity than Gobius exposed to contaminated water alone. Hardisty et al. (1974b) noted that bearded rockling (Ciliata mustela) had higher Cd, Pb, and Zn concentrations than the sandy goby (Gobius minutus). They attributed these findings to differences in the diet of the two species. The diet of bearded rockling was composed of 90% crustaceans, whereas that of the sandy goby was only 10% crustaceans. There is probably no single factor causing differences in trace metal accumulation. Jenne and Luoma (1977) stated that the interaction of physiological, ecological, and chemical factors affects the assimilation rate of a trace element by an organism more than any single factor.

The availability of trace metals to fish in the natural environment is, therefore, very complex and poorly understood. Each aquatic system is an unique environment that responds differently to both man-induced and natural influences.

There is a general lack of information concerning the accumulation of trace metals by common carp. Much of this type of information has been gathered on sport fish such as rainbow trout. Rough fish species, such as common carp, have not received much attention even though the common carp is an important commercial species in many locations. Commercial harvest of common carp in the Upper Mississippi River exceeds that of any other species harvested in the Upper Mississippi River

(Farabee 1979).

### Life History of Common Carp

The common carp is predominantly found in large streams, lakes, and impoundments that have elevated production levels as a result of natural fertility or anthropogenic inputs of nutrients. The adults are associated with the shallow shoreline of lakes and the deeper pools of streams that have submerged cover (Pflieger 1975).

Common carp do not have strong schooling tendencies but often form loose aggregations. Feeding activity occurs mainly during late evening and early morning and is concentrated primarily on the bottom, although some surface feeding will occur at times (Pflieger 1975). Common carp tend to be aggressive feeders, roiling bottom sediments and uprooting vegetation. Common carp are omnivorous and ingest a variety of animal and plant materials. Animal materials generally consist of aquatic insect larvae, crustaceans, molluscs, and annelids. Plant materials consist primarily of aquatic plant fragments, seeds, and dead plant material (Frey 1940, Moen 1953, Sigler 1958, Rehder 1959, Scott and Crossman 1973, and Pflieger 1975).

Common carp spawn in the spring and early summer at water temperatures of 14.5 to 20.0°C over plant material, debris, or rubble in shallow water (Carlander 1969). The eggs are deposited randomly and no parental care is given (Pflieger 1975). The eggs require about a week to hatch. Growth rates are variable, depending on food availability, temperature, and other factors.

## MATERIALS AND METHODS

Common carp were collected by electrofishing on 28 July 1980 (summer), 22 May 1981 (spring), and 3 August 1981 (summer). Following capture, the fish were weighed and measured (total length) to the nearest 5 g and mm, respectively, placed in polyethylene bags, and held on ice. Specimens were returned to the laboratory where the livers were removed with stainless steel implements, washed with deionized water, placed in Whirl-Pak<sup>®</sup> bags, and frozen. The frozen livers were transferred to petri dishes and lyophilized at -33°C for 48 h. The livers from the 28 July 1980 sample were oven-dried at 65°C for 24 h. The dried tissue was then homogenized by crushing the liver with a glass stirring rod and thoroughly shaking the liver in the petri dishes. The tissue was stored in a dessicator until digestion.

A mass of 250±0.2 mg of dried liver tissue was digested in 15-ml porcelain crucibles with 2 ml of Ultrex<sup>®</sup> HNO<sub>3</sub>. The tissue was allowed to digest at room temperature for 15 to 20 h to prevent excessive foaming during heating. The tissue was then digested on a hot plate at a temperature sufficient to cause gas evolution. Digestion was terminated when gas evolution ceased and a volume of approximately 1 ml remained. The digestate was allowed to cool and then transferred to a 100-ml volumetric flask with washings and brought to volume. The diluted digestate was filtered (to remove lipid residue) through a type A/E glass fiber filter into a polyethylene container and stored at 4.4°C until analysis.

Prior to use, all glassware, filters, and other containers were soaked in 50% HNO<sub>3</sub> for at least 20 h, rinsed 4 to 6 times with tap

water, and then rinsed 4 to 6 times with deionized water.

Metal analyses were conducted with an Instrumentation Laboratory Model 257 atomic absorption spectrophotometer equipped with a Model 655 furnace atomizer and Model 254 auto-sampler. Cadmium and Mn concentrations were determined by flameless (graphite furnace) atomization, and Zn concentrations were measured by flame atomization. A microboat technique was used for Cd to reduce interferences during analysis (Conley et al. 1981). Instrument parameters and furnace programs are listed in Table 2.

Standards were prepared from Fisher certified atomic absorption standards in 1% Ultrex<sup>®</sup> HNO<sub>3</sub>. Procedural blanks were used to evaluate contamination from reagents and containers. United States National Bureau of Standards (NBS) bovine liver (Standard Reference Material 1577) and spiked samples were analyzed to validate digestion and analytical procedures. Matrix interferences were evaluated for each metal by the method of standard additions. Replicate analyses were also conducted for each metal to assess tissue homogeneity and procedural contamination and to estimate precision.

Pearson correlation coefficients ( $r$ ) were determined between metal concentration and total length, wet weight, and Fulton's condition factor ( $K = \frac{1000w}{l^3}$ ;  $w$  = weight,  $l$  = length) (Ricker 1975) of the fish. Analysis of covariance (ANCOVA) (Snedecor and Cochran 1967) was conducted on all metal data using the Statistical Package for the Social Sciences (SPSS) (Nie et al. 1975) to determine the effects of sex, season, and length on metal concentrations. An ANCOVA was used to adjust for possible sources of bias, because the size of the fish varied among seasons and between male and female fish. Season and sex were the

Table 2. Instrument parameters for Instrumentation Laboratory Model 257 atomic absorption spectrophotometer, Model 655 furnace atomizer, and Model 254 auto-sampler.

Parameter	Cd	Mn	Zn
A. A. spectrophotometer			
Wavelength (nm)	228.5	279.5	213.6
Lamp current (mA)	3.5	5.5	3.0
Voltage (V)	620	700	900
Bandpass (nm)	1.0	0.5	0.5
Peak height	--	X <sup>a</sup>	--
Peak area	X	--	--
Single beam	X	X	--
Double beam	--	--	X
Background correction (D <sub>2</sub> )	X	X	X
Integration mode	--	--	auto
Gases	--	--	air/acetylene
Integration (sec)	--	--	2
Furnace			
Operation mode	pressurization	auto	--
Gases	N/air	N/air	--
Graphite cuvette	pyrolytic, rectangular w/ microboat	uncoated, round	--
Step number			
1 sec	0	0	--
temp	--	--	--
2 sec	5	5	--
temp	180	120	--
3 sec	10	20	--
temp	350	400	--
4 sec	15	20	--
temp	450	400	--
5 sec	0	10	--
temp	1600	1900	--
6 sec	5	5	--
temp	1600	1900	--
Auto-sampler			
Delay (sec)	8	8	--
Deposit (sec)	11	14	--
Integration (sec)	3.5	14	--
Step number	6	5	--
Flush rate	high	high	--

<sup>a</sup>X = parameter used during metal analysis.

factors and length was the covariate. Two-way ANCOVA was performed on the Cd and Zn data. One-way ANCOVA was conducted on the Mn data because non-additivity was demonstrated for the two-way ANCOVA. One-way ANCOVA was also performed on the Cd data to determine the effects of length on Cd concentrations for each season. All means for significant factors were compared using Tukey's honestly significant difference (HSD) test (Steel and Torrie 1960). Manganese and Zn data were log-transformed to achieve homogeneity among variances prior to ANCOVA. Statistical analyses were judged at the  $\alpha = 0.05$  (significant) and  $\alpha = 0.01$  (highly significant) levels.

## RESULTS AND DISCUSSION

Quality Assurance

The results of the standard additions and recoveries from spiked samples showed no substantial matrix interferences (Tables 3 and 4). The slopes of the simple linear regressions for the standard additions were comparable to the slopes of the standard curves for all three metals. Sample concentrations obtained from standard additions were generally similar to those obtained from the standard curves. The standard addition values for Zn averaged 111% of the standard curve values in liver of common carp and 108% in NBS bovine liver. For Cd, mean values were 95.7% in liver of common carp and 91.0% in NBS bovine liver. The mean values for Mn were 103% in common carp liver and 90.9% in NBS bovine liver. Recoveries of Cd, Mn, and Zn from spiked samples were acceptable for both common carp liver and NBS bovine liver, ranging from 95.6 to 103% (Table 4).

The observed concentrations of Cd, Mn, and Zn in NBS bovine liver were within the certified concentration ranges for these metals (Table 4). Ten of the common carp livers were analyzed in triplicate for each metal (Table 4). Precision was acceptable for Zn (mean relative standard deviation, RSD = 2.2%), Mn (mean RSD = 9.7%), and Cd (mean RSD = 15.5%). Contamination of procedural blanks from reagents and containers was minor (Table 4).

Table 3. Regression coefficients (slopes) for simple linear regressions and metal concentrations from standard additions (SA) and standard curves (SC) for liver tissue of common carp from Lake Pepin and NBS bovine liver.

Matrix and Metal	Sample Identification Code	Method	Slope	Metal Concentration <sup>a</sup>	Ratio <sup>b</sup> (%)
Common carp liver					
Cd	90	SA	0.162	0.283	92.5
		SC	0.164	0.306	
	8	SA	0.101	0.851	90.1
		SC	0.098	0.945	
	59	SA	0.153	0.305	105
		SC	0.146	0.292	
Mn	1	SA	0.0038	6.16	109
		SC	0.0040	5.68	
	6	SA	0.0042	4.63	97.9
		SC	0.0044	4.73	
Zn	Exp. 3	SA	0.888	0.149	121
		SC	0.822	0.123	
	15	SA	0.775	0.219	122
		SC	0.772	0.180	
	27	SA	0.786	0.182	121
		SC	0.772	0.151	
	62	SA	0.494	0.239	104
		SC	0.473	0.231	
	62	SA	0.989	0.213	86.9
		SC	0.965	0.245	
Bovine liver					
Cd	S	SA	0.136	0.225	93.4
		SC	0.136	0.241	
	U	SA	0.158	0.240	88.6
		SC	0.164	0.271	
Mn	S	SA	0.0046	8.72	92.2
		SC	0.0046	9.46	
	T	SA	0.0028	9.22	89.5
		SC	0.0028	10.30	
Zn	R	SA	0.982	0.191	106
		SC	0.887	0.181	
	U	SA	0.481	0.165	111
		SC	0.473	0.149	

<sup>a</sup>Cd and Mn concentrations in  $\mu\text{g}/\text{l}$ , Zn concentrations in  $\text{mg}/\text{l}$ .

<sup>b</sup>Metal concentration from standard addition divided by metal concentration from standard curve multiplied by 100. Metal concentrations are those of the digestate.

Table 4. Results of quality assurance procedures for metal analyses of liver tissue of common carp from Lake Pepin.

Procedure	Cd	Mn	Zn
Analysis of NBS bovine liver			
Certified concentration range ( $\mu\text{g/g}$ dry wt.)	$0.27 \pm 0.04$	$10.1 \pm 1.0$	$130 \pm 13$
Observed values			
Mean concentration	0.31	9.9	135
RSD (%) <sup>a</sup>	9.8	3.6	3.8
n	4	3	6
Recovery from spiked samples			
Common carp liver			
Mean recovery (%)	101	95.6	103
RSD (%)	2.8	0.4	2.9
n	6	4	10
Bovine liver			
Mean recovery (%)	97.3	99.2	101
RSD (%)	2.2	0.9	1.5
n	4	4	4
Triplicate analyses of common carp liver			
Mean RSD (%)	15.5	9.7	2.2
n	10	10	10
Blank analyses			
Blanks (%) <sup>b</sup>	73	80	100
n	15	15	15

<sup>a</sup>RSD = relative standard deviation.

<sup>b</sup>Percent of blanks having concentrations less than 10% of the mean metal concentration in liver tissue of common carp.

### Metal Concentrations in Common Carp

Thirty common carp were collected during each of three sampling dates. Female common carp averaged slightly larger in size (total length and wet weight) than males (Table 5). In general, the ranks for mean size and condition factor among seasons were: S1 > S2 > S3. Data on total length, wet weight, Fulton's condition factor, and metal concentrations for individual fish are listed in Appendix A.

### Comparisons of Metals in Common Carp from Lake Pepin to Those of Other Waters

Mean Cd concentrations for female common carp (range 0.585-0.751  $\mu\text{g/g}$ , Table 6) were slightly greater than those found in male common carp (range 0.388-0.510  $\mu\text{g/g}$ ). In contrast, Zn concentrations in males ranged from 712 to 897  $\mu\text{g/g}$ , while those in females ranged from 542 to 812  $\mu\text{g/g}$ . Male common carp had slightly greater mean Mn concentrations than the females for S2 (males 1.66  $\mu\text{g/g}$ , females 1.30  $\mu\text{g/g}$ ) and S3 (males 2.98  $\mu\text{g/g}$ , females 2.51  $\mu\text{g/g}$ ) samples. However, for S1 the mean Mn concentrations for females and males were 12.3 and 4.8  $\mu\text{g/g}$ , respectively.

Only limited data on metal concentrations in common carp liver tissue are available in the literature. Wiener et al. (in press) found a mean Cd concentration of 1.03  $\mu\text{g/g}$  in livers of common carp from Pool No. 4 of the Upper Mississippi River, which is about double the mean levels found in this study (0.467-0.591  $\mu\text{g/g}$ , Table 6). Mean Cd concentrations in liver tissue of common carp from the Wisconsin

Table 5. Description of common carp collected from Lake Pepin. Ranges of total length, wet weight, and Fulton's condition factor (K) are given in parentheses below each mean.

Sex/Sample <sup>a</sup>	n	Mean Total Length (mm)	Mean Wet Weight (kg)	Mean K
<b>Males</b>				
S1	14	561 (392-622)	2.76 (0.93-4.46)	1.51 (1.27-1.88)
S2	22	461 (335-655)	1.60 (0.67-4.05)	1.53 (1.18-1.86)
S3	18	483 (430-575)	1.52 (1.14-2.53)	1.33 (1.18-1.47)
<b>Females</b>				
S1	16	609 (488-727)	3.67 (1.78-5.05)	1.59 (1.31-1.80)
S2	8	614 (460-740)	3.37 (1.42-6.10)	1.40 (1.16-1.57)
S3	12	539 (465-695)	2.11 (1.39-3.22)	1.33 (0.96-1.51)
<b>Sexes pooled</b>				
S1	30	587 (392-727)	3.24 (0.93-5.05)	1.55 (1.27-1.88)
S2	30	502 (335-740)	2.07 (0.67-6.10)	1.50 (1.16-1.86)
S3	30	506 (430-695)	1.75 (1.14-3.22)	1.33 (0.96-1.51)

<sup>a</sup>S1 = 28 July 1980 (summer), S2 = 22 May 1981 (spring), 3 August 1981 (summer).

Table 6. Mean concentrations ( $\mu\text{g/g}$  dry weight) of Cd, Mn, and Zn in liver tissue of common carp from Lake Pepin. Metal concentration ranges are in parentheses.

Sex/Sample <sup>a</sup>	n	Cd	Mn	Zn
Males				
S1	14	0.510 (0.118-1.07)	4.80 (0.68-48.0)	818 (357-1940)
S2	22	0.400 (0.062-1.35)	1.66 (0.54-7.55)	897 (248-2131)
S3	18	0.388 (0.153-1.35)	2.98 (0.79-17.7)	712 (254-2892)
Females				
S1	16	0.663 (0.183-1.42)	12.3 (0.40-94.8)	812 (303-1364)
S2	8	0.751 (0.432-1.18)	1.30 (0.75-1.82)	780 (340-1251)
S3	12	0.585 (0.133-1.72)	2.51 (0.78-12.9)	542 (260-1090)
Sexes pooled				
S1	30	0.591 (0.118-1.42)	8.79 (0.40-94.8)	815 (303-1940)
S2	30	0.493 (0.062-1.35)	1.57 (0.54-7.55)	866 (248-2131)
S3	30	0.467 (0.133-1.72)	2.79 (0.78-17.7)	644 (254-2892)

<sup>a</sup>S1 = 28 July 1980 (summer), S2 = 22 May 1981 (spring), S3 = 3 August 1981 (summer).

River (Findley et al. In preparation) were similar to those reported here. The mean Zn concentration (7.06  $\mu\text{g/g}$ ) in the liver of common carp from the Danube River (Rehwooldt et al. 1976) was much lower than those found in this study (644-866  $\mu\text{g/g}$ ). Data on Cd, Mn, and Zn concentrations in liver tissue of other fish species have been reported. Mean Cd levels in liver tissue of Artic cod (Boreogadus saida) (Bohn and McElroy 1976) were similar to those reported in Lake Pepin common carp. Bohn and Fallis (1978) found mean Cd concentrations in liver tissue of shorthorn sculpin (Myoxocephalus scorpius) and Artic char (Salvelinus alpinus) that were 3 to 9 fold greater than those reported here. Wiener and Giesy (1979) reported mean Mn concentrations in liver tissue of bluegill, largemouth bass, chain pickerel, and bowfin (Amia calva) from Skinface Pond in South Carolina that were similar to those found in this study for common carp (1.57-2.81  $\mu\text{g/g}$ ). Mean Zn concentrations in liver tissue of Artic cod (19  $\mu\text{g/g}$ ) (Bohn and McElroy 1976), shorthorn sculpin (100  $\mu\text{g/g}$ ) and Artic char (130  $\mu\text{g/g}$ ) (Bohn and Fallis 1978), and bluegill (39.7  $\mu\text{g/g}$ ), largemouth bass (74.4  $\mu\text{g/g}$ ), chain pickerel (337.9  $\mu\text{g/g}$ ), and bowfin (85.7  $\mu\text{g/g}$ ) (Wiener and Giesy 1979) were much lower than those found in common carp from Lake Pepin.

Because comparable trace metal data for common carp is very limited, it is difficult to assess whether the Cd, Mn, and Zn concentrations found in Lake Pepin fish are typical. Only analysis of common carp from systems free from man-induced contamination will reveal true baseline metal concentrations. However, this approach must be viewed with caution, because factors affecting metal accumulation in fish from one system may not be typical of another, even when the systems are free from man-induced contamination.

Effects of Total Length, Wet Weight, and Fulton's Condition Factor

Pearson correlation coefficients ( $\underline{r}$ ) of Mn and Zn concentrations in common carp (sexes pooled) with total length, wet weight, and Fulton's condition factor were not significant (Table 7). However, the following  $\underline{r}$  values were significant: for Cd concentrations (sexes pooled) with total length and wet weight; Cd concentrations in males with total length and wet weight; and Mn concentrations in females with Fulton's condition factor. Although significant, these correlations were small (all  $\underline{r} < 0.4$ ). Two-way ANCOVA indicated significant effects of total length on Cd concentrations (Table 8). However, one-way ANCOVA conducted separately for each sample showed S3 to have the only significant length effects on Cd. Thus, the relationship between total length and pooled Cd concentrations was not consistent among sampling periods. One-way ANCOVA further showed significant effects of total length on Cd concentrations in males. Small sample size made it difficult to draw any conclusions about the relation between Cd concentration and total length in male fish.

For Mn, significant length effects were demonstrated in the S1 and male fish. However, when two fish with unusually high Mn concentrations were removed from the S1 data set and the one-way ANCOVA conducted on the remaining data, total length was no longer significant in either S1 or male fish (Table 8). Small sample size made it difficult to draw any conclusions about the relation between Mn concentrations in females and Fulton's condition factor.

For Zn, two-way ANCOVA indicated no significant length effects on Zn concentrations (Table 8). Thus, there were no consistent

Table 7. Pearson correlation coefficients ( $r$ ) for metal concentrations in liver tissue of common carp from Lake Pepin.

Variates	Cd	Mn	Zn
Total length			
Sexes pooled	0.39**	0.10	-0.08
Males	0.35**	-0.21	-0.05
Females	0.19	-0.09	0.19
Wet weight			
Sexes pooled	0.37**	0.17	-0.03
Males	0.38**	-0.21	-0.05
Females	0.13	0.01	0.27
Fulton's condition factor			
Sexes pooled	0.07	0.17	0.14
Males	0.11	-0.03	0.08
Females	0.03	0.38*	0.28

\*  $p \leq 0.05$ .

\*\*  $p \leq 0.01$ .

Table 8. Results of one-way and two-way ANCOVA (p values) performed on metal concentrations in liver tissue of common carp from Lake Pepin. Sex and season were factors and length was the covariate.

Procedure	Cd	Mn	Mn <sup>a</sup>	Zn
Two-way ANCOVA				
Season, sex, and length effects				
Season	0.840	--	--	0.039
Sex	0.173	--	--	0.827
Length	0.012	--	--	0.658
One-way ANCOVA				
Sex and length effects				
S1 <sup>b</sup>				
Sex	0.351	0.003	0.004	--
Length	0.540	0.005	0.432	--
S2 <sup>b</sup>				
Sex	0.173	0.799	0.799	--
Length	0.360	0.869	0.869	--
S3 <sup>b</sup>				
Sex	0.958	0.881	0.881	--
Length	0.005	0.422	0.422	--
Season and length effects				
Males				
Season	0.871	0.100	0.091	--
Length	0.017	0.033	0.605	--
Females				
Season	0.825	0.005	0.012	--
Length	0.411	0.173	0.452	--

p based on F with effects of all other factors removed.

<sup>a</sup> ANCOVA performed with data for two fish, numbers 12 and 13 (Appendix A), removed from S1 data set.

<sup>b</sup> S1 = 28 July 1980 (summer), S2 = 22 May 1981 (spring), S3 = 3 August 1981 (summer).

correlations between Cd, Mn, and Zn concentrations (sexes pooled) and total length, wet weight, or Fulton's condition factor of common carp from Lake Pepin. These results generally agree with those of other investigators for other fish species and tissue types (Mathis and Kevern 1975, Wiener and Giesy 1979, Bohn and Fallis 1978, and Vinikour et al. 1980).

#### Effects of Season and Sex

Two-way ANCOVA indicated no significant seasonal effects on Cd concentrations, but seasonal effects were found for Zn concentrations (Table 8). One-way ANCOVA showed significant effects of season on Mn concentrations in females but not for males. The mean Zn concentration for S3 was judged to be significantly less than S1 but means for S1 and S2 and S2 and S3 did not differ when evaluated with Tukey's honestly significant difference (HSD) test. This test also found mean Mn concentrations in females for S2 and S3 to be different from S1 but not from each other. In both of these situations, fish from one of the summer samples (S1) had significantly greater metal concentrations than the other summer sample (S3). If seasonal effects were present, both of the summer samples should have had similar mean metal concentrations. Because this was not the case, seasonal effects on Zn concentrations and Mn concentrations in females were not truly evident. Therefore, there was no relation between season and Cd, Mn, or Zn concentrations in liver tissue of common carp from Lake Pepin. Seasonal changes in metal concentrations have been reported by Hardisty et al. (1974a), Fletcher and King (1978), and Van Den Broek (1979), as

discussed previously.

Two-way ANCOVA revealed no significant effects of sex on Cd or Zn concentrations (Table 8). Significant sex effects were noted for Mn concentrations in S1 only (one-way ANCOVA). Therefore, there was no relation between sex and Cd, Mn, or Zn concentrations in liver tissue of common carp from Lake Pepin. Chernoff and Dooley (1979) found significant differences in whole body concentrations of Zn between male and female mummichog, but not for Cd and Mn.

## SUMMARY AND CONCLUSIONS

Liver tissue of common carp from Lake Pepin was analyzed for concentrations of Cd, Mn, and Zn to: (1) compare metal concentrations in common carp from Lake Pepin to those of other waters; (2) assess relations between metal concentrations in fish tissue and length, weight, and condition factor of the fish; (3) determine whether metal concentrations varied seasonally; (4) determine whether metal concentrations varied with sex; and (5) provide baseline information for future monitoring.

Concentrations of Cd and Mn in common carp from Lake Pepin were comparable to those in common carp and other fish species from other aquatic systems. Concentrations of Cd in common carp were not as high as those reported earlier for common carp from this navigation pool (No. 4). The Zn concentrations of Lake Pepin common carp were higher than those reported for other fish species from other aquatic systems.

Although statistical analyses indicated significant effects of sex, season, total length, wet weight, or Fulton's condition factor for Cd, Mn, and Zn concentrations in certain cases, these effects were not consistent. Based on the data collected, it appears that there was no relation between metal concentrations in liver tissue (sexes pooled) and total length, wet weight, or Fulton's condition factor. However, there may have been a relation between Cd concentrations in males and total length and wet weight and between Mn concentrations in females and Fulton's condition factor. There did not appear to be any seasonal variations in metal concentrations, or any variations in metal concentrations between male and female fish.

## LITERATURE CITED

- Bailey, P. A. and R. G. Rada. 1983. Distribution and enrichment of trace metals (Cd, Cr, Cu, Ni, Pb, Zn) in bottom sediments of Navigation Pools 4 (Lake Pepin), 5, and 9 of the Upper Mississippi River. In J. G. Wiener, R. V. Anderson, and D. R. McConville eds. Contaminants in the Upper Mississippi River. Ann Arbor Science Publishers, Ann Arbor, Michigan.
- Benoit, D. A., E. N. Leonard, G. M. Christensen, and J. T. Fiantt. 1976. Toxic effects of cadmium on three generations of brook trout (Salvelinus fontinalis). Trans. Am. Fish. Soc. 105: 550-560.
- Bohn, A. and R. O. McElroy. 1976. Trace metals (As, Cd, Cu, Fe, and Zn) in Arctic cod, Boreogadus saida, and selected zooplankton from Strathcona Sound, Northern Baffin Island. J. Fish. Res. Board Can. 33: 2836-2840.
- Bohn, A. and B. W. Fallis. 1978. Metal concentrations (As, Cd, Cu, Pb, and Zn) in shorthorn sculpins, Myoxocephalus scorpius (Linnaeus), and Arctic char, Salvelinus alpinus (Linnaeus), from the vicinity of Strathcona Sound, Northwest Territories. Water Res. 12: 659-663.
- Cairns, J., Jr., T. K. Bahns, D. T. Burton, K. L. Dickson, R. E. Sparks, and W. T. Waller. 1971. The effects of pH, solubility, and temperature upon the acute toxicity of zinc to the bluegill sunfish (Lepomis macrochirus Raf.). Trans. Kansas Acad. Sci. 74: 81-92.
- Calamari, D., R. Marchette, and G. Vailati. 1980. Influence of water hardness on cadmium toxicity to Salmo gairdneri Rich. Water Res. 14: 1421-1426.
- Carlander, K. D. 1969. Handbook of freshwater fishery biology. Iowa State University Press, Ames, Iowa. 752 pp.
- Carrol, J. J., S. J. Ellis, and W. S. Oliver. 1979. Influence of hardness constituents on the acute toxicity of cadmium to brook trout (Salvelinus fontinalis). Bull. Environ. Contam. Toxicol. 22: 575-581.
- Chernoff, B. and J. K. Dooley. 1979. Heavy metals in relation to the biology of the mummichog, Fundulus heteroclitus. J. Fish Biol. 14: 309-328.
- Conley, M. K., J. J. Sotera, and H. L. Kahn. 1981. Reduction of interferences in furnace atomizer atomic absorption spectroscopy. Instrumentation Laboratory AID Report Number 149. 7 pp.
- Edgren, M. and M. Notter. 1980. Cadmium uptake by fingerlings of perch (Perca fluviatilis) studied by Cd-115m at two different temperatures. Bull. Environ. Contam. Toxicol. 24: 647-651.

- Eisler, R. 1971. Cadmium poisoning in Fundulus heteroclitus (Pisces: Cyprinodontidae) and other marine organisms. J. Fish. Res. Board Can. 28: 1225-1234.
- Enk, M. D. and B. J. Mathis. 1977. Distribution of cadmium and lead in a stream ecosystem. Hydrobiologia 52: 153-158.
- Farabee, G. B. 1979. Life histories of important sport and commercial fishes of the Upper Mississippi River. In J. L. Rasmussen ed. A compendium of fishery information on the Upper Mississippi River. 2nd edition. Upper Mississippi River Conservation Committee, Rock Island, Illinois. 41-68.
- Farmer, G. J., D. Ashfield, and H. S. Samant. 1979. Effects of zinc on juvenile Atlantic salmon Salmo salar: Acute toxicity, food intake, growth and bioaccumulation. Environ. Pollut. 19: 103-118.
- Findley, J. E., S. K. Littlejohn, R. G. Rada, and J. G. Wiener. In preparation. Distribution of potentially toxic metals in bed sediments and fish of the Upper Wisconsin River.
- Fletcher, G. L. and M. J. King. 1978. Seasonal dynamics of Cu, Zn, Ca, and Mg in gonads and liver of winter flounder (Pseudopleuronectes americanus): Evidence for summer storage of Zn for winter gonad development in females. Can. J. Zool. 56: 284-290.
- Forstner, U. and G. Wittmann. 1979. Metal pollution in the aquatic environment. Springer-Verlag, New York. 486 pp.
- Frey, D. G. 1940. Growth and ecology of the carp Cyprinus carpio Linnaeus, in four lakes of the Madison region, Wisconsin. PhD Thesis. University of Wisconsin, Madison. 248 pp.
- Giesy, J. P., Jr., L. A. Briese, and G. J. Leversee. 1978. Metal binding capacity of selected Maine surface waters. Environ. Geol. 2: 257-268.
- Hardisty, M. W., R. J. Huggins, S. Katar, and M. Sainsbury. 1974a. Ecological implications of heavy metal in fish from the Severn Estuary. Mar. Pollut. Bull. 5: 12-15.
- Hardisty, M. W., S. Katar, and M. Sainsbury. 1974b. Dietary habits and heavy metal levels in fish from the Severn Estuary and the Bristol Channel. Mar. Pollut. Bull. 5: 61-63.
- Hodson, P. V. 1975. Zinc uptake by Atlantic salmon (Salmo salar) exposed to a lethal concentration of zinc at 3, 11, and 19°C. J. Fish. Res. Board Can. 32: 2552-2556.
- Holcombe, G. W., D. A. Benoit, and E. N. Leonard. 1979. Long-term effects of zinc exposures on brook trout (Salvelinus fontinalis).

- Trans. Am. Fish. Soc. 108: 76-87.
- Iverson, W. P. and F. E. Brinckman. 1978. Microbial metabolism of heavy metals. In R. Mitchell ed. Water pollution microbiology. Vol. 2. Wiley-Interscience, New York. 201-232.
- Jenne, E. A. and S. N. Luoma. 1977. Forms of trace elements in soils, sediments, and associated waters: An overview of their determination and biological availability. In Biological implications of metals in the environment. U. S. Energy Res. Develop. Admin. Symp. Series CONF-750929. 110-143.
- Jensen, S. and A. Jernelov. 1969. Biological methylation of mercury in aquatic organisms. Nature 223: 753-754.
- Langley, D. G. 1973. Mercury methylation in an aquatic environment. J. Water Pollut. Control Fed. 45: 44-51.
- Lloyd, R. 1960. The toxicity of  $ZnSO_4$  to rainbow trout. Ann. Appl. Biol. 48: 84-94.
- Lloyd, R. M. 1965. Factors that affect the tolerance of fish to heavy metal poisoning. Biological problems in water pollution, third seminar, 1962. U. S. Dept. Health, Education and Welfare. 181 pp.
- Mathis, B. J. and T. F. Cummings. 1973. Selected metals in sediments, water, and biota in the Illinois River. J. Water Pollut. Control Fed. 45: 1573-1583.
- Mathis, B. J. and N. R. Kevern. 1975. Distribution of mercury, cadmium, lead, and thallium in a eutrophic lake. Hydrobiologia 46: 207-222.
- Mathis, B. J., T. F. Cummings, M. Gower, M. Taylor, and C. King. 1979. Dynamics of manganese, cadmium, and lead in experimental power plant ponds. Hydrobiologia 67: 197-206.
- Matthiessen, P. and A. E. Brafield. 1977. Uptake and loss of dissolved zinc by the stickleback Gasterosteus aculeatus L. J. Fish Biol. 10: 399.
- McHenry, J. R., M. C. Ritchie, C. M. Cooper, and J. Verdon. 1983. Recent rates of sedimentation in the Upper Mississippi River. In J. G. Wiener, R. V. Anderson, and D. R. McConville eds. Contaminants in the Upper Mississippi River. Ann Arbor Science Publishers, Ann Arbor, Michigan.
- Minnesota Pollution Control Agency. 1978. Minnesota lakes and streams. A compilation of analytical data from the routine water quality monitoring program. Vol. 9. October 1975-September 1977. Div. Water Qual., Surface and Groundwater Sect., Roseville, Minnesota. 483 pp.

- Moen, T. E. 1953. Food habits of the carp in northwest Iowa lakes. Proc. Iowa Acad. Sci. 60: 665-686.
- Murphy, B. R., G. J. Atchison, and A. W. McIntosh. 1978a. Cadmium and zinc in muscle of bluegill (Lepomis macrochirus) and largemouth bass (Micropterus salmoides) from an industrially contaminated lake. Environ. Pollut. 17: 253-257.
- Murphy, B. R., G. J. Atchison, A. W. McIntosh, and D. J. Kolar. 1978b. Cadmium and zinc content of fish from an industrially contaminated lake. J. Fish Biol. 3: 327-335.
- Nie, N. H., C. H. Hull, J. G. Jenkins, K. Steinbrenner, and D. H. Bent. 1975. Statistical package for the social sciences. 2nd. ed. McGraw-Hill Book Company, New York. 675 pp.
- Patrick, F. M. and M. W. Loutit. 1978. Passage of metals to freshwater fish from their food. Water Res. 12: 395.
- Pflieger, W. L. 1975. The fishes of Missouri. Missouri Dept. Conser. 343 pp.
- Rehder, D. D. 1959. Some aspects of the life history of the carp, Cyprinus carpio, in the Des Moines River, Boone County, Iowa. Iowa State J. Sci. 34: 11-27.
- Rehwooldt, R., D. Karimian-Teherani, and H. Altmann. 1976. Distribution of selected metals in tissue samples of carp, Cyprinus carpio. Bull. Environ. Contam. Toxicol. 15: 374-377.
- Renfro, W. C., S. W. Fowler, M. Heyraud, and J. LaRosa. 1975. Relative importance of food and water in long-term zinc-65 accumulation by marine biota. J. Fish. Res. Board Can. 32: 1339-1345.
- Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. 191: 382 pp.
- Scott, W. B. and E. J. Crossman. 1973. Freshwater fishes of Canada. Bull. Fish. Res. Board Can. 184: 966 pp.
- Sigler, W. F. 1958. The ecology and use of carp in Utah. Utah State Univ. Agric. Exp. Sta. Bull. 405: 1-63.
- Sinley, J. R., J. P. Goettl Jr., and P. H. Davies. 1974. The effects of zinc on rainbow trout (Salmo gairdneri) in hard and soft water. Bull. Environ. Contam. Toxicol. 12: 193-200.
- Snedecor, G. W. and W. G. Cochran. 1967. Statistical methods. 6th ed. Iowa State University Press, Ames, Iowa. 507 pp.
- Spangler, W. J., J. L. Spigarelli, J. M. Rose, R. S. Flippin, and H. H.

- Miller. 1973. Degradation of methylmercury by bacteria isolated from environmental samples. *Appl. Microbiol.* 25: 488-493.
- Sprafka, J. M. 1981. Evaluation of heavy metal loadings at the Metropolitan Wastewater Treatment Plant. Qual. Control Dept., Metro. Waste Control Comm., St. Paul, Minnesota.
- Steel, R. G. D. and J. H. Torrie. 1960. Principles and procedures of statistics, with special reference to the biological sciences. McGraw-Hill, New York. 481 pp.
- U. S. Environmental Protection Agency. 1975. A compendium of lake and reservoir data collected by the National Eutrophication Survey in the northeast and north-central United States. Working Paper No. 474. Corvallis, Oregon. 210 pp.
- Van Den Broek, W. L. F. 1979. Seasonal levels of chlorinated hydrocarbons and heavy metals in fish and brown shrimps from the Medway Estuary, Kent. *Environ. Pollut.* 19: 21-38.
- Vinikour, W. S., R. M. Goldstein, and R. V. Anderson. 1980. Bioconcentration patterns of zinc, copper, cadmium, and lead in selected fish species from the Fox River, Illinois. *Bull. Environ. Contam. Toxicol.* 24: 727-734.
- Wiener, J. G. and J. P. Giesy Jr. 1979. Concentrations of Cd, Cu, Mn, Pb, and Zn in fishes in a highly organic softwater pond. *J. Fish. Res. Board Can.* 36: 270-279.
- Wiener, J. G., G. A. Jackson, T. W. May, and B. C. Cole. In press. Longitudinal distribution of trace elements (As, Cd, Cr, Hg, Pb, and Se) in fishes and sediments of the Upper Mississippi River. In J. G. Wiener, R. V. Anderson, and D. R. McConville eds. *Contaminants in the Upper Mississippi River*. Ann Arbor Science Publishers, Ann Arbor, Michigan.
- Williams, D. R. and J. P. Giesy Jr. 1978. Relative importance of food and water sources to cadmium uptake by Gambusia affinis (Poeciliidae). *Environ. Res.* 16: 326-332.

Appendix A. Sex, total length, wet weight, Fulton's condition factor, and metal concentration in liver tissue of individual common carp from Lake Pepin.

Date of Collection and Fish Identification Number	Sex <sup>a</sup>	Total Length (mm)	Wet Weight (kg)	Fulton's Condition Factor (K)	Concentration ( $\mu\text{g/g}$ dry wt.)		
					Cd	Mn	Zn
28 July 1980							
1	F	610	3.97	1.75	0.593	7.37	610
2	F	600	3.70	1.71	0.904	29.50	800
3	F	696	4.91	1.46	0.183	5.09	608
4	F	610	4.02	1.77	1.420	10.30	1310
6	F	650	4.50	1.64	0.282	6.93	556
7	F	652	4.14	1.49	0.323	1.88	1177
8	F	638	4.37	1.68	0.772	2.40	730
9	M	622	3.63	1.51	0.264	0.68	476
10	M	592	3.31	1.60	0.954	0.87	796
11	F	520	1.97	1.40	0.431	18.40	666
12	F	520	2.27	1.61	0.284	94.80	746
13	M	392	0.93	1.55	0.162	48.00	750
14	F	627	3.81	1.54	0.506	9.65	1364
15	M	619	4.46	1.88	0.726	2.25	357
16	M	586	2.56	1.27	0.238	2.70	804
17	F	570	2.87	1.55	0.999	1.38	846
18	M	552	2.60	1.55	1.070	1.27	628
19	M	577	2.73	1.42	0.613	4.43	794
20	M	503	1.88	1.47	0.309	0.94	1006
21	M	604	3.40	1.54	0.334	0.74	1940
22	F	727	5.05	1.31	0.997	1.98	834
23	M	577	2.60	1.35	0.221	0.72	380
24	M	576	2.93	1.53	0.756	0.94	1139
25	M	565	3.00	1.66	0.986	1.38	772
26	F	565	2.85	1.58	0.863	0.64	780
27	F	698	5.21	1.53	0.634	0.40	303
28	F	566	3.26	1.80	0.723	3.46	520
29	M	578	2.56	1.32	0.389	1.23	470
30	F	488	1.78	1.53	0.696	2.39	1137
Exp. 1	M	515	2.00	1.46	0.118	1.02	1144
22 May 1981							
33	F	600	2.84	1.32	0.658	0.75	1168
34	F	590	2.61	1.27	1.180	1.12	475
35	F	610	3.57	1.57	0.432	1.48	595
36	M	605	2.95	1.33	0.635	0.87	482
37	M	525	1.88	1.30	0.124	0.54	1706
38	M	530	1.76	1.18	0.314	2.06	950
39	M	490	1.77	1.50	1.110	0.94	320
40	M	390	1.06	1.79	0.062	1.01	932
41	M	515	1.91	1.40	0.637	0.98	653
42	F	460	1.42	1.46	1.150	1.34	340
43	M	430	1.19	1.50	1.350	0.72	1369
44	M	425	1.26	1.64	0.144	1.37	1408
45	M	520	2.02	1.44	0.387	0.71	604
46	M	410	1.06	1.54	0.196	1.76	332
47	M	355	0.83	1.86	0.172	1.09	248
48	M	385	0.85	1.49	0.150	0.55	938
49	M	380	0.95	1.73	0.179	2.01	530
50	M	575	2.86	1.50	0.913	1.63	900
52	M	475	1.63	1.52	0.624	7.55	1464

## Appendix A. Continued.

Date of Collection and Fish Identification Number	Sex <sup>a</sup>	Total Length (mm)	Wet Weight (kg)	Fulton's Condition Factor (K)	Concentration (µg/g drv wt.)		
					Cd	Mn	Zn
53	M	405	1.04	1.57	0.271	3.29	1242
54	M	350	0.67	1.56	0.210	1.83	277
55	M	335	0.70	1.86	0.205	1.31	2131
56	F	625	3.59	1.47	0.868	0.98	856
57	M	420	1.18	1.59	0.210	0.77	468
58	M	545	2.42	1.50	0.439	1.34	1046
59	M	655	4.05	1.44	0.319	1.50	398
60	F	650	3.18	1.16	0.602	1.82	1111
61	M	415	1.08	1.51	0.145	2.74	1328
62	F	635	3.64	1.42	0.542	1.12	444
63	F	740	6.10	1.51	0.580	1.79	1251
3 August 1981							
64	F	610	3.08	1.36	0.678	1.18	724
65	F	570	2.42	1.31	0.521	0.78	482
66	M	455	1.33	1.41	0.679	2.81	854
67	M	430	1.14	1.43	0.447	1.00	292
68	F	480	1.39	1.26	0.133	2.11	584
69	F	465	1.52	1.51	0.167	1.37	534
70	M	490	1.51	1.28	0.155	1.02	1383
71	F	475	1.54	1.44	0.339	12.90	362
72	F	490	1.65	1.40	0.772	1.14	402
73	M	520	1.79	1.27	0.351	0.79	811
75	M	455	1.18	1.25	0.208	2.44	462
76	F	560	2.31	1.32	0.673	1.26	731
77	F	575	2.76	1.45	1.720	1.09	504
78	F	695	3.22	0.96	1.190	3.18	260
79	M	470	1.45	1.40	0.214	1.42	770
80	M	470	1.22	1.18	0.218	1.36	690
81	M	440	1.17	1.37	0.218	1.55	2892
82	M	450	1.26	1.38	0.153	1.69	440
83	M	490	1.50	1.28	0.218	3.14	550
84	M	445	1.21	1.37	0.371	1.21	254
85	M	565	2.15	1.19	0.265	1.41	282
86	F	570	2.26	1.22	0.384	1.60	420
87	M	490	1.72	1.46	1.350	2.72	323
88	M	575	2.53	1.33	1.130	1.19	739
89	M	495	1.57	1.29	0.203	5.03	492
90	F	495	1.67	1.38	0.257	0.88	1090
91	M	450	1.34	1.47	0.285	17.70	684
93	M	485	1.38	1.21	0.332	3.85	416
94	M	525	1.84	1.27	0.203	3.23	485
95	F	480	1.47	1.33	0.189	2.69	414

<sup>a</sup>F = female; M = male.