1976

Mercury Levels in Muscle Tissue of Stream-Dwelling Fish

Tom Frost
Eastern Illinois University

MERCURY LEVELS IN MUSCLE TISSUE

OF STREAM-DWELLING FISH

(TITLE)

BY

Tom Frost
B.S. in Zoology, S.I.U., 1974

THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF

Master of Science

IN THE GRADUATE SCHOOL, EASTERN ILLINOIS UNIVERSITY

CHARLESTON, ILLINOIS

1976

YEAR

I HEREBY RECOMMEND THIS THESIS BE ACCEPTED AS FULFILLING

THIS PART OF THE GRADUATE DEGREE CITED ABOVE

30 July 1976

DATE

30 July 1976

DATE

PAPER CERTIFICATE #2

TO: Graduate Degree Candidates who have written formal theses.

SUBJECT: Permission to reproduce theses.

The University Library is receiving a number of requests from other institutions asking permission to reproduce dissertations for inclusion in their library holdings. Although no copyright laws are involved, we feel that professional courtesy demands that permission be obtained from the author before we allow theses to be copied.

Please sign one of the following statements:

Booth Library of Eastern Illinois University has my permission to lend my thesis to a reputable college or university for the purpose of copying it for inclusion in that institution's library or research holdings.

Aug. 2, 1976
Date

I respectfully request Booth Library of Eastern Illinois University not allow my thesis be reproduced because ______________________________

____

____

Date   Author

pdm

ACKNOWLEDGEMENTS

I would like to express my appreciation to Dr. L. Stephen Whitley for his help and guidance through-out this project. I am also indebted to Dr. N.D. Smith of the E.I.U. Chemistry Dept. for his help in setting up the Atomic Absorption Unit. Special mention is also due to Dr. L. Durham and Dr. W.J. Keppler who offered suggestions for improving the final draft.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Mercury is a metallic element, and was among the first to be mined and utilized by man. The pyrolysis of red cinnabar (mercuric sulfide), an ore found at depths of less than fifteen hundred feet, provides most of the commercial mercury. Mercury has an atomic number of 80 and an atomic weight of 200.59, and occurs as sixteen isotopes with mass numbers from 189 to 205. Mercury, also known as quicksilver, has always been considered somewhat sinister because of its unique property as the only metal that is a liquid at room temperature. Alchemists took a keen interest in mercury during medieval times because of the element's fascinating properties. Mercury's toxic properties were put to use as agents of suicide and murder. Napoleon, Ivan the Terrible, and Charles II of England are all reported to have died of mercurial poisoning.

Though mercury has been known as a toxic agent since earliest history the first environmental involvement of mercury became apparent only in the 1950's when an epidemic of poisonings caused 46 deaths in Minamata, Japan. The ingestion of methylmercury in contaminated fish produced a condition in which a loss of vision and hearing, and a progressive loss of coordination, resulted in the deaths. Following a second similar poisoning in 1964, the Japanese Government undertook research which resulted in an announcement in 1968 that industrial wastes containing methylmercury were the toxic agents.

Two major sources provide mercury to the environment. First, mercury occurs naturally in deposits, which are not a result of man's action. Secondly, however are the sources of mercury in the environment from the direct or indirect result of man's action. The major industries utilizing mercury include production of electronic components, industrial control instruments, and the chlor-alkali industry. Organo-mercurial compounds are widely used in industry as bacteriocidal-fungicidal agents applied prior to application of water-based paints and to retard fungus attacks upon painted surfaces under damp and humid conditions. The paper and pulp industry uses mercury compounds as slimicides. Organo-mercurials are used in agriculture for a spectrum of applications which include seed dressings, foliage sprays, and lawn and garden applications. Sewage system disposal of unwanted chemicals and release from fossil fuels are two other possible sources of mercury pollution. Joensuu (1971) speculated that the amount of mercury released by combustion of coal far exceeded that released by weathering. The indirect sources assoiciated with mercury-related technology result from the use, misuse and disposal of mercury and mercury-containing industrial and consumer products.

The medical implications of mercury pollution are well documented. Hughes (1957) found that when metallic mercury accumulates in nervous tissue, neuron metabolism is blocked. Gage (1961) found that while methylmercury salts caused damage

to the central nervous system in rats, phenylmercury did not produce this effect. "Minamata" disease (methylmercury poisoning) is characterized in humans by weakening of muscles, loss of vision, impairment of cerebral functions, paralysis, and in severe cases, death. Methylmercury is of prime importance because of its propensity for the nervous system, long retention in the body, and its effect on developing tissues (Nelson , 1970).

Acute effects of mercury on aquatic organisms have only recently been studied. Behavioral alterations in the mosquitofish have been demonstrated (Kania and O'Hara, 1974). At levels of greater than .01 ppm mercury, mosquitofish were impaired when trying to avoid predation by bass. Kendall (1975) found that at high levels of mercury acute damage was done to the kidneys of channel catfish.

In order to control the amount of mercury which an individual may ingest a Food and Drug Administration regulation prohibits the commercial sale of fish containing levels of mercury greater than 0.5 ppm. It also issues advisories concerning consumption of fish containing mercury. The Public Health Service has set o.5 ppb as the upper level of mercury in water fit for human consumption. As of January 1, 1976, it was found that some fish in Lake Shelbyville, Illinois, exceeded the 0.5 ppm limit. The State of Illinois advised fishermen taking largemouth bass from the lake to eat only One-half of a pound of the fish during any given week.

METHYLATION IN THE ENVIRONMENT

Background mercury levels vary widely in aquatic ecosystems due to the multiple forms of the complex ions that can occur (see figure 1). Prior to 1966, it was assumed that mercury found in fish was either inorganic mercury or phenylmercury. Westoo (1966) disputed this by the use of gas chromotography and showed that approximately 85 to 95% of the mercury contained in fish was methylmercury. The process of methylation becomes of primary importance. Jenson and Jernelov (1969) speculated that microbes in bottom sediments converted inorganic or phenylmercury to both mono and dimethylmercury. As a result two reactions were postulated:

$$Hg^{++} + 2R \rightarrow CH_3\text{-}CH_3HgCH_3 \rightarrow CH_3Hg^+$$

$$Hg^{++} + R\text{-}CH_3 \rightarrow CH_3Hg^+ \xrightarrow{R\text{-}CH_3} CH_3HgCH_3$$

Wood, et al., (1968) supported this theory by showing that methanogenic bacteria used methylcobalamin (CH_3-(Co), a B_{12} analog) to form di and monomethylmercury. The methyl moiety, in mild reducing conditions, is transferred from Co^{++} to Hg^{++} in biological systems. It was also postulated that this is a nonenzymatic process, enhanced by anaerobic conditions and increased numbers of bacteria.

Since anaerobic conditions enhance bacterial methylation of mercury the occurrence deserves some attention. Jernelov (1969) showed that under permanent anaerobic conditions mercuric sulfide in mud is not readily methylated. However

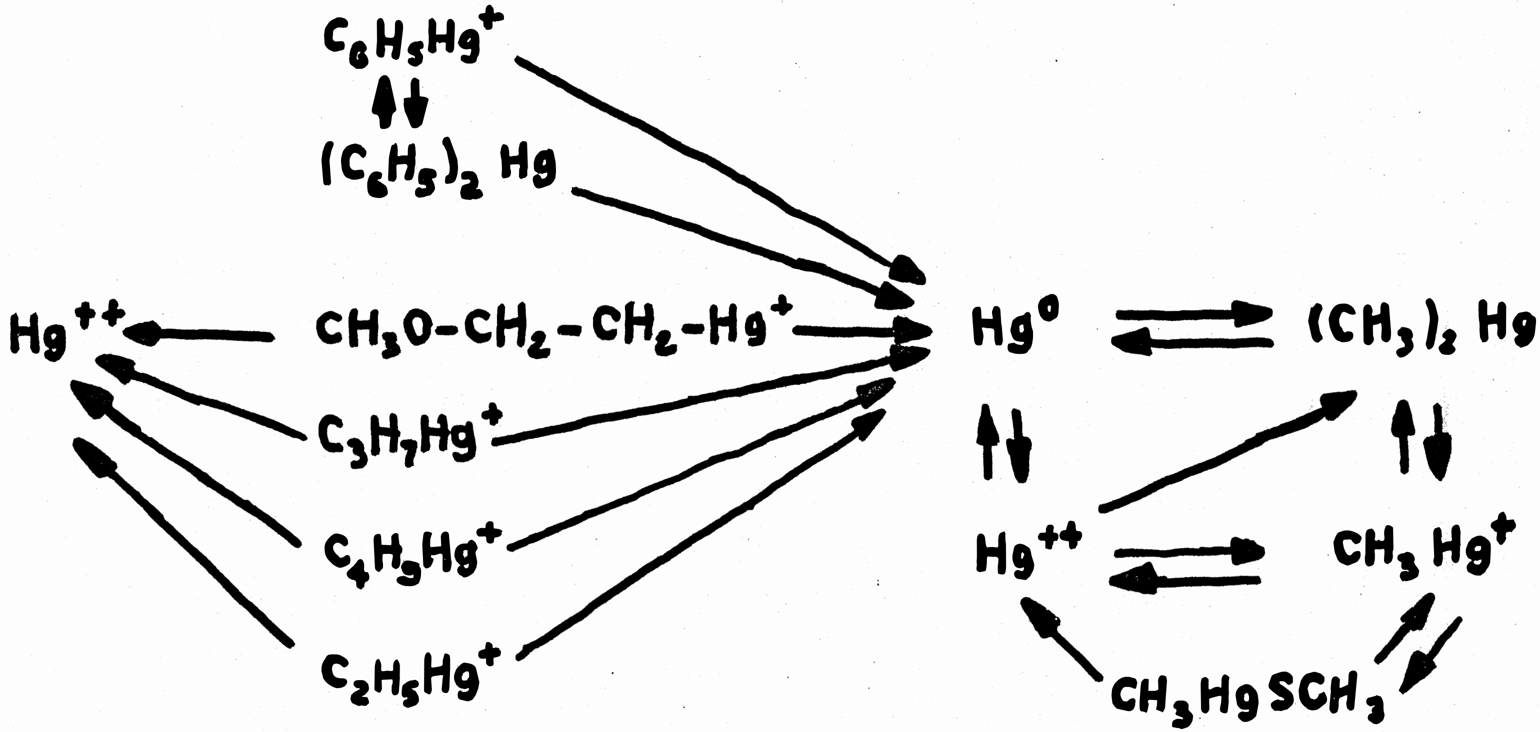

FIGURE 1. A HYPOTHETICAL MODEL OF THE CONVERSION OF MERCURY IN THE AQUATIC ENVIRONMENT

Fagerstrom and Jernelov (1970) found that mercuric sulfide is available for biological methylation in aerobic conditions. Gillespie (1972) showed that under aerobic conditions there was a gradual mobilization of mercury from sediments containing mercuric chloride or mercuric sulfide. Mercury bound to organic substances can be methylated in the prescence of hydrogen sulfide (Jernelov, 1969).

Microbial methylation of mercury produces mono and dimethylmercury (Jensen and Jernelov, 1969; Wood, et al., 1968). Bainbridge (1973) demostrated that the factors of an aquatic system which determine the proportions in which they occur are mercury concentration and pH. At high levels of mercuric ion concentration and low pH, methylmercury is favored, while at lower levels of mercuric ion concentration and higher pH dimethyl formation is favored.

For methylation to occur mercury usually must be present in the mercuric ion form (Hg^{++}). Five categories of mercury which most commonly occur in aquatic systems are:

1. Inorganic mercury, Hg^{++}
2. Metallic mercury, Hg^{o}
3. Phenylmercury, $C_6H_5Hg^+$
4. Alkoxymercury, $CH_3OCH_2CH_2Hg^+$
5. Methylmercury, CH_3Hg^+

All these forms can be converted to divalent mercury (Jernelov, 1969). The mercuric ions are then available for the biological methyl transfer reaction. These conversions are depicted shematically in Fig. 1 (Bainbridge, 1973).

PURPOSE OF STUDY

Since methylmercury is dangerous to human health and because it can be readily produced by aquatic ecosystems, the importance of information concerning the levels of mercury in fish is obvious. Mercury concentrations in fish have been extensively studied in lakes but little research has been carried out concerning mercury concentrations in fish in lotic environments.

The purpose of this research is to examine the mercury concentrations of fish in rivers and streams in the Coles County Area. The objectives sought are:

1. To see if mercury concentrations vary between trophic levels, as demonstrated in previous work done in lakes.

2. To speculate on the effect of weight and length of fish on mercury concentrations in a river as opposed to a lake.

MATERIALS AND METHODS

Collecting

Fish were collected by seine from various streams and rivers in Coles County from Oct. 1975 to March 1976. The majority of the fish were taken in the Embarras River and Polecat Creek. No specific sites were chosen along these waterways for the collections, although certain areas were seined more than others in order that a greater number of fish could be collected. Each fish was weighed and measured, and then frozen until used for analysis. An attempt was made to collect various sizes of each fish, in order to prevent as little bias as possible when comparing species. Variety of size would also allow the observation of any correlations which may exist between individual fish size and mercury level. Extremely small fish were not kept because the muscle tissue available was insufficient for analysis.

Determination of Mercury Levels

Each speciman was dissected and 2 to 5 grams of lateral muscle were removed. From this muscle, a one half gram sample, separated into two duplicate samples, was placed in a 100 ml. Erlenmeyer flask. Five ml. of concentrated sulfuric acid were added and the mixture was digested at 70°C for 30 minutes. The preparation was next cooled in an ice bath and 15.0 ml. of 6% potassium permanganate solution was added, with flask

swirling to reduce heating of the sample. The contents were removed from the ice bath and cooled at room temperature for 30 minutes. The solution was then heated on the steam bath, at 70°C, for 30 minutes, with occasional swirling. An additional 5.0 ml. of 6% potassium permanganate was added and the flask was heated to boiling for 30 seconds. The contents were cooled and quantitatively transferred into a 50 ml. volumetric flask and 10% hydroxylamine hydrochloride added until the solution cleared. The flask was filled to volume with distilled water.

Ramirez-Munoz (1975) provided the basic procedure used in the mercury testing. The procedure was altered somewhat due to the unavailibility of certain equipment. A Beckman Model 495 Atomic Absorption Spectrophotometer connected to a Ten-Inch Potentiometer Recorder was used. The instrumental set-up is diagrammed in figure 2. A 25 ml. aliquot from the 50 ml. sample was transferred to the reaction vessel. The mercury in the solution was reduced by adding stannous chloride solution. Readings were obtained and compared with readings of corresponding standards. The results were reported on a wet weight basis, in parts per million.

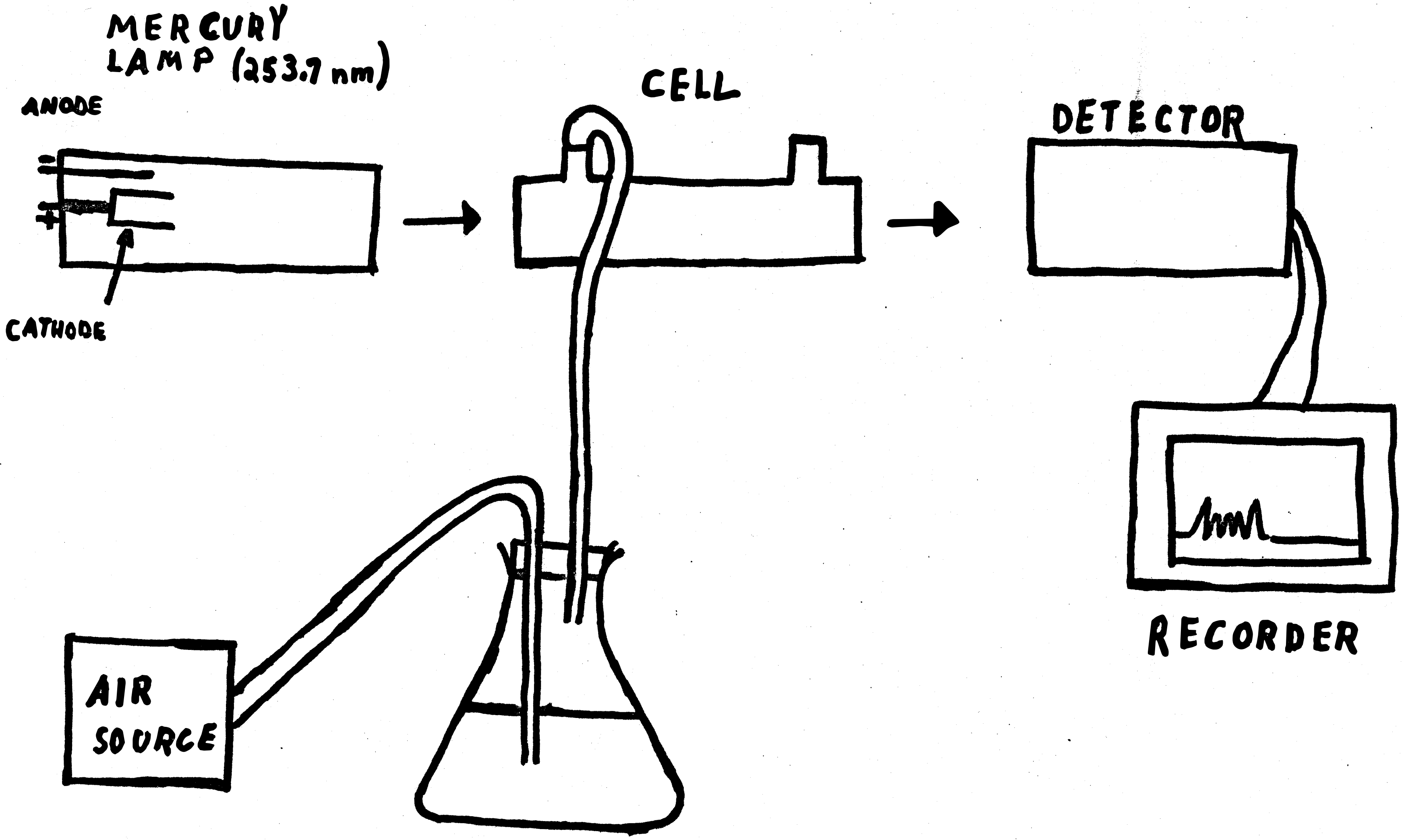

FIGURE 2. BECKMAN ATOMIC ABSORPTION SPECTROPHOTOMETER WITH FLAMELESS ACCESSORY

RESULTS

Mercury content of fish

The fish are lsited by species in Table 1, with weight and length given for each individual. A summary of these data is shown in Table 2.

D'Intri (1972) categorized fish according to their ability to accumulate mercury. The categories are:

> Category I-Predators(highest accumulation)
> Category II-Carp and bluegills
> Category III-Bottom feeders(lowest accumulation)

Using the D'Intri system, an analysis of variance was run on the fish in the present study. The results were found to be significant at the 0.05 level (Table 3). A Newman-Keuls Multi-Range Test was run to determine where this difference was occurring (Table 4). It was found that each group mean was significantly different from each other group mean at the 0.05 level.

Fish cataloged by category were:

> Category I-Largemouth bass(*Micropterus salmoides*), grass pickerel(*Esox americanus*), white crappie (*Pomoxis annularis*)
>
> Category II-Carp(*Cyprinus carpio*), bluegill(*Lepomis macrochirus*)
>
> Category III-White sucker(*Catostomus commersoni*), creek chubsucker(*Erimyson oblongus*), striped shiner (*Notropis chrysocephalus*), quillback(*Carpiodes cyprinus*), shorthead redhorse(*Moxostoma macrolepidotum*), yellow bullhead(*Ictalurus natalis*)

The predacious fish (Group I) had significantly higher levels of mercury in their muscle tissues than either group II or III. Group II had higher levels of mercury than Group III.

Correlation of Mercury Content to a Weight-Length Ratio

Previous studies have indicated that the mercury content of fish increases with increasing age, length, or weight (Bache, et al., 1971)(Fagerstrom, et al., 1974)(Smith, et al., 1975). Scott and Armstrong (1972) reported that fish condition (fatness) can be correlated to mercury concentration. There have been studies(Bainbridge 1973; and Wobeser, et al., 1970), however, in which these parameters could not be correlated to mercury concentration. Preliminary correlations were run comparing mercury levels to weight and mercury levels to length. It was found that the mercury levels were not correlated to the weight of the fish nor to the length of the fish. These tests, however, did not seem to represent a true mercury correlation indicative of the situation in Coles County. Mercury concentrations were then correlated to a fish weight/length ratio. The results are shown in Table 5. Correlations were run for only five of the species because of insufficient data for the other species.

Of the five species on which correlations were calculated, three showed significant results. Two species showed significant results at the 0.05 level (largemouth bass and carp), while a third (yellow bullhead) showed a significant correlation

at the 0.1 level. Use of the weight/length ratio as the comparision parameter did allow significant results; whereas a weight correlation or length correlation did not. It appears this ratio would be a better measurement of a particular species ability to accumulate mercury than either of the two parameters separately. It should be noted, however, that in this study white crappie and bluegills did not have significant correlations.

Table 1. Levels of Mercury in Fish Collected from Coles County, Illinois, from Oct. 1975 to March 1976

	ppm	weight (grams)	length (mm.)	W/L ratio
Largemouth Bass	.08	10.0	86.4	.12
	.06	28.2	127.0	.22
	.40	524.5	297.2	1.76
	.31	315.6	261.6	1.21
	.47	501.4	299.7	1.67
	.29	287.3	226.1	1.27
	.25	351.5	266.7	1.32
	.31	402.3	287.0	1.40
	.30	523.0	297.1	1.76
White Crappie	.24	153.1	213.4	.72
	.21	147.5	210.8	.70
	.26	53.5	152.4	.35
	.20	197.6	226.1	.87
	.25	248.8	246.4	1.02
	.12	84.3	177.8	.47
	.31	52.0	149.8	.35
	.23	213.1	231.2	.92
	.24	191.7	218.4	.88
	.30	236.2	236.2	1.00
	.21	127.0	193.1	.66
	.21	198.6	223.5	.89
White Sucker	.16	88.5	190.5	.46
	.19	40.9	147.3	.28
	.11	18.6	119.9	.16
Bluegill	.09	33.0	114.3	.29
	.14	35.2	121.9	.29
	.11	41.8	127.0	.33
	.13	54.3	154.9	.35
	.08	37.4	121.9	.31
Striped Shiner	.07	56.2	170.2	.33
	.10	14.5	109.5	.13
Creek Chubsucker	.19	78.0	177.8	.44
	.15	123.6	228.7	.54
	.09	68.9	161.1	.44
Shorthead Redhorse	.11	184.6	241.3	.77
	.11	192.3	254.4	.76
	.09	178.4	243.8	.73
Grass Pickerel	.10	63.1	193.0	.33
	.12	52.5	198.2	.26

Quillback	.18	654.0	363.2	1.80
	.15	278.5	274.7	1.01
Carp	.14	981.0	393.7	2.49
	.22	1155.8	444.5	2.60
	.22	502.5	335.8	1.50
	.17	855.5	416.9	2.05
	.21	960.7	408.9	2.35
	.32	494.0	335.2	1.47
	.16	678.6	386.0	1.75
	.19	781.8	388.6	2.01
	.31	1100.1	434.2	2.53
	.21	978.9	411.4	2.38
Yellow Bullhead	.12	201.6	254.6	.79
	.07	115.6	210.8	.55
	.11	153.7	231.2	.66
	.10	148.2	226.0	.66
	.07	93.5	213.4	.44
	.11	112.2	203.8	.55
	.09	225.5	254.0	.89
	.07	184.7	248.9	.74
	.08	71.0	180.3	.39
	.11	148.2	215.9	.69

Table 2. Length, Weight, and Mercury Levels($\bar{X}$+SD) for Fish Collected in Coles County, Illinois, from Oct. 1975 to March 1976

Species	Number	Weight(g)	Length(mm)	ppm Hg
White Crappie	12	159±68	207±32	.23±.05
Carp	10	849±246	396±37	.22±.07
Yellow Bullhead	10	145±49	224±24	.09±.02
Largemouth Bass	9	327±196	239±79	.27±.13
Bluegill	5	40±8	128±16	.11±.03
White Sucker	3	49±36	153±35	.15±.04
Creek Chubsucker	3	90±29	190±35	.14±.05
Shorthead Redhorse	3	185±7	247±7	.11±.01
Striped Shiner	2	35±29	140±43	.09±.02
Pickerel	2	58±7	196±4	.11±.01
Quillback	2	466±266	319±63	.16±.02

Table 3. Analysis of Variance for Mercury Levels in Fish Samples Taken in Coles County, Illinois, from Oct. 1975 to March 1976 (ppm on a wet weight basis)

	Category I	Category II	Category III
$\bar{X}$	.24	.18	.11
n_i	23	15	23
$\frac{(x)}{n_i}$	1.300	.485	.300
Σx^2	1.505	.557	.412

Source of Variation	SS	DF	MS
Total	.554	60	
Groups	.165	2	.0825
Error	.389	58	.0067

F-12.31

$F_{2,58}$-3.16 P<.05

Table 4. Newman-Keauls Multi-Range Test of Data from Table 3.

Ranks of sample $\bar{X}$	Category III	Category II	Category I
	.12	.18	.24

B vs. A	$(\bar{X}_b - \bar{X}_a)$	SE	q	q.05 58,p	Conclusion
3 vs. 1	.124	.017	7.29	3.41	$u_3 \neq u_1$
3 vs. 2	.058	.019	3.05	2.83	$u_3 \neq u_2$
2 vs. 1	.066	.019	3.47	2.83	$u_2 \neq u_1$

The means of the categories are significantly different at the .05 level

Table 5. Correlation coefficients for the relationships of weight/length ratio to the muscle tissue mercury of the various species of fish collected from the Coles County Area

Species of Fish	Correlation Coefficients
Largemouth Bass (*Micropterus salmoides*)	.9800*
White Crappie (*Pomoxis annularis*)	.4902
Carp (*Cyprinus carpio*)	.6586*
Yellow Bullhead (*Ictalurus natalis*)	.6173**
Bluegill (*Lepomis macrochirus*)	.6923

*significant at 0.05 level

**significant at 0.1 level

DISCUSSION

Bioamplification of Mercury

From the results of this work it is obvious that higher trophic levels (predators)have greater concentrations of mercury than lower trophic levels (omnivores and bottom-feeders). Previous studies have also shown this bioamplification (Aronson and Spiesman, 1976)(Bainbridge, 1973)(Henderson, et al., 1972) (Koirtyohann, et al., 1976)(Potter, et al., 1975)(Richins, et al., 1975)(Walter, et al., 1974). An explaination for these results will now be presented.

There are two modes of concentrating mercury in aquatic organisms: direct uptake from water or by ingestion in to the food chain. Direct uptake is accomplished by crossing the gills or epithelium from the surrounding media. Mercury can be transported through the food chain in either one of two ways: first by direct incorporation by phytoplankters, which are then consumed by zooplankton and fish, or by methylmercury-producing microbes in the sediment which are then eaten by benthic invertebrates and consumed by fish.

Direct uptake may well be dependent upon the size of the fish studied. Burrows (1973) reported that the methylmercury-203 concentration in bluegills remained constant, after 5 days of exposure, at 20 per cent per gram of fish per liter of water. Several other investigaters have concurred (Fagerstrom, et al.,

1974)(Underdal 1971).

Environmental factors play an important role in direct uptake of mercury. MacLeod and Pessah (1973) found that temperature influences both mercury accumulation and elimination. Mercury accumulation ranged from a ratio of 4(mercury in tissue/mercury in water) at 5°C, to a ratio of 22 at 20°C. Higher temperatures appear to increase the rate of mercury elimination. Uthe, et al., (1973) found a stream-caged rainbow trout had rapid uptake during the warm summer period. Inorganic mercury is more easily translocated from water to fish under low pH conditions (Shen-Ching, et al., 1975). Under alkaline conditions some mercury complexes were found to be relatively unreactive.

These environmental conditions (pH and temperature) would fluctuate under natural conditions. How this might affect the mercury concentrations of the fish collected in this study cannot readily be determined. It should be noted, however, that colder water conditions were prevalent during the collection period. This may have given lower levels of mercury than would have normally been encountered during warmer periods.

Predacious species of fish have a higher rate of respiration than more sluggish omnivores. These predacious species require greater amounts of oxygen and thus obtain greater amounts of mercury directly from the water due to a greater rate of gill irrigation. This could account for part of the higher levels of mercury seen in the predatory fish in this study.

Jernelov and Lann (1971) discussed the transport of mercury through the food chain. They postulated that there was only a 10% effeciency in mercury transport to higher trophic levels. A northern pike receives 60 per cent of its mercury from food whereas species on lower trophic levels concentrate more of their mercury from the surrounding waters. Methylmercury transport from benthic fauna to bottom feeding-fish was found to be insignificant. Thus mercury bioaccumulation is actually a function of a predator adding uptake from water to a "basic level" found in the food chain.

There is no conclusive evidence to show whether direct uptake from the water or accumulation in the food chain plays a more important role in the concentrating of mercury in fish. Many authors (Jernelov and Lann, 1971)(Underdal and Hastein, 1971) feel it is a combination of both with the extent of mercury pollution playing an important role. It seems to the author that bioamplification is more evident in lakes where conditions would be more stable than in the rivers and streams sampled in this study.

By comparing smaller fish of each species it is quite apparent that younger fish of different trophic levels do not tend to show as marked bioamplification. These younger fish have very similar levels of mercury concentration. As the fish ages, the biological accumulation of mercury is a function not only of the species and its exposure interval, but also of the feedings habits, metabolic rate, size of the fish, and the various water quality parameters, as well as the degree of

mercury pollution. Mercury uptake is a complex combination of various parameters affected by environmental conditions and species habits.

Correlation of Weight/Length Ratio to Mercury Concentration

Preliminary tests showed no correlation between mercury concentration and length, or concentration and weight. However studies have shown correlations between mercury concentrations and a combination of the weight and length of the species (Bache, et al., 1971)(Fagerstrom, et al., 1974)(Scott and Armstrong, 1972)(Smith, et al., 1975). Bainbridge (1973) and Wobeser, et al., (1970) have contradicted this. It is significant, however, that in the studies showing significant correlations, the study areas for the most part were lakes, while the contradictory studies were done in rivers.

Bainbridge (1973) states that greater variation in mercury content to weight of individual fish could be expected in flowing water situations. This results from variability in duration of exposure of individual fish to variable concentrations of mercury. This situation is not present in lakes, where the concentration of mercury is fairly uniform throughout the aquatic system. His studies were done in a highly contaminated river and did not consider such factors as pH, temperature, and concentrations of electrolytes, in discussing the cause of the variability.

The present study was done in a less contaminated area, but the initial correlations testing mercury concentration

against fish length and mercury concentration against fish weight proved not significant. This would suggest that the variability of individual fish is more a product of the physical environment (river as opposed to lake) than the extent of mercury contamination. This variability may occur because of the differing features present in rivers, for example riffles versus pools. In lakes there would be a more static situation lending to a more uniform distribution of mercury in the water.

Even though the physical environment is a more important parameter, the extent of mercury pollution does contribute to the variability within a species. Mercury present in the water within a highly polluted area, such as an industrial site, would become diluted as it flowed downstream. Fish downstream would have less of an opportunity for direct uptake of mercury, thus providing for lower concentrations for these fish. Similar sized fish of the same species near the area of contamination might have higher mercury concentrations because of the higher levels in the environment.

Observing no correlations between mercury concentration and individual weight, and concentration and length, a new measurement was sought. It was felt by the author that a weight/length ratio may be a truer measurement of an individual fish's ability to concentrate mercury. This ratio would take into an account the individual "condition" of the fish. Scott and Armstrong (1972) have shown a correlation by the use of a similar ratio.

Of the five species on which correlations were calculated, three were found to show significant results. Largemouth bass and carp were significant at the 0.05 level, while yellow bullheads were significant at the 0.1 level. It must be remembered that at no time will there be a "base zero" level of mercury concentration. Hence, smaller fish of these species may bias the results.

A few conclusions can be drawn from a significant weight/length ratio correlation. As this ratio increases, that is as a fish becomes stouter, it also increases the level of mercury concentration. This could be a function of changing food habits and/or of age. A species difference in this ratio correlation can be attributed to the different physical make-up of the fish species. Hence it is not surprising that the more stout species (largemouth bas, yellow bullhead, carp) had significant correlations while the slimmer species (bluegill, white crappie) did not show significant results.

There are several advantages to setting up a correlation between mercury concentration and weight/length ratios. If a firm relationship could be established, then commercial fisheries would greatly benefit. There might be positive correlations strong enough to establish size limits within which safe mercury concentrations should be found. This would be time-saving and economical to fishermen and a further safety check for the general public. A positive correlation would allow health officials to set size levels to certain species

and not close all the fishing in an area. In fish populations it is known that the overall biomass may increase though the average size of individuals decreases. Since large carnivorous fish have the greatest chance of exceeding the 0.5 ppm limit, a method of fishing could be developed which permitted undamaged return of these larger, more highly contaminated fish. These would then constiture the spawning population without resort to any decrease in average age or size at reproduction. This would be a health safeguard against highly contaminated fish and also sound fisheries management.

In rivers and streams a weight/length ratio would appear to be the best physical attribute of fish to use when correlating with mercury concentrations. In lakes, where correlations have been established for mercury concentrations and weight, and mercury concentrations and length, length of the fish should be chosen as the correlation factor over weight since it is less likely to be subject to major day-to-day fluctuations. Weight is highly influenced by feeding. These two differing situations have to be taken into account if any meaningful mercury graphs are to be established.

Further research

Many further measurements of mercury levels in fish around Coles County area would be needed to firmly establish a weight/length ratio to mercury concentration correlation. Further is also needed in the following areas:

1. Determination of the amount of mercury a carnivorous fish, an omnivorous fish, or a bottom-feeder concentrates through food consumption vs. concentration by respiration.

2. In the above, contrast a flowing water situation(river) with a still water situation(lake or pond). Also a determination of the level at which mercury excretion by the fish would exceed mercury concentration, if at all.

3. Establishment of TLm levels, taking into account the various physical factors(pH, turbidity, thermal conditions, etc.) and the biological factors(parasitism, size of fish, species of fish, etc.)

Mercury Pollution in Coles County: An Overview

None of the fish in this study exceeded the recommended limit of 0.5 ppm set forth by government officials. Personal correspondence with Dr. Ken Smith of the Illinois Natural History Survey has shown that some of the largemouth bass in Lake Shelbyville have greatly exceeded this limit (up to 1.2 ppm). It would seem that in comparision with this study, as in previous research, mercury concentrations of fish in lakes are greater than concentrations of fish in rivers. Lakes would seem to have the feature of concentrating mercury in their sediments, while rivers have currents to move the contaminant downstream and not allow concentrations to build up. This would especially be true of man-made lakes and perhaps explains some of the extremely high mercury readings in Lake Shelbyville.

As a result of the extent of the mercury contamination in Lake Shelbyville, certain precautions have been set up for local fishermen. Only one half of a pound of largemouth bass over two pounds should be eaten per week. All fishing in Lake Shelbyville need not be closed down since only the largemouth bass exceeded the 0.5 ppm limit.

Since there are no large industrial centers in Coles County the question arises as to the source of the mercury. Possible sources include products containing mercury for agricultural use, sewage disposal systems, and natural occurring

mercury. The natural background levels are sometimes lost in the shuffle by some environmentalists and media personnel when bringing the mercury problem to the attention of the public. In mildly polluted areas, such as in Coles County, natural background levels make up a larger portion of mercury concentrations in fish than would occur in more highly polluted areas. Mercury pollution in Coles County is not a serious health hazard, although constant monitoring is essential to avoid any future problems.

Summary

From this study it is possible to conclude that in moderately polluted streams and rivers bioamplification of mercury does occur. Although the exact cause of bioamplification is a combination of a number of factors, the trophic level of the individual fish is the main force behind the concentrating of higher levels of mercury. Predacious fish were found to concentrate from two to three times as much mercury as fish on lower trophic levels.

Correlations between mercury concentrations and weight/length ratios were found for largemouth bass, carp, and yellow bullhead. White crappie and bluegill were found not to have this significant correlation. These latter fish were, on the whole, less stout than the fish with significant weight/length ratios. It seems that the more stout an individual fish becomes, the greater its ability to concentrate mercury. A weight/length ratio should be used as the parameter correlated to mercury concentrations in fish tested from rivers and streams.

The mercury levels found in the fish in this study were not above the recommended levels. Some of the larger fish tested did approach this level of 0.5 ppm. This, however, did not alter the fact that mercury pollution in Coles County is not a serious health hazard.

LITERATURE CITED

Amend, Donald F. 1970. Retention of mercury by salmon. The Progressive Fish-Culturist. 32(4):192-194.

Armstrong, F.A.J. and J.F. Uthe. 1971. Semi-automated determination of Hg in animal tissues. Atomic Absorption Newsletter. 10(5):101-108.

Aronson, James E. and Marjorie Spiesman. 1976. Note on the distribution of mercury in fish species in three Ohio lakes. Environmental Pollution. 10(1):1-7.

Bainbridge, Kent Lamont. 1973. Mercury dynamics in a warm water stream. Technical Report No. 39. Institute of Water Research, Michigan State University. 71pp.

Burrows, W.D. and Peter A. Krenkal. 1973. Studies on the uptake and loss of methylmercury-203 by bluegills. Environmental Sci. and Tech. 7(13):1127-1130.

D'Intri, F.M. 1972. Mercury in the aquatic ecosystem. Bioassay Techniques and Environmental Chemistry. pp.3-70.

D'Intri, F.M. 1973. The Environmental Mercury Problem. CRC Press. Cleveland, Ohio. 124pp.

Evans, Ronald J., Jack D. Bails, and Frank D'Intri. 1972. Mercury levels in muscle tissue of preserved museum fish. Environmental Sci. and Tech. 6(10):901-905.

Fagerstrom, TorJorn and Arne Jernelov. 1970. Formation of methylmercury from pure mecuric sulfide in aerobic organic sediment. Water Research. 51:121-122.

Fagerstrom, T., B. Åsell, and A. Jernelov. 1974. Model for accumulation of methyl-mercury in northern pike *Esox lucius*. Oikos. 25:14-20.

Fimreite, N., W.N. Holworth, J.A. Keith, P.A. Pearce, and I. M. Gruchy. 1971. Mercury in fish and fish-eating birds near sites of industrial contamination in Canada. Canadian Field Naturalist. 85(3):211-220.

Freeman, H.C., and H.A. Horne. 1973. The total mercury and methylmercury content of the American Eel (*Anguilla rostrata*). Jour. Fish. Res. Bd. Can. 30:454-456.

Friberg, Lars and Jeroslav Vostal. 1972. Mercury in the Environment. CRC. 214 pp.

Gage, J.C. and A.B. Swan. 1961. The toxicity of alkyl and aryl mercury salts. Biochemical Pharmacology. 8:77.

Gavis, Jerome and John F. Ferguson. 1972. The cycling of mercury through the environment. Water Research. 6(9):989-1008.

Gillespie, D.C. 1972. Mobilization of mercury from sediments into guppies(Poecillia reticulata). Jour. Fish. Res. Bd. Can. 29:1035-1041.

Goldwater, Leonard J. 1971. Mercury in the environment, Sci. American. 224(5):15-21.

Henderson, Croswell, Anthony Inglis, and Wendall L. Johnson. 1972. Mercury residues in fish, 1969-70-National Pesticide Monitoring Program. Pest. Moni. Jour. 6(3):144-159.

Hughes, Walter J. 1957. A physiological rationale for the biological activity of mercury and its compounds. Ann. New York Acad. Sci. 65:454-460.

Jensen, S. and A. Jernelov. 1969. Biological methylation of mercury in aquatic organisms. Nature. 223:753-754.

Jernelov, Arne. 1970. Release of methyl mercury from sediments with layers containing inorganic mercury at different depths. Limnology and Oceanography. 15(6):958-960.

Jernelov, Arne and H. Lann.1971. Mercury accumulation in food chains. Oikos. 22:403-406.

Joensuu, Oive I. 1971. Fossil fuels as a source of mercury pollution. Science. 171(3986):1027-1028.

Kania, Henry J. and James O'Hara. 1974. Behavioral alterations in a simple predator-prey system due to sublethal exposure to mercury. Trans. Amer. Fish. Soc. 103(1):134-136.

Kendall, Michael W. 1975. Acute effects of methyl mercury toxiciry in channel catfish(Ictalurus punctatus)kidney. Bull. Enviro. Cont. and Toxi. 13(5):570-578.

Knight, Luther A. and Jack Herring. 1972. Total mercury in Largemouth bass(Micropterus salmoides) in Ross Barnett Reservoir, Miss.-1970 and 1971. Pest. Moni. Jour. 6(2):103-106.

Koirtyohann, S.R., Richard Merrs, and L.K. Graham. 1974. Mercury levels in fishes from some Missouri lakes with and without known mercury pollution. Enviro. Res. 8(1):1-11.

Lockhart, W.L., J.F. Uthe, A.R. Kenny, and R.M. Mehrle. 1972. Methylmercury in northern pike(Esox lucious):distribution, elimination, and some biochemical charactoristics of contaminated fish. Jour. Fish. Res. Bd. Can. 29:1519-1523.

Potter, Loren, David Kidd, and Donald Standiford. 1975. Mercury levels in Lake Powell, bioamplification in man-made reservoir. Enviro. Sci. and Tech. 9(1):41-46.

MacLeod, J.C. and E. Pessah. 1973. Temperature effects on mercury accumulation, toxicity, and metabolic rate in rainbow trout. Jour. Fish. Res. Bd. Can. 30:485-492.

Nelson, Norton, 1970. Hazards of mercury. Enviro. Res. 4(1):1-69.

Olson, K.R., and P.C. Fromm. 1973. Mercury uptake and ion distribution in gills of rainbow trout(Salmo gairdneri): tissue scans with an electron microscope. Jour. Fish. Res. Bd. Can. 30:1575-1578.

Olson, Gayle F., Donald Jo Mount, Virginia M. Smarski, and Todd W. Thorsland. 1975. Mercury residues in fathead minnows, Pimephales promelas, chronically exposed to methylmercury in water. Bull. Enviro. Cont. and Toxi. 14(2):129-134.

Peakall, David B. and Raymond J. Lovett. 1972. Mercury:Its occurrence and effects in the ecosystem. Bioscience. 22(1):20-25.

Ramirez-Munoz, J. 1975. Determination of mercury by non-flame atomic absorption techniques. Flame Notes. 7(1):49-56.

Richins, Robert T., and Arthur C. Risser. 1975. Total mercury in water, sediment, and selected aquatic organisms, Carson River, Neveda-1972. Pest. Moni. Jour. 9(1):44-54.

Rucker, Donald R. and Robert F. Ament. 1969. Absorption and retention of organic mercurials by rainbow trout, and chinook and sockeye salmon. The Progressive Fish-Culturist. 31(4):197-201.

Scott, D.P., and F.A. Armstrong. 1972. Mercury concentration in relation to size in several species of freshwater fishes from Manitaba and northwestern Ontario. Jour. Fish. Res. Bd. Can. 29:1685-1690.

Shan-Ching Tsai, G. Mallory Boush, and Furio Matsumura. 1975. Importance of water pH in accumulation of inorganic mercury in fish. Bull. Enviro. Cont. and Toxi. 13(2):188-193.

Smith, Eric C., Fikret Berkes, and John A. Spence. 1975. Mercury levels in fish in the La Frande River Area, Northern Quebec. Bull. Enviro. Cont. and Toxi. 13(6):673-677.

Underdal, B. and T. Hastein. 1971. Mercury in fish and water from a river and a fiord in South Norway. Oikos. 22: 101-105.

Uthe, J. F. and E.G. Bligh. 1971. Preleminary survey of heavy metal contamination of Canadian fish. Jour. Fish. Res. Bd. Can. 28:786-788.

Uthe, J.F., F.M. Atton and L.M. Royer. 1973. Uptake of mercury by caged rainbow trout(Salmo gairdneri) in the South Sashatchewan River. Jour. Fish. Res. Bd. Can. 30:634-650.

Walter, Carl M., Harold G. Brown, and Charles P. Hensley. 1974. Distribution of total mercury in the fishes of Lake Oahe. Water Research. 8:413-418.

Westoo, G. 1966. Determination of methylmercury compounds in foodstuffs. Part. I. Methylmercury in fish, identification, and determination. Acta Chem. Scand. 20:2131-2137.

Wobeser, G., N.O. Nielson, R.H. Dunlop, and F.M. Atton. 1970. Mercury concentrations in tissues of fish from the Saskatchewan River. Jour. Fish. Res. Bd. Can. 27:830-834.

Wood, J.M., F. Scott Kennedy, and C.G. Rosen 1968. Synthesis of mercury compounds by extracts of a methanogenic bacterium. Nature. 220:173-174.

Zitko, V., B.J. Finlayson, D.J. Wildish, J.M. Anderson, and A.C. Kohler. 1971. Methylmercury in freshwater and marine fishes in New Brunswick, in the Bay of Fundy, and on the Nova Scotia Banks. Jour. Fish. Res. Bd. Can. 28:1285-1291.