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AN ANALYSIS OF MERCURIALS IN THE ELEPHANT BUTTE SYSTEM

Technical Completion Report

Project No. A-040-NMEX

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ABSTRACT

Analyses of samples for mercury from Elephant Butte Lake collections were made by a flameless atomic absorption procedure.

Mercury levels are expressed on a wet weight basis for animal tissues and on a dry weight basis for other materials. Analyses revealed mean ppb mercury concentrations of 0.027 in water, 57 in bottom sediments, 109 in phytoplankton, 277 in attached algae and bryophytes, 95 in plant debris, 69 in zooplankton, 90 in crayfish muscle, 26 in visceral mass of mussels, 97 in muscle of nonpredaceous fish, 125 in muscle of small predaceous fish, 253 in muscle of large predaceous fish, and 266 in muscle of two turtle species.

Walleye muscle displayed a mean level above 500 ppb, while other predaceous fish exhibited lower levels. Muscle values above 500 ppb were found in at least one specimen of flathead catfish and white bass. Significant direct relationships between mercury level in muscle and weight and length, or both, were shown by white bass and channel catfish, while general but not significant trends were indicated by other larger predators. Smaller predators and nonpredaceous fish showed few relationships of this kind.

Mercury distribution patterns in fish and turtle species were similar to each other. Mean mercury levels in

liver exceeded 500 ppb in flathead catfish, white bass, walleye, and two turtle species. Values above 1,000 ppb in liver were exhibited by at least one specimen of each of the two turtle species. Mean levels in kidney approached or exceeded those in muscle and liver for a few individual specimens of walleye, white bass, and flathead catfish. Flathead catfish, walleye, white bass, channel catfish, largemouth bass, longear sunfish, green sunfish, river carpsucker and two turtle species displayed highest levels in liver. Black crappie displayed highest levels in kidney. Northern pike and warmouth bass displayed highest levels in muscle and buffalofish displayed highest levels in stomach. White crappie, bluegill, carp, and gizzard shad displayed highest levels in spleen.

Tissues grouped by relative levels for the sixteen fish species show consistently lower levels in bone, skin, gills, and eyes; intermediate levels in stomach, intestine, heart, and brain; and higher levels in spleen, muscle, kidney, and liver. General bioamplification at higher trophic levels appears to be diet related, but the relationship does not hold for lower trophic levels.

Mercury levels in the water indicate a decreasing gradient from inlet to dam, while sediments display an increasing gradient from inlet to dam.

Arguments are given which attempt to account for concentration in some higher trophic level species. There appears to be evidence which suggests that mercury levels are related to seasonal conditions. A bioamplification scheme and concentration factors are presented which describe the status of mercury concentrations in existing trophic levels. Recommendations regarding the potential hazards of Elephant Butte fish to human health are discussed.

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INTRODUCTION

A number of biological studies have been conducted at Elephant Butte Reservoir. These can arbitrarily be grouped into studies related to population changes, fish management, and life histories. Other investigations relate to water condition, nutrients, productivity, and phytoplankton community structure. The former include investigations by Hazzard (1935); Huntington and Hill (1956); Huntington and Navarre (1957); Huntington and Jester (1958); Rael and Ozmina (1965); Rael (1966); Patterson (1968a, 1968b); Sanchez (1970); Jester (1971, 1972); Jester and Jensen (1972); Moody (1970); Jennings (1969); and Padilla (1972). The latter include studies by Greenbank (1937); Ellis (1940); and Kidd and Johnson (1971).

This investigation was encouraged by several news releases between October 1970 and June 1971 to local media by the New Mexico Department of Health and Social Services. These releases referred to high mercury concentrations in fish from Navajo, Avalon, Ute, Caballo, and Elephant Butte Lakes.

Specimens of four fish species from Elephant Butte Lake were reported to have shown mercury concentrations in excess of the maximum allowable concentration of 500 ppb. The species involved and the reported concentrations were channel catfish (*Ictalurus punctatus*), 630 ppb; white bass (*Morone chrysops*), 910 ppb; flathead catfish (*Pylodictus olivaris*), 690 ppb; and walleye (*Stizostedion vitreum*), 1,290 ppb. Other than these reported analyses, no previous investigation of this nature or magnitude has been conducted at any aquatic site in New Mexico.

The general objectives of this investigation are (1) to assess the level of mercury in sediments, water and biota; (2) to confirm or negate the findings of high mercury concentrations previously reported; (3) to recognize, evaluate, and interpret patterns of mercury accumulation and distribution in aquatic animal tissues; (4) to investigate possible bioamplification of mercury through food chains; (5) to establish whether there is a relationship between amount of mercury accumulation and length or weight within and among species; (6) to assess the potential hazard of mercury to consumers of fish taken from Elephant Butte Lake; (7) to assess the source of mercury in the reservoir; (8) and to identify specific animal tissues which may best serve as indicators of high mercury concentrations.

THE CONCEPTUAL BASIS

Mercury as well as many of its compounds have been known since antiquity and many of their beneficial and toxic properties have long been recorded. This kind of information is well documented by King (1957) and by D'Itri (1972b).

Although mercury has only recently emerged as an environmental problem, there is an authentically recorded case of mercury pollution by industrial wastes occurring in 1700 in the town of Finale, Italy, where an injunction was sought against a mercuric chloride factory which emitted noxious gases which had resulted in the deaths of several residents of the town (Goldwater, 1971).

Investigations on mercury hazards are numerous and clearly indicate that industrial mercury poisoning in the past has not been uncommon.

We can generalize that, although in a limited way, the mercury problem has been present for some time, its effects are known to be widespread and often severe. Man has increased the inputs of mercury greatly and often in forms which do not allow natural cycles to return it to a less available form. It has been estimated that natural decontamination processes may take between ten and one hundred years (D'Itri, 1972b).

Consequently, toxic mercury forms are available to all forms of life through natural cycles. The potential sources of mercury released into the environment in the United States are undoubtedly great. For example, King (1957) and D'Itri (1972a) both estimate over 3,000 common uses for mercury. D'Itri (1972b) reports that the U. S. annual consumption is 5.7 million pounds, most of which is used by eleven major industries.

Because mercury pollution appears widespread earlier baseline values are important for comparison to present findings. Stock and Cucuel (1934) were among the first to indicate bioamplification of mercury through the food web.

It is now known that many ionic species of mercury as well as mercury complexes are held tightly by a variety of organic materials and soils, and that solubility of certain compounds is pH dependent as indicated by Wershaw (1970), Hem (1970), and Matida and Kumada (1969). These phenomena have been suggested by White, Hinkle, and Barnes (1970) as the explanation for low mercury concentration in waters even in areas where mercury contamination was suspected.

Studies of mercurials in relation to toxic effects on fish are common since the late 1940's. Van Horn and Katz (1946), Rucker (1948), Snieszko (1949), Burrows and Palmer (1949) all verified toxic symptoms in fish when using phenylmercuric acetate, also called pyridylmercuric acetate (PMA), as a prophylactic for gill disease. Rodgers et al. (1951), using the same compound, also noted toxic symptoms in fish. Concentrations of PMA used in these studies ranged from 2,500-10,000 ppb. Later studies by Rucker and Amend (1969), using ethylmercury phosphate at levels of 1-1.33 ppm indicated the dangers of mercurials for such treatment and recommended their use be discontinued. They gave evidence for accumulation in various tissues and demonstrated bioamplification.

The first major incident of industrial mercury poisoning occurred in 1953 when an undiagnosed neurological disorder, later termed "Minamata Disease", caused the deaths of 41 persons and disablement among a large number of individuals along Minamata Bay, Kyushu, Japan (Kiyoura, 1962). There have been several similar incidents in Japan.

The etiology of the disease was traced to alkylmercury compounds in fish and shellfish taken from the contaminated rivers and bays and eaten by the populace of these localities. Tsuruga (1963) indicates that the chemical form of the mercurial ingested is equally as important as the concentrations administered. It is now known that the most toxic mercurials and most rapidly and easily accumulated are the methyl and ethyl forms.

High concentrations have been noted in analyses of some Swedish foodstuffs which revealed mercury concentrations above 1,000 ppb (Johnels and Westermark 1969; Westoo 1969; Johnels et al., 1967). Mercury concentrations above 1,000 ppb were so common in fish from forty lakes, that the Swedish Medical Board banned their sale (Goldwater, 1971).

Since the late 1960's fish from many areas in Canada and the U. S. have been found to contain levels of mercury above 500 ppb (Hartung, 1972).

Investigations on the path of mercury through food chains, by Japanese, Swedish, and American investigators, have shed light on the biotransformation of mercurials. Jernelöv (1970) demonstrated the ability of microorganisms to methylate mercury in sediments under slightly acidic conditions.

Jernelöv (1972b) also demonstrated that mercury accumulation in pike followed the efficiency relationship of roughly 10% between food intake and growth. He determined levels in organisms making up the food chain which led to pike. He then compared these levels to those found in pike and found that accumulation from dietary sources was 10-15%. He suggests that mercury in foods will contribute to concentrations in such a way that it provides a basic level above which fish then continue to accumulate the metal directly from the water.

Following the incidents of human mercury poisoning which had occurred in Japan and because it became apparent that mercury pollution was widespread it became necessary to determine tolerance levels and find methods to detect high concentrations before tolerance limits were exceeded. Berglund and Berlin (1969) report that eight $\mu g/g$ represented a critical level in human brain tissue above which symptoms of poisoning often occurred. Determination of levels in the diet required for the critical level to be reached were calculated to be 0.6 mg/day or 0.42 mg/week. Blood levels would reach 70 ppb at this intake. Levels of intake of 0.06 mg/day were recommended as safe. From a knowledge of foods comprising the Swedish diet which may include 2-4 fish meals per week, they determined that the intake of mercury would not normally exceed the 0.06 mg/day level. A level of 1,000 ppb was set as the maximum allowable concentration in Swedish fish used for food.

In the United States the U. S. Department of Public Health has recommended a permissible limit of 5 ppb in drinking water. In foods, the U. S. Food and Drug Administration proposed a limit of 500 ppb (Wershaw, 1970).

These considerations serve to conceptualize the problem and place the following investigation in perspective.

SITE DESCRIPTION

Elephant Butte Reservoir is located in Sierra County in southcentral New Mexico, five miles (eight km) northeast of Truth or Consequences, New Mexico, and is New Mexico's oldest reservoir and second largest impoundment. It was impounded on the main channel of the Rio Grande River in 1915 primarily for storage of water for irrigation of the lower Rio Grande Valley of southern New Mexico, extreme west Texas, and northcentral Chihuahua, Mexico. Other uses include sport fishing, water oriented recreation, and power generation (Jester, 1972).

By original survey it had a maximum storage capacity of 2,638,000 acre ft (3,257 x 10^6 m^3). By 1969 storage capacity had been reduced to 2,137,000 acre ft (2,640 x 10^6 m^3) due to silt deposition. Since 1949 water storage has not exceeded 544,000 acre ft (670 x 10^6 m^3) (U. S Department of the Interior, 1970).

Water storage fluctuates greatly as a result of seasonal inflow and drawdown for irrigation. Water storage varied between 239,100 acre ft (295 x 10^6 m^3) and 35,400 acre ft (43 x 10^6 m^3) during the course of this study (U. S. Bureau of Reclamation, 1972).

Lake elevation is approximately 4,500 ft (1,646 m) in a landscape of low rolling hills and mesas, interspersed by numerous canyons. The region is characterized by a mixture of igneous and sedimentary rocks (Bushnell et al., 1955).

Mean annual rainfall in this area is about eight inches (U. S. Department of Commerce, 1970). Surrounding vegetation consists of desert shrubs of the northern Chihuahuan Desert. Near the lake extensive strands of *Tamarix pentandra* occur, expecially along the northwest shore. These plants contribute to the organic debris washed into the lake. The abundant annuals near the shore consist of dense stands of cocklebur, *Xanthium saccharatum* and jimson weed, *Datura stramonium* which quickly invade bare areas left open by the receding water level during spring and summer drawdown. These also contribute debris to the reservoir.

At the extreme northwest shore at the inlet of the reservoir scattered stands of *Typha latifolia* also occur. These areas are regularly visited by feeding schools of nonpredaceous fish. Extreme fluctuations of water level prevent establishment of permanent rooted littoral vegetation in all of these areas.

The phytoplankton population of Elephant Butte includes some seventy species, only four of which are dominants (Kidd and Johnson, 1972). Attached green and bluegreen algal forms are occasionally abundant growing on buoys, rocks and also often in sheltered quiet coves along the shore. The bryophyte Plumatella sp. is also periodically abundant during July and August near the Elephant Butte Marina and along the boomline where it grows attached to artificial substrates.

The zooplankton consists primarily of copepods, cladocerans, protozoa, rotifers, insect larva, invertebrate eggs, and minute fry. Benthic organisms consist of a sparse population of Chironomidae, Oligochaeta and Chaoborinae (Jester, 1972). Macroinvertebrates include one species of mussel of the genus Anodonta, and crayfish Oronectes causeyi Jester, both of which are relatively abundant at Elephant Butte Lake.

The aquatic vertebrates include two turtle species, Trionyx spinifer and Pseudemys scripta, and 27 fish species representing 6 orders and 10 families (Table 1).

Chemical characteristics of the lake water include a relatively stable water chemistry with dissolved oxygen ranging from 5.5-8.5 mg/liter; total hardness from 175-225 mg/liter; and pH usually near 8.3 but may vary from 7.5-9.2 (Jester 1972). Total alkalinity ranges from 124 mg/liter to 160 mg/liter; phosphates range from 0.090-1.08 mg/liter; and nitrate nitrogen ranges from 0.212-0.933 mg/liter (Kidd and

Johnson, 1971).

Bottom types vary little along the main river channel from inlet to the dam. Silt differs primarily in the amount of organic matter it contains. The bottom varies more along the eastern shore from north to south with the rocky and sand-gravel slopes contributing to a silt-rock mixture near the shoreline.

The trophic status of Elephant Butte has been termed oligotrophic by Jester (1972), because of its sparse plankton and benthic populations. According to Kidd and Johnson (1971), the lake is eutrophic, because of its nutrient content and phytoplankton community structure. Personally I feel that it is more like a eutrophic lake during the maximum late summer drawdown, and more like an oligotrophic lake during the peak of winter inflow and storage.

Elephant Butte has no true thermocline, but it is considered by Jester (1972) to be a modified dimictic lake because temperature uniformity occurs late in September to early October and in April to May, causing fall and spring overturns.

TABLE 1. Check-list of fish known to occur in Elephant Butte Lake, New Mexico. Those marked with an asterisk(*) are rarely taken (Jester, 1971)

Family Clupeidae - shad	
Gizzard shad	_Dorosoma cepedianum_
Family Salmonidae - trout	
*Rainbow trout	_Salmo gairdneri_
*Brown trout	_Salmo trutta_
Family Esocidae - pikes	
Northern pike	_Esox lucius_
Family Cyprinidae - carp and minnows	
*Goldfish	_Carassius auratus_
Carp	_Cyprinus carpio_
*Red shiner	_Notropis lutrensis_
*Flathead minnow	_Pimephales promelas_
Family Catostomidae - suckers	
River carpsucker	_Carpiodes carpio_
*White sucker	_Catostomus commersoni_
Smallmouth buffalo	_Ictiobus bubalus_
Family Ictaluridae - catfish	
*Blue catfish	_Ictalurus furcatus_
*Black bullhead	_Ictalurus melas_
*Yellow bullhead	_Ictalurus natalis_
Channel catfish	_Ictalurus punctatus_
Flathead catfish	_Pylodictis olivaris_
Family poeciliidae - livebearers	
*Mosquitofish	_Gambusia affinis_
Family Percichthyidae - temperate basses	
White bass	_Morone chrysops_
Family Centrarchidae - sunfish	
Warmouth	_Lepomis gulosus_
Green sunfish	_Lepomis cyanellus_
Bluegill	_Lepomis macrochirus_
Longear sunfish	_Lepomis megalotis_
Largemouth bass	_Micropterus salmoides_
White crappie	_Pomoxis annularis_
Black crappie	_Pomoxis nigromaculatus_
Family Percidae - perch	
*Yellow perch	_Perca flavescens_
Walleye	_Stizostedion v. vitreum_

MATERIALS AND METHODS

Collection

Samples were collected between late May 1971 through October 1972 from 45 sites (Figure 1). Sediments were collected with an Eckman dredge, sixteen fish species were taken by gill nets, crayfish and mussels were caught by hand, and two turtle species were taken with traps. Algae were harvested from 4 x 4 inch glass slides and also from natural substrates, floating organic debris was hand collected from the water's surface, water was collected with a 1,200 ml Kemmerer bottle, and zooplankton was taken by pumping water through a #20 mesh silk cloth.

Preservation

All samples except water and turtles were placed in polyethylene bags, labeled in the field, and kept in an ice chest until they could be frozen (usually 3-4 hours). Preservation procedures are described by Cope (1960). Fish and turtles were measured and weighed live in the field. Turtles were returned live and slowly frozen, then stored in polyethylene bags until analysis. Water samples were preserved with 3 ml/liter 50% nitric acid as recommended by Chau and Saitoh (1970). For comparison of techniques some water samples were preserved by adding 20 ml of 1 N sulfuric acid per gallon of water as recommended by Cope (1960).

Water was analyzed within 1-2 weeks after collection.

Analysis and Sample Preparation

All material was analyzed using a Perkin-Elmer Model 306 Atomic Absorption Spectrophotometer and a flameless technique described by Hatch and Ott (1968) and Uthe, Armstrong, and Stainton (1970).

Water was analyzed without additional preparation and also by concentrating mercury from the water by the dithazone extraction method of Chau and Saitoh (1970). Prepared samples all were of 100 ml volumes.

Where possible three or more replicates per tissue type were prepared. Separate percentage recovery experiments were run on most material analyzed. The percentage of mercury recovered from spiked samples was frequently between 85-95% with some values above 100% or below 80%. The coefficient of variation between replicates was most frequently less than 10%. Portions of sediment and plant material were weighed and saved for dry weight comparison. Fourteen tissue types within each fish and fifteen tissue types within each turtle were analyzed where possible. For smaller crayfish entire organisms were analyzed while four tissue types were analyzed for larger specimens (Table 2).

For freshwater mussel only two types of tissue were analyzed.

Data Analysis

Initial data analysis was made using the Student-Newman-Keuls Multiple Range Test (Sokal and Rohlf, 1969). Patterns of interest were then subjected to correlation analysis using a BMD Asymmetrical Correlation Program. Significance level selected was *P* = 0.05.

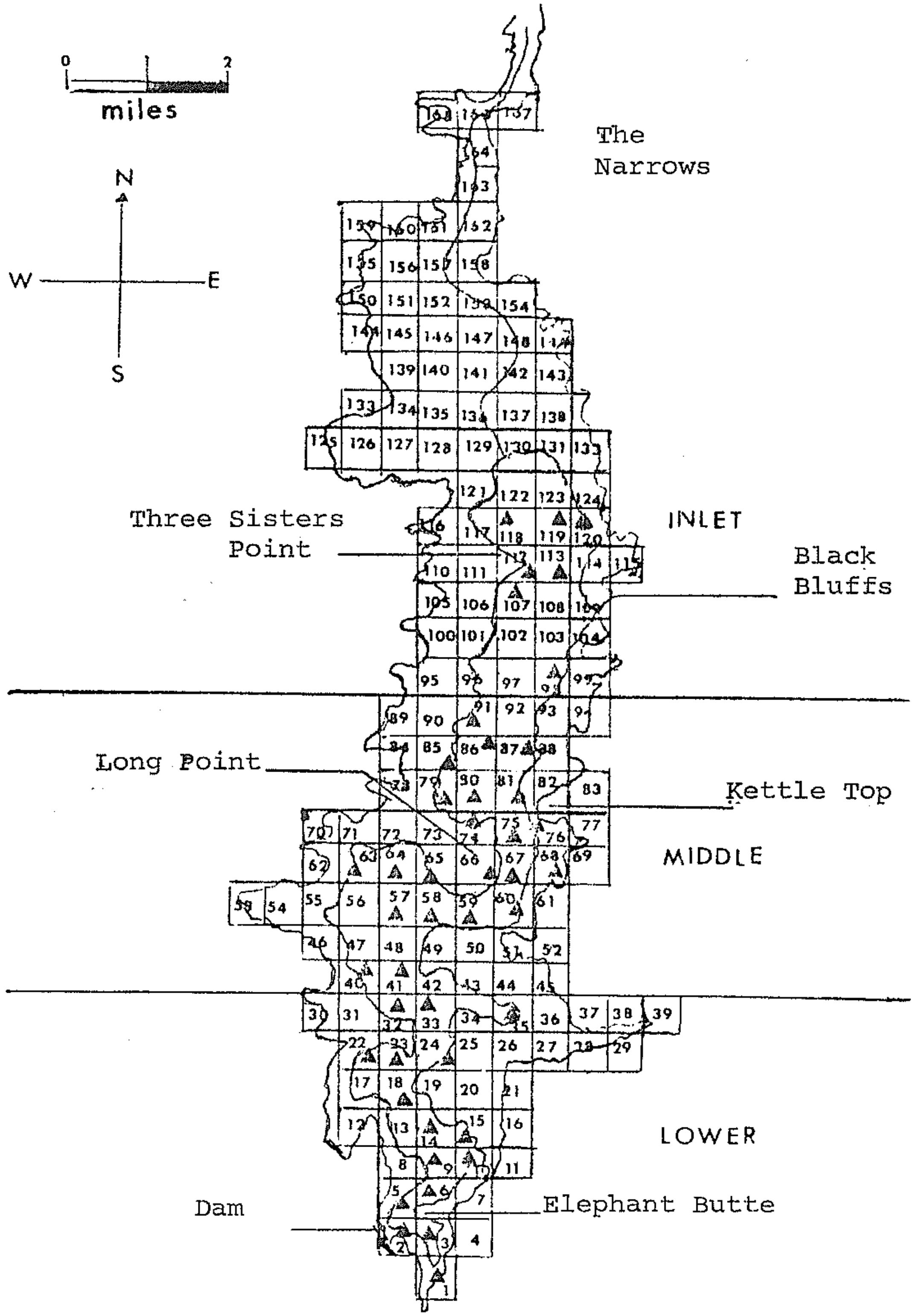

FIGURE 1. Elephant Butte Lake map with superimposed grid system. Inner contour represents the approximate average shoreline during this study. Each square represents an area with one half mile sides. Each grid square with a triangle represents a general area for a collection site.

TABLE 2. Key to tissue types referred to on tables 4-6, 13-18, and 20-22

Tissue no.	Tissue type all fish	Tissue type *T. spinifer*	Tissue type *P. scripta*
1	Skin	Skin	Skin
2	Muscle	Muscle	Muscle
3	Eyes	Eyes	Eyes
4	Gills	Lungs	Lungs
5	Brain	Brain	Brain
6	Stomach	Stomach	Stomach
7	Intestine	Intestine	Intestine
8	Liver	Liver	Liver
9	Spleen	Spleen	Spleen
10	Air bladder	Cartilage	Blood
11	Gonad	Gonad	Gonad
12	Kidney	Kidney	Kidney
13	Heart	Heart	Heart
14	Bone	Urinary bladder	Urinary bladder

Tissue no.	Tissue type crayfish
1	Abdominal muscle
2	Gills
3	Internal organs
4	Exoskeleton
5	Homogenate from entire small crayfish

RESULTS AND DISCUSSION

Sediments

Sediments had a mean mercury concentration (Table 3) of 57 ppb with a range of 39-89 on a dry weight basis. The lower one-third of the reservoir has mean mercury levels of 69 ppb; the middle one-third, 55 ppb; and the upper one-third, 45 ppb. The differences are significant and probably reflect differential siltation patterns. Since sediments, higher in organic content, are known to have higher mercury concentration then the fact that the upper one-third has, sediments with lower organic content would lead to the expectation of lower mercury concentration. Higher mercury levels down reservoir are accounted for both on the basis of increasing sediment stability and higher organic content.

Mercury levels for sediments analyzed in this investigation are considered to be normal background concentrations. Pierce, Botbol, and Learned (1970) report that the range of mercury concentrations in rocks, soils, and sediments in the Western United States is 50-200 ppb. Kidd and Potter (1972) report a range of 4-53 ppb for sediments of Lake Powell -- an impoundment on the Colorado River near Page, Arizona, which is believed to be free of artificial mercury contamination. There is no reason to believe that Elephant Butte Lake is receiving any man caused mercury inputs. Apparently if there was pollution, it occurred some years ago, but by now the contaminated sediments would be covered by siltation. More likely, erosion of geologic deposits represents the source of mercury in the Elephant Butte ecosystem.

Water

Water displayed a mean mercury concentration (Table 3) of 0.027 ppb with a range of 0.018 to 0.047 ppb. Mean values were lower in the lower one-third of the reservoir and higher in the upper one-third near the inlet. The trend is the reverse of the sediment pattern. Levels were 0.024, 0.028, and 0.029 ppb respectively from the lower one-third to the upper one-third. The upper one-third values were significantly different from the lower one-third of the lake.

Higher mercury concentrations near the inlet probably reflect the higher silt content of water. No attempt was made to filter out the silt before analysis, a defect of this investigation. One should remember that mercury is readily adsorbed to silt particles (Fleischer, 1970).

The important realization is that no major mercury inputs of Elephant Butte Lake are taking place via the Rio Grande River. Mercury concentrations reported here are lower than most natural levels reported for the United States and foreign countries. Wershaw (1970) reports that the normal range is 0.1-17 ppb -- values higher than

TABLE 3. Average mercury levels in sediment and water samples. Location no. refers to grid no. (Figure 1). Lines indicate non significant ranges. No lines indicate means are significantly different

Sediment (dry weight) Location no.	N	Mean Hg ppb	Water Location no.	N	Mean Hg ppb
81	15	39	113	14	0.018
75	15	41	2	25	0.020
79	15	43	60	18	0.021
120	15	43	33	5	0.024
107	15	46	80	5	0.025
113	15	46	64	5	0.025
67	15	51	5	5	0.026
6	5	53	18	5	0.026
87	15	54	75	5	0.027
98	5	55	41	5	0.028
91	15	58	118	10	0.041
59	5	58	91	14	0.047
2	30	63			
41	5	65			
1	15	66			
18	5	68			
57	5	70			
5	5	71			
60	5	75			
33	5	75			
14	5	89			

Combined location values. Water

95-118	24	0.029 Inlet
40-94	52	0.028 Middle
1-39	40	0.024 Lower

Combined location values. Sediments

95-113	45	45 Inlet
40-94	130	55 Middle
1-39	70	69 Lower

concentrations found in Elephant Butte waters. Mercury concentrations of water were similar to concentrations (< 0.1 ppb) found at Lake Powell (Kidd and Potter, 1972).

The next question to be considered is whether the mercury is in a form, in the water, which can be taken up and passed from lower to higher trophic levels. The argument is deductive and based upon development of a theory which simply says, "given these water chemistry parameters, what do we expect regarding mercury in the water".

<u>Postulates of the theory</u>

1. Inorganic mercury in water exists either as Hg^{o}, Hg^{+}, or Hg^{++}.

2. Mercury exists as Hg^{o} or HgS when the average of chlorine species is 36,000 ppb and sulfur species is 96,000 ppb (Hem, 1970).

3. These mercury forms will be in equilibrium with other mercury forms under the possible pH and Eh values found between anaerobic to aerobic conditions (Hem, 1970).

4. Mercury exists as $HgCl_2$ and $Hg(OH)_2$ under aerobic conditions and circum-neutral pH.

5. Mercury exists as $Hg(OH)_2$ at pH values above neutral.

6. In sediments, under aerobic conditions and pH values up to 9.5, mercury exists as insoluble HgS and

$Hg(SH)_2$ (Hem, 1970).

7. Inorganic chloride complexes and Hg^o are soluble in organic solvents and are expected to pass into gills via the lipid substances making up cell membranes.

8. Alkylation of inorganic sulfides by microorganisms in the upper few centimeters of sediments takes place under aerobic conditions only if the pH of the sediment-water interphase is slightly acidic which favors the formation of monomethylmercury (Jernelöv, 1970).

9. Alkylation of inorganic mercury compounds by microorganisms in sediments takes place under anaerobic conditions and basic pH levels which favors the formation of dimethylmercury (Wood, Kennedy, and Rosen, 1968; Jernelöv, 1972a).

10. Organo-mercurials produced in sediments are released into the water phase and are absorbed through cell membranes and complex with -SH groups in amino acids and proteins present in protoplasm (Matida and Kumada, 1969).

11. Death and decay of the organisms releases -SH bound mercury compounds back into the environment.

Deductions from the theory

Water chemistry conditions at Elephant Butte Lake include a pH of 7.5-9.2, chloride in the range of 31,000-91,000 ppb, and sulfate in the range of

81,000-180,000 ppb. Dissolved oxygen usually ranges from 5.5-8.5 mg/liter. Lower dissolved oxygen values have been recorded at times within the impoundment. On the basis of the postulates and known water chemistry conditions one may deduce that: (1) mercury is present in the neutral and sulfide form and is in equilibrium with other forms; (2) it may also be present in chloride and hydroxide compounds; (3) in the surface sediments mercury is present as insoluble HgS and $Hg(SH)_2$; (4) anerobic conditions conducive to mercury release from bottom sediments are probably seasonal or intermittent; (5) mercury is available in the water at all seasons for either adsorption or absorption by the lake's biota; (6) biota whose behavior dictates that they live in benthic waters would be expected to receive intermittent mercury inputs and may display low mercury concentrations or at least be quite variable in mercury values within and among tissues; and (7) biota more in contact with surface waters, or waters well above the influence of the sediment-water interphase would be expected to be in contact with a more consistent input of mercury and therefore develop higher mercury levels.

Ramifications of this theory, its strengths and weaknesses are tested by considering mercury concentrations in the biota.

Fish

Variations in the mercury level between tissues within fish species grouped into three trophic levels

Examination of Table 4 (top predators), reveals distinctive tissue groups within each species whose mercury level is significantly different from other tissue groups, but among these species there is no general ordered pattern of tissue groups for all top predators.

In all top predators except northern pike tissue 8 (liver) forms a distinctive group, significantly higher than all other tissue groups. Tissue 2 (muscle) also forms a distinctive group. Further examination of the table yields a somewhat distinctive pattern also for tissue 12 (kidney) and tissue 9 (spleen). A general pattern for low mercury levels is indicated for tissue 14 (bone). No other distinctive ordered pattern of tissues from low to high mercury concentrations is evident for this trophic level.

In top predators tissues 8 (liver) and 2 (muscle) and possibly tissue 12 (kidney) represent indicator tissues of high mercury concentration.

Examination of Table 5 (small predators), shows distinctive patterns of tissue groups within each species, but no ordered pattern of groups characteristic of this trophic level, in spite of the fact that four of these species belong to the

TABLE 4. Mercury distribution patterns in tissues of top predaceous fish. Numbers refer to tissue type (Table 2). Lines indicate nonsignificant ranges. Tissues are ranked from low to high concentration within each species

	Flathead catfish	Walleye	White bass	Channel catfish	Largemouth bass	Northern pike
Low	14	14	3	14	3	1
	5	3	14	10	14	4
	10	1	1	1	5	14
	1	5	5	4	1	9
	11	10	12	3	4	10
	3	4	4	5	13	3
	4	11	13	11	6	11
	6	7	10	7	11	5
	13	6	7	6	10	6
	9	9	6	13	9	12
	7	13	9	9	7	8
	2	12	2	2	12	13
	12	2	11	12	2	7
	8	8	8	8	8	2
High						

TABLE 5. Mercury distribution patterns in tissues of small predaceous fish. Numbers refer to tissue type (Table 2). Lines indicate nonsignificant ranges. Tissues are ranked from low to high concentration within each species

Longear sunfish	Green sunfish	Black crappie	White crappie	Warmouth bass	Bluegill
Low					
1	1	4	4	3	14
11	3	1	11	14	3
14	4	3	3	1	1
4	14	7	14	4	4
3	6	11	6	11	11
7	7	14	7	6	5
9	13	6	1	5	7
6	9	13	10	7	6
5	11	5	13	10	8
2	5	10	12	13	2
12	12	8	8	12	10
13	2	2	2	9	13
8	10	9	5	8	12
	8	12	9	2	9
High					

TABLE 6. Mercury distribution patterns in tissues of nonpredaceous fish. Numbers refer to tissue type (Table 2). Lines indicate nonsignificant ranges. Tissues are ranked from low to high concentration within each species

	Buffalofish	Carp	River carpsucker	Gizzard shad
Low	4	4	14	3
	1	1	3	14
	7	3	5	5
	14	10	4	1
	11	11	1	5
	10	7	11	11
	3	14	13	10
	13	12	7	2
	5	6	6	6
	9	5	10	7
	8	13	12	8
	12	8	2	13
	2	2	9	12
High	6	9	8	9

same genus. Tissues 8 (liver) and 9 (spleen) do appear more frequently with the highest mercury levels, but the pattern does not indicate a clear cut indicator tissue for this group.

Examination of Table 6 (nonpredators), reveals no ordered pattern of tissue groups which is characteristic of this trophic level. Tissue 9 (spleen) does appear more frequently with higher levels but they are not significantly higher than concentrations found in other tissues for members of this group. No clear cut indicator tissue is evident for this trophic level.

The following generalizations are evident: (1) liver, muscle, or both are significant indicator tissues for top predators, but the same tissues in small predators and nonpredators are less useful as indicators. (2) spleen and kidney tissue may have some value as indicator tissues for some individual species.

<u>Relative mercury concentrations in tissue-group patterns between fish species</u>

Although mercury levels vary considerably in tissue types within and between species, distribution patterns appear similar for certain tissue groups regardless of species, weight or trophic level.

When fish species were treated as belonging to groups (trophic levels), and compared (Tables 4-6) certain patterns appeared characteristic for top predators which were not evident for lower trophic levels. When all species are compared together, general patterns of tissue groups are revealed which may apply to fish in general.

A frequency table (Table 7) was constructed to display the number of times a tissue within a species displayed low to high mercury levels. Since there were fourteen tissues, fourteen positions were designated. Position one is the lowest mercury level and position fourteen is the highest mercury level.

Examination of this table shows that three species out of the sixteen have lowest values in skin tissue. The number three means that skin occupied position one three times out of the sixteen possible times or for 18.7% of the species. If we wish to determine in what percentage of the species skin occurs in positions one-five we would sum the percentages and learn that skin occurs in this group 93% of of the time. Similarly, percentages at any given position or for any number of positions may be determined for all tissues. Conversely, one can find the percentage of time that a tissue of a species occurs at position one-five.

Further examination of the table reveals that skin, eyes, gills, and bone form groups with relatively low

TABLE 7. Frequency distribution of the number of species out of sixteen whose particular tissue type was ranked at the position 1, 2,...14. Positions are arranged according to increasing concentration of mercury from 1 (low) to 14 (high). Species (S), Position (P)

	Low mercury											High mercury		
Positions (P)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Tissue type														
Skin														
no. of S at P	3	3	5	3	1		1							
% S at P	18.8	18.8	31.3	18.8	6.3		6.3							
Muscle														
no. of S at P								1		2		7	4	2
% S at P								6.3		12.5		43.8	25.0	12.5
Eyes														
no. of S at P	4	4	3		2	2	1							
% S at P	25.0	25.0	18.8		12.5	12.5	6.3							
Gills														
no. of S at P	4	1	2	5	1	2	1							
% S at P	25.0	6.3	12.5	31.3	6.3	12.5	6.3							
Brain														
no. of S at P		1	2	2	1	2	1	1	3	2			1	
% S at P		6.3	12.5	12.5	6.3	12.5	6.3	6.3	18.8	12.5			6.3	

TABLE 7. continued

Positions (P)	Low mercury 1	2	3	4	5	6	7	8	9	10	11	High mercury 12	13	14
Tissue type														
Stomach														
no. of S at P					2	1	2	3	6	1			1	
% S at P					12.5	6.3	12.5	18.8	38.0	6.3			6.3	
Intestine														
no. of S at P			1	1		4	1	4	1	1	2		1	
% S at P			6.3	6.3		25.0	6.3	25.0	6.3	6.3	12.5		6.3	
Liver														
no. of S at P									1		5	1	1	8
% S at P									6.3		31.3	6.3	6.3	50.0
Spleen														
no. of S at P				1			1	1		4	2	1	2	4
% S at P				6.3			6.3	6.3		25.0	12.5	6.3	12.5	25.0
Air bladder														
no. of S at P		1	1	1	2	1	1	2	2	2	1		1	
% S at P		6.3	6.3	6.3	12.5	6.3	6.3	12.5	12.5	12.5	6.3		6.3	
Gonad														
no. of S at P		2			6	2	3	1	1				1	
% S at P		12.5			37.5	12.5	18.8	6.3	6.3				6.3	

TABLE 7. continued

	Low mercury											High mercury		
Positions (P)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Tissue type														
Kidney														
no. of S at P					1			1		2	4	3	4	1
% S at P					6.3			6.3		12.5	25.0	18.8	25.0	6.3
Heart														
no. of S at P						1	3	2	2	2	2	3	1	
% S at P						6.3	18.8	12.5	12.5	12.5	12.5	18.8	6.3	
Bone														
no. of S at P	5	4	2	3		1	1							
% S at P	31.	25.0	12.5	18.8		6.3	6.3							

mercury levels for all species. Brain, intestine, and air bladder are groups which show greater variation with no distinctive group pattern. Stomach and gonad form groups in a more central position. Spleen and kidney form groups with higher levels. The pattern displayed by heart is somewhat similar to that for kidney and spleen. Liver and muscle are groups showing highest levels.

An overview of this table reveals that eight species show highest mercury concentrations in liver, two species show highest levels in muscle, one species shows highest levels in kidney, four species show highest levels in spleen and one species shows the highest level in stomach.

Treatment of data, as was done for skin, indicates that liver and muscle occurred in positions 10-14 93% of the time, kidney occurred in positions 10-14 87% of the time, spleen occurred in positions 10-14 81% of the time, and stomach occurred in positions 10-14 only 12% of the time.

Variations in the mean mercury concentrations of individual tissues compared between 16 fish species

Average concentrations in muscle (Table 9) compared for all species indicate that there is no significant difference in the range of mercury levels between 13 species whose range varies from 79 to 198 ppb. Only white bass, flathead catfish, and walleye exhibit mercury levels which are significantly greater than this range. White bass and flathead catfish however, show levels of 306 and 327 ppb respectively, which is significantly lower than the level of 603 ppb found in walleye.

Average levels for skin (Table 9) do not exceed 100 ppb in any species and no one species displays levels which are significantly different from the others. White bass, flathead catfish, and walleye display significantly higher levels than found in most species although there is no significant difference between them.

Eye tissue (Table 9) does not show an average mercury level equal to 100 ppb for any species, and no one species is significantly different from the others. Although channel catfish, northern pike, flathead catfish, and walleye show levels which do not differ significantly from each other, collectively their levels are significantly higher than found in most species.

Average levels in gill tissue (Table 10) do not reach 100 ppb except in walleye and white bass which show a level of 129 and 184 ppb respectively. The difference is significant. These mercury levels are also significantly higher than those found in all other species.

The range of average mercury levels in brain tissue (Table 10) reaches values above 100 ppb and less than 150 ppb only in white crappie and white bass. These values are not significantly higher than the range which includes all species except river carpsucker. When river carpsucker is included in another range however, then the concentrations in white crappie and white bass are significantly higher than in the other fourteen species.

Average concentrations in stomach tissue (Table 10) reveal that only white bass (231 ppb) and walleye (234 ppb) exhibit concentrations which do not differ significantly, from each other, but which are significantly higher than levels found in all other species.

The range of concentrations of average values for intestinal tissue (Table 11) between species is from 29 to 216 ppb. No one species has a significantly higher level than all others, but the larger predaceous species generally display significantly higher levels than do nonpredators and smaller predaceous species. For example, flathead catfish, largemouth bass, walleye, and white bass generally are included in ranges which are significantly higher in their concentrations than most species.

Average concentrations in liver (Table 11) vary considerably between species with all but channel catfish, flathead catfish, white bass, and walleye being in the same nonsignificant range which includes species with levels between 57 and 261 ppb. Concentrations from 458 to 534 ppb are not significantly different between the two catfish species and white bass, but are significantly higher than the values for twelve other species. Mercury levels in walleye are significantly higher than in all other species except flathead catfish and white bass. With the exception of northern pike and largemouth bass the larger predaceous species display significantly higher levels.

Average levels in spleen (Table 11) indicate that only buffalofish and northern pike exhibit significantly lower levels when compared to the range of values for the other fourteen species.

Average concentrations in air bladder (Table 12) show no significant difference within the range of 23 to 144 ppb. Only white bass is excluded, with a significantly higher value of 202 ppb. A second nonsignificant range from 124 to 202 ppb includes largemouth bass, green sunfish, bluegill, and white bass. White bass is significantly higher in concentration when compared to the range including eleven of the other fish species. With the exception of white bass, larger predaceous fish do not show values significantly higher than nonpredators.

Gonad tissue (Table 12) exhibits a relatively wide range of average mercury values between species. The values for species within the range of concentrations from 26 to 117 ppb are not significantly different from one another. Only walleye with 156 ppb and white bass with 339 ppb are significantly higher than the given range. Only the value for white bass is significantly higher than levels found in the other species. A second nonsignificant range extending from longear sunfish with 39 ppb and including walleye with 156 ppb clearly indicates that carp, buffalofish, river carpsucker, and white crappie have significantly lower mercury levels than fish species included in this range.

Average levels in kidney tissue (Table 12) vary greatly between species, but there is no significant difference in the range of values from 31 to 218 ppb which includes all species except flathead catfish with a level of 351 ppb and walleye with a level of 419 ppb. These species display concentrations which are significantly higher than that found in all other species, but are not significantly different from each other.

Average concentrations in heart muscle (Table 8) exhibit a wide range. The range of values for fourteen species is from 39 to 157 ppb, a difference which is not significant. Only white bass and walleye display levels greater than this range. Walleye with a level of 278 ppb is significantly higher than all other species. A second nonsignificant range from 42 to 195 ppb includes white bass and indicates that its mercury level is not significantly higher than the levels contained by all other species except carp and buffalofish.

Average concentrations in bone show all species with levels between 12 and 76 ppb. River carpsucker, with 12 ppb, has the lowest level. Walleye, with 76 ppb, has the highest level.

The general pattern which is evident when comparing tissues between species is that the tissues skin, eyes, and bone consistently display average levels below 100 ppb in all species. All other tissues show greater variation, but muscle, liver, kidney, and sometimes spleen, most often show the highest levels.

The three species which most frequently show the highest levels for most tissues are walleye, white bass, and flathead catfish. The three species which most frequently show the lowest levels in all tissues are carp, buffalofish, and river carpsucker.

If all fish species are arranged according to the average mercury concentrations for all tissues, then the arrangement of species from lowest to highest level would be as follows: carp < buffalofish < river carpsucker < longear sunfish < white crappie < black crappie < green

TABLE 8. Average mercury levels in heart, and bone compared between 16 fish species. Species code for Tables 8-12 are given at the right. Lines connecting means indicate nonsignificant ranges. No lines indicate the means are significantly different. M = no. of fish. Mercury values are ppb (wet weight)

Heart			Bone			Common name
Species code	Mean ppb	M/N	Species code	Mean ppb	M/N	Species code
C	39	5/7	RCS	12	5/14	RCS river carp-sucker
BUF	40	7/13	C	30	5/15	C common carp
RCS	42	5/5	BUF	32	7/21	BUF buffalofish
BC	60	5/5	BG	33	5/14	BG bluegill
GS	71	5/5	WMB	35	5/15	WMB warmouth bass
WC	71	5/13	FHC	37	5/15	FHC flathead cat-fish
LMB	88	5/5	WC	41	5/15	WC white crappie
WMB	104	5/5	GS	41	5/15	GS green sunfish
CC	111	5/11	LES	42	6/16	LES longear sunfish
NP	131	6/11	CC	43	5/15	CC channel catfish
SH	134	8/7	SH	50	8/18	SH gizzard shad
BG	145	5/5	LMB	51	5/15	LMB largemough bass
LES	148	6/6	BC	52	5/15	BC black crappie
FHC	157	5/8	WB	56	6/18	WB white bass
WB	195	6/8	NP	59	6/17	NP northern pike
W	278	6/17	W	76	6/18	W walleye

TABLE 9. Average mercury levels in muscle, skin, and eyes compared between 16 fish species. Species code (Table 8). Lines connecting means indicate non-significant ranges. No lines indicate the means are significantly different. M = no. of fish. Mercury values are ppb (wet weight)

Muscle			Skin			Eyes		
Species code	Mean ppb	M/N	Species code	Mean ppb	M/N	Species code	Mean ppb	M/N
LES	79	6/17	C	21	5/15	C	22	5/8
BUF	88	7/21	LES	27	6/17	RCS	25	7/10
RCS	93	5/15	GS	30	5/14	LMB	31	5/9
C	98	5/15	BUF	30	7/21	WMB	34	5/8
SH	110	8/27	RCS	31	5/15	GS	37	5/6
BC	115	5/15	WMB	36	5/15	WB	37	5/15
WC	121	5/15	BC	37	5/15	BUF	37	7/17
GS	123	5/15	NP	40	6/18	BG	39	5/9
BG	129	5/15	BG	44	5/15	WC	39	5/9
NP	154	6/18	CC	50	5/15	BC	44	5/6
WMB	185	5/15	SH	50	8/21	SH	44	8/12
LMB	197	5/15	WC	58	5/15	LES	51	6/6
CC	198	5/20	LMB	68	5/15	CC	64	5/9
WB	306	6/18	WB	69	6/17	NP	70	6/15
FHC	327	5/15	FHC	70	5/15	FHC	79	5/9
W	603	6/19	W	86	6/15	W	84	6/18

TABLE 10. Average mercury levels in gills, brain, and stomach compared between 16 fish species. Species code (Table 8). Lines connecting means indicate nonsignificant ranges. No lines indicate the means are significantly different. M = no. of fish. Mercury values are ppb (wet weight)

Gills			Brain			Stomach		
Species code	Mean ppb	M/N	Species code	Mean ppb	M/N	Species code	Mean ppb	M/N
C	17	5/15	RCS	25	5/7	C	33	5/7
BUF	22	7/20	C	39	5/5	WC	53	5/8
BC	24	5/7	BUF	45	7/7	GS	53	5/5
RCS	28	5/15	FHC	57	5/7	BC	56	5/5
WC	33	5/11	LMB	62	5/5	RCS	63	5/7
GS	40	5/6	CC	65	5/5	WMB	71	5/10
WMB	44	5/10	SH	74	8/7	LES	75	6/6
LES	47	6/6	BG	77	5/5	BG	97	5/5
BG	50	5/10	WMB	77	5/5	LMB	102	5/14
SH	50	8/23	LES	78	6/6	BUF	106	7/17
NP	51	6/18	NP	79	6/6	NP	106	6/18
CC	57	5/14	BC	88	5/5	CC	106	5/15
LMB	79	5/14	GS	97	5/5	FHC	110	5/15
FHC	80	5/15	W	98	6/6	SH	113	8/7
W	129	6/18	WC	124	5/5	WB	231	6/16
WB	184	6/17	WB	133	6/6	W	234	6/18

TABLE 11. Average mercury levels in intestine, liver, and spleen compared between 16 fish species. Species code (Table 8). Lines connecting means indicate the means are significantly different. M = no. of fish. Mercury values are ppb (wet weight)

Intestine			Liver			Spleen		
Species code	Mean ppb	M/N	Species code	Mean ppb	M/N	Species code	Mean ppb	M/N
C	29	5/10	C	57	5/7	BUF	55	7/6
BUF	31	7/18	BUF	57	7/18	NP	61	6/7
BC	44	5/5	BC	106	5/5	LES	67	6/2
WC	54	5/6	WC	108	5/6	GS	79	5/1
GS	55	5/6	RCS	113	5/15	RCS	97	5/5
LES	57	6/6	NP	115	6/18	C	103	5/5
RCS	59	5/14	BG	121	5/5	BC	117	5/5
WMB	81	5/10	SH	130	8/10	LMB	131	5/6
BG	88	5/5	GS	161	5/5	WMB	140	5/2
CC	105	5/10	LES	177	6/6	WC	161	5/4
SH	121	8/11	WMB	185	5/9	FHC	170	5/9
NP	135	6/18	LMB	261	5/13	CC	175	5/6
LMB	155	5/13	CC	458	5/15	SH	255	8/5
FHC	175	5/14	FHC	518	5/14	BG	255	5/2
W	191	6/17	WB	534	6/13	WB	260	5/6
WB	216	6/17	W	642	6/18	W	277	6/12

TABLE 12. Average mercury levels in air bladder, gonad, and kidney compared between 16 fish species. Species code (Table 8). Lines connecting means indicate nonsignificant ranges. No lines indicate the means are significantly different. M = no. of fish. Mercury values are ppb (wet weight)

Air bladder			Gonad			Kidney		
Species code	Mean ppb	M/N	Species code	Mean ppb	M/N	Species code	Mean ppb	M/N
C	23	5/7	C	26	5/10	C	31	5/6
BUF	35	7/18	BUF	34	7/18	BUF	74	7/17
CC	44	5/12	WC	35	5/10	RCS	78	5/11
FHC	58	5/15	RCS	37	5/15	WC	103	5/5
NP	61	6/17	LES	39	6/2	LES	113	6/6
WC	62	5/3	BC	46	5/4	WMB	113	5/5
RCS	69	5/14	WMB	53	5/8	NP	115	6/17
WMB	86	5/2	BG	58	5/7	GS	118	5/4
SH	102	8/6	FHC	73	5/12	LMB	158	5/7
BC	106	5/4	NP	75	6/18	BC	167	5/4
W	111	6/18	CC	77	5/9	WB	180	6/6
LMB	124	5/4	GS	83	5/6	BG	207	5/5
GS	130	5/2	SH	101	8/9	SH	208	8/7
BG	144	5/1	LMB	117	5/8	CC	218	5/13
WB	202	6/4	W	156	6/18	FHC	351	5/14
			WB	339	6/4	W	419	6/17

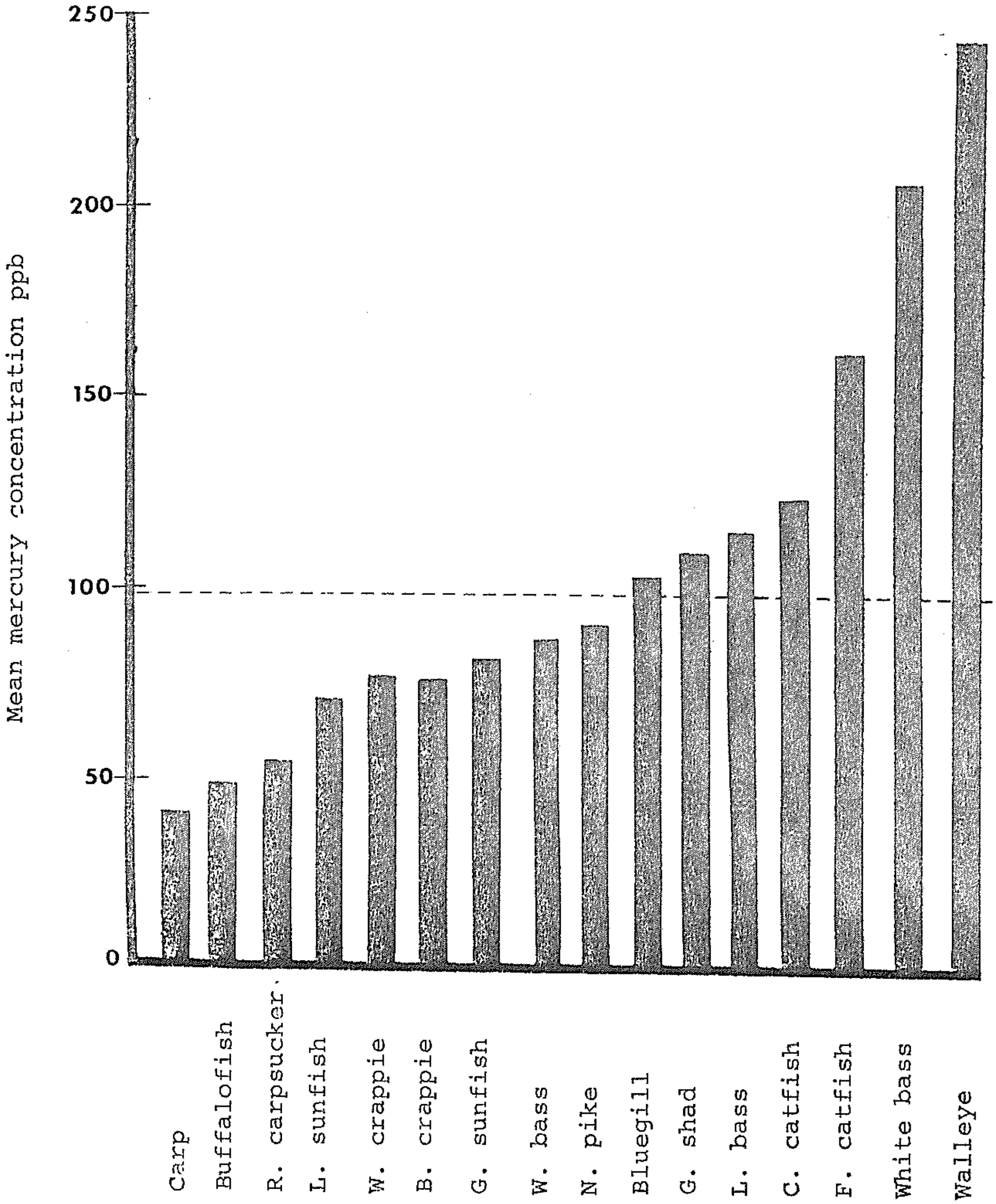

FIGURE 2. Average mercury concentration of all tissues for each species. Dashed line is the average mercury concentration of all tissues for all species.

sunfish < warmouth bass < northern pike < bluegill < gizzard shad < largemouth bass < channel catfish < flathead catfish < white bass < walleye. The five fish species with higher levels are the larger predatory types and of the large predators northern pike is not among them. Based on position in the trophic scheme and assuming bioamplification between trophic levels, only gizzard shad and northern pike appear to be out of place in the arrangement (Figure 2).

The relationship between mercury levels in tissues and the length and weight of individuals

Each tissue type for each fish species was evaluated in terms of whether there was a direct relationship between increasing mercury concentration and weight of fish. The rankings of individual fish weights are indicated from 1...n where 1 is the lightest fish and n is the heaviest. The mean mercury levels arranged from low to high by the Student-Newman-Keuls (SNK) test indicate a generally direct relationship for tissues where lowest concentration levels appear in fish 1 and increase progressively to highest levels in fish n.

For top predators (Tables 13-18) direct relationships are not indicated for any tissues in flathead catfish, northern pike, or white bass. However, a direct relationship is shown for tissue 4 (gills) in walleye (Table 14). The

TABLE 13. Average mercury levels in tissues of flathead catfish. Tissue no. refers to tissue type (Table 2). Lines connecting means indicate nonsignificant ranges. No lines indicate means are significantly different. Numbers above average values for each fish refer to weight, 1 = lightest, 5 = heaviest. Mercury values are ppb (wet weight)

5 Flathead catfish. Avg weight = 2,896 g. Range = 1,040-6,390 g. Avg length = 62 cm. Range = 52-73 cm.

Tissue no.	N	Mean	Avg mercury level for each fish				
14	15	37	10 (2)	40 (1)	42 (4)	43 (5)	50 (3)
5	6	57	17 (5)	30 (2)	63 (1)	68 (3)	150 (4)
10	15	58	25 (4)	34 (2)	40 (1)	71 (5)	119 (3)
1	15	70	26 (2)	28 (1)	37 (4)	72 (5)	189 (3)
11	12	73	36 (2)	61 (3)	70 (1)	71 (4)	114 (5)
3	9	79	41 (4)	51 (5)	65 (2)	85 (1)	158 (3)
4	15	80	31 (2)	36 (4)	53 (1)	83 (5)	217 (3)
6	15	110	50 (1)	70 (2)	119 (5)	120 (3)	290 (4)
13	8	157	66 (1)	77 (2)	127 (4)	192 (5)	239 (3)
9	9	170	50 (2)	68 (1)	145 (4)	201 (5)	222 (3)
7	14	175	74 (1)	96 (2)	180 (4)	237 (5)	291 (3)
2	15	327	143 (2)	153 (1)	165 (4)	552 (5)	622 (3)
12	14	351	82 (1)	187 (2)	263 (4)	548 (3)	585 (5)
8	15	518	110 (2)	129 (1)	517 (4)	670 (5)	1163 (3)

TABLE 14. Average mercury levels in tissues of walleye. Tissue no. refers to tissue type (Table 2). Lines connecting means indicate nonsignificant ranges. No lines indicate means are significantly different. Numbers above average values for each fish refer to weight, 1 = lightest, 6 = heaviest. Mercury values are ppb (wet weight)

6 Walleye. Avg weight = 2,664 g. Range = 1,910-2,035 g.
Avg length = 64 cm. Range = 60-67 cm.

Tissue no.	N	Mean	Avg mercury level for each fish					
			4	3	1	2	6	5
14	18	76	52	58	75	81	93	96
			3	4	1	2	5	6
3	18	84	40	57	81	99	108	114
			4	3	6	1	5	2
1	18	86	41	50	59	68	106	189
			4	3	2	6	1	5
5	6	98	26	62	109	115	121	153
			4	5	3	6	1	2
10	18	111	59	65	84	97	102	262
			1	2	3	4	5	6
4	18	129	61	77	82	104	175	271
			4	3	6	5	2	1
11	18	156	90	111	119	164	173	279
			4	3	6	5	2	1
7	17	191	62	113	148	205	280	341
			4	3	2	6	1	5
6	18	234	72	135	197	240	349	443
			4	3	6	5	1	2
9	12	277	113	268	273	312	317	639
			4	3	2	6	1	5
13	17	278	93	151	263	298	323	536
			4	3	2	1	6	5
12	17	419	111	241	446	468	525	730
			3	4	2	1	6	5
2	19	603	365	373	526	562	745	1119
			4	3	1	2	6	5
8	18	642	274	361	697	720	825	972

TABLE 15. Average mercury levels in tissues of northern pike. Tissue no. refers to tissue type (Table 2). Lines connecting means indicate nonsignificant ranges. No lines indicate means are significantly different. Numbers above average values for each fish refer to weight, 1 = lightest, 6 = heaviest. Mercury values are ppb (wet weight)

6 Northern pike. Avg weight = 1,718 g. Range = 479-2,700 g.
Avg length = 61 cm. Range = 42-74 cm.

Tissue no.	N	Mean	Avg mercury level for each fish					
1	18	40	2: 22	5: 23	6: 34	4: 39	3: 40	1: 78
4	18	51	1: 31	5: 40	6: 46	4: 51	2: 61	3: 80
14	18	61	1: 30	4: 45	5: 50	3: 59	2: 88	6: 92
9	7	61	4: 32	5: 33	1: 36	6: 48	2: 77	3: 100
10	17	61	1: 26	2: 34	4: 51	5: 62	6: 68	3: 114
3	15	70	1: 28	5: 39	4: 66	6: 79	2: 94	3: 108
11	18	75	1: 26	2: 43	4: 57	5: 65	6: 106	3: 155
5	6	79	2: 32	6: 37	4: 46	5: 73	1: 130	3: 153
6	18	106	1: 31	2: 77	4: 88	3: 129	6: 139	5: 174
12	17	115	5: 45	1: 46	4: 76	2: 87	6: 178	3: 233
8	18	115	4: 62	5: 64	1: 71	2: 76	6: 94	3: 125
13	11	131	1: 66	2: 85	4: 97	5: 110	6: 135	3: 238
7	18	135	1: 25	4: 55	3: 126	5: 150	6: 193	2: 260
2	18	154	1: 46	2: 74	4: 142	6: 150	5: 158	3: 356

TABLE 16. Average mercury levels in tissues of largemouth bass. Tissue no. refers to tissue type (Table 2). Lines connecting means indicate nonsignificant ranges. No lines indicate means are significantly different. Numbers above average values for each fish refer to weight, 1 = lightest, 5 = heaviest. Mercury values are ppb (wet weight)

5 Largemouth bass. Avg weight = 938 g. Range = 104-1,777 g.
Avg length = 38 cm. Range = 25-47 cm.

Tissue no.	N	Mean	Avg mercury level for each fish				
			1	5	3	4	2
3	9	31	19	22	25	47	47
			1	3	2	4	5
14	15	51	36	41	53	56	75
			2	3	1	5	4
5	5	63	42	54	61	66	86
			2	1	5	3	4
1	15	68	47	49	57	71	114
			2	1	3	4	5
4	14	79	22	24	98	102	129
			2	1	3	4	4
13	13	88	31	34	85	98	155
			1	2	3	4	5
6	14	102	29	41	108	111	198
			3	2	1	5	4
11	8	117	45	46	74	148	157
			2	5	3	4	
10	4	124	89	114	128	166	
			3	2	5	4	
9	6	131	62	63	121	123	
			1	2	4	3	5
7	13	155	45	121	157	159	218
			3	1	4	2	5
12	7	159	120	139	148	166	195
			1	2	3	4	5
2	15	197	63	148	225	261	287
			1	2	4	3	5
8	13	261	34	128	311	329	353

TABLE 17. Average mercury levels in tissues of channel catfish. Tissue no. refers to tissue type (Table 2). Lines connecting means indicate nonsignificant ranges. No lines indicate means are significantly different. Numbers above average values for each fish refer to weight, 1 = lightest, 5 = heaviest. Mercury values are ppb (wet weight)

5 Channel catfish. Avg. weight = 1,131 g. Range = 251-2,709 g.
Avg length = 46 cm. Range = 32-59 cm.

Tissue no.	N	Mean	Avg mercury level for each fish				
			1	2	3	4	5
14	15	43	18	26	44	50	47
			1	2	3	4	5
10	12	44	10	28	32	41	93
			2	3	1	4	5
1	15	50	18	36	50	73	76
			1	2	3	4	5
4	14	57	19	39	59	63	131
			2	4	1	3	5
3	9	64	18	45	65	78	93
			5	3	2	1	4
5	5	65	28	38	56	81	123
			2	3	4	1	5
11	9	77	19	19	28	58	171
			2	1	3	4	5
7	15	105	35	63	104	131	186
			2	1	3	4	5
6	15	106	33	60	90	149	200
			2	3	4	5	1
13	8	111	28	76	76	146	193
			1	4	2	3	5
9	6	175	121	140	145	169	239
			2	1	3	4	5
2	15	198	62	131	147	188	476
			2	3	1	4	5
12	13	218	55	143	161	186	472
			2	1	4	3	5
8	13	458	113	134	373	626	819

TABLE 18. Average mercury levels in tissues of white bass. Tissue no. refers to tissue type (Table 2). Lines connecting means indicate nonsignificant ranges. No lines indicate means are significantly different. Numbers above average values for each fish refer to weight, 1 = lightest, 6 = heaviest. Mercury values are ppb (wet weight)

6 White bass. Avg weight = 483 g. Range = 46-1,332 g.
Avg length = 29 cm. Range = 17-42 cm.

Tissue no.	N	Mean	Avg mercury level for each fish					
3	12	37	18 (2)	22 (4)	25 (1)	35 (5)	41 (6)	83 (3)
14	18	56	31 (2)	39 (1)	61 (5)	64 (4)	67 (6)	76 (3)
1	17	69	29 (2)	52 (1)	66 (6)	68 (4)	82 (3)	103 (5)
5	6	133	58 (6)	61 (5)	109 (2)	124 (1)	159 (4)	289 (3)
12	6	180	45 (1)	88 (3)	111 (2)	220 (4)	303 (5)	312 (6)
4	17	184	26 (2)	42 (1)	79 (6)	142 (3)	261 (5)	316 (4)
13	8	195	42 (2)	85 (1)	163 (6)	268 (4)	295 (3)	379 (5)
10	4	202	138 (4)	151 (6)	170 (2)	347 (5)		
7	13	216	50 (2)	62 (1)	184 (4)	240 (3)	253 (5)	302 (6)
6	16	231	28 (1)	38 (2)	173 (6)	274 (3)	284 (5)	286 (4)
9	6	260	113 (1)	173 (6)	183 (2)	308 (3)	314 (4)	469 (5)
2	20	306	58 (2)	94 (1)	347 (5)	358 (4)	359 (3)	583 (6)
11	8	339	96 (3)	100 (1)	140 (4)	230 (6)	840 (5)	
8	13	534	131 (1)	144 (2)	356 (4)	441 (3)	657 (6)	885 (5)

two other top predators, largemouth bass (Table 16) and channel catfish (Table 17) do show a few tissues where such a relationship exists. For example, largemouth bass shows tissue 2 (muscle) and tissue 6 (stomach) with lowest mercury concentrations in fish one higher levels increasing in order to fish five. Channel catfish shows this order for tissue 4 (gills), tissue 10 (air bladder), and tissue 14 (bone).

Several tissues within each species however, are only slightly out of order such as tissue 8 (liver) in white bass where fish number three and four are reversed in position. Tissues such as this one, and others showing similar patterns, as well as those which showed a clearly direct relationship were then subjected to correlation analysis to determine the degree of association between mercury level and both weight and length of fish. Treated in this manner some tissues revealed a correlated association with weight or length not indicated by the SNK test. This occurred where there was little difference in the weights or mercury levels of the fish whose positions were reversed. For example, tissue 8 (liver) in white bass (Table 18) showed mercury concentration correlated with both length and weight (Table 19). Similarly, tissues which appear in direct order of fish weight, 1...n, with corresponding ordered increases in mercury concentrations may not show significant correlations. For example, tissue 2 (muscle) in largemouth bass does not show a significant correlation (Table 19) even though the mercury level is shown to increase in order from fish one to fish five (Table 16).

Flathead catfish tissues did not show correlations between mercury level for either length or weight in spite of the large difference in the range of lengths (52-73 cm), and the large weight range (1,040-6,390 g). The important correlations shown by other top predators are given in (Table 19).

Similar treatment of the data for small predators and nonpredators revealed few relationships. The significant relationships include length:mercury correlations for gonad and kidney in longear sunfish, kidney and liver in shad, gill and heart in green sunfish, and spleen in warmouth bass and white crappie. Significant weight and mercury correlations were shown by brain in river carpsucker, liver in shad, and for spleen in warmouth bass, bluegill, and white crappie.

Some generalizations which are evident after correlation analysis are (1) significant mercury:length and weight relationships are not necessarily related to trophic level; (2) a consistent pattern of progressive and significant

TABLE 19. Correlation coefficients between mercury concentration in various tissues and length and weight of four top predaceous fish

Sample size, species and tissue	Correlation coefficients[1] Hg:length	Hg:weight
5 Largemouth bass		
Muscle	.843	.827
Stomach	.814	.936
Spleen	.967	.816
Liver	.944	.865
5 Channel catfish		
Muscle	.886	.955
Stomach	.921	.851
Intestine	.952	.958
Liver	.948	.860
Kidney	.926	.847
Gills	.901	.984
Bone	.994	.984
Air bladder	.936	.979
6 White bass		
Muscle	.885	.852
Kidney	.937	.894
Liver	.944	.839
6 Walleye		
Gills	.526	.852

[1]Correlation coefficients required for significance at P = .05 are .878 for a sample size of 5 and .811 for a sample size of 6.

accumulation of mercury in all tissues of large predators with increasing weight, length or both, does not occur; (3) white bass and channel catfish are both good indicator species for length and weight mercury relationships if muscle is used as an indicator tissue; (4) white bass is the best indicator species for both mercury:length and weight relationships for muscle, liver, and kidney, while channel catfish is the best indicator species for mercury: length relationships; (5) fish species at lower trophic levels have little utility as indicators of mercury:length and weight relationships for muscle, but may have some value if spleen is used as an indicator tissue.

Perhaps a larger sample size for each species with a greater number of distinct size classes (length and weight) are needed to establish unquestionable evidence for mercury: length and weight relationships, particularly for those species showing near significant correlations such as largemouth bass.

There are only a few investigators who have clearly reported significant or general mercury:length and weight relationships. Some of them also indicate that such relationships are not applicable to other situations. For example, Johnels et al. (1967), and Johnels and Westermark (1969) clearly indicate a linear relationship of mercury level to both weight and length, in pike muscle which contained concentrations below 1,000 ppb. They do not show this to be true at higher levels. In fact they state that under highly polluted conditions extreme variations in mercury levels occur resulting in no relationship in size. Tejning (1967) indicates a general relationship between mercury and weight in pike muscle, but states that the relationship is not significant. He compared mercury levels in 131 fish from 31 locations and with weights varying from 0.4 kg to 9.3 kg. These fish were generally from polluted areas and many had concentrations above 1,000 ppb. Hannerz (1968) does not report any significant relationship between weight and mercury level, but reports negative correlations for mercury: length relationships in several tissues of pike including muscle and liver. In addition, he reports extreme variation within the same and different size pike and cod from similar experimental situations. Kidd and Potter (1972) indicate a linear relationship between weight and mercury level in muscle of largemouth bass taken from Lake Powell. Johnels et al. (1967) demonstrated a linear increase in mercury level with age in pike and Bache, Gutenmark, and Lisk (1971) demonstrated this for lake trout.

Personally I believe that an increase in mercury concentration as a function of length or weight is more evident in fish taken from natural waters than from experimental situations. This is evident from the contradictory findings of Hannerz (1968) versus Johnels and Westermark (1969). The evidence of both these investigators suggests that concentration and duration of exposure to mercury change these relationships, and therefore the correlation may be more or less pronounced in fish of the same species from different localities which vary in mercury concentration.

Some of the observations on pike by Johnels and Westermark (1969) show some patterns of mercury levels related to weight which are similar to those reported in this study. These include the following. For mercury levels below 200 ppb less variation occurs in all tissues among individuals regardless of weight or species. A slight increase sometimes occurs with weight, but when the average mercury level is higher the relationship to weight is usually more pronounced. The latter is particularly noticeable in comparisons between individuals with large weight differences and for tissues where mercury level was correlated with weight or length.

Reported Investigations Related to this Study

There is much evidence supporting the observation that liver, kidney, and muscle are regularly found with higher mercury concentrations than other tissues in fish. The reported evidence which follows will become important when explaining possible reasons for mercury levels in fish from Elephant Butte Lake.

The evidence comes from one type of experiment done in ponds or tanks stressed with specific amounts of mercury in the water, food or both. These have been performed by Hannerz (1968) using pike and cod, and Rucker and Amend (1969) using rainbow trout, chinook, and sockeye salmon. Other investigations of this nature have been performed by Tsuruga (1963), and by Gomez and Shields (1972). These experiments indicate a progressive increase in tissue mercury concentration with duration of exposure until high levels are reached by all tissues.

The experiments also demonstrated a time lag between tissues in attaining high mercury levels. This suggests that there is a specific pathway for mercury uptake and subsequent tissue distribution. From water the suggested pathway is from gills to blood to liver to kidney to muscle. The suggested pathway from ingested mercury is from intestine to blood to liver to kidney to muscle.

Other investigations which involve determination of mercury concentrations in fish collected from their natural habitats generally reflect the same trends found in this investigation. Matida and Kumada (1969) found concentrations above 1,000 ppb in a large number of tissues. Their results were based on fish from polluted Japanese waters. The order of tissues from low to high concentration were muscle, kidney, and liver.

Many other investigators including Ulfvarson (1969); Tejning (1967); Joselow, Goldwater, and Weinberg (1967); and Dustman, Stickel, and Elder (1972) confirm that liver and kidney are the principal organs which accumulate and retain mercury in fish and other animals. Other investigations have also shown that muscle may retain methylmercury for long periods of time. Investigations by Wood (1972) show that the biological half-life of methylmercury in muscle of marine eels is about 1,000 days. Bails (1972) reports a half-life of 400 days for methylmercury in pike and perch muscle.

Other investigations involving mercury concentrations in fish from natural habitats reveal mercury levels in muscle which are often greater than those found in Elephant Butte fish. For example, the investigations of Johnels and Westermark (1969), and Johnels et al. (1967) show a range of mercury in pike muscle from 850-9,800 ppb. Kidd and Potter (1972) show a range of 181-339 ppb for carp muscle, a range of 56-127 ppb for muscle of bluegill, and a range of 192-653 ppb in muscle of largemouth bass. Only the range given for bluegill is less than that found in these same fish species taken at Elephant Butte Lake.

Greig and Seagran (1972) report the average mercury levels or ranges of concentrations in fish taken from Lake St. Clair, Lake Huron, and Lake Erie. From Lake St. Clair they report a mean level of 600 ppb in carp muscle, and a range of 1,900-2,500 ppb in walleye. Both of these fish species from Elephant Butte Lake displayed lower concentrations. From Lake Huron they report mean levels of 350 ppb in walleye muscle, but state that one specimen displayed a concentration of 6,800 ppb. The mean of 350 ppb is lower than the mean value of 603 ppb found in walleye from Elephant Butte Lake, while the higher value is much greater. From Lake Erie they report a range of levels from 900-2,000 ppb in pike muscle and a range of 300-1,000 ppb in white bass. Pike from Elephant Butte Lake did not approach the lower value given. White bass from Elephant Butte Lake displayed a mean value of 306 ppb and a range of 58-583 ppb which is also less than the range for Lake Erie fish. In the Lake Erie investigation the average level in channel catfish was approximately half of that found in walleye, while in gizzard shad it was approximately one-tenth. In these same species from Elephant Butte Lake the average levels in white bass was approximately one-half of the mean for walleye, while the mean for gizzard shad was approximately one-sixth that of walleye.

Kleinert (1972) determined mean mercury levels of 190 ppb in muscle for all Wisconsin fish. If mercury levels in muscle of all Elephant Butte Lake fish species are similarly computed the mean concentration is 183 ppb.

The general concern over variations in mercury levels and tissue distribution patterns in fish from experimental versus natural situations is related to the detection of various degrees of mercury pollution in aquatic environments. Generally, experimental situations are analogous to highly polluted environments where relatively high mercury levels are maintained in water and food. Consequently, high mercury uptake occurs by both routes.

Evidence supporting mercury uptake from water via the gills is given by Hannerz (1968). He reports that the most important route of mercury accumulation seems to be directly from the water through exposed epithelial tissue. Lindahl and Hell (1970) state that "For freshwater fish the main route of entry seems to be the gills." In addition, Rucker and Amend (1969) show immediate higher mercury levels of up to 18,000 ppb in the gills within two hours after exposure. These investigators have also shown that mercury can be accumulated to high levels through the food source.

The question to be considered now is "what is the most important route of mercury uptake by fish species from Elephant Butte Lake?" In answer to this question I propose the following hypothesis. In natural situations which are relatively unpolluted higher mercury uptake and subsequent accumulation in fish is more dependent on accumulated mercury present in foods than on mercury present in water. Rationale for this hypothesis is that low mercury levels in water alone would not be great enough to allow high accumulation and higher trophic level species will show higher mercury levels which reflect levels in the food source. This hypothesis does not deny that some mercury uptake from water does occur and it does not deny differences in metabolic abilities to accumulate or eliminate mercury.

Higher mercury levels in larger predaceous fish species from Elephant Butte Lake suggest that mercury accumulation is more related to food ingested than to mercury in water. The evidence from this study does not confirm that water is the main source of mercury. If the water was the main source, high mercury concentrations would be expected in gills and skin. Low mercury levels were displayed by both skin and gills of all fish. In addition, fish showing higher mercury levels in muscle also displayed higher mercury levels in stomach and intestinal tissue than in skin or gills. Other evidence from Elephant Butte Lake which suggests that water is not the primary source of mercury includes the following: (1) the shallow more turbid water at the inlet third of the lake is significantly higher in mercury than water near the dam; (2) nonpredators spend more time grazing in the shallow turbid water, yet show lower mercury levels than predators; (3) gills and skin generally show significantly lower levels of mercury than other tissues, yet gill tissue levels are especially lower in nonpredators; (4) freshwater mussels are always found in shallow areas where high turbidity is common, yet mercury values in their tissues are low; and (5) gills and exoskeleton display low mercury levels in crayfish. High mercury levels would be expected in gills and possibly in the softer exoskeleton found in smaller specimens if mercury was largely derived from the water.

Mercury Levels in Other Species

Turtles

Examination of Table 20-21 reveals that the mercury distribution patterns in tissues of the hard-shell turtle (*Pseudemys scripta*) are similar to those in the soft-shell turtle (*Trionyx spinifer*).

In both species no clear significant differences in mercury levels exist between tissues except for tissue 8 (liver), and tissue 12 (kidney), both of which contain mercury levels greater than 500 ppb. Mercury levels for these tissues are neither significantly different from one another, nor between these species.

Mercury levels above 500 ppb occur in some tissues of individual specimens of the soft-shell turtles. For example, tissue 9 (spleen), tissue 3 (eyes), and tissue 2 (muscle). In addition, tissue 12 (kidney) and tissue 8 (liver), exhibit mercury levels above 1,000 ppb in some individuals.

The hard-shell turtle does not exhibit concentrations above 500 ppb in any individuals except for tissue 8 (liver), and tissue 12 (kidney), both of which may display levels greater than 1,000 ppb in some individuals.

No direct relationship between mercury concentration and weight is shown for these species. However, the weight classes were not very different. The heaviest two specimens of the hard-shell turtle and the three heaviest soft-shell turtles frequently exhibited higher levels.

A comparison of the mercury levels in individual tissue types between the two species revealed significantly higher levels in the soft-shell turtle for all tissues except stomach, intestine, liver, spleen, kidney, bone, and urinary bladder.

A comparison to mean values for all species of fish revealed similar mercury levels and tissue distribution

TABLE 20 Average mercury levels in tissues of soft-shell turtles. Tissue no. refers to tissue type (Table 2). Lines connecting means indicate nonsignificant ranges. No lines indicate means are significantly different. Numbers above average values for each turtle indicate weight, 1 = lightest, 5 = heaviest. Mercury values are ppb (wet weight)

Tissue no.	N	Mean	Avg mercury level for each turtle				
14	15	112	3 64	4 107	5 115	1 132	2 140
10	15	175	3 110	1 165	5 165	4 205	2 230
7	15	190	1 142	3 172	2 190	5 206	4 237
6	15	192	2 91	1 139	5 140	3 228	4 363
4	15	219	1 126	2 144	3 192	5 305	4 325
5	5	226	3 178	2 200	4 217	5 254	1 270
1	15	244	2 211	1 227	3 254	4 264	5 270
13	13	244	1 169	2 218	5 251	3 289	4 295
15	5	245	2 201	1 237	5 241	3 261	4 287
11	11	257	2 186	1 222	3 252	4 278	5 329
9	5	337	1 132	2 207	4 376	3 448	5 523
3	5	351	2 229	4 273	3 340	1 359	5 554
2	15	359	2 256	4 280	1 283	3 396	5 580
12	11	839	1 296	2 422	5 977	3 1058	4 1374
8	15	893	1 213	2 489	4 1135	5 1309	3 1318

5 Soft-shell turtles (*Trionyx spinifer*). Avg weight = 432 g.
Range = 298-538 g. Avg length = 17.5 cm. Range = 16-19 cm.

TABLE 21. Average mercury levels in tissues of hard-shell turtles. Tissue no. refers to tissue type (Table 2). Lines connecting means indicate nonsignificant ranges. No lines indicate means are significantly different. Numbers above average values for each turtle indicate weight, 1 = lightest, 5 = heaviest. Mercury values are ppb (wet weight)

Tissue no.	N	Mean	Avg mercury level for each turtle				
			2	1	3	5	4
10	20	57	15	34	55	79	89
			2	1	3	5	4
14	15	83	26	39	47	68	237
			2	1	5	3	4
5	5	96	57	70	73	104	177
			2	1	3	5	4
3	5	106	52	72	118	126	163
			2	1	3	5	4
4	15	116	42	47	106	151	233
			2	1	3	5	4
1	15	125	59	91	136	143	196
			1	2	5	3	4
13	6	145	41	90	153	177	253
			1	2	3	5	4
6	15	145	64	67	146	203	245
			2	1	5	3	4
15	5	149	37	93	148	183	286
			1	2	3	5	4
7	15	157	70	82	159	170	306
			2	1	4	3	5
2	15	172	98	107	119	254	284
			1	3	2	5	4
11	6	193	81	182	198	203	289
			1	2	3	5	4
9	5	208	100	140	213	257	328
			1	2	3	5	4
12	8	783	186	210	532	581	1823
			1	2	4	5	3
8	15	792	318	401	824	1033	1385

5 Hard-shell turtles (*Pseudemys scripta*) Avg weight = 402 g.
Range = 206-552 g. Avg length = 15.5 cm. Range = 13-19 cm.

patterns. The concentrations in liver and kidney were significantly higher in turtle species than in fish and a greater range of mercury levels occurred in these tissues.

When turtle weights are compared to fish weights it can be observed that larger predaceous fish are much heavier, yet mercury levels of turtles are comparable or sometimes exceed those found in some fish tissues. Both turtle species are largely carnivorous and feed directly on live fish. This enables them to accumulate mercury from fish of all species. In addition, both species are scavengers and may therefore be taking in more methylmercury from dead and decaying fish. Jensen and Jernelöv (1969) demonstrated higher methylmercury content in decaying fish then in fresh specimens. Hannerz (1968) demonstrated that methylmercury was more rapidly accumulated than other mercurials. Therefore, higher levels might be expected in scavengers. The soft-shell turtle is considered to be the more carnivorous of the two species and does exhibit higher overall levels than the hard-shell turtles. The soft-shell turtle, as an adult, also feeds on plant material and is found in more turbid waters (Stebbins, 1954). These behavioral habits may account for differences in mercury concentrations between the two species.

Crayfish

Examination of Table 22 reveals that among crayfish tissues only tissue 1 (abdominal muscle) is significantly higher in mercury concentration than other tissues. No tissue type exhibits an average level equal to or greater than 100 ppb. Variations in concentration occur with size and weight in all tissues, but they do not show a direct order of increase in level with either weight or length. The range of 58-152 ppb (average 90 ppb) for tissue 1 (abdominal muscle) is clearly similar to mercury levels in nonpredator and smaller predator fish muscle. The higher value of 152 ppb is comparable to the average value of 154 ppb in muscle of northern pike.

Because of the large gill area which crayfish expose to the water and because of their role as scavengers, it would appear that higher mercury levels might be expected. On the other hand, they generally were found to inhabit less turbid water and therefore were subject to less exposure to mercury adsorbed to suspended particles.

Takeuchi (1972) reports levels ranging from 1,000-36,000 ppb for lobster and crab taken from mercury polluted Japanese waters, indicating that similar crustaceans have the ability to accumulate high levels.

The low levels in crayfish seem to suggest that the mercury concentrations required for greater accumulation are not present or maintained in either the water or their diet.

TABLE 22. Average mercury levels in tissues of crayfish. Tissue no. refers to tissue type (Table 2). Numbers above mean values for each crayfish refer to weight, 1 = lightest, 10 = heaviest. Lines indicate nonsignificant ranges. Mercury values are ppb (wet weight)

Tissue no.	N	Mean	Avg mercury level for each crayfish									
			2	3	1	5	4					
5[1]	25	16	10	14	17	18	20					
			6	2	1	5	4	3	8	9	10	7
4	36	25	9	13	13	15	15	19	20	32	38	70
			6	4	8	5	2	1	10	3	7	9
3	19	34	6	10	18	22	23	26	27	36	56	61
			5	10	8	1	6	2	3	4	7	9
2	16	34	15	23	24	30	31	33	33	34	46	56
			1	3	6	5	2	8	9	4	10	7
1	30	90	58	59	62	63	64	69	89	112	115	152

[1]Entire small crayfish. Numbers above average values for each crayfish indicate the following: 1 = 3 crayfish 1 g, 2 = 7 crayfish 1.5-1.7 g, 3 = 7 crayfish 2.0-3.0 g, 4 = 1 crayfish 4 g, 5 = 2 crayfish 5 g. Average weight of all other crayfish = 23 g, range = 14-40 g. Average length = 10 cm, range 9-13 cm

In addition, it may be that their mercury excretory mechanisms rapidly release mercury back into the water.

Freshwater mussel

Examination of Table 23 reveals no clearly significant differences in mercury level related to location for either visceral mass or shell, but the average level of 26 ppb in visceral mass was found to be significantly higher than the 20 ppb displayed by shell. Mercury values are generally lower than found in all other materials except water and crayfish weighing less than 5 grams. The range of 16-43 ppb for visceral mass and a range of 18-25 ppb for shell is also small.

Even though this invertebrate species showed low levels, the values appear reasonable when considering that levels in water averaged only 0.027 ppb.

Burton and Leatherland (1971) report average mercury values of 80 ppb for a similar but larger bivalve (*Mercenaria mercenaria*) from natural waters containing 100 ppb mercury in Southhampton, England. The bottom sediments were also higher in mercury than those at Elephant Butte Lake. Bails (1972) reports levels of 200 ppb for freshwater mussel in Lake St. Clair.

The ability of bivalve mollusks to accumulate high levels is shown by Tsugura (1963). He exposed short-neck

TABLE 23. Average mercury levels in visceral mass and shell of freshwater mussel (*Anodonta* sp.). Lines indicate nonsignificant ranges. Location no. refers to grid no. (Figure 1). Mercury levels are ppb (wet weight)

Location no.	112	35	63	32	120	76	74	23	60	85	87	10	79	91
Visceral mass N	5	5	5	5	5	5	5	5	5	5	4	5	5	5
Mean mercury ppb	16	20	20	20	21	22	23	23	29	30	31	32	38	43
Location no.	60	91	120	74	112	10	63	87	85	76	35	32	23	79
Shell N	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Mean mercury ppb	18	18	18	19	19	19	20	20	20	20	21	21	21	24

Grand mean
Visceral mass = 26 ppb[1]

Grand mean
Shell = 20 ppb

[1]Significantly higher than shell *P* = .05

clam and sea mussel to levels of 30-500 ppb mercuric chloride in water and found levels up to 33,200 ppb in sea mussel after four days and levels up to 9,500 ppb in short-neck clam in eight days. This ability to concentrate mercury is further demonstrated by Matida and Kumada (1969), Irukayma (1966), and Ui (1966). They report levels of mercury in bivalves ranging from 480-12,300 ppb in polluted areas in Japan. The findings of these investigators suggests that freshwater mussel may be good indicators of high mercury pollution levels.

The low levels in freshwater mussel from Elephant Butte Lake suggests that the low mercury levels in water and in organisms making up their diet are inadequate for accumulation.

Zooplankton

The mercury levels determined for zooplankton are relatively low having a mean of 69 ppb and a range of 48-91 ppb.

The organisms were filtered only from the deeper, clearer waters of the lake as high turbidity in other areas did not permit collection of silt-free material.

These low values probably reflect the low levels found in the water at Elephant Butte Lake. Relatively higher values (5-60 ppb) in water can be lethal. Evidence by

Anderson (1948) demonstrated that levels of 60 ppb mercuric chloride added to Lake Erie water were lethal to Daphnia magna. The U. S. Geol. Surv., Prof. Paper 713 gives lethal mercury values in water of 5-20 ppb for two Daphnia species (1970).

The reported higher levels by other investigators can be due partly to adsorption.

Copeland (1972) reports mercury levels of 440 ppb for samples collected at Lake Michigan. He states that Lake Michigan is relatively free of mercury pollution.

Nonvascular plants

Examination of Table 24 displays mercury levels in nonvascular plants (mixed algae and bryophytes) from five locations and for phytoplankton collected by filtering water from many locations. The range is 87-947 ppb (dry weight) with an average of 277 ppb.

The highest value is not believed to be representative of mercury levels in these species. The average value of 109 ppb for phytoplankton and also for organisms from the other four locations might be more realistic considering the low mercury levels in the water. Higher levels of mercury in the water (6-60 ppb) can be lethal. Evidence given by Ukeles (1962) indicate mercury levels of 6-60 ppb are lethal to some algae species. Harris, White, and McFarlane (1970) also demonstrated that levels of 50 ppb are lethal to several marine and freshwater phytoplankton species.

Copeland (1972) gives an average dry weight value of 2,200 ppb for algae from Lake Michigan. He states the wet weight value is approximately 80% less. He then gives a wet weight value of 300 ppb. If the highest value of 947 ppb in this study is similarly converted, it would be 189 ppb. Other samples as well as the average of 277 ppb would all be less than 100 ppb on a wet weight basis.

Mercury Levels in Other Material

Organic debris

Table 24 indicates a range of mercury levels from 52-195 ppb and an average of 95 ppb for organic debris. The average is lower than that of 382 ppb given by Kidd and Potter (1972) for similar material collected at Lake Powell. This suggests less initial mercury in plant material for the Elephant Butte source than in the source for Lake Powell. There is some evidence that mercury in this material may be due in part to adsorption from water. Analysis of organic material from Lake Powell by Standiford (1973) revealed higher levels in submerged plants than in the same species before submergence. Hannerz (1968) also demonstrated that submerged parts of reeds contained 10-20 times higher mercury levels than emergent parts.

TABLE 24. Average mercury levels in nonvascular plants and organic debris. Lines indicate nonsignificant ranges. Location no. refers to grid no. (Figure 1). Mercury values are ppb (dry weight)

Nonvascular plants			Organic debris		
Location no.	N	Mean	Location no.	N	Mean
74	10	92	86	5	52
3	10	93	82	15	55
2	35	117	91	10	76
86	15	135	60	10	89
80	10	947	1	15	195
		$\bar{X}$ = 277			$\bar{X}$ = 93
Phytoplankton[1] (mixed locations)	4	109			

[1]Range = 87-133 ppb

Bioamplification

The mercury levels particularly in tissues of larger predaceous fish and turtle species verify bioamplification. This is best illustrated by describing food habits. Specific investigations on food habits of some Elephant Butte fish species have been conducted by personnel from New Mexico State University, Las Cruces, New Mexico, fisheries section. These studies indicate that gizzard shad is the major food source of large predators including walleye, channel catfish, white bass, largemouth bass, and northern pike. Flathead catfish feeds principally on carp. Nonpredaceous fish including river carpsucker, buffalofish, and carp feed primarily on organic debris whereas shad consumes phytoplankton, zooplankton, and organic debris. Small predators have not been studied specifically at Elephant Butte Lake, but personal observation of the stomach contents of bluegill and other small members of the sunfish family reveal mostly crayfish. Koster (1957) confirms that crustaceans are among the major food items consumed by these species.

Investigators who have conducted life history studies on fish agree that food ingested by any species is variable and may depend on size of fish, location, and season. Specific preferences may exist for various foods, but items consumed are probably determined by abundance and availability.

The mercury levels in muscle of all fish species from Elephant Butte Lake display concentration factors relative to food which increase gradually from lower fish species to higher predators with two exceptions. Longear sunfish appears out of place and should be found nearer other members of this genus and the position of northern pike and warmouth bass should be reversed (Table 25). Concentration factors of one or less than one indicate that no amplification has occurred in three lower fish species.

The concentration factors for both turtle species (Table 26) are also comparable to those given for the larger predaceous fish. The concentration factors for invertebrate species (Table 26) are similar to those found in lower fish species with the exception of mussels and small crayfish.

Further evidence that mercury bioamplification is diet related are the low mercury levels in water and the large concentration factors relative to it. These are larger than those given by Hannerz (1968) and are too large to assume that the mercury accumulation in tissues could be due primarily to mercury in water. Hannerz (1968) states that when mercury uptake from water is known, and when high concentration factors result, this would mean very rapid elimination. If rapid elimination is the case, then the

TABLE 25. Mercury concentration factors for muscle of 16 fish species relative to mercury in water, sediment, and major food component. M = muscle, S = sediment, Cf = concentration factor

Species	Mean Hg ppb	Cf = Hg in M / Hg in water	Cf = Hg in M / Hg in S	Cf = Hg in M / Hg in food
Longear sunfish	79	2,929	1.40	.88
Buffalofish	88	3,251	1.55	.93
Rivercarpsucker	93	3,448	1.65	.99
Common carp	98	3,625	1.73	1.03
Gizzard shad	110	4,088	1.95	1.21
Black crappie	115	4,259	2.03	1.27
White crappie	121	4,444	2.13	1.33
Green sunfish	123	4,537	2.16	1.35
Bluegill	129	4,785	2.29	1.43
Northern pike	154	5,714	2.73	1.40
Warmouth bass	185	6,851	3.27	2.05
Largemouth bass	197	7,296	3.49	1.78

TABLE 25. continued

Species	Mean Hg ppb	$Cf = \frac{\text{Hg in M}}{\text{Hg in water}}$	$Cf = \frac{\text{Hg in M}}{\text{Hg in S}}$	$Cf = \frac{\text{Hg in M}}{\text{Hg in food}}$
Channel catfish	198	7,318	3.50	1.79
White bass	306	11,329	5.41	2.77
Flathead catfish	327	12,107	5.79	3.34
Walleye	603	22,314	10.66	5.46

Table 26. Mercury concentration factors for muscle of two turtle species, crayfish abdominal muscle, visceral mass of mussels, and zooplankton relative to mercury in water, sediment, and major food component, and for nonvascular plants (attached algae and bryophytes), and phytoplankton relative to mercury in water and sediments. T = tissue, S = sediments, Cf = concentration factor

Species	Mean Hg ppb	$Cf = \frac{Hg\ in\ T}{Hg\ in\ water}$	$Cf = \frac{Hg\ in\ T}{Hg\ in\ S}$	$Cf = \frac{Hg\ in\ T}{Hg\ in\ food}$
Hard-shell turtle	172	6,381	3.04	2.06
Soft-shell turtle	359	13,277	6.35	3.24
Crayfish	90	3,340	1.60	1.08
Zooplankton	69	2,555	1.22	.63
Mussel	26	970	.46	.29
Nonvascular plants	277	10,252	4.90	
Phytoplankton	109	4,037		

relatively high mercury levels in higher predaceous fish would not have occurred.

Observation of the trophic level scheme (Figure 3) reveals that the mercury concentrations of lower trophic species are generally lower than those at higher trophic levels. Some exceptions which are not readily explained do occur. For example, higher mercury levels might be expected in mussels which strain phytoplankton from the water, and in nonpredaceous fish which utilize organic debris. These exceptions might be explained by intermittent exposure to mercury in the known food source. For example, organic debris is not abundant at Elephant Butte Lake, particularly during periods of drawdown. During these periods nonpredaceous fish possibly utilize whatever food source is more available to them. They are known to scoop up materials in sediments and are also known to exhibit omnivory. Similarly, phytoplankton availability for mussels is almost nonexistent when water levels have receded below the physical limits of their natural habitat. During these periods, the sand and mud flats, where mussels are found, may almost dry up. When these areas are in such a state mussels probably utilize bacteria and other particulate matter to a greater extent than would normally be expected.

Several other explanations for accumulation of mercury

FIGURE 3. Trophic level scheme showing the relationship of mercury levels and concentration factors to Elephant Butte Lake biota. Mercury values for fish, turtles, and crayfish are levels in muscle; values for mussels are for levels in visceral mass; values for zooplankton and phytoplankton are for entire collections of organisms; values for attached algae and plants are for combined masses of filaments. Concentration factors for animals are based on major food component, and for plant material they are based on levels in the water. ppb = $\frac{\text{mean}}{\text{range}}$ and Cf = concentration factor.

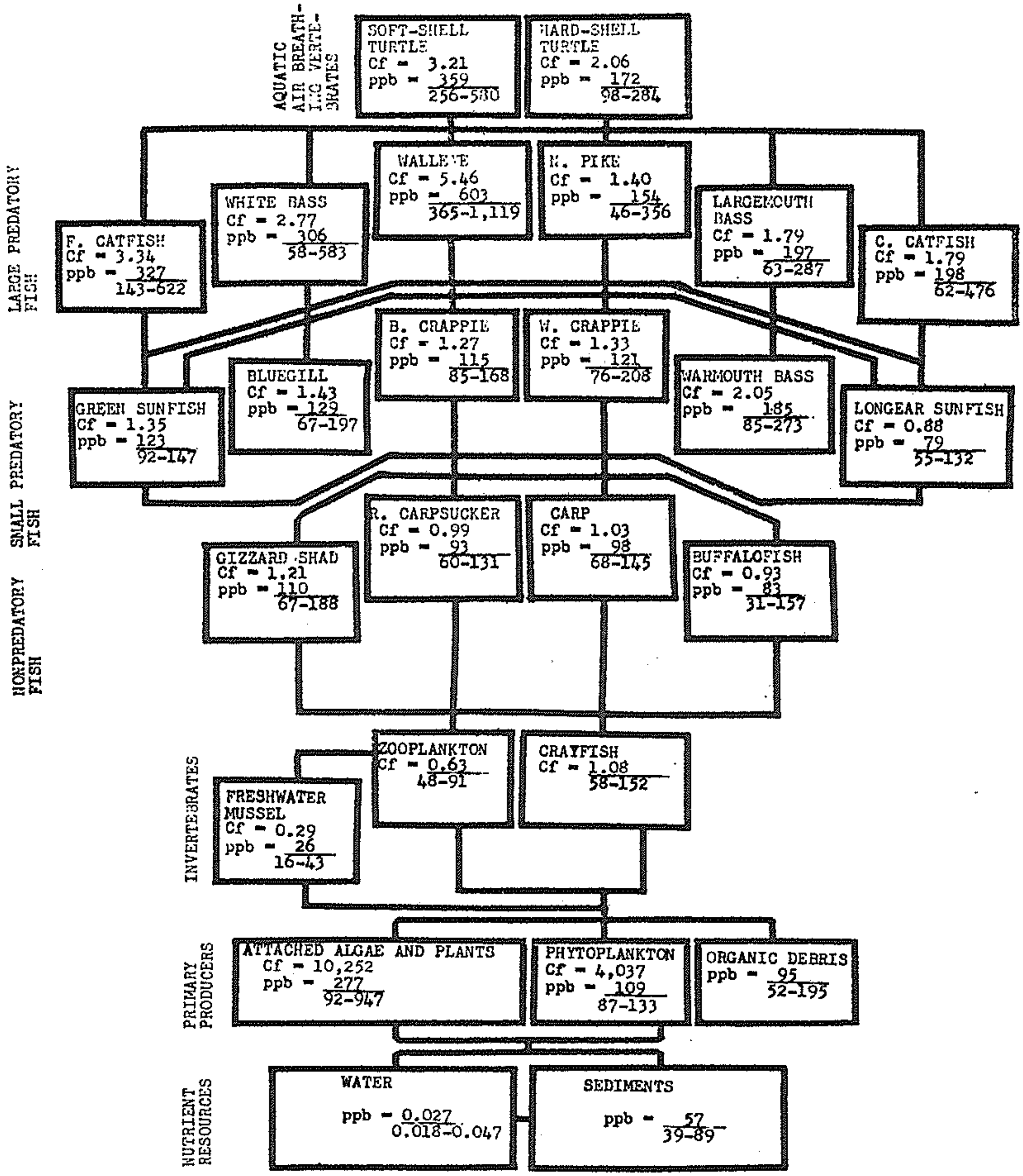
AQUATIC AIR BREATHING VERTEBRATES
SOFT-SHELL TURTLE Cf = 3.21 ppb = 359 / 256-580
HARD-SHELL TURTLE Cf = 2.06 ppb = 172 / 98-284
LARGE PREDATORY FISH
F. CATFISH Cf = 3.34 ppb = 327 / 143-622
WHITE BASS Cf = 2.77 ppb = 306 / 58-583
WALLEYE Cf = 5.46 ppb = 603 / 365-1,119
N. PIKE Cf = 1.40 ppb = 154 / 46-356
LARGEMOUTH BASS Cf = 1.79 ppb = 197 / 63-287
C. CATFISH Cf = 1.79 ppb = 198 / 62-476
SMALL PREDATORY FISH
GREEN SUNFISH Cf = 1.35 ppb = 123 / 92-147
BLUEGILL Cf = 1.43 ppb = 129 / 67-197
B. CRAPPIE Cf = 1.27 ppb = 115 / 85-168
W. CRAPPIE Cf = 1.33 ppb = 121 / 76-208
WARMOUTH BASS Cf = 2.05 ppb = 185 / 85-273
LONGEAR SUNFISH Cf = 0.88 ppb = 79 / 55-132
NONPREDATORY FISH
GIZZARD SHAD Cf = 1.21 ppb = 110 / 67-188
R. CARPSUCKER Cf = 0.99 ppb = 93 / 60-131
CARP Cf = 1.03 ppb = 98 / 68-145
BUFFALOFISH Cf = 0.93 ppb = 83 / 31-157
INVERTEBRATES
ZOOPLANKTON Cf = 0.63 / 48-91
CRAYFISH Cf = 1.08 / 58-152
FRESHWATER MUSSEL Cf = 0.29 ppb = 26 / 16-43
PRIMARY PRODUCERS
ATTACHED ALGAE AND PLANTS Cf = 10,252 ppb = 277 / 92-947
PHYTOPLANKTON Cf = 4,037 ppb = 109 / 87-133
ORGANIC DEBRIS ppb = 95 / 52-195
NUTRIENT RESOURCES
WATER ppb = 0.027 / 0.018-0.047
SEDIMENTS ppb = 57 / 39-89

FIGURE 3.

by non-diet related mechanisms have been proposed by various investigators. Some of these mechanisms are related to the water chemistry and physical conditions of Elephant Butte Lake.

Hannerz (1968) demonstrated that higher metabolic rates resulted in mercury accumulation in smaller pike. Rucker and Amend (1969) show higher mercury levels in fingerlings of rainbow trout than in adult specimens. Amend, Yasutke, and Morgan (1969) demonstrated that metabolic rates induced by low dissolved oxygen levels (DO), and temperatures at or above 14.4^{o} C resulted in higher mercury accumulation in rainbow trout. Higher mercury accumulation occurred when the chloride ion content of the water was at least 9 ppm. For example, at DO levels of 9 ppm rainbow trout accumulated mercury up to 10,200 ppb, while levels up to 16,000 ppb were accumulated when DO levels were 5 ppm.

These findings suggest that conditions of DO, temperature, and chloride ion at Elephant Butte Lake may contribute to mercury accumulation in the more oxygen-requiring species. The following hypotheses are proposed: (1) larger predators which displayed higher mercury levels may be more oxygen requiring and will then accumulate greater amounts of mercury when DO levels are low; (2) smaller prey species (fingerlings) may also accumulate higher mercury levels at low DO levels and are therefore important mercury sources for these predators; and (3) nonpredators have lower DO requirements and are less affected by changes which result in higher mercury accumulation in predators.

Jester (1972) shows DO levels at Elephant Butte Lake below 9 ppm for the months of June, July, August, and September even at depths up to 27 m. The DO range for these months is shown to be 2.6-7.6 ppm at depths of 8-27 m. Water temperatures are also shown to be above 15 C (19-23 C), even at depths of 17-23 m during these same months. Chloride levels of 35-91 ppm are also shown to be present.

The chloride ion forms more lipid soluble chloride complexes of mercury which are more readily taken up by the gills during increased metabolism (Amend et al., 1969). It follows then, if higher metabolic rates are induced by DO levels less than 9 ppm during the months mentioned, then higher mercury levels can be expected in the species affected. Similarly, if the prey species (fingerlings), accumulate more mercury at low DO levels, then higher mercury levels may also be expected in the predator. The lower known DO requirements of species such as carp might also account for their lower mercury levels.

Hannerz (1968) suggests differences in osmoregulatory mechanisms between fish can account for differences in mercury accumulation from the water. He demonstrated that cod and pike did not take up methylmercury at the same rate from fresh, saline, and brackish water. Uptake of mercury from fresh water was greater than in saline or brackish water, but lower for pike than for cod in each experiment. It follows then, that differences in osmoregulatory mechanisms in Elephant Butte Lake fish are also possible.

Differences in seasonal mercury availability have been shown to occur by Jernelöv (1972b). He studied the ability of skin slime microorganisms to methylate inorganic mercury. Pike sampled in April yielded slime microorganisms which could methylate 90% of the inorganic mercury supplied to them in only two hours. Organisms taken from pike sampled in July could only convert 10% of the inorganic mercury to methylmercury. Further investigation revealed that the predominant organisms responsible for methylation were abundant only during late winter to early spring. Differences in elevated mercury levels in fish during periods of methylation are indicated. Similar microorganisms whose abundance is seasonally controlled may also exist in at least some Elephant Butte fish.

Other suggested reasons to explain differences in mercury levels in fish species may be related to feeding patterns. These patterns may be related to fish size, seasonal availability and abundance of food, and food preferences. They may also be related to feeding habits during periods of mating and spawning, when fish may reject food for long periods of time. Mercury accumulation may also be related to degree and duration of exposure which may vary with local habitat conditions. For example, fish will move throughout a lake, but there is evidence that most predators occupy the cooler, deeper waters for longer periods of time then do nonpredators. Higher mercury levels were found in sediments from deeper water which suggests possible greater intermittent exposure to mercury for predators. In other words I am suggesting that the availability of mercury is not equal at all times for all fish species. It follows then, that the degree or duration of exposure is also not equal.

There are a large number of other possible explanations which may relate mercury availability to accumulation. Similarly, there are many possible mechanisms which may account for mercury uptake. The many factors involved only contribute to the complexity of the situation.

Tissue Mercury Levels and Inferences

There is some indication that mercury levels in certain tissues may be clues which reveal the recency, degree, and duration of exposure to mercury. Some patterns of distribution of mercury in tissues may indicate whether or not mercury levels are changing.

I am proposing an hypothesis which is based on the suggested pathways of mercury accumulation between tissues. If mercury accumulation from food or water follows the ordered pattern from intestine or gills to blood to liver to kidney to muscle, then present or changing levels in these tissues might be explained. For example, relatively high mercury levels in gills would indicate very recent exposure to high levels because increases in the gills occur within a few hours. If high levels were continuously found in gills, then all tissues would also show high mercury levels because rapid transfer also occurs from the gills. If high levels are found in the blood, but not in the gills, then relatively recent exposure, but not current, would be indicated because blood mercury levels increase later. In like manner tissues of interest may be used to make similar inferences.

In other words we would expect mercury levels to appear in a predictable sequence for the tissues mentioned following a time lag between intake and distribution. Furthermore, if the retention time sequence follows an ordered pattern for tissue types in the order, from low to high retention time, such as from gills to blood to muscle to liver to kidney for mercury taken up from water, or a pattern of stomach, intestine, blood, spleen, muscle, liver to kidney for mercury taken up from food, then we can make other inferences about the mercury level in a tissue type which relates to retention time. For example, kidney is one of the tissues known to retain mercury for long periods of time. Therefore, if a low mercury level is found in kidney but a high level is found in blood, exposure would have been recent enough that the expected time lag had not been sufficient for accumulation to have occurred in the kidney. Another possible situation is that no high levels of exposure had occurred for some time and that the kidney had enough time to eliminate higher mercury levels it may once have contained. If the kidney and liver show lower mercury levels than muscle, then mercury has increased sufficiently to allow buildup in the muscle. It's retention time should be lower than that of liver and kidney. If liver shows higher levels than kidney this would also indicate a condition of increasing environmental mercury and that the time lag had not yet been sufficient for the mercury accumulated to be shown by the kidney. Also it might be indicated that kidney, which should have a longer retention time might have had enough time between exposures to eliminate mercury from the last exposure. If mercury levels in liver and kidney are higher than in muscle, the indication would be that muscle would soon also show higher levels following the necessary time lag in spite of having a lower mercury retention time. We would assume that the accumulation pattern would be followed. Higher levels in liver and muscle with respect to lower levels in kidney would indicate increasing environmental mercury levels.

If these arguments are true then the seasonal fluctuations might be expected to have occurred where tissues with low mercury retention times showed higher levels than those which generally have longer retention times. In other words mercury accumulation patterns and retention times should correspond to the sequences given.

From these arguments the following may be inferred for Elephant Butte fish and turtle species: (1) gill tissue displayed low mercury levels in all fish species indicating no recent severe exposure to high mercury levels in the water and (2) turtle blood displayed the lowest mercury level found in all tissues indicating no relatively recent exposure to high mercury concentrations in food.

If we consider all fish and turtle species and observe the mercury levels in liver, muscle, and kidney then a general trend may be more apparent. Higher mercury levels were displayed in liver by eight fish species and both turtle species. Two fish species showed highest levels in muscle, one species displayed highest levels in kidney, four showed highest levels in spleen, and one showed highest levels in stomach.

The conclusions are that for eight fish species and the two turtle species mercury levels were increasing in either the food, water, or both. The one species with highest levels in kidney displayed the expected pattern of mercury retention corresponding to constant levels of exposure. One species with highest levels in stomach indicates recent exposure to higher mercury levels in the food. Four species with higher levels in spleen also indicate relatively recent exposure. The total picture suggests that there are at least two possibilities for mercury uptake which may operate together: (1) fish with higher mercury levels are accumulating mercury from both food and water and (2) fish with lower mercury levels are accumulating mercury at different rates because of differences in osmoregulatory abilities or because of differences in food habits. There are other possibilities, but these seem most probable in view of the report by Jernelöv (1972b) in which he states that Swedish whitefish take up 10% of the mercury from food and 90% from the water, while pike takes up mercury about equally from food and water. The latter statement is not supported by the lower mercury levels found in pike in this investigation, but may be true for other large predatory species.

RECOMMENDATIONS

Regardless of whatever factors or mechanisms might have been involved in mercury accumulation by fish at Elephant Butte Lake, the fact is that individuals of three predaceous species exhibited levels in muscle above 500 ppb and one individual of another species showed a level near 500 ppb. The previous findings reported by the New Mexico Department of Health and Social Services (1970-71) also showed higher levels in the same species. The reported findings reviewed and compared are given below.

	1970-71 Reported levels	Findings of this study	
Species	Mercury ppb	Mean ppb	Range
Channel catfish	630	198	62-476
Flathead catfish	690	327	143-622
White bass	910	306	58-583
Walleye	1,210	603	365-1,119

Although the mean levels determined in this investigation are much lower than previous findings, the higher values are not doubted.

In view of this evidence the following recommendations concerning Elephant Butte Lake are made:

(1) Suggest that the New Mexico Department of Game and Fish include a warning statement in the annual brochure of

fishing information and regulations which is available to all fishermen. The statement should include: a) a list of species known to potentially contain high mercury levels, b) a reminder that larger fish usually contain higher mercury levels than smaller ones, and c) a recommendation to fish eaters that they consume no more than two fish meals per week if they consist of the potentially hazardous species. Swedish findings indicate that 350 g of fish per meal for two to four fish meals per week will not cause accumulation which exceeds the hazardous levels of 8 µg/g mercury in brain tissue. Their maximum allowable concentrations in foods is 1,000 ppb which is double the maximum allowed in the United States. Therefore, one-half of their recommendation should certainly allow a reasonable margin of safety for the consumption of Elephant Butte Lake fish.

(2) It is also recommended that Elephant Butte fish which have displayed high mercury levels be analyzed at regular and frequent intervals. This can be accomplished without extensive fish sampling by establishing a site where fishermen can leave fish organs (indicator tissues) such as the liver. These samples can be labeled with the information revealing species, size of fish, and date caught. The information obtained from analysis should help determine if mercury levels are increasing at Elephant Butte Lake and

whether or not the mercury concentrations vary with seasonal patterns or related changes in water storage.

(3) The commercial harvest of buffalofish can continue because this species does not amplify mercury to dangerous levels.

SUMMARY

Elephant Butte Reservoir is located in southcentral New Mexico, near Truth or Consequences. It is New Mexico's oldest and second largest reservoir and was impounded in 1915, primarily for the storage of water for irrigation.

During the period of this study water storage was lower than the usual volumes reported for previous years and varied between 239,100 acre ft (295 x 10^6 m^3) and 45,000 acre ft (1,646 x 10^6 m^3).

Samples of the major biota, organic debris, water, and sediments were collected between late May 1971 through October 1972 from 45 general collection areas, but from several locations within each area. Mercury determinations were made by a flameless atomic absorption procedure and levels are expressed on a wet weight basis for animal tissues and on a dry weight basis for plant materials and sediments.

Surface water samples exhibited a mean mercury value of 0.027 ppb. A significant gradient of decreasing levels is shown to exist from the inlet toward the dam and the levels are 0.029 (inlet), 0.028 (middle), and 0.024 ppb (dam). Higher levels at the inlet might be related to high turbidity which results in mercury adsorption on suspended particles. Lower levels in samples from the region near the dam might be related to a greater mercury dilution due to greater

water volume as well as to low turbidity.

Bottom sediments displayed mean levels of 57 ppb with lower levels increasing toward the dam in the order of 45 (inlet), 55 (middle), and 69 ppb (dam). The gradient is the reverse of that found for water. Relative instability of bottom conditions at the inlet created by fluctuating water levels, and lower organic content of sediments might explain lower levels in these sediments. Microorganism abundance or their activities involving methylation may be limited under these conditions. Higher organic content in sediments and increasing stability of bottom conditions occur progressively from inlet to dam and may result in greater abundance of organisms associated with methylating activity.

Attached algae and bryophytes displayed mean mercury levels of 277 ppb, but this average included algae from one location which displayed a mean value of 947 ppb. Organisms from four other locations show no significant differences in mercury levels. The mean for these was 109 ppb. Since the attached forms with the high level of 947 ppb were located on a mud flat adsorption of suspended particles was suggested. However, sediments taken from this location did not yield values above 89 ppb and phytoplankton filtered from lake water at this location showed a lower mean value than the mean for phytoplankton from all lake stations (109 ppb). These facts do not support the adsorption possibility.

Zooplankton samples exhibited a mean value of 69 ppb. Shell and visceral mass samples for mussels exhibited mean values of 20 to 26 ppb, respectively. This difference is significant. The values for these organisms were lower than for all other animals in the lake except for small crayfish weighing no more than 5 grams.

Crayfish tissues including gills, exoskeleton, internal organs, and abdominal muscle were less than 100 ppb. Only abdominal muscle with a mean of 90 ppb was significantly higher than values for other tissues. Homogenates from small crayfish yielded the lowest mercury value of 16 ppb which was not significantly different than levels of 25 ppb in exoskeletons of other specimens. Abdominal muscle exhibited a value of 152 ppb in one specimen which is comparable to the level of 154 ppb found in northern pike muscle. The average of 90 ppb (muscle) is comparable to the average of 97 ppb found for muscle of nonpredatory fish. No direct order of increase in mercury level with size is indicated for crayfish, but larger ones generally exhibited higher levels.

Top predator fish species generally had higher mercury levels than lower trophic level fish species. This indicates that ingestion of food accounts for mercury levels in these species. Walleye exhibited a mean mercury level in muscle above 500 ppb which was the highest mean level among all fish. Some specimens of flathead catfish and white bass also displayed mercury levels above 500 ppb in muscle. Another large predator, channel catfish, had only one individual with a mercury level near 500 ppb in muscle. Mean mercury muscle concentrations were 253 ppb in top predators, 125 in small predators, and 97 in nonpredators.

Significant relationships comparing mercury level in muscle to weight, length, or both did not show consistent patterns for all top predators, but did apply to white bass and channel catfish. Largemouth bass, northern pike, and flathead catfish displayed only general trends, with larger individuals displaying higher but not significantly different levels.

Small predators, including white and black crappie and members of the bluegill group (sunfish), did not show positive relationships related to length or weight for mercury level in muscle. The same applies to nonpredators such as carp, buffalofish, and gizzard shad. Among nonpredators, shad exhibited the highest mean mercury level in muscle (110 ppb).

The two turtle species were similar to each other in mercury distribution patterns. The soft-shell turtle displayed higher levels in most tissues than did the hard-shell turtle. The mean mercury muscle level of both species (266 ppb) was comparable to mercury level in muscle of top predaceous fish.

Mercury tissue distribution patterns were most similar between top predaceous fish and turtle species. Average mercury levels were generally higher in liver of turtles than in all tissue types of all fish species. Mean mercury values above 500 ppb in liver were exceeded by flathead catfish, walleye, white bass, and the two turtle species. Levels above 1,000 ppb occurred in at least one specimen of each turtle species. Eight fish species and both turtle species displayed the highest values in liver, one fish species displayed the highest value in kidney, two displayed the highest value in muscle, one displayed the highest value in stomach, and four displayed the highest levels in spleen.

When tissues were grouped according to the relative mercury levels which were most consistently displayed by all fish species, then relatively lower levels were found in bone, skin, eyes, and gills; intermediate levels in stomach, intestine, heart, and brain; and relatively higher levels in spleen, muscle, kidney, and liver.

The ability of all species to accumulate high mercury levels is shown to exist from reported experimental situations and from reports of levels in organisms from polluted areas. It is suggested that on this evidence, as well as on the findings of this investigation, that Elephant Butte Lake is not seriously polluted with mercury. All materials analyzed except muscle of some top predators exhibited levels that would be considered as background according to published information. To explain the higher values in some top predators possible hypotheses are suggested. These include species differences related to food habits, which may vary with availability and abundance of specific food items; sporadic seasonal feeding corresponding to spawning, mating, or size of individuals; species differences in metabolic rates, or seasonally related changes in metabolic rate which correspond to periods of low dissolved oxygen levels; and differences in availability and amount of mercury which correspond to fluctuations in abundance of methylating microorganisms.

An hypothesis is proposed to relate mercury content of tissue types to mercury exposure, based on suggested pathways of mercury accumulation between tissues and upon retention time reported in the literature for various tissues. The hypothesis suggests the availability of mercury as well as degree and duration of exposure is not equal for all species and that higher mercury levels in liver indicate increasing levels for certain fish.

Recommendations are made for periodic but continued analysis of Elephant Butte Lake materials to determine if the mercury levels are indeed increasing and to determine if changes are associated with seasonal patterns and fluctuations in water storage. Recommendations are made to the New Mexico Department of Game and Fish to include a warning statement in their annual fishing information brochure concerning potentially hazardous mercury levels in certain large game fish and to request limited consumption of these fish.

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