Mercury Accumulation by Largemouth Bass *(Micropterus salmoides)* in Recently Impounded Reservoirs

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Reports of elevated mercury levels in fish in Lake St. Clair, Ontario, in 1970 prompted widespread investigation of the occurrence of mercury in fish and other aquatic life in waters of the United States (GREIG and SEAGREN 1972). Mercury accumulation in fish has generally been associated with industrial discharges of mercury to natural waters (D'ITRI 1972; KLEINERT and DEGURSE 1972). Mercury concentrations lower than approximately 0.5 part per million (ppm) have been widely accepted as representative of natural mercury levels in fish of unpolluted environments (HOLDEN 1975); however, fish mercury levels greater than 0.5 ppm under natural conditions have been reported (HOLDEN 1972; KLEINERT and DEGURSE 1972). Mercury accumulation in the absence of polluted conditions is considered to reflect the presence of low levels of mercury in the environment due to natural and man-caused weathering processes. In this paper, we report observations on mercury accumulation in largemouth bass (*Micropterus salmoides*) in reservoirs in the southeastern United States which are not subject to industrial discharges of mercury-bearing effluents, and relate the observed pattern of mercury accumulation to ecological conditions in these aquatic systems.

Materials and Methods

The reservoirs from which specimens were collected were Lakes Hartwell, Keowee, and Jocassee in western South Carolina. Lake Hartwell is a 22,800 hectare multipurpose hydroelectric impoundment on the Savannah River which was filled in 1962. Lake Keowee is a 7500 hectare multipurpose hydroelectric reservoir on the Keowee River, a tributary of the Savannah above Lake Hartwell, which was filled in 1970. Lake Jocassee is a 3000 hectare hydroelectric impoundment of the headwaters of the Keowee River immediately above Lake Keowee, and was filled in 1973. Lake Hartwell and Lake Keowee are located in the upper Piedmont physiographic province, while Lake Jocassee is located at the junction of the upper Piedmont and the Blue Ridge escarpment.

Fish muscle tissue, sediments, suspended sediment loads, and water were analyzed for total mercury content by atomic absorption spectrophotometry as described by the U.S. ENVIRONMENTAL PROTECTION AGENCY (1972). Mercury concentrations were determined with a Perkin Elmer Model 403 atomic absorption spectrophotometer. Mercury standar were prepared from reagent grade mercuric chloride in nitric acid solution. Mercury concentrations are reported in ug/g (ppm) or in

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ug/l (ppb). Limits of sensitivity were 0.05 ppm (wet weight basis) in fish tissue, 0.01 ppm (dry weight basis) in sediments and suspended loads, and 0.01 ppb in water. Certain specimens were divided and replicates were analyzed for mercury content by the South Carolina Department of Health and Environmental Control, Columbia, South Carolina, and the National Marine Fisheries Service Fishery Products Technology Laboratory, College Park, Maryland.

Largemouth bass were obtained between March, 1973, and November, 1975, with the cooperation of sport fishermen, the U.S. Fish and Wildlife Service, and the South Carolina Wildlife and Marine Resources Department. Bass from each lake were considered to be representatives of a single population within the lake for the purposes of this study. Axial muscle specimens were taken from an area adjacent to the dorsal fin, placed in acid-washed glass vials, and stored frozen until analyzed for mercury content.

Sediment samples were obtained by hand or with an Eckman dredge. The samples were stored in acid-washed glass jars and dried at 60 C before analysis. Suspended sediment loads were collected approximately 30 cm above the bottom at the mouths of tributary streams and in lake waters using a Van Dorn bottle. Samples were placed in acid-washed plastic bottles and filtered upon return to the laboratory. The filtrate was dried in a desiccator prior to mercury analysis. Water samples were collected with a Van Dorn bottle at or near the surface, placed in acid-washed plastic bottles and returned to the laboratory, where they were filtered before analysis.

Results and Discussion

Mercury concentrations detected in largemouth bass muscle specimens analyzed by the three cooperating laboratories are shown in Table I. The results of analyses performed by the independent laboratories compared favorably with our analyses.

Mercury levels in largemouth bass from Lakes Hartwell, Keowee, and Jocassee are presented in Table II. These data indicate a correlation of mercury concentration with size and weight of fish, as observed in other species (SCOTT and ARMSTRONG 1972; SCOTT 1974). Product-moment correlation coefficients for axial muscle mercury concentration versus length and weight for bass from Lake Jocassee and Lake Keowee are presented in Table III. Lake Keowee bass more than 305 mm or 680 grams, and Lake Jocassee bass more than 203 mm or 340 grams contained more than 0.5 ppm total mercury in axial muscle. Lake Hartwell bass mercury levels were not unusual compared to those which have been reported elsewhere (GEORGIA WATER QUALITY CONTROL BOARD 1971).

Within comparable size classes, mercury levels were lowest in bass from Lake Hartwell and highest in bass from Lake Jocassee. Lake Keowee bass were intermediate in mercury content. These data were transformed to logarithms and differences in mercury levels of bass from the three lakes were tested for significance by analysis of covariance (SCOTT 1974). The results indicated that the differences between lakes were highly significant ($p<0.01$). The presence of

TABLE I

Comparison of mercury concentrations detected in replicate largemout bass axial muscle specimens analyzed at the Clemson University Environmental Systems Engineering Department (ESE), the South Caroli Department of Health and Environmental Control (DHEC), and the National Marine Fisheries Service (NMFS).

Specimen Number:	Mercury concentrations, ppm:		
	ESE	DHEC	NMFS
1	4.10	3.30	4.14
2	3.45	2.98	3.74
3	4.42	4.01	4.21

TABLE II

Mercury concentrations detected in axial muscle of largemouth bass from Lakes Hartwell, Keowee, and Jocassee, South Carolina, 1973-197*l*

Size class, mm	Mercury concentration, ppm± S.E.[a]		
	Hartwell	Keowee	Jocassee
< 230		0.34±0.04(8)[b]	2.08±0.09(10)
231-340	0.38±0.02(2)	0.58±0.07(11)	1.87±0.12(14)
341-380	0.39±0.08(3)	0.66±0.08(2)	3.99±0.76(4)
> 380	0.68±0.09(11)	3.99±0.90(2)	4.49±0.23(12)

[a] Single classification analysis of covariance of log-transformed data indicates that differences between fish of different reservoirs are highly significant ($p<0.01$).

[b] Sample size in parentheses.

mercury at these levels in bass of Lakes Keowee and Jocassee prompted investigation of possible sources of environmental mercury in the Keowee-Jocassee watershed.

Mercury concentrations in waters of Lake Jocassee and its tributary streams were low, generally less than 0.1 ppb (Table IV). These mercury levels are comparable to those detected in other fresh waters of the southeastern United States (JENNE 1972; U.S. GEOLOGICAL SURVEY 1970). The slight variations in mercury concentrations among locations may be due to the presence of variable amounts of suspended organic materials in water samples. As discussed below, suspended organic particulates have high affinity for mercury (CRANSTON and BUCKLEY 1972; LAMBOU 1972). Slight variations in filtering efficiency could therefore cause noticeable variations in water mercury concentrations.

TABLE III

Product-moment correlation coefficients[a] for correlations among length, weight, and total mercury concentration of axial muscle for largemouth bass from Lake Keowee and Lake Jocassee, South Carolina.

Origin	Sample size	Mercury concentration, ppm, vs: Length	Weight
Lake Jocassee	40	0.82	0.81
Lake Keowee	23	0.68	0.67

[a]All correlations were significant at the 0.01 level in tests of H_o: R=0.

TABLE IV

Mercury concentrations detected in water (ppb), sediments (ppm), and suspended loads (ppm) of Lake Jocassee and its tributaries.

Origin	Mercury concentration: Water	Sediment	Suspended load
Lake Jocassee			
West Fork	0.06	0.04	
Upper East Fork	N.D.[a]	0.03	
Lower East Fork	0.05	0.04	
Tributaries			
Whitewater River	N.D.	0.01	8.0
Toxaway River		0.04	14.0
Thompson River	0.12	0.02	4.4
Coley Creek	0.06	0.02	
Bearcamp Creek	0.10	0.02	13.0
Laurel Fork Creek	0.03	0.03	4.1
Horsepasture River	N.D.	0.04	1.3
Howard Creek	0.04	0.05	6.6

[a]N.D.: none detected

Sediment and suspended load mercury levels in Lake Jocassee and its major tributaries were also low, generally less than 0.05 ppm in sediments and 8 ppm in suspended loads (Table IV). Mercury levels of 0.05 to 0.15 ppm in clay- or organic-rich sediments of unpolluted aquatic systems have been reported elsewhere (HOLDEN 1972; KONRAD 1972). Few data are available concerning mercury content of suspended materials in unpolluted streams. The high affinity of fine organic particulates and clay minerals for heavy metals makes the mercury levels of 4 to 14 ppm in our suspended load samples appear reasonable. CRANSTON and BUCKLEY (1972) reported that suspended matter mercury levels may be as much as 300 times higher than mercury levels of sediments in the same area, and concluded that transport of mercury by fine particulates was important in aquatic systems.

The mean mercury level of soils of the Lake Jocassee area has been reported to be 82 ppb (dry weight basis) by SHERER (1975). This is comparable to the 112 ppb mean soil mercury level reported for the United States by SHACKLETTE et al. (1971), but slightly higher than the 62 ppb mean reported by SHERER (1975) for other soils in South Carolina. Elevated mercury levels in suspended loads are probably related to the presence of fine organic particulates from soil erosion.

The absolute amounts of mercury present in fish of Lakes Jocassee and Keowee are relatively small, and could easily have been provided by background levels of mercury which were present in topsoil which formed the sediments of the reservoirs after filling. Assuming a soil mercury content of 80 ppb, nearly 9×10^4 grams of mercury would have been present in the original surface inch of sediment in Lake Jocassee following impoundment. An assumed present fish standing crop of approximately 50 kg/hectare with a mean mercury content of 5 ppm would contain only 8×10^2 grams of mercury, or about one percent of that originally present in the surficial sediments of the reservoir.

In the absence of other recognized geologic or industrial mercury inputs in the Keowee-Jocassee system, it was hypothesized that the elevated mercury levels observed in largemouth bass of these reservoirs are related to the ages, trophic states, and water quality characteristics of the reservoirs.

Lake Hartwell is the oldest of the reservoirs, and has the lowest mercury levels in bass. Lake Jocassee is the youngest reservoir, and has the highest levels of mercury in bass. Lake Keowee is intermediate in both respects. Methylation of mercury by microorganisms is favored by aerobic conditions (BISOGNI and LAWRENCE 1975). Mobilization of trace amounts of mercury from sediments as organic mercurials which may enter food webs may proceed more rapidly in young lakes than in older ones due to the less anaerobic condition of sediments in the early stages of lake succession. Older reservoirs develop reducing conditions in sediments which would be less favorable to methylation of mercury. Under reducing conditions, mercury would tend to become bound to sulfur compounds and organic substances, which would remove it from the food web.

Low pH (MATSUMURA et al. 1972), low phosphate concentration (TSAI et al. 1975), and alkalinity less than 50 ppm (KLEINERT and DEGURSE 1972) have been reported to favor mercury accumulation by fish. A survey of water quality data for the Hartwell-Keowee-Jocassee system (Table V) indicates that Lake Jocassee is a slightly acidic, oligotrophic lake compared to Lake Hartwell, which has higher pH, turbidity, and nutrient levels. Lake Keowee is

TABLE V

Surface water quality data[a] for Lakes Hartwell, Keowee, and Jocassee, South Carolina[b].

	Hartwell	Keowee	Jocassee
Conductivity, umhos	22 ± 3	23 ± 2	14 ± 1
pH	7.0 ± 0.2	6.6 ± 0.1	6.3 ± 0.1
Alkalinity, ppm $CaCO_3$	9.0 ± 0.4	7.6 ± 0.6	5.2 ± 0.4
Turbidity, JTU	14 ± 2	8 ± 1	9 ± 1
NO_3-NO_2-N, ppm	0.15 ± 0.01	0.12 ± 0.008	0.08 ± 0.011
Total P, ppm	0.028 ± 0.002	0.025 ± 0.004	0.021 ± 0.004

[a]Values are means $\pm$ S.E. of determinations made at representative stations on each reservoir between December 1973 and March 1974.

[b]Duke Power Company, Charlotte, North Carolina

TABLE VI

Mercury concentrations detected in axial muscle of 231-340 mm largemouth bass from Lake Jocassee, South Carolina in 1974 and 1975.

Year	Sample Size	Mercury concentration, ppm$\pm$SE
1974	11	1.90 ± 0.12
1975	12	0.69 ± 0.06

intermediate between Lakes Hartwell and Jocassee in these respects. All of these reservoirs are low in nutrients. Fish have been shown to accumulate mercury by uptake through the gills (RUCKER and AMEND 1969). Under some circumstances this route of accumulation is more important than ingestion of mercury with food. The relative lack of nutrients in oligotrophic waters may facilitate uptake of mercury by fish due to a lack of competing ions. D'ITRI et al. (1971) found that fish in an unpolluted oligotrophic lake in Michigan had higher mercury levels than fish in a similarly remote eutrophic lake in the same area. Higher primary and secondary productivity in a eutrophic system results in increased suspended organic load in the water column. This organic matter would tend to bind mercury and transport it to bottom sediments, where it would be retained under anaerobic conditions, unavailable for recycling in the ecosystem.

As a test of the hypothesis that mercury accumulation by bass in Lake Jocassee and Lake Keowee is related to successional trends, additional largemouth bass in the 231-340 mm size class were collected from Lake Jocassee during 1975, and were analyzed for muscle mercury content (TableVI). The 1975 mercury levels are lower than those previously observed in Lake Jocassee in bass of similar size (Studen t, $p < 0.01$). This observation, together with consideration of the water quality data, lends support to the hypothesis that elevated mercury levels in fish are characteristic of certain newly impounded reservoirs.

Elevated mercury levels in fish of new reservoirs is probably transitory, declining within 3 to 5 years after reservoir filling under conditions which exist in the systems we have studied. Mercur levels observed in largemouth bass of Lake Hartwell are probably representative of mercury levels which will occur in bass of Lakes Keowee and Jocassee when these lakes have aged for several years. The generality of this phenomenon will depend upon biological, chemical, and physical properties of individual reservoirs and their drainages.

Summary

Mercury levels of largemouth bass from three reservoirs in the southeastern United States were highest in the younger, relatively oligotrophic reservoirs and were significantly lower in an older, more eutrophic reservoir in the same drainage system. The reservoir with the highest mercury levels in bass is the reservoir farthest upstream, and is not subject to inputs of municipal or industrial wastes. The source of mercury in these reservoirs appears to be the soil which formed their original sediments. Preliminary data indicate that mercury levels in largemouth bass in these systems decline as the reservoirs age. Elevated mercury levels in fish appear to be a transitory phenomenon in newly impounded, relatively oligotrophic reservoirs.

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References

BISOGNI, J.J., and A.W. LAWRENCE: J.Water Poll. Control Fed. 47, 135 (1975).

CRANSTON, R.E., and D.E. BUCKLEY: Environ. Sci. Technol. 6,274 (197

D'ITRI, F.M.: Sources of mercury in the environment. Pp. 5-25 in: R. Hartung and B.D. Dinman, eds. Environmental mercury contamination. Ann Arbor, Michigan, Ann Arbor Science Publishers (1972).

D'ITRI, F.M., C.S. ANNETT, and A.W. FAST: J. Marine Technol. Soc. 5,10 (1971).

GEORGIA WATER QUALITY CONTROL BOARD: Mercury pollution investigation in Georgia, 1970-1971. Atlanta, Georgia Water Quality Control Board (1971).

GREIG, R.A., and H.L. SEAGREN: Survey of mercury concentrations in fishes of Lakes St. Clair, Erie, and Huron. Pp. 38-45 in: R. Hartung and B.D. Dinman, eds. Environmental mercury contamination. Ann Arbor, Michigan, Ann Arbor Science Publishers (1972).
HOLDEN, A.V.: Present levels of mercury in man and his environment. Pp. 142-168 in: Mercury contamination in man and his environment. Vienna, Int. Atomic Energy Agency (1972).
JENNE, E.A.: Mercury in waters of the United States, 1970-1971. U.S.D.I. Geol. Survey Report, Water Res. Div., Menlo Park, California (1972).
KLEINERT, S.J., and P.E. DEGURSE: Wis. Dept. Nat. Resour. Tech. Bull. No. 52 (1972).
KONRAD, J.G.: Mercury contents of bottom sediments from Wisconsin rivers and lakes. Pp. 52-58 in: R. Hartung and B.D. Dinman, eds. Environmental mercury contamination. Ann Arbor, Michigan, Ann Arbor Science Publishers (1972).
LAMBOU, V.W.: U.S. Environmental Protection Agency Report to the Working Party on Mercury, Sector Group on Unintended Occurrence of Chemicals in the Environment, O.E.C.D. (1972).
MATSUMURA, F., Y. GOTOH, and G.M. BOUSCH: Bull. Environ. Contam. Toxicol. 8, 267 (1972).
RUCKER, R.R., and D.F. AMEND: Progress. Fish Culturist 31, 197 (1969)
SCOTT, D.P.: J. Fish. Res. Board Canada 31, 1723 (1974).
SCOTT, D.P., and F.A.J. ARMSTRONG: J. Fish. Res. Board Canada 29, 1685 (1972).
SHACKLETTE, H.T., J.G. BOERNGEN, and R.L. TURNER: Geol. Survey Circ. No. 644. Washington, D.C., U.S.D.I. (1971).
SHERER, R.W.: Preliminary report, Lake Jocassee mercury study. Columbia, S.C., S.C. Dept. Health and Environ. Control (1975).
TSAI, S.C., G.M. BOUSCH, and F. MATSUMURA: Bull. Environ. Contam. Toxicol. 13, 188 (1975).
U.S. ENVIRONMENTAL PROTECTION AGENCY: Provisional methods: Mercury. Cincinnati, Ohio, U.S.E.P.A. National Environ. Res. Center (1972).
U.S. GEOLOGICAL SURVEY: Geological Survey Professional Paper No. 713. Washington, D.C., U.S. Government Printing Office (1970).