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Total Mercury in Fishes and Selected Biota in Lahontan Reservoir, Nevada: 1981

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The use of mercury compounds by man date back to Roman times. Mercury has been used for many years for industrial, agricultural and medicinal purposes (D'ITRI 1972). Recent discoveries have demonstrated the undesirable effects mercury may have on the aquatic environment. In the 1950's and 1960's Japanese and Swedish researchers found that fish accumulated a higher concentration of mercury than their environment and the consequences of human exposure to these concentrations were unveiled (IRUKAYAMA 1966; BORG et al. 1966). Marine and freshwater sport and commercial fisheries have been contaminated within the United States rendering fish unsafe for consumption.

Mercury was introduced into the Carson River of northern Nevada during the mining of gold and silver in the Comstock Lode, near Virginia City. After railroad lines connected Virginia City with 12 millsites along the Carson River from Empire to Dayton in 1869, nearly all the processing of Comstock ore was carried out at these sites because of the availability of water power (SMITH 1943).

Large amounts of liquid mercury were imported and used in the amalgamation of the precious metals known as the "Washoe Process" in the ratio of 1:10, quicksilver:ore (SMITH 1943). The average loss of quicksilver was 0.68 kg for each ton of ore milled. During the 30 year peak of the Comstock (1865-1895) it is estimated that 200,000 flasks of mercury or 6.75×10^6 kg (7,500 tons) were lost in the milling process (BAILEY & PHOENIX 1944); about 0.5% of that amount was later recovered.

In 1973 the U.S. Geological Survey reported that background mercury levels in the upper 7 cm of sediment upstream from pre-1900 milling sites on the Carson River were less than 0.1 mg/kg (VAN DENBURGH 1973). Downstream concentrations were measured up to 200 times background (20 mg/kg). The highest concentrations were found just upstream from Lahontan Reservoir. Concurrent with this study was one undertaken by the College of Agriculture Extension Service, University of Nevada, Reno, which focused on the accumulation of mercury by crop plants and domestic livestock raised in the area.

RICHINS (1973) was the first to document that aquatic organisms in the Carson River, including Lahontan Reservoir, contained levels of mercury in the muscle tissue which exceeded concentrations considered safe by the U.S. Food and Drug Administration (FDA). The U.S. Environmental Protection Agency (EPA) and Nevada Division of Environmental Protection (NDEP) have also collected data suggesting bioaccumulation of mercury within the system. In addition, there are also data collected downstream from Lahontan Reservoir on the Carson River system, near Fallon, substantiating high levels of mercury in fishes (EKECHUKWU 1976).

The objectives of this study are: 1) to present concentrations of mercury found in fish and other selected biota collected from Lahontan Reservoir, Nevada, 2) compare mercury concentrations between fish species to test if a greater accumulation occurred within those highest on the food chain, and 3) compare mercury concentrations found during this study to past studies conducted on the system.

STUDY SITE

Lahontan Reservoir, located 72 km southeast of Reno, was created in 1915 when the Carson River was impounded for the Newlands Irrigation Project. The reservoir receives the entire flow of the Carson River which averaged 3.26 X 10^8 m^3 (264,000 a-ft.) per year between 1913 and 1970 (KATZER 1971). Water is diverted from the Truckee River to Lahontan Reservoir and the Carson River Basin by way of the Truckee Canal that since 1964 has supplied an average of 2.18 X 10^8 m^3 (176,500 a-ft.) annually to the impoundment or approximately 40 percent of the yearly contribution. Other morphologic and hydrologic characteristics of the reservoir are presented (Table 1).

Table 1. Morphologic and hydrologic characteristics of Lahontan Reservoir, Nevada.

Characteristic	Value
Maximum length	27 km
Maximum width	4 km
Maximum depth	26 m
Mean depth	8.1 m
Surface area	4,410 ha
Spillway elevation	1,269 m
Capacity	3.57 X 10^8 m^3
Hydraulic residence time	0.77 yrs.

Lahontan Reservoir, in addition to storage of irrigation water, is also used extensively for recreation. The reservoir has become one of the most heavily used recreation areas in northern Nevada and is within the Nevada State Park System.

METHODS

During the summer of 1981 fish were collected for analysis using a variety of methods including gill netting, beach seining and dip netting. Freshly collected fish were measured for length and weight before being placed on ice, transferred to the laboratory in Reno and frozen.

Cold vapor atomic absorption was selected as the analytical technique for determining mercury concentration in the fish tissue. Procedures followed were developed by STEWART (1977). Approximately 10 g of muscle tissue was taken below the dorsal fin and above the lateral line and macerated in a tissue grinder. Small species or young-of-the-year were macerated whole after removal of the viscera. Liver and heart tissue, pooled by species, were prepared similarly. The wet tissue was weighed, lyophilized and reweighed to determine percent moisture content. The dried sample was then ground to a powder with a mortar and pestle and weighed in a teflon parr bomb cup with 2.5 ml concentrated HNO_3, 1.0 ml of 30 percent H_2O_2 and 25 mg $K_2S_2O_8$. The sample was then digested in a parr bomb for 8 hours at 100-110 C.

Recovery studies spiked prior to digestion averaged 92 percent. Results are presented as the concentration of total mercury per wet weight of tissue. Variation between fish groups was analyzed using a one-way analysis of variance with unequal sample sizes (KOH 1973).

RESULTS AND DISCUSSION

Results indicate that significant mercury accumulation is occurring within fishes of Lahontan Reservoir (Table 2). Mercury concentrations in muscle tissue collected from 11 species ranged from 0.11 mg/kg in young-of-the-year white bass (*Morone chrysops*) to 9.52 mg/kg in a striped bass (*Morone saxatilis*) with a known residence time within the waterbody of 16 years (COOPER & VIGG in press). Of 53 muscle tissue samples analyzed 36 (68%) exceeded the 1 mg/kg "action level" considered safe by the FDA. Heart tissue ranged from 0.17 mg/kg in carp (*Cyprinus carpio*) to 5.58 mg/kg in striped bass. Liver tissue was consistantly higher than heart tissue and ranged from 0.21 mg/kg in brown bullhead (*Ictalurus nebulosus*) to 23.65 mg/kg in striped bass. These levels represent residues which are considerably higher than the 0.20 mg/kg considered as background for fish (D'ITRI 1972). Crayfish (*Pacifastacus* sp.) and California seagull (*Larus californicus*) also exhibited elevated total mercury concentrations.

In general mercury concentration within species increased with fish weight. A significant positive correlation was found between fish weight and mercury muscle concentration for yellow perch (*Perca flavescens*) ($r=0.82$; $P <0.05$), white crappie (*Pomoxis annularis*) ($r=0.83$; $P <0.01$), white catfish (*Ictalurus catus*) ($r=0.66$; $P <0.05$) and white bass ($r=0.85$; $P <0.01$). The other species

Table 2. Concentrations of total mercury in selected fishes and other selected organisms from Lahontan Reservoir, Nevada

Species	Tissue	Total Fish Weight (g)	Wet Weight Hg Concentration (mg/kg)
Sacramento blackfish	muscle	41	0.81
(Orthodon microlepidotus)	muscle	52	0.44
	muscle	88	0.84
	muscle	104	1.92
	muscle	291	0.80
	WYOY*	composite	0.18
	heart	composite	0.19
Carp	muscle	37	0.74
(Cyprinus carpio)	muscle	97	0.71
	muscle	1146	2.34
	WYOY*	composite	0.21
	heart	composite	0.17
	liver	composite	2.62
Tahoe sucker	muscle	97	0.68
(Catostomus tahoensis)	muscle	101	0.65
	muscle	149	1.64
	muscle	256	1.10
	muscle	320	0.89
Brown bullhead	muscle	98	0.95
(Ictalurus nebulosus)	muscle	119	1.09
	liver	composite	0.21
Yellow perch	muscle	10	0.30
(Perca flavescens)	muscle	17	0.23
	muscle	67	1.14
	muscle	80	2.83
	muslce	101	2.81
	muscle	111	1.67
	WYOY*	composite	0.13
	heart	composite	1.80
	liver	composite	2.45
White catfish	muscle	16	1.58
(Ictalurus catus)	muscle	26	0.82
	muscle	27	0.69
	muscle	58	1.25
	muscle	72	1.03
	muscle	135	2.34
	muscle	173	1.79
	muscle	193	1.63
	heart	composite	0.72
	liver	composite	2.03
Channel catfish	muscle	56	1.18
(Ictalurus punctatus)	muscle	75	1.29
	muscle	115	1.01
	muscle	348	1.65
	muscle	429	2.36
	muscle	772	1.20
	muscle	926	1.22
	muscle	994	1.94
	heart	composite	1.13
	liver	composite	3.29

Table 2. (Continued).

Species	Tissue	Total Fish Weight (g)	Wet Weight Hg Concentration (mg/kg)
White crappie	muscle	38	0.15
(Pomoxis annularis)	muscle	48	0.34
	muscle	56	2.22
	muscle	98	1.66
	muscle	420	3.40
	muscle	535	3.42
	muscle	673	3.19
	heart	composite	2.07
	liver	composite	8.25
White bass	muscle	43	1.37
(Morone chrysops)	muscle	44	0.97
	muscle	139	2.28
	muscle	183	1.82
	muscle	188	1.90
	muscle	192	3.55
	muscle	226	3.76
	muscle	257	3.95
	WYOY*	composite	0.11
	heart	composite	1.58
	liver	composite	3.14
Striped bass (16 year old fish)	muscle	15,165	9.52
(Morone saxatilis)	heart		5.58
	liver		23.65
Mosquito fish	whole fish	1	0.53
(Gambusia affinis)			
Crayfish	abdomen	14	0.57
(Pacifastacus sp.)	abdomen	34	1.79
	abdomen	52	5.72
California seagull	muscle		0.36
(Larus californicus)	liver		0.97
	egg		0.13
	egg		0.19

*WYOY - whole young of year

either showed no significant correlation or sample size was not large enough for statistical analysis.

These results are consistant with the general patterns found by previous studies (D'ITRI 1972; SCOTT & ARMSTRONG 1972; SCOTT 1974; RICHINS & RISSER 1975) in that mercury concentration in fish increases with size and age. This relationship in the current study was strongest for piscivores. Studies have demonstrated that fish concentrate mercury in two ways, absorption through the gills and ingestion of contaminated food (RUCKER & AMEND 1969; HAMMOND 1971). Assuming this were the case in Lahontan Reservoir, then it follows that those species highest on the food chain would show the highest correlation between size, age and mercury concentration.

Previous studies have shown evidence of trophic level magnification of mercury (D'ITRI 1972; RICHINS & RISSER 1975; POTTER et al. 1975) and others have not (WOBESER et al. 1970). Various literature sources were used to determine the adult feeding habits of the 10 major species of fish analyzed for mercury during this study (Table 3). Blackfish, carp and sucker were categorized as omnivores; bullhead, perch and catfish as second order piscivores; and crappie and bass as first order piscivores. The omnivores generally eat both plant and low trophic level animal material. Second order piscivores also eat plant material, but they have a preference for animals in a higher trophic level. Fish usually dominate the diet of the first order piscivores with lesser quantities of other animal material.

Using a-priori comparisons a significant difference was found among mean muscle mercury concentrations of the three selected trophic groups of fish ($P < 0.05$). Subsequently, a-priori comparisons were made between selected groups. A significant difference was found between mean mercury concentration in the omnivores (1.16 mg/kg) compared to second order piscivores (1.64 mg/kg) ($P < 0.05$). Likewise, mean mercury concentrations of the second order piscivores were significantly lower than first order piscivores (3.39 mg/kg) ($P < 0.001$). Concentration of mercury in heart and liver tissue also increased from the lower to the higher trophic level species. The above analysis suggests that biomagnification of mercury is occurring within the fishes of Lahontan Reservoir.

The concentration of mercury in Lahontan Reservoir fishes reported in this paper are generally within the range documented by previous studies of the Carson River drainage. In 200 fish, representing seven species, the levels of total mercury ranged from 0.02 to 2.72 mg/kg; the highest concentration being in the piscivorous white bass from Lahontan Reservoir (RICHINS 1973; RICHINS & RISSER 1975). These studies also found that concentrations increased in aquatic organisms in a downstream direction from early Comstock milling sites. In addition, their results demonstrated highly significant correlations between fish weight and mercury content of five of the species analyzed.

Table 3. Typical food items and feeding strategy of the 10 fish species analyzed for total mercury from Lahontan Reservoir, Nevada (derived from following literature: Murphy 1950; La Rivers 1962; Scott and Crossman 1973; Moyle 1976).

Species	Feeding Strategy	Common Adult Diet	Total Mercury in Adult Muscle Tissue (mg/kg) Range	Mean
Sacramento blackfish (*Orthodon microlepidotus*) Carp (*Cyprinus carpio*) Tahoe sucker (*Catostomus tahoensis*)	Omnivores	detritus, algae, vascular plants, terrestrial and aquatic insects, crustaceans, annelids, amphipods, zooplankton, etc.	0.71-2.34	1.16
Brown bullhead (*Ictalurus nebulosus*) Yellow perch (*Perca flavescens*) White catfish (*Ictalurus catus*) Channel catfish (*Ictalurus punctatus*)	Second Order Piscivores	large terrestrial and aquatic insects, decapods, leeches, algae, fish, ostracods, molluscs, crayfish, amphipods, detritus, etc.	0.95-2.83	1.64
White crappie (*Pomoxis annularis*) White bass (*Morone chrysops*) Striped bass (*Morone saxatilis*)	First Order Piscivores	fish, crayfish, aquatic and terrestrial insects, amphipods, zooplankton, etc.	1.66-9.52	3.39

Other studies have shown that Lahontan Reservoir is not the ultimate sink for mercury in the system. EKECHUKWU (1976) found levels in carp taken below the reservoir ranging from 5.0 to 11.5 mg/kg, indicating bioaccumulation. Six individual fish were collected for analysis by the FDA in 1970 in the Newlands Irrigation Project downstream from Lahontan Reservoir on the Carson River drainage. These included white bass (3.2 mg/kg), white catfish (3.0 mg/kg), largemouth bass (*Micropterus salmoides*), (1.6 mg/kg), rainbow trout (*Salmo gairdneri*), (1.3 mg/kg), yellow perch (0.97 mg/kg) and black bullhead (*Ictalurus melas*), (1.1 mg/kg); all suggesting excessive accumulation of mercury.

Although mercury in a watercourse is present predominantly in inorganic form, an organo-mercurial (methyl mercuric ion) is the form usually present in aquatic organisms (WESTÖÖ 1968; D'ITRI & D'ITRI 1977). Production of methyl mercury is generally believed to be biologically controlled (JERNELÖV 1970; WRIGHT & HAMILTON 1982); bacteria associated with organic enrichment increase the methylation potential. Recent limnological studies of Lahontan Reservoir categorize the impoundment as eutrophic based on the degree of primary production (COOPER & VIGG 1983). Water quality models applied to the reservoir predict that upstream nutrient control programs will be beneficial in reducing algal growth in the future. Thus, with the anticipated improvement in water quality should also come a lesser potential for the in-reservoir conversion of mercury from the relatively innocuous inorganic to the methylated form that is capable of entering the food chain.

Future studies on the mercury problem in the Carson River system should focus on methods to control the release of mercury from the sediments of the Carson River and Lahontan Reservoir. FEICK et al. (1972) outlines various programs combining field and laboratory experiments which could lead to decisions on how to decontaminate sediments. A large sample size of the sport fishes should be analyzed for mercury content so that reliable regression equations can be developed between fish size and mercury concentration. Such predictions would allow for selective fishing, and the fisherman could weigh his catch in the field to determine mercury content.

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