IDAHO WATER RESOURCES RESEARCH INSTITUTE

THE ACCUMULATION AND DISTRIBUTION OF ORGANOCHLORINES AND SOME HEAVY METALS IN AMERICAN FALLS RESERVOIR FISHES, WATER, AND SEDIMENT

by

James C. Kent

Thesis Abstract, Idaho State University, 1976

Chlorinated hydrocarbon residues (DDT metabolites, dieldrin, and PCB's) were found in fish flesh samples and sediment in American Falls Reservoir. The concentration and type of chlorinated hydrocarbon varied with fish species and age. The mean value for PCB's in large suckers was 671 µg/kg. The Environmental Protection Agency has recommended that PCB concentrations in any sample consumed by any bird or mammal be no greater than 500 µg/kg. Chlorinated hydrocarbons were not detected in the water samples.

Mercury and cadmium were found in all species analyzed for those particular metals. Results indicate that the Food and Drug Administration's standard of 0.5 mg/kg may be exceeded in crappie, suckers, and large rainbow trout. The mean value for mercury in water was 0.9 µg/l. The Environmental Protection Agency

has recommended for the protection of fish and predatory aquatic organisms, that total mercury concentration in unfiltered water should not exceed 0.2 μg/l at any time or place. The World Health Organization has recommended daily intake of cadmium not be more than 70 μg/day. Consumption of fishes from the reservoir would exceed the recommended limit. The maximum concentration of cadmium in the water was seven times the value given by the National Academy of Sciences, considered to be an environmental threat.

Arsenic was found only in the sediments and water. It was not detected in any of the fishes sampled.

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James C. Kent

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SECTION I--ORGANOCHLORINES

Introduction

American Falls Reservoir provides an important sport fishery for area residents. The reservoir is heavily fished during the summer months and ice fishing is becoming more popular every year. Water quality has been and is a problem in the reservoir (1). In 1970 the Idaho Health Department reported mercury concentrations in some fishes from the reservoir exceeded the Food and Drug Administration (FDA) standard of 0.5 mg/kg. Recommendations were made that suckers, bullhead, and yellow perch caught in the reservoir not be eaten. The fate of other pollutants, such as organochlorines, in American Falls Reservoir, their accumulation and effects on uses of reservoir water and its fishes, has not been previously studied.

The introduction of organochlorines into the biosphere has produced many adverse side effects. The aquatic environment has been particularly vulnerable to degradation by these chemicals. Two hundred thirty-one kills attributed to pesticides, totaling 50 million fish, were reported during 1970. These reports covered an area of 1,384 km of stream and 4,330 surface hectares (2).

Pesticides may enter the aquatic environment from the atmosphere, with industrial effluents, with silt and sediment in runoff waters, and from direct application. The major source of contamination is probably runoff from irrigation and flooding of agricultural lands. Laboratory and field data indicate that pesticides are readily adsorbed on particulate matter and are carried in the runoff water to the aquatic environment where they are concentrated in the sediment. In a laboratory experiment water containing DDT was kept over soil covered by filter paper and in 24 hours 78% of the pesticide was found in the sediment (3). Seasonal increases in pesticide residues that coincide with peak periods of agricultural uses have been reported (4, 5). These reports indicate that silt (particulate matter) is a transportation vehicle into the aquatic environment. It has been stated, however, that only a small portion of the residues in fresh water gets there via drainage or runoff from agricultural lands (6).

Insecticides virtually disappear from water within 24 hours after application (7). Immediately after spraying a Montana forest with DDT at 1 lb/acre (1.12 kg/ha) a concentration of 0.10 mg/l DDT existed in the water. Thirty minutes later 0.33 mg/l was detected in the water, but after 27 hours no DDT was detected (8).

Adsorption to suspended particulate matter places the compounds in a finely dispersed and available form (9). Extensive fish die-offs were reported after a rain in a bayou; mud contained 520 μg/kg DDT (10). Adsorption on the sediment facilitates the transfer of pesticides to the benthic invertebrates and other silt-dwelling organisms and in turn to fish. This can lead to the elimination of invertebrate populations and subsequently starve the fish who feed on those invertebrates.

Recent discovery of the presence of PCB's in the aquatic environment has also generated a great deal of concern. They have become ubiquitous in world ecosystems in quantities similar to those of DDT (11). These chemicals are products of modern industry and their escape into the aquatic environment has created a serious problem. In 12 Alaskan bald eagles, median PCB residues were 1.65 mg/kg, lower than the median of 9.7 mg/kg for 11 eggs from Maine, Michigan, Minnesota, and Florida. Median concentration of PCB's found in eggs of royal tern nesting in the same area was 5.5 mg/kg (11). Both salmon and striped bass from the upper Hudson River and Lake Ontario contained PCB's in concentrations from 5 to 20 mg/kg, well above the 2 mg/kg Canadian limit for edible fish (12).

Health problems associated with PCB's in the environment have been established. Many investigators have shown that PCB's interfere with reproduction in rodents, fish, fowl, and primates. Animals fed PCB's develop intestinal ailments, enlarged livers, gastro-intestinal lesions, and abnormalities in the lymphatic system. In rodents fed 100 mg/kg PCB, malignant liver tumors have been observed (12). PCB's also produce adverse effects in man. In 1968, 1,291 Japanese exhibited the same effects shown by laboratory animals when they consumed cooking oil which had been contaminated with PCB's (12). These chemicals may enter the aquatic environment in a similar fashion to other chlorinated hydrocarbons, *i.e.*, direct application or adsorbed on particulate matter in runoff.

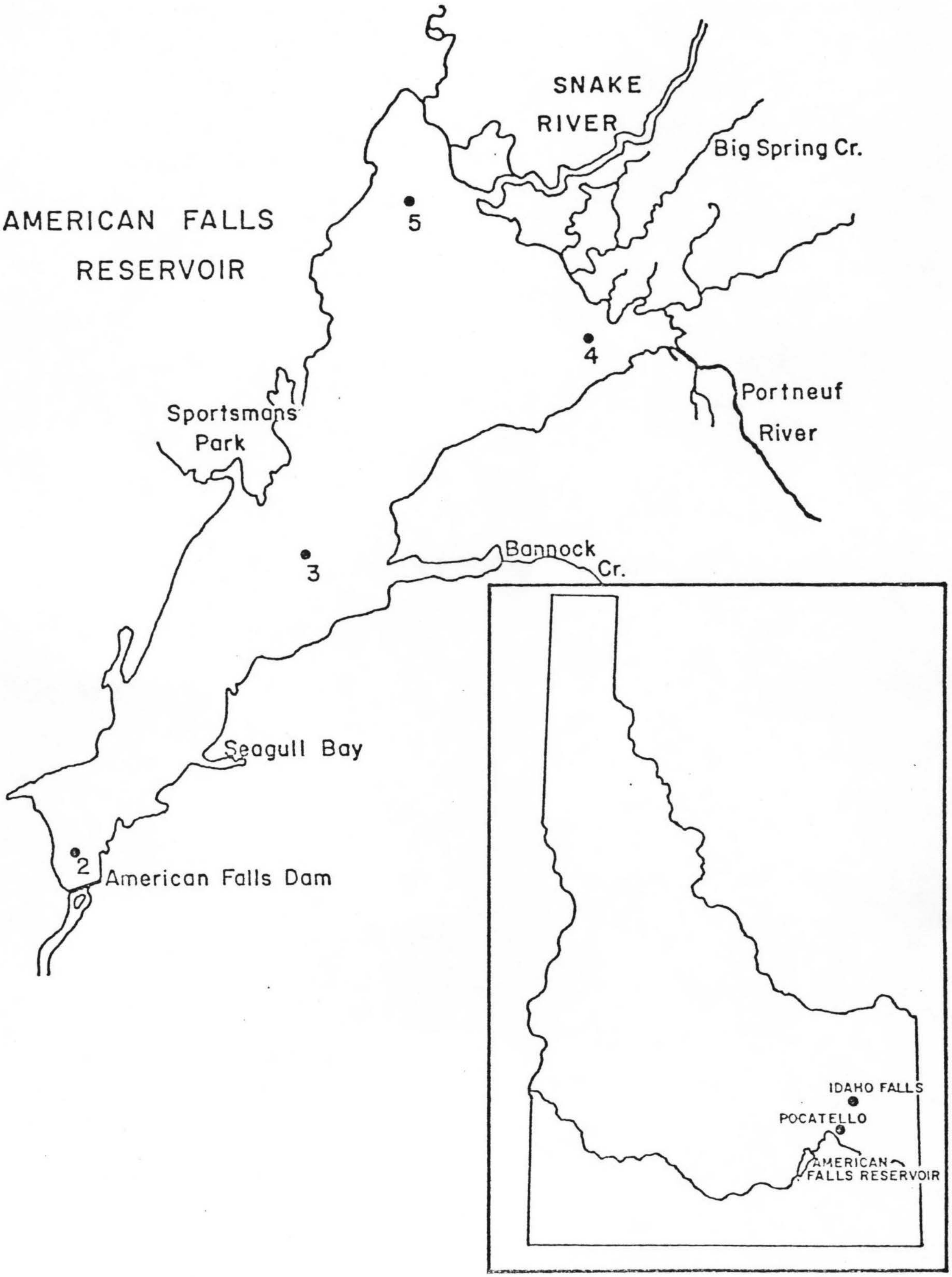
Silt laden with either pesticides or PCB's is carried by the current until it is deposited in slow-moving waters. Such is the case in reservoirs, where contaminated silt accumulates on the bottom.

Forage fishes, such as the Utah sucker, are vulnerable to this accumulation in the sediment. The white sucker is among the most susceptible species to DDT (13). These fish are usually found in large numbers in disturbed habitats, such as reservoirs, where an abundance of detrital food sources are found. Fry of these forage fish are an important part of the diet of the game fishes of American Falls Reservoir. Maintenance of the sports fishery is dependent on an adequate forage fish population. Bioaccumulation of pollutants by the adults could affect the reproductive success or the survival of the adults, and could result in a decrease in available prey for game fishes. Effects on fry can produce morphological and behavioral changes which may result in increased predation. These fry also contribute to biomagnification in the food chain, with higher concentrations of chlorinated hydrocarbons being found in the game species which consume them. The health of the fishes is not the only concern. The health of other predators including sports fishermen and their families, as well as birds, who consume fishes from the reservoir is threatened.

Research indicates that determination of pesticides in water alone is an inadequate measure for determining the safety of a fish population in a given habitat (14). Keith's studies emphasized the need to analyze both water and sediment samples (15). These values can be combined with other biological information such as fish residue values to give a good pesticide-pollution index (2).

The objectives of this study were to (1) analyze the concentration of chlorinated hydrocarbons in fish, water, and sediment in American Falls Reservoir; (2) compare these concentrations of organochlorines to Federal standards established to protect aquatic biota and public health; and (3) determine the distribution of these pollutants in the reservoir.

Description of the study area. American Falls Reservoir is located on the Snake River in Southeastern Idaho downstream from Idaho Falls and Pocatello (Fig. 1).



SNAKE
RIVER
Big Spring Cr.
AMERICAN FALLS
RESERVOIR
5
4
Portneuf
River
Sportsmans
Park
3
Bannock
Cr.
Seagull Bay
2
American Falls Dam
IDAHO FALLS
POCATELLO
AMERICAN
FALLS RESERVOIR

The reservoir has a capacity of approximately 2.0 x 10^9 cubic meters when full and a surface area of 22,663 ha. The reservoir is 35 km long and varies in width from 1.6 km at the dam to 16 km at the upper end. It has shoreline of 249 km and a maximum depth of 21 meters (1). During this study the maximum storage capacity was reduced by 34% because of structural deterioration of the dam.

The upper Snake and Portneuf River watersheds are the major sources of reservoir waters; however, Big Spring Creek and several smaller springs contribute as much as 22% of the reservoir inflow (Fig. 1). Inflow data by individual sources are given in Table 1. The Snake River watershed above the reservoir is 35,224 square kilometers and has averaged nearly 2 x 10^9 cubic meters of runoff per year. Water released at the dam is the only outlet from the reservoir. This water is used for the generation of power and irrigates 3.6 x 10^5 ha. A highly successful, diversified agriculture has developed during the half century since irrigation has been intensified. The principal crops grown in this area are cereals, potatoes, beans, sugar beets, alfalfa hay and pasture.

Table 1. Inflow data for American Falls Reservoir from May 7 to September 30, 1968, to the nearest 50 acre feet (16).

Body of water	Minimum inflow	Maximum inflow
Snake River	20,450	419,650
Portneuf River	500	20,700
Big Spring	7,900	18,900
Springs	4,650	13,050
Total inflow	72,850	546,900

Several species of fish are present in the reservoir. Native game fish present are the cutthroat trout (*Salmo clarki*) and mountain whitefish (*Prosopium williamsoni*). Game fish which have been introduced include rainbow trout (*Salmo gairdneri*), brown trout (*Salmo trutta*), kokanee (*Oncorhynchus nerka*), yellow perch (*Perca flavescens*), black crappie (*Pomoxis nigromaculatus*), white crappie (*Pomoxis annularis*), largemouth bass (*Micropterus salmoides*) and the black bullhead (*Ictalurus melas*). Native non-game species include the Utah sucker (*Catostomus ardens*), Utah chub (*Gila atraria*), longnose dace (*Rhinichthys cataractae*), speckled dace (*Rhinichthys osculus*) and sculpin (*Cottus* sp.), as well as introduced redside shiner (*Richardsonius balteatus*), mirror and common carp (*Cyprinus carpio*), and fathead minnow (*Pimephales promelas*). Carp and sucker are harvested commercially and sold for human consumption and fish food.

The trout fishery in American Falls Reservoir is the result of annual planting of rainbow trout by the Idaho Fish and Game Department (IFG). From 1963 to 1973 an average of 65,000 trout were planted in the reservoir. In 1974 the number dropped to 50,000 (17).

Peak fishing pressure occurs during June and July when a large number of anglers troll. From late August to December a small number of anglers are normally present near the dam. Ice fishing occurs from January to March. Yellow perch are an important component of the ice-fishing catch. From April to May the pressure slowly increases. There are no precise estimates of angling pressure at the reservoir; however, it has been estimated that between 15,000 and 25,000 angler days and between 45,000 and 75,000 angler hours occur annually (17).

Materials and Methods

Four stations (Fig. 1) were selected, from which water and sediment samples were collected. Fish samples were not confined to these stations. Water samples were collected from the mud-water interface using a Van Dorn water bottle. The water sample was brought to the surface and placed in a one-gallon glass jar which was then sealed with a lid lined with aluminum foil. Sediment samples were placed in one-quart glass jars which were then sealed with aluminum foil. Water and sediment samples were frozen until analyses were performed.

The five species of fish collected for residue analysis were Utah chub, yellow perch, black crappie, black bullhead, and the predominant forage fish, the Utah sucker. Fish samples were collected using otter trawl, gill nets, a commercial seine, and a D. C. shocking unit mounted on a 19-foot work boat. Whole fish were frozen except for large suckers, where sections of epaxial muscle were taken just anterior to the dorsal fin. Fish samples were wrapped in aluminum foil and frozen.

Pesticide separation was accomplished by using the Hesselberg and Johnson technique (18). Sulfur interferences in sediment samples were removed by the addition of copper. In samples where PCB's and other chlorinated hydrocarbons were present, separation was accomplished using the method described in the Manual of Analytical Methods (19).

Analyses were performed using a Hewlett-Packard, Series 7400 gas chromatograph (GC) with an electron-capture detector. The operating conditions were as follows:

Column: 6-ft glass, packed with 1.5% SP-2250/ 1.95% SP-2401 on 100/120 Supelcon AW-DMCS

Temperature:	Column	200°C
	Detector	210°C
	Injector	220°C

Carrier gas: Nitrogen at a flow of 25 ml/min

Volume injected: Approximately 5 ul of extract

Each sample was analyzed for endrin, aldrin, dieldrin, heptachlor, heptachlor epoxide, lindane, DDT, DDE, DDD, and PCB's. Quantitative analysis was accomplished by using the internal standardization technique. Qualitative analysis was achieved by using two separate chromatography columns and thin layer chromatography. The recovery was 71 to 98 percent. Residue values were not corrected for percent recovery. Quantitative and qualitative analysis for PCB's was performed by matching the unknown peaks on the chromatogram to the nearest commercial preparation and measuring the areas of four corresponding peaks (20). Area measurements were made by an electronic integrator. Linear regression was used in the analysis of data (21).

Results and Discussion

Only four organochlorines were detected in American Falls Reservoir. DDE and DDD were found in all fish and sediment samples. Dieldrin was found in only two species and polychlorinated biphenyls (PCB) were present in only one species. PCB's were also detected in the sediments.

Water. None of the water samples contained measurable quantities of organochlorines. This is to be expected because of the low solubility of these compounds: 3.4 μg/l DDT (22), 12.5 μg/l dieldrin (23), and 100 to 1000 μg/l PCB's, depending on the formulation (24). Residues in the reservoir are bound to the sediment and not associated with the water phase.

Sediment. Residues in the reservoir sediments are low and are bound tightly on soil particles, as expected in sediments which are composed of organic muck (24, 25). DDE and DDD were detected in all samples analyzed. The concentration varies with reservoir sampling stations. Sample areas 4 and 5 have a larger concentration of DDE than DDD. These two areas are exposed to more turbulence and do not develop anaerobic conditions. The reverse is true for areas 2 and 3 where anaerobic conditions develop and DDD is present in larger amounts (Table 2).

Table 2. Concentration of organochlorines in American Falls Reservoir sediments.

Area	n[1]	μg/kg (ppb)--wet wgt--sediments		
		DDD	DDE	PCB
2	3	1.55[2] (1.42-1.79)	1.46 (1.18-1.73)	22.65[3]
3	3	1.04 (0.79-1.31)	2.13 (1.69-2.53)	ND[4]
4	3	1.64 (0.53-3.60)	2.18 (1.09-3.80)	ND
5	3	1.68 (0.81-1.96)	2.21 (0.45-2.79)	28.74

1/ Sample size

2/ Mean (Range)

3/ Detected in a single sample

4/ Not detected

EPA has found a similar distribution in areas 2 and 3 (personal communication); they did not sample areas 4 and 5. DDT and BHC break down rapidly in bottom sediments (26, 27). Degradation is probably achieved via reductive dechlorination by anaerobic bacteria (27). Consequently, bacteria in reservoirs are important in the degradation and removal of certain pesticides from the aquatic ecosystem. PCB's were not as ubiquitous as DDD and DDE in reservoir sediments. The samples in two of the four areas sampled contained a mixture of Arochlor 1248 and 1254.

Fish. Although all fish sampled had organochlorines present, the type and quantity varied considerably between species (Table 3). DDE and DDD were found in all species sampled. Dieldrin appeared in the yellow perch and black bullhead. Two gravid bullhead contained markedly greater residues of dieldrin than the other bullheads sampled (Fig. 2). The ten perch analyzed were of varying size classes with the greatest concentrations of DDE, DDD, and dieldrin being found in the larger fish (Fig. 3). Since the yellow perch and black crappie have similar diets, it is interesting that no dieldrin residues were detected

Table 3. Chlorinated hydrocarbon residues in American Falls Reservoir fishes greater than 2 years old.

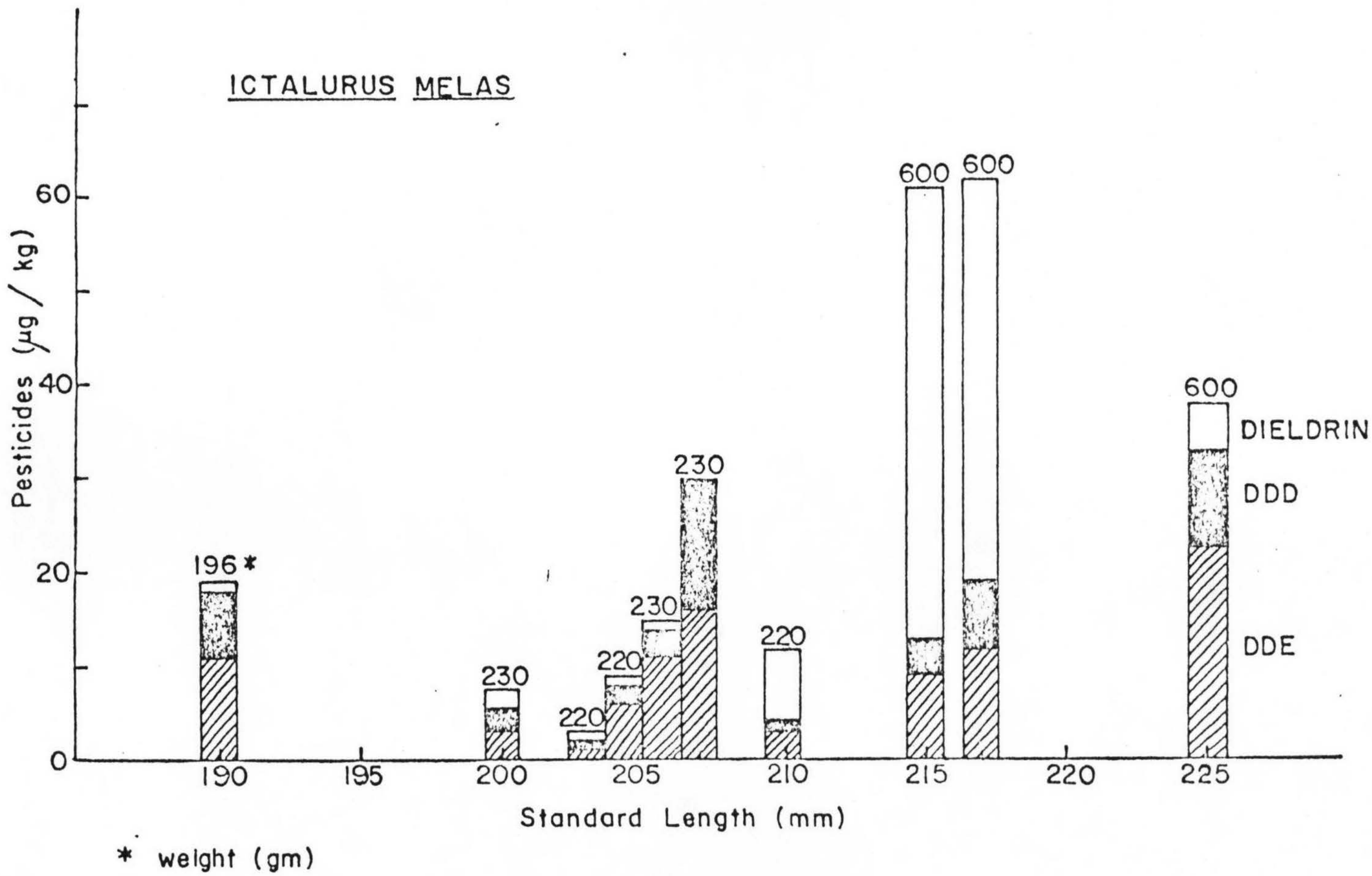
Species	n[1/]	Flesh residue--µg/kg (ppb)--wet weight DDE	DDD	Dieldrin	PCB's
Catostomus ardens	14	28.4 ± 6.8[2/] (1.1-82.1)[3/]	187.4 ± 68.6 (13.9-781.7)	ND	671.7 ± 89.0 (0-1144)
Perca flavescens	10	14.7 ± 7.8 (2.3-28.6)	5.7 ± 3.6 (1.2-13.4)	34.4 ± 3.2 (0-160.4)	ND
Ictalurus melas	10	9.5 ± 2.1 (1.0-22.6)	5.1 ± 1.4 (0.9-14.0)	11.0 ± 6.6 (0-48.4)	ND
Pomoxis nigromaculatus	20	20.7 ± 4.0 (3.0-67.2)	14.0 ± 3.1 (2.0-52.3)	ND	ND

[1/]sample size

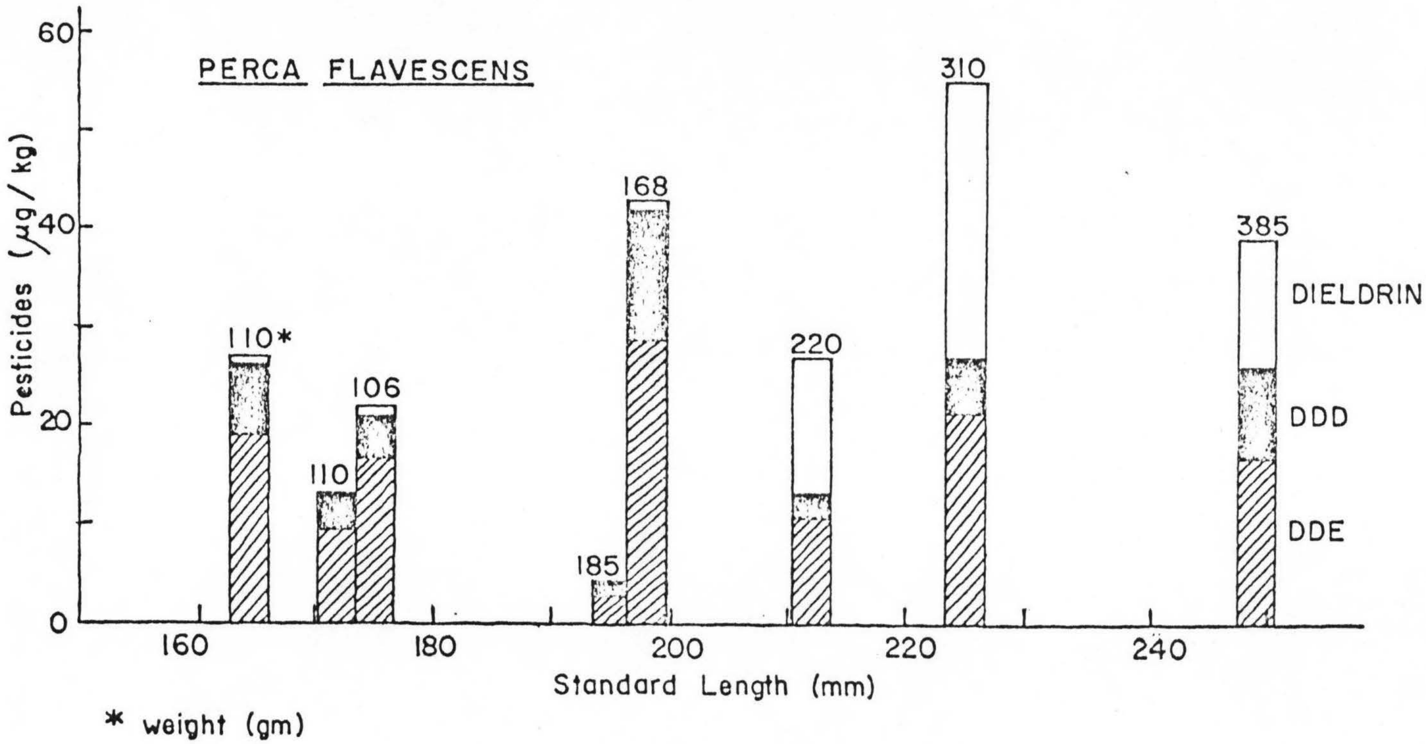
[2/]Mean ± standard error

[3/]Range

[4/]Not detected



ICTALURUS MELAS
Pesticides (µg / kg)
0
20
40
60
196 *
230
220
220
230
230
220
600
600
600
DIELDRIN
DDD
DDE
190
195
200
205
210
215
220
225
Standard Length (mm)
* weight (gm)



PERCA FLAVESCENS
Pesticides (µg / kg)
0
20
40
60
110*
110
106
185
168
220
310
385
DIELDRIN
DDD
DDE
160
180
200
220
240
Standard Length (mm)
* weight (gm)

in the black crappie (Table 3). Dieldrin was not detected in sediment from the areas sampled (Table 2). Sediment analysis by EPA in 1973 did indicate the presence of dieldrin in one of the six areas which they sampled (personal communication). Dieldrin is not ubiquitous in reservoir sediments and exposure to fish may be dependent upon the area which they inhabit.

The Utah sucker contained the highest concentration of organochlorines (Table 3). Constant contact of the detritus-feeding sucker with the sediment allows continuous exposure to the pesticides. This was the only species to contain polychlorinated biphenyls (PCB's). PCB's were not found in suckers less than two years old. Younger fishes inhabit the water near the shore and may not be exposed to PCB's. All sediment samples were collected from mid-reservoir. Near-shore samples have not been analyzed. Initial sampling indicates that the PCB's are not ubiquitous in the sediments; therefore, absence of PCB's in the younger suckers may be due to lack of exposure. Any definite conclusions will have to await further analysis of reservoir distribution of PCB's.

Young suckers, two years and less, have a greater concentration of DDE than DDD; older members of this species have a greater concentration of DDD than DDE (Table 4). This may result from metabolic changes associated with sexual maturation. Steroidogenesis may be particularly important in this metabolism. DDT metabolism has been increased by injecting rats with steroid hormones (28). The steroids induce the synthesis of non-specific hepatic microsomal oxidases which increase the metabolism of DDT. Similar action could occur in maturing Utah sucker. The variation will also depend on the degree of exposure of the two age groups to different concentrations of DDE and DDD in the sediments.

Residue levels of DDE and DDD in American Falls Reservoir suckers and yellow perch are similar to residues found in suckers and yellow perch from lakes and rivers used as sampling stations in the National Pesticide Monitoring Program (NPMP) (29). PCB's in the sucker and dieldrin in the black bullhead were also similar. Black crappie and black bullhead had DDE and DDD residues lower than those found by the NPMP. NPMP values were, however, calculated on a whole

Table 4. Chlorinated hydrocarbons in American Falls Reservoir *Catostomus ardens* by age group.

Age (yrs)	n[1]	Flesh residue-µg/kg(ppb)-wet wgt DDE	DDD	PCB's
2	6	5.4 ± 1.2[2] (1.5-8.0)[3]	3.0 ± 1.1 (0-7.8)	ND
2-3	6	12.2 ± 2.9 (1.1-19.3)	43.0 ± 7.7 (13.9-71.4)	570 ± 156 (0-1029)
3	8	40.5 ± 9.8 (3.3-82.1)	295.6 ± 106.5 (23.4-781.7)	748 ± 104 (179-1144)

1/Sample size

2/Mean ± Standard Error

3/Range

4/Not Detected

fish basis. The values given for American Falls Reservoir fishes are based on edible muscle tissue. The differences between values obtained for whole fish and muscle can be seen by comparing Tables 3 and 5. In all species except the sucker the concentration of pesticides present in whole fish are greater than those concentrations found in edible tissue. Fishes used in the determination of whole fish residues were younger and much smaller (1 to 10 g). Fishes analyzed for organochlorines in edible tissue ranged from 21 to 2112 g for suckers, 196 to 600 g for black bullheads, 60 to 385 g for yellow perch, and 260 to 690 g for black crappie. Fishes of this size serve as food for fish-eating birds and predatory game fish in the reservoir. Therefore, it appears that exposure of larger fishes in the reservoir may be considerably greater than indicated by values given for muscle tissue. These whole fish samples indicate that American Falls Reservoir fishes contain residues which may exceed those found by the NPMP. Information concerning whole fish concentrations is most important in evaluating exposure to fish-eating birds and possible effects on survival and maintenance of fish

Table 5. Concentrations of organochlorines in whole fishes from American Falls Reservoir.

Species	n[1/]	µg/kg-whole fish-wet weight DDE	µg/kg-whole fish-wet weight DDD
Ictalurus melas	39	88.9[2/] (±11.6)[3/]	127.0 (± 26.7)
Catostomus ardens	81	68.7 (± 9.8)	51.6 (± 5.9)
Pomoxis nigro-maculatus	18	75.0 (± 4.1)	37.2 (± 3.6)
Perca flavescens	30	50.7 (± 2.6)	42.9 (± 3.2)
Gila atraria	11	51.0 (± 5.9)	29.6 (± 2.8)

[1/]Sample size

[2/]Mean

[3/]Standard Error

species in the reservoir. The human and public health threat are best evaluated by flesh residues and have been emphasized here.

The concentration of dieldrin in yellow perch from American Falls Reservoir was equal to that found in yellow perch from Lake Huron (30) and exceeded values (0.001 to 0.015 mg/kg) found in yellow perch from lakes and streams in Ontario, Canada (31). Lake Huron values were based on whole fish samples. DDT metabolites found in whole body samples of Ontario suckers were in quantities similar to those found in flesh of suckers from American Falls Reservoir. The average sediment residues for DDE, DDD, and dieldrin in Ontario waters were for the most part much higher than those found in American Falls Reservoir, yet suckers taken from American Falls contained amounts of DDE and DDD equal to those from Ontario waters. Fish from McNary Refuge, Washington contained 0.7 to 6.4 mg/kg DDT and DDD, with 0.1 to 0.4 mg/kg DDT and DDD in associated sediments; at Deer Flat, Idaho, where sediments had 68.0 to 94.0 mg/kg DDD, the maximum for fish was 0.2 mg/kg DDD (32). In a third reservoir (Tuttle Creek, Kansas), while no DDT, DDE, DDD, or dieldrin was found in the sediments, they were present in the fish with a maximum of 0.17 mg/kg

DDT and 0.17 mg/kg dieldrin (33). There appears to be no correlation between sediment residue and bio-concentration in fishes.

Chlorinated hydrocarbon residues in American Falls Reservoir did not exceed FDA recommended standards of 5 mg/kg DDT, .3 mg/kg dieldrin, and 2 mg/kg for PCB's. In the larger suckers, total DDT metabolites approach 1 mg/kg. These suckers are the ones which are harvested and sold for human consumption. At this level EPA has recommended that precautionary measures should be taken to avoid endangering the health of those who consume them (21).

The FDA maximum allowable limit for PCB's is 2 mg/kg. EPA has recommended that PCB concentrations in any sample consumed by any bird or mammal be no greater than 0.50 mg/kg (21). The U. S. Fish and Wildlife Service regards the presence of 0.50 mg/kg in a fish as an indication of a pollution problem (34). Average concentration for suckers from American Falls Reservoir was 0.67 mg/kg. Consumption of fishes from the reservoir may present a problem to their predators.

The problem of egg shell thinning in birds which consume contaminated food sources is well documented. The concentration of DDT residues in carnivorous birds are 10 to 100 times those in the fish they consume (35). Eagles, eating fish with hundredths to tenths of mg/kg PCB, had muscle concentrations from 150 to 240 mg/kg (36). It seems apparent that fish-eating birds at American Falls Reservoir could accumulate dangerous levels of chlorinated hydrocarbons.

Gravid black bullheads from the reservoir contained greater concentrations of pesticides (Fig. 3), particularly dieldrin, than other bullheads sampled. There was a highly significant correlation ($P < .01$) between dieldrin and condition factor and a significant correlation ($P < .05$) between the weight of this species and dieldrin concentration. The larger weight and condition factors were the result of mature gonads. The increase in dieldrin during critical reproductive stages could significantly affect the survival of the young. DDT and other organochlorines are stored to a greater extent in the lipoprotein, phospholipid, and fat of eggs. There is greater affinity for the glyceride fats of the egg and yolk. Upon absorption of the yolk containing DDT residues, rainbow trout fry developed a distended air bladder and air in the intestinal tract and died (37).

The continuance of a sports fishery in the reservoir is dependent upon the reproductive success of all reservoir fish populations. Organochlorines are concentrated in the gonads. DDT in lake trout (Salvelinus namaycush) at 2.93 mg/kg caused 100% mortality of fry. Death occured after absorption of the yolk sac (37). Egg hatchability, mean time of hatching, and alevin survival and growth all decreased when coho salmon (Oncorhynchus kisutch) eggs and alevins were exposed to 4.4 µg/l Arochlor 1254 (38). Adult sheephead minnows (Cyprinodon variegatus) exposed to 0.1, 0.32, 1.0, 3.2, or 10.0 µg/l of PCB-1254 also had reduced embryo and fry survival (39). DDT inhibits spermatogenesis in rats (40). Similar effects may occur in fish. Concentration of pesticides by prey species may affect their reproductive success. Chlorinated hydrocarbon residue levels in American Falls Reservoir prey species appear to justify this concern.

The Utah sucker is the predominant forage fish in the reservoir and is an essential part of the diet of many game species. The reproductive success of this species is important in maintaining a stable community structure. Organochlorine residues are higher in the

Utah sucker than in other species of the reservoir; they contain DDT metabolites and PCB's in high concentrat-tions. Adult sheephead minnows, exposed to PCB 1254 in a range from 0.1 to 10.0 µg/l for four weeks, produced eggs with a PCB concentration as high as 201 µg/g. Although fertilization success was unimpaired, survival of embryos and fry were reduced. Fry from eggs containing 7.0 µg/g or more began dying 24 to 48 hours after hatching (38). Although no PCB's were found in American Falls Reservoir water, and large numbers do not spawn in the reservoir where PCB's have been found, the possible effects of PCB's on reproduction are not negated.

During the summer of 1975, 75% of the suckers collected had fungus-like growths on their heads or sides. Similar symptoms developed with exposure of pinfish to 5 µg/l Arochlor 1254 (36). After these fish were returned to flowing water, free from PCB's, most died. Much higher concentrations were found in the larger sucker of American Falls Reservoir than in the experimentally exposed pinfish. Although the PCB's in the reservoir were not demonstrated to have directly caused the lesions and fungus-like growth on the sucker, it is a possible explanation.

The presence of organochlorines alone places stress upon the fishes and affects the health and behavior of the fish species. Certain environmental parameters, especially temperature, add to the problem (41). DDT toxicity increases with decreasing temperature (41, 42). This presents a paradoxical situation. Most fish seek colder water where sufficient oxygen content is present, increasing the toxicity of DDT. On the other hand DDT (50 µg/kg) has been found to affect the thermoregulatory ability of fish and cause them to seek warmer temperatures, placing additional stress on the fish (43).

Organochlorines in American Falls Reservoir sediments are accumulated in fishes of the reservoir. Consumption of these fishes may be a health hazard to sports fishermen and their families. Suckers sold for human consumption contain residues of PCB's and DDT metabolites at levels which are considered hazardous by the Environmental Protection Agency. Suckers from the reservoir are sold for human consumption. A more intensive sampling program is needed to indicate if there is a need to prohibit the use of suckers and other fishes for human consumption.

SECTION II--

MERCURY, CADMIUM, AND ARSENIC

Introduction

The significance of heavy metals as pollutants of aquatic ecosystems has received greater attention since the discovery of mercury as the causative agent in "Minamata Disease." The potential hazards that can arise from continual deposition of heavy metals in lakes and rivers require detailed investigation of their toxicity and accumulation in aquatic organisms. While mercury has received the most attention, other metals, such as arsenic and cadmium, also contribute to the pollution of aquatic ecosystems.

Since the "Minamata incident," excessive amounts of mercury have been discovered in the aquatic habitat of other areas of the world. In 1970 the discovery of sizable quantities of mercury in Lake St. Clair and the Detroit River resulted in a ban on the sale of commercial catches of fish from these waters (44). Elevated mercury levels were also found in 10 species of fish from the Saskatchewan River (45). Fish sold from this area were restricted to those containing less than 0.5 mg/kg mercury. Over a three to four month period one million pounds of fish were destroyed. In December 1970, two and one-third million cans of tuna were confiscated because one percent had a mercury content above the Food and Drug Administration (FDA) standard of 0.5 mg/kg. More recent studies of fishes from Idaho, California, Oregon, and Washington revealed maximum levels up to 1.9 mg/kg mercury (46).

Mercury ore occurs in shale, slate, and limestone. Cinnabar ore (HgS) occurs naturally in the environment and is commonly associated with minerals such as pyrite. A second source of contamination is through the activities of man. Mercury may enter the aquatic environment as a by-product of zinc, copper, lead, and gold processing. In 1969, 1,082,000 pounds of mercury were used in these processes. Phenylmercuryacetate is used by the paper and paint industry to retard growth of micro-organisms. Mercuric fungicides have also been used to coat seeds. The burning of coal, which may contain up to 8.0 mg/kg mercury, may also be a mechanism by which mercury enters natural waters (47).

Once mercury enters the aquatic environment, it is available to all components of the ecosystem for biomagnification and accumulation. In Lake Powell, with mercury levels of 0.01 μg/kg in the water, 34 μg/kg was found in plant leaves, 28 μg/kg in algae, and 232 μg/kg in fish muscle (48). The effects mercury may have on the stability and development of aquatic habitats are not fully understood.

Even though widespread pollution of the aquatic environment by cadmium has not been reported, incidents of cadmium pollution have been found. In 1970 the Japanese proved that cadmium was the cause of the disease "itai-itai." It was contracted by eating rice that had been irrigated with river water polluted by runoff from a cadmium mine (44). Cadmium is present in natural waters in very low amounts (49). A nationwide survey of 720 lakes and rivers in the United States revealed that only 4% of the samples were greater than 10 μg/l (50). Missouri mine waters had cadmium levels as high as 1000 mg/l (51). Although pure cadmium is not found in commercial quantities in nature (52), it is obtained as a by-product of zinc, lead, and copper smelting as well as several other industrial processes. Phosphate fertilizers contain 50 to 170 mg/kg cadmium (53). Waters located in phosphate mining and processing areas in Idaho, as well as downstream reservoirs, should be monitored for potential cadmium pollution.

It is not known whether man's contribution has significantly increased the levels of cadmium in the ocean. Sea water contains 0.1 mg/l cadmium (54). Marine organisms, particularly molluscs, concentrate cadmium from very low levels. The cadmium is concentrated in the calcerous tissues and in the viscera (55). Fishes from the North Atlantic contained cadmium levels from less than 0.1 to 2.1 mg/kg. In herring, cod, and whiting from the coastal area of southern Norway, cadmium concentrations ranged from 0.002 to 0.12 mg/kg. Little data are available on cadmium residues in freshwater fish. Fishes from 49 freshwater sources in New York had an average concentration of 20 ug/kg or below. A mean value of 94 μg/kg was found in four species of fish from the Great Lakes (56).

Arsenic was found in less than 6% of water sampled in 1962 by the Federal Water Quality Administration. Four percent of the samples from Lake Erie had an average of 0.038 mg/l arsenic (44). Accumulation of arsenic in aquatic organisms has not been well documented. Fishes of the North Atlantic contain concentrations of arsenic from less than 1.0 to 19.0 mg/kg (57). Mean values of 5.6 to 80.0 μg/kg were found in 15 species of fish from the Great Lakes (56). Poisoning from high levels of arsenic in water are rare; however, such poisonings have occured in New Zealand (58).

Arsenic occurs in nature in small amounts in the elemental form; it is found mostly in arsenides of metals or as pyrites. Copper, lead, zinc, and tin ores contain arsenic and it can enter the aquatic habitat in effluent from their processing. The major use of arsenic has been as a pesticide and wood preservative. It has been used in Southern Idaho to kill potato vines prior to harvest. It has been replaced, for the most part, by the more popular organochlorines, organophosphates, and burning of potato vines. In waters carrying or in contact with natural colloidal materials, the dissolved arsenic content may be decreased to a low level by adsorption.

All of these metals may attain high concentrations in the water and sediments of aquatic habitats. Reservoirs are particularly prone to act as a "trap" for silt and suspended particulate matter in runoff. The metals are concentrated in the bottom sediments and are available to detrital feeding organisms. Biomagnification by fishes may occur, rendering them unfit for consumption. Such has been the case in Idaho. In 1970 the Idaho Health Department collected 160 fish from Idaho waters and analyzed them for mercury content. Approximately 19% of the fish collected exceeded the FDA standard of 0.5 mg/kg (59). Thirty percent of the fish taken from American Falls Reservoir had levels exceeding 0.5 mg/kg. Similar mercury concentrations were found in fish taken from other impoundments on the lower and middle Snake River. Further investigations in 1971 revealed that rainbow trout (Salmo gairdneri) in American Falls Reservoir had a mean value of 0.33 mg/kg with a maximum of 0.91 mg/kg (59). Elevated levels were also detected in brown trout (Salmo trutta) and cutthroat trout (Salmo clarki). Yellow perch (Perca flavescens) from the reservoir had concentrations in muscle tissue of 0.09 to 0.84 mg/kg with 57% of the total sample at or above 0.5 mg/kg (59). Mercury concentration in American Falls Reservoir fishes has been a problem. Has mercury continued to be accumulated in the reservoir and are other metals, such as arsenic and cadmium, being transported into the reservoir and accumulated by the sediment and fishes?

The objectives of this study were (1) to determine mercury, arsenic, and cadmium concentrations in fishes, water, and sediments from American Falls Reservoir; (2) to compare these concentrations of heavy metals to Federal standards established to protect aquatic biota and public health; and (3) to determine the distribution of these pollutants within the fish community.

Materials and Methods

American Falls Reservoir is a Snake River impoundment in Southeast Idaho and has been described in some detail elsewhere (60). Sediment and water samples were collected from four areas of the reservoir to determine the distribution and quantity of cadmium, arsenic, and mercury. Fish samples were collected from numerous locations.

Water samples were collected using a Van Dorn water bottle. The sample was placed in a one-liter plastic container and concentrated nitric acid was added (61). Sediment samples were collected using an

Ekman dredge. The samples were placed in one-quart glass jars, which were then sealed with aluminum foil.

Five species of fish were collected for heavy metal analysis: rainbow trout (Salmo gairdneri), yellow perch (Perca flavescens), black crappie (Pomoxis nigromaculatus), black bullhead (Ictalurus melas), and the predominant forage fish, Utah sucker (Catostomus ardens). Samples of rainbow trout were difficult to collect. Those obtained from sports fishermen limited the amount of tissue available for analysis. Rainbow trout were, therefore, analyzed only for mercury and arsenic. Whole fish were collected except for rainbow trout and the larger suckers where large sections of epaxial muscle were taken just anterior to the dorsal fin. Fish samples were wrapped in aluminum foil and frozen.

All samples were analyzed using a Varian 1200 atomic absorption spectrophotometer with a Model 63 carbon rod atomizer and the Model 64 As/Se/Hg Analysis Kit. A Neff 401 recorder was used to record the results.

The vapor generation technique was used for the determination of mercury in fish, water, and sediments (62). Arsenic was determined using Duncan and Parker's technique (62). Lead and cadmium in water were determined by direct application to the carbon rod unit. Fish samples (.5 g) were digested with 10 ml of nitric acid and analyzed directly on the carbon rod (63). Sediment samples (.5g) were digested with 10 ml of nitric acid and diluted to 20 ml with distilled water. These samples were analyzed directly on the carbon rod. Quantitative analysis was achieved by using the standard addition technique (64). Values were not corrected for percent recovery. Linear regression was used in analysis of data (65).

Results and Discussion

In determining contamination of an aquatic ecosystem by heavy metals all components (water, sediments, and fauna) should be analyzed. This gives a complete picture of the total contamination of the system. Examination of only one contaminant does not properly reveal the hazards to the aquatic ecosystem. Synergistic effects could render a "safe" level of one contaminant lethal and result in the decline and elimination of certain species. Other heavy metals alone might be lethal.

Studies on American Falls Reservoir have not taken this approach. Mercury accumulation in water, sediment, and trout, as well as other species of game fish, have been determined (66). The U. S. Environmental Protection Agency (personal communication) determined the concentration of arsenic, mercury, and cadmium in water. These reports have been based on analysis of only one contaminant or one component of the aquatic ecosystem.

Cadmium, mercury, and arsenic were determined in this study for fish, water, and sediments. These analyses provided additional information and a more complete picture of the total contamination of American Falls Reservoir. Cadmium and mercury were found in water, sediment, and fish. Arsenic was found only in the water and sediment.

Mercury concentrations in water varied at each sample site (Table 6). The maximum value found in water samples was 1.78 µg/l. The Idaho Health Department found a maximum of 1.8 ug/l and Runyan found 1.3 µg/l (66). Analysis for mercury in 73 rivers in the United States showed 27 had a range of 0.1 to 1.0 µg/l (67). Mercury in an uncontaminated river of

Table 6. Heavy metals in American Falls Reservoir water and sediment.

Area		n	Mercury	Cadmium	Arsenic
2	Water[1/]	3	0.72[3/] (0.25-1.52)	9.23 (6.42-11.26)	12.60 (6.42-11.26)
	Sediment[2/]	3	0.35 (0.21-0.42)	0.62 (0.60-0.64)	2.02 (1.57-2.40)
3	Water	3	0.70 (0.45-1.20)	14.64 (6.62-24.47)	15.67 (3.0-25.50)
	Sediment	3	0.49 (0.42-0.53)	0.39 (0.36-0.64)	1.83 (1.38-2.20)
4	Water	3	1.02 (0.55-1.78)	6.64 (1.67-10.63)	16.50 (3.50-30.50)
	Sediment	3	0.53 (0.21-0.95)	0.43 (0.14-0.72)	1.56 (1.40-1.75)
5	Water	3	1.02 (0.30-1.47)	5.95 (1.0-9.67)	4.67 (3.0-8.0)
	Sediment	3	0.32 (0.32-0.32)	0.94 (0.64-1.24)	1.38 (1.36-2.04)

[1/] μg/l

[2/] mg/kg

[3/] mean (range)

	Mercury	Cadmium	Arsenic
Environmental threat in excess of EPA standard	0.2 μg/l	2.0 μg/l	50.0 μg/l

Sweden had a concentration of 0.13 µg/l. Ground waters have been found to contain from 0.02 to 0.07 µg/l (68). Mean values of mercury in American Falls Reservoir ranged from 0.70 to 1.02 µg/l, 70 to 100 times those for Lake Powell, a desert reservoir. Lahontan Reservoir in Nevada contained 2.10 µg/l in surface waters (69). These values are above the 0.03 µg/l level presumed to be the mean natural mercury content for uncontaminated water (70). They also exceed the Federal criteria of 0.2 µg/l (personal communication).

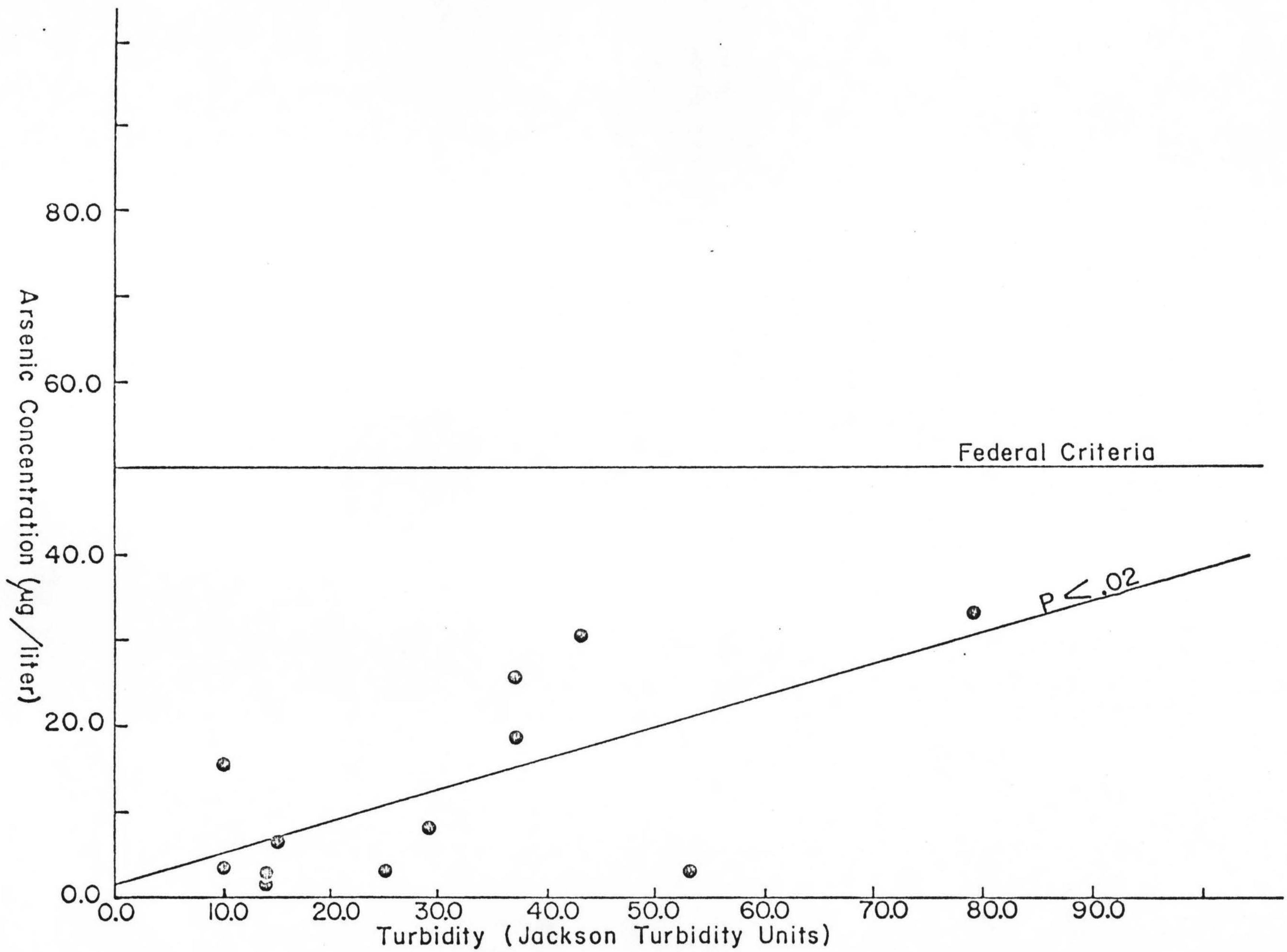
Cadmium concentrations from 1.0 to 24.5 µg/l were found in American Falls Reservoir. It appears that most lakes and rivers in the United States contain 10 µg/l or less. Analysis of 720 lakes and rivers revealed that 41 percent had concentrations from 1 to 10 µg/l and 4% of the waters sampled ranged from 12 to 130 µg/l (50). In 1962 the Federal Water Quality Administration found an average of 10 µg/l in 130 sampling sites across the United States (44). Values in American Falls Reservoir were similar to those in Foundry Cove, Hudson River, a known recipient of cadmium waste. The concentration in Foundry Cove ranged from 5 to 26 µg/l (49). The National Academy of Sciences considered 2.0 μg/l harmful to aquatic life (personal communication).

Arsenic compounds have been found to occur naturally in some waters of the Western states (51). In American Falls Reservoir, arsenic concentrations ranged from 1.50 to 33.0 μg/l (Table 6). Similar values have been reported from other areas of the country. Water in Kansas contained 2.6 μg/l arsenic, while in Lake Erie and the St. Lawrence River concentrations of 0.308 and 0.058 μg/l, respectively, were found (71, 44).

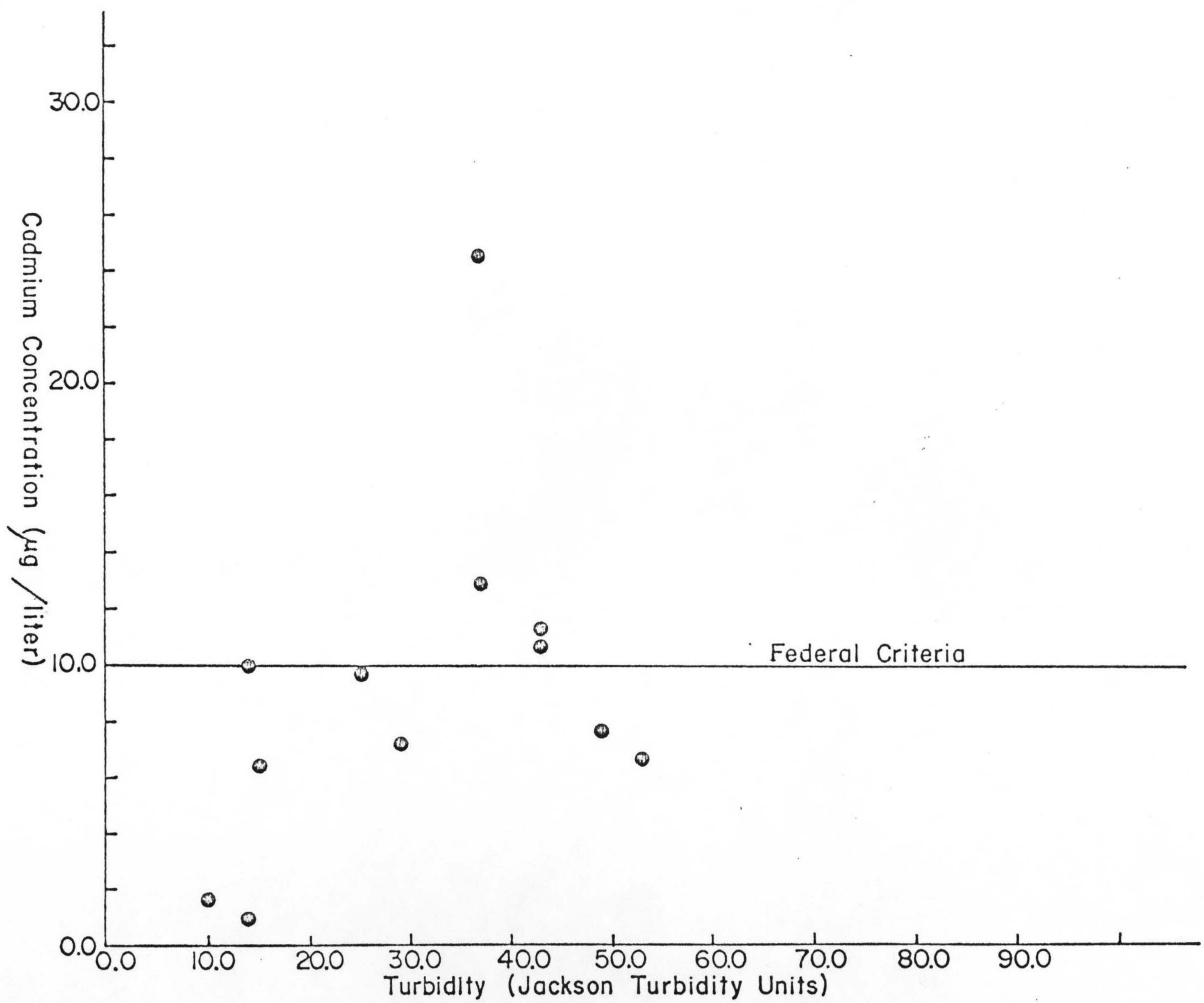
Heavy metals are adsorbed on particulate matter and their concentration in water may be correlated with the degree of turbidity (72). The correlation between turbidity and heavy metal concentration in American Falls Reservoir is illustrated in Figures 4, 5, and 6.

Levels of heavy metals present in water may not indicate the total amount present in the aquatic system. Sediments should also be analyzed. Since heavy metals are adsorbed on particulate matter, it is in the sediment that the greatest concentrations are usually found.

Cadmium concentrations in the Illinois River water ranged from 0.10 to 2.0 μg/l. Sediment from the same



Federal Criteria
P ≤ .02
Arsenic Concentration (μg/liter)
0.0
20.0
40.0
60.0
80.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
Turbidity (Jackson Turbidity Units)


Cadmium Concentration (µg /liter)
30.0
20.0
10.0
0.0
Federal Criteria
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
Turbidity (Jackson Turbidity Units)

river contained 0.2 to 12.1 mg/kg (73). The Hudson River had little dissolved cadmium, 3.0 to 6.0 μg/l, but the mud had a cadmium content of 162 mg/kg. Four Alabama rivers had 6, 12, 65 and 90 μg/l cadmium; however, cadmium was found only at the source and not downstream. Fish from the Hudson River contained 0.2 to 304 mg/kg cadmium, while those from the Alabama Rivers had a maximum of 0.08 mg/kg (49). We should, therefore, be concerned with the sediment concentration, as well as water levels. These instances indicate there may be no correlation between water and sediment concentrations. This is true for American Falls Reservoir; linear regression analysis between concentration of cadmium in the water and its concentration in the sediment exhibited no correlation at the .05 level. Cadmium concentration in the sediments in American Falls Reservoir are low (Table 6). Sediments in the Illinois River had a mean value of 2.0 mg/kg.

Mercury exhibited the same distribution between water and sediment as cadmium. Mercury concentrations in American Falls Reservoir sediment ranged from 0.32 to 0.53 mg/kg (Table 6), 300 to 700 times the concentration found in the water. In Lake Powell .03 mg/kg were found in the sediment. Mercury concentration in the water was only 0.01 µg/l (48). Sediment samples from the western shores of Lake Erie had values less than 0.05 mg/kg (74). Values reported from California sediment investigations ranged from 0.04 to 33.0 mg/kg (75).

Methylation of mercury takes place in bacteria present in the sediment. This reaction is important because the solubility of methylmercury permits the compound to be directly absorbed across the gills of fish (76).

Arsenic is easily transported to the sediments since it is readily adsorbed by colloidal and suspended matter (52). In American Falls Reservoir a significant correlation ($p < .05$) existed between turbidity and concentration of arsenic. Arsenic concentrations ranged from 1.36 to 2.40 mg/kg.

Pita and Hyne (1975) studied the deposition of heavy metals in a reservoir and noted that they were adsorbed on suspended materials and carried by water flowing through the reservoir. The higher concentrations were found in the deeper water sediments (72). Only arsenic in American Falls Reservoir exhibits this type of distribution. Mercury and cadmium in sediments were not depth dependent.

Background levels of mercury in fish have been generally accepted as being 0.20 mg/kg (70). Mean values of mercury for yellow perch, black bullhead, and hatchery stocked trout do not exceed this value. Utah sucker, black crappie and larger rainbow trout have mean values greater than 0.2 mg/kg (Table 7). These values approach the FDA standard of 0.5 mg/kg for fish flesh (46). Thirteen percent of the Utah suckers, 21% of the black crappie, and the large rainbow trout exceeded this standard. The mean value of mercury for all fishes from American Falls Reservoir was 0.31 mg/kg. Fishes from Lake Powell contained 0.23 mg/kg (48). Fishes from Ross Barnett Reservoir (Mississippi) and Lahontan Reservoir (Nevada) ranged from 0.05 to 0.74 mg/kg and 0.20 to 2.72 mg/kg, respectively, in mercury content (77, 69). Mercury concentrations for hatchery trout and yellow perch from American Falls Reservoir were similar to those found in 1971 (66); however, concentrations found in suckers increased from 0.11 to 0.37 mg/kg and black bullhead concentrations decreased from 0.36 to 0.1 mg/kg.

Table 7. Mercury in American Falls Reservoir fishes.

Species	n[1]	mg/kg (ppm)--wet weight Mean	S.E.[2]	Range
Catostomus ardens	15	0.37	0.06	0.10-0.82
Perca flavescens	10	0.19	0.02	0.11-0.33
Ictalurus melas	10	0.17	0.03	0.10-0.34
Pomoxis nigro-maculatus	14	0.37	0.06	0.12-0.80
Salmo gairdneri Hatchery stock (20 cm)	16	0.13	0.02	0.05-0.30
Carry-over	1	0.64	--	--

[1]Sample size

[2]Standard Error

Accumulation of mercury by fishes may or may not be directly correlated with age, length, or weight. Positive correlations between mercury concentration and all of the above factors have been reported by various authors (48, 78, 79, 80). Runyan reported no correlation between weight and mercury concentration in rainbow trout from American Falls Reservoir, but a significant correlation at the .05 level between length and mercury concentration (66). Other authors have reported no correlation between either weight or length and concentration of mercury (45, 78). There was no significant correlation between weight, age, length, or condition factor and mercury concentration for any species analyzed in this study. Fish of the same size and species, with identical exposure, showed maximum concentrations up to 10 times the minimum (81). Chronic exposure to low levels of mercury resulted in fishes acquiring about the same tissue concentrations regardless of size (82). It appears, therefore, that the conditions at the time of exposure are more influential than age, weight, length, condition factor, or concentration.

Cadmium present in the reservoir does not seem to be concentrated in fish as readily as mercury (Table 8). Cadmium is not as easily mobilized from the sediments as mercury. The high calcium carbonate, hard water of American Falls Reservoir may cause cadmium to precipitate out (83) and collect in the bottom sediment, probably causing exposure to be dependent upon ingestion of contaminated fish or particulate matter. The degree of correlation between suspended particulate matter and water concentration of cadmium is presented in Fig. 5. There is no evidence that cadmium is absorbed across the gill epithelia. In the Illinois River where sediments had an average of 2.0 mg/kg cadmium, fishes contained 0.03 mg/kg (73). Larger concentrations of cadmium, ranging from 0.06 to 1.4 mg/kg, were found in Great Lakes fishes (56). Black bullhead, black crappie, and yellow perch from New York waters had levels of 27.3 µg/kg, 20.0 to 23.10 µg/kg, 12.0 to 14.70 µg/kg and 16.40 to 51.0 µg/kg cadmium, respectively (84). From the data available it appears that the mean values for cadmium in American Falls Reservoir fishes are higher than those previously found elsewhere. There was no correlation between size

Table 8. Cadmium in American Falls Reservoir fishes.

Species	n[1]	mg/kg (ppm)--wet weight		
		Mean	S.E.[2]	Range
Catostomus ardens	16	0.19	±0.04	0.08-0.60
Perca flavescens	9	0.23	±0.03	0.14-0.44
Ictalurus melas	10	0.15	±0.05	0.04-0.30
Pomoxis nigro-maculatus	16	0.19	±0.03	0.03-0.45

[1]Sample size

[2]Standard Error

and cadmium concentration in fishes analyzed from American Falls Reservoir. A similar absence of relationship was found in fishes from New York waters (84).

Arsenic was not found in fishes from American Falls Reservoir. Accumulation may be dependent upon the valence state of arsenic. Arsenate (pentavalent) is accumulated and excreted rapidly through the kidneys and probably does not accumulate in the tissues (69). Fish collected from a lake 21 days after application of arsenic showed no significant increase in arsenic accumulation, although water concentrations reached a maximum of 7.0 mg/l (85). This explains the absence of arsenic in American Falls Reservoir fishes.

It should be recognized that the chemical and physical characteristics of aquatic ecosystems may limit, enhance, or modify the uptake by and toxicity of heavy metals to fishes. Methylation of mercury in the sediments by bacteria is a critical step in increasing mercury availability to fish. Practically all mercury in fish is methylmercury (46). Mobilization and methylation from sediment is dependent on several factors. Low concentrations in the sediment are mobilized and methylated faster than higher concentrations. These processes occur more readily in aerobic than in anaerobic conditions. The addition of the nutrients carbon, phosphate, nitrogen and other trace elements also increases the rate of methylation, presumably by stimulating an increase in methylating bacteria (86, 87). Methylmercury is easily absorbed through the gills. Mercury may be present in several inorganic forms. The amount of inorganic mercury in the water and absorbed by fish is pH dependent. In alkaline conditions, as in American Falls Reservoir, inorganic mercury is readily released from the sediment into the water (87). Inorganic mercury is not readily absorbed by fish from water with a high pH. Halides, such as florides, in American Falls Reservoir water might form complexes with inorganic mercury facilitating its absorption by fish. Sulfides also increase the uptake of inorganic mercury (87). Since hydrogen sulfide develops in the anerobic bottom waters of the reservoir, it may be brought up to the surface waters when overturn occurs in autumn, facilitating absorption of inorganic mercury. Inorganic mercury can be methylated in the fish (88). Increased temperature increases the uptake of both organic and inorganic mercury (89, 90). In rainbow trout lethal levels of mercury decreased with increased water temperature, chloride ion content, or with a decrease in oxygen (91).

The "hard water" of American Falls Reservoir decreases the availability and toxicity of cadmium by precipitating it out as cadmium carbonate. Precipitation would result in decreased levels of cadmium in water and an underestimation of the amount of cadmium present in the reservoir, if only water samples were utilized. In the presence of zinc, cadmium toxicity is increased (92). Zinc values for rainbow trout, Utah sucker, yellow perch, and bullhead taken from American Falls Reservoir were as high as 12.8, 9.2, 11.4, and 1.05 mg/kg, respectively (93). Absorption of cadmium together with zinc will result in lower toxicity levels than reported from acute toxicity tests with cadmium alone. In the low oxygen and anaerobic waters of the reservoir, arsenate may be converted to arsenite, the more lethal form of arsenic (71). Modification of toxicity by chemical and physical parameters points out the need to redefine "safe" levels in aquatic environments. Each aquatic system is unique and "safe" levels of contaminants should be determined which reflect the characteristics of the system.

The significance of accumulation of heavy metals in fishes in American Falls Reservoir and subsequent effects on their survival and reproductive success is unknown. Suffocation of adult fishes and fry by coagulation of gill mucus caused by heavy metals may contribute to a declining population; however, the accumulation of heavy metals in the gonads may be more important. Little information exists on the effects of heavy metals on the developmental stages of fishes.. Exposure to cadmium inhibited red blood cell circulation in embryo of the fathead minnow (_Pimephales promelas_) (94). Laboratory animals exposed to cadmium developed damage to the reproductive organs, birth defects, life shortening, inhibition of growth and central nervous system damage (83). Similar effects may take place in fish. There is a need to evaluate the effects of heavy metal accumulation on all the life stages of fish.

There is a higher concentration of heavy metals in the kidney, liver, gonads and gills than in muscle tissue. Although large amounts of mercury may be found in the organs of the body, the major acute effect of mercury is exerted on the gills. Large amounts of mucus are produced and suffocation results due to coagulation of the mucus by mercury. Epithelial necrosis and hyperplasia in the gills has been observed in fish exposed to mercury (95). Mercury present in the body of fishes acts as a neurotoxin; lesions usually develop in the neurological system, resulting in death (96). Highest concentrations of cadmium are located in the liver and kidney where enzymatic processes are inhibited. Oxidative phosphorylation, a key enzyme-mediated process by which high-energy phosphate bonds are formed, was completely halted by a concentration of 0.67 mg/kg cadmium (87). Lesions in the intestine and kidney result from cadmium exposure. The rate and degree of the lesions are significantly affected by pH, salinity, oxygen, and temperature of the water (97). Kidney dysfunction results from this exposure (98). In sufficient concentrations, cadmium may exert its toxic effects on fish by coagulation of external gill mucus, causing anoxia, as well as altered salt balance and secretion of waste products (99). Little is known about the effects of arsenic in fish. Arsenic is also an enzyme inhibitor. Effects similar to those of cadmium could result from exposure to arsenic.

Consumption of fish from American Falls Reservoir presents a health problem. Mercury concentrations in suckers, black crappie, and large rainbow trout exceed the FDA standard of 0.5 mg/kg (Table 7). The Idaho Health Department issued the following warning concerning consumption of fish from waters known to be contaminated with mercury: (1) that persons not eat more than

1/2 pound of fish per week from Idaho waters; (2) that pregnant women, infants, and young children not eat fish taken from waters known to be contaminated with mercury; and (3) catfish, yellow perch, and suckers taken from the Snake River between American Falls Reservoir and Hells Canyon should not be eaten. The World Health Organization has suggested that maximum daily intake of cadmium be 70 µg/day (98). Daily intake of cadmium from food sources averages 50 µg/day in the U.S.A. (98) and the FDA has stated that at this level "we may have reached the safe upper limit for cadmium"(100). Consumption of fishes from American Falls Reservoir would increase daily intake of cadmium in excess of the 70 µg/day limit.

Although consumption of fishes contaminated with heavy metals may lead to no immediate adverse effects, heavy metals are concentrated in vital organs of the body. Large amounts are usually found in the kidneys and may result in renal dysfunction. Other effects of mercury and cadmium accumulation are well documented (101, 98, 102).

Mercury and cadmium accumulation in fishes from American Falls Reservoir exceeds human health standards set by FDA and WHO. Consumption of fishes from the reservoir may endanger the health of sports fishermen and their families. The stocking of rainbow trout annually is important to the sports fishery of the reservoir, since fishermen fish almost exclusively for these trout. Trout, therefore, serve as a source of cadmium and mercury to fishermen. It appears that further utilization of American Falls Reservoir as a sports fishery should not be encouraged and perhaps should be restricted.

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