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TRACE ELEMENTS IN SEDIMENT AND FISH FROM NATIONAL WILDLIFE REFUGES ON THE COLORADO RIVER, ARIZONA

by

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ABSTRACT--Sediment and fish were collected from Imperial, Cibola and Havasu National Wildlife Refuges (NWR) in 1988-89 to assess levels and potential effects of selenium and other trace elements on fish and wildlife of the lower Colorado River. All sediment trace element means were similar among refuges and there were no differences between site means and Arizona background levels. There was a 2- to 4-fold increase in chromium and a 3- to 5-fold increase in selenium concentrations in sediments from 1986 to 1989 at Topock Marsh (Havasu NWR).

Cadmium in fish equalled or exceeded background levels in three samples. Chromium residues were usually higher in fish from Martinez Lake (Imperial NWR) than in samples from Cibola Lake (Cibola NWR) and Topock Marsh. Copper was present at background levels in Cibola Lake samples; however, four of seven samples from Martinez Lake and one of four from Topock Marsh contained elevated copper. Lead was not detected in Martinez Lake fish but was present in all Cibola and Topock whole body samples. Mercury was below background levels at all sites. All selenium concentrations in fish were greater than the National Contaminant Biomonitoring Program (NCBP) 85th percentile indicating widespread selenium contamination of lower Colorado River backwater habitats. Whole body levels varied from 0.89 to 4.39 æg/g wet weight, considerably above the NCBP 85th percentile level of 0.73 æg/g. Fifty-three percent of the fish samples exceeded the minimum threshold level where selenium effects on fish reproduction have been noted. Mean selenium levels have remained stable in Colorado River fish from 1984 to 1989.

Arsenic and mercury in fish pose little hazard of secondary poisoning to fish-eating avian predators. Cadmium, however, exceeded the concern level for secondary poisoning in one sample. Selenium levels in fish were within the range

of those that affected reproduction of some laboratory birds, but below levels found in food chain organisms at highly contaminated Kesterson Reservoir.

Humans consuming carp from Cibola Lake could exceed the maximum daily intake of cadmium by eating more than 200 g (7 oz.) of fillets. Chromium in one largemouth bass and one carp fillet from Martinez Lake equalled or exceeded the normal dietary intake. A person would exceed the maximum permissible selenium intake of 224 æg if that person ate more than 45.0 to 49.1 grams (1.6-1.7 ounces) per day of largemouth bass fillets from Martinez Lake. Similarly, the allowable daily selenium intake could be exceeded if a person ate more than 58.6 g (2.1 oz) of bass fillets from Cibola Lake and 38.5 g (1.4 oz) of largemouth bass from Topock Marsh a day. Since consumption of as little as 2.1 ounces of largemouth bass fillets on a daily basis from some locations on any of the refuges could exceed the acceptable intake, we recommend that each refuge consider fish consumption advisories in selected areas of known high contamination.

INTRODUCTION

Hazards to wildlife associated with elevated selenium concentrations were first documented at Kesterson National Wildlife Refuge (NWR), California in 1986 when numerous waterbird embryos were found dead and deformed with high selenium concentrations in tissues and eggs (Ohlendorf et al. 1986). Water used to irrigate crops in the San Joaquin Valley, California dissolved naturally occurring selenium salts in the soil. When the selenium laden irrigation water was drained from agricultural fields into Kesterson Reservoir, potentially harmful levels of selenium accumulated in fish and aquatic invertebrates used as foods by waterbirds (Ohlendorf et al. 1986, Ohlendorf et al. 1988). The discovery of waterbird mortalities on a National Wildlife Refuge linked to selenium toxicosis focused attention on other refuges where wildlife may also have been affected. Of particular concern was the potential for selenium contamination on refuges located in western United States where soil selenium was known to be elevated and where crop irrigation could exacerbate the potential problem. In a nationwide sampling program conducted by the U.S. Fish and Wildlife Service (Service) for contaminants in fish, the National Contaminant Biomonitoring Program (NCBP) revealed that five of the ten highest mean selenium concentrations occurred in fish from the lower Colorado River (Schmitt and Brumbaugh 1990). Follow-up sampling in 1986-87 at numerous sites along the lower Colorado River confirmed that selenium concentrations in water exceeded the 75 percent (%) national baseline level and selenium in fish approached concentrations associated with reproductive impairment (Radtke et al. 1988). Of particular importance was the potential effects of selenium on the reproduction and survival of the endangered razorback sucker (Xyrauchen texanus) and Yuma clapper rail (Rallus longirostris yumanensis) which inhabit aquatic habitats along the lower Colorado River. In response to those concerns, this investigation was undertaken to document selenium and other trace element levels in sediments and fauna of Imperial, Cibola and Havasu NWRs (Fig. 1).

STUDY AREAS AND METHODS

Approximately 20% of the 260 ha (640 acre) Martinez Lake lies within the boundaries of Imperial NWR. The remaining 80% is managed by the State of Arizona. There are dredged channels at both north and south ends of the lake that permit restricted water exchange with the Colorado River. There are limited agricultural return flows into the lake from farm fields on Imperial NWR. Sediment and fish were collected from Martinez Lake on May 2-3,1988.

Fish were collected from Cibola Lake (Cibola NWR) during November 1988 and May 1989 and sediment was taken in May 1989. Water control structures at each end of the lake connect the 240 ha (640 acre) Cibola Lake to the Colorado River. The lake does not receive irrigation return flows.

3

At Havasu NWR, fish were collected from Topock Marsh during September and December, 1988, and sediment samples were taken during May, 1989. Topock Marsh receives water from the Colorado River via a 6.4 km inlet. A series of dikes contain and divert water to different parts of the 1 ,600 ha (4,000 acre) impoundment. Topock marsh does not receive agricultural return flows. Martinez Lake, Cibola Lake and Topock Marsh are considered `backwater areas;' areas that have limited flow or flushing from Colorado River waters.

Five sediment subsamples were taken at each site by Ekman dredge and then homogenized using a stainless steel spoon and pan into a single composite sample. Approximately the top 10 cm of sediment was collected with each subsample. The composite sample was then placed in an acid rinsed tared glass jar, weighed, sealed with a teflon lined lid and placed on wet ice until the sample could be transferred to a commercial freezer. Fish were collected by electroshocking, gill, trammel or seine net, or by hook and line. Fish were weighed and measured then pooled in five-specimen composites of near equal length and weight for each species. For fish commonly caught for human consumption, both whole body samples and fillets (edible portions) were taken. These included largemouth bass (Micropterus salmoides), common carp (Cyprinus carpio), channel catfish (Ictalurus punctatus), black crappie (Pomoxis nigromaculatus), and blue tilapia (Tilapia aurea). Whole body samples only were taken for flathead catfish (Pylodictis olivaris), bluegill sunfish Lepomis macrochirus), redear sunfish (L. microlophus) and striped bass Morone saxatilis). Both whole body and fillet samples were wrapped in aluminum foil and placed on wet ice until they were transferred to a commercial freezer for storage until chemical analyses. The number of samples and species of fish collected at each site is listed in Table 1.

Fish from Cibola Lake and Topock Marsh were analyzed for aluminum, antimony, arsenic, beryllium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, thallium and zinc. Sediment samples from all three areas and fish from Martinez Lake were analyzed for the same trace elements listed above, plus barium, boron, magnesium, molybdenum, silver, strontium and vanadium. Selenium and arsenic were analyzed by atomic absorption hydride and mercury by cold vapor reduction. All other trace elements were analyzed by inductively coupled plasma atomic emission spectroscopy. Samples were analyzed at the Environmental Trace Substances Research Center, Columbia, Missouri. Chemical methodology and reports met or exceeded Patuxent Analytical Control Facility Quality Assurance and Quality Control standards. Trace element concentrations are reported on a dry weight basis with wet weight equivalents listed where appropriate.

Trace element concentrations in sediments were compared among sites using a one-way analysis of variance (ANOVA). When no differences were detected

4

among sites, the data were combined to form a larger sample size and then compared with Arizona and western United States baseline sediment values using a Student's t-test (Table 2). There was an insufficient number of fish samples per site to run statistical comparisons. Trace element concentrations in fish were compared with levels reported in the NCBP for fish collected in 1976-1984 from 109 stations nationwide (Schmitt and Brumbaugh 1990). Concentrations of an element were considered elevated when they exceeded the 85th percentile of the nationwide geometric mean. The 85th percentile was not based on toxicity hazard to fish, but provides a frame of reference to identify elements of potential concern.

RESULTS AND DISCUSSION

Sediment--Eighteen of 22 trace elements were detected in sediment samples (Table 2). None of the trace element means varied significantly among the three areas (Pò 0.1616, ANOVA). When the data were combined for all three sites, there was no difference between sample site means and Arizona background levels (P = 0.1259, t-test). Concentrations of three elements fell outside the expected 95% range developed by Radtke et al. (1988) using data of Shacklette and Boerngen (1984) for trace elements in soils in western United States. Both barium and molybdenum were below the 95% range. Selenium at 2.4 æg/g dry weight, however, was well above the 95% expected range of 0.039-1.4 æg/g.

No historical data are available for contaminant levels in Martinez Lake sediments. At Cibola Lake, concentrations of arsenic, beryllium, chromium, copper, iron, manganese, nickel, and zinc in sediments collected in 1989 (this study) were about one-half those in sediments collected in 1990 (Rusk 1991). The significance of these differences is not clear.

Topock Marsh sediments collected in 1989 contained concentrations of only two elements, chromium and selenium, that were significantly different than levels in samples collected in 1986 (Radtke et al. 1988). In 1986, chromium varied from 41 to 43 æg/g dry weight in three samples collected near the marsh inlet (Radtke et al. 1988); those levels were two-to four-times greater than the 10 and 21 æg/g from our 1989 study. Selenium in Topock sediment samples collected in 1986 (Radtke et al. 1988) ranged from not detected (one sample) to 0.6 æg/g (two samples) and were considerably lower than the 1.5 and 2.2 æg/g values recorded in our 1989 samples.

Fish--Thirteen trace elements were recovered in fish tissues (Tables 3,4, and 5). Aluminum was present in all whole body and fillet samples. Whole body concentrations ranged from 11 æg/g dry weight in striped bass from Martinez Lake (Table 3) to 807 æg/g in blue tilapia from Cibola Lake (Table 4).

Largemouth bass, a largely predatory species, contained relatively low levels of aluminum (5.3-8.5 æg/g) compared to other species collected at the same site. Four composite samples of five whole body carp each collected from Topock Marsh in 1986 contained from 18 to 27 æg/g aluminum (Radtke et al. 1988) which was slightly lower than the 39.3 æg/g aluminum recorded in carp from Topock Marsh during this study.

Arsenic was present in 14 of 15 whole body samples and in all fillets. Whole body concentrations ranged from not detected to 0.75 æg/g dry weight (Tables 3 and 4). None of the whole body samples contained elevated (ò NCBP 85th percentile) arsenic residues (Table 6).

Beryllium was recovered in six of seven whole body samples from Martinez Lake, in three of five samples from Cibola Lake and in one sample from Topock Marsh (Tables 3,4,5). Beryllium was present in all species except largemouth bass. The maximum concentration was 0.12 æg/g dry weight in a Martinez Lake carp. Background levels of beryllium in fish tissues have not been established; therefore, interpretation of concentrations found in this study are not possible.

Boron was analyzed only in Martinez Lake samples. Boron was present in all sediment samples (Table 2) but was not detected in fish (Table 3).

Cadmium was detected in 13 of 15 whole body fish samples. None of the fillets from Martinez Lake contained cadmium, whereas all fillets from Cibola Lake and three of four from Topock Marsh had measurable cadmium concentrations. The highest whole body concentration, 0.2 æg/g dry weight, was present in both catfish and blue tilapia from Cibola Lake and in catfish and carp from Topock Marsh. Cadmium equalled or exceeded the NCBP 85th percentile of 0.05 æg/g wet weight in three samples (Table 6). A black crappie from Topock Marsh contained 0.25 æg/g cadmium, about five times the background level.

Chromium was generally present in whole body samples at ó2.4 æg/g dry weight. The one exception was a carp from Martinez Lake with 4.1 æg/g. Available evidence suggests that >4.0 æg/g dry weight chromium in fish tissues should be viewed as evidence of chromium contamination (Eisler 1986). Chromium residues were usually higher in fish from Martinez Lake than in those from Cibola Lake and Topock Marsh.

Copper was extremely elevated level, 18.8 æg/g wet weight, in one carp sample from Martinez Lake (Table 3). This concentration was about eight times greater than the next highest level in fish from any of the three refuge sites and was similar to the highest copper concentration (23.1 æg/g) detected during the 1976-1984 NCBP sampling (Schmitt and Brumbaugh 1990). Copper levels varied greatly among species and among areas. At Martinez Lake, copper varied more

than 15-fold within the same species (Table 3). None of the samples from Cibola Lake had elevated copper levels. In contrast, four of seven samples from Martinez Lake and one of four from Topock Marsh contained copper at greater than the NCBP 85th percentile (Table 6). Four composite samples of carp collected from Topock Marsh in 1986 varied from 0.38 to 0.49 æg/g wet weight (Radtke et al. 1988) which was slightly lower than the 0.74 æg/g wet weight detected in the topock Marsh carp sample collected during this study.

Iron and manganese were present in all whole body samples and dry weight concentrations varied from 64-802 and 3.1-24.6 æg/g, respectively. Background levels for these trace elements in fish and their propensity to bioaccumulate through the aquatic food chain to predators are not well known.

Lead was not detected in Martinez Lake fish but was present in all Cibola Lake and Topock Marsh whole body samples. None of the Cibola Lake fillets contained lead; however, lead was recovered in three of four fillet samples from Topock Marsh. The NCBP 85th percentile for lead was 0.22 æg/g wet weight (Schmitt and Brumbaugh 1990). All whole body samples from Cibola Lake and three of four from Topock Marsh exceeded background levels. The highest concentration (0.94 æg/g) was more than four times greater than the NCBP concern level (Table 6). We have no explanation as to why elevated lead levels were detected in almost all Cibola Lake and Topock Marsh whole body samples, but lead was not present in Martinez Lake fish.

Mercury was present in all whole body and fillet samples and individual concentrations ranged from 0.01 to 0.06 æg/g wet weight. All mercury levels were below the NCBP 85th percentile of 0.17 æg/g wet weight (Table 6). For the protection of sensitive species of birds that regularly consume fish and other aquatic organisms, total mercury concentrations in prey items should probably

not exceed 0.1 æg/g wet weight (Eisler 1987). None of the whole body fish samples collected during this study approached the 0.1 æg/g concern level. Unlike most other trace elements, mercury residues were higher in the fillets than in whole body samples, suggesting that mercury concentrates in muscle tissue. The highest mercury concentration detected in fish fillets from the lower Colorado River Refuges was 0.12 æg/g wet weight, well below the suggested U.S. Environmental Protection Agency (EPA) maximum acceptable daily intake level of <1.0 æg/g (EPA 1985).

Nickel was recovered in all but two samples from Martinez Lake and in one from Cibola Lake but was not detected in fish from Topock Marsh. Nickel residues >0.9 æg/g wet weight in fish can be considered elevated (R. Erwin unpub. data.) The highest level recorded in our study was 0.4 æg/g (Table 3). There are no national standards to determine at what level nickel is toxic to predators. The potential for bioaccumulation of nickel also is not well known.

All selenium concentrations in fish were greater than background levels indicating widespread selenium contamination of the lower Colorado River backwater habitats. Whole body concentrations varied from 0.89 to 4.39 æg/g wet weight, considerably above the NCBP 85th percentile level of 0.73 æg/g. There was no consistent pattern as to which fish species accumulated selenium to highest levels. Selenium in the largemouth bass fillet sample collected from Cibola Lake was 8.6 æg/g dry weight, slightly higher than the 5.1 æg/g reported by Welsh and Maughan (1993) for largemouth bass fillets collected from Cibola Lake in 1990. The highest mean NCBP selenium concentration in whole body fish sampled in 1984 was 2.3 æg/g wet weight in common carp from Martinez Lake (Schmitt and Brumbaugh 1990). Selenium concentrations in carp sampled during this study varied from 2.18 to 2.37 æg/g wet weight indicating that selenium levels have remained fairly constant at Martinez Lake since 1984. At Topock Marsh, largemouth bass and carp collected in 1980 contained 3.3 and 2.9 æg/g wet weight selenium, respectively (Radtke et al. 1988), slightly higher than the 2.18 and 1.54 æg/g recorded in bass and carp collected from the same area in 1989.

During the 1984-85 NCBP nationwide monitoring program, carp collected from four Colorado River stations (Lake Powell, Lake Mead, Lake Havasu, and Martinez Lake) contained from 1.35 to 2.3 æg/g selenium. All samples exceeded the NCBP 85th percentile. Carp from Martinez Lake contained the highest selenium level (2.3 æg/g) of fish collected from the four stations. Smallmouth bass also were collected from four Colorado River stations (Lake Powell, Lake Havasu, Martinez Lake and the Colorado River at Yuma). All selenium concentrations in bass exceeded the NCBP 85th percentile and the highest concentration (2.08 æg/g) was also recorded in samples from Martinez Lake.

Zinc was recovered at elevated (ò 34.2 æg/g wet weight) concentrations in 27% (4/15) of the whole body samples (Table 6). Martinez Lake had the greatest mean zinc level of 32.6 æg/g and the highest individual concentration of 82.1 æg/g. Little is known about bioaccumulation of zinc through the aquatic food chain to predators such as fish-eating birds.

Residue implications for fish--It was not possible to compare residue levels among species because too few samples were collected at each location. However, the following generalizations can be made regarding contaminant levels in individual species. At each lake, largemouth bass generally were the least contaminated species and common carp the most contaminated. All whole body carp samples had elevated concentrations of three trace elements. Carp from Martinez Lake had higher than background levels of copper, selenium and zinc whereas carp from Cibola and Topock Marsh had elevated concentrations of lead, selenium and zinc. Carp accumulated zinc more readily than other species; all whole body samples (n = 4) contained zinc in excess of the NCBP 85th percentile. This finding is consistent with conclusions of other authors who reported that the

8

common carp apparently accumulates zinc to a greater extent than other species (Lowe et al. 1985, Schmitt and Brumbaugh 1990).

With the possible exception of selenium, levels of trace elements were below concentrations known to affect fish survival and reproduction. The highest wet weight whole body selenium concentration recorded in this study was 4.39 æg/g, slightly below the 6.9-7.2 æg/g wet weight level associated with selenium induced reproductive failure of bluegills at selenium contaminated Hyco Reservoir in North Carolina (Gillespie and Baumann 1986). In a comprehensive summary of selenium threshold effect levels, Lemly and Smith (1987) reported that selenium induced reproductive failure was associated with whole body selenium concentrations of approximately 2.76 æg/g wet weight, (converted from 12 æ/g dry weight assuming 77% moisture). A related study concluded that levels of 2 æg/g wet weight or more selenium may be indicative of concentrations that could cause toxic effects (Baumann and May 1984). Fifty-three percent of our fish samples exceeded 2.0 æg/g wet weight selenium confirming that about one-half of the refuge samples were at the threshold where selenium effects on fish reproduction have been noted. Selenium-sensitive species such as bluegill and largemouth bass were present in all backwater areas sampled. However, we do not know if they were recruited in backwater areas or if juvenile fish moved into the backwaters from other areas.

Residue implications for fish-eating--The trace elements most likely to cause reproductive problems in birds are arsenic, cadmium, mercury and selenium (Eisler 1985, 1987, 1988; Ohlendorf 1986, 1988). While the acute effects of arsenic have been investigated, little is known about sublethal chronic effects except that arsenic is readily accumulated by aquatic organisms. Based on data summarized by Eisler (1988), arsenic at levels recovered in Colorado River fish from the three NWRs, apparently poses little hazard of secondary poisoning to avian and mammalian predators. Secondary hazards of cadmium poisoning to avian predators might be expected if dietary levels reach 0.1 æg/g (Eisler 1985). Only the Topock Marsh black crappie sample exceeded this concern level. The maximum concentration above which mercury effects on fish-eating avian predators can be expected is 0.1 æg/g wet weight (Eisler 1987). None of the fish samples contained mercury at concentrations that approached this 0.1 æg/g concern level.

An assessment of the secondary hazards of selenium to waterbirds is complicated by its occurrence in nature in many different chemical forms that vary greatly in their toxicity (Heinz, in press). The ability of selenium to interact with other elements also complicates an interpretation of toxic thresholds. In laboratory studies, diets containing 5 and 7 æg/g dry weight selenium as sodium selenite caused reduced hatching success in chickens (Ort and Latshaw 1978). Mallards (Anas platyrhynchos) fed a dietary concentration of 25 æg/g sodium

9

selenite also experienced reproductive problems (Heinz et al. 1987). Selenium levels greater than 5 and 7æg/g (the lowest levels to affect birds in laboratory studies) occurred in 87% of the whole body fish samples from our lower Colorado River sites. Mean selenium levels in insects commonly consumed by birds at selenium contaminated Kesterson Reservoir varied from 22.1 to 104 æg/g dry weight. The level of selenium contamination detected in fish from the lower Colorado River was within the range that affected reproduction of laboratory birds, but below levels found in food chain organisms at the highly contaminated Kesterson Reservoir where massive avian reproductive failure and adult mortality occurred.

Residue implications for humans--In the United States, there is no U.S. Food and Drug Administration (FDA) action level for lead in fish, but an edible tissue guideline often cited as the upper limit for consumption by adults is 0.3 mg/day (EPA 1980). Lead was not detected in fish fillets from Martinez and Cibola lakes. The highest concentration in fish fillets from Topock Marsh was 0.2 æg/g. At this concentration, an adult would have to consume 1500 g (3.3 pounds) of fish fillets to ingest 0.3 mg of lead.

Unlike most other trace elements, mercury residues were higher in the fillets than in whole body samples. The highest mercury concentration detected in fish fillets from the lower Colorado Refuges was 0.12 æg/g wet weight, well below the FDA standard of 1.0 æg/g (EPA 1985).

Under the best case scenario for human health protection, cadmium dietary intake should not exceed 12 æg/day wet weight (Eisler 1985). The maximum cadmium concentration in fillet samples was 0.06 æg/g wet weight in a blue tilapia from Cibola Lake. A person should eat no more than 200 g (7 oz.) per day to maintain a best case scenario.

Estimates vary from 0.03 to 0.3æg/g wet weight for the normal dietary intake of total chromium in the human diet (Ecological Analysts 1981). One largemouth bass and one carp fillet sample from Martinez Lake equalled or exceeded 0.3 æg/g total chromium listed as the maximum normal human dietary intake.

Except for a drinking water standard of 10 æg/L (EPA 1986) there is no current FDA action level for selenium in food for human consumption. In California, the Department of Health Services (CDHS) has established an interim, internal guidance level for selenium in the human diet. CDHS will consider or issue a health advisory when selenium concentrations in waterfowl flesh approach or exceed 2 æg/g wet weight or about 7.7 æg/g dry weight (Fan et al. 1988, Saiki et al. 1991). CDHS and the California Department of Fish and Game (CDFG) issue consumption advisories in the CDFG annual Sport Fishing Regulations warning "Because of elevated selenium levels, no one should eat more than 4 oz. of fish from the Grassland area, Merced County, in any two week period. Women who are pregnant, or may soon become pregnant, nursing mothers, and children age 15 and under should not eat any fish from this area." (CDFG 1989). All fillet samples from Martinez Lake, two of four from Cibola Lake, and three of four fillets from Topock Marsh approached or exceeded the 2 æg/g California concern level.

Selenium concentrations in two largemouth bass fillets from Martinez Lake were 2.22 and 2.42 æg/g wet weight (Table 3). Selenium in bass fillets from Cibola Lake and Topock Marsh were 1.86 and 2.83 æg/g, respectively. EPA (1986) set the allowable daily intake of selenium in the human diet at 224 æg per day for subchronic exposure (several weeks to several months). This acceptable daily intake has a 15-fold safety factor applied to the lowest intake concentration, 3,200 æg/day, associated with human toxicity (Yang et al. 1983). Estimates for daily selenium intake for the U.S. population vary 60 to 170 æg/day (in Fan et al. 1988, Welsh and Maughan 1993). Using the formula proposed by Fan et al. (1988), the Maximum Permissible Intake (MPI) of fish for human consumption can be calculated as follows:

$$MPI = \frac{ADI - DI}{C}$$

Where:
ADI = Acceptable Daily Intake - 224 æg/day;
DI = Daily Intake from all other sources;
C = Concentration of selenium in fish.

Assuming a daily selenium intake from other sources of 115 æg/day (midpoint in the EPA estimated 60-170 æg consumption range for U.S. citizens), an adult would exceed the Maximum Permissible Intake level of 224 æg if they ate more than 45.0 to 49.1 grams (1.6-1.7 ounces) per day of largemouth bass fillets from Martinez Lake. Similarly, the daily intake could be exceeded if an adult ate more than 58.6 g (2.1 oz) of bass fillets daily from Cibola Lake and 38.5 g (1.4 oz) of largemouth bass from Topock Marsh. Our results for daily intake levels are slightly lower than those of Welsh and Maughan (1993) who reported that the subchronic allowable daily intake of selenium could be exceeded if a person ate ò 164 g (5.8 oz) per day of bass fillets from Cibola Lake based on 1.0 æg/g selenium in bass fillets collected in 1990.

The average fish consumption in Arizona is 6.5 g/day (Welsh and Maughan 1993), the same as the national per capita consumption of freshwater and esturaine fish (EPA 1980). The risk to the average Arizonan of consuming excessive selenium via fish in the diet is unknown; however, subpopulations exist which may consume large quantities of fish from the Colorado River (Welsh and Maughan 1993). Migrant and semi-permanent agricultural workers as well as native Americans in the lower Colorado River valley likely supplement their diet on

a regular basis with fish caught from the river and riverine backwater habitats. Also, fishing is a popular hobby with winter visitors who spend several months each year along the Colorado River. It seems likely that some Colorado River valley residents and visitors could easily exceed the maximum allowable daily intake of selenium by consuming only a small portion of locally caught fish per day.

RECOMMENDATIONS

Although selenium concentrations in fish have remained relatively stable in recent years, levels are just below the range where fish reproduction may be affected. Based on current high selenium concentrations that approach the critical reproductive effect threshold level in more than one-half the samples, regular monitoring of fish on the lower Colorado River on a three-year basis is recommended. Selenium concentrations in fish may also be within the range that affect reproduction of fish-eating birds resident or wintering in the area. Endangered species concerns also dictate that monitoring be continued, and possibly expanded, to assess levels and effects of selenium and other contaminants on the Yuma clapper rail and razorback sucker populations inhabiting the Colorado River and associated backwater areas as well as other aquatic habitats that receive Colorado River water such as the Cienega de Santa Clara in Mexico. A single unified contaminant monitoring plan should be developed for all lower Colorado River National Wildlife Refuges.

In addition to routine contaminant monitoring, an aggressive bioassessment initiative is needed to determine the viability of fish populations in backwater and riverine habitats. Subpopulations of selenium sensitive species such as sunfish, crappie and bass should be investigated to assess age and sex ratios, reproductive, and overall body condition. Special emphasis should be placed on determining if reproduction is occurring in backwater areas and if reproduction is adequate to maintain stable populations. It should also be determined if toxicity is associated with areas of sedimentation and on-site bioaccumulation connected with the life histories of species primarily resident in backwater habitats.

On the basis of human health concerns, continued monitoring of fish commonly caught for consumption is most urgent. Selenium and possibly cadmium and chromium concentrations in fish fillets are at levels where only small portions consumed on a daily basis may adversely affect human health. While this study focused on backwater areas where contaminant levels were suspected to be highest, future monitoring should include all regularly fished waters.

Monitoring efforts should be expanded to include waterfowl wintering on refuge lands. Potential human exposure to selenium from eating waterfowl flesh, and

12

particularly livers, may be as great or greater than selenium intake via fish. Consumption advisories, similar to those issued in contaminated habitats of California, should be considered for areas where fish and waterfowl contain sufficiently high selenium and other trace element contamination to pose a potential human health risk.

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LITERATURE CITED

Baumann, P.C. and T.W. May. 1984. Selenium residues in fish from inland waters of the United States. Workshop Proceedings: the effects of trace elements on aquatic ecosystems. Electric Power Research Institute, EPRI EA-3329. Proj. 1631,16 pp.

California Department of Fish and Game. 1989. 1989 California Sport Fishing Regulations. 13 pp.

Ecological Analysts, Inc. 1981. The sources, chemistry, fate, and effects of chromium in aquatic environments. American Petroleum Inst. Washington, DC. 207 pp.

Eisler, R. 1985. Cadmium hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish Wildl. Serv. Biol. Rep. 85(1.2). 46 pp.

Eisler, R. 1986. Chromium hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish Wildl. Serv. Biol. Rep. 85(1.6). 60 pp.

Eisler, R. 1987. Mercury hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish Wildl. Serv. Biol. Rep. 85(1.10). 90 pp.

Eisler, R. 1988. Arsenic hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish Wildl. Serv. Biol. Rep. 85(1.12). 92 pp.

13

Environmental Protection Agency. 1980. Ambient Water Quality Criteria for Lead. U.S. Environ. Protection Agency Rept. 440/5-80-057. 81 pp.

Environmental Protection Agency. 1980. Ambient Water Quality Criteria for Mercury. U.S. Environ. Protection Agency Rept. 440/5-80-058. 217 pp.

Environmental Protection Agency. 1985. Ambient Water Quality Criteria for Mercury - 1984. U.S. Environ. Protection Agency Rept. 440/5-84-026. 136 pp.

Environmental Protection Agency. 1986. Quality Criteria for Water, 1986. EPA 440/5-86-001, U.S. Government Printing Office. Washington, D.C. ??? ck this ref.

Fan, A.M., S.A. Book, R.R. Neutra and D.M. Epstein. 1988. Selenium and human health implications in California's San Joaquin Valley. J. Toxicol. Environ. Health 23:539-559.

Gillespie, R.B. and P.C. Baumann. 1986. Effects of high tissue concentrations of selenium on reproduction by bluegills. Trans. Amer. Fish Soc. 115: 208-213.

Heinz, G.H. Selenium in birds. in Interpreting Contaminant Residues in Wildlife. W.N. Beyer and G.H. Heinz (eds.). in press.

Heinz, G.H., D.J. Hoffman, A.J. Krynitsky, and D.M.G. Weller. 1987. Reproduction in mallards fed selenium. Environ. Toxicol. and Chem. 6:423-443.

Kepner, W.G. 1988. San Bernardino National Wildlife Refuge Contaminant Study. Arizona Ecological Services Report. U.S. Fish and Wildlife Service. Phoenix, Arizona. 18 pp.

Lemly, A.D. and G.J. Smith. 1987. Aquatic cycling of selenium: implications for fish and wildlife. U.S. Fish and Wildl. Ser., Fish Wildl. Leafl. 12. 10 pp.

Lowe, T.P., T.W. May, W.G. Brumbaugh, and D.A. Kane. 1985. National contaminant biomonitoring program: concentrations of seven elements in freshwater fish, 1978-81. Arch. Environ. Contam. Toxicol. 14:363-388.

Ohlendorf, H.M., D.J. Hoffman, M.K. Saiki, and T.W. Aldrich. 1986. Embryonic mortality and abnormalities of aquatic birds: apparent impacts of selenium from irritation drainwater. The Science of the Total Environment 52:49-63.

Ohlendorf, H. M., A.W. Kilness, J.L. Simmons, R.K. Stroud, D.J. Hoffman and J.F. Moore. 1988. Selenium toxicosis in wild birds. J. Toxicol. Environ. Health 24:67-

Ort, J.F. and J.D. Latshaw. 1978. The toxic level of sodium selenite in the diet of laying chickens. J. Nutrition. 108:1114-1120.

Radtke, D.B., W.G. Kepner, and R.J. Effertz. 1988. Reconnaissance investigation of water quality, bottom sediment, and biota associated with irrigation drainage in the lower Colorado River valley, Arizona, California, and Nevada, 1986-87. U.S. Geological Survey, Water-Resources Investigation Report 88-4002. 77 pp.

Rusk, M.K. 1991. Selenium risk to Yuma clapper rails and other marsh birds of the lower Colorado River. MS thesis. School of Renewable Natural Resources. University of Arizona, Tucson.

Saiki, M.K., M.R. Jennings, and S.J. Hamilton. 1991. Preliminary assessment of the effects of selenium in agricultural drainage on fish in the San Joaquin Valley. pp 369-385 in The Economics and Management of Water and Drainage in Agriculture. A. Dinar and D. Zilberman, eds. Kluwer Academic Publishers, Boston.

Schmitt, C.J. and W.G. Brumbaugh. 1990. National contaminant biomonitoring program: concentrations of arsenic, cadmium, copper, lead, mercury, selenium, and zinc in U.S. freshwater fish, 1976-1984. Arch. Environ. Contam. Toxicol. 19:731-747.

Shacklette, H.T. and J.G. Boerngen. 1984. Element concentrations in soils and other surficial materials of the conterminous United States. U.S. Geological Survey Professional Paper 1270. 105 pp.

Shomo, L.S. and O.E. Maughan. 1991. An investigation of selenium in aquatic systems associated with a coal-fired power plant in the arid southwest. Completion Report. University of Arizona. Arizona Cooperative Fish and Wildlife Research Unit. Tucson, Arizona.

Welsh, D. and O.E. Maughan. 1993. Selenium in aquatic habitats at Cibola National Wildlife Refuge. A Final Report. University of Arizona Cooperative Fish and Wildlife Research Unit Report. 22 pp.

Yang, G., W. Shuzhen, R. Zhou and S. Sun. 1983. Endemic selenium intoxication of humans in China. Amer. J. Clinical Nutrition. 37:872-888.

See Table/Figure

(SEE ORIGINAL)

Figure 1. Location of Havasu, Cibola and Imperial National Wildlife Refuges in Arizona

Table 1. Mean length, weight and moisture content of samples collected at Martinez Lake, Cibola Lake and Topock Marsh, Arizona- 1988-89.

Area and sample	N[sup]1	Component	Mean length (mm)	Mean weight (g)ý	Prcnt Moist
Martinez Lake					
Sediment	5	NA[sup]3	NA	NA	54.8
Sediment	5	NA	NA	NA	39.9
Sediment	5	NA	NA	NA	52.9
Largemouth bass	5	whole body	393	342	75.7
Largemouth bass	5	edible portion	278	228 (79)	79.8
Largemouth bass	5	edible portion	335	383 (119)	79.8
Flathead catfish	4	whole body	422	708	78.5
Common carp	5	whole body	368	656	76.3
Common carp	5	whole body	362	565	75.5
Common carp	5	edible portion	355	623 (128)	79.2
Bluegill sunfish	5	whole body	148	71	75.7
Redear sunfish	5	whole body	199	115	76.6
Striped bass	5	whole body	380	519	72.6
Cibola Lake					
Sediment	5	NA	145	NA	42.0
Sediment	5	NA	130	NA	63.0
Largemouth bass	5	whole body	263	357	75.7
Largemouth bass	5	edible portion	421	1175 (384)	78.4
Channel catfish	4	whole body	400	532	77.1
Channel catfish	5	edible portion	336	527 (128)	82.4
Common carp	5	whole body	416	930	76.1
Common carp	5	edible portion	429	1036 (231)	79.2
Blue tilapia	5	whole body	187	129	72.5
Blue tilapia	5	edible portion	192	144 (41)	78.1
Topock Marsh					
Sediment	5	NA	NA	174	46.6
Sediment	5	NA	NA	159	66.8
Largemouth bass	5	whole body	287	352	75.8
Largemouth bass	5	edible portion	309	412 (134)	79.8
Channel catfish	5	whole body	328	249	79.3
Channel catfish	5	edible portion	443	49 (110)	80.8
Common carp	5	whole body	404	808	76.3
Common carp	5	edible portion	380	677 (171)	79.2
Black crappie	5	whole body	189	106	75.5
Black crappie	5	edible portion	133	121 (40)	80.9

1[sup]N = number of individuals in each composite sample.
2[sup]whole body weight with fillet weight in parenthesis.
3[sup]NA = not applicable.

17
See Table/Figure
Table 2. Comparison of trace elements in sediments from three National Wildlife Refuge lakes located on the lower Colorado River Arizona, with background levels, 1988-89

(SEE ORIGINAL)

18
See Table/Figure
Table 3. Trace element and heavy metal concentrations in fish from Martinez Lake, Imperial National Wildlife Refuge, Arizona- 1988

(SEE ORIGINAL)

19
See Table/Figure
Table 4. Trace element and heavy metal concentrations in fish from Cibola Lake, Cibola National Wildlife Cibola National Wildlife Refuge, Arizona- 1989

(SEE ORIGINAL)

20
See Table/Figure
Table 5. Trace element and heavy metal concentrations fish from Topock Marsh, Havasu National Wildlife Refuge, Arizona- 1989

(SEE ORIGINAL)

21
See Table/Figure
Table 6. Comparison of trace element concentrations in whole body fish samples from Martinez Lake, Cibloa Lake and Topock Marsh, Arizona with the national baseline levels

(SEE ORIGINAL)