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ENVIRONMENTAL CONTAMINANTS IN FISH AND WILDLIFE OF HAVASU NATIONAL WILDLIFE REFUGE, ARIZONA

by

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ABSTRACT

Sediment, vegetation, clams, fish, waterbirds and waterbird eggs were collected at Havasu National Wildlife Refuge (NWR) during April-August 1993 for organochlorine compound and trace element analysis. Organochlorines were not detected in sediment or clams and only low levels of DDE were recovered in coot carcasses. Current residues of organochlorine compounds are low enough that even the most sensitive species of fish and wildlife are not likely to be affected.

Elevated levels of several trace elements were detected throughout the Havasu NWR ecosystem. Arsenic in clams averaged about 2.5-times background levels. Cadmium and selenium concentrations also were elevated in clams to the point that wildlife feeding on clams may be adversely affected. Cadmium, copper, and lead in most fish samples exceeded background levels, but concentrations were below toxic thresholds.

Selenium was the primary element of concern and bioaccumulation of selenium through the aquatic food chain was evident. Vegetation samples contained selenium concentrations that exceeded levels associated with food chain accumulation that can lead to reproductive failure in sensitive species of fish and avian herbivores. Selenium in four of five coot livers was higher than the "normal" or background range. Concentrations of selenium in eggs of western and Clark's grebes were two-to-four times the threshold level associated with toxic effects and embryo teratogenesis. Selenium was pervasive throughout the ecosystem, and levels were potentially high enough to adversely affect reproduction of fish and fish-eating birds.

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INTRODUCTION

Previous studies evaluated potential effects of selenium contamination on wildlife along the lower Colorado River Valley where the combination of selenium-rich soils and irrigated agricultural practices occur (Radtke et al. 1988, Rusk 1991, King et al. 1993, Lusk 1993, Welsh and Maughan 1993, Martinez 1994, McCaulou et al. 1994). Selenium in invertebrates, fish, and waterbirds from backwater areas of the lower Colorado River within Cibola and Imperial National Wildlife Refuges (NWRs) was potentially high enough to cause reproductive impairment, suggesting that biomagnification of selenium in aquatic food chains may be adversely affecting fish and endangered Yuma clapper rail (*Rallus longirostris yumanensis*) populations (Rusk 1991, Lusk 1993, Martinez 1994). It is presumed the source of selenium in the lower basin reflects influence of the upper basin where selenium is most likely mobilized by natural weathering of seleniferous shales, combustion of coal at hydroelectric generating stations, extraction of uranium ore and coal, and possibly irrigation-based agriculture (Radtke et al. 1988).

While selenium concentrations in fish and wildlife of Cibola and Imperial NWRs have been well documented, little is known about levels of selenium and other pollutants in fish and migratory birds of the Colorado River adjacent to and within Havasu NWR, located upriver from Cibola and Imperial NWRs. This study was designed to assess organochlorine pesticide and trace element concentrations in fish and migratory birds of Havasu NWR and to compare contaminant concentrations among species and among areas. Our investigation represents the first comprehensive assessment of contaminants in fish and wildlife of Havasu NWR.

Havasu NWR is located along the Colorado River and extends for 26 miles from Needles, California to Lake Havasu City, Arizona (Figure 1). Franklin D. Roosevelt created

Havasu NWR in 1941 to provide habitat for wildlife resources. The 37,515 acre (15,182 hectares) refuge is primarily a migratory bird sanctuary and includes portions of the Pacific and Central Flyways. Refuge habitat provides critical winter food and resting areas for thousands of geese, ducks, and many other migratory species. Herons and egrets nest in rookeries on the refuge. Numerous species of shore and marsh birds use the refuge, as well as the endangered Yuma clapper rail, southwestern willow flycatcher (*Empidonax traillii extimus*), peregrine falcon (*Falco peregrinus*), and the threatened bald eagle (*Haliaeetus leucocephalus*).

FIGURE 1.

STUDY AREA

Topock Marsh, a 4,000-acre (1,619 hectares) wetland managed by Havasu NWR for migratory birds, is fed by a four-mile long (6.4 kilometers) inlet canal. Water levels are maintained by a dike with a water control outlet structure. Catfish Paradise, Pintail Slough, North Dike, and Glory Hole lie within Topock Marsh. Pintail Slough is north of North Dike which is the northern boundary of the marsh (Figure 2). Pintail Slough is an old meander of the Colorado River and is managed for emergents and other vegetation commonly used by aquatic birds for nesting, feeding, and roosting. The Colorado River forms the seven-mile (11 kilometers) long western boundary of the Topock Marsh Unit.

The Colorado River bisects the 19-mile (31 kilometers) long Topock Gorge Unit. It is bordered by marshes isolated by emergent zones of cattail (*Typha* sp.) and bulrush (*Scirpus* sp.). The river flows into Lake Havasu at the most southern portion of this unit. Colorado River flows are managed by the Bureau of Reclamation and dictated by weather conditions, irrigation interests, and hydroelectric power demands.

Samples were collected from the mainstream of the Colorado River within Topock Gorge (Blankenship Bend, Devils Elbow) as well as backwater lakes, and from Catfish Paradise, Glory Hole, North Dike, and Pintail Slough in Topock Marsh (Figure 2). Species were selected for collection based on their availability and our ability to assure a representative sample of aquatic biota on Havasu NWR. Sediment was collected from Catfish Paradise, Glory Hole, North Dike, Pintail Slough, Devils Elbow, and Blankenship Bend. Vegetation was taken from backwater lakes within Topock Gorge, and Asiatic clams (*Corbicula fluminea*) were sampled from Catfish Paradise, Glory Hole, and North Dike. Fish were collected from Topock Marsh and backwater areas of Topock Gorge. American coots

(*Fulica americana*) were also sampled from backwater lakes within Topock Gorge, and western and Clark's grebe (*Aechmophorus occidentalis, A. clarkii*) eggs were removed from nests located in backwater areas within Topock Gorge and Topock Marsh.

FIGURE 2.

METHODS

Sample collections:

Sediment, plant material, invertebrates, fish, birds, and bird eggs were collected from Havasu NWR between April and August 1993. Five sediment subsamples were taken at each site using a stainless steel spoon and pan, then homogenized into a single composite sample per site. Approximately the top 10 cm of sediment was collected for each subsample. Spoonful-aliquots of the homogenous composite mixture were placed in an acid-rinsed glass jar, weighed, sealed with a teflon-lined lid, and placed on wet ice until the sample could be transferred to a commercial freezer. Sediment samples were analyzed for organochlorine pesticides and trace elements. Spiny naiad (*Najas marina*), a submergent aquatic plant, was taken in backwater areas from Blankenship Bend and Devils Elbow. The uppermost portion of two to three plants was broken by hand, composited by site, and stored in plastic zip-lock bags prior to trace element analyses. Clams were collected by hand from three marsh mudflats in Topock Marsh. Whole clams were frozen. Later, tissues were removed, blotted to remove excess water, weighed, then refrozen until organochlorine and trace element analyses were performed. Channel catfish (*Ictalurus punctatus*), largemouth bass (*Micropterus salmoides*), and common carp (*Cyprinus carpio*) were collected by use of a boat-mounted electroshocking unit and by monofilament gill nets. Fish were composited by species (n = 2-5) at each site (with the exception of the Topock Marsh channel catfish sample, in which only one individual was obtained and analyzed). Whole body samples were weighed and measured, wrapped in aluminum foil, and placed on wet ice until they were transferred to a commercial freezer where they were stored prior to trace element analyses. Five American coots were collected from Topock Gorge by shotgun using steel shotshells and by a .22 caliber rifle. The bills, lower legs, wingtips, feathers, and gastrointestinal tracts were removed and discarded.

Carcasses were frozen and later submitted for organochlorine analyses, and the livers and kidneys were extracted and analyzed for trace elements. The kidneys of three coots were submitted for selenium analysis only. There was insufficient tissue mass available from two coot kidneys for chemical analyses due to gunshot vitiation. Western and Clark's grebe eggs (n = 5 each) were collected, one egg per nest, and analyzed for trace elements. Eggs were weighed and processed in accordance with the guidelines of the Patuxent Analytical Control Facility (U. S. Fish and Wildlife Service 1990).

Chemical analysis:

Sediment, spiny naiad, clams, fish, coot livers and kidneys, and grebe eggs were analyzed for aluminum, arsenic, barium, beryllium, boron, cadmium, chromium, copper, iron, lead, magnesium, manganese, mercury, molybdenum, nickel, selenium, strontium, vanadium, and zinc at Research Triangle Institute, Research Triangle Park, North Carolina. Mercury concentrations were quantified by cold vapor atomic absorption. Arsenic and selenium were analyzed by hydride generation atomic absorption spectrophotometry. All other elements were quantified by using inductively coupled plasma emission spectroscropy (ICP) following preconcentration to lower detection limits. Trace element concentrations in all samples are reported in μg/g (parts per million) wet weight unless otherwise specified. Percent moisture is listed in most tables to facilitate wet weight to dry weight conversions. Wet weight values can be converted to dry weight equivalents by dividing the wet weight values by one minus percent moisture. This is illustrated in the following equation:

$$\text{Dry weight} = \frac{\text{wet weight}}{1 - \text{percent moisture}}$$

Sediment, clams, and coot carcasses were analyzed for organochlorine compounds including o,p'-and p,p'-DDE, o,p'-and p,p'-DDD, o,p'-and p,p'-DDT, dieldrin, heptachlor epoxide, hexachlorobenzene (HCB), alpha, beta, delta, and gamma BHC, alpha and gamma chlordane, oxychlordane, *trans*-nonachlor, *cis*-nonachlor, endrin, toxaphene, mirex, and total polychlorinated biphenyls (PCB) at Mississippi State Chemical Laboratory, Mississippi State, Mississippi. For each analysis, the sample was homogenized and mixed with anhydrous sodium sulfate and soxhlet extracted with hexane for seven hours. The extract was then concentrated by rotary evaporation to dryness for lipid determination. The weighed lipid sample was dissolved in petroleum ether and extracted four times with acetonitrile saturated with petroleum ether. Lipids were removed by Florisil column chromatography (Cromartie et al. 1975). The column was then eluted with diethyl ether/petroleum ether and separated into two fractions. One fraction was concentrated to appropriate volume for quantification of residues by packed or capillary column electron capture gas chromatography. The other fraction was concentrated and transferred to a Silicic acid chromatographic column for additional cleanup required for separation of PCBs from other organochlorines. Each fraction was concentrated to appropriate volume for quantification of residues by packed or megabore column, electron capture gas chromatography. The lower limit of quantification was 0.01 μg/g for most organochlorine pesticides and 0.05 μg/g for toxaphene and PCBs. Organochlorine compounds are expressed in μg/g wet weight unless otherwise specified.

Statistical analysis:

Whenever possible, element concentrations in fish were compared with those reported in the National Contaminant Biomonitoring Program (NCBP) for fish collected in 1976-1984 from 117 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 provided a frame of reference to identify elements of potential concern. However, caution should be exercised when comparing the 85th percentile to selenium levels in fish collected from the western United States. Generally, levels of selenium occur at lower concentrations in the eastern states and, subsequently, lower the 85th percentile. We have, in addition to using NCBP data, included concentrations of selenium specifically from studies in Arizona with which to compare our data.

A set of statewide data containing background concentrations of metals in Arizona soils was obtained by the U. S. Geological Survey (USGS) during a 14-year period from 1961 to 1975. They analyzed 47 soil samples from various locations across the state to determine the concentration of selected metals in Arizona soils (Boerngen and Shacklette 1981). In order to compare our sediment data from Havasu NWR with USGS data, we will refer to the Arizona background level as the mean " two standard deviations.

The limited number of individual samples collected and analyzed in this study necessitated the use of a Student's *t*-distribution to determine statistical differences between means. *T*-tests were used to compare selected trace element means between western and Clark's grebe eggs as well as to analyze coot contaminant concentrations between areas (Havasu NWR and Imperial NWR). Samples analyzed exhibited homogeneity of variance; therefore, log-transformation of concentrations prior to statistical analysis was not warranted. Analysis of variance (ANOVA) employing the GLM procedure was utilized to compare copper concentrations in carp from Topock Marsh with concentrations reported in other recent studies of carp from Topock Marsh. Both *t*-tests and ANOVAs were performed employing SAS utilizing a significance level of P # 0.05.

RESULTS AND DISCUSSION

Organochlorines:

Organochlorine compounds were not detected in sediment or clams. DDE (a metabolite of DDT) was the only organochlorine compound recovered in coot carcasses from

Topock Gorge (Table A-1). Although the use of DDT was suspended in the United States in 1972, residues of DDE and DDT continue to occur at high levels in certain parts of the United States (Stickel et al. 1984). Levels of DDE in coot carcasses ranged from 0.01 to 0.31 μg/g wet weight. DDE residues in coot carcasses were generally below levels associated with chronic poisoning and reproductive problems in most species of birds (Stickel 1973, Blus et al. 1977). Organochlorine compounds do not appear to present environmental hazards to clams or coots of Havasu NWR.

Trace Elements:

Trace elements in sediment:

Seventeen of nineteen trace elements were detected in sediment from six sites (Table A-2). Aluminum was present in all sediment samples, and concentrations ranged from 2,269 to 12,580 μg/g dry weight. These levels are well below the average background level of 55,213 μg/g for Arizona soils (Boerngen and Shacklette 1981).

Arsenic concentrations ranged from 3.9 to 13.1 μg/g dry weight. These levels bracketed the average (9.8 μg/g) of Arizona soils (Boerngen and Shacklette 1981). Concentrations greater than 7.0 and 11.0 μg/g dry weight have been considered elevated and heavily polluted in other areas (Ingersoll and Nelson 1989, Beyer 1990, Crayton and Jackson 1991). Four of six sediment samples from backwater sites on Havasu NWR contained concentrations above 7.0 μg/g.

Barium was recovered at concentrations ranging from 78.2 to 282.2 μg/g dry weight (Table A-2). Sediment with barium concentrations greater than 60 μg/g dry weight were classified as heavily polluted in the Great Lakes harbors (Beyer 1990). Barium levels in all of our samples exceeded this pollution classification. However, no data are available on the

threshold levels and effects of barium on fish and wildlife, therefore, interpretation of these data is not possible. The barium concentration
(530 μg/g dry weight) reported by Radtke et al. (1988) in sediment collected from Topock Marsh in 1986 was greater than those in our study.

Beryllium concentrations in sediment samples ranged from 0.46 to 1.59 μg/g dry weight. These levels are near or above the Arizona soils background average of
0.52 μg/g (Boerngen and Shacklette 1981).

Boron was detected in five of six sediment samples at concentrations ranging from 7.13 to 12.29 μg/g dry weight. These levels were considerably higher than that reported by Radtke et al. (1988) collected from Topock Marsh in 1986 (0.63 μg/g). There are no Arizona background levels available for boron with which to compare our data.

Cadmium concentrations in sediment samples ranged from 0.37 to 1.12 μg/g (Table A-2). Radtke et al. (1988) reported cadmium concentration in sediment from Topock Marsh as < 2.0 μg/g. There are no Arizona background levels for cadmium with which to compare our data.

Chromium was recovered in sediment from all six sites. Concentrations ranged from 7.49 to 17.61 μg/g dry weight (Table A-2). Radtke et al. (1988) reported chromium concentrations in sediment collected from Topock Marsh in 1986 as 41.6 μg/g. Sediment with chromium concentrations of 25 to 75 μg/g dry weight were classified as moderately polluted and greater than 75 μg/g as heavily polluted in Great Lakes harbors (Beyer 1990). The average background concentration of chromium in Arizona soils was 61.3 μg/g dry weight (Boerngen and Shacklette 1981). Chromium concentrations in sediment samples from this study are well below background levels. Although most chromium in sediment is unavailable to living organisms (Eisler 1986), concentrations reported in this study indicate no need for concern of chromium toxicity to fish and wildlife of Havasu NWR.

Copper ranged from non-detected to 34.29 µg/g in sediment samples (Table A-2). Copper was present in sediment from all sample sites with the exception of North Dike. The mean (16.5 µg/g) concentration reported here is consistent with that reported by Radtke et al. (1988) from sediment samples collected in 1986 from Topock Marsh (mean = 18.3 µg/g). Boerngen and Shacklette (1981) reported the Arizona background average for copper as 30 µg/g dry weight.

Lead was detected in sediment at concentrations that ranged from 9.27 to 41.13 µg/g dry weight (mean = 22.9 µg/g [Table A-2]). These levels are similar to those reported by Radtke et al. (1988) for sediment samples taken from Topock Marsh in 1986 (mean = 22.0 µg/g). Sediment with lead concentrations < 40 µg/g dry weight were classified as non-polluted in Great Lakes harbors (Beyer 1990).

Magnesium and manganese concentrations ranged from 1,969 to 10,350 µg/g, and 56.3 to 331.2 µg/g dry weight, respectively. There are no established background levels for either element; however, Radtke et al. (1988) reported an average manganese concentration of 466.7 µg/g in sediment from Topock Marsh in 1986.

Nickel concentrations ranged from 6.99 to 23.54 µg/g dry weight (mean = 14.5 µg/g [Table A-2]). Beyer (1990) considered nickel concentrations in sediment between 20 and 50 µg/g dry weight to be moderately polluted. Radtke et al. (1988) reported a mean nickel concentration of 17.3 µg/g in sediment collected from Topock Marsh in 1986, and Ruiz (1994) reported a mean nickel concentration of 25.6 µg/g in sediment collected in 1993 at Bill Williams River near its confluence with the Colorado River.

Selenium in sediment is particularly important to long-term habitat quality because aquatic microorganisms readily mobilize selenium into food chains and thereby facilitate its dietary exposure to fish and wildlife (Lemly and Smith 1987). Selenium was detected in five of six sediment samples from sites within Topock Gorge and Topock Marsh. Concentrations ranged from <0.50 to 1.26 μg/g dry weight (Table A-2). These levels are comparable to concentrations in sediment previously collected from Topock Marsh (Radke et al. 1988, Rusk 1991, King et al. 1993). These levels are, however, slightly higher than those reported by Ruiz (1994) in sediment from Bill Williams NWR, but well below the 4 μg/g dry weight concentration suggested by Lemly and Smith (1987) that may cause food chain contamination.

Strontium was detected in all sediment samples at concentrations ranging from 64.7 to 260.3 μg/g dry weight (mean = 147.8 μg/g). There are no established background levels for strontium, however, the mean strontium concentration in sediment from the confluence of the Colorado and Bill Williams Rivers collected in 1992-93 by Ruiz (1994) was 120.3 μg/g dry weight, a level relatively consistent with that reported here.

Zinc was recovered in sediment samples from all sites, and concentrations ranged from 17.93 to 116.5 μg/g dry weight (mean = 60.4 μg/g)(Table A-2). The mean reported here is comparable to the findings of Radtke et al. (1988) in sediment collected from Topock Marsh in 1986 (mean = 63.6 μg/g). There are no established background levels for zinc in Arizona soils.

Mercury and molybdenum were not detected in any sediment samples. Sediment from Blankenship Bend contained the highest concentration of boron. Devils Elbow sediment had the highest concentrations of beryllium, cadmium, chromium, copper, magnesium, nickel, and lead. The North Dike sediment sample contained the highest concentration of arsenic, and Pintail Slough sediment had the highest concentrations of aluminum, barium, iron, manganese, selenium, strontium, vanadium, and zinc. North Dike samples contained the lowest concentrations of 14 trace elements while Glory Hole contained the lowest concentrations of arsenic and selenium.

Trace elements in spiny naiad:

Fifteen of nineteen inorganic elements were recovered in spiny naiad plant tissue collected from Blankenship Bend and Devils Elbow within Topock Gorge (Table A-3). Aluminum concentrations were 49.0 and 154.4 µg/g wet weight, which were well below those found in spiny naiad taken from Topock Marsh by Radtke et al. (1988) and below levels in spiny naiad from irrigation drainages (Baker et al. 1992) in the Yuma Valley (Table 1).

Table 1. Comparison of mean concentrations of selected trace elements in spiny naiad (*Najas marina*) from Havasu National Wildife Refuge with data from other studies in Arizona.

	Trace element concentrations, µg/g wet weight								
Area/Year	**Al**	**As**	**B**	**Cr**	**Cu**	**Ni**	**Pb**	**Se**	**Zn**
Topock Gorge 1993[1]	101.65	0.38	1.61	0.37	0.85	0.38	0.37	0.42	2.25
Topock Marsh 1986[2]	1165	0.58	BDL[3]	3.65	0.72	1.46	0.49	BDL	4.35
Yuma Irrigation Drainages 1989[4]	1037.4	2.28	NA[5]	0.94	1.70	1.14	0.92	0.10	3.57

[1] This study (Concentrations represent a mean of 2 samples)
[2] Radtke et al. 1988 (Concentrations represent a mean of 4 samples)
[3] BDL - Below detection limit (Because boron was not detected in 3 of 4 samples, we report it here as BDL)
[4] Baker et al. 1992 (Concentrations represent a mean of 5 samples from 5 irrigation drainages in the Yuma Valley)
[5] NA - Data not available

Arsenic concentrations, 0.14 and 0.62 μg/g wet weight (2.07 and 5.12 μg/g dry weight), were slightly lower than levels reported by Radtke et al. (1988) for spiny naiad collected from Topock Marsh (Table 1), but higher than arsenic concentrations Hothem and Ohlendorf (1989) observed in widgeongrass (*Ruppia maritima*) at Kesterson Reservoir (0.72 to 1.9 μg/g dry weight). Arsenic dietary concentrations as low as 30 μg/g dry weight adversely affect the growth, physiology, and development of ducklings (Camardese et al. 1990). Eisler (1988a) suggested a dietary level of 120 μg/g wet weight may cause adverse effects in aquatic organisms. Arsenic concentrations in our samples were well below these threshold levels.

Barium concentrations were detected at 17.1 and 17.3 μg/g wet weight (Table A-3) in spiny naiad, levels slightly higher than those reported by Radtke et al. (1988) from Topock Marsh in 1986 (mean = 11.65 μg/g).

Boron was recovered at 0.96 and 2.26 μg/g wet weight (Table A-3). Three of four spiny naiad samples collected by Radtke et al. (1988) from Topock Marsh in 1986 did not contain detectable concentrations of boron. Boron was recovered in one sample at a concentration of 4.8 μg/g wet weight. Because less than half of the samples Radtke et al. (1988) collected contained detectable levels of boron, we have reported the concentration of boron in Table 1 as below the detection limit.

Beryllium, cadmium, and mercury were not detected in spiny naiad in this study nor in collections by Radtke et al. (1988) from Topock Marsh in 1986.

Chromium was recovered at 0.23 and 0.50 μg/g wet weight, as little as one-sixth the concentrations reported by Radtke et al. (1988) for samples from Topock Marsh and one-half those reported by Baker et al. (1992) for spiny naiad collected from irrigation drainages in the Yuma Valley (Table 1).

Copper in spiny naiad was detected at 0.29 and 1.40 μg/g wet weight (Table A-3). These levels are consistent with those Radtke et al. (1988) reported in spiny naiad collected from Topock Marsh in 1986 and approximately one-half the concentrations Baker et al. (1992) reported in spiny naiad collected from irrigation drainages in the Yuma Valley (Table 1).

Magnesium was present at 323.7 and 692.3 μg/g wet weight, levels slightly lower than the mean Radtke et al. (1988) found in 1986 in Topock Marsh (872.5 μg/g wet weight).

Lead was detected at 0.20 and 0.54 μg/g and nickel at 0.18 and 0.57 μg/g wet weight. Concentrations of both elements were lower than those presented by Radtke et al. (1988) and Baker et al. (1992 [Table 1]).

Nickel in spiny naiad was detected at concentrations of 0.18 and 0.57 μg/g wet weight (mean = 0.38 μg/g). This mean is well below the mean (1.46 μg/g) Radtke et al. (1988) reported in collections of spiny naiad from Topock Marsh in 1986 (Table 1).

Selenium was recovered at 0.35 and 0.49 μg/g wet weight (5.22 and 4.06 μg/g dry weight). These levels are well above background concentrations of 0.4 μg/g dry weight (Ohlendorf et al. 1986a). Selenium was not dectected in spiny naiad collected from Topock Marsh in 1986 (Radtke et al. 1988 [Table 1]). However, selenium concentrations reported in this study are consistent with those reported by Lusk (1993) from the Colorado River within Imperial NWR (5.72 and <4.76 μg/g dry weight). As a dietary source for waterfowl, spiny naiad selenium levels exceeded the concentration

(3 μg/g dry weight) that may cause reproductive failure or mortality in waterfowl due to food-chain bioconcentration (Lemly and Smith 1987).

Strontium was present in spiny naiad samples at 14.4 and 56.9 μg/g wet weight (mean = 35.7 μg/g). This mean is less than the mean (45.5 μg/g) reported by Radtke et al. (1988) from his collections of spiny naiad in Topock Marsh in 1986.

Vanadium was recovered at 0.17 and 0.72 μg/g wet weight (mean = 0.45 μg/g), which is less than the mean (0.93 μg/g) reported by Radtke et al. (1988) from spiny naiad collected from Topock Marsh in 1986.

Zinc was detected at 1.7 and 2.8 μg/g wet weight in spiny naiad collected from Topock Gorge (Table A-3). Radtke et al. (1988) reported zinc concentrations ranging from 1.1 to 8.1 μg/g wet weight in spiny naiad collected from Topock Marsh in 1986. Baker et al. (1992) reported concentrations ranging from 2.51 to 5.26 μg/g wet weight in spiny naiad taken from irrigation drainages in the Yuma Valley (Table 1).

Trace elements in clams:

Trace elements detected in freshwater clams are presented in Table A-4. Aluminum was recovered in all clam samples at comparable levels among sites. Concentrations ranged from 177.2 to 180.4 μg/g dry weight (Table A-4), which are almost twice as high than Lusk (1993) reported in clams collected from several backwater lakes within Imperial NWR (mean = 92.82 μg/g). However, aluminum concentrations in our study are considerably lower than those reported by Tadayon et al. (In press) in clams collected in 1995 from the lower Colorado River and Yuma Valley irrigation drainwater ditches (mean = 492.67 μg/g).

Arsenic was detected at all sites within Topock Marsh at concentrations ranging from 10.23 to 11.79 μg/g dry weight. These levels were lower than those reported by Lusk (1993) in clams collected from several backwater lakes within Imperial NWR (mean = 16.76 µg/g). However, arsenic levels reported here are higher than those reported by McCaulou et al. (1994) for clams collected in 1992 within Topock Marsh (geometric mean = 8.14 µg/g), as well as concentrations in clams collected from the lower Colorado River and Yuma Valley irrigation drainwater ditches (mean = 8.6 µg/g) (Tadayon et al. In press). Arsenic acts as a cumulative poison (Jenkins 1981) and is listed by the Environmental Protection Agency (EPA) as one of 129 priority pollutants (Keith and Telliard 1979). The potential for bioaccumulation or bioconcentration of arsenic is high to very high for mollusks (Jenkins 1981). Background arsenic concentrations in biota are usually less than 1 µg/g wet weight (3 - 4 µg/g dry weight) (Eisler 1988a). All of our samples were above this background level. Although arsenic concentrations were within the background range in sediment, arsenic bioaccumulated to relatively high levels in clams.

Beryllium was recovered only in the North Dike composite clam sample at a concentration of 0.49 µg/g dry weight. Beryllium has not been an element of concern in the lower Colorado River. Lusk (1993) and McCaulou et al. (1994) did not detect beryllium in clams from backwater lakes within Imperial NWR or from Topock Marsh in their earlier studies. This element may have been recovered at North Dike as a result of importation of dike material during construction in the late 1980's.

Cadmium was detected in clams from all sites with concentrations ranging from 0.29 to 1.94 µg/g dry weight (Table A-4). The highest concentration came from the North Dike site. Cadmium, like arsenic, acts as a cumulative poison (Jenkins 1981), and wildlife that feed on clams with high concentrations may potentially experience cadmium toxicity causing behavioral, growth, or physiological problems (Rompala et al. 1984). Cadmium is listed by the EPA as a priority pollutant (Keith and Telliard 1979). It is toxic to a variety of fish and wildlife and tends to bioaccumulate in clams (Schmitt et al. 1987). Cadmium concentrations in clams, particularly from the North Dike site, were higher than those (mean = 0.59 µg/g dry weight) reported by Lusk (1993) in clams from backwater lakes of the Colorado River on Imperial NWR and higher than Topock Marsh clams collected in 1992 (McCaulou et al. 1994).

Chromium was recovered in clams only at the Glory Hole and North Dike sites at concentrations of 1.56 and 1.96 µg/g dry weight, respectively. The organs and tissues of fish and wildlife that contain >4.0 µg/g total chromium dry weight should be viewed as presumptive evidence of chromium contamination (Eisler 1986). Samples in this study did not exceed this level of concern.

Copper was detected in clams at all sites. Concentrations at the Catfish Paradise and Glory Hole sites were similar (29.45 and 30.10 µg/g dry weight) and about one-half the concentration in clams from the North Dike site (71.93 µg/g [Table A-4]). Lusk (1993) reported only one site in his study that contained higher copper concentrations than those reported at North Dike. All copper levels in clams collected by McCaulou et al. (1994) in Topock Marsh were less than those at the North Dike site. This element may have been recovered at elevated levels as a result of importation of the dike material during its construction. However, copper was not detected in sediment collected from North Dike. These differences suggest that copper in the area of North Dike may be spatially concentrated.

Lead was recovered in clams from all sites. Lead concentrations in clams from Catfish Paradise and Glory Hole were similar at 2.86 and 2.79 µg/g dry weight (0.32 and 0.27 µg/g wet weight). However, concentrations in clams collected from North Dike were nearly three-times higher (7.82 µg/g dry weight, 0.69 µg/g wet weight) than concentrations at other sites. Lead was not detected in clams collected from Topock Marsh in 1992; concentrations were below the 0.50 μg/g wet weight lower limit of detection (McCaulou et al. 1994). Although lead is toxic to aquatic organisms and bioaccumulates in clams (Eisler 1988b), it is not known if lead in concentrations found at the North Dike sample represents a concentration harmful to clams or hazardous to predators that feed on them.

Selenium is an essential trace element in animal diets, but is toxic at concentrations only slightly above required dietary levels (Sharma and Singh 1984). Selenium concentrations in clams from Topock Marsh ranged from 8.81 to 18.64 μg/g dry weight. Concentrations in clams varied only slightly among sites, but all sites contained higher levels ($3 μg/g dry weight) than that which can be potentially lethal to fish and aquatic birds that consume them (Lemly 1993). Reductions in egg hatchability and teratogenic effects were experienced when mallards (*Anas platyrhynchos*) were fed a diet containing 10 μg/g selenium (dry weight [Heinz et al. 1987]). Birds that feed on clams in Topock Marsh could experience impaired reproduction.

Strontium and vanadium were present in most clam samples from Topock Marsh (Table A-4). Background levels for strontium and vanadium in molluscs and the tendency for strontium and vanadium to bioaccumulate through the aquatic food chain are not well known. Data are presented here as a baseline for future comparisons.

Zinc was detected in clams from all sites at concentrations that ranged from 109 to 147.4 μg/g dry weight (12.36 to 14.24 μg/g wet weight [Table A-4]). Zinc is ubiquitous in tissues of plants and animals and is essential for normal growth and reproduction (Eisler 1993). Zinc concentrations reported here are less than those reported from 1992 collections of clams from Topock Marsh (22.50 to 210.61 μg/g wet weight [McCaulou et al. 1994]).

Trace elements in fish:

Sixteen trace elements recovered in fish tissues are presented in Table A-5. NCBP data are available for seven elements: arsenic, cadmium, copper, lead, mercury, selenium, and zinc (Schmitt and Brumbaugh 1990).

Aluminum was detected in all fish samples in concentrations ranging from 6.81 to 73.6 μg/g wet weight (Table A-5). We found no consistent pattern of aluminum levels in fish collected from Topock Gorge compared to fish collected from Topock Marsh. Aluminum concentrations in carp and bass were higher than those reported by King et al. (1993) from samples taken at Topock Marsh in 1989 (Table 2). However, aluminum in catfish from Topock Marsh was twice as high in 1989 as the levels reported here.

Arsenic was recovered in four of nine whole body fish samples, and concentrations ranged from 0.10 to 0.20 μg/g wet weight (Table A-5). All levels were below the NCBP 85th percentile of 0.27 μg/g (Schmitt and Brumbaugh 1990). Walsh et al. (1977) considered arsenic concentrations >0.5 μg/g wet weight a level that could harm fish. Levels in this study were well below this harmful threshold. Arsenic concentrations in fish from Topock Marsh were lower than those from fish collected in other studies in the lower Colorado River valley (Table 2).

Barium was present in all samples, and concentrations ranged from 0.29 to 2.80 μg/g (Table A-5). Concentrations were highest in carp from Topock Gorge and lowest in catfish from Topock Marsh. No comparable data are available to assess whether barium concentrations reported in this study were elevated or within normal background range.

Table 2. Comparison of concentrations (µg/g wet weight) of selected trace elements in fish from Topock Marsh, Havasu National Wildlife Refuge, to levels reported in other studies in the lower Colorado River Valley.

	Trace element concentrations, µg/g wet weight								
Area and species	**Al**	**As**	**B**	**Cd**	**Cu**	**Fe**	**Hg**	**Se**	**Zn**
NCBP 85th percentile[1]	NA[2]	0.27	NA	0.05	1.0	NA	0.17	0.73	34.2
Topock Marsh 1993[3]									
Carp	73.6	BDL[4]	BDL	0.02	3.08	56.0	BDL	2.43	64.37
Largemouth bass	9.6	BDL	BDL	BDL	1.81	22.0	0.02	2.27	15.75
Channel catfish	6.81	BDL	0.28	BDL	0.37	53.0	BDL	1.02	14.0
Topock Marsh 1986-87 [5]									
Carp	24.0	<0.05[6]	13.0	BDL	0.42	54.25	BDL	1.55	54.0
Topock Marsh 1988[7]									
Carp	39.3	0.09	NA	NA	0.74	71.6	0.01	1.54	45.0
Largemouth bass	7.3	0.12	NA	0.02	0.34	17.5	0.01	2.18	13.6
Channel catfish	14.5	0.10	NA	0.04	0.52	25.5	0.06	0.89	17.4
Bill Williams NWR 1992-93 [8]									
Carp	NA	0.57	NA	0.03	1.50	NA	0.06	1.42	73.1
Largemouth bass	NA	0.26	NA	0.02	0.56	NA	0.13	0.80	14.3
Cibola Lake 1988-89 [9]									
Carp	28.2	0.10	NA	0.02	0.70	38.0	0.02	1.17	48.8
Largemouth bass	8.5	0.12	NA	0.02	0.30	15.0	0.01	1.53	15.5
Channel catfish	35.9	0.09	NA	0.05	0.70	37.0	0.01	1.67	22.0
Martinez Lake 1988 [10]									
Carp	50.4	0.10	NA	0.01	10.0	115.0	0.01	2.28	72.6
Largemouth bass	5.3	0.02	NA	0.01	0.30	15.0	0.02	2.02	16.1

[1] National Contaminant Biomonitoring Program 85th Percentile (Schmitt and Brumbaugh 1990)

[2] Data not available

[3] This study

[4] Below detection limit

[5] Radtke et al. 1988 (Concentrations represent a mean of 4 samples)

[6] Only one sample was above detection limit at a concentration of 0.070 μg/g.

[7] King et al. 1993

[8] Ruiz 1994

[9] King et al. 1993

[10] King et al. 1993 (Concentrations represent a mean of 2 samples)

Boron was recovered in four of nine samples. Boron concentrations ranged from 0.18 to 0.28 μg/g (Table A-5). All whole body fish levels were comparable between species and sites. Carp and bass from Topock Marsh, and catfish and bass from Topock Gorge, contained less than the lower limit of detection. No comparable data are available to assess whether boron concentrations reported in this study were elevated or within normal background range. However, carp collected by Radtke et al. (1988) from Topock Marsh in 1986 contained a mean concentration of 13.0 μg/g wet weight (Table 2).

Cadmium was present in five of nine samples, and concentrations ranged from 0.02 to 0.08 μg/g wet weight (Table A-5). Levels in all fish samples approached or exceeded the NCBP 85th percentile of 0.05 μg/g (Schmitt and Brumbaugh 1990). Concentrations of cadmium in this study were similar to those in fish collected from Topock Marsh in 1993-94 by Ruiz (1994) as well as collections in 1988 by King et al. (1993). Comparisons of levels of trace elements among this and other studies are presented in Table 2. None of the samples in our study contained cadmium above the 0.5 μg/g threshold considered harmful to fish and predators (Walsh et al. 1977). Although the cadmium concentrations we found were above background levels, these current concentrations are not considered toxic; therefore, cadmium is not a contaminant concern at Havasu NWR.

Chromium was detected in all samples. Concentrations ranged from nearly three to five times higher in carp from Topock Gorge (1.27 μg/g and 2.08 wet weight, 5.61 and 8.08 μg/g dry weight), than in carp from Topock Marsh (0.46 μg/g wet weight) (Table A-5). Concentrations in bass and catfish were similar to that in carp from Topock Marsh. Available data suggest that >4.0 μg/g dry weight chromium in fish tissues should be viewed as evidence of chromium contamination (Eisler 1986). Two carp samples from Topock Gorge contained >4.0 μg/g dry weight (Table A-5). Chromium concentrations in carp from our study are considerably higher than those reported by King et al. (1993) in carp collected from from Topock Marsh in 1988 (0.07 µg/g wet weight).

Copper was detected in all fish samples, and concentrations ranged from 0.37 µg/g in channel catfish to 3.08 µg/g wet weight in carp from Topock Marsh. Copper concentrations in carp were significantly higher (P = 0.0035) than those reported by King et al. (1993) and Ruiz (1994) in carp from Topock Marsh (Table 2). All but two samples were above the NCBP 85th percentile of 1.0 µg/g (Schmitt and Brumbaugh 1990); therefore, copper remains a contaminant of potential concern on Havasu NWR.

Iron, magnesium, and manganese are essential nutrients and were present in all fish samples. Concentrations ranged from 22 to 162 µg/g, 191 to 338 µg/g, and 1.0 to 3.9 µg/g wet weight, respectively (Table A-5). Background levels for these trace elements in fish and their tendency to bioaccumulate through the aquatic food chain are not well known.

Lead was detected in six of nine samples, and concentrations ranged from 0.14 to 1.0 µg/g (Table A-5). Eighty-three percent (83%) of the samples exceeded the NCBP 85th percentile of 0.22 µg/g. The highest level (1.0 µg/g) came from a channel catfish sample from Topock Gorge. Lead is highly toxic to aquatic organisms, especially fish (Rompala et al. 1984). The biological effects of sublethal concentrations of lead include delayed embryonic development, suppressed reproduction, inhibition of growth, increased mucous formation, neurological problems, enzyme inhibition, and kidney disfunction (Rompala et al. 1984, Leland and Kuwabara 1985). Lead concentrations in whole body fish exceeding 0.5 µg/g wet weight have the potential to harm fish reproduction and survival (Walsh et al. 1977). Because two samples from Topock Gorge contained lead concentrations in excess of the 0.5 µg/g threshold level, and 83% of the fish samples exceeded normal background levels. Lead is a contaminant of concern on Havasu NWR.

Mercury was recovered in six of nine fish samples, and concentrations ranged from 0.02 to 0.08 μg/g wet weight, all well below the NCBP 85th percentile of 0.17 μg/g. Comparing our data with those of King et al. (1993), concentrations of mercury have remained relatively unchanged over time (Table 3). Mercury concentrations were also relatively consistent among sites. 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 0.10 μg/g wet weight (Eisler 1987). None of the whole body fish samples collected during this study approached the 0.10 μg/g level of concern. Mercury does not appear to present a contaminant hazard to fish on Havasu NWR.

Nickel was detected in all samples, and concentrations ranged from 0.30 to 1.19 μg/g (Table A-5). Nickel concentrations >0.9 μg/g wet weight in fish can be considered elevated (Irwin 1988). Three samples contained nickel that exceeded the 0.9 μg/g concern level. Little information is available on the effects of nickel on fish and wildlife, and there are no national baseline data with which to compare our data. Therefore, the significance of nickel concentrations in whole body fish from Havasu NWR can not be established.

Table 3. Trace element concentrations in composite whole body fish (μg/g wet weight) collected from To
National Wildlife Refuge in 1988[1] and 1993.

Sample	Year	Al	As	Cd	Cr	Cu	Fe	Hg	Mn
Common carp	1988	39.3	0.09	0.05	0.07	0.74	71.6	0.01	3.4
Common carp	1993	73.6	<0.10	0.02	0.46	3.08	56	<0.02	2.0
LM bass[2]	1988	7.3	0.12	0.02	0.07	0.34	17.5	0.01	0.9
LM bass	1993	9.6	<0.10	<0.02	0.50	1.81	22	0.02	1.0
Channel catfish	1988	14.5	0.10	0.04	0.14	0.52	25.5	0.06	2.0
Channel catfish	1993	6.81	<0.12	<0.02	0.65	0.37	53	<0.02	1.3

[1] From King et al. 1993
[2] LM bass = Largemouth bass

Selenium was recovered in all fish samples, and concentrations ranged from 0.79 to 2.60 µg/g wet weight (Table A-5), all of which exceeded the NCBP 85th percentile of 0.73 µg/g (Schmitt and Brumbaugh 1990). Dry weight conversions of selenium levels ranged from 2.98 to 11.36 µg/g, which are nearly equal to and exceed the concentration (3.0 µg/g dry weight) considered potentially lethal to fish and aquatic birds that consume them (Lemly 1993). Fish taken from the Colorado River within Havasu NWR contained some of the highest mean selenium concentrations among fish sampled nationwide (Schmitt and Brumbaugh 1990). Selenium levels of 2.0 µg/g wet weight or greater, may cause reproductive impairment and lack of recruitment in fishes (Baumann and May 1984). Gillespie and Baumann (1986) suggested that selenium levels of 6.9 to 7.2 µg/g wet weight is the threshold associated with selenium induced reproductive failure of bluegills at selenium contaminated Hyco Reservoir in North Carolina. Selenium toxicity was also responsible for declines in the largemouth bass population at Hyco Lake. In a comprehensive summary of selenium threshold effect levels, Lemly and Smith (1987) reported selenium induced reproductive failure in fish associated with whole body selenium concentrations of 12 µg/g dry weight. The selenium levels reported in this study fall well below Gillespie and Baumann's (1986) suggested threshold level, but are near Lemly and Smith's (1987) level suggested for reproductive failure in fish. Despite variations in suggested selenium toxicity levels, those reported in this study are among the highest selenium concentrations reported in carp and largemouth bass from major Arizona rivers (Radtke et al. 1988, King et al. 1991, King et al. 1993, Baker and King 1994, Ruiz 1994, King and Baker 1995). In this study, mean selenium concentrations in fish from Havasu NWR (1.73 µg/g) exceeded the mean selenium concentrations in fish collected in 1984 from Lake Havasu during Schmitt and Brumbaugh's (1990) National Contaminants Biomonitoring Program (1.43 µg/g). Lake Havasu, as well as four other sample stations on the Colorado River, were among 10 stations with the highest mean selenium concentrations in fish from 117 stations sampled nationwide (Table 4). Selenium levels in fish from Havasu NWR suggest potential selenium toxicity, which in time, may affect reproduction and recruitment of fish, as well as birds that feed on them.

Table 4. The ten highest selenium concentrations (μg/g wet weight) in fish among the 117 stations sampled nationwide in the National Contaminant Biomonitoring Program (Schmitt and Brumbaugh 1990).

Station	Mean selenium concentration
Lake Martinez, Arizona	2.23
Waikele Stream, Hawaii	1.91
San Joaquin River, California	1.71
Arkansas River, Colorado	1.65
Lake Powell, Arizona	1.59
Lake Havasu, Arizona	1.43
Colorado River, Yuma, Arizona	1.36
Lake Mead, Arizona	1.36
Pecos River, Texas	1.09
Green River, Utah	1.05

For comparison, mean selenium concentration in fish from this study was 1.73 μg/g wet weight.

In Ruiz's (1994) study of Bill Williams NWR, all fish collected at the confluence of Bill Williams River and the Colorado River contained elevated selenium levels that may pose a health risk to the organisms, as well as the predators that feed on them. Fish collected in the Bill Williams River upstream of the confluence did not contain elevated levels of selenium, with the exception of red shiners (*Cyprinella lutrensis*), which contained elevated levels throughout the Bill Williams River. Ruiz (1994) suggested that elevated selenium levels in biota originate from contact with water from the Colorado River and not from the Bill Williams River.

Strontium was present in all fish samples with concentrations ranging from 7.23 to 40.80 μg/g wet weight (Table A-5). Concentrations were highest in the carp samples and lowest in the channel catfish samples. Concentrations of strontium in fish collected from Havasu NWR in 1993 are within the range of those collected from other Arizona locations (Baker and King 1994, Andrews et al. 1995, King et al. In prep, Tadayon et al. In press).

Vanadium was detected only in two of nine fish samples (Table A-5). Carp collected from Topock Gorge contained vanadium at 0.22 to 0.30 μg/g wet weight. These levels were low compared to those in fish collected from other Arizona locations (Baker and King 1994, Andrews et al. 1995, Tadayon et al. In press).

Zinc was detected in all fish samples and concentrations ranged from 13.10 to 64.87 μg/g wet weight (Table A-5). All samples, except three carp, contained levels well below the NCBP 85th percentile of 34.2 μg/g. Although zinc is an essential element, at high concentrations, it can be toxic to fish, cause mortality, growth retardation, and reproductive impairment (Sorenson 1991). Fish can accumulate zinc from both the surrounding water and from their diet (Eisler 1993). Carp from Topock Gorge and Topock Marsh contained from 55.55 to 64.87 μg/g zinc, levels which are generally consistent with those from carp taken from other areas associated with the Colorado River (Table 2). Zinc tends to bioaccumulate more readily in carp than in most fish species (Lowe et al. 1985, Schmitt and Brumbaugh 1990); therefore, comparing zinc in Havasu NWR carp with the national background level composed of many species of fish would not be a valid comparison.

Trace elements in birds and eggs:

Exposure of birds to trace elements can be measured by analyzing their food, eggs, and selected body tissues. Analysis of the liver is appropriate for assessing recent exposure of birds to most elements (Ohlendorf 1993). Selenium should be measured in both the liver and kidneys, because the ratio of concentrations helps assess environmental exposure. Further review of kidney:liver ratios is discussed at the end of this section.

Seventeen of nineteen trace elements were detected in coot livers. The following discussion is limited to those elements with a propensity to bioaccumulate to potentially harmful levels and possibly harm aquatic wildlife. However, all elements are listed in Table A-6 for informational purposes.

Aluminum was detected in all livers. Four livers contained concentrations that ranged from 8.65 μg/g to 14.45 μg/g dry weight. Liver tissue from the fifth coot contained an unusually high spike of 93.0 μg/g. Because retention of aluminum in the absence of kidney dysfunction is minimal even when dietary levels are high, aluminum concentrations in such tissues as liver and kidney will not necessarily reflect increased exposure to aluminum (Scheuhammer 1987). Because the toxic potential of dietary aluminum in healthy animals is low, we do not attribute dietary origins to this elevated level in one coot. This particular bird was collected by use of a .22 caliber rifle. It is unlikely that the aluminum spike is a result of residual shot or the bullet having been lodged in the tissue and subsequently analyzed because other element concentrations (i.e. copper, lead) in the coot would also have been elevated. We are unable to explain this anomaly of an elevated aluminum concentration in the liver of one coot.

Boron was recovered in all livers and ranged from 0.67 μg/g to 2.73 μg/g dry weight. Mallards fed 1000 μg/g boron in a laboratory study produced 60% fewer ducklings than controls; livers of the adults contained 33 µg/g dry weight boron (Smith and Anders 1989). Livers of coots collected from a boron contaminated wetland in central California that was sustained by agricultural drainwater contained 33 µg/g dry weight boron (Paveglio et al. 1992). Boron concentrations in coot livers in our study do not appear high enough to affect reproduction or recruitment. Boron may be transmitted to eggs and adversely affect hatchability or development of embryos (Ohlendorf et al. 1986a). Boron was recovered in only one grebe egg (Table A-7) at a concentration slightly above the detection limit, suggesting that boron is not of biological concern for western or Clark's grebes of Havasu NWR.

Cadmium concentrations in coot livers ranged from 0.10 to 0.92 µg/g wet weight (0.35 to 3.36 µg/g dry weight [Table A-6]). As a monitor of total exposure, or as an indicator of the body burden of cadmium, the cadmium concentration of liver tissue is probably the best measure (Scheuhammer 1987). There are no background cadmium levels for coots specifically, but Di Giulio and Scanlon (1984) reported background cadmium concentrations in most wild, freshwater duck species as <3 µg/g dry weight. Levels that exceed this concentration would be indicative of increased environmental exposure to cadmium. All coot livers analyzed in this study were well below this level of concern except one, which was only slightly above this threshold (Table A-6). Eggs are not considered useful for assessing exposure of birds to cadmium (Scheuhammer 1987, Leonzio and Massi 1989). Little cadmium is transferred to eggs regardless of dietary levels consumed. Cadmium was not detected in any grebe eggs from Havasu NWR. Cadmium concentrations are normally higher in the liver than in eggs produced by the bird (Scheuhammer 1987, Ohlendorf 1989, 1993, Ohlendorf and Skorupa 1989).

Copper concentrations ranged from 21.15 to 36.24 µg/g dry weight in coot livers

(Table A-6). Livers of wigeon (*Anas penelope*) and mallards collected from relatively unpolluted areas in England contained mean copper concentrations of 116.3 and 114.8 μg/g dry weight, respectively (Parslow et al. 1982). The mean copper concentration from three composites of coot livers and kidneys collected from Las Vegas NWR, New Mexico was 36.7 μg/g dry weight (Bristol and Shomo 1993). Acute copper toxicosis in immature Canada geese (*Branta canadensis*) from Indiana was associated with copper concentrations in liver tissue that ranged from 56 to 97 μg/g wet weight (. 187 to 323 μg/g dry weight) (Henderson and Winterfield 1974). If these values represent background levels, copper concentrations in coot livers collected from Havasu NWR are well within "normal" range.

Copper was detected in all grebe eggs at concentrations that ranged from 2.19 to 3.40 μg/g dry weight. Mean copper concentrations in royal tern (*Sterna maxima*) eggs collected in a relatively unpolluted area (Sundown Island in Matagorda Bay) in Texas averaged 1.09 μg/g wet weight (. 3.63 μg/g dry weight assuming 70% moisture [King et al. 1983]). Little information is available on background copper concentrations in bird eggs; however, if the Sundown Island copper concentrations in tern eggs represent "normal" levels, then copper does not appear to present a biological concern to western and Clark's grebe eggs from Havasu NWR.

Iron concentrations in western grebe eggs ranged from 97.51 to 117.1 μg/g dry weight. Those in Clark's grebe eggs ranged from 104.6 to 148.8 μg/g (Table A-7). Although iron levels in the grebe species are statistically different (P = 0.03), these results do not indicate a biological significance due to the low toxicity of iron and the ability of the body to regulate iron absorption in accordance with body needs (Morris 1987).

Lead was recovered in all coot livers, and concentrations ranged from 0.27 to

1.04 μg/g wet weight (Table A-6). Scheuhammer (1987) suggested that female birds accumulate lead at a greater rate than males. Although our sample size is small, our data support this assumption. Longcore et al. (1974) studied the effect of lead exposure on captive mallards and suggested that lead levels between 6 to 20 μg/g wet weight in the liver should be considered an indication of recent, acute lead exposure and diagnostic of active lead intoxication. Lead concentrations in coot livers in this study were well below this threshold level. However, Schuehammer (1987) suggested that normal background levels of lead in tissues of adult bird species are 0.5 to 5.0 μg/g dry weight in livers. All coot livers sampled in this study were within this range.

Lead was detected in only one grebe egg at a concentration (0.69 μg/g dry weight), slightly above the detection limit (Table A-7). Some lead is transferred to eggs (primarily incorporated into the eggshells), but concentrations are typically low and do not correlate well with dietary exposure (Ohlendorf 1993). Lead does not appear to present a biological concern for coots or grebes within Havasu NWR.

Mercury readily bioconcentrates in the food chain and accumulates in birds. Low levels can be highly neurotoxic (Peterle 1991). Peakall and Lovett (1972) suggested that birds at the top of freshwater food chains were those at highest risk of mercury poisoning. Mercury was not detected in coot liver samples.

Mercury concentrations in bird eggs reflect exposure of the female to that element (Ohlendorf et al. 1978, Scheuhammer 1987, Ohlendorf 1989). Mercury was recovered in all western grebe eggs and in one of five Clark's grebe eggs at concentrations that ranged from 0.19 to 0.86 μg/g dry weight. Because mercury was not detected in four of five Clark's grebe eggs, we could not statistically compare egg concentrations between species. Although these levels are within the "normal" background range (Ohlendorf 1993), we found it interesting that mercury concentrations in western grebe eggs were consistently higher than those in Clark's grebe eggs (Table A-7). The reason for this difference is not clear; however, we offer the following considerations. Food habits of the two species are similar. Their diets consist primarily of fish, aquatic invertebrates, few amphibians, and feathers (Ehrlich et al. 1988). However, ecological segregation between the two species is suspected. Nuechterlein (1981) hypothesized that the two "color phases" may be segregating behaviorally into two subtly different ecological forms specialized for feeding at different depths. (In the sixth edition of the American Ornithologists' Union's check-list [1985], Clark's grebe was designated a separate species from the western grebe. Prior to this separation, Clark's grebe was considered the light color phase of the western grebe.) Previous research indicated that Clark's grebes feed farther from shore than western grebes (Nuechterlein 1981, Ratti 1985). If the two species of grebes are feeding at different depths, they may also be feeding on different size and species of fish. Feerer (1977) reported that Clark's grebe females' stomachs contained significantly smaller fish than those of western grebe females, but he found no significant differences between males of the two species. If western and Clark's grebes feed on different species of fish, there may be a correlation between their diet and the differing concentrations of mercury in their eggs. Data on preferred habitats and food habits are essential to understanding and interpreting bioaccumulation rates.

Different wintering areas of both species may also contribute to the dissimilar concentrations of mercury in western and Clark's grebe eggs; however, Rosenberg et al. (1991) suggested that Clark's grebes are resident on Lake Havasu with numbers remaining relatively stable at 500 to 700 birds. Little is known about the winter distribution of Clark's grebes except that they are less abundant than western grebes in most locations throughout the United States and Canada (Nuechterlein and Storer 1989, Ratti 1981). Ratti (1979) suggested a clinal variation in the relative abundance of dark- and light-phase grebes. Large winter concentrations of western grebes occur from Lake Havasu north to Lake Mead and in surrounding wetlands (M. Cressman, J. Kahl pers. comm). According to Rosenberg et al. (1991), western grebes represent the bulk of Lake Havasu's wintering birds (as compared to Clark's grebes). However, recent surveys by refuge personnel indicate a higher year-round proportion of Clark's grebes to western grebes on Havasu NWR (C. Smith pers. comm). Data from 1991 and 1992 Christmas Bird Counts (Lyons 1992, 1993) indicated large wintering numbers of western grebes and few Clark's grebes in the Lake Mead area. Ratios of western grebes to Clark's grebes were 20:1 in 1991 and 39:1 in 1992. While considering the relative abundance of western grebes tabulated during Christmas Bird Counts, we should be cautious ant not assume that these data accurately represent the proportion of each species for a specific location. These data are from short-term observations that may be biased annually by number of observers and hours observed. Further studies on differences between western and Clark's grebes are needed, particularly on feeding habits and seasonal distribution.

Ruiz (1994) collected one Clark's grebe at the confluence of the Bill Williams River and the Colorado River. Chemical analyses of the liver and kidney revealed 3.65 and 5.38 μg/g wet weight mercury, respectively. These levels are well below the "extremely hazardous" concentration of 20 μg/g wet weight suggested by Finley et al. (1979). Mercury does not appear to be a contaminant concern in western or Clark's grebes on the Colorado River within Havasu or Bill Williams NWR.

Although selenium is an essential nutrient, this element can become toxic to fish and wildlife at concentrations above a relatively low threshold. Relatively low concentrations of selenium will bioaccumulate and biomagnify throughout the ecological food chain. The effects of elevated levels of selenium levels in birds and fish can include teratogenesis, reproductive failure, and mortality (Lemly and Smith 1987). Selenium was recovered in all coot livers at concentrations that ranged from 2.59 to 3.39 μg/g wet weight (9.37 to 12.43 μg/g dry weight) and in kidneys ranging from 2.84 to 4.23 μg/g wet weight (17.42 to 20.05 μg/g dry weight). Selenium concentrations for coot livers and kidneys are presented in Table 5. In livers of birds from selenium "normal" environments, selenium usually averages less than 10 μg/g dry weight (Schroeder et al. 1988, Ohlendorf 1993, Skorupa et al. In review). Four of five coot livers exceeded this "normal" or background range (Table 5). There were no significant differences ($P > 0.05$) between selenium concentrations in coot tissues (livers and kidneys) from Havasu NWR and coot tissues taken from backwater lakes on Imperial NWR (Martinez 1994). However, selenium concentrations in coot tissues from Havasu NWR were significantly higher ($P = 0.0005$, liver; $P = 0.0017$, kidney) than those in coots collected from seep lakes on Imperial NWR. Martinez (1994) concluded that birds taken from backwater lakes, had significantly higher selenium levels in their tissues than those taken from seep lakes, regardless of species. Backwater lakes are those directly connected to the river by one or more canals, whereas seep lakes receive water from the river only via seepage.

Table 5. Selenium concentrations (μg/g) in coot livers and kidneys from Topock Gorge, Colorado River, Havasu National Wildlife Refuge, 1993.

	Liver		**Kidney**	
Sample	**Wet weight**	**Dry weight**	**Wet weight**	**Dry weight**
Coot 1	3.39	12.43	4.23	20.05
Coot 2	2.98	10.70	NA[1]	NA
Coot 3	3.20	12.14	2.84	18.92
Coot 4	2.59	9.37	4.03	17.42

Coot 5	3.00	11.57	NA	NA

[1] Insufficient tissue mass available for analysis.

Skorupa et al. (in review) reported that water bird populations with mean liver selenium concentrations between 10 and 30 μg/g dry weight had elevated incidence of adverse biological effects and should be studied for reproductive performance. Selenium concentrations in adult coot livers from the highly contaminated Kesterson Reservoir averaged >80 μg/g dry weight. All birds experienced selenosis (Ohlendorf et al. 1988). At Volta, the control area for the Kesterson study, selenium concentrations averaged <6 μg/g dry weight in livers of healthy adult coots.

Selenium concentrations in a Clark's grebe liver and kidney taken from Bill Williams NWR in 1992 were 12.90 and 9.62 μg/g dry weight (Ruiz 1994). However, because grebes are primarily piscivores (they also consume invertebrates) and coots primarily herbivores, caution should be exercised when comparing interspecific trace element concentrations. Species differences in selenium concentrations may be attributed to differences in food habits, residence time, and foraging range (Ohlendorf et al. 1990, Martinez 1994, Skorupa, In review). However, because aquatic invertebrates bioaccumulate selenium more readily than aquatic plants (Hothem and Ohlendorf 1989, See et al. 1992), one would expect higher selenium levels in grebes than in coots.

Dietary selenium levels are reflected in eggs of aquatic birds. Selenium concentrations in eggs are the best predictors of reproductive impairment, but concentrations of selenium in liver of females have been shown to be correlated with concentrations in their eggs (Paveglio et al. 1992). Selenium concentrations in western and Clark's grebe eggs ranged from 6.60 to 11.54 μg/g dry weight, and 10.51 to

14.17 μg/g respectively (Table A-7). Elevated amounts of selenium in the diet have been associated with decreased egg hatchability in laboratory studies of mallards and domestic chickens (Arnold et al. 1973, Ort and Latshaw 1978, Heinz et al. 1987, Heinz and Fitzgerald 1993) and in free ranging aquatic birds at Kesterson Reservoir (Ohlendorf et al. 1986b). The threshold level at which teratogenic or toxic effects may occur in aquatic bird eggs is 3 μg/g dry weight (Lemly 1993). Selenium concentrations in western and Clark's grebe eggs were two-to-four times higher than this concern level. Ohlendorf (1993) reported toxic levels of selenium in aquatic bird eggs to be greater than 8 μg/g dry weight. Eighty percent (80%) of grebe eggs we collected contained >8.0 μg/g selenium. Clark's grebe eggs from Topock Marsh contained significantly (P = 0.02) higher selenium concentrations than western grebe eggs from Topock Gorge. Previous studies (Lusk 1993, Martinez 1994) documented higher selenium levels in biota within backwater areas on the lower Colorado River. Because Topock Marsh exemplifies a backwater area, there may be a higher incidence of selenium accumulation in individuals occupying the area. The majority of our sediment and fish samples from Topock Marsh contained higher selenium levels than those from Topock Gorge.

Although wintering areas of Clark's grebes may be a consideration regarding differences in mercury levels, it is an unlikely factor concerning selenium differences. Birds feeding in a selenium-contaminated site will quickly accumulate high levels of selenium in their liver and likewise, will quickly lose selenium when removed from the site (Heinz et al. 1990).

Vanadium was detected in four of five coot livers and ranged from 0.60 to 1.51 μg/g dry weight (0.15 to 0.41 μg/g wet weight [Table A-6]). Vanadium concentrations in coot livers from Havasu NWR contained higher levels than those in livers of mallards fed a diet containing 10 μg/g vanadium (0.06 μg/g wet weight) and lower than livers of mallards fed a diet containing 100 μg/g vanadium (0.66 μg/g wet weight [White and Dieter 1978]).

Little information is available on the toxic effects of vanadium to aquatic birds. Double-crested cormorants (*Phalacrocorax auritus*) collected from Topock Marsh in 1986 contained vanadium concentrations in tissues of <0.10 μg/g wet weight (below detection limit [Radtke et al. 1988]). Coots are primarily herbivores. If levels of vanadium in spiny naiad are indicative of concentrations in aquatic plants taken by coots, then there is little potential for bioaccumulation of vanadium to toxic levels.

Zinc was recovered in all coot livers, and concentrations ranged from 153.6 to 212.9 μg/g dry weight (Table A-6). Little information is available on the toxicity of zinc to aquatic birds; however, Reece et al. (1986) reported normal zinc concentrations in livers of domestic aviary birds at 21 to 33 μg/g dry weight and toxic levels of zinc at 75 to 156 μg/g. Zinc concentrations in coot livers collected in this study were predominantly well above those reported as toxic to domestic birds. Sample parameters of whole body coots are presented in Table 6.

Table 6. Sample parameters of coot carcass, liver, and kidney tissues collected from Topock Gorge, Colorado River, Havasu National Wildlife Refuge, 1993.
All weights are reported in grams.

Sample	**Sex**	**Age**	**Whole body weight**	**% Moisture liver**	**Liver weight**	**% Moisture kidney**	**Kidney weight**
Coot 1	&	Adult	595	72.76	18.43	78.92	7.83
Coot 2	&	Adult	635	72.14	25.06	NA[1]	NA
Coot 3	%	Adult	785	73.68	19.34	84.99	9.33
Coot 4	%	Adult	741	72.40	19.86	76.86	5.76
Coot 5	%	Adult	736	74.03	20.33	NA	NA

[1] Insufficient tissue mass for analysis.

Kidney:Liver Ratio:

Selenium accumulates in birds in the tissues associated with detoxification, such as the liver, and elimination, such as the kidney (Fairbrother and Fowles 1990). Ratios of selenium in kidneys and livers have been used to correct for toxicity differences among species and diets (Ohlendorf et al. 1990). Dietary selenium levels are assumed to be "normal" when kidney:liver ratios are greater than 1, and elevated when they are less than 1 (Ohlendorf and Skorupa 1989, Ohlendorf et al. 1990).

All (n = 3) coots for which we were able to establish kidney:liver ratios, had ratios greater than one. For coots 1, 3, and 4, ratios were 1.61, 1.56, and 1.86, respectively (Table 7). These ratios would suggest dietary levels were "normal" based on the criteria of Ohlendorf et al. (1990). Selenium concentrations in coot kidneys were greater than those in livers in this study indicating low dietary levels of selenium.

Table 7. Selenium concentrations (μg/g dry weight) in coot kidneys and livers and kidney:liver ratios from Topock Gorge, Colorado River, Havasu National Wildlife Refuge, 1993.

Sample	**Kidney**	**Liver**	**Ratio**
Coot 1	20.05	12.43	1.61
Coot 3	18.92	12.14	1.56
Coot 4	17.42	9.37	1.86

CONCLUSIONS

Organocholorine compounds likely do not present a threat to fish and wildlife resources of Havasu NWR. No organochlorine compounds were recovered in sediment or clams, and low concentrations of DDE were present in coot carcasses. In order to fully assess the possible exposure of biota of Havasu NWR to organochlorines, fish and piscivorous birds should be collected and analyzed.

We found several elements that may be a concern to fish and wildlife of Havasu NWR. These include arsenic, cadmium, chromium, copper, lead, and selenium. Selenium is the element of greatest concern in the lower Colorado River aquatic ecosystem. Elevated selenium levels have been well documented in the lower Colorado River, particularly in areas adjacent to Imperial and Cibola NWRs. This study documents elevated selenium levels in the Colorado River system upstream as far as Havasu NWR.

Selenium concentrations were elevated in all biota. Spiny naiad contained concentrations well above the background level, clams and fish had levels high enough to possibly impair reproduction of the birds that feed on them, coot tissues contained above background levels, and western and Clark's grebe eggs contained selenium concentrations above the threshold level at which terotegenic or toxic effects could occur. Continued research on levels and effects of selenium in fish and piscivorous birds, including monitoring reproductive success and teratogenesis, should be given high priority.

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APPENDIX A

Analytical Results

Table A-1. DDE residues (μg/g) in American coot (*Fulica americana*) carcasses collected from Topock Gorge, Havasu National Wildlife Refuge, 1993.

Sample	Sex	Age	Whole body weight (g)	Carcass weight[1] (g)	Percent moisture	Percent lipid	DDE (dry we
Coot 1	&	Adult	595	336	66.8	13.4	0.93
Coot 2	&	Adult	635	326	75.6	2.9	0.04
Coot 3	%	Adult	785	434	68.8	8.2	0.06

Coot 4	%	Adult	741	334	70.6	7.1	0.1
Coot 5	%	Adult	736	359	74.2	5.6	0.0

[1] Carcass = plucked bird with bill, feet, wingtips, liver, kidney, and gastrointestinal tract removed.

Table A-2. Trace element concentrations in sediment (μg/g dry weight) from Havasu National Wildlife Refuge, 1993.

Site[1]	**Al**	**As**	**B**	**Ba**	**Be**	**Cd**	**Cr**	**Cu**	**Fe**	**Mg**	**Mn**	**Ni**	
BB	4036	4.8	12.29	110.3	0.97	0.86	7.49	9.42	5470	5127	174.7	10.96	1
CP	7183	7.1	7.13	134.3	0.91	0.61	11.60	16.81	9212	6215	220.9	18.72	1

DE	11080	9.3	7.25	265.1	1.59	1.12	17.61	34.29	14610	10350	315.5	23.54	4
GH	5345	3.9	8.86	145.9	0.78	0.60	9.16	13.02	7600	7551	307.5	10.56	2
ND	2269	13.1	<4.81	78.2	0.46	0.37	8.25	<4.81	3994	1969	56.3	6.99	9
PS	12580	8.6	10.01	282.2	0.94	0.42	12.53	23.06	15090	10170	331.2	16.40	3

[1] BB - Blankenship Bend; CP - Catfish Paradise; DE - Devils Elbow; GH - Glory Hole; ND - North Dike; PS - Pintail Slough

Mercury and molybdenum were not detected in any samples.

Table A-3. Trace element concentrations (μg/g wet weight / dry weight) in spiny naiad (*Najas marina*) from Topock Gorge, Havasu National Wildlife Refuge, 1993.

Site[1]	**Al**	**As**	**B**	**Ba**	**Cr**	**Cu**	**Fe**	**Mn**	**Mg**	**Ni**	
DE	154.4	0.62	2.26	17.1	0.50	1.4	236.0	37.3	692.3	0.57	0

	1270	5.12	18.6	140.6	4.09	11.5	1941	306.9	5693	4.69
BB	48.9 737.6	0.14 2.07	0.96 14.48	17.3 260	0.23 3.47	0.29 4.41	74.2 1117	13.1 198	323.7 4875	0.18 2.66

[1] DE - Devils Elbow
BB - Blankenship Bend

Beryllium, cadmium, mercury, and molybdenum were not detected in any samples.

Table A-4. Trace element concentrations (μg/g wet weight / μg/g dry weight) in Asiatic clams (*Corbicula fluminea*) from Topock Marsh, Havasu National Wildlife Refuge, 1993.

Site[1]	**Al**	**As**	**Ba**	**Be**	**Cd**	**Cr**	**Cu**	**Fe**	**Mg**	**Mn**	**Mo**	**Ni**
CP	20.46 180.4	1.16 10.23	4.44 39.19	BDL[2] BDL	0.03 0.29	BDL BDL	3.34 29.45	41.36 364.7	144.9 1278	13.54 119.4	BDL BDL	0.65 5.73

GH	17.12 177.2	1.07 11.12	2.06 21.35	BDL BDL	0.06 0.60	0.15 1.56	2.91 30.10	41.26 427.1	112.1 1160	2.50 25.88	0.19 1.93	0.35 3.66
ND	15.90 179.5	1.04 11.79	1.86 20.99	0.04 0.49	0.17 1.94	0.17 1.96	6.37 71.93	41.45 467.8	111.1 1254	7.58 85.5	0.11 1.29	0.60 6.72

[1] CP - Catfish Paradise; GH - Glory Hole; ND - North Dike
[2] BDL - Below detection limit

Boron and mercury were not detected in any samples.

Table A-5. Trace element concentrations (μg/g wet weight) in whole body fish collected from Topock Gorge and Topock Marsh, Havasu National Wildlife Refuge, 1993.

Sample	**Site**	**Al**	**As**	**B**	**Ba**	**Cd**	**Cr**	**Cu**	**Fe**	**Pb**	**Mg**	**Mn**	**H**
NCBP 85[1]		NA[2]	0.27	NA	NA	0.05	NA	1.0	NA	0.22	NA	NA	0.

CRP[3]	TG[4]	43.1	<0.11	0.18	2.53	0.02	1.27	..1.80	107	0.22	283	3.0	0.
CRP	TG	53.2	0.16	0.18	2.80	0.08	2.08	1.86	129	0.80	282	3.9	0.
CRP	TM[5]	73.6	<0.10	<0.11	2.53	0.02	0.46	3.08	56	0.36	338	2.0	<0
LMB[6]	TG	15.4	0.10	<0.10	1.97	<0.02	0.64	2.92	162	0.14	325	2.6	0.
LMB	TG	9.6	<0.12	<0.18	1.19	0.06	0.44	1.78	27	<0.12	270	1.3	0.
LMB	TM	9.6	<0.10	<0.11	0.99	<0.02	0.50	1.81	22	<0.11	288	1.0	0.
CC[7]	TG	14.0	0.20	0.22	0.62	<0.03	0.40	1.32	39	0.24	220	1.7	0.
CC	TG	16.2	0.19	<0.13	2.52	0.03	0.39	0.53	42	1.0	225	1.7	<.
CC	TM	6.81	<0.12	0.28	0.29	<0.02	0.65	0.37	53	<0.12	191	1.3	<0

[1] National Contaminant Biomonitoring Program 85th Percentile (Schmitt and Brumbaugh 1990).
[2] Data not available.
[3] CRP = Common carp (*Cyprinus carpio*)
[4] TG = Topock Gorge
[5] TM = Topock Marsh
[6] LMB = Largemouth bass (*Micropterus salmoides*)
[7] CC = Channel catfish (*Ictalurus punctatus*)

Vanadium was detected in common carp from Topock Gorge at 0.30 and 0.22 μg/g. Beryllium was not detected in any samples.

Table A-6. Trace element concentrations (μg/g dry weight) of American coot (*Fulica americana*) livers from Topo
Havasu National Wildlife Refuge, 1993.

Sample	% Moisture	Al	B	Ba	Be	Cd
Coot 1	72.76	11.85	1.90	BDL[1]	0.17	3.36
Coot 2	72.14	8.65	2.73	0.91	BDL	0.35
Coot 3	73.68	12.35	0.67	BDL	0.14	0.75
Coot 4	72.40	93.0	1.83	1.21	BDL	0.44
Coot 5	74.03	14.45	0.69	BDL	BDL	0.66

Sample	Mg	Mn	Mo	Ni	Pb	Se
Coot 1	783.6	8.92	4.04	1.11	2.43	12.73
Coot 2	769.0	7.09	4.86	BDL	3.74	10.70
Coot 3	868.0	8.48	3.88	0.96	1.03	12.14
Coot 4	758.4	6.03	2.13	0.54	1.41	9.37
Coot 5	1053.0	8.38	4.14	0.77	2.18	11.57

[1] BDL - Below detection limit.

Arsenic and mercury were not detected in any samples.

Table A-7. Trace element concentrations (μg/g dry weight) in Clark's and western grebe (*Aechmophorus clarkii*, *A.* collected from Topock Marsh and Topock Gorge, Havasu National Wildlife Refuge, 1993.

Sample	**Collection Site**	**Embryo Age (Days)**	**% Moisture**	**Al**	**Ba**	**Cu**	**Fe**	**Hg**	**Mg**	**Mn**
Clark's grebe (CG) eggs										
CG1[1]	Topock Marsh	1	76.65	7.79	0.66	2.41	148.8	BDL[2]	364.4	1.08
CG2	Topock Marsh	1	78.34	8.41	0.61	2.34	121.8	BDL	363.6	1.84
CG3[3]	Topock Marsh	1	77.23	17.34	0.53	2.82	140.4	0.19	446.2	2.20
CG4	Topock Marsh	6	79.73	5.02	BDL	2.19	117.4	BDL	390.2	2.17
CG5	Topock Marsh	6	79.43	6.00	BDL	2.71	104.6	BDL	413.5	1.74
Western grebe (WG) eggs										
WG1	Topock Gorge	10	78.58	BDL	BDL	2.34	97.51	0.34	393.0	3.04
WG2	Topock Gorge	23	76.16	4.86	BDL	2.34	97.51	0.29	393.0	3.04
WG3	Topock Gorge	1	78.00	5.51	BDL	2.81	117.1	0.86	343.5	2.06
WG4	Topock Gorge	6	73.04	10.62	BDL	2.63	101.6	0.23	385.6	2.00
WG5	Topock Gorge	6	77.92	5.51	BDL	3.40	104.0	0.30	446	2.38

[1] CG1 also contained 0.70 μg/g chromium.

[2] BDL - Below detection limit.

[3] CG3 also contained 0.59 μg/g boron and 0.69 μg/g lead.

Arsenic, beryllium, cadmium, nickel, and vanadium were not detected in any samples.