Corbiculae fluminea as a Bioindicator

on

The Lower Colorado River

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Abstract

Tissue samples from Asiatic clam (Corbicula fluminea) from the lower Colorado River were analyzed for trace element concentrations Selenium and arsenic were elevated above U.S. background levels at 89% and 83% (respectively), of the sites. Selenium concentrations were significantly higher in backwaters than at river sites. The incidence of Se concentrations above background levels for samples of a variety of biota and sediments (recently collected at specific sites) was used to classify the contamination state of these sites. Classification of the contamination state of these sites based on selenium in clams agreed with the contamination state of a site based on other measures at least 78% of the time. There is a strong correlation between selenium concentrations in clams and selenium concentrations in vascular aquatic plants (rý = 0.98) and carnivorous birds (rý = 0.999).
C. fluminea can he used as a bioindicator of selenium contamination on the lower Colorado River. Selenium levels in clams at several sites exceeded levels that have been shown to result in teratogenicity for birds in laboratory studies. Birds that eat clams in the study area could have increased risk of lowered reproductive success.

1.0 INTRODUCTION

The National Contaminant Biomonitoring Program (NCBP) documented that arsenic, cadmium, copper, lead, mercury, selenium and zinc in fish from the lower Colorado River were above background levels (Lowe el al. 1985). Subsequent studies have reported that selenium concentrations were above background levels in fish (Radtke et at 1988) and in marsh birds (Rusk 1991) in the lower Colorado River and in biota from Cibola National Wildlife Refuge (CNWR) (Welsh 1992) and Imperial National Wildlife Refuge (INWR) (Lusk 1991).

The Colorado River watershed contains soils that are naturally high in selenium (Se). Reservoir storage and high evaporation rates may increase the selenium concentration in water. Selenium is deposited in sediments from reservoirs and irrigated lands and may enter aquatic food chains through deposition in the sediments and then be remobilized by rooted plants and benthic feeders (Lemly 1987). Corbicula fluminea, the Asiatic clam, is a filter feeding benthic bivalve that feeds on phytoplankton and detritus. Such animals may be some of the first to be affected by high levels of Se. Rusk (1991) noted that C. fluminea tissues generally had selenium levels above background along the lower Colorado River. She also noted that C. fluminea was an important food item for carnivorous birds and fish. It would be beneficial to managers if such an organism could be used as a bioindicator of the availability of contaminants to animals at higher trophic levels and of baseline levels within the system.

1.1 Bioindicators

Contaminant levels in bioindicator organisms can be more useful than records of concentrations in water because contaminant levels in biota reflect exposure over time and the magnitude of exposure. They also provide an indication of long-term effects on the

ecosystem and possible effects on other taxa. Bioindicators are used to make hazard assessments (analysis of the potential exposure and effects from contaminants at a particular site) and for surveillance (routine monitoring of current and long-term trends in levels of exposure). They also can be used to measure effectiveness of remedial or management actions. Phillips (1977) suggests that indicator organisms for trace elements contamination should:

1. accumulate the pollutant without suffering mortality,
2. be sedentary,
3. have a life span sufficiently long to allow for the sampling of more than one year

class,
4. be abundant in the study region,
5. be large enough to allow adequate tissue samples for analysis,
6. be easy to sample and hardy enough to be maintained in the laboratory,
7. tolerate brackish water,
8. exhibit a high metal concentration factor,
9. have a simple correlation between the metal concentration of the organism and the average metal concentration in the surrounding water,
10. exhibit the same correlation between their metal content and that of the surrounding water for all locations studied under all biotic and abiotic conditions.

C. fluminea fits the first seven of these criteria (Cherry et at. 1980, Rodgers et al. 1980, Graney et al. 1983). C. fluminea also fulfills criteria 8 and 9 for Cd, Cu and possibly Zn (Graney et al. 1983). It fails to satisfy criterion 10 because substrate, pH and temperature effect cadmium uptake (Graney el al. 1984). However, the effects of violating criterion 10 can be minimized by documenting pH, temperature, and substrate at sites of collection.

Bivalve mollusks have been used extensively for trace elements assessment (Phillips 1976). Tessier et al. (1984) investigated the relationships between partitioning of trace metals (Pb, Fe, Zn, Cu and Mn) in sediments and their accumulation in the tissues of the mollusk Elliptio complanata. Abaychi and Mustafa (1988) found a correlation between metal content in mollusks and metal content in particulate matter. Abaychi and Mustafa (1988) established that C. fluminea is capable of accumulating and eliminating trace elements in relation to their concentration in ambient water and concluded that C. fluminea is a suitable bioindicator for monitoring trace metal pollution. Doherty (1990) concurs that C. fluminea is a valid bioindicator of trace metal contamination and satisfies the criteria established by Phillips (1977). Johns et al. (1988) successfully used C. fluminea as an indicator of selenium distribution in San Francisco Bay.

1.2 Objectives

The objectives of this study were to:

1. Determine levels of trace metals in C. fluminea and correlate these data with records of contaminants in a variety of species and sediments collected at the same sites in previous studies (within the past 3 years or less) in order to evaluate the efficacy of using C. fluminea as a bioindicator of some contaminants.

2. Provide an evaluation of the spatial distribution and magnitude of selenium contamination in the lower Colorado River as reflected in body burden of C. fluminea

3. Document habitat parameters of C. fluminea.

1.3 Corbicula fluminea

The Asiatic clam is an exotic filter-feeding freshwater bivalve that feeds primarily on phytoplankton (Foe and Knight 1985). C. fluminea has been documented in the lower Colorado River since 1953 and is abundant as far upstream as Separation Rapids, 450 miles upstream from the International Boundary with Mexico (Kubly and Landye 1984). C. fluminea's abundance and distribution make it a prime candidate as a bioindicator in the lower Colorado River.

In filter-feeders, uptake of trace elements occurs in the soluble state via respiration (bioconcentration) and via ingestion of particulate matter (bioaccumulation). Filter-feeding mollusks may be particularly good bioindicators since they reflect contaminants that are available through three different avenues: biotic particulate matter, soluble ions available in the water column, and ions associated with sediment. Fowler and Benayoun (1976) and Phillips (1977) determined that most selenium uptake is by bioaccumulation in C. fluminea, since it has an extremely high filtering rate (Foe and Knight 1986).

C. fluminea is hermaphroditic and capable of self-fertilization; gonads contain mature eggs all year long (Kraemer 1986). Spermatogenesis occurs during the reproductive seasons when temperatures rise above 17 C (Kraemer 1986). Marsupial larvae brood about 1 month and are released as planktonic pediveligers or juveniles (Eng 1977, Kraemer 1986). C. fluminea spawn biannually in North America, in the spring/early summer and also in late summer. Spawning seems to be tied to favorable thermal conditions (Eng 1977, Kraemer 1986). Thousands of juveniles, (<200 æm), are released fully formed with bivalves, digestive system, statocysts, foot and gills. Juveniles develop a byssus after spawning and have been seen attached to soil particles in the water column (Kraemer 1977). Juveniles attach to the sides of streams and are eventually recruited to the bottom as they grow larger (Eng 1977). Clams in bottom sediments of

concrete-lined Delta Mendota Canal of central California attained shell lengths (SL) of over 40 mm and lived at least 4 years (Eng 1977). Eng (1977) reported that younger, smaller clams, on the sides of canals, were yellow-green, whereas clams in bottom sediments were dark brown and exhibited heavy erosion of their shells.

C. fluminea exhibits life history traits (self-fertilization, high fecundity, and biannual reproductive periods) that enable it to survive in unstable environments. Growth rates of C. fluminea are high initially, but slow down as clams get older. Growth peaks at 25 C and ceases during cold winter months (Mattice and Wright 1986). Up to 89% of assimilation goes to tissue production (Foe and Knight 1986). Initial rapid growth helps the mollusk to evade predators at an early life-stage. C. fluminea has the highest population production rates for any species of freshwater bivalve (Burky 1983).

C. fluminea in Texas State parks were found in three major microhabitats: 1) areas of intermediate flow in streams with sandy or rock substrate; 2) loose gravel substrata in shallow pools between riffles in streams, 3) lake shores where wave action removes silt and clay particles (Neck 1986).

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2.0 STUDY AREA

The lower Colorado River (LCR) stretches for 276 river miles (RM) from Davis Dam near Laughlin, Nevada, south to the International Boundary between the U.S. and Mexico. The river forms the boundary between California and Arizona. There are numerous large dams that have caused the river to back up into old channels and oxbow lakes and created a diversity of waterfowl habitats. The marsh-like backwaters have many cattails (Typha spp.) and bulrush (Scirpus spp.) and have become feeding and nesting habitat for migratory birds.

Clams were collected in backwater sites (lentic) and in river sites (lotic) to compare trace element accumulation in each type of environment. Eighteen collection sites were selected: eight backwater sites and 10 river sites. Previous data (Lusk 1991, Rusk 1991), indicated that selenium concentrations were higher in backwater sites than in river sites. Selection of sites was based, in part, on sample locations of previous studies so that body burden of contaminants in C. fluminea could be compared to the body burden of other species. River channel sites spanned much of the lower Colorado River so that the spatial distribution of selenium could be determined (Figure 1).

2.1 Backwater Sites

Mittry Lake is located between Imperial and Laguna dams (RM 43). It was previously an oxbow lake (Rusk 1991) of the Colorado River and now receives water via a diversion canal from Imperial Reservoir. Data from Mittry Lake are available for selenium concentrations in sediment, crayfish and birds (Rusk 1991).

Cable and Island lakes are located on Imperial National Wildlife Refuge (INWR) and receive minimal flow from the river. There are previous data for Cable and Island

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See Table/Figure

Figure 1. Location of 18 sample sites for Corbicula fluminea along the lower Colorado River.

lakes for selenium concentrations in sediments, plants, aufwuchs, crayfish, shrimp and fish
(Lusk 1991), and birds (Rusk 1991).

Palo Verde Oxbow Lake is located on Cibola National Wildlife Refuge (CNWR)
This lake receives little water from the river and may experience anoxic conditions. A
yellow sediment released a noxious smelling gas. Welsh (1992) collected sediment,
sunfish (Lepomis microlophus), and largemouth bass (Micropterus salmoides) from this lake

Topock Marsh (RM 234) is located on Havasu National Wildlife Refuge (HNWR).
The marsh receives inflow from the river via a concrete canal at the northern end. This
site contains large amounts of phytoplankton. Rusk (1991) collected sediment, crayfish
and birds at this site.

2.2 River Sites

Collections were made from two river sites on INWR and two on CNWR (~RM
103). Collections were also made from river sites near RM 145 and RM 196, and at
Topock Gorge (~RM 228), and Needles marina (~RM 245). We collected at two river
sites that had no measurable flow; the confluence of the Bill Williams River (~RM 192)
and Imperial Oasis just above Imperial Dam (RM 49).

3.0 METHODS

3.1 Collection

Samples were taken during 3 weeks in July 1992 to reduce the possible impact of
seasonal variability. Clams were detected and removed by digging into the substrate with
hands or a shovel. Clams were stored in plastic bags on ice in the field and frozen on the
evening of the day of collection. Within 2 weeks the frozen body tissue was removed
from the shells with a stainless steel knife and placed them into inert plastic bags and shell
length (SL) was measured. Four composite samples were obtained at all sites except Palo
Verde Oxbow Lake at CNWR; where only one sample of six clams was collected (after an
intensive 4-hour search). Composites ranged from four to 29 clams. At each site the
clams were sorted into the largest and smallest. Two subsamples from each size category
were obtained. "Large" and "small" size designations are relative to the size of clams
collected at a site. Samples were sent to Patuxent Analytical Control Facility for trace
metal analysis on September 28, 1992.

Temperature, substrate and depth were noted at each site; these parameters can affect trace metal uptake (Nielsen 1974, Fowler and Benayoun 1976, Graney et al. 1984).

Clams were collected at the northern and southern ends of three backwater sites (Mittry Lake, Island Lake and Topock Marsh). There is a net downstream flow through these areas (generally from north to south), although daily fluctuations in volume and direction of flow occur.

3.2 Residue Analysis

All of the samples collected were analyzed by Hazelton Laboratories, Madison, WI. A multi-element scan was performed for selected metals plus As and Se. Quality assurance methods included procedural blanks, duplicate samples and spiked samples. All

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samples had acceptable quality assessment (Patuxent Analytical Control Facility Quality Assessment Report 1993).

Samples were analyzed for 16 elements (Al, Ba, Be, B, Cd, Cr, Cu, Fe, Pb, Mg, Mn, Mo, Ni, Sr, Vn, & Zn) by Inductively Coupled Plasma Spectroscopy (ICP). After homogenization in a tissue miser, 5 grams of clam tissue were combined in an acid washed Teflon vessel with 5 mL of nitric acid and digested in a microwave digestor. After transfer to a 50-mL volumetric flask, the contents were diluted to 50 mL with 0.005% Triton X-100 solution. Each analyte concentration in the sample was determined by comparing its emission intensity with the emission intensities of a known series of analyte standards with a spectrophotometer.

Clam tissue was tested for arsenic and selenium residues by Graphite Furnace Atomic Absorption (GFAA). Each sample of clam tissue was homogenized and 1 g was digested with nitric acid in a microwave digestor. The digestate was transferred to a 100-mL volumetric flask and diluted with deionized water. Element absorbance values were used to determine the concentration of that element.

Mercury in homogenized clam samples was detected by Cold Vapor Atomic Absorption. Clam tissue (2 g) was digested with a mixture of sulfuric and nitric acid and diluted to 100 mL Mercury was reduced with sodium borohydride. The amount of mercury was determined when the sample was compared with the signal of standard solutions as measured by the atomic absorption spectrophotometer with the MHS-20 hydride generation unit.

Moisture content was determined by weighing a prepared sample into a tared aluminum dish and drying in an oven to constant weight (about 12-18 hours). This method quantifies moisture to 0.1%.

3.3 Data Analysis

Nonparametric statistical tests were run on residue analyses since the data did not have equal variances, sample composite numbers were not equal, and data within site classes (river vs. backwater sites) were not normally distributed. Wilcoxon Rank Sum tests were used for comparisons between she classes. The Kruskal-Wallis procedure was used to compare data within site classes. Statistical comparisons were made on wet weight concentrations of As and Se in parts per million (ppm).

A student's T-test was used for comparison of clam sizes (arithmetic means) in backwater and river sites. Dry weight values were used for bioindicator comparisons because previous investigators have reported Se tissue concentrations on a dry weight basis.

3.4 Bioindicator Analysis

3.4.1 Species Comparison

Selenium concentrations were compared in categories of species collected by other investigators with Se concentrations in clams. Sediment Se concentrations were also compared to clam Se concentrations. Species categories are based on diet.

Table 1. Species categories for bioindicator species comparison.

Plants	Scavengers	Omnivorous fish	Carnivorous fish	Herbivorous birds	Carnivorous birds
Spiny naiad	Crayfish	Carp	Gambusia	Ruddy duck	Herons
	Shrimp	Threadfin shad	Sunfish	American coot	Sora rail
			Largemouth bass	Common moorhen	Clark's grebe
			Channel catfish		Least bittern
			Black crappie		Virginia rail

See appendix C-4 for scientific names.

3.4.2 Site Comparison

Selenium concentrations in samples collected by other investigators within the prior 3 years were compared to Se concentrations in clams at nine sites (appendix C-2).
Background threshold limits from Lemly (1985) and Radtke et al. (1988) were used to determine if samples were above background concentrations for Se (appendix C-3). Each of the nine sites had a minimum of four sediment and/or biota samples taken recently

by
other investigators. Each prior sample was assigned a rating. Samples that were below background criteria for Se were assigned a "below" rating and samples that exceeded background criteria were assigned an "exceed" rating (appendix C-1). Ratings were then
totaled for that site and compared to the rating for Se concentrations in clams at the same
site (appendix C-2). If the ratings of 50% or more of the samples from other recent investigators were the same as those for selenium in clams, then clams were considered
successful at predicting the contamination state of the site. We felt that requiring at least
50% of prior samples to exceed background levels before a site was rated as "exceeding
background" was a conservative approach since evidence of contamination in only a few samples could be interpreted as sufficient evidence for classifying a site as "exceeding"
background levels.

4.0 RESULTS

4.1 Biological Analysis

We collected 629 clams for trace metal analysis at the 18 sites: we took four composite samples from each of 17 sites and one composite sample from one site, Mean clam size by site ranged from 19.98 to 49.56 mm SL (appendix B-1A & B). Clams in backwater sites were significantly larger than clams in mainstream sites ($P<0.01$). This
difference would be even greater if the data from the two river sites without measurable
velocity were deleted from the data set for riverine sites.

Clams were found in many different substrates (coarse sand, fine sand and rich organic detritus). Larger clams, primarily from backwaters, were located in areas with
rich detritus. The smallest clams were located in fine grained sandbars (e.g., Needles river
site). In backwaters, where flow was minimal, most clams lay on the bottom. In mainstream reaches of high flow, clams were embedded in the substrate.

4.2 Residue Analysis

All samples had detectable Se and As residues (appendix A-2). These also, were the only elements that reached levels of concern. There was no relationship between size
of clams and Se body burden within sites (>0.60) or across sites. There was no relationship between water temperature and Se body burden (see Appendix B-2 for water temperature data). Se concentrations in clams exceeded U.S. background levels of 0.78 ppm wet weight (Lemly 1985) at 16 out of 18 sites. This background value was derived for mollusks from drainages with non-seleniferous soils. Clams from nine out of 10 river
sites had elevated levels of Se (90%) and clams from seven out of eight backwater sites
had elevated Se levels (88%). Background values from Lemly (1985) were used to evaluate the potential of C. fluminea as a bioindicator (appendices C-2 and C-3).

There was no geographic trend (upstream/downstream) in Se contamination. However, at three backwater sites (Mittry Lake, Island Lake and Topock Marsh) with direct connections to the river, Se body burden in clams was higher at the northern end of the lake than at the southern end.

Table 2. Geometric mean Se residues (ppm wet weight) at the northern and southern ends of backwaters that have direct connections to the river.

Site	Northern	Southern
Mittry Lake	0.82	0.74
Island Lake	1.57	1.52
Topock Marsh	1.78	1.24

Doherty (1990) reported background arsenic levels in C. fluminea collected at five sites to be 0.43-0.72 ppm wet weight. Sixteen out of 18 sites in our study had clams with As levels >0.72 ppm wet weight (appendix A-4). Arsenic body burden in clams from backwater sites was not significantly different than As body burden at mainstream sites ($P>0.40$,[Wilcoxon Rank Sum]). There were however, significantly higher ($P<0.01$) Se concentrations in clams from backwaters than at river sites.

Contaminant levels in clams were compared within site classes with the Kruskal-Wallis procedure. Selenium concentrations among river sites were significantly different ($P< 0.001$). Clams from Imperial Oasis, the Indian Reservation river site and Havasu Refuge sites had higher Se body burdens (à = 0.10) than clams at other river sites. Selenium concentrations in clams among backwater sites were also significantly different ($P<0.05$); levels in clams from Oxbow and Cable Lakes were higher (à = 0.10) than levels at other backwaters.

Arsenic concentrations in clams were significantly different ($P<0.01$) among river sites. Clams from River reach 1 and River reach 2 had significantly higher As body burdens (à = 0.10) than at other river sites. Clams at backwater sites also had significantly different levels of As ($P<0.003$); clams from both Island Lake sites had significantly higher values (à = 0.05) than clams from other backwaters.

4.3 Bioindicator Analysis

4.3.1 Species Comparison

Selenium concentrations in clams were compared with Se concentrations in other biota collected within the prior 3 years at the same sites by five other investigators. Biota were grouped into plants, scavengers, omnivorous fish, carnivorous fish, herbivorous birds, and carnivorous birds. Se concentrations in clams had no or weak (rý < 0.60) correlation with Se concentrations in sediment, scavengers, and omnivorous fish. The median correlation (rý = 0.70) of Se in clams with Se in carnivorous fish was not significant. There were strong correlations between Se concentration in clams and Se concentrations in plants (rý = 0.98) and carnivorous birds (rý = 0.999) (Fig. 3 and 4).

4.3.2 Site Comparison

Selenium concentrations in clams at nine sites were compared to Se in sediment and biota reported from five earlier studies at the same sites to determine if C. fluminea is a good indicator of Se contamination in the LCR. Each of the nine sites had a minimum of four sediment and/or biota samples. At seven out of nine sites (78%), ratings of Se concentrations in clams agreed with ratings based on other biota (Table C-2). Contaminant ratings based on analysis of clams did not agree with ratings for other biota

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See Table/Figure

Figure 3. Correlation of Se residues in clams vs. spiny naiad collected at the same sites along the lower Colorado River by Lusk (1991) and Ruiz (pers. commun.). Sites listed in order of Se concentration from low to high, in spiny naiad. (BW = Bill Williams confluence, RR1 = River reach 1 on INWR, IL= Island Lake, DC= Cable Lake)

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See Table/Figure

Figure 4. Correlation of Se residues in clams vs. carnivorous bird livers collected at the same sites along the lower Colorado River by Rusk (1991) and Ruiz (pers. commun.). Sites listed in order of Se concentration from low to high, in birds. (ML = Mittry Lake, BW = Bill Williams, TM = Topock Marsh, IO = Imperial Oasis)

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or sediment at two out of the nine sites (22%) Contaminant levels in clams from Bill Williams and the Cibola river site did not agree with levels in other biota; that is, Se body burdens for clams were above background levels at both sites but the majority of levels in other animals/plants collected earlier was below background levels.

5.0 Discussion

5.1 Biological Analysis

Clams collected at backwater sites were significantly larger than clams collected at river sites. Warm water, low flow rates, and high phytoplankton productivity in backwaters may be conducive to high growth rates in C. fluminea. Clams also have a greater probability of surviving long enough to grow to a large size in the stable backwaters as compared to the high probability of loss due to scouring at unstable river sites. Recruitment of juveniles to the substrate is low when many adults are present (Eng 1977) thus small, juvenile clams would be relatively rare in backwaters.

Along 359 km (233 miles) of the lower Colorado River, clams were found in three different microhabitats. McMahon (1991) reported that the asiatic clam is a generalist and is able to adapt to a wide variety of environmental conditions. The greatest number and largest clams were located in warm lentic-like environments (~30 C) with soft, highly organic substrates. Intermediate sized clams occurred in slow flowing, warm water (~26 C) and were embedded in the sides of the river bank among the roots of cattails; a more permanent substrate than sand bars. The smallest clams occurred on sandy substrate in fast flowing reaches of the mainstream. These reaches had unstable substrate and relatively cool water (21 C).

5.2 Residue Analysis

5.2.1 Selenium

Se concentrations in clam tissue did not increase from upstream to downstream in the Colorado River but were closely related to habitat type. Se residues in clams from backwaters were significantly higher than in clams from river sites. Although clams were larger in backwaters than at river sites, we found no correlation between size of clams and

Se body burden either within sites or across all sites. Zhang et al. (1990) previously reported such a relationship. Significant differences in Se residues in clams across different backwaters and across different river sites probably precluded a direct relationship between size of clams and Se body burden in our study. Also, there was no relationship between water temperature and Se body burden, although C. fluminea have been reported to have increased metabolic rates at higher temperatures (McMahon 1991).

The highest geometric mean Se concentration (20.99 ppm dry weight) for clams collected at a backwater site occurred at Cable Lake. This value far exceeds the predator protection level of 5.00 ppm dry weight (Skorupa and Ohlendorf 1991).

Selenium body burden in clams was elevated above U.S. background levels (0.78 ppm wet weight) established by Lemly (1985) at 16 out of 18 sites. The two exceptions were Cibola old channel and Mittry Lake southern site. The highest wet residues in clams occurred at Imperial Oasis (located at Imperial Reservoir) and Topock Marsh (2.09 and 1.78 ppm wet weight, respectively). These areas contain abundant nesting sites for many birds. Clams were abundant at Imperial Oasis, and are probably an important part of the diet of some carnivorous birds in the area. Island Lake on INWR also had Se levels of concern; 1.57 and 1.52 ppm wet weight. This backwater lake provides nesting sites for birds and has an abundance of fish (Lusk 1991). Studies of bird reproductivity could tell us whether Se loads are adversely affecting birds in the area. Of the ten river sites, River reaches 1 and 2 on INWR had significantly higher levels of Se residues than other river sites. The Se concentration of clams for those sites were 1.12 and 1.13 ppm wet weight, respectively. These concentrations exceed the U.S. background level of 0.78 ppm wet weight and are above the predator protection level.

Se body burdens of clams were always higher at the northern collection sites of backwaters than at the southern downstream sites. This trend and the fact that clams in

backwater lakes have higher Se concentrations than at river sites suggests that backwater lakes are sinks for Se. Since backwater areas provide a high proportion of feeding and nesting sites for birds along the lower Colorado River, bioaccumulation of Se may present a hazard to higher trophic level species such as the Yuma Clapper Rail (Rallus longirostris yumananansis) (Rusk 1991) and fish-eating birds.

5.2.2 Arsenic

Arsenic in clam tissues was elevated at 15 out of 18 sites (above the U.S. background value of 0.72 ppm wet weight reported by Doherty, 1990). The three lowest readings were from Oxbow Lake (0.33 ppm), Bill Williams confluence (0.68 ppm) and Topock Marsh 2 (0.72 ppm wet weight). Island Lake had the two highest levels (2.54 and 2.76 ppm wet weight). High As residues in this area may be a threat to wildlife on INWR
Other sites with As levels above background (0.72 ppm) are river reaches 1 & 2, Cable Lake (all on INWR), and Imperial Oasis. The five sites from the refuge were among the eight highest As residue levels we recorded. Additionally, Mittry Lake had mean As levels above 1.70 ppm in clam tissue. Mittry Lake provides many nesting sites for birds and

is
used by the endangered Yuma Clapper Rail.

Residues of As were not significantly higher in backwaters than in the main river. Some pesticides and herbicides are high in arsenic (Goyer 1991), and are presumably the source of high As residues on INWR. Imperial Dam causes the river to slow and form lakes and backwaters in INWR. Much sediment carried by the river is deposited in areas above the dam. The deposition of these sediments could be the reason that Se and As residues are particularly high on INWR.

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5.2.3 Residue Analysis Conclusions

Geometric mean Se and As concentrations in clams from two sites on Island lake were in the top five of the 18 collection sites. Se residues at this site approach a level that has caused a 79% decline in offspring in mallards (10 ppm dry weight, Heinz 1989). Island Lake may require further study to establish whether reproductivity of carnivorous fish and birds in the backwater is adversely affected. Additionally, Cable Lake, Imperial Reservoir, and the Indian Reservation site also have levels of Se and As residues in clams that may cause harm to animals that eat clams.

5.3 Bioindicator Analysis

5.3.1 Species Comparisons

Dry weight Se concentrations in clams had a strong correlation with dry weight Se concentrations in spiny naiad (Najas marina) collected recently in some areas (Lusk 1991, Ruiz 1992). These data suggest that asiatic clams and some aquatic plants may be nearly equivalent indicators of Se contamination in this system.

There is a strong correlation of Se (dry weight) levels in clams and in the livers of carnivorous birds (Rusk 1991, Ruiz pers. commun.). This correlation shows that C. fluminea could be used as an indicator of Se contamination in predators on clams such as birds. Se levels (dry weight) in carnivorous birds averaged 1.86 times higher (1.46 - 4.95) than Se in clams. Geometric mean Se residue in clams collected at Cable Lake was 20.99 ppm dry weight. A conservative estimate based on the ratio above predicts that birds from this area could have liver residues of 39 ppm dry weight. This level exceeds the level of residues found in duck livers (Ohlendorf 1989) at Kesterson National Wildlife Refuge in 1983 where reproduction was severely compromised.

5.3.2 Site Comparisons

Se body burdens in C. fluminea were indicative of levels in at least 50% of other species or sediments (78%) collected earlier at seven sites but were not indicative of levels in at least 50% of the samples at two sites (the confluence of the Bill Williams and Colorado rivers and the Cibola NWR river site); in both cases Se levels in clams were higher than levels in other species or sediments (Appendix C-2).

Most biota collected at the confluence of the Bill Williams River with the Colorado River did not contain elevated levels of Se. However, Se levels in clams were slightly elevated (6.90 ppm dry weight) above background levels. Levels were also elevated in bluegill (Lepomis macrochirus) and mosquitofish (Gambusia affinis). Green sunfish (L. cyanellus) can accumulate Se at faster rates than other fish such as catfish (Ictalurus spp.), (Lemly 1985). Since clams and sunfish contained high Se residues, it is possible that theses species are better indicators of Se levels than other biota. Thus, the lack of agreement between "ratings" of clam Se concentrations and "ratings" of Se concentrations in biota and sediments collected in prior years does not necessarily indicate the failure of clams to reflect the current conditions at the site.

Levels of Se in biota from the old river channel site on Cibola National Wildlife Refuge were below U.S. baseline standards (Welsh 1992). Clam data from our study did not agree; levels in clams from this area were above baseline (7.25 ppm dry weight). One possible reason why these results differ is that (Welsh 1992) collected data in 1989-90 and we collected in 1992. Over the 2 to 3-year period changes have occurred in the area that may have caused Se residues to increase. Welsh (1992) reported fresh water inflow into the area. However, during our study fresh inflow from the river had stopped, and over half of the lake appeared to be anoxic. The northern half of the lake was shallow (< 1 meter) and emergent vegetation was brown and wilted. Anaerobic conditions can lead to

the remobilization of Se from sediments and entry into the food chain. Therefore, again, the lack of agreement between data for clams and data for other biota and sediments does not necessarily indicate the failure of clams to reflect the current conditions at the site.

The majority of biota collected by Lusk (1991) at River reach 1 on INWR exceed national baseline standards for Se. Selenium in C. fluminea at this site also exceed the national baseline standard. This site should be studied further to determine if there are any actions that could reduce the exposure and uptake of Se in biota.

Se residues in clams from Topock Marsh (13.85 ppm dry weight) were higher than dietary levels (7 ppm dry weight) that have been reported to cause impaired reproduction in chickens (Heinz 1987). Heinz reported that liver concentrations in mallards fed 10 ppm dry weight Se leveled off in only 8 days and that a diet containing 15 ppm dry weight Se affected egg production and hatching success after only 1 week. Topock Marsh provides nesting habitat for many different species of waterfowl including the endangered Yuma Clapper Rail. If the data off Heinz (1987) can be extrapolated to waterbirds, birds occupying the area for only short periods of time could encounter diet items with selenium levels high enough to impair reproduction.

Mittry Lake does not appear to have a Se problem. Eighty percent of the samples collected by Rusk (1991) contained Se body burdens that were lower than U.S. background levels. The geometric mean value for clams (5.97 ppm dry wt.) for this site was also below U.S. baseline values (6.35 ppm dry weight), but above the predator protection level.

Nine out of 12 (75%) of the samples collected by Lusk (1991) at Island Lake during 1991 and 1992 had Se concentrations that exceed background levels. The geometric mean of Se concentrations in clams at Island Lake was 10.3 ppm dry weight.

This value also exceeds the predator protection level and reaches a level that could adversely affect reproductivity.

Welsh (1992) collected four sediment and biota samples at Oxbow Lake in 1990 and 1991. Two of those samples were above U.S. background values and two were below. My composite sample of clams had an extremely high Se concentration (14.55 ppm dry weight). Both sunfish (Lepomis spp.) and bass (Micropterus salmoides) samples collected by Welsh (1992) also showed high Se concentrations (11.00 and 14.00 ppm dry weight, respectively). As stated previously; sunfish have been shown to be sensitive to Se contamination. Therefore, clams may predict high Se levels before levels show up high in other less sensitive species.

Eighty percent of the samples collected by Lusk (1991) at Cable Lake had Se concentrations that exceed background levels. The geometric mean of the clam body burden of Se (20.99 ppm dry weight) also exceeded background threshold levels. This mean reflects four composite samples (a total of 32 clams) and is the highest dry weight mean for any site in this study. The concentration of Se in clams at this site was three times the Se concentration in the diets of chickens that had impaired reproductivity. Cable Lake presently receives very little water flow from the main river channel and appears to have become an area of high Se concentration.

5.3.3 Bioindicator Conclusions

C. fluminea was a good bioindicator of Se levels as shown by species and site comparisons. The clams we collected showed a significant relationship between the Se levels in their tissue and those in both vascular plants and carnivorous birds at the same sites. Projection of concentrations of contaminants in clams leads to the conclusion that

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birds at several of these study sites may have Se levels in livers that have been shown to be both toxic and teratogenic. Se levels in clams reflected the site condition based on levels of contaminants in other biota and sediments collected earlier at least 78% of the time. Predictability might have been improved if clams and other species had been collected during one time period. However, most of the sites in our study that have been sampled repeatedly over time have shown a relatively consistent record of contamination.

Se levels in some sites were statistically higher than those in other sites and predators of clams are at greater risk at sites with higher residue levels. The sites where predators are at the greatest risk are in backwater lakes with high productivity. Ten out of 18 sites had Se levels above 10 ppm dry weight. These high levels cluster around INWR but also occur at more northern locations. Levels of Se below 10 ppm dry weight have been shown to impair waterfowl reproductivity (Saiki and Lowe 1987, Heinz 1989).

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APPENDIX A

Trace element analysis

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Appendix A-1   Identification code for samples.

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1st two characters:		3rd character:	
BW:	Bill Williams confluence	1:	First site
CR:	Cibola old river channel	2:	Second site
DC:	Cable Lake		
HR:	Topock Gorge		
IL	Island Lake		

IO Imperial Oasis

IR Indian Reservation

ML: Mittry Lake

NR: Needles river

OL: Palo Verde Oxbow Lake

RR: Imperial NWR river

SP: Sand Point

TM: Topock Marsh

4th character:

C: Clam samples

5th character:

1 & 2: Small clams for site

3 & 4: Large clams for site

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Appendix A-2 Trace element residues (ppm wet wt.) in clams.

	Sample						
Element	BW1C1	BW1C2	BW1C3	BW1C4	CR1C1	CR1C2	CR1C3
Al	61.20	253.00	32.60	38.20	45.90	28.70	35.20
As	1.11	0.54	1.47	0.24	0.85	0.86	1.49
Ba	2.69	7.98	1.92	2.11	1.96	1.53	1.72
Be	<.02	<.02	<.02	<.02	<.02	<.02	<.02
B	<0.40	0.57	<0.40	<0.39	0.43	<0.40	<0.40
Cd	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Cr	0.13	.45	<0.10	0.11	0.10	<0.10	<0.10
Cu	2.79	4.67	3.06	3.03	2.76	2.10	4.55
Fe	96.20	386.00	56.10	63.80	126.00	85.20	109.00
Pb	<0.49	<0.50	<0.50	<0.49	<0.50	<0.50	<0.50
Mg	118.00	267.00	116.00	111.00	122.00	116.00	111.00
Mn	8.36	31.60	4.80	4.79	12.30	12.30	10.10
Hg	0.01	0.01	0.01	0.0.1	<0.01	<0.01	0.01
Mo	<0.39	<0.40	<0.40	<0.39	<0.40	<0.40	<0.40
Ni	0.13	0.44	0.18	0.16	0.16	0.20	

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Se	1.27	1.23	0.82	1.06	0.70	0.59	0.62
Sr	3.96	9.00	4.17	4.26	4.19	4.76	4.57
Vn	0.24	0.90	0.08	0.16	0.18	0.13	0.14
Zn	12.40	27.90	14.50	11.80	14.90	15.60	16.10

Appendix A-2. Continued.

	Sample						
Element	CR1C4	CR2C1	CR2C2	CR2C3	CR2C4	DC1C1	DC1C2
Al	9.41	76.50	28.30	29.70	25.30	19.80	15.30
As	1.37	0.38	0.83	1.26	1.68	1.50	2.31
Ba	1.11	3.73	1.75	2.07	1.71	9.03	21.00
Be	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
B	0.41	0.50	<0.40	<0.40	<0.40	<0.40	<0.40
Cd	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Cr	<0.10	0.13	<0.10	<0.10	<0.10	<0.10	<0.10
Cu	4.11	3.15	2.24	4.68	34.24	3.06	6.06
Fe	48.30	217.00	101.00	103.00	99.30	37.60	56.10
Pb	<0.50	<4.08	<0.48	<0.50	<0.50	<0.50	<0.50
Mg	89.30	194.00	133.00	104.00	107.00	79.00	69.30
Mn	9.54	28.20	16.20	14.10	10.90	6.37	5.35
Hg	0.01	0.01	<0.01	0.01	0.01	0.02	0.02
Mo	<0.40	<0.38	<0.40	<0.40	<0.40	<0.40	<0.40
Ni	0.27	0.31	0.33	0.23	0.39	0.22	0.18
Se	0.68	1.35	0.92	0.50	0.92	0.97	1.23
Sr	4.55	7.17	4.52	4.26	4.78	5.53	5.03
Vn	<0.05	0.30	0.10	0.10	0.09	0.13	0.16
Zn	13.90	31.10	119.70	12.70	16.70	7.86	6.12

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Appendix A-2. Continued.

Element	Sample DC1C3	DC1C4	HR1C1	HR1C2	HR1C3	IL1C1	IL1C2
Al	43.30	9.80	127.00	145.00	58.90	54.50	10.80
As	1.16	1.91	1.20	1.24	0.94	2.31	2.46
Ba	78.10	27.10	4.83	5.63	3.00	1.95	1.35
Be	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
B	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.39
Cd	0.18	0.07	<0.06	<0.06	<0.06	<0.06	<0.06
Cr	0.15	<0.10	0.25	0.28	0.13	0.11	<0.10
Cu	16.60	7.07	2.92	3.57	2.25	4.99	5.01
Fe	131.00	37.20	201.00	224.00	102.00	75.00	26.60
Pb	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.49
Mg	157.00	67.00	230.00	246.00	158.00	133.00	87.00
Mn	37.60	3.47	6.40	7.32	3.91	6.88	1.94
Hg	0.08	0.02	<0.01	<0.01	<0.01	<0.01	<0.01
Mo	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.39
Ni	0.37	0.12	0.55	0.54	0.30	0.20	<0.12
Se	3.51	1.08	1.49	1.85	1.20	1.28	1.49
Sr	24.80	5.05	6.18	6.59	4.32	4.48	3.49
Vn	0.44	0.12	0.52	0.59	0.27	0.16	<0.05
Zn	20.30	6.83	23.50	23.90	18.20	12.50	7.96

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Appendix A-2. Continued.

Element	Sample IL1C3	IL1C4	IL2C1	IL2C2	IL2C3	IL2C4

							IO1C1
Al	18.90	36.70	39.60	59.40	37.20	1.70	26.70
As	2.85	2.22	2.59	3.11	2.69	2.69	1.25
Ba	8.39	3.92	2.61	3.72	2.45	1.43	1.77
Be	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
B	<0.40	<0.40	<0.39	<0.40	<0.40	<0.40	<0.40
Cd	0.08	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Cr	0.10	<0.10	0.11	0.15	0.11	<0.10	<0.10
Cu	10.30	7.33	4.95	5.28	7.42	6.83	4.44
Fe	69.70	63.60	56.70	96.90	79.40	24.50	58.50
Pb	<0.50	<0.50	<0.49	<0.50	<0.50	<0.50	<0.50
Mg	117.00	93.30	133.00	192.00	89.00	101.00	120.00
Mn	4.85	2.36	4.85	6.78	1.50	2.01	2.60
Hg	0.02	<0.01	0.03	<0.01	0.01	<0.01	<0.01
Mo	<0.40	<0.40	<.039	<0.40	<0.40	<0.40	<0.40
Ni	<0.12	<0.12	0.24	0.15	<0.12	<0.12	0.31
Se	2.08	1.54	1.58	2.05	1.45	1.13	1.96
Sr	9.13	3.73	5.96	8.08	3.94	4.96	3.42
Vn	0.16	0.16	0.13	0.21	0.19	0.06	0.10
Zn	13.60	8.56	14.70	20.80	7.54	10.30	17.20

Appendix A-2. Continued.

	Sample						
Element	IO1C2	IO1C3	IO1C4	IR1C1	IR1C2	IR1C3	IR1C4
Al	13.20	20.30	59.20	50.90	44.90	31.40	31.30
As	1.17	1.68	1.49	1.10	1.10	1.05	1.51
Ba	1.58	1.83	2.87	3.26	2.88	2.49	2.26
Be	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02

B	<0.40	<0.39	<0.40	<0.40	<0.39	<0.39	<0.39
Cd	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Cr	<0.10	<0.10	0.13	0.13	0.13	<0.10	<0.10
Cu	3.54	5.95	9.50	3.68	4.73	12.60	10.30
Fe	44.20	43.10	92.20	88.50	75.60	59.40	65.20
Pb	<0.49	<0.49	<0.50	<0.50	<0.49	<0.49	<0.49
Mg	114.00	123.00	139.00	131.00	129.00	91.40	93.20
Mn	2.80	2.16	3.78	6.44	6.13	2.66	3.41
Hg	<0.01	0.02	<0.01	0.01	0.02	0.05	0.03
Mo	<0.40	<0.39	<0.40	<0.40	<0.39	<0.39	<0.39
Ni	0.29	0.38	0.25	0.34	0.46	0.29	0.46
Se	1.58	2.05	3.03	1.53	1.29	1.44	1.63
Sr	3.35	5.16	4.44	3.51	3.34	5.85	3.34
Vn	0.06	0.07	0.20	0.23	0.21	0.11	0.14
Zn	14.50	17.10	17.20	21.30	22.60	15.70	22.10

Appendix A-2. Continued.

	Sample						
Element	ML1C1	ML1C2	ML1C3	ML1C4	ML2C1	ML2C2	ML2C3
Al	12.60	18.90	17.00	28.50	40.60	28.40	25.10
As	1.55	1.44	1.84	2.64	1.42	1.50	1.57
Ba	11.30	17.20	30.50	62.40	1.85	1.73	1.49
Be	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
B	<0.39	<0.40	<0.40	<0.40	<0.40	<0.40	<0.39
Cd	<0.06	<0.06	0.07	0.14	<0.06	<0.06	<0.06
Cr	<0.10	<0.10	<0.10	<0.10	0.11	<0.10	<0.10
Cu	4.23	2.98	5.15	7.73	1.89	1.74	2.49
Fe	23.90	24.40	30.00	54.00	71.00	51.10	40.20

Pb	<0.49	<0.50	<0.50	<0.50	<0.50	<0.50	<0.49
Mg	101.00	89.00	112.00	136.00	120.00	115.00	102.00
Mn	2.38	2.61	3.31	3.86	6.66	5.31	3.49
Hg	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01
Mo	<0.39	<0.40	<0.40	<0.40	<0.40	<0.40	<0.39
Ni	0.20	0.13	0.16	0.16	0.13	0.13	<0.12
Se	0.81	0.45	1.05	1.17	0.84	0.84	0.66
Sr	6.11	4.45	8.06	11.10	4.83	4.50	4.20
Vn	0.09	0.08	0.08	0.16	0.16	0.11	0.09
Zn	12.10	9.32	15.50	20.10	20.00	20.00	13.60

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Appendix A-2. Continued.

	Sample						
Element	ML2C4	NR1C1	NR1C2	NR1C3	NR1C4	OL1C1	RR1C1
Al	16.70	40.10	22.20	16.10	22.70	<0.98	7.52
As	1.73	1.21	1.04	1.17	1.18	0.33	1.95
Ba	1.53	2.84	2.21	1.68	2.53	1.11	1.45
Be	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
B	<0.39	<0.40	<0.40	<0.39	<0.39	<0.39	<0.39
Cd	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Cr	<0.10	1.03	<0.10	<0.10	<0.10	<0.10	<0.10
Cu	2.77	2.75	2.06	3.54	3.10	1.52	4.46
Fe	30.50	81.40	50.00	51.40	56.40	10.40	35.20
Pb	<0.49	<0.50	<0.50	<0.49	<0.49	<0.49	<0.49
Mg	99.10	139.00	122.00	94.20	103.00	76.70	111.00
Mn	4.03	4.35	3.94	2.68	3.51	1.48	2.51
Hg	<0.01	0.01	0.06	0.02	0.01	<0.01	<0.01
Mo	<0.39	<0.40	<0.40	<0.39	<0.39	<0.39	<0.39

Ni	<0.12	0.40	0.29	0.22	0.24	0.16	0.49
Se	0.66	1.60	1.18	1.14	1.27	1.63	1.03
Sr	4.94	3.95	4.07	4.51	4.31	7.33	3.55
Vn	0.06	0.28	0.17	0.14	0.19	<0.05	<0.05
Zn	14.50	16.70	15.40	11.40	12.70	10.80	19.50

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Appendix A-2. Continued.

Element	Sample RR1C2	RR1C3	RR1C4	RR2C1	RR2C2	RR2C3	RR2C4
Al	10.30	1.00	14.70	59.60	24.30	14.40	7.90
As	2.15	1.49	1.39	1.72	1.67	1.54	1.92
Ba	1.96	1.33	1.62	3.97	3.05	2.41	1.38
Be	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
B	<0.39	<0.40	<0.39	<0.39	<0.40	<0.40	<0.40
Cd	<0.08	0.07	10.06	<0.06	<0.06	<0.06	<0.06
Cr	<0.10	<0.10	<0.10	0.13	<0.10	0.15	<0.10
Cu	7.19	8.07	7.64	4.07	3.84	5.23	5.17
Fe	39.10	26.60	47.50	111.00	61.40	45.60	34.50
Pb	<0.49	<0.50	<.049	<0.49	<0.50	<0.50	<0.50
Mg	103.00	90.30	95.70	164.00	143.00	131.00	121.00
Mn	3.04	1.41	1.97	7.83	6.73	2.50	2.14
Hg	<0.01	0.01	0.01	<0.01	<0.01	<0.01	<0.01
Mo	<0.39	<20.40	<0.39	<0.39	<0.40	<0.40	<0.40
Ni	0.38	0.53	0.42	0.44	0.58	0.80	0.47
Se	1.48	1.08	0.94	1.21	0.98	1.17	1.17
Sr	3.43	3.48	4.17	3.97	4.07	3.24	3.15
Vn	<0.05	<0.05	0.06	0.22	0.12	0.08	<0.05
Zn	19.60	17.10	16.70	22.10	22.00	22.00	21.40

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Appendix A-2. Continued.

Element	SP1C1	SP1C2	SP1C3	SP1C4	TM1C1	TM1C2	TM1C3
Al	4.95	7.95	1.19	2.48	33.00	40.10	20.40
As	0.62	0.64	0.99	0.95	0.55	0.59	6.71
Ba	1.22	1.29	1.81	1.14	6.73	3.93	11.10
Be	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
B	<0.40	<0.40	<0.40	<0.40	<0.39	<0.39	<0.33
Cd	0.07	0.07	0.06	0.08	0.10	<0.06	0.07
Cr	<0.10	<0.10	<0.10	<0.10	0.11	<0.10	0.11
Cu	1.28	1.41	3.40	4.68	4.89	2.83	5.26
Fe	27.50	30.80	18.70	22.30	71.30	65.50	42.70
Pb	<0.50	<0.50	<0.50	<0.50	<0.49	<0.49	<0.42
Mg	81.30	88.10	68.10	59.80	170.00	138.00	133.00
Mn	1.51	1.57	0.72	0.68	3.76	3.09	2.42
Hg	<0.01	0.14	0.01	0.01	0.07	<0.01	<0.01
Mo	<0.40	<0.40	<0.40	<0.40	<0.39	<0.39	<0.33
Ni	<0.12	0.14	0.14	<0.12	0.59	0.31	0.26
Se	0.92	1.15	1.09	0.98	2.33	2.19	2.68
Sr	2.57	2.60	3.17	3.42	5.68	3.46	5.18
Vn	0.06	0.07	<0.05	<0.05	0.15	0.16	0.12
Zn	15.00	17.10	12.00	12.70	44.30	22.50	22.90

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Appendix A-2. Continued.

Sample

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Element	TM1C4	TM2C1	TM2C2	TM2C3	TM2C4
Al	4.55	2.47	4.20	8.18	3.70
As	0.57	0.30	1.14	0.97	0.79
Ba	2.42	3.09	3.87	6.93	3.29
Be	<0.02	<0.02	<0.02	<0.02	<0.02
B	<0.40	<0.39	<0.40	<0.40	<0.40
Cd	0.06	<0.06	<0.06	<0.06	<0.06
Cr	<0.10	<0.10	<0.10	<0.10	<0.10
Cu	3.42	1.56	1.75	2.17	2.95
Fe	16.20	14.70	19.20	27.20	16.90
Pb	<0.50	<0.49	<0.50	<0.50	<0.50
Mg	88.60	102.00	108.00	89.20	82.40
Mn	1.54	2.30	2.52	3.16	2.03
Hg	<0.10	<0.10	<0.10	<0.10	<0.10
Mo	<0.40	<0.39	<0.40	<0.40	<0.40
Ni	0.32	0.32	0.46	0.36	0.51
Se	0.73	1.32	1.09	1.29	1.29
Sr	3.40	3.43	4.46	4.14	4.78
Vn	<0.05	<0.06	<0.06	<0.09	0.07
Zn	210.61	152.21	197.85	149.46	151.14

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Appendix A-3. Geometric mean (with minima and maxima) of selenium residues in clams as determined by GFAA analysis.

Site	Mean ppm wet wt.	Mean ppm dry wt.	% moisture	n
Bill Willaims	1.08	6.90	84	4
	(0.82 - 1.27)	(4.33 - 9.07)		
Cibola Refuge 1	0.66	5.92	89	4
	(0.59 - 0 70)	(5.19 - 7.05)		
Cibola Refuge 2	0.87	8.58	90	4
	(0.50 - 1.35)	(7.12 - 11.44)		
Cable Lake	1.46	20.99	93	4
	(0.97 - 3.51)	(16.20 - 31.34)		
Topock Gorge	1.48	13.92	90	3
	(1.20 - 1.85)	(12.24 - 17.79)		
Island Lake 1	1.57	11.26	86	4
	(1.28 - 2.08)	(8.89 - 16.04)		
Island Lake 2	1.52	9.41	83	4
	(1.13 - 2.05)	(8.31 - 11.79)		
Imperial Oasis	2.09	14.23	85	4
	(1.58 - 3.03)	(11.33 - 20.75)		
Indian Reservation	1.47	13.65	89	4

	(1.29 - 1.63)	(10.57 - 15.65)		

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Appendix A-3. Continued.

Site	Mean ppm wet wt.	ppm dry wt.	% moisture	n
Mittry Lake 1	0.82 (0.45 - 1.17)	6.29 (3.84 - 9.14)	87	4
Mittry Lake 2	0.74 (0.66 - 0.84)	5.66 (4.85 - 6.74)	87	4
Needles river	1.29 (1.14 - 1.60)	10.11 (8.64 - 13.01)	87	4
Oxbow Lake	1.63	14.55	89	1
Imperial NWR 1	1.12 (0.94 - 1.48)	7.84 (6.16 - 10.35)	86	4
Imperial NWR 2	1.13 (0.98 - 1.21)	8.19 (7.03 - 9.36)	86	4
Sand Point	1.03 (0.92 - 1.15)	12.22 (11.23 - 13.41)	92	4
Topock Marsh 1	1.78 (0.73 - 2.68)	14.86 (11.02- 18.61)	87	4
Topock Marsh 2	1.24 (1.09 - 1.32)	12.92 (11.68- 14.66)	90	4

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Appendix A-4. Geometric mean (with minima and maxima) of arsenic residues per site as determined by GFAA analysis (n represents the number of composite samples).

Site	Mean ppm wet wt.	Mean ppm dry wt.	% moisture	n
Bill Williams	0.68 (0.24 - 1.47)	4.30 (1.57 - 7.93)	84	4
Cibola Refuge 1	1.11 (0.85 - 1.49)	10.14 (8.57 - 12.52)	89	4
Cibola Refuge 2	0.90 (0.38 - 1.68)	8.86 (3.18 - 18.26)	90	4

Cable Lake	1.66 (1.16 - 2.31)	23.94 (10.36 - 40.53)	93	4
Topock Gorge	1.12 (0.94 - 1.24)	10.48 (9.59 - 11.92)	90	3
Island Lake 1	2.54 (2.31 - 2.46)	18.16 (15.77 - 26.56)	86	4
Island Lake 2	2.76 (2.59 - 3.11)	17.12 (13.12 - 21.87)	83	4
Imperial Oasis	1.38 (1.17 - 1.68)	9.40 (8.87 - 10.21)	85	4
Indian Reservation	1.18 (1.05 - 1.51)	10.96 (9.02 - 13.36)	89	4

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Appendix A-4. Continued.

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Site	Mean ppm wet Wt.	Mean ppm dry Wt.	% moisture	n
Mittry Lake 1	1.81 (1.44 - 2.64)	13.95 (12.02-20.62)	87	4
Mittry Lake 2	1.55 (1.42 - 1.73)	11.81 (10.71 - 12.72)	87	4
Needles river	1.15 (1.04 - 1.21)	9.02 (8.19 - 9.84)	87	4
Oxbow Lake	0.33	2.99	89	1
Imperial NWR 1	1.72 (1.39 - 2.15)	12.07 (9.14 - 15.35)	86	4
Imperial NWR 2	1.71 (1.54 - 1.92)	12.40 (10.00 - 14.01)	86	4
Sand Point	0.78 (0.62 - 0.99)	9.28 (6.90 - 13.07)	92	4
Topock Marsh 1	1.06 (0.55 - 6.71)	8.85 (3.28 - 46.60)	87	4
Topock Marsh 2	0.72 (0.30 - 1.14)	7.43 (2.66 - 12.26)	90	4

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APPENDIX B

Biological data

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Appendix B-1 A. Arithmetic mean size (mm, shell length) of Corbicula fluminea at 10 river sites along the lower Colorado River, 1992.

River Site	Mean clam size	N
Bill Williams*	40.18	32
Cibola Refuge 1	31.05	32
Cibola Refuge 2	30.14	32
Topock Gorge	19.98	69
Imperial Oasis*	38.63	32
Indian Reservation	28.02	34
Needles River	20.00	67
Imperial NWR 1	41.56	32
Imperial NWR 2	34.36	32
Sand Point	25.72	48
Mean for river sites	30.96	

* These sites had low water velocity, atypical for "river sites".

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Appendix B-1B. Arithmetic mean size (mm, shell length) of Corbicula fluminea at 8 backwater sites along the lower Colorado River, 1992.

Backwater Site	Mean clam size	N
Cable Lake	42.76	32
Island Lake 1	47.70	32
Island Lake 2	49.56	32
Mittry Lake l	37.11	32
Mittry Lake 2	32.59	32

Oxbow Lake	27.33	5
Topock Marsh 1	31.30	22
Topock Marsh 2	32.91	32
Mean for backwater sites	38.73	

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Appendix B-2. Temperature of water by site.

Site	Temperature (degrees Celsius)
Bill Willaims	31
Cibola Refuge 1	27
Cibola Refuge 2	27
Topock Gorge	22
Imperial Oasis	not taken
Indian Reservation	26
Needles River	21
Imperial NWR 1	27
Imperial NWR 2	26
Sand Point	32
Cable Lake	not taken
Island Lake	28
Mittry Lake	30
Oxbow Lake	29
Topock Marsh 1	24
Topock Marsh 2	29

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APPENDIX C

Bioindicator data

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Appendix C-1 Se concentration of sediment and biota by site (ppm dry wt.).

River Reach 1

Sample (# of samples)	Mean Se	Rating	Investigator
sediment (2)	0.78	below	Lusk
naiad (1)	5.24	exceed	Lusk
cattail leaves (2)	<.12	below	Lusk
cattail litter (2)	2.54	exceed	Lusk
cattail rhizomes (2)	7.37	exceed	Lusk
aufwuchs (2)	3.19	exceed	Lusk
bluegill (3)	9.01	exceed	Lusk
carp (2)	7.57	exceed	Lusk
bass (2)	6.16	exceed	Lusk
crayfish (3)	5.57	below	Lusk
shrimp (3)	12.73	below	Lusk

Bill Williams

Sample (#)	Mean Se	Rating	Investigator
sediment (2)	.03	below	Ruiz
naiad (2)	1.18	below	Ruiz
bass (2)	3.83	below	Ruiz
bluegill (2)	5.66	exceed	Ruiz
carp (1)	3.62	below	Ruiz
mosquitofish (3)	8.47	exceed	Ruiz
grebe liver (1)	12.90	below	Ruiz

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Appendix C-1 Continued.

River Reach 2

Sample (#)	Mean Se	Rating	Investigator
sediment (2)	0.89	below	Lusk
cattail leaves (1)	<.14	below	Lusk
cattail litter (2)	4.00	exceed	Lusk
cattail rhizomes (2)	7.54	exceed	Lusk
aufwuchs (2)	4.02	exceed	Lusk
bass (2)	7.05	exceed	Lusk
shad (3)	4.16	below	Lusk
carp (2)	6.49	exceed	Lusk
bluegill (1)	10.74	exceed	Lusk
crayfish (3)	7.86	exceed	Lusk
damselfly nymphs (4)	13.97	below	Lusk
shrimp (3)	13.36	exceed	Lusk

Cibola River

Sample (#)	Mean Se	Rating	Investigator
sediment (2)	0.03	below	Welsh
plants (1)	1.02	below	Welsh
sunfish (1)	2.00	below	Welsh
crayfish (2)	1.65	below	Welsh

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Appendix C-1 Continued.

Topock Marsh

Sample (#)	Mean Se	Rating	Investigator

sediment (1)	1.89	exceed	Rusk
bass (2)	11.50	exceed	King et al.
carp (2)	7.95	exceed	King et al.
catfish (2)	5.55	exceed	King et al.
crappie (2)	17.75	exceed	King et al.
least bittern (3)	26.77	exceed	Rusk
crayfish (6)	1.78	below	Rusk
shrimp (3)	6.76	below	Rusk

Mittry Lake

Sample (#)	Mean Se	Rating	Investigator
sediment (3)	3.88	exceed	Rusk
Virginia rail (4)	15.37	exceed	Rusk
least bittern (1)	13.60	below	Rusk
coot (2)	8.10	below	Rusk
moorhen (2)	4.15	below	Rusk
night heron (2)	8.45	below	Rusk
sora (2)	7.65	below	Rusk
green heron (1)	5.60	below	Rusk
ruddy duck (1)	2.60	below	Rusk
crayfish (3)	1.76	below	Rusk

Appendix C-1 Continued.

Island Lake

Sample (#)	Mean Se	Rating	Investigator
sediment (1)	2.59	exceed	Lusk

naiad (2)	6.59	exceed	Lusk
cattail leaves (1)	<.09	below	Lusk
cattail litter (2)	14.09	exceed	Lusk
aufwuchs (2)	4.97	exceed	Lusk
bass (3)	13.08	exceed	Lusk
bluegill (4)	13.06	exceed	Lusk
carp (2)	6.35	exceed	Lusk
mosquitofish (3)	10.40	exceed	Lusk
shad (6)	4.82	below	Lusk
crayfish (3)	10.64	exceed	Lusk
shrimp (3)	9.00	below	Lusk

Oxbow Lake

Sample (#)	Mean Se	Rating	Investigator
sediment (2)	0.62	below	Welsh
bass (2)	14.00	exceed	Welsh
sunfish (2)	11.00	exceed	Welsh
crayfish (2)	3.60	below	Welsh

Appendix C-1 Continued.

Cable Lake

Sample (#)	Mean Se	Rating	Investigator
sediment (2)	3.20	exceed	Lusk
naiad (2)	15.93	exceed	Lusk
cattail leaves (1)	<.09	below	Lusk
cattail litter (2)	10.16	exceed	Lusk
cattail rhizomes (2)	13.37	exceed	Lusk

aufwuchs (4)	5.54	exceed	Lusk
bass (2)	10.09	exceed	Lusk
bluegill (3)	9.29	exceed	Lusk
carp (2)	7.69	exceed	Lusk
catfish (1)	9.35	exceed	Lusk
mosquitofish (4)	12.30	exceed	Lusk
shad (2)	4.71	below	Lusk
crayfish (3)	10.20	exceed	Lusk
damselfly nymphs (2)	15.50	exceed	Lusk
shrimp (3)	11.23	below	Lusk

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Appendix C-2 Bioindicator site evaluation for selenium.

Site	% samples below	% samples¦ exceed	Clams[sup]b	Agreement[sup]C
River reach 1	36%	64%	exceed	yes
Bill Williams	71%	29%	exceed	no
River reach 2	33%	67%	exceed	yes
Cibola River	100%	0%	exceed	no
Topock Marsh	25%	75%	exceed	yes
Mittry Lake	80%	20%	below	yes
Island Lake	25%	75%	exceed	yes
Oxbow Lake	50%	50%	exceed	yes
Cable Lake	20%	80%	exceed	yes

¦ Ifò 50% of samples of sediment and biota at a site exceed their respective background levels for Se, then the contamination state of the site is classified as "exceed".
[sup]b exceed = Se concentration in clams ò 6.35 ppm dry wt.
[sup]c "Agreement" = Clam and other sediment/biota samples agree on contamination state of the site.

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Appendix C-3 References for background threshold limits of selenium.

Sample	Background Threshold	Author	Date
Sediment	1.4 ppm dry wt.	Radtke et al	1988
Plants	1.34 ppm dry wt.	Radtke et al	1988
Fish	5.0 ppm dry wt.	Radtke et al	1988
Birds (liver)	14 ppm dry wt.	Radtke et al	1988
Crayfish	7.26 ppm dry wt.	Lemly	1985
Shrimp	11.56 ppm dry wt.	Lemly	1985
Insects	6.40 ppm dry wt.	Lemly	1985
Mollusks	6.35 ppm dry wt.	Lemly	1985

Appendix C-4 Scientific names of plants and animals used for bioindicator species comparisons.

Common name	Scientific name
Spiny naiad	Najas marina
Crayfish	Procambarus clarkii
Shrimp	Palaemonetes paludosus
Threadfin shad	Dorosoma petenense
Bluegill	Lepomis macrochirus
Carp	Cyprinus carpio
Mosquitofish	Gambusia affinis
Sunfish	Lepomis spp.
Largemouth bass	Micropterus salmoides
Channel catfish	Ictalurus punctatus
Black crappie	Pomoxis nigromaculatus
Ruddy duck	Oxyura jamaicensis
American coot	Fulica americana
Common moorhen	Gallinula cloropus
Green backed heron	Butorides striatus
Black-crowned night heron	Nicticorax nicticorax

Sora rail	Porzana Carolina
Clark's grebe	Aechmophorus clarkii
Least bittern	Ixobrychus exilis
Virginia rail	Rallus limicola

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