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# *Corbicula fluminea* as a bioindicator on the lower Colorado River

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# *CORBICULA FLUMINEA* AS A BIOINDICATOR ON THE LOWER COLORADO RIVER

by

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## Abstract

I determined that *Corbicula fluminea* can be used as a bioindicator on the lower Colorado River. I analyzed tissue samples 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. Selenium in clams predicts the contamination state of a site 78% of the time. There is a strong correlation between selenium concentrations in clams and selenium concentrations in vascular aquatic plants ($r^2 = 0.98$) and carnivorous birds ($r^2 = 0.999$). The white morph of *C. fluminea* is more prevalent at northern and backwater sites than the purple morph. 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 levels of arsenic, cadmium, copper, lead, mercury, selenium and zinc were high in water, sediment and biota from the lower Colorado River. Subsequent studies have shown that selenium concentrations were high in fish (Radtke *et al.* 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 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 high selenium levels 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 metal 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 al.* 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 *et 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 metal 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 my 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.
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 found 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 *et al.* 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 *et al.* (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 $\mu$m), 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) found 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).

*C. fluminea* exhibit ecophenotypic characteristics, that is, there is a wide variety of morphs in response to the environment (Smith *et al.* 1977, Mcleod 1986). There is much debate on the number of species of *Corbicula* in North America. Electrophoretic studies have determined that there are two distinct genetic morphs (Mcleod 1986). These morphs have been delineated "purple" and "white" for the color of the nacreous layer. The white morph is traditionally known as *Corbicula fluminea* (Mcleod 1986).

# 2.0 STUDY AREA

The lower Colorado River (LCR) stretches for 276 river miles 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.

I collected clams in backwater sites (lentic) and in river sites (lotic) to compare trace metal accumulation in each type of environment. I selected 18 collection sites: eight backwater sites and 10 river sites. Previous data (Lusk 1991, Rusk 1991), have shown that selenium concentrations are higher in backwater sites than in river sites. My 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. I chose river channel sites that spanned much of the lower Colorado River so that I could determine the spatial distribution of selenium (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

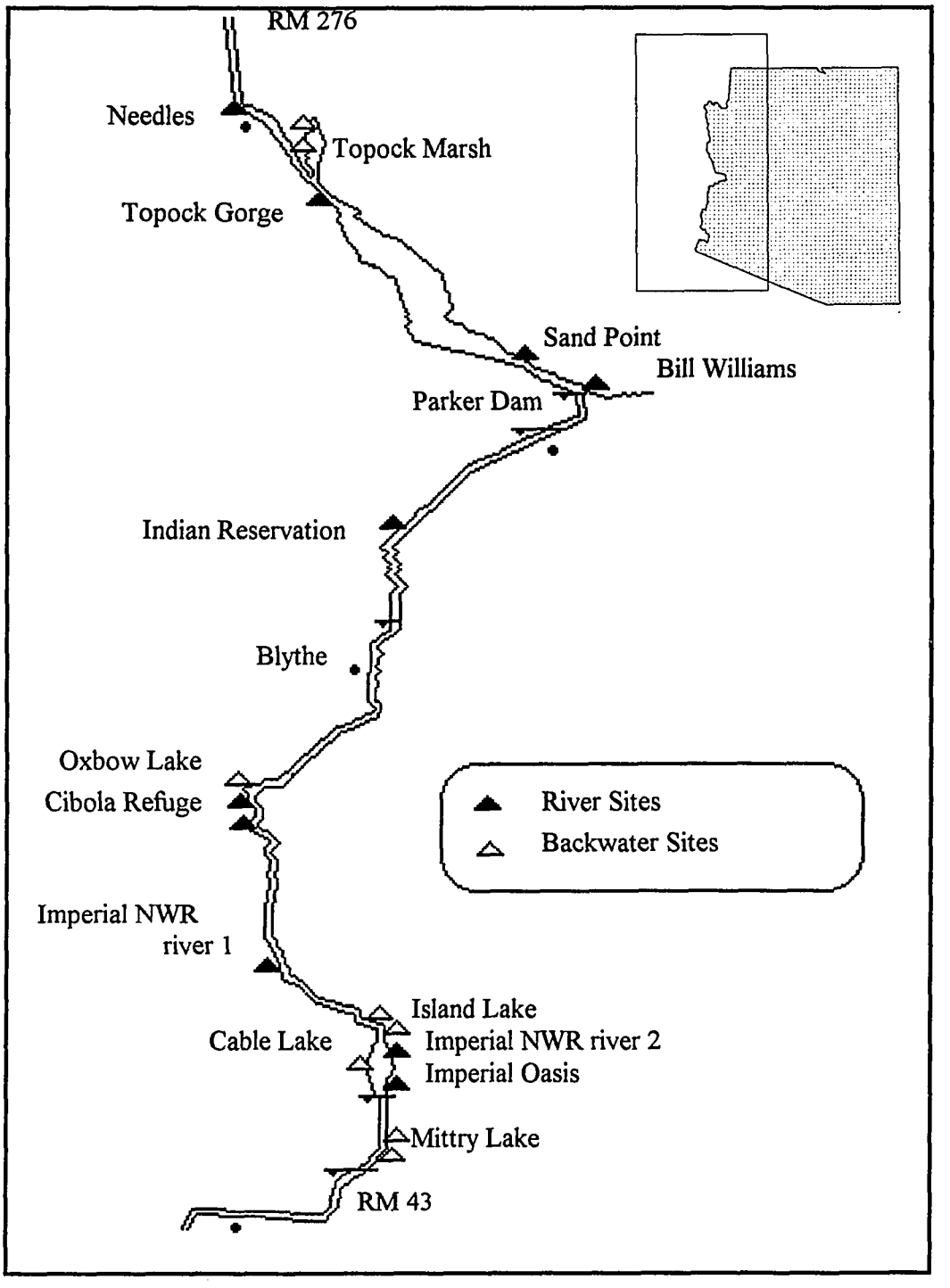


Figure 1. Location of 18 sample sites along the lower Colorado River.

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

Palo Verde Oxbow Lake is located on Cibola National Wildlife Refuge (CNWR). This lake gets little water from the river and may experience anoxic conditions. A yellow sediment released a noxious smelling gas. Welsh (1991) 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

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

# 3.0 METHODS

## 3.1 Collection

I took samples during 3 weeks in July 1992 to reduce the possible impact of seasonal variability. I detected and removed clams by digging into the substrate with my hand 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, I removed frozen body parts from the shells with a stainless steel knife and placed them into inert plastic bags and measured shell length. I collected and evaluated 617 clams for shell color morph. I obtained four composite samples at all sites except Palo Verde Oxbow Lake at CNWR; I could collect only one sample of six clams (after an intensive four hr search). Composites ranged from four clams to a maximum of 29 clams. At each site I sorted the clams into the largest and smallest. I obtained two subsamples from each size category. "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 *et al.* 1976, Graney *et al.* 1984).

At three backwater sites (Mittry Lake, Island Lake and Topock Marsh) I collected clams at the northern and southern ends of the backwater lake. 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 I collected were analyzed by Hazelton Laboratories, Madison, WI. A multi-element scan was performed for all metals plus As, Se and Hg. Quality assurance methods included procedural blanks, duplicate samples and spiked samples. All

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

Samples were analyzed for 16 element residues (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 detects 0.1% moisture.

### 3.3 Data Analysis

I ran nonparametric statistical tests 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 normal. I used Wilcoxon Rank Sum tests for comparisons between site classes . I used the Kruskal-Wallis procedure to compare data within site classes. My statistical comparisons were made on wet weight concentrations of As and Se in parts per million (ppm).

I used a student's T-test for comparison of clam sizes (arithmetic means) in backwater and river sites. I used dry weight values 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

I compared Se concentrations 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 | Bluegill | Gambusia | Ruddy duck | Heron |
| | Shrimp | Carp | Sunfish | American coot | Sora rail |
| | Threadfin shad | | 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

I compared Se concentrations in samples collected by other investigators to Se concentrations in clams at nine sites (appendix C-2). I used background threshold limits from Lemly (1986) and Radtke (1988) to determine if samples were high in Se (appendix C-3). Each of the nine sites had a minimum of four sediment and/or biota samples. Each 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 Se concentrations in clams at the same site (appendix C-2). If levels in 50% or more of the samples were the same as those in clams, (either above or below threshold limits) then clams are successful at predicting the contamination state of the site.

# 4.0 RESULTS

## 4.1 Biological Analysis

I collected 629 clams for trace metal analysis at the 18 sites. I took four composite samples from 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 are removed.

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, large clams lay on the bottom. In mainstream reaches of high flow, clams were embedded in the substrate.

Clams at the northern end of my collection area were 100% white morph *Corbicula*. Purple morph clams were generally more prevalent at the southern sites except for some backwaters with little direct connection to the mainstream of the river (Fig. 2).

## 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 ($P>0.60$). 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 is derived for mollusks from

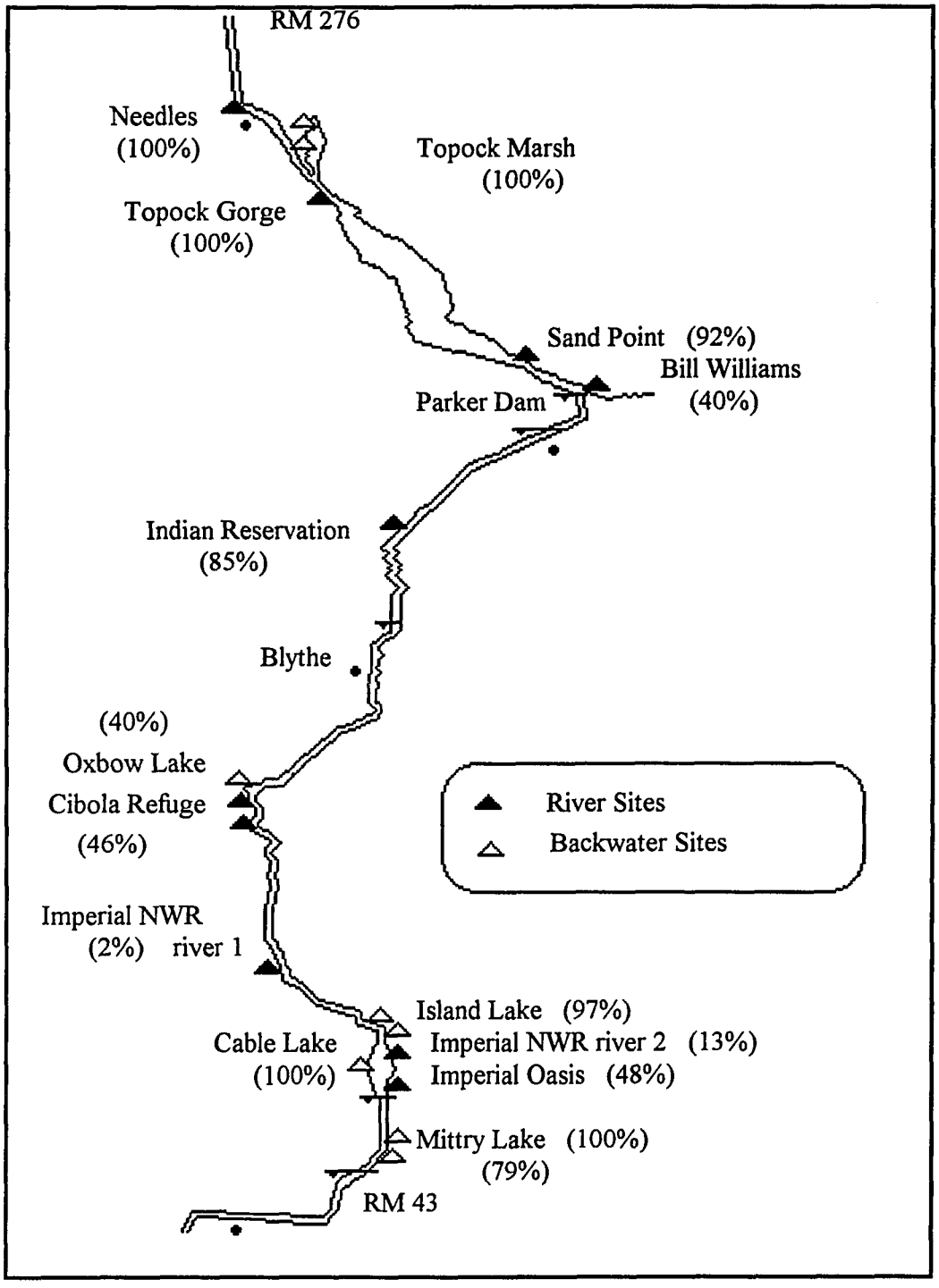


Figure 2. Percentage white morph clams per site.

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%). I used the background value from Lemly (1985) in my analysis 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 than 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 my 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 ($P>0.40$).

I used Wilcoxon Rank Sum tests for comparisons of wet weight body burdens in clams in backwaters vs. river sites. There was no significant difference in As concentrations ($P>0.40$) between site classes. There was however, significantly higher ($P<0.01$) Se concentrations in clams from backwaters than at river sites.

I compared contaminant levels in clams 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 river site and Havasu Refuge sites had higher Se body burdens ($\alpha = 0.10$) 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 ($\alpha = 0.10$) 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 ($\alpha = 0.10$) 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 ($\alpha = 0.05$) than clams from other backwaters.

### 4.3 Bioindicator Analysis

#### 4.3.1 Species Comparison

I compared Se concentrations in clams and in other biota collected at the same sites by five other investigators. I grouped biota into plants, scavengers, omnivorous fish, carnivorous fish, herbivorous birds, and carnivorous birds. Se concentrations in clams had no or weak ($r^2 < 0.60$) correlation with Se concentrations in sediment, scavengers, and omnivorous fish. The median correlation ($r^2 = 0.70$) of Se in clams with Se in carnivorous fish was not significant. I found strong correlations between Se concentration in clams and Se concentrations in plants ($r^2 = 0.98$) and carnivorous birds ($r^2 = 0.999$) (Fig. 3 and 4).

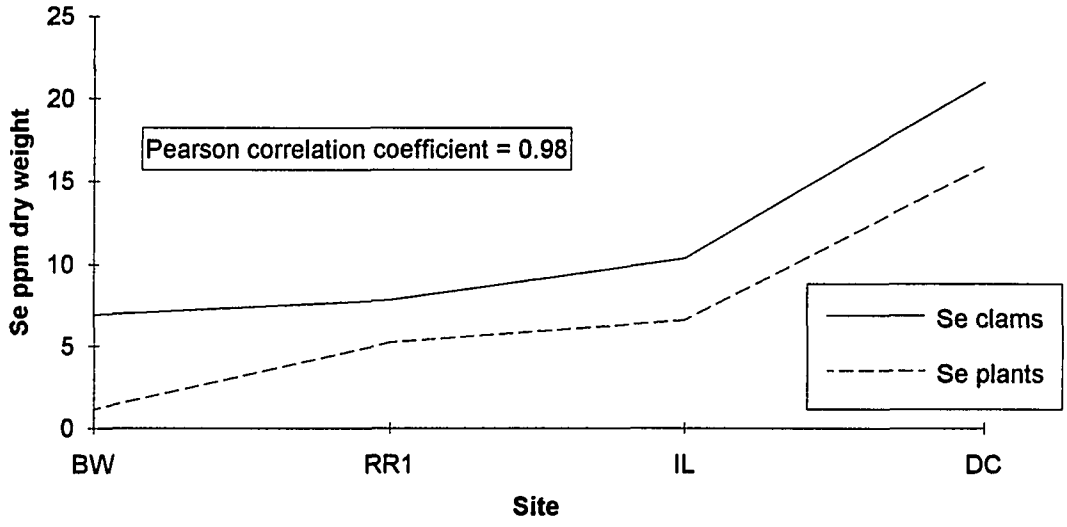


Figure 3. Correlation of Se residues in clams vs. spiny naiad collected at the same sites along the lower Colorado River by Lusk (1991) and Ruiz (pers. commun.). Sites listed in order of Se concentration from low to high, in spiny naiad. (BW = Bill Williams confluence, RR1 = River reach 1 on INWR, IL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

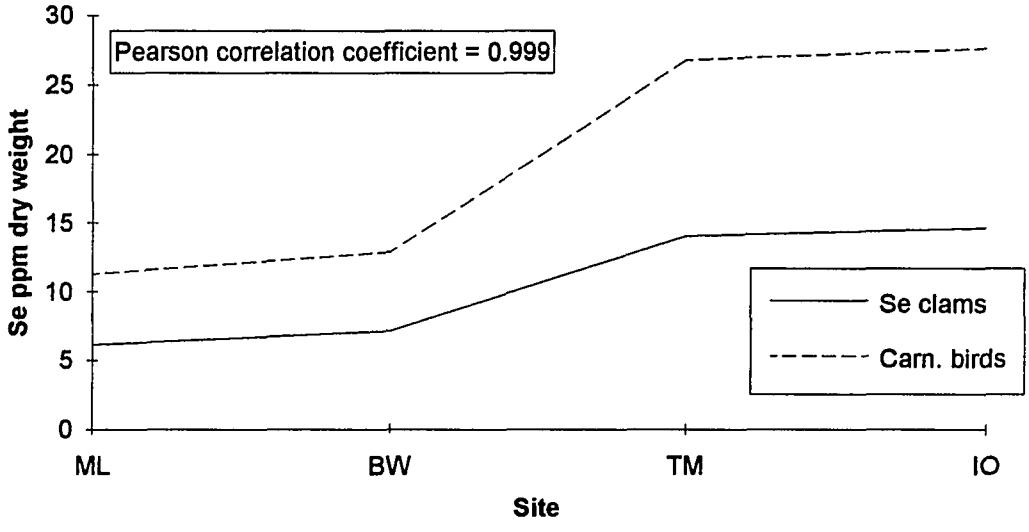


Figure 4. Correlation of Se residues in clams vs. carnivorous bird livers collected at the same sites along the lower Colorado River by Rusk (1991) and Ruiz (pers. commun.). Sites listed in order of Se concentration from low to high, in birds. (ML = Mittry Lake, BW = Bill Williams, TM = Topock Marsh,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

### 4.3.2 Site Comparison

I compared Se concentrations in clams to Se in sediment and biota reported from five studies (nine collection 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%), clam ratings agreed with ratings based on other biota. Contaminant ratings based on analysis of clams did not agree with ratings for other biota at two out of the nine sites (22%). Contaminant levels in clams from Bill Williams and the Cibola river site do not agree with levels in other biota; that is, Se body burdens for clams were high but the majority of levels in other animals/plants was low.

# 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 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 233 miles of the lower Colorado River, I found clams in three different microhabitats. McMahon (1991) has reported that the asiatic clam is a generalist and is able to adapt to a wide variety of environmental conditions. I found the greatest number and largest clams in low flow areas with highly organic substrates. Larger (adult) clams were prevalent in soft, highly organic sediments in warm lentic-like environments (~30 C). 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).

All of the clams collected at the three most northern sites were white morph *C. fluminea*. The most northern site with purple morph clams was Sand Point; located about 10 river miles north of Parker Dam. The Bill Williams site is about 9 river miles south of Sand Point and had 60% purple morphs. These clams were large adults that were of a 2-3 year-class size. Therefore, the purple morph must have gained access to the Bill Williams confluence at least 2-3 years ago and may be moving upstream. There were no purple

morph clams at a southern backwater lake located on INWR, (Cable Lake) that currently receives little direct inflow of water from the river. Also, one collection site on Mittry Lake contained no purple morphs. Overall, backwater lakes had lower proportions of purple morphs than did river sites. The highest incidence of purple morph clams was at river reach 1 located on INWR (98%). These data may indicate that the purple morph of *Corbicula* is a more recent invader of the system than the white morph.

## 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 was closely related to habitat type. Se residues in clams from backwaters were significantly higher than in clams from river sites. Availability of Se to higher trophic levels is higher in backwater lakes where productivity is high and birds nest in emergent vegetation. However, I found no relationship between size of clams and Se body burden although Zhang *et al.* (1990) had previously reported such a relationship. I also found 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). I found the highest geometric mean (20.99 ppm dry weight) for a backwater site (Cable Lake). This value far exceeds the predator protection level of 5.00 ppm dry weight for food set by Skorupa and Ohlendorf (1991).

Selenium body burden in clams was elevated above U.S. background levels (0.78 ppm wet weight) established by Lemly (1986) 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 sites are nesting sites for many birds along the

lower Colorado River. Clams were abundant at Imperial Oasis, and are probably an important part of the diet of 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 high Se loads are impacting 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 this conclusion raises questions relative to risks to birds.

### 5.2.2 Arsenic

Arsenic levels 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 high levels of As 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 I recorded. Additionally, Mittry Lake had high As levels in clam tissue. Mittry

Lake provides many nesting sites for birds and is used by the endangered Yuma Clapper Rail (*Rallus longirostris yumanensis)* (Rusk 1991).

As residues were not significantly higher in backwaters than in the main river. Agricultural products such as 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. The Colorado River virtually ends at the dam and there is deposition of nearly all the sediment load of the river. The deposition of these sediments could be the reason that Se and As residues are particularly high on INWR.

### 5.2.3 Residue Analysis Conclusions

Clams from two sites on Island Lake are in the top five geometric means for Se and As concentrations. Se residues at this site approach a level (10 ppm dry weight) that has caused a 79% decline in offspring in mallards (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 has extremely high Se and As residues in clams (1.46 and 1.66 wet weight, respectively). Imperial Reservoir and the Indian Reservation site also have high levels of both contaminants. The Indian Reservation site and Imperial Oasis are not located on INWR.

## 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 by two investigators (Lusk 1991,

Ruiz 1992). These data suggest that asiatic clams can be used as an indicator of Se contamination of some aquatic plants 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 were an average 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 shows that birds from this area could have liver residues of 39.04 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 at seven sites but were not indicative of levels in at least 50% of the samples at two sites; in both cases Se levels in clams were higher than levels in other species. At seven sites (78%), data for clams and for other species lead to the same conclusions about degree of contamination (Appendix C-2).

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.

Most biota collected at the confluence of the Bill Williams River with the Colorado River did not show elevated levels of Se. However, Se levels in clams were slightly elevated (6.90 ppm dry weight). Levels were also elevated in bluegill *(Lepomis*

*macrochirus)* and *Gambusia affinis*. Green sunfish (*Lepomis cyanellus)* can accumulate Se at faster rates than other fish such as catfish (*Ictalurus spp.)*, (Lemly 1985, White *et al.* 1989). Bluegill are omnivorous and eat both plants and aquatic invertebrates. Since clams and sunfish show high Se residues it is possible that theses species are better indicators of Se levels than other biota.

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 did not agree; levels in clams from this area were elevated (7.25 ppm dry weight). One possible reason why my results differ from those of Welsh (1992) is that he collected data in 1989-90 and I 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 my 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.

Se residues in clams from Topock Marsh (13.85 ppm dry weight) were higher than dietary levels (7 ppm dry weight) that have been proven to cause impaired reproduction in chickens ( Heinz 1987). Heinz showed that liver concentrations in mallards fed 10 ppm dry weight Se leveled off in only 8 days and that levels of 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 Yuma Clapper Rail. If the data of 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) showed 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 my 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 I 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 clam concentrations leads to the conclusion that birds at several of my study sites may have Se levels in livers that have been shown to be both toxic and teratogenic. Se levels in clams reflect the site condition at least 78% of the time. Predictability might be improved if clams and other species were collected during one time period.

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 1987, Heinz 1989).

# APPENDIX A

Trace metal analysis

Appendix A-1 Identification code for samples.

| 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 | 4th character: | |
| IR: | Indian Reservation | C: | Clam samples |
| ML: | Mittry Lake | | |
| NR: | Needles river | | |
| OL: | Palo Verde Oxbow Lake | | |
| RR: | Imperial NWR river | 5th character: | |
| SP: | Sand Point | 1 & 2: | Small clams for site |
| TM: | Topock Marsh | 3 & 4: | Large clams for site |

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

| Sample | 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 | 0.01 | <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 | 0.33 |
| 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 | 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 |

Appendix A-2. Continued.

| 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 |

Appendix A-2. Continued.

| 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 | 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 | 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 |

Appendix A-2. Continued.

| Sample | 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 |

Appendix A-2. Continued.

| 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 | <0.06 | <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 |

Appendix A-2. Continued.

| Sample | 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 |

Appendix A-2. Continued.

| Sample | 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 |

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

| Site | ppm wet wt. | 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) | | |

Appendix A-3. Continued.

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

Appendix A-4. Geometric mean (with minima and maxima) of arsenic residues per site as determined by GFAA analysis.

| Site | ppm wet wt. | ppm dry wt. | % moisture | n |
|---|---|---|---|---|
| Bill Willaims | 0.68 | 4.30 | 84 | 4 |
| | (0.24 - 1.47) | (1.57 - 7.93) | | |
| Cibola Refuge 1 | 1.11 | 10.14 | 89 | 4 |
| | (0.85 - 1.49) | (8.57 - 12.52) | | |
| Cibola Refuge 2 | 0.90 | 8.86 | 90 | 4 |
| | (0.38 - 1.68) | (3.18 - 18.26) | | |
| Cable Lake | 1.66 | 23.94 | 93 | 4 |
| | (1.16 - 2.31) | (10.36 - 40.53) | | |
| Topock Gorge | 1.12 | 10.48 | 90 | 3 |
| | (0.94 - 1.24) | (9.59 - 11.92) | | |
| Island Lake 1 | 2.54 | 18.16 | 86 | 4 |
| | (2.31 - 2.46) | (15.77 - 26.56) | | |
| Island Lake 2 | 2.76 | 17.12 | 83 | 4 |
| | (2.59 - 3.11) | (13.12 - 21.87) | | |
| Imperial Oasis | 1.38 | 9.40 | 85 | 4 |
| | (1.17 - 1.68) | (8.87 - 10.21) | | |
| Indian Reservation | 1.18 | 10.96 | 89 | 4 |
| | (1.05 - 1.51) | (9.02 - 13.36) | | |

Appendix A-4. Continued.

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

# APPENDIX B

Biological data

Appendix B-1A. 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".

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 1 | 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 | |

Appendix B-2. Temperature of water by site.

| Site | Temperature (degrees Celcius) |
|---|---|
| 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 |

Appendix B-3. Number of clams in each race by site.

| Site | # purple | # white | Total |
|---|---|---|---|
| Needles River | 0 | 55 | 55 |
| Topock Marsh #2 | 0 | 12 | 12 |
| Topock Gorge | 0 | 50 | 50 |
| Sand Point | 3 | 33 | 36 |
| Bill Williams | 15 | 10 | 25 |
| Indian Reservation | 4 | 23 | 27 |
| Cibla Refuge #1 | 33 | 22 | 55 |
| Cibola Refuge #2 | 29 | 25 | 54 |
| Imperial River #1 | 44 | 1 | 45 |
| Imperial River #2 | 74 | 11 | 85 |
| Island Lake #1 | 1 | 29 | 30 |
| Cable Lake | 0 | 27 | 27 |
| Imperial Oasis | 25 | 23 | 48 |
| Mittry #1 | 0 | 29 | 29 |
| Mittry #2 | 8 | 31 | 39 |
| **Total** | | | 617 |

# APPENDIX C

Bioindicator data

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

## River Reach 1

| Species (# 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 |
| awfuchs (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

| Species (#) | 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 |
| gambusia (3) | 8.47 | exceed | Ruiz |
| grebe liver (1) | 12.90 | below | Ruiz |

Appendix C-1 Continued.

## River Reach 2

| Species (#) | 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 |
| awfuchs (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

| Species (#) | 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 |

Appendix C-1 Continued.

## Topock Marsh

| Species (#) | Mean Se | Rating | Investigator |
|---|---|---|---|
| sediment (1) | 1.89 | exceed | Rusk |
| bass (2) | 11.50 | exceed | King |
| carp (2) | 7.95 | exceed | King |
| catfish (2) | 5.55 | exceed | King |
| crappie (2) | 17.75 | exceed | King |
| least bittern (3) | 26.77 | exceed | Rusk |
| crayfish (6) | 1.78 | below | Rusk |
| shrimp (3) | 6.76 | below | Rusk |

## Mittry Lake

| Species (#) | 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

| Species (#) | 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 |
| awfuchs (2) | 4.97 | exceed | Lusk |
| bass (3) | 13.08 | exceed | Lusk |
| bluegill (4) | 13.06 | exceed | Lusk |
| carp (2) | 6.35 | exceed | Lusk |
| gambusia (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

| Species (#) | 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

| Species (#) | 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 |
| awfuchs (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 |
| gambusia (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 |

Appendix C-2 Bioindicator site evaluation for selenium.

| Site | % samples below | % samples[a] exceed | Clams[b] | Agreement[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 |

[a] If $\geq$ 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".
[b] exceed = Se concentration in clams $\geq$ 6.35 ppm.
[c] "Agreement" = Clam and other sediment/biota samples agree on contamination state of the site.

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

| Sample | Background Threshold | Author | Date |
|---|---|---|---|
| Sediment | 1.4 ppm dry wt. | Radtke | 1988 |
| Plants | 1.34 ppm dry wt. | Radtke | 1988 |
| Fish | 5.0 ppm dry wt. | Radtke | 1988 |
| Birds (liver) | 14 ppm dry wt. | Radtke | 1988 |
| Crayfish | 7.26 ppm dry wt. | Lemly | 1986 |
| Shrimp | 11.56 ppm dry wt. | Lemly | 1986 |
| Insects | 6.40 ppm dry wt. | Lemly | 1986 |
| Mollusks | 6.35 ppm dry wt. | Lemly | 1986 |

Appendix C-4 Scientific names of animals and plants in 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* |
| Gambusia | *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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