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Contaminants Program

CONTAMINANTS IN BATS ROOSTING IN ABANDONED MINES AT IMPERIAL NATIONAL WILDLIFE REFUGE, ARIZONA, 1998 -1999

by

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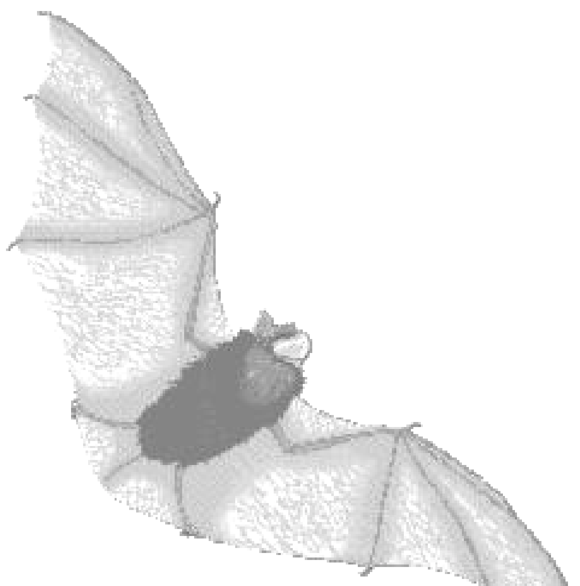

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ABSTRACT

This report documents levels and potential effects of trace element and organochlorine pesticide concentrations in four bats species collected from four abandoned mines on Imperial National Wildlife Refuge (NWR) and from three southern Arizona reference sites. With the exception of arsenic in the big brown bat *(Eptesicus fuscus)* and copper in California myotis *(M. californicus)* and Yuma myotis *(M. yumanensis)*, there appears to be little potential for heavy metal related adverse effects in bats. Lead concentrations in Yuma myotis collected from the Eureka Mine were 5- to 10-times higher than concentrations in samples from the reference site; however, it is not known what concentrations of lead are associated with sublethal effects such as impaired learning and behavior. Bats collected from an abandoned mine in the intensively cultivated lower Gila River valley, approximately 137 km east of Imperial NWR, contained significantly higher organochlorine concentrations, including residues of DDT, than those from other sites; but, maximum concentrations were below adverse effect thresholds.

The population of Yuma myotis roosting at Imperial NWR's Eureka Mine, a mine complex with multiple entrances, appeared to consist of several sub-populations based on chemical profiles of bats collected at different entrances. Samples collected from three entrances exhibited significant differences in whole body burdens of aluminum, cadmium, chromium, copper, iron, manganese, selenium, and zinc. These unique entrance-specific contaminant profiles suggested that: 1) individuals from each entrance either fed in separate Colorado River habitats, and/or 2) bats from each entrance wintered in distinct environments, and/or 3) contaminant profiles were modified at the roost site by ingestion or inhalation of dust containing different ratios of various elements.

At Sheep Tank Mine, a reference site at Kofa NWR, barium, manganese, and zinc were detected in soil at concentrations at least 10-times higher than previously reported in Arizona. Big brown bats from the same mine also contained significantly higher concentrations of these elements than big brown bats collected from three other sites. Metals acquired at the roost site may be at least as important as those bioaccumulated through the food chain. Further studies are scheduled to test the hypothesis that body burdens in bats may, in part, be a reflection of ingestion of metals through the grooming process, and/or through inhalation of metal-laden dust particles at the roost site.

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Bioaccumulation of selenium and other elements in plants, invertebrates, fish, and migratory birds in the lower Colorado River ecosystem has been well documented (Radtke et al. 1988, Schmidt and Brumbaugh 1990, Schmidt et al. 1990, King et al. 1993, Martinez 1994, Andrews et al. 1997, Tadayon et al. 1997). Selenium concentrations approach levels known to cause reproductive abnormalities in fish and birds. However, the potential adverse effects of selenium on mammals has not been addressed. This study focused on bioaccumulation of selenium in bats, particularly those species that feed over water in the lower Colorado River ecosystem.

An alarming 56% of the 43 bat species found in the United States and Canada are endangered or are under consideration for listing (Anonymous 1995). Bats now have the highest percentage of endangered and candidate species among all land mammals in the United States and Canada. More than 20% of Arizona's bat populations are declining (Noel and Johnson 1993). Nineteen of 28 species found in Arizona use mines to some extent as day, night, transitory, maternity, or hibernating roosts (Castner et al. 1995). Seventeen species of bats may occur on Imperial National Wildlife Refuge (NWR) on the lower Colorado River (Castner et al. 1995). Seventy-nine percent of the Refuge's 107 abandoned mines surveyed by Castner et al. (1995) contained evidence of bat use suggesting that abandoned mines represent important habitat. The proximity of these mines to the Colorado River makes them ideal for insectivorous bat species as the river and associated vegetation supports a high density and diversity of insects.

This report documents the extent of trace element and organochlorine compound bioaccumulation in bats collected on Imperial NWR and assesses the potential for contaminant-induced reproductive effects.

STUDY AREA

This study focused on bats roosting in four abandoned mines on Imperial NWR. The Arizona/California state line runs along the Colorado River which bisects the Refuge; about two-thirds of the Refuge is located in Arizona and one-third in California. Two study sites (Eureka Mine and Adit 78a) were located in Arizona; two others (Golden Dream and USGS) were located in California (Fig. 1). Eureka Mine is a 'mine complex' with multiple entrances and bats were collected from three entrances. For the purposes of this study, the entrances were named Eureka 1, Eureka 2, and Eureka 3. It was our intention to focus this investigation on the Yuma myotis (*Myotis yumanensis*) because they frequently feed on insects over water thereby optimizing the potential to bioaccumulate harmful levels of selenium. However, during our inspection of more than 20 abandoned mines, Yuma myotis were observed only at the Eureka Mine. Therefore, we expanded our study to include other species and other sites. Castner et al. (1995) reported Yuma myotis roosting in an adit (a short horizontal exploratory tunnel) that they designated as Adit 78a. We did not encounter Yuma myotis roosting in this adit; however, we collected a small sample of California myotis

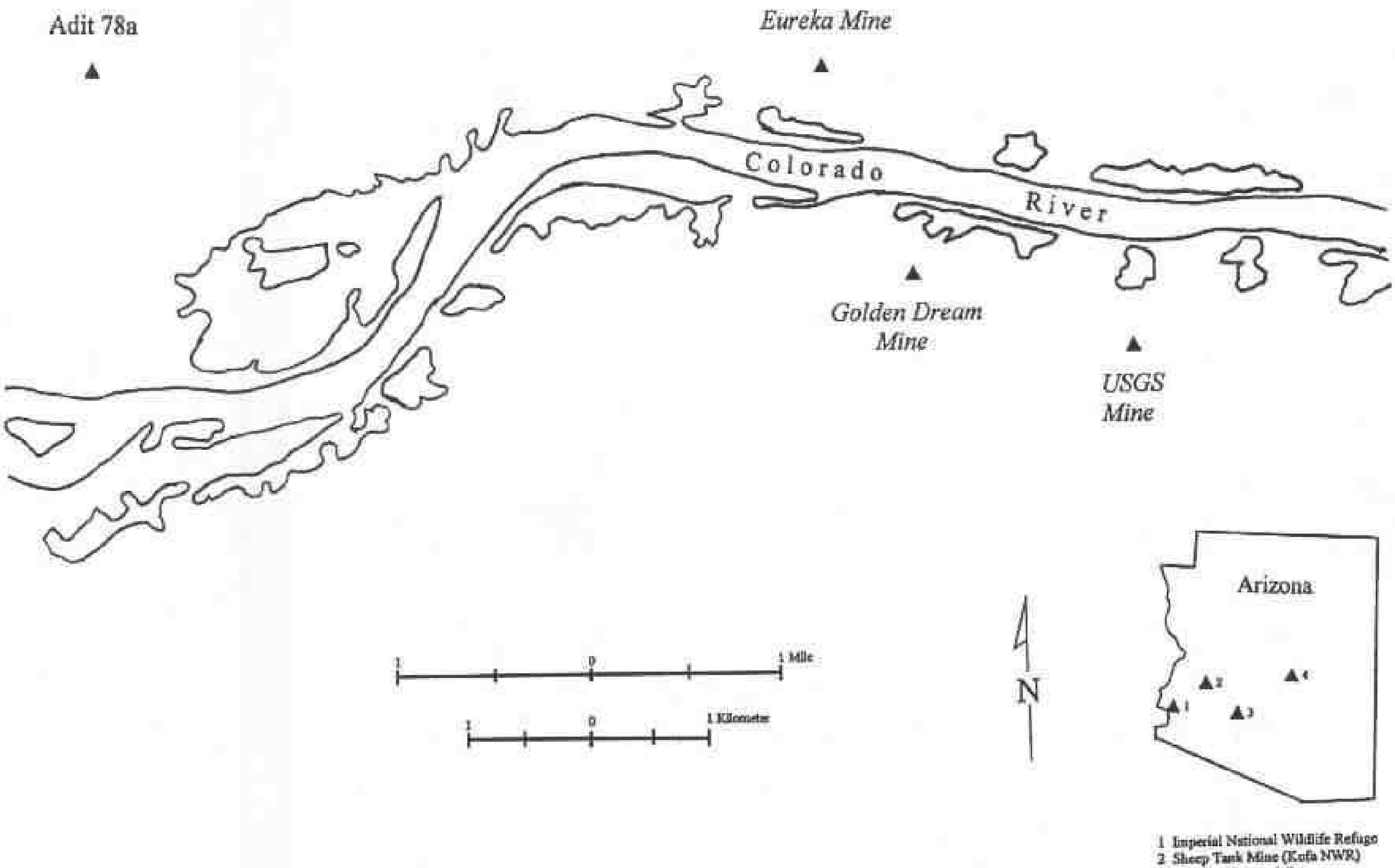

Figure 1. Location of abandoned mine study sites, Imperial National Wildlife Refuge, 1998 - 1999

(M. californicus) from this location. Bats were also collected from the Golden Dream Mine and an unnamed mine, in Imperial County, California. We informally designated the unnamed mine as the USGS Mine because of its proximity to an abandoned USGS gauging station. Sheep Tank Mine on Kofa NWR served as one reference site (Figure 1). Sheep Tank Mine is located approximately 80 km (50 mi) NE of the Imperial NWR study sites. A bat roost located in an abandoned transformer building near the base of Roosevelt Dam (Roosevelt Lake) served as a second reference site. The Roosevelt Lake reference site is approximately 322 km (200 mi) east north east of Imperial NWR. A third reference area, Buckeye Copper Mine, was located in the Gila Bend Mountains approximately 137 km (85 mi) east of the Colorado River. It is unlikely that bats roosting at any of these reference areas were feeding in Colorado River riparian habitats.

METHODS

<u>Sample collections:</u> Field collections were completed from July 16 to August 25, 1998 and on August 10, 1999. We collected bats from mid- to late summer, just before the fall migration, so our sample would contain only bats that had been roosting in the area for several months. Bats were collected primarily during exit flights using a mist net placed across the mine entrance. We also collected bats directly by hand from the walls and ceilings of some mines. Usually, collections were made at only one entrance per night. Bats were euthanized by cervical dislocation and placed in entrance-specific labeled plastic bags. No attempt was made to separate individual bats in the field. The bags were then stored on wet ice.

<u>Sample preparation:</u> Upon return to the lab, usually within four hours of collection, the species of the bats was confirmed and individual samples were weighed, measured, and sexed. Individuals were not aged. Bats collected in 1998 were submitted as unwashed whole body samples including gastrointestinal tract. All females were collected post-lactation. The average weight of some species, Yuma myotis and California myotis *(M. californicus)* was $\leq$5.0 grams; therefore, to obtain sufficient mass for chemical analysis, two individuals were often combined into a single composite sample. Collection techniques were similar for bats collected in 1999; however, methods of preparation for analysis varied slightly from those used in 1998. Because the chemical profile of some bats collected in 1998 closely matched the profile of dirt/dust collected from the mine floor, we felt it was possible that bats were ingesting mine dust through the grooming process. In 1999, we analyzed the skin/fur, feet and wings (outer tissues) separately from the carcass remainder in an attempt to determine if bats were picking up a significant portion of their contaminant load through the grooming process. Gastrointestinal tracts were dissected out and discarded. Whole body burdens were later calculated by adding micrograms of an element detected in the outer tissues to micrograms of the element detected in the carcass and dividing the sum by the total weight of the composite sample, following the general technique described by Simpson et al. (1998) for fish. Therefore, with the exception of the removal of the GI tract,

whole body concentrations in bats collected from Eureka 3 in 1999 could be directly compared with those collected from the same site in 1998. Samples collected in 1998 were analyzed for both metals and organochlorine compounds; bats collected in 1999 were analyzed only for metals. We also collected one sample of soil from Kofa NWR's Sheep Tank Mine at the Refuge Manager's request. Soil was collected from five cave floor locations and mixed together into a single homogenous sample and stored in a plastic bag.

Chemical analyses: Bats were analyzed for aluminum, arsenic, beryllium, boron, cadmium, chromium, copper, iron, lead, mercury, molybdenum, nickel, selenium, strontium, vanadium, and zinc at the Service's Patuxent Analytical Control Facility (PACF), Laurel, Maryland. Arsenic and selenium concentrations were determined by graphite furnace atomic absorption spectrophotometry (USEPA 1984). Mercury was quantified by cold vapor atomic absorption (USEPA 1984). All other elements were analyzed by inductively coupled plasma atomic emission spectroscopy (Dahlquist and Knoll 1978, USEPA 1987). Blanks, duplicates, and spiked samples were used to maintain laboratory quality assurance and quality control (QA/QC). QA/QC was monitored by PACF. Analytical methodology and reports met or exceeded PACF QA/QC standards. Metal concentrations are expressed in µg/g (ppm) dry weight. The lower limits of analytical quantification varied by element and by sample and are listed in Appendix 1 and 2. Percent moisture is also presented to permit wet weight to dry weight conversions (Appendix 1 and 2). Dry weight values can be converted to wet weight equivalents by subtracting the percent moisture (as a decimal) from 1.0 and multiplying the resulting number by the dry weight value as illustrated in the following equation:

$$\text{wet weight} = 1 - \%\ \text{moisture} \times \text{dry weight}$$

Bats were also analyzed for organochlorine insecticides and total polychlorinated biphenyls (PCBs). The organochlorine scan included o,p'- and p,p'-DDE, o,p'- and p,p'-DDD, o,p'- and p,p'-DDT, dieldrin, heptachlor epoxide, hexachlorobenzene (HCB), alpha, beta, delta, and gamma BHC, alpha and gamma chlordane, oxychlordane, *trans*-nonachlor, *cis*-nonachlor, endrin, toxaphene, mirex, and PCBs. Samples were analyzed at PACF. Methods of organochlorine compound analyses for were identical to those described by King et al. 1997. The lower limit of quantification was 0.01 µg/g (parts per million) for most organochlorine pesticides and 0.05 µg/g for toxaphene and PCBs. Organochlorine compounds are expressed in µg/g wet weight.

Statistical analysis: When a metal or organochlorine compound was detected in ≥ 50 % of the samples, the geometric mean was calculated. For those samples for which no residues were detected, a value of one-half the lower limit of detection was substituted for the not detected value to facilitate the calculation of means. For metals, geometric means were first compared using a 3-way ANOVA (species, location, year). When significant differences were noted for each variable, the data were then analyzed using a 2-way or 1-way ANOVA. Residue data were normalized by log-transformation before mean comparisons. The

Bonferroni multiple comparison method (Neter and Wasserman 1974) was used to test for mean separation when ANOVA showed significant differences. We evaluated differences in metal levels among the different collection sites by comparing geometric means for Yuma myotis (collected from four locations) and the big brown bat *(Eptesicus fuscus)*, also collected from four locations. Statistical analysis of organochlorine compounds was complicated by a relatively small sample size, a large number of species collected (4) at a large number of locations (7). The data were combined regardless of species or collection location and analyzed by a one-way ANOVA.

RESULTS

Four bat species were collected from abandoned mines on Imperial NWR (Table 1): the Yuma myotis, the big brown bat, the California leaf-nosed bat *(Macrotus californicus)*, and the California myotis. A comparative sample of two of those four species was taken from selected reference sites (Table 1). We also collected a small sample of pallid bats (*Antrozous pallidus)* from the abandoned Buckeye Copper Mine to assess organochlorine compound bioaccumulation in an area of known high residues in other wildlife (King et al. 1997). Also, a small sample of the Southwestern cave myotis *(Myotis velifer)* was collected from the Roosevelt Lake reference site and analyzed for organochlorine compounds and metals. Yuma myotis were trapped only at Eureka Mine and at the Roosevelt Lake reference site. Big brown bats were collected at two Refuge sites, the Golden Dream Mine and the USGS Mine and at two reference locations (Table 1). California leaf-nosed bats were netted at Imperial's USGS Mine and from Kofa's Sheep Tank Mine. In 1999, we collected a follow-up sample of Yuma myotis (n = 17) from Eureka 3 for a comparison of metal concentrations with Yuma myotis collected from this site in 1998.

Metals-

<u>Yuma myotis (1998)</u>: Aluminum was present in all Yuma myotis samples and geometric mean concentrations ranged from 40 to 426 μg/g (Table 2). Geometric mean concentrations were significantly higher in bats from Eureka 1 and Eureka 2 than in samples from Eureka 3 and Roosevelt Lake. Arsenic was not detected in Yuma myotis. Barium was recovered in all samples and geometric mean concentrations ranged from 2.65 to 3.73 μg/g and were similar among sites (Table 2). Boron was present in >50% of the Yuma myotis samples from Eureka 1 and Eureka 3 and geometric mean concentrations were similar between sites. Cadmium concentrations were highest in Yuma myotis from Eureka 2 (0.19 μg/g); geometric mean levels at all other sites (0.09 - 0.15) were similar ($P > 0.05$). Geometric mean chromium and iron concentrations mirrored those of cadmium; highest levels occurred in Yuma myotis from Eureka 2. Although not statistically significant, copper concentrations also were highest in samples from Eureka 2 (8.49 μg/g). Lead was detected in all but one sample. Geometric mean lead was significantly higher in bats collected from all three Eureka mine entrances (16.9 - 32.6 μg/g) than in samples taken at Roosevelt Lake (3.15 μg/g). Magnesium was recovered in all samples and individual residues ranged from 972 to 1634 μg/g dry weight. Geometric mean magnesium concentrations were similar

among areas. Geometric mean manganese concentrations ranged from 4.86 to 18.5 µg/g and levels in Yuma myotis from Eureka 2 (16.8 µg/g) and Roosevelt Lake (18.5 µg/g) were significantly higher than those from Eureka 1 (4.86) and Eureka 3 (6.94 µg/g). Mercury was detected in only 1 of 5 samples from Eureka 1 and was not present in samples from Eureka 2. However, 5 of 7 samples from Eureka 3 and all 6 from Roosevelt Lake contained mercury. Geometric mean mercury concentrations were significantly higher in Yuma myotis from Roosevelt Lake (0.67) than in bats from Eureka 3 (0.12 µg/g). The frequency of occurrence of nickel varied greatly in bats collected from different Eureka Mine entrances. Only 1 of 5 and 2 of 7 Yuma myotis collected from Eureka 1 and Eureka 3 contained nickel, but nickel was present in 6 of 6 samples from Eureka 2. The geometric mean in Eureka 2 samples was about 3-times higher than that from Roosevelt Lake. Selenium was detected in all Yuma myotis samples and geometric means ranged from 3.02 to 4.75. Selenium concentrations were significantly higher in bats from Eureka 1 (4.75 µg/g) than those from Eureka 3 (3.02 µg/g). Bats from Roosevelt Lake (3.16 µg/g) contained significantly ($P<0.05$) lower selenium concentrations than those from Eureka 1 (4.75 µg/g), but Roosevelt Lake geometric means were similar to Eureka 2 and Eureka 3. Strontium was present in all samples and geometric means were similar among Eureka mine entrances ($P>0.05$). Strontium in bats from different Eureka mine entrances (31.3 - 39.9 µg/g) was about two-times higher ($P<0.05$) than in bats from Roosevelt Lake (16.1 µg/g). Geometric mean zinc concentrations ranged from 72.2 to 101.0 µg/g. Bats from Eureka 2 (101.0 µg/g) contained significantly higher zinc concentrations than those from Eureka 1 (72.2 µg/g). Geometric means of bats from Eureka 3 and Roosevelt Lake were intermediate.

Yuma myotis were collected from Eureka 3 in both 1998 and 1999. Geometric means for seven metals were similar between years ($P> 0.05$, Table 3). The frequency of occurrence of mercury, nickel, and vanadium in Yuma myotis samples was ≤ 50% in one or both years, negating a statistical comparison of means between years. Boron, barium, cadmium, and strontium geometric means were greater in 1998 than 1999 ($P < 0.05$). Geometric mean copper and selenium concentrations were higher in bats collected in 1999 than in those collected in 1998.

<u>Yuma myotis (1999)</u>: We compared the relative distribution of metals in outer tissues (skin/fur, wings, feet) with concentrations in carcass remainders (Table 4). Generally higher concentrations of arsenic, nickel, boron, and aluminum occurred in the outer tissues. Concentrations of copper, iron, and magnesium were highest in the carcass remainder.

<u>Big brown bat</u>: Aluminum was detected in all samples (Table 5). Highest geometric mean concentrations occurred in samples from Imperial's Golden Dream and USGS mines (208.7 and 93.8 µg/g) and in Kofa's Sheep Tank Mine (72.7 µg/g). Arsenic was present only in samples from Golden Dream, Sheep Tank, and Roosevelt Lake and geometric mean concentrations were highest in samples from Golden Dream (4.87) and Sheep Tank (2.24 µg/g). Only bats from Buckeye Copper Mine and Sheep Tank Mine contained boron in >50% of the samples. Barium was detected in all samples and geometric mean

concentrations ranged from 2.98 to 36.8 µg/g. Samples from Sheep Tank Mine (36.8 µg/g) contained significantly higher concentrations of barium than those from other mines (2.98 - 7.12 µg/g). Geometric mean boron concentrations were significantly higher in bats from Buckeye (19.3) than those from Sheep Tank (2.47). Cadmium was present in 39% (11/28) of the bat samples. The frequency of occurrence of cadmium was > 50% only in samples from Sheep Tank Mine. Iron and magnesium were detected in all big brown bats and concentrations of both elements were similar among sites. Lead was detected in 89% of big brown bat samples. Lead concentrations from Golden Dream (10.2 µg/g) samples was significantly higher than that in the nearby USGS Mine (0.60 µg/g). All other sites had intermediate concentrations. Mercury was present in 61% (17/28) of the samples. Geometric mean mercury concentrations were similar among sites. The frequency of occurrence of nickel in big brown bats was greatest in samples from Sheep Tank Mine (6/6) and Roosevelt Lake (3/5) and geometric mean concentrations were similar between sites. Nickel was present in < 50% of the samples from other sites. Selenium was detected in all but three big brown bats. Mean concentrations ranged from 0.27 - 2.54 µg/g. Selenium concentrations in bats from USGS Mine (2.54), the Golden Dream Mine (2.01), and Roosevelt Lake (1.66 µg/g) were statistically similar and higher than selenium concentrations in big brown bats from Buckeye Copper Mine (0.77) and Sheep Tank Mine (0.27 µg/g). Strontium was recovered in all samples. Geometric mean concentrations were significantly higher in Golden Dream (41.4) and USGS (40.3 µg/g) samples than those at Sheep Tank Mine (9.81) and Roosevelt Lake (16.5 µg/g). Geometric mean strontium concentrations in big brown bats from Buckeye Copper Mine were intermediate (22.6 µg/g). Zinc was also present in all samples. Geometric mean zinc concentrations in bats from Sheep Tank Mine (63.0 µg/g) were significantly higher than those in bats from all other areas (geometric mean 40.3 - 48.5).

California leaf-nosed bat, California myotis and the southwestern cave myotis: California leaf-nosed bats were collected only at the Imperial's USGS Mine and at Kofa's Sheep Tank Mine. A small subset of leaf-nosed bats (n=4) collected at Sheep Tank Mine was analyzed for organochlorine compounds. California myotis were collected only at Imperial NWR's Adit 78a. We were unable to locate a comparable reference site containing California myotis. Geometric mean metal concentrations for both species are presented in Table 6 and individual concentrations are listed in Appendix 1. Southwestern cave myotis (cave myotis) were collected only at the Roosevelt Lake reference site. We were unable to locate a comparable population of cave myotis on either Imperial or Kofa National Wildlife Refuges. Concentrations of metals and organochlorine compounds in cave myotis are listed in Appendix 1 and 3. Overall levels in cave myotis were extremely low and will not be further discussed.

Soil: Soil was collected only at Kofa's Sheep Tank Mine. Extremely high concentrations of arsenic, barium, manganese, lead, and zinc were recovered in mine soil (Table 7). Zinc (3,122 µg/g) was present at 20-times the 150 µg/g ambient Arizona maximum. Manganese was recovered at 18-times, and arsenic at more than 14-times the Arizona maximum. Barium and mercury were recovered at about 10-times the Arizona maximum (Table 7).

Organochlorine compounds-
DDE was recovered in 19 of 22 Imperial NWR bat samples. Frequency of occurrence of DDE in reference site samples was highly variable; only 1 of 4 samples from Kofa NWR contained DDE, but DDE was present in all samples from Buckeye Copper Mine and Roosevelt Lake. Geometric mean DDE residues were similar among collection sites. DDT, the parent compound, was detected in all 5 samples from Buckeye Copper Mine and in 3 of 5 samples from Eureka 3. DDT was present in fewer than one-half the individuals from other collection sites. DDT residues were significantly higher in bats from the Buckeye Copper Mine than in bats from Eureka 3.

DISCUSSION

Population trends-
Although more than 20% of Arizona's bat populations are declining (Noel and Johnson 1993), little is known about population trends of bats roosting on Imperial NWR. Annual exit counts have been conducted only at Eureka Mine where Yuma myotis and California leaf-nosed bats have been documented in past years. Exit counts conducted from 1994 to 2000 (except 1998) of total bats have been highly variable (292 - 9,811) depending on the month the counts were taken. Given the resources available, it was also impossible to break down the exit counts by species. Exit counts taken during July of 1995 (5263), 1997 (3642), 1999 (2480), and 2000 (4035) indicated that the Eureka Mine bat population (all species) was highly variable from year to year. Additional standardized data are needed to establish long-term trends.

Most bat species in northern and mid-latitudes of the U.S. hibernate and do not remain active during winter months (Tuttle 1991). Seasonal ‘migrations’ of many western species represent elevational rather than latitudinal movements (Tuttle 1991). The hibernation patterns of three of five species studied has been documented (Noel and Johnson 1993). Little is known about the winter habits of the Yuma myotis and pallid bat. California myotis remains ‘fairly active’ throughout the winter. In contrast, California leaf-nosed bats do not hibernate nor do they migrate (Noel and Johnson 1993) which makes them excellent biomonitors of the local environment. The big brown bat is the only species we studied that truly hibernates. For hibernating species, contaminant body burdens are acquired almost exclusively during warmer months when the bats are actively feeding near summer roost sites. Little feeding occurs during winter months. Of the five species studied, the California leaf-nosed bat and the big brown bat are more likely to accurately reflect local contamination levels.

Metals-
Few studies are available in the scientific literature that report on the effects of metals on bats. Eisler (1985a, 1985b, 1987, 1988a, 1988b, 1997) published a series of synoptic reviews on the levels and effects of metals including arsenic, cadmium, copper, lead, mercury, and selenium in wildlife, but bats were not included in any of these reports. In reviews of mercury and lead in terrestrial mammals, Wren (1986), Ma (1996), and Thompson (1996), made no mention of concentrations of these elements in bats. We located only two studies that addressed metals in whole body bats; Clark (1979) reported lead concentrations in big brown and little brown bats *(Myotis lucifugus)* and Martin (1992) summarized concentrations of eight elements detected in whole body grey bats *(Myotis grisescens)* found dead in Oklahoma caves.

Metal bioaccumulation in mammals varies greatly with the dietary classification of the species (i.e., herbivores vs. insectivores). When comparing results of this study with those of others, we limited comparisons of our data to bioaccumulation of metals in bats or other insectivorous mammal species such as shrews (Sorex spp.). This study documented the concentrations of 18 elements, however, only a small portion of those elements have the potential to be toxic under ambient environmental conditions. The elements most likely to bioaccumulate to toxic levels include arsenic, cadmium, lead, mercury, and selenium (Eisler 1985a, 1985b, 1987, 1988a, 1988b, Ohlendorf et al. 1988, Hoffman et al. 1990).

Arsenic: Arsenic acts as a cumulative poison (Jenkins 1981) and is listed by the USEPA as one of 129 priority pollutants (Keith and Telliard 1979). Arsenic may be absorbed by ingestion, inhalation, or through permeation of the skin or mucous membranes (Gearheart and Waller 1994). Most arsenic is excreted in the urine during the first few days after exposure (Gearheart and Waller 1994); therefore, the presence of above background levels of arsenic in bats suggests continuous daily exposure. Background arsenic concentrations in biota are usually less than 1 μg/g wet weight (Eisler 1988a) or about 4.5 μg/g dry weight. Arsenic was present in a relatively small proportion (17/62) of the samples. Arsenic was detected only in samples collected from Imperial's Golden Dream Mine (geometric mean = 4.87 μg/g dry weight), Kofa's Sheep Tank Mine (2.24 μg/g), and the Roosevelt Lake reference site (0.69 μg/g). The occurrence of arsenic was an "all-or-nothing" phenomenon; either it was recovered in all samples from a mine, or it was not present in any of the samples. For example, arsenic was detected in all big brown bats collected from Golden Dream Mine, but it was not detected in big brown bats from the nearby (0.95 km) USGS Mine. This suggests that these two populations are feeding in unique habitats with different levels of environmental arsenic, or there is local contamination within the mines that is being incorporated into their tissues. Only 3 of 62 bat samples contained arsenic at concentrations that exceeded the 4.5 μg/g dry weight background level reported by Eisler (1988a). With the exception of arsenic in big brown bats roosting at Golden Dream Mine (2.56 - 36.3 μg/g dry weight), there appears to be little potential for arsenic related problems in bats at the southern Arizona sites we sampled.

Cadmium: Cadmium has no known biological function (Eisler 1985a). Its toxicity may originate through exposure via respiration or ingestion (Cooke and Johnson 1996). Absorption from the diet is low; usually less than 5% of the ingested cadmium is absorbed. In a recent review of data from 13 studies conducted between 1974 and 1987, the average whole body cadmium concentration in shrews (an insectivorous mammal) from uncontaminated sites ranged from 1.2 to 4.0 µg/g dry weight (Talmage and Walton 1991). In our study, the maximum individual concentration in bats from all sites was 0.47 µg/g, well within the background range. Cadmium does not appear to be bioaccumulating to potentially hazardous levels in bats from Imperial NWR or other southern Arizona areas.

Copper: While usually not considered one of the metals most likely to bioaccumulate to toxic levels in terrestrial mammals, we include a short discussion of copper because copper was mined in the area and copper was found at exceptionally high concentrations in California myotis collected from Adit 78a. Copper bioaccumulates but does not biomagnify, and uptake and accumulation appear to be more species dependent than most other metals (Gearheart and Waller 1994). Copper is an essential dietary element for plants and animals, and while copper can be toxic to freshwater and marine biota (USEPA 1980), birds and mammals are relatively resistant to copper poisoning. Copper can combine with other elements such as mercury and zinc to produce additive toxic effects in some species (Hilmy et al. 1987, Eisler 1997). Carcasses of shrews (*Sorex* spp.) collected within 3 km (1.9 mi) of a lead-zinc smelter, an area also contaminated with copper, contained 21.2 -21.7 µg/g dry weight copper (Read and Martin 1993). Individuals collected 23 km (14 mi) distant from the smelter contained considerably lower levels ranging from 11.9 - 13.1 µg/g. Geometric mean concentrations of copper in bats collected in 1998 from Eureka, USGS, and Golden Dream mines (5.38 - 11.0 µg/g dry weight) were within the normal or background range. In contrast, Yuma myotis collected from Eureka Mine in 1999 had considerably elevated concentrations of copper, 4-times higher than levels reported in 1998. A partial explanation for the striking differences between years in copper concentrations may be related to the sex of the samples collected; the 1998 sample consisted almost exclusively of females, and the 1999 sample consisted entirely of males. Concentrations of copper in Yuma myotis collected from Eureka Mine in 1999 (geometric mean = 26.2 , range = 13.63 - 47.87 µg/g) were comparable to copper concentrations detected in shrews collected from highly copper contaminated areas (21.2 - 21.7 µg/g).

California myotis collected from Adit 78a contained exceptionally high copper levels, up to 80 µg/g dry weight. The geometric mean for all samples from this site was 53.0 µg/g dry weight. Concentrations of copper in California myotis from Adit 78a were about 2.5-times higher than those reported by Read and Martin (1993) in shrews collected from a highly copper-contaminated area located near a zinc smelter. While copper concentrations in Yuma myotis from Eureka Mine (1999), and California myotis from Adit 78a, was well above the background levels, additional study is needed to assess the source of contamination and the effects of whole body copper concentrations of this magnitude in relation to the health of these populations.

Lead: Lead is neither essential nor beneficial to living organisms; all existing data show that its metabolic effects are negative (Eisler 1988b). Only two other studies were located that assessed lead levels in whole body bats (Clark 1979, Martin 1992). Lead concentrations in bats from all southern Arizona locations (1.67 - 32.6 µg/g dry weight) were considerably lower than whole body concentrations in big brown (31.49 - 46.56 µg/g wet weight (~143 - 212 µg/g dry weight) and little brown bats *(Myotis lucifugus)* (16.9 7µg/g wet weight (~77.3 µg/g dry weight) collected from lead-contaminated areas in Maryland (Clark 1979). Geometric mean lead in whole body tissues of bats from Imperial NWR ranged from 16.9 to 32.6 µg/g dry weight in Yuma myotis and 0.60 to 10.2 µg/g in big brown bats. Lead concentrations in Yuma myotis collected from the Eureka Mine were 5- to 10-times higher ($P < 0.05$) than concentrations in Yuma myotis from the Roosevelt Lake reference site. It is not known for certain what concentrations of lead in whole body carcasses can be associated with sublethal effects, or what effects such concentrations would have on the learning and behavior of young bats.

Lead was significantly higher in big brown bats from Golden Dream Mine (geometric mean = 10.2 µg/g dry weight) than big brown bats from the nearby (0.95 km) USGS Mine (0.60 µg/g). This suggests that either big brown bats are feeding in unique habitats or there is local contamination within the mines that is being accumulated by the bats.

Mercury: Mercury concentrations are of special concern because mercury can bioconcentrate in organisms and biomagnify through the food chain (Eisler 1987). Mercury has no known biological function and its presence in cells of living organisms is undesirable and potentially hazardous. Less than one-half of the bats sampled (all species) from Imperial NWR contained detectible concentrations of mercury. The maximum concentration in an individual sample was 0.48 µg/g dry weight. The background concentration of mercury in biota from uncontaminated sites is <1.0 µg/g wet weight, or about ≤4.5 µg/g dry weight (Eisler 1987); therefore, there is little potential for adverse affects of mercury alone on adult bats. Mercury, however, when ingested in combination with other compounds and elements such as parathion, cadmium, and copper can have additive or synergistic toxic effects (Eisler 1987, Hoffman et al. 1990, Calabrese and Baldwin 1993).

Selenium: Selenium is an essential trace element in animal diets, but it is toxic at concentrations only slightly above required dietary levels. Mammals are much less susceptible to selenium toxicosis than birds (Eisler 1985b). No published studies documenting selenium concentrations in whole body bats were located. Selenium in whole body ornate shrews *(Sorex ornatus)* collected from a selenium contaminated area of Merced County, California, averaged 47.9 µg/g dry weight (Clark 1987). Geometric mean selenium concentrations in bats collected from Imperial NWR ranged from 2.01 to 4.75 µg/g dry weight, and were far lower than concentrations in shrews collected from highly contaminated areas. Selenium does not appear to be a contaminant of concern for Yuma myotis or other bat species feeding in lower Colorado River aquatic habitats.

Some results of this study were unexpected, puzzling, and difficult to explain. We expected that Yuma myotis collected from three entrances to Eureka Mine would contain similar contaminant burdens. However, this was not the case. Individuals collected from different entrances had statistically significant differences in whole body burdens of aluminum, cadmium, chromium, copper, iron, manganese, selenium, and zinc (Table 5). These unique within-species entrance-specific contaminant profiles suggest that, 1) individuals from each entrance are feeding in separate Colorado River habitats, and/or 2) bats from each entrance/exit are wintering in distinct environments, and/or 3) contaminant profiles are modified at the roost site by ingestion or inhalation of dust containing different ratios of various elements.

It seems unlikely that Yuma myotis collected from three Eureka Mine entrances are foraging in uniquely separate habitats, but our data suggest that this could be the case. While some elements are cumulative and body burdens are acquired throughout a lifetime, others, such as selenium, are bioaccumulated and excreted within a period of days or months. In experimental studies with birds, selenium reached about 95% of maximum levels within 12-14 days of birds being placed on diets high in selenium (Heinz et al. 1990). Selenium is depurated from body tissues at about the same rate. One would expect that if bats were feeding in common areas of the Refuge, that body burdens of selenium would be similar. However, geometric mean concentrations of selenium were significantly higher in Yuma myotis collected from Eureka 1 than in Yuma myotis from Eureka 3 (Table 2). Overall concentrations were generally low and there was overlap in selenium levels among the three Eureka sites. The differences could be an artifact of a relatively small sample size.

Kofa NWR: Although Kofa NWR was selected as a reference site, concentrations of several elements were higher there than at Imperial NWR. Some elements detected at elevated levels in whole body tissues were also present at high levels in roost site soil. This led to the hypothesis that body burdens may, at least in part, be a reflection of ingestion or inhalation of contaminants in dust at the roost site. Barium, manganese, and zinc were detected in soil from Sheep Tank Mine at levels at least 10-times higher than the previously reported Arizona ambient *maximum* (Table 7). Similarly, big brown bats from Sheep Tank Mine contained significantly higher concentrations of barium, manganese, and zinc than big brown bats from three other collection sites (Table 5).

Barium was present at 15,291 µg/g in soil from Sheep Tank Mine (Table 7) which was more than 10-times higher than the ambient Arizona maximum (Boerngen and Shacklette 1981, Earth Technology 1991). Barium was also recovered in tissues of big brown bats from Sheep Tank Mine at concentrations (geometric mean = 36.8 µg/g dry weight) significantly higher than those in big brown bats collected from three other sites (geometric means ranged from 2.98 to 7.12 µg/g) (Table 5). The soluble salts of barium can be toxic to mammals (USEPA 1999). Inhalation as well as ingestion are important routes of exposure. Approximately 91% of the total body burden of barium is found in the bone (USEPA 1999), yet in our study, bat carcasses which included the majority of body bone tissues, contained just 55%, of the total body burden of barium. This is strong circumstantial evidence that the outer tissues consisting of skin/fur, wings, and feet may have been contaminated with barium-laden particles. We were unable to locate relevant literature to determine if barium concentrations in whole body bats approached toxic levels.

Manganese was also present at exceptionally high levels in Sheep Tank Mine soil and bat tissues (Table 7). A composite soil sample from the mine floor had more than 180,000 μg/g manganese, 18-times the previously recorded Arizona maximum of 10,000 μg/g (Boerngen and Shacklette 1981, Earth Technology 1991). Big brown bats from Sheep Tank Mine contained significantly higher manganese (geometric mean =134 μg/g dry weight) than big brown bats collected from all other sites (geometric means ranged from 3.29 to 8.44 μg/g) (Table 5). Inhalation as well as ingestion are important routes of exposure. Excess manganese is usually excreted from the body within a few days (ATSDR 1990); therefore, the relatively high concentrations of manganese in bat tissues reflect recent local exposure. No data were located on toxic thresholds for manganese in bats or other insectivorous mammals.

Zinc in Sheep Tank Mine soil (3,122 μg/g dry weight) was 21-times higher than the Arizona maximum (150 μg/g) (Table 7). Zinc was also present in Sheep Tank Mine big brown bats tissues (geometric mean = 63.0 μg/g) at significantly higher levels than in big brown bats from all other collection sites (geometric means = 40.3 - 48.5 μg/g) (Table 5). Inhalation as well as ingestion are important routes of exposure (Opresko 1992). In mammals, zinc is present in all tissues, with highest concentrations in the kidney, liver, heart, and pancreas (Opresko 1992). Because most zinc is located in major body organs, one would expect the carcass to display markedly higher zinc concentrations than the outer tissues. However, there was a nearly even ratio (47:53) in zinc distribution in carcass vs. outer tissues. We suspect that the disproportionately high concentrations in outer tissues may have resulted from zinc-contaminated particles adhering to the fur.

The potential correlation of metals in soil to metals in bat tissues, however, is not simple or straightforward. Arsenic and lead were also present in Sheep Tank Mine soil at levels (1,468 and 843 μg/g dry weight), which were about 14- and 8-times higher than the Arizona maximum of 97 and 100 μg/g, respectively (Table 7). However, arsenic and lead did not bioaccumulate in big brown bats tissues to significantly higher concentrations than those in big brown bats collected from other areas (Table 5). We have no explanation for this apparent exception.

We expected that metal concentrations in Yuma myotis collected from Eureka 3 in 1998 would be similar to concentrations in bats collected from the same area in 1999 but, there were a number of year-to-year differences (Table 3). Geometric mean concentrations of barium, cadmium, and strontium were lower in samples collected in 1999 than in those collected in 1998. Conversely, chromium, copper, and selenium were higher in samples collected in 1999. The greatest between year difference occurred in copper concentrations; geometric mean copper levels in samples collected in 1999 (26.2 μg/g) were almost 4-times greater ($P<0.05$) than in samples collected in 1998 (6.49 µg/g). One possible explanation for these year-to-year differences relates to the sex of the samples collected; in 1998, six composite samples (2 bats per sample) contained only females and the seventh sample contained one female and one male. In contrast, all bats collected from Eureka 3 in 1999 were males.

Organochlorine compounds-

Organochlorine compound contamination in bats collected from southwestern Arizona was generally low (Table 8). DDE concentrations reported in our study were considerably lower than those (median = 92 ppm, range 50 - 300 µg/g) in young Mexican free-tailed bats (*Tadarida brasiliensis)* collected from Carlsbad Caverns in 1974 (Geluso et al. 1976). Geluso et al. (1976) concluded that whole body DDE residues, ranging from 50 - 300 µg/g wet weight in young bats, represented a serious threat during migration. In this study, the most contaminated individuals were pallid bats from the Buckeye Copper Mine. The mine is located about 11 km (7 mi) from the highly agriculturalized Gila River valley, an area of known high organochlorine contamination (Johnson and Lew 1970, Cain 1981, Bunck et al. 1987, King et al. 1997). Pallid bats contained residues of six organochlorine insecticides. DDE ranged up to 9.02 µg/g wet weight in individual samples. All pallid bat samples contained residues of p,p'-DDT, indicating recent exposure to that compound. Mean DDT residues in carcasses of four bat species collected within two months after a DDT forest spray program ranged from 1.50 - 5.42 µg/g wet weight (Henny et al. 1982). The geometric mean DDE residue in pallid bats (2.85 µg/g wet weight) collected in this study fell within the range of residues reported in bat carcasses collected shortly after the DDT spray program.

The brain is the preferred diagnostic tissue for assessing potentially lethal levels of DDE. When residues reach certain concentrations in carcass lipids, they begin to appear in the brain, and from that point on, brain and carcass lipid concentrations are significantly correlated (Clark 1981). Minimum lethal carcass DDE concentrations have been estimated at 66,000 µg/g on a lipid weight basis for Mexican free-tailed bats, and 79,000 µg/g for little brown bats (Clark and Shore 2001). The maximum DDE residues in a pallid bat carcass was 99.13 µg/g expressed on a lipid weight basis. Although DDE residues in pallid bats were elevated relative to DDE concentrations in other Arizona species, carcass concentrations were far below the lethal range.

The organochlorine profile of California leaf-nosed bats collected at Imperial's USGS Mine appeared to be different than that of leaf-nosed bats collected at Kofa's Sheep Tank Mine (Table 8). Four of five USGS samples contained DDE compared to only 1 of 4 Sheep Tank Mine samples with DDE. Also, dieldrin was recovered in 4 of 5 leaf-nosed bats from the USGS Mine, but none of California leaf-nosed bats collected at Sheep Tank Mine contained detectible dieldrin residues. California leaf-nosed bats do not migrate (Noel and Johnson 1993); therefore, their contaminant profiles represent organochlorine and metal concentrations accumulated in the immediate area.

Are contaminant levels in bats high enough to be of concern to higher trophic level predators such as falcons, hawks, and owls that regularly consume bats as prey items? In the lower Colorado River area, large-scale raptor predation on bats near roost sites is relatively rare, but there may be individual exceptions (Pat Brown pers. comm. UCLA Dept. Physiological Sci., and Brown-Berry Biological Consultants, Bishop, CA). The low frequency of occurrence and generally low levels of arsenic and cadmium minimize concern for accumulation of these elements to higher predators. Copper concentrations in all bat samples, except Yuma myotis (1999) and California myotis, were low. Levels of lead below 100 μg/g wet weight (<400 μg/g dry weight) in the diet usually cause few significant reproductive effects in birds (Scheuhammer 1987). The maximum concentration of lead in bats collected in this study was 54 μg/g dry weight; therefore, lead is not a contaminant of concern with respect to bioaccumulation to higher trophic level species. In an extensive review of the chronic toxicity of mercury in birds, Scheuhammer (1987) reported that the lowest level of mercury in food items to adversely affect birds was 0.3-0.4 μg/g wet weight (appx. 1.4 - 1.8 μg/g dry weight). None of the bat samples exceeded this dietary threshold of concern for mercury. Ironically, several field and laboratory studies indicated that even background selenium levels in food items, concentrations as low as 3-8 μg/g dry weight, could cause adverse reproductive effects in sensitive aquatic bird species (Heinz et al. 1987, Lemly and Smith 1987, Hoffman et al. 1991, Skorupa and Ohlendorf 1991). Forty percent (25/62) of the samples collected in 1998 exceeded the 3 μg/g dry weight threshold, none exceeded 8μg/g. This dietary threshold was developed using aquatic bird species; it is unknown whether these thresholds are applicable to terrestrial birds of prey.

Many raptorial and fish-eating bird species are susceptible to DDE-induced eggshell-thinning and reproductive failure (Hickey and Anderson 1968, Ohlendorf et al. 1979, Blus 1996). In laboratory studies, as little as ≤3.0 μg/g wet weight DDE in the diet has resulted in a significant degree of eggshell thinning in a variety of birds (Wiemeyer and Porter 1970, McLane and Hall 1972, Mendenhall et al. 1983). Under field conditions, however, much lower levels of DDE in the diet have been associated with eggshell thinning and population declines, including ≤0.39 μg/g in bald eagles (*Haliaeetus leucocephalus*) (Wiemeyer et al. 1978), and 0.2 - 1.9 μg/g in osprey (*Pandion haliaetus*) (Wiemeyer et al. 1975). DDE residues in all five pallid bat samples exceeded concentrations known to cause reproductive failure in DDE-sensitive species of birds.

RECOMMENDATIONS

Bats may be accumulating contaminants at the roost site by ingesting metal-contaminated particles during grooming or by inhalation of contaminated dust. Further research is scheduled for 2001. If this hypothesis proves correct, those mines that are most contaminated, those that present the greatest potential threat to bats, can be modified or closed.

Imperial NWR: The distribution of arsenic in bats collected from Imperial NWR showed distinct roost-site specific patterns. Arsenic was not detected in any samples from six mines, but where it was detected (n = 3 mines), it was recovered in all individuals. This suggests that arsenic may be a mine-specific contaminant problem. The site-specific nature of arsenic contamination offers management opportunities to minimize exposure to bats in these areas. Additional research is needed to determine if areas of high arsenic occur throughout the mine or if there are localized "hot spots" within the mine. Depending on results, the entire mine, or just localized areas, could then be closed off from further use by bats.

California myotis collected from Adit 78a contained exceptionally high copper levels. While concentrations represented a high level of contamination, effects on the health of this population remains unknown. We were unable to locate another colony of California myotis for comparison with those in Adit 78a; therefore, we cannot determine if the relatively high copper concentrations are related to minerals in the adit, or are a species phenomenon. Additional work is needed to determine whether or not these high levels of copper are associated with excessive copper concentrations within Adit 78a.

Lead in Yuma myotis from all three Eureka Mine entrances (geometric means 16.9 - 32.6 µg/g dry weight) was considerably higher than concentrations in all other bat samples (geometric mean 0.60 - 10.2). Concentrations of lead in bat tissues do not directly correlate with high levels in soil as evidenced by samples of tissues and soil collected at Sheep Tank Mine. It is possible that lead is present in Eureka Mine soil at levels higher than those in Sheep Tank Mine soil. Additional work is needed to assess the source of lead in Yuma myotis from Eureka Mine.

Kofa NWR: Barium, manganese, and zinc were recovered at elevated levels in both soil and bat tissues from Sheep Tank Mine. Our investigations established a circumstantial link between soil and tissue concentrations. Further study is needed to assess the potential link between elevated soil and tissue levels.

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Table 1. Bat samples collected at Imperial National Wildlife Refuge and at reference sites in southern Arizona, 1998

Study sites	Latitude - longitude	Common name	Scientific name	No. of analyses	
				Metals	OCS
Eureka 1	N 33º02'20" W 108º33'53"	Yuma myotis	*Myotis yumanensis*	5	3
Eureka 2	N 33º02'20" W 108º33'52"	Yuma myotis	*Myotis yumanensis*	6	4
Eureka 3	N 33º02'21" W 108º33'52"	Yuma myotis	*Myotis yumanensis*	7	5
USGS	N 33º10'45" W 108º33'03"	Big brown bat	*Eptesicus fuscus*	8	5
USGS	N 33º01'46" W 108º33'03	California leaf-nosed bat	*Macrotus californicus*	6	5
Golden Dream	N 33º01'51" W 108º33'37"	Big brown bat	*Eptesicus fuscus*	6	0
Adit 78a	N 33º02'12" W 108º35'41"	California myotis	*Myotis californicus*	4	0
Reference sites					
Sheep Tank Mine	N 33º22'25" W 113º45'23"	Big brown bat	*Eptesicus fuscus*	6	0
Sheep Tank Mine	N 33º22'25" W 113º45'23"	California leaf-nosed bat	*Macrotus californicus*	0	4
Roosevelt Lake	N 33º40'11" W 111º09'48"	Southwestern cave myotis	*Myotis velifer*	5	3
Roosevelt Lake	N 33º40'11" W 111º09'48"	Yuma myotis	*Myotis yumanensis*	6	4
Buckeye Copper Mine	N 33º13'43" W 112º52'21"	Big brown bat	*Eptesicus fuscus*	3	0
Buckeye Copper Mine	N 33º13'43" W 112º52'21"	Pallid bat	*Antrozous pallidus*	0	5

Table 2. Comparison of metals in whole body *Myotis yumanensis* bats (µg/g dry weight) collected from three entrances to Eureka Mine complex, Imperial National Wildlife Refuge, and from a reference site at Roosevelt Lake, Arizona 1998

		Geometric mean concentration (number of samples with detectible concentrations) / range[1]						
Entrance	N	aluminum	barium	boron	cadmium	chromium	copper	iron
Eureka 1	5	426 (5) A[2] 251 - 748	2.65 (5) A 2.09 - 4.10	14.5 (5) A 8.14 - 27.3	0.12 (4) A ND - 0.18	0.74 (5) A 0.47 - 0.99	8.32 (5) A 8.05 - 8.68	345 (5) A 291 - 383
Eureka 2	6	341 (6) A 222 - 519	2.96 (6) A 2.13 - 4.37	---- (2) ND - 5.37	0.19 (4) B ND - 0.30	2.07 (6) B 0.89 - 2.40	8.49 (6) A 7.62 - 9.45	600 (6) B 439 - 828
Eureka 3	7	40 (7) B 25.9 - 66.3	3.39 (7) A 2.34 - 4.70	17.3 (4) A ND - 22.4	0.15 (7) A 0.07 - 0.21	0.68 (7) A 0.45 - 0.86	6.49 (7) B 5.34 - 8.97	350 (7) A 268 - 403
Roosevelt	6	49 (6) B 29.3 - 76.6	3.73 (6) A 2.49 - 5.14	---- (2) ND - 5.38	0.09 (3) A ND - 0.44	0.90 (6) A 0.79 - 1.08	7.73 (6) AB 6.59 - 8.13	339 (6) A 301 - 398

		Geometric mean concentration (number of samples with detectible concentrations) / range							
Entrance	N	lead	magnesium	manganese	mercury	nickel	selenium	strontium	zinc
Eureka 1	5	16.9 (5) A 11.4 - 42.7	1385 (5) A 1263 - 1474	4.86 (5) A 3.56 - 6.36	---- (1) ND - 0.16	---- (1) ND - 0.34	4.75 (5) A 4.01 - 6.04	31.3 (5) A 26.3 - 36.9	72.2 (5) A 63.7 - 88.5
Eureka 2	6	32.6 (6) A 18.3 - 46.7	1482 (6) A 1340 - 1664	16.8 (6) B 10.4 - 26.8	---- (0) ND	0.76 (6) A 0.36 - 1.06	4.25 (6) AB 3.43 - 5.37	34.5 (6) A 30.3 - 43.1	101. (6) B 82.1 - 140.
Eureka 3	7	19.6 (7) A 11.3 - 37.6	1289 (7) A 972 - 1634	6.94 (7) A 4.12 - 11.2	0.12 (5) A ND - 0.18	---- (2) ND - 0.63	3.02 (7) B 2.04 - 4.12	39.9 (7) A 26.7 - 54.1	88.5 (7) AB 63.3 - 103
Roosevelt	6	3.15 (5) B ND - 6.55	1428 (6) A 1274 - 1510	18.5 (6) B 14.0 - 25.4	0.67 (6) B 0.34 - 0.96	0.25 (3) B ND - 0.52	3.16 (6) B 2.10 - 4.10	16.1 (6) B 15.2 - 18.7	72.9 (6) A 60.2 - 94.6

[1]Arsenic and molybdenum were not detected in any samples. Vanadium was recovered in only one sample at 0.55 µg/g dry weight.
[2]Means in a column sharing a common letter are not significantly different (P > 0.05).

Table 3. Between year comparisons of metal concentrations in whole body *Myotis yumanensis* bats (µg/g dry weight) collected from Eureka Mine (Entrance 3), Imperial National Wildlife Refuge, Yuma County, Arizona 1998-1999[a]

		Geometric mean concentration (number of samples with detectible concentrations) / range[b]							
Year	N	aluminum	boron	barium	cadmium	chromium	copper	iron	lead
1998	7	39.9 (7) A[c] 25.9 - 66.3	12.13 (7) A ND - 22.4	3.39 (7) A 2.34 - 4.70	0.15 (7) A 0.07 - 0.21	0.68 (7) A 0.45 - 0.86	6.49 (7) A 5.34 - 8.97	350 (7) A 268 - 403	19.6 (7) A 11.3 - 37.6
1999	17	51.7 (17) A 28.4 - 122.2	9.43 (11) A 3.86 - 27.97	1.92 (17) B 1.01 - 2.88	0.07 (15) B 0.02 - 0.24	1.34 (17) B 0.89 - 1.73	26.20 (17) B 13.63 - 47.86	418 (17) A 340 - 779	19.8 (17) A 12.3 - 42.3

		Geometric mean concentration (number of samples with detectible concentrations) / range							
Year	N	magnesium	manganese	mercury	nickel	selenium	strontium	vanadium	zinc
1998	7	1289 (7) A 972 - 1634	6.94 (7) A 4.12 - 11.2	0.12 (5) ND - 0.18	---- (2) ND - 0.63	3.02 (7) A 2.04 - 4.12	39.9 (7) A 26.7 - 54.1	----- (1) ND - 5.49	88.5 (7) A 63.3 - 103
1999	17	1015 (17) A 1066-1564	5.54 (17) A 3.70 - 8.84	---- (0) ND	0.60 (17) 0.34 - 1.52	4.51 (17) B 2.70 - 6.17	23.4 (17) B 13.8 - 39.1	----- (1) ND - 0.39	96.9 (17) A 75.4 - 153

[a]Note: the seven composite samples collected in 1998 included 13 females and one male; whereas, the 1999 sample included only males. Also, 1998 data were of whole body bats including GI tract, and 1999 data did not include the GI tract and are 'reconstructed' (skinned whole body + outer tissues).

[b]Arsenic and molybdenum were not detected in 1998 samples LLOD = 0.01 µg/g. Arsenic was present only in 'outer tissues' of 1999 samples. Reconstructed whole body residues = 0.02 µg/g.

[c]Means sharing the same letter are statistically similar ($P > 0.05$).

Table 4. Relative distribution of metals in carcass tissues vs. outer tissues of *Myotis yumanensis* collected at Imperial National Wildlife Refuge, Yuma County, Arizona 1999

	Outer tissues[1]		Carcass tissues[2]		Reconstructed Whole body		Relative percent of an element in	
Metal	µg	total g	µg	total g	total µg	total g	outer tissue	carcass
Al	3696.[3]	30.14[4]	1453.	69.45	5149	99.59	72	28
As	2.17	"	ND[5]	"	2.17	"	100	0
B	708.9	"	428.6	"	1137.5	"	62	38
Ba	86.87	"	104.34	"	191.21	"	45	55
Cd	2.57	"	4.40	"	6.97	"	37	63
Cr	76.46	"	56.99	"	133.45	"	57	43
Cu	251.	"	2358.	"	2609.	"	10	90
Fe	12328.	"	29301	"	41629.	"	30	70
Pb	1239	"	733.	"	1972.	"	63	37
Mg	44780	"	56304	"	101084	"	44	66
Mn	331.71	"	220.02	"	551.73	"	60	40
Hg	ND	"	ND	"	ND	"	ND	ND
Ni	27.57	"	32.13	"	59.7	"	86	14
Se	166.96	"	282.19	"	449.15	"	37	63
Sr	862.9	"	1467	"	2330	"	37	63
V	ND	"	ND	"	ND	"	ND	ND
Zn	5088.	"	4562	"	9650.	"	53	47

[1]Outer tissues = skin/fur, feet, and wings.
[2]Carcass = whole body minus skin/fur, feet, wings and GI tract.
[3]Total micrograms of an element in 17 samples.
[4]Total weight of 17 samples.
[5]ND = Not detected.

Table 5. Comparison of metals in whole body big brown bats (µg/g dry weight) collected from abandoned mines on Imperial and Kofa National Wildlife Refuges, and from the Buckeye Copper Mine reference site, Arizona 1998

		Geometric mean concentration (number of samples with detectible concentrations) / range[1]							
Mine	N	aluminum	arsenic	barium	boron	cadmium	chromium	copper	iron
USGS	8	93.8 (8) A[2] 39.1 - 199	---- (0)	2.98 (8) A 2.09 - 6.13	---- (3) ND - 6.29	---- (3) ND - 0.18	0.91 (8) A 0.64 - 1.41	6.71 (8) AB 4.47 - 14.2	337 (8) A 207 - 553
Golden Dream	6	208.7 (6) A 68.9 - 722	4.87 (6) A 2.56 - 36.6	4.31 (6) A 2.25 - 16.3	---- (1) ND - 6.25	---- (1) ND - 0.12	0.70 (4) A ND - 3.36	11.0 (6) A 6.17 - 45.2	389 (6) A 196 - 1777
Sheep Tank	6	72.7 (6) AB 41.1 - 109	2.24 (6) AB 1.32 - 8.48	36.8 (6) B 16.5 - 238	2.47 (4) A ND - 9.53	0.15 (5) ND - 0.28	1.65 (6) A 0.70 - 2.26	4.55 (6) B 4.10 - 5.29	375 (6) A 237 - 818
Buckeye	3	17.5 (3) B 10.4 - 36.8	---- (0)	4.98 (3) A 2.38 - 9.07	19.3 (3) B 16.1 - 27.5	---- (0)	---- (0)	8.76 (3) AB 5.08 - 13.7	224 (3) A 132 - 304

		Geometric mean concentration (number of samples with detectible concentrations) / range							
Mine	N	lead	magnesium	manganese	mercury	nickel	selenium	strontium	zinc
USGS	8	0.60 (5) A ND - 1.36	1142 (8) A 1030 - 1229	3.29 (8) A 1.67 - 6.46	0.22 (6) A ND - 0.48	---- (2) ND - 0.92	2.54 (8) A 1.76 - 4.85	40.3 (8) A 28.4 - 53.1	48.5 (8) A 37.9 - 57.2
Golden Dream	6	10.2 (6) B 4.09 - 54.8	1317 (6) A 1039 - 1684	4.93 (6) A 2.63 - 28.1	0.32 (3) A ND - 0.44	---- (1) ND - 3.12	2.01 (6) AB 1.79 - 2.83	41.4 (6) A 24.2 - 58.8	46.7 (6) A 38.1 - 56.6
Sheep Tank	6	2.79 (6) AB 1.04 - 9.11	969 (6) A 707 - 1099	134. (6) B 67.2 - 544	0.16 (4) A ND - 0.49	1.19 (6) A 0.50 - 1.36	0.27 (4) C ND - 0.66	9.81 (6) C 7.03 - 14.6	63.0 (6) B 45.0 - 98.7
Buckeye	3	5.10 (3) AB 2.04 - 11.0	1089 (3) A 699 - 1569	3.29 (3) A 1.84 - 8.04	0.26 (3) A 0.16 - 0.48	---- (0)	0.77 (2) BC ND - 1.88	22.6 (3) AB 16.4 - 42..0	40.3 (3) A 25.4 - 63.6

[1]Molybdenum was not detected in any samples. Vanadium was recovered in 5 samples (0.33 - 2.49 µg/g dry weight).
[2]Means sharing a common letter are not significantly different (P> 0.05).

Table 6. Geometric mean concentrations of metals (µg/g dry weight) in *Myotis californicus* and *Macrotus californicus* collected from two different abandoned mines on Imperial National Wildlife Refuge, Arizona 1998

			Geometric mean concentration (number of samples with detectible concentrations) / range[1]							
Species	N	Coll. Site	aluminum	barium	boron	cadmium	chromium	copper	iron	lead
Myotis calif.	4	Adit 78a	774 (4) A[2] 462 - 1099	7.24 (4) A 5.45 - 13.1	8.32 (3) A ND[3] - 45.2	----- (0)	1.22 (4) A 0.63 - 2.83	53.0 (4) A 28.8 - 80.8	569 (4) A 415 - 1135	1.67 (4) A 0.93 - 4.70
Macrotus calif.	6	USGS Mine	188 (6) B 122 - 388	1.25 (6) B 0.68 - 1.92	7.09 (5) A ND - 25.5	---- (4) ND - 0.47	0.74 (6) A 0.54 - 1.26	5.38 (6) B 4.44 - 8.50	292 (6) B 219 - 373	2.09 (3) A ND - 19.5

			Geometric mean concentration (number of samples with detectible concentrations) / range							
Species	N	Coll. Site	magnesium	manganese	mercury	nickel	selenium	strontium	vanadium	zinc
Myotis calif.	4	Adit 78a	1634 (4) A 1405 - 2239	17.3 (4) A 11.8 - 44.1	0.31 (4) A 0.25 - 0.42	---- (1) ND - 1.56	3.97 (4) A 3.18 - 4.77	34.5 (4) A 23.0 - 54.6	0.49 (3) ND - 1.50	51.7 (4) A 45.6 - 70.8
Macrotus calif.	6	USGS Mine	1162 (6) B 940 - 1342	2.07 (6) B 1.40 - 2.73	0.22 (6) B 0.18 - 0.28	---- (1) ND - 0.38	1.77 (6) B 1.51 - 2.60	17.1 (6) B 14.8 - 18.7	---- (1) ND - 0.39	58.1 (6) A 48.4 - 64.1

[1]Arsenic and molybdenum were not detected in any samples, LLOD = 0.01 µg/g.
[2]Means sharing the same letter are statistically similar.
[3]ND = not detected.

Table 7. Comparison of metals in soil of Kofa National Wildlife Refuge's Sheep Tank Mine with Arizona background levels. Relative relationship of metals in Sheep Tank Mine soil with body burdens in *Eptesicus fuscus*

	Soil			Wildlife
	Arizona background level[1]		Kofa NWR Sheep Tank Mine Soil	Kofa NWR *Eptesicus fuscus*
Metal	Mean	Maximum		
Al	55,213	100,000	1,421	41.1 - 109
As[2]	9.8	**97**	**1,468**	1.32 - 8.48
B	NA[3]	NA	24.0	ND-9.53
Ba[3]	565	**1,500**	**15,291**	**16.5 - 238**
Be	0.52	5	3.03	ND
Cd	NA	NA	6.75	ND - 0.28
Cr	61.3	300	42.6	1.33 - 2.11
Cu	30	200	53.6	4.10 - 5.29
Fe	NA	NA	71,857	237 - 818
Hg[2]	0.10	**0.57**	**5.63**	ND - 0.49
Mg	NA	NA	596	707 - 1099
Mn[2]	NA	**10,000[2]**	**180,505**	**67.2 - 544**
Mo	3.0	9.0	21	ND - 1.46
Ni	27.5	150	3.53	0.50 - 1.36
Pb[2]	23.4	**100**	**843**	1.04 - 9.11
Se	0.3	1.6	<0.09	ND - 0.66
Sr	NA	NA	613	7.03 - 14.6
V	71.3	300	277	ND - 1.56
Zn[2]	62	**150**	**3,122**	**45.0 - 98.7**

[1]Arizona background data from Boerngen and Shacklette (1981) and Earth Technology (1991).

[2]Elements in bold and/or red type are of special concern because concentrations in soil exceed Arizona background *maximum* and/or concentrations in Kofa NWR *Eptesicus fuscus* bats are significantly higher than those in *Eptesicus fuscus* from all other collection sites (Table 5).

[3]NA = not available. Arizona data not available.

Table 8. Geometric mean organochlorine insecticide residues in whole body bats collected in southern Arizona, 1998

			Geometric mean residue, µg/g wet weight (number of samples with detectible residues) / range[1]					
Collect. location	Species	N	p,p'-DDE	p,p'-DDT	Hept Epox.	Total chlordane	Dieldrin	Total BHC
Buckeye	Pallid bat	5	2.86 (5) A 1.45 - 9.02	0.13 (5) A 0.05 - 0.40	0.07 (3) ND[2] - 0.14	0.04 (4) ND - 0.20	0.04 (5) A 0.01 - 0.09	0.02 (3) ND - 0.10
Eureka 3	Yuma myotis	5	0.61 (5) A 0.27 - 1.85	0.01 (3) B ND - 0.02	---- (0)	---- (0)	---- (0)	---- (0)
Eureka 1	Yuma myotis	3	0.28 (2) A ND - 2.64	---- (0)	---- (0)	---- (0)	---- (0)	---- (0)
Eureka 2	Yuma myotis	4	0.23 (4) A 0.01 - 4.25	---- (1) ND - 0.01	---- (0)	---- (0)	---- (0)	---- (0)
Kofa	Calif. leaf-nosed bat	4	---- (1) ND - 1.72	---- (0)	---- (0)	---- (0)	---- (0)	---- (0)
Roosevelt	Southwestern cave myotis	3	0.07 (3) A 0.01 - 0.30	---- (0)	---- (0)	---- (0)	---- (0)	---- (0)
Roosevelt	Yuma myotis	4	0.45 (4) A 0.35 - 0.72	---- (1) ND - 0.01	---- (0)	---- (0)	---- (0)	---- (0)
USGS	Calif. leaf-nosed bat	5	0.21 (4) A ND - 2.96	---- (0)	---- (0)	---- (0)	0.01 (4) B ND - 0.02	---- (0)
USGS	Big brown bat	5	0.24 (4) A ND - 2.31	---- (0)	---- (0)	---- (1) ND - 0.01	---- (0)	---- (0)

[1]Means sharing the same letter are statistically similar ($P > 0.05$).

[2]ND = None detected.

Appendix 1. Metals in whole body bats collected from mines on Imperial and Kofa National Wildlife Refuges and at reference sites in southwestern Arizona, 1998

Area	Collect. location	Species[1]	Sex[2]	Contaminant concentration, µg/g dry weight																	Moist (%)
				Al	As	B	Ba	Cd	Cr	Cu	Fe	Hg	Mg	Mn	Ni	Pb	Se	Sr	V	Zn	
Imperial	Eureka 1	MYYU	NA	251	<.49	24.2	2.20	0.18	0.47	8.37	291	<.13	1263	5.18	<.325	11.4	4.40	28.7	<.32	63.7	63.5
		MYYU	NA	528	<.50	27.3	2.77	0.08	0.99	8.46	369	<.13	1455	5.03	<.333	15.1	6.04	32.3	<.33	69.4	65.7
		MYYU	NA	298	<.50	11.8	2.51	0.12	0.68	8.68	383	<.13	1474	6.36	.336	14.7	5.11	26.3	<.33	88.5	66.3
		MYYU	NA	473	<.50	10.1	4.10	<.07	0.79	8.05	320	0.16	1338	3.56	<.333	12.6	4.01	36.9	<.33	73.2	66.7
		MYYU	NA	748	<.46	8.14	2.09	0.14	0.90	8.10	370	<.12	1407	4.60	<.305	42.7	4.44	33.3	<.30	68.7	66.9
Imperial	Eureka 2	MYYU	FF	519	<.50	5.37	4.37	0.17	2.40	9.45	828	<.13	1664	26.8	1.03	46.7	5.37	43.1	0.55	102.	65.4
		MYYU	MM	418	<.50	2.71	3.15	0.20	1.30	7.62	512	<.13	1558	13.0	.963	36.6	4.56	37.1	<.33	102.	66.0
		MYYU	FF	271	<.50	<1.33	3.59	0.14	1.76	7.96	627	<.13	1449	21.1	.809	31.2	3.43	35.3	<.33	140.	66.4
		MYYU	MM	472	<.48	<1.28	3.44	0.30	1.48	8.91	761	<.13	1366	24.8	1.06	39.3	3.90	31.3	<.32	98.1	64.5
		MYYU	FF	254	<.50	<1.33	2.56	<.07	1.09	9.13	439	<.13	1340	10.4	.359	18.3	4.84	30.3	<.33	82.1	68.7
		MYYU	FF	222	<.49	<1.30	2.13	<.06	0.89	8.04	527	<.13	1540	11.7	.628	31.4	3.71	31.6	<.32	89.3	63.3
Imperial	Eureka 3	MYYU	FF	47.4	<.49	<1.30	4.70	0.12	0.57	6.70	381	0.18	1342	11.2	<.325	20.9	3.95	38.5	<.32	102.	61.9
		MYYU	FF	32.9	<.48	<1.32	3.20	0.21	0.56	6.96	393	0.14	1239	6.02	<.329	37.6	3.33	32.9	<.33	75.4	67.5
		MYYU	FF	38.1	<.49	<1.30	2.57	0.13	0.45	5.34	308	0.14	972	5.32	<.325	13.4	2.09	26.7	<.32	87.4	51.8
		MYYU	FF	25.9	<.46	19.9	3.58	0.14	0.81	8.97	403	0.14	1634	10.6	<.309	20.5	2.96	54.1	<.31	86.4.	68.4
		MYYU	FF	34.0	<.49	22.4	4.07	0.07	0.84	6.25	340	<.13	1384	6.82	.627	27.5	3.33	49.8	<.32	103.	60.3
		MYYU	FF	46.8	<.46	17.1	2.34	0.20	0.77	5.52	268	<.12	1118	7.27	.433	16.4	2.04	42.8	<.31	112.	52.3
		MYYU	MF	66.3	<.49	11.8	3.87	0.13	0.86	6.29	377	0.14	1445	4.12	<.325	11.3	4.12	41.2	<.32	63.3	60.5
Reference	Roosevelt	MYYU	FF	37.8	<.47	5.38	5.14	0.33	0.98	6.59	330	0.34	1324	22.7	<.316	1.91	4.10	18.7	<.32	66.3	60.7
		MYYU	FF	29.3	<.48	5.18	3.64	0.15	0.86	7.98	355	0.96	1496	15.6	<.321	6.55	3.36	15.2	<.32	70.8	63.7
		MYYU	FF	76.6	<.50	<1.33	3.59	<.07	0.91	8.13	398	0.75	1274	14.8	0.39	3.18	3.08	15.2	<.33	70.7	65.8
		MYYU	MM	51.6	<.50	<1.33	5.15	0.44	1.08	7.54	329	0.68	1492	25.4	<.333	2.54	3.97	16.0	<.33	79.4	64.1
		MYYU	FF	52.4	<.50	<1.33	2.49	<.07	0.79	7.75	329	0.73	1495	14.0	.524	<.33	2.81	14.3	<.33	60.2	63.6
		MYYU	FF	57.3	<.46	<1.22	3.11	<.06	0.79	6.75	301	0.77	1510	21.3	.305	3.10	2.10	17.4	<.30	94.6	63.2

Appendix 1 (Cont.). Metals in whole body bats collected from mines on Imperial and Kofa National Wildlife Refuges and at reference sites in southwestern Arizona, 1998

Area	Collection location	Species[1]	Sex	Contaminant concentration, µg/g dry weight																	Moist (%)
				Al	As	B	Ba	Cd	Cr	Cu	Fe	Hg	Mg	Mn	Ni	Pb	Se	Sr	V	Zn	
Imperial	Golden Dream	EPFU	F	722	36.6	6.25	16.3	<.07	3.36	45.2	1777	0.32	1684	28.1	3.12	54.8	2.07	56.8	2.49	49.5	62.5
“	“ ”	EPFU	F	93.3	2.82	<1.30	2.25	<.06	0.53	6.17	332	<.13	1059	3.43	<.325	4.28	1.79	24.2	<.32	43.9	59.2
“	“ ”	EPFU	M	191	2.85	<1.22	2.25	<.06	0.33	8.60	259	<.12	1039	2.72	<.305	8.71	2.83	32.1	<.30	38.1	61.8
“	“ ”	EPFU	F	635	2.56	<1.27	4.60	<.06	0.41	8.04	303	0.44	1449	4.64	<.316	4.09	1.92	48.1	0.41	48.3	60.3
“	“ ”	EPFU	M	68.9	5.56	<1.30	3.72	<.06	<.32	9.18	196	<.13	1226	2.63	<.325	21.9	2.40	49.0	<.32	45.6	58.4
“		EPFU	F	147	3.20	<1.33	4.57	0.12	<.33	10.1	382	0.24	1582	4.48	<.333	6.08	2.40	48.2	<.33	56.6	60.2
Imperial	USGS	EPFU	M	199	<.49	6.29	3.49	0.13	0.84	9.05	478	<.13	1183	5.64	<.325	1.36	2.60	42.2	.33	54.9	69.2
“	“	EPFU	F	128	<.50	3.67	2.58	<.07	0.91	14.2	444	<.13	1164	5.07	.457	1.14	1.85	28.4	.37	54.1	61.0
“	“	EPFU	F	45.0	<.06	1.67	2.31	<.07	1.24	5.60	207	0.13	1139	1.67	<.333	<.33	3.07	38.3	<.33	45.2	57.6
“	“	EPFU	F	39.1	<.47	<1.27	2.96	<.06	0.87	4.47	209	0.38	1056	1.76	<.309	<.31	2.06	40.1	<.31	54.3	57.7
“	“	EPFU	M	176	<.48	<1.28	6.13	<.06	1.41	7.07	553	0.13	1118	6.46	.924	0.44	4.85	53.1	.36	55.9	63.7
“	“	EPFU	F	127	<.47	<1.27	2.74	0.18	0.86	5.11	343	0.48	1230	3.59	<.316	<.32	2.81	51.1	<.32	57.2	64.2
“	“	EPFU	M	47.3	<.50	<1.23	2.09	<.06	0.64	5.16	224	0.18	1030	2.11	<.321	1.16	1.76	29.3	<.32	37.9	53.6
“	“	EPFU	F	127	<.46	<1.27	2.85	<.06	0.72	7.01	427	0.13	1229	3.36	<.316	0.10	2.41	47.2	<.32	42.0	62.2
Kofa	Sheep Tank	EPFU	M	41.8	1.32	9.53	28.0	0.16	2.11	5.01	386	0.30	1099	106	1.36	3.04	0.66	9.14	0.34	61.0	62.5
“	“	EPFU	M	82.6	1.55	6.80	16.5	0.16	1.43	4.17	237	<0.13	981	67.2	0.73	2.24	<0.32	10.6	0.44	45.0	59.2
“	“	EPFU	M	41.1	1.89	3.60	23.5	0.24	1.78	4.10	310	<0.12	707	100	0.87	2.87	<0.31	7.03	<0.31	54.0	61.8
“	“	EPFU	M	104.	2.49	2.69	37.0	<0.06	1.33	5.29	375	0.20	1053	166	0.50	2.57	0.35	9.79	0.80	66.6	60.3
“	“	EPFU	F	91.6	1.54	<1.27	26.0	0.28	1.44	4.21	320	0.19	1068	90.8	0.72	1.04	0.35	9.14	0.33	64.1	58.4
“	“	EPFU	M	109.	8.48	<1.27	238.	0.23	1.94	4.65	818	0.49	967	544	0.90	9.11	0.54	14.6	1.56	98.7	60.2
Reference	Buckeye Mine	EPFU	M	14.1	<.47	16.4	2.38	<.06	<.32	5.08	132	0.24	699	1.84	<.316	2.04	<0.47	16.4	<.32	25.4	47.8
“	“	EPFU	M	36.8	<.50	16.1	5.72	<.07	<.33	9.67	304	0.48	1569	8.04	<.333	11.0	1.88	42.0	<.33	63.6	57.2
“	“	EPFU	M	10.4	<.47	27.5	9.07	<.06	<.32	13.7	281	0.16	1178	2.40	<.316	5.90	1.01	16.7	<.32	40.6	53.2

Appendix 1 (Cont.). Metals in whole body bats collected from mines on Imperial and Kofa National Wildlife Refuges and at reference sites in southwestern Arizona, 1998

Area	Collect. location	Species[1]	Sex	Contaminant concentration, µg/g dry weight																	Moist (%)
				Al	As	B	Ba	Cd	Cr	Cu	Fe	Hg	Mg	Mn	Ni	Pb	Se	Sr	V	Zn	
Imperial	Adit 78a	MYCA	NA	662	<.50	45.2	5.47	<.07	0.80	80.8	415	0.25	1405	14.3	<.333	4.70	3.56	23	<.33	45.6	61.8
“	“	“	NA	1099	<.48	24.8	5.45	<.06	0.63	59.6	420	0.33	1451	12.1	<.321	1.84	4.58	34.1	.38	46.2	64.1
“	“	“	MM	1069	<.49	<1.30	13.1	<.06	2.83	57.2	1135	0.42	2239	44.1	1.56	0.96	3.18	54.6	1.50	70.8	58.3
“	“	“	MM	462	<.50	7.15	7.04	<.07	1.57	28.8	530	0.28	1516	11.8	<.333	0.93	4.77	33.0	.62	48.2	60.1
Imperial	USGS	MACA	M	123	<.49	<1.30	1.35	<.06	0.64	5.88	325	0.23	1332	2.46	<.325	<.32	2.60	17.3	<.32	59.6	59.7
“	“	“	M[2]	141	<.48	25.5	1.92	0.29	0.95	8.50	373	0.18	1342	2.73	.382	1.24	1.74	18.2	<.32	64.1	61.1
“	“	“	M	284	<.50	15.1	1.45	0.21	0.70	4.81	281	0.28	1255	1.90	<.333	19.5	1.81	14.8	<.33	63.4	59.5
“	“	“	M	388	<.47	12.9	1.87	0.47	1.26	5.01	333	0.21	1192	2.21	<.312	0.38	1.60	18.2	<.31	56.0	58.3
“	“	“	M	122	<.46	8.26	0.68	<.06	0.54	4.53	219	0.22	978	1.97	<.309	<.31	1.57	18.7	<.31	58.6	61.2
“	“	“	M	187	<.47	5.18	0.79	0.06	0.57	4.44	250	0.24	940	1.40	<.312	<.31	1.51	16.3	.39	48.4	61.3
Reference	Roosevelt	MYVE	F	23.0	0.83	<1.33	12.4	<0.07	1.24	6.12	211	<0.13	1192	20.3	0.45	2.06	2.01	21.1	<.33	45.7	61.0
“	“	“	F	30.9	0.49	<1.33	6.8	<0.07	0.93	5.13	176	<0.13	1087	5.37	0.69	0.38	1.37	12.6	<.31	36.3	57.6
“	“	“	F	29.4	0.54	<1.30	5.3	<0.07	0.70	5.12	175	<0.13	1033	7.86	<0.32	0.95	1.92	15.4	<.31	37.4	57.7
“	“	“	F	8.9	0.69	<1.28	6.4	0.14	2.26	6.91	221	0.56	1286	6.89	0.35	20.30	1.31	19.8	<.32	44.1	63.7
“	“	“	F	55.9	1.00	<1.32	6.4	0.32	1.04	7.63	225	0.29	1322	7.28	<0.33	2.18	1.84	14.9	<.32	52.0	64.2

[1]Species: MYYU = *Myotis yumanensis*, EPFU = *Eptesicus fuscus*, MYCA = *Myotis californicus*, MACA = *Macrotus californicus*, MYVE = *Myotis velifer*.
[2]This sample also contained 1.46 µg/g dry weight molybdenum.
[3]Sex: Because some species averaged about 5 grams each, two or more individuals were combined to attain sufficient mass for analytical analysis. Like sexes were combined whenever possible. Therefore, MM = 2 males, M = 1 male, and F = 1 female.

Appendix 2. Metals in whole body Yuma myotis bats collected at Imperial National Wildlife Refuge, 1999[1]

Sample Number	Contaminant concentration, µg/g dry weight															Moist (%)
	Al	As	B	Ba	Cd	Cr	Cu	Fe	Mg	Mn	Ni	Pb	Se	Sr	Zn	
MYYU1	109	0.01	20.1	1.70	0.11	1.73	45.2	448	1317	8.64	0.90	37.9	2.70	17.0	153	64.1
MYYU2	44	0.01	9.67	2.17	0.01	1.42	22.9	779	1335	5.49	0.39	16.0	4.27	15.7	95	70.1
MYYU3	54	0.01	28.0	1.88	0.07	1.39	77.9	404	1308	6.12	0.86	23.9	4.16	20.4	99	70.5
MYYU4	54	0.02	22.9	2.02	0.05	1.46	47.9	351	1203	7.24	0.39	42.3	4.78	19.7	109	69.9
MYYU5	59	0.01	12.0	1.01	0.05	0.89	32.7	368	1131	5.78	0.56	13.8	5.32	18.2	99	70.1
MYYU6	48	0.01	15.6	2.28	0.07	1.29	30.9	422	1263	5.58	0.56	15.8	4.75	23.0	92	69.2
MYYU7	52	0.01	14.1	1.46	0.07	1.35	19.0	422	1273	5.95	0.59	19.6	5.26	14.7	96	72.8
MYYU8	49	0.01	11.6	1.52	0.05	1.21	18.1	325	1066	5.12	0.57	19.1	3.86	13.8	87	66.8
MYYU9	48	0.01	11.3	1.88	0.14	1.59	34.8	595	1382	5.72	0.66	16.3	5.63	19.9	95	69.9
MYYU10	48	0.01	13.7	1.72	0.11	1.60	15.9	422	1403	5.68	0.40	16.5	4.93	20.0	98	69.7
MYYU11	122	0.03	5.24	2.28	0.09	1.28	18.6	423	1463	4.44	0.35	25.8	4.32	36.0	86	68.9
MYYU12	37	0.03	5.08	1.65	0.03	1.18	15.3	340	1413	4.46	1.52	12.3	5.31	30.9	91	72.9
MYYU13	55	0.03	5.67	2.72	0.03	1.23	14.9	429	1564	4.33	0.65	15.7	6.17	32.7	86	74.7
MYYU14	28	0.03	4.90	2.88	0.03	1.21	13.6	411	1419	3.70	0.34	19.6	4.65	29.4	75	81.3
MYYU15	44	0.04	8.13	2.31	0.24	1.48	36.9	396	1418	6.22	0.81	33.9	3.88	39.0	108	70.7
MYYU16	38	0.03	3.93	2.02	0.02	1.35	28.7	365	1360	5.67	0.92	15.2	4.23	32.2	98	68.3
MYYU17	41	0.03	3.86	2.24	0.16	1.35	28.6	370	1318	5.83	0.59	16.7	3.74	38.3	99	67.3

[1]All samples collected at the Eureka 3 mine entrance. All individuals were male. Individual concentrations are reconstructed values.
[2]Mercury, molybdenum, and vanadium were not detected in any samples. Lower limit of detection = 0.01 µg/g.

Appendix 3. Organochlorine compound residues in bat carcasses collected in Arizona and California, 1998

			Residue (μg/g wet weight)[1]								
Species	Area[2]	Sex[3]	p,p'-DDE	p,p'-DDD	p,p'-DDT	Hept Epox	Total Chlor	Diel-drin	Total BHC	Moist (%)	Lipid (%)
Yuma myotis	Eureka 1	Un	ND	ND	ND	ND	ND	ND	ND	64.9	6.85
Yuma myotis	Eureka 1	Un	0.86	ND	ND	ND	ND	ND	ND	69.3	6.10
Yuma myotis	Eureka 1	Un	2.64	ND	ND	ND	ND	ND	ND	69.3	6.70
Yuma myotis	Eureka 2	FF	4.25	ND	0.01	ND	ND	ND	ND	ND	6.31
Yuma myotis	Eureka 2	FF	0.23	ND	ND	ND	ND	ND	ND	ND	5.80
Yuma myotis	Eureka 2	FF	0.01	ND	ND	ND	ND	ND	ND	66.5	7.58
Yuma myotis	Eureka 2	FF	0.31	ND	ND	ND	ND	ND	ND	69.3	4.81
Yuma myotis	Eureka 3	FF	0.27	ND	ND	ND	ND	ND	ND	64.7	16.5
Yuma myotis	Eureka 3	FF	0.69	ND	0.02	ND	ND	ND	ND	67.5	12.6
Yuma myotis	Eureka 3	FF	1.85	ND	ND	ND	ND	ND	ND	64.5	14.8
Yuma myotis	Eureka 3	FF	0.88	ND	0.01	ND	ND	ND	ND	58.7	24.7
Yuma myotis	Eureka 3	FF	0.28	ND	0.02	ND	ND	ND	ND	67.0	6.48
California leaf-nosed bat	USGS	M	0.40	ND	ND	ND	ND	0.01	ND	68.6	5.89
California leaf-nosed bat	USGS	M	0.19	ND	ND	ND	ND	0.01	ND	64.7	10.1
California leaf-nosed bat	USGS	F	ND	ND	ND	ND	ND	ND	ND	69.8	5.33
California leaf-nosed bat	USGS	M	0.39	ND	ND	ND	ND	0.01	ND	70.2	6.21
California leaf-nosed bat	USGS	M	2.96	ND	ND	ND	ND	0.02	ND	71.3	5.64
Big brown bat	USGS	F	ND	ND	ND	ND	ND	ND	ND	71.6	2.68
Big brown bat	USGS	F	0.24	ND	ND	ND	ND	ND	ND	68.5	9.38
Big brown bat	USGS	M	2.31	ND	ND	ND	0.01	ND	ND	65.2	12.5
Big brown bat	USGS	F	0.35	ND	ND	ND	ND	ND	ND	67.2	6.45
Big brown bat	USGS	F	0.90	ND	ND	ND	ND	ND	ND	69.1	6.20
Southwestern cave myotis	Roosevelt	F	0.10	ND	ND	ND	ND	ND	ND	65.5	7.23
Southwestern cave myotis	Roosevelt	F	0.01	ND	ND	ND	ND	ND	ND	64.9	11.3
Southwestern cave myotis	Roosevelt	F	0.30	ND	ND	ND	ND	ND	ND	61.3	8.25
Yuma myotis	Roosevelt	MFF	0.35	ND	ND	ND	ND	ND	ND	63.0	9.36
Yuma myotis	Roosevelt	FF	0.40	ND	ND	ND	ND	ND	ND	67.7	8.06
Yuma myotis	Roosevelt	FF	0.41	ND	ND	ND	ND	ND	ND	62.0	8.77
Yuma myotis	Roosevelt	FF	0.72	ND	0.01	ND	ND	ND	ND	66.0	8.53
California leaf-nosed bat	KOFA	F	ND	ND	ND	ND	ND	ND	ND	71.6	4.52
California leaf-nosed bat	KOFA	M	1.72	ND	ND	ND	ND	ND	ND	67.5	7.36
California leaf-nosed bat	KOFA	F	ND	ND	ND	ND	ND	ND	ND	72.5	4.47
California leaf-nosed bat	KOFA	F	ND	ND	ND	ND	ND	ND	ND	66.2	6.81
Pallid bat	Buckeye	F	3.71	ND	0.05	0.14	ND	0.06	ND	31.0	24.0
Pallid bat	Buckeye	M	9.02	0.02	0.07	ND	0.04	0.01	ND	63.6	9.12
Pallid bat	Buckeye	M	1.45	0.40	0.25	0.05	0.20	0.09	0.06	63.0	10.4
Pallid bat	Buckeye	M	1.53	ND	0.40	0.05	0.10	0.07	0.10	65.7	13.1
Pallid bat	Buckeye	F	2.57	ND	0.11	ND	0.02	0.02	0.01	45.5	20.0

[1]Samples were analyzed for the following compounds: HCB; total PCB; alpha, beta, and gamma BHC, alpha chlordane, cis-nonachlor, dieldrin, endrin, gamma chlordane, heptachlor epoxide, mirex, o,p'-DDD, o,p'-DDE, o,p'-DDT, oxychlordane, p,p'-DDD, p,p'-DDE, p,p'-DDT, toxaphene, and trans-nonachlor. If the compound does not appear in the above table, then no residues of that compound were detected at 0.01 μg/g.

[2]Area: Eureka 1 = Eureka Mine entrance 1, Eureka 2 = Eureka Mine entrance 2, Eureka 3 = Eureka Mine entrance 3, USGS = Imperial NWR mine complex (CA), Roosevelt = Roosevelt Dam Transformer Bldg., KOFA = Kofa NWR Sheep Tank Mine, Buckeye = Buckeye Copper Mine.

[3]Sex: Because *Yuma myotis* averaged about 5 grams each, two or more individuals were combined to attain sufficient mass for analytical analysis. Like sexes were combined whenever possible.   Therefore, F = 1 female, FF = 2 females, and MFF = 1 male and 2 females.

[4]ND = not detected. The lower limit of detection = 0.01 μg/g wet weight.