Contaminants Assessment affecting Selected Palustrine and Lacustrine Habitats of the Great Salt Lake, 1996-2000

By
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1.0 INTRODUCTION

The Great Salt Lake (GSL) is the fourth largest natural water body, and the largest saline lake in the United States. Although its saline waters host a deceptively simple food-chain dominated by invertebrates, the biomass produced by this system annually hosts millions of birds that stop on the lake during migration to rest, molt, and re-fuel for the completion of their journeys. The GSL also sits at the downstream end of the largest city and metropolitan area in Utah, and has for the last century been the receiving water body for the waste waters generated by these communities and their supporting industries. Because of concerns regarding potential impact of these wastes on the migratory birds and their habitats that are the trust resources of the United States Fish and Wildlife Service (FWS), agency biologists undertook a comprehensive survey of contaminants and other indicators in the wetlands and open waters of the GSL between 1996 and 2000. Raw data and interim reports of the findings of this study have been used since then to inform policy discussions and to provide background information for a variety of investigations; however this report provides a comprehensive presentation and interpretation of the findings of this study, as well as management recommendations based on current conditions and concerns on the GSL.

1.1 Physical and Biological Setting of the Great Salt Lake

Hydrologic Setting—The GSL is located at the eastern edge of the Great Basin. Along with Mono Lake in California and Pyramid Lake in Nevada, the GSL is one of several vestigial remnants of large Pleistocene lakes that once filled the Great Basin between the Sierra Nevada Mountains to the west and the Wasatch Mountains to the east. As the glaciers that fed these lakes disappeared, the lakes have decreased in size and become saline, terminal basins.

Lake levels in the GSL are controlled by precipitation (inflow) and evaporation (outflow). The effective watershed of the GSL encompasses approximately 55,000 km^2 (21,000 $miles^2$) in northern Utah, southeastern Idaho and southwestern Wyoming (**Figure 1-1**) ((Environmental Management Research Group 2004))(Aldrich & Paul 2002). The majority of inflow enters the southern and eastern shores of the lake via three river systems. From north to south these are: the Bear River, which drains the northern Wasatch Mountains as well as the northern slope of the Uinta Mountains (located approximately 50 miles east of the GSL); the Weber and Ogden Rivers, which drain the central Wasatch Mountains but merge in a broad delta and floodplain on the edge of the lake; and the Jordan River, which drains the south-central Wasatch Mountains as well as the southwestern slope of the Uinta mountains via the Provo River, and then enters the Jordan River drainage system at Utah Lake. Despite these freshwater inflows, the GSL is highly saline, ranging from 12 - 15 percent salinity in the open water of the South Arm (**Figure 1-1**) and nearing saturation at 24 to 26 percent salinity in the North Arm of the lake (J. Luft, Utah Division of Wildlife Resources, pers. comm.). The high salinity is the result of the accumulation of minerals that has occurred in this closed system over the last 10,000 years. By comparison, sea water has a salinity of approximately 3.5 percent.

The GSL is very shallow for its size. The lakebed gradually slopes to a maximum depth of about 10 meters (33 ft); however, the lake's average depth is about 4 m (13 ft) when the lake is at its mean elevation of 1,281 m (4,200 ft) above sea level (ASL) (Arnow 1980). The surface area of the lake at this elevation is approximately 4,400 km^2 (1,700 mi^2) (Environmental Management Research Group 2004). Because of the shallow profile, small fluctuations in lake elevation result in large changes in size and

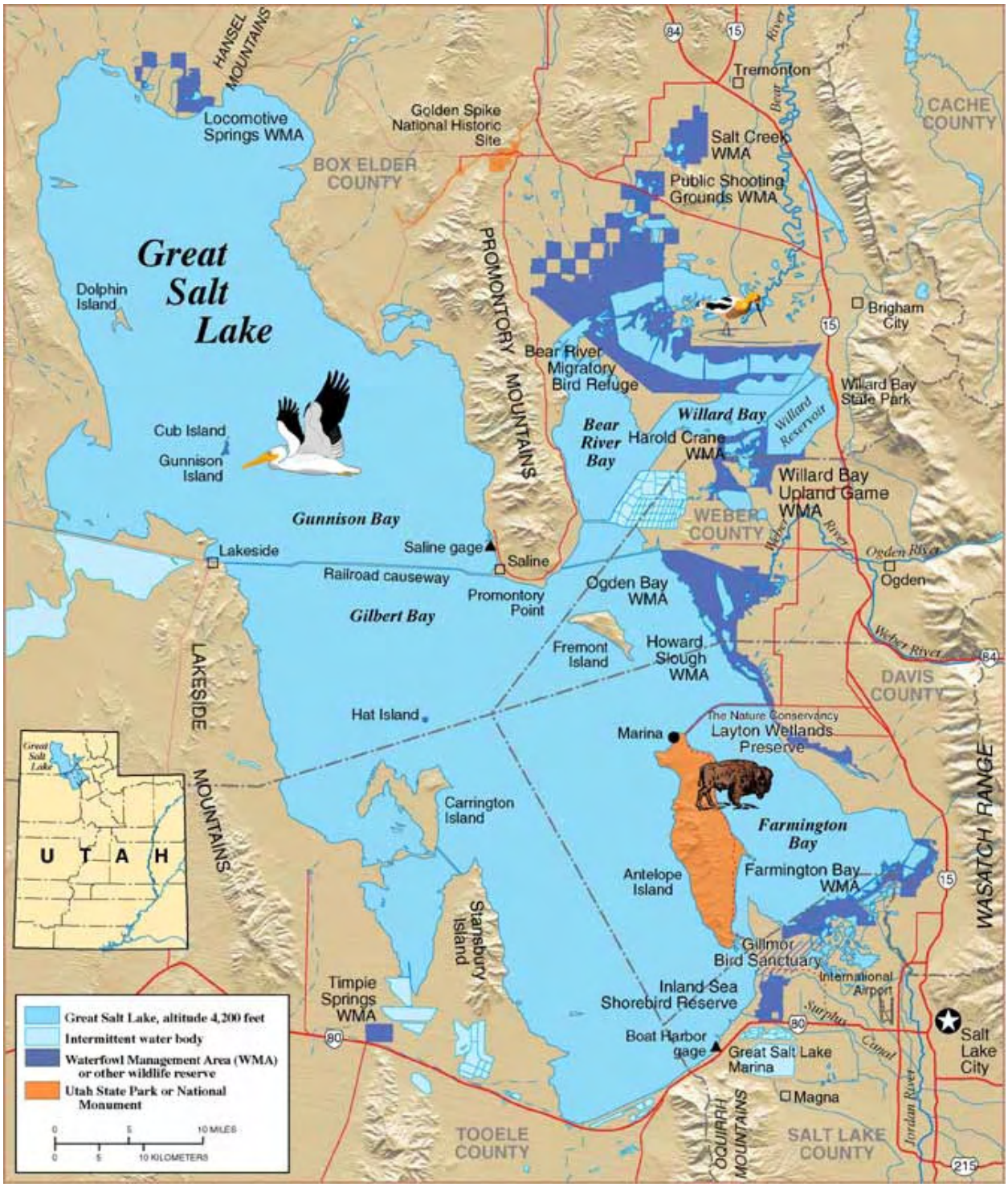

Figure 1-1 Geographic Features and Landmarks of the Great Salt Lake, Utah

habitat type in the lakeshore and delta areas. For example between 1999 and 2001,lake elevations ranged between 1280 m (4,199 ft) and 1282 m (4,205 ft) ASL, with a corresponding change in the surface area of the lake of 207 km^2 (80 mi^2) (U.S. Geological Survey 2001a). Changes in lake level are primarily caused by medium-to-long term trends in both temperature and precipitation and influence all aspects of the lake's ecology, including salinity, populations of in-lake biota, and shifts in both quantity and type of wetland vegetation around the lake.

Biological Communities—Extensive permanent and seasonal wetlands occur at the margins of the GSL, where freshwater inflows from the Jordan, Weber, and Bear Rivers enter the lake in broad alluvial deltas forming a gradient of fresh to brackish water conditions similar to marine estuaries. Dense stands of emergent wetland plant species typically ring areas of deeper open water, dominated by species including bulrush (*Scirpus* spp.) cattail (*Typhus* spp.), and both native and non-native (and invasive) species of "canary reed grass" (*Phragmites* spp.). The invertebrate community of these wetlands includes large numbers of midges (Chironomidae) and water boatment (Corixidae). While the GSL wetland communities are dominated by a relatively small number of species, they provide breeding and feeding habitat for a diverse range of avian species. Similarly, the saline open-water ecosystem of GSL itself is relatively spare, supporting one species of brine shrimp (*Artemia franciscana*) and two species of brine flies (*Ephydra gracilis* and *Ephydra hians*) (Rawley 1980). These species are in turn supported by a group of planktonic and benthic photosynthetic organisms dominated by a few species of algae (including the green alga, *Dunaliella viridis*) and diatoms (U.S. Geological Survey 2001b). However, what this system lacks in complexity it makes up for with an incredibly high volume of biomass, exemplified by a commercial brine shrimp harvesting industry that harvests up to 25 million pounds of brine shrimp eggs (cysts) each year (Utah Division of Wildlife Resources 2005).

The tremendous production of invertebrate biomass within the GSL ecosystem supports a large number of avian species throughout the year, including both migratory transients and breeding birds. On a yearly basis, the lake supports between 2 and 5 million shorebirds, up to 3 million eared grebes (*Podiceps nigricollis*), and hundred of thousands of waterfowl during spring and fall migration periods (Paton et al. 1992; Jehl et al. 1998; Fellows & Edwards 1991). Birds begin arriving in large numbers in early spring, including many migratory transients that use the wetlands as stopovers enroute to breeding areas in the northern United States and Canada, but peak avian numbers occur between April and September, which spans breeding and migratory periods. The wetlands and uplands included in the GSL ecosystem provide important nesting habitat for significant numbers of birds, particularly American avocet (*Recurvirostra americana*), black-necked stilt (*Himantopus mexicanus*), white-faced ibis (*Plegadis chihi*) and California gull (*Larus californicus*). The playas and mudflats surrounding the GSL are also a major nesting area for the snowy plover (*Charadrius alexandrinus*) (Paton & Edwards 1990; Paton & Edwards 1991; Paton & Edwards 1991). During the peak periods (April-September), an average of over one million birds are present on the lake or its associated wetland habitats at any one time, with average one-day species counts (recorded between 1997 and 2001) including 122,000 green-winged teal (*Anas crecca*); 93,000 eared grebe; 89,000 northern pintail (*Anas acuta*); 56,000 northern shoveler (*Anas clypeata*), 127,000 Wilson's phalarope (*Phalaropus tricolor*), 94,000 American avocet, and 80,000 California gulls (Manning & Paul 2003). However, even these numbers substantially underestimate the total avian use of the GSL as the study did not cover up to 73% of the total wetlands associated with the lake, including several high-value areas specifically managed as waterfowl habitat (Manning & Paul 2003). As a reflection of the lake's importance as a shorebird migratory staging area, the GSL was recognized in 1992 as a site of hemispheric importance to shorebirds by the Western Hemisphere Shorebird Reserve Network (Manomet Center for Conservation Science).

The GSL is vitally important to several species in which significant proportions of their total (global) population may be present on the lake at any one time. For example, up to one million Wilson's phalaropes, which is more than two-thirds of the world's population, annually migrate through GSL as they travel from their breeding grounds in the nearctic to their wintering area in the high Andes (Jehl 1988) (Colwell & Jehl 1994). Over half of the world's population of eared grebes, which exceeded 2.5 million birds on GSL in 2007 (John Luft, pers. comm.), rely on the open waters of GSL for up to four

months during fall migration as a place to molt and regrow flight feathers, and feed on brine shrimp to rebuild energy reserves prior to the final leg of their migration (Jehl 1988). In addition, GSL hosts the largest nesting colony of American white pelicans (*Pelecanus erythrorhynchos*) west of the continental divide (King & Anderson 2005; King & Anderson 2005) with over 14,000 breeding adults on Gunnison Island in 2007 (John Luft pers. comm.). The Intermountain West region is the most important breeding area for the American avocet with up to 50% of the global population occurring around GSL (Sutter et al. 2005).

1.2 Contaminant Concerns on the Great Salt Lake

Approximately 1.7 million people, or about 77 percent of the current population of 2.2 million in the state of Utah, live within watersheds draining into the GSL (Fisher 2006). The convergence of rivers, and rolling uplands with the rich wetlands of the GSL shoreline drew ancestral groups to Paiute, Shoshone and other tribes into the Salt Lake valley far prior to European exploration. With the establishment of Salt Lake City and other communities by Mormon pioneers in the mid-1800's, the process of agricultural and industrial use of the valley's resources began; by the late 1800's, a thriving mineral extraction industry had grown up along the Jordan River, and emissions from smelter stacks clouded the air of the valley. Throughout the 20th century, agriculture in the Salt Lake valley was gradually replaced by industrial and urban development. By 1970, much of the current industrial infrastructure of the Great Salt Lake watershed was in place (e.g., refineries, smelters, factories, wastewater treatment plants, railroads, roads, etc.), almost all of it based on access to process water and wastewater receiving streams. These included minerals refining, industrial manufacturing, rail transportation and petroleum refining. Discharge of wastewaters directly into the Jordan River and other tributaries feeding the GSL was common until pollution controls were implemented in the 1970's and 1980's with environmental regulations such as the Clean Water Act and the Clean Air Act. Many of the earlier industrial sites later were found to be contaminated by waste management practices. In the 1980's and 1990's cleanups under the U.S. Environmental Protection Agency's "Superfund" (Comprehensive Environmental Response, Compensation and Liability Act, or CERCLA) hazardous waste cleanup program were initiated at many of these sites.

Other waterways entering the lake have also carried industrial and urban wastes into the GSL ecosystem. These include the Northwest Oil Drain (NWOD, aka Sewer Canal) and the Ogden River. The NWOD was built to carry wastewaters from the northwest industrial quadrant of Salt Lake City (including refineries, railroad yards and other heavy industries) into the GSL, and also to carry high-water flows of the Jordan River in the spring. Further north, the city of Ogden was an early railroad switching and maintenance hub, and wastes from that industry, along with wastes from large meat packing plants and other industries on the west side of town, were discharged near the confluence of the Ogden and Weber rivers upstream of Ogden Bay on the GSL.

The list of contaminants that have been discharged into the GSL is large and diverse, and includes metals from smelting and refining industries (e.g., arsenic, cadmium, copper, lead, mercury, selenium and zinc), petroleum hydrocarbons including polynuclear aromatic hydrocarbons (PAHs) from refineries, polychlorinated biphenyls (PCBs) from electrical transformers and other industrial uses, and pesticide products associated with orchards, farming, livestock, and industry. Post-war agriculture and pest control practices also contributed a variety of long-lasting organochlorine (OC) pesticide residues, including DDT, endrin and dieldrin, benzene hexcachloride (BHC; lindane), chlordane and others. Another major source of contaminants to the watersheds is municipal wastewater and stormwater, which has been increasing in volume and importance as agricultural lands around the lake have been converted to residential and light industrial development. Contaminants associated with urban development include oil, grease, particulate metals, nutrients, and a variety of herbicides and pesticides in stormwater; and nutrients, ammonia, and trace metals from sanitary wastewater treatment discharges. The latter also includes pharmaceutical residues and other "emerging contaminants" that are largely unaffected by wastewater treatment processes, and which have a newly-recognized potential for environmental disturbance to the GSL watershed. These include natural and synthetic antibiotics, hormones (e.g.,

estradiol from birth control pills), plasticizers, and other chemicals that may have largely uncharacterized endocrine-disrupting effects (U.S. Geological Survey 2002).

Previous Contaminant Studies—Despite the GSL's position at the receiving end of the industrial and sanitary discharges of the Salt Lake Valley, there had been no comprehensive evaluation of potential environmental contaminant issues within the wetlands surrounding the GSL or the lake itself prior to this investigation. Scattered, small-scale studies around the lake occasionally included evaluations of contaminants such as organochlorines in the late 1970's when they were first realized as a potential problem (Lindvall & Low 1979) or investigations of analyte groups that happened to include contaminants of concern to wildlife managers. Sampling by the Service in 1994 documented that some inorganic constituents, in particular selenium, were present at levels of concern in brine shrimp at certain sites within the South Arm of the Great Salt Lake (Waddell et al. 1999).

The cumulative effect of releases from industrial sites (particularly those that had been in operation prior to modern practices and regulations) around the GSL have typically been investigated in the context of CERCLA or other regulatory-directed cleanups. These investigations typically identify releases on-site or immediately down gradient, with evaluation of off-site or downstream effects usually omitted due to technical, legal and economic limitations. In most cases in the Salt Lake valley, tight clay soils which originated as lakebed sediments do not allow contaminants to travel far off site. But there have been cases where contaminant plumes have intersected active groundwater systems, adversely impacting down gradient wetlands. The most notable example of this within the GSL ecosystem is the Kennecott Utah Copper Corporation (KUCC) metals smelter and refinery on the south shore of the GSL. At this site, water-soluble metals from the refining process (including arsenic and selenium) stored in unlined lagoons or bunkers were dissolved into groundwater at the facility, which then traveled downgradient and intersected groundwater supplying a large wetland complex on the south shore of the lake. A second industrially-linked contaminant source to the GSL is the Northwest Oil Drain, discussed previously. However, even in cases where contaminant impacts to the GSL ecosystem were suspected, assessment and cleanup action boundaries were relatively tightly drawn around these facilities, and the distribution and/or effects of contaminants further downstream in the GSL ecosystem were frequently not part of the initial problem identification process.

1.3 Need and Purpose for Study

This study was initiated due to concerns regarding the potential impact of contaminants on the health of migratory birds (which are a "trust resource" of the U.S. Department of Interior and the FWS) and other species in the high quality wetland habitats surrounding the GSL. Also, as environmental cleanup investigations and actions have taken place on the lake's shore, there has been a need for better data regarding the impact of contaminants associated with these sites on the GSL wetlands. Other environmental regulatory decisions such as the development of water quality criteria to protect the GSL and its biological resources also require better characterization of baseline contaminant conditions. These needs have become more acute over the last decade as pressures from development, demand for recreation, and interest in preservation have increased. This purpose of this study was to collect data to increase the quality and quantity of data that would help to characterize the nature, extent and magnitude of contaminants within the wetlands and the open-waters of the GSL in order to support the setting of priorities regarding source control and other management activities. Since the study was initiated at the beginning of a period of accelerated economic and population growth within northern Utah, it can also provide a baseline contaminant characterization that agencies and other organizations working to preserve and mitigate wetland habitats on the lake can use to understand potential management issues or limitations in these areas. The primary purpose of the investigation was to collect data to evaluate 1) if (and where) effects of contamination in birds and or their habitats currently exist, and 2) if these effects were occurring at sufficient magnitude to warrant further study that could eventually lead to remedies such as changes in resource management or cleanup of contaminated areas.

2.0 STUDY OBJECTIVES, AREA, AND DESIGN

The overall objectives for the GSL Wetlands and Open Water study included:

1. Reconnaissance—Assess the general distribution and degree of contamination in GSL wetlands that are representative of wetland types and locations most significant to migratory birds.
2. Advanced Reconnaissance—Conduct detailed contaminant assessments of specific wetland types and locations considered at risk from contaminant sources and loading, and evaluate pathways of exposure posing significant hazards to migratory birds.
3. Analyze spatial and temporal correlations between contaminant sources, wetland types, degree of contamination, and impacts on migratory birds in the southern GSL system.

2.1 Study Area

Based on the first study objective described above, wetlands around the GSL were selected for investigation in an effort to encompass both the diversity of habitats that support Service trust resources within the GSL ecosystem and to include areas where contaminant inputs were known or suspected. The open waters of the GSL, focusing on Gilbert Bay (also referred to as the South Arm) were also included in the assessment because it is highly productive of the algae, brine shrimp and brine flies that characterize the biomass of the GSL ecosystem, and supports a large number of migrating and wintering avian species. While Gilbert Bay is not directly connected to runoff and effluents from the urban and industrial sources surrounding the GSL, lake currents and other transport processes (e.g., atmospheric deposition) bring land-based contaminants into the open water system.

Wetland habitats evaluated in this study included both riverine (associated with river floodplains) and palustrine (ponded, shallow-water, with submerged and/or emergent vegetation) types, with selected areas extending from the Great Salt Lake State Park on the southern shore to the Ogden Bay Waterfowl Management Area on the east-northeast side of the lake (**Figure 1-1**). This study area includes hundreds of square miles of wetlands which are fed by freshwater inflows to the lake. Wetlands in an industrialized area of North Salt Lake, which are remnants of a large wetland complex that had been extensively filled and altered in the early 20th century, were also included in the study. While the extent and quality of these wetlands are impaired by urbanization and development, they still provide habitat for shorebirds and waterfowl, and can potentially expose birds to contaminants associated with the industrial activities occurring near them, which include refineries, wastewater treatment plants and chemical manufacturing and storage facilities. Finally, ponds, marshes and seeps on the mainland and shore of Antelope Island, located about 7 miles off the eastern shore of the GSL, were also included in the study because there has previously been little or no characterization of these areas and because they have not been influenced by inflows from the surrounding watershed.

Within these broad geographic areas, specific study sites were chosen based on available access, recognized potential for contamination, conservation status (e.g., wildlife areas or sites being considered for wetland mitigation), and availability of proposed sample media (e.g., sediments, fish, avian eggs). The 31 study sites were grouped into 9 geographic units for analysis and reference throughout this report. Location codes for these sites are presented in **Table 2-1; Figure 2-1** shows the location of these sites around the GSL. A brief description of the habitat types and potential site-specific contaminant issues at each location is presented in Table 2-2.

2.2 Sampling Rationale for GSL Wetlands Synoptic Survey (1996-1997)

The primary objective of the initial reconnaissance phase of the GSL study (1996-1997) was to obtain a representative overview of environmental contaminants in and upstream of important GSL wetland habitats. Study sites were selected based on the history of the individual area, including known or

Table 2-1 Geographic Areas, Sample Site Designations and Location Codes for data collection sites in and around the Great Salt Lake.

Code	Site Name
GSL Open water	
GU	Gilbert Bay- USGS Sites
GG	Gilbert Bay
GC	Gilbert Bay C-7 Ditch Delta
GD	Gilbert Bay Goggin Drain Delta
GL	Gilbert Bay Lee Creek Delta
Antelope Island (WS)	
AE	Antelope Island East
AS	Antelope Island South
AO	Antelope Island, offshore
Great Salt Lake South Shore (WS)	
LS	Saltair/GSL State Park
LC	C-7 Ditch
South Shore Wetlands (WS)	
SI	Inland Sea Shorebird Reserve
SG	Gillmor Sanctuary
SD	Goggin Drain
SN	North Point Canal
SA	Airport Mitigation Site
SE Shore Industrial-area wetlands (WS)	
IP	Petrochem Ponds
IB	Beck Hot Springs
IS	SLC Sewage Treatment Plant
IO	Oil Drain Canal
Farmington Bay South (WS)	
FN	New State Duck Club
FP	Bountiful Pond
FS	State Canal
FC	Farmington Bay WMA- Crystal Unit
FU	Farmington Bay WMA- Unit 1
FO	Northwest Oil Drain Delta
Farmington Bay North (WS)	
FB	Bair Creek
FK	Kaysville Marsh
Ogden Bay (WS)	
OH	Howard Slough
OC	Ogden Bay WMA- South Canal
OS	Ogden Bay WMA- South
OW	Ogden Bay-Weber River
ON	Ogden Bay WMA- North
Bear River Bay	
BR	Bear River Migratory Bird Refuge entrance *(note: this area included only as a reference area for the study described in section 4.6)*

WS=1996-1997 GSL Synoptic Wetlands Survey

suspected contaminants issues, which are summarized in **Table 2-2**. Factors such as access, time and funding constraints on sampling and analysis were also considered.

The general approach at each wetland location was to sample and analyze sediments, whole-body fish, bird eggs, and species of invertebrates eaten by birds for total metals and organochlorine (OC) compounds (primarily persistent chlorinated pesticides such as DDT, chlordane, dieldrin, etc.) in order to develop a weight-of-evidence approach to identify trends and/or hotspots in contaminant concentrations. In selected locations, a suite of biomarkers was analyzed in fish to look for evidence of exposure and/or effect due to certain contaminants. Subsets of samples were evaluated for location-specific or specialized contaminants, including sediments that were analyzed for total petroleum hydrocarbons (TPH), a general measure of the presence of petroleum products. A small number of sediment and tissue samples were also evaluated for dioxins and furans, which are highly toxic and bioaccumulative compounds that are by-products of industrial contamination and incomplete combustion. Sample media, numbers and analytes for the areas covered by this study are summarized in **Appendix Table A-1**, and results are presented and discussed in Section 4 (wetlands) and Section 5 (open waters)

In addition to contaminant residues, biomarkers were analyzed in carp collected from wetlands with freshwater inflows as an indirect and/or direct indicator of potential contaminant exposure to wildlife

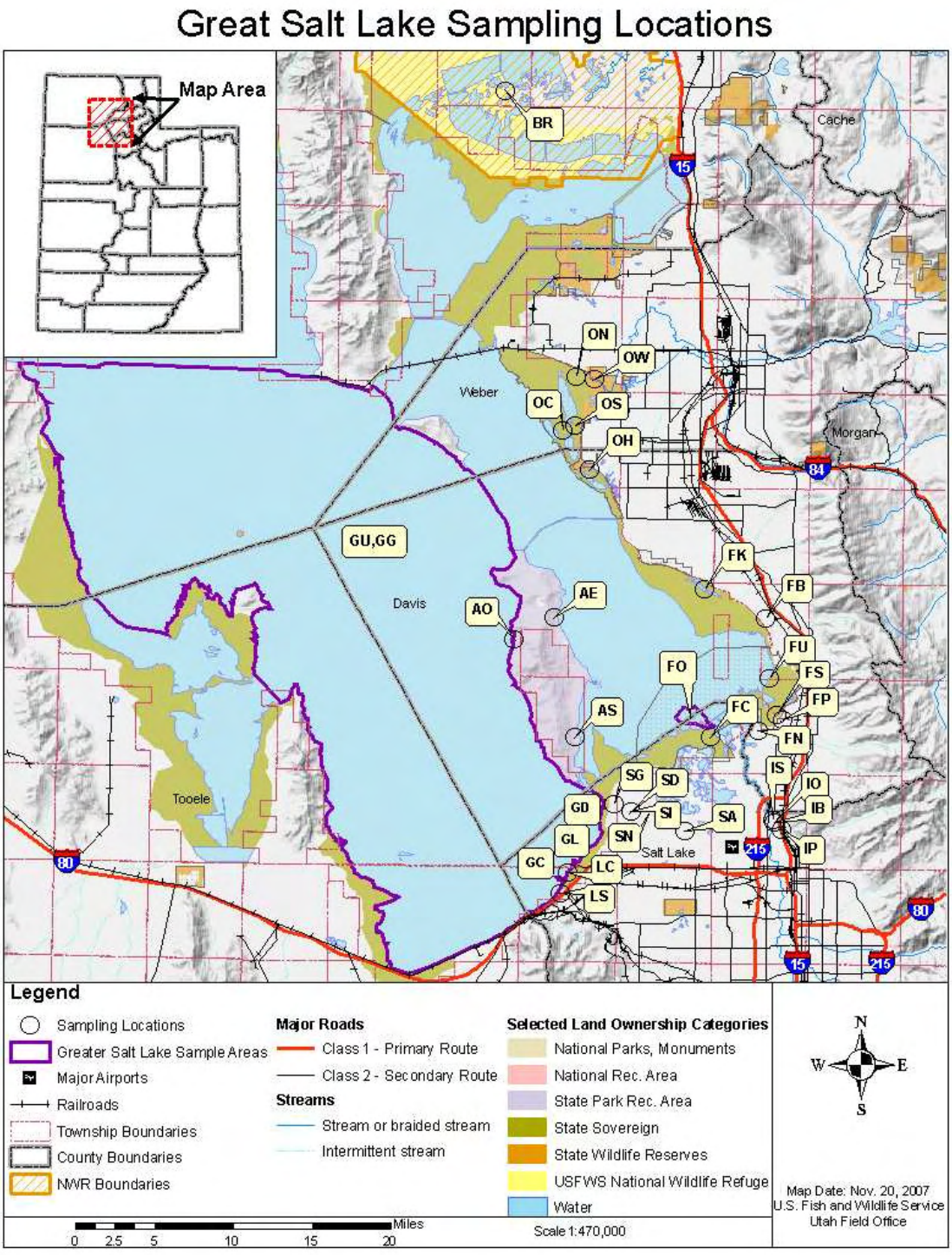

Figure 2-1 Location of Sample Sites included in Great Salt Lake Wetland and Open Water Contaminants Assessment, 1996-2000.

Table 2-2 Summary of habitat types and potential contaminant issues at wetlands and open water sites included in the Great Salt Lake Contaminants Assessment, 1996-2000 (*page 1 of 3)*

Loc. Code	Site Name	Site Description	Year(s) Sampled	Rationale for Inclusion in Study
GSL Open Water				
GU	Gilbert Bay USGS Stations	Stations (lat/long locations) in Gilbert Bay established by USGS to assess physical and biological characteristics of the lake; points randomly selected.	1996	Baseline contaminant survey of GSL open water habitat
GG	Gilbert Bay FWS Stations	Stations (lat/long locations) established by FWS.	1997, **1998, 1999**, **2000**	*same as above* (1997) FOLLOW-UP STUDISS (grebes, sediments, and brine shrimp)
GC	Gilbert Bay offshore of C-7 Ditch delta	Near outfall of copper smelter wastewater discharge on south shore of GSL.	**2000**	Assessment of potential source of contaminant exposure
GD	Gilbert Bay near Goggin Drain delta	Near delta of Goggin Drain on south shore of GSL.	**2000**	*same as above*
GL	Gilbert Bay offshore of Lee Creek delta	Near delta of stream on south shore of GSL which receives return flows from western side of Salt Lake valley and the Oquirrh Mountains.	**2000**	*same as above*
Antelope Island				
AE	Antelope Island-East	Mudflats and seasonally inundated playa on the eastern shore of Antelope Island.	1996	Baseline contaminant survey (remote, relatively undisturbed site, minimal contaminant history)
AS	Antelope Island-South	Ponded, constructed inland wetland on the southeastern side of Antelope Island.	1996	*same as above*
AO	Antelope Island-offshore	Saltflat with shallow water just off western shore of Antelope Island.	1996	*same as above*
Great Salt Lake South Shore				
LS	Saltair / Great Salt Lake State Park	Emergent spring-fed wetlands and mudflats downgradient from area with groundwater contamination.	1996, 1997	Baseline contaminant survey of GSL shoreline wetland; assessment of potential source of contaminant exposure
LC	C7 Ditch	Wastewater canal from copper smelter facility to GSL; bordered by riparian wetland habitat.	1996, 1997	Assessment of source of contaminant exposure to GSL wetland habitats and open water
South Shore Wetlands				
SI	Inland Sea Shorebird Reserve	Estuarine wetland complex; mix of naturally-occurring and created wetlands; wetland mitigation site.	1996	Baseline contaminant survey in important GSL wetland habitat
SG	Gilmore Sanctuary	Estuarine wetland complex; conservation area.	1996, 1997	*same as above*
SA	Airport Mitigation Site	Constructed palustrine wetland (ca. 100 acres) several miles SE of the GSL south shore.	1997	*same as above*
SD	Goggin Drain	Agricultural drain, water from a diversion of the Jordan River. Minimal habitat for birds or fish but forms delta on shoreline.	1996	*same as above*

Table 2-2 Summary of habitat types and potential contaminant issues at wetlands and open water sites included in the Great Salt Lake Contaminants Assessment, 1996-2000 (*page 2 of 3)*

Loc. Code	Site Name	Site Description	Year(s) Sampled	Rationale for Inclusion in Study
South Shore Wetlands (continued)				
SN	North Point Canal	Canal draining western Salt Lake Valley and receives flow from Surplus Canal. Minimal habitat for birds or fish; supplies water to Sites SI & SA.	1996, 1997	Baseline contaminant survey in important GSL wetland habitat
Great Salt Lake Southeast Shore Industrial-area Wetlands				
IP	Petrochem Ponds	Small spring-fed palustrine wetlands, <1acre. Downgradient from the Petrochem CERCLA Site and near railroad and other industrial facilities.	1996	Baseline contaminant survey of wetland with suspected contaminant exposure.
IB	Beck Hotsprings	Ephemerally wetted playa, remnant of a historically larger wetland. Geothermally warmed water is open year-round. Surrounded by heavy industry.	1996	*same as above*
IO	Northwest Oil Drain Canal (aka Sewer Canal)	Canal originating near refineries and industrial facilities in N. Salt Lake. Supplies water to Farmington Bay. Sediments of main canal remediated under CERCLA.	1996	*same as above*
IS	SLC Wastewater Treatment Plant	Constructed wetlands demonstration project at large wastewater treatment plant using effluent as water supply.	1996, 1997	*same as above* <u>Note:</u> *Samples in 1997 collected due to observation of deformed bird embryo in 1996*
Farmington Bay- South				
FN	New State Duck Club	Estuarine wetland located at entry of Jordan River Delta into Farmington Bay.	1996	Baseline contaminant survey in important GSL wetland habitat
FP	Bountiful Pond	Large (8-10 ac) created palustrine wetland, downgradient of urban industrial area, upgradient of important GSL wetland habitat.	1997	Baseline contaminant survey of wetland near industrialized area Assessment of potential source of contaminant exposure to downstream habitats
FS	State Canal	Estuarine wetland located at inlet of fresh water to Farmington Bay WMA (within WMA).	1996, 1997	Baseline contaminant survey in important GSL wetland habitat
FC	Farmington Bay WMA-Crystal Unit	Managed ponds, emergent wetlands and dikes within Farmington Bay WMA. Located south of the point of entry of the State Canal into the WMA.	1996, 1997, **2000**	Baseline contaminant survey in important GSL wetland habitat. <u>*FOLLOW-UP STUDY(2000)-*</u> *mercury and methyl mercury in bird eggs*
FU	Farmington Bay WMA-Unit 1	Managed ponds, emergent wetlands and dikes within Farmington Bay WMA. Is located west and north of the point of entry of the State Canal.	1997	Baseline contaminant survey of important GSL wetland habitat
FO	Oil Drain Delta	Shallow emergent sediment deposition area where Oil Drain canal enters directly into Farmington Bay; within Farmington Bay WMA.	1997, **2000**	Baseline contaminant survey of important GSL wetland habitat potentially impacted by industrial discharge. <u>*FOLLOW-UP STUDY (2000)*</u>*- petroleum-related contaminants in sediments*

Table 2-2 Summary of habitat types and potential contaminant issues at wetlands and open water sites included in the Great Salt Lake Contaminants Assessment, 1996-2000 (*page 3 of 3)*

Loc. Code	Site Name	Site Description	Year(s) Sampled	Rationale for Inclusion in Study
Farmington Bay- North				
FB	Baer Creek	Alluvial delta downstream of Central Davis County WWTP and upstream of Farmington Bay WMA. Agriculture, residential and light industrial upstream land use.	1997	Assessment of potential source of contaminant exposure to downstream habitats
FK	Kaysville Marsh	Small creek with urban/agricultural upstream land use that flows into significant conservation wetland (Layton Marsh) that forms estuary in northern Farmington Bay.	1996, 1997	Baseline contaminant survey of important GSL wetland habitat
Ogden Bay				
OH	Howard Slough	Large estuarine marsh supplied by water from Ogden and Weber rivers, flowing into northeast Gilbert Bay. Significant agricultural and increasingly urban land uses upstream.	1997	Baseline contaminant survey of important GSL wetland habitat
OC	Ogden Bay-South Canal	Canal supplying water to the southern portion of the Ogden Bay WMA. Much of the water volume is return flows from agricultural areas SE of Ogden Bay.	1996	Assessment of potential source of contaminant exposure to important GSL wetlands
OS	Ogden Bay WMA- South	A shallow estuarine wetland area in southern portion of Ogden Bay WMA, managed with dikes to form a series of shallow ponds.	1996	Baseline contaminant survey of important GSL wetland habitat
OW	Ogden Bay-Weber River	The Weber River as it flows into Ogden Bay WMA. Significant industrial upstream land use, including Ogden Railyard, a remediated CERCLA site.	1996	Assessment of potential source of contaminant exposure to important GSL wetlands
ON	Ogden Bay WMA- North	Shallow ponds and emergent wetlands in the northern portion of the Ogden Bay WMA; downstream of SiteOW	1996, 1997, **1999**	Baseline contaminant survey of important GSL wetland habitat. *FOLLOW-UP STUDY(1999)- uptake of PAHs from foodchain into barn swallows*
Bear River				
BR	Bear River Migratory Bird Refuge	Major freshwater inflow into the northeastern portion of the GSL. Similar terrain, water quality and habitat as site ON, but without industrialized upstream land use	**1999**	Reference area for study evaluating potential exposure and effects of PAHs at site ON

* NOTE: Years in **BOLD** type indicate follow-up studies

ABBREVIATIONS

CERCLA: *Comprehensive Environmental Response, Compensation & Liability Act*
WMA: *Waterfowl Management Area*
WWTP: *Wastewater treatment plant*
USGS: *United States Geological Survey*

(including migratory birds and waterfowl) in those areas. Two enzyme endpoints were evaluated, acetyl cholinesterase (AChE) enzyme activity, which is a direct indicator of exposure to organophosphate (OP) and carbamate pesticides; and ethoxyresorufin-o-deethylase (EROD) activity, which can indicate exposure to organochlorine and polynuclear aromatic hydrocarbon (PAH) compounds. Fish liver bile was also evaluated for PAH metabolites which can indicate recent exposure to PAHs--either via petroleum products (e.g., oil and fuel spills or releases) or from atmospheric deposition of incompletely combusted hydrocarbons. Finally, plasma sex steroid hormones 17β-estradiol (E_2), 11-ketotestosterone (11-KT) and vitellogenin, were measured in fish blood. In combination with other data, including both contaminant concentrations and habitat and fish health factors, these endpoints can provide evidence of exposure to contaminants that are associated with endocrine disruption which can indicate (based on evaluation of overall and relative concentrations in male and female fish) exposure to endocrine disrupting compounds. The findings of these investigations are presented in Section 4.

The open waters of Gilbert Bay were sampled concurrently with the GSL wetland investigations, with sediments, brine shrimp and livers from eared grebes (*Podiceps nigricollis*) analyzed to characterize contaminant exposure and distribution through the open water ecosystem. Samples were primarily analyzed for metals. Eared grebes were selected for analysis because they have the potential to be highly exposed to food-chain contaminants on the GSL as they spend three to five months during fall migration on the open waters of the lake, during which they feed almost exclusively on brine shrimp. These results are presented in Section 5.

2.3 Follow-up Studies of Selected Areas (1998-2000)

Based on preliminary evaluation of the GSL wetlands and open water data collected in 1996-1997, we conducted additional sampling and/or subsequent investigations at selected sites where there was evidence of potential contaminant exposure. These efforts included:

- additional sampling of the open waters of the GSL to collect data on potential seasonal trends in contaminant exposure on the open lake, and additional sampling of sediments at three "deltas" on the south shore of the GSL formed by freshwater drains and effluents that have historically carried industrial effluents and irrigation return flows (**Section 5**);
- a follow-up evaluation of mercury in eggs of piscivorous birds in the Crystal Unit of the Farmington Bay Waterfowl Management Area (FBWMA) (**Section 6**)
- sampling of sediments at the mouth of the Northwest Oil Drain (NWOD), a canal initially built to carry industrial effluents to the GSL. This canal enters the GSL within the FBWMA, forming a depositional delta which supports a large number of sediment-foraging birds (**Section 7**)

A fourth follow-up investigation of potential uptake and effects of PAHs in barn swallows (*Hirundo rustica)* in Ogden Bay (site ON), was also conducted to evaluate potential impacts from effluents from rail yards and other industries on the Ogden Bay Waterfowl Management Area (OBWMA). A reference site at the Bear River Migratory Bird Refuge (BRMBR), located in a separate watershed north of Ogden Bay was selected as a reference site. Results of this investigation were inconclusive due to logistic and other issues, and are not reported here. However, complete PAH data for the media evaluated (sediments, benthic macroinvertebrates, and barn swallow eggs and nestlings at both sites) are presented in **Appendix E**.

3.0 MATERIALS AND METHODS

Samples of environmental media for this study were collected using procedures designed to prevent cross-contamination and were stored and transferred to preserve the integrity of the sample (e.g., cold storage, fixation and analysis within accepted sample holding times). In general, samples were collected using decontaminated and/or chemically clean collecting equipment and appropriate sample containers. Re-usable equipment (e.g., stainless steel sampling spoons, pans, etc.) was decontaminated before use by washing with a laboratory-grade detergent (e.g., Alconox™), a laboratory-grade 10% nitric acid solution, and a laboratory-grade non-polar solvent such as acetone or hexane, with each step followed by a deionized water rinse. In many cases, site water was used as a final rinse prior to equipment use.

Additional field data collected along with analytical samples included basic water quality field parameters (temperature, conductivity, pH, and dissolved oxygen), meteorological conditions, avian species composition and approximate numbers of birds. This information was recorded into field notebooks or data forms and was retained on file at the field office for later use.

3.1 Collection and Sampling Methods

Sediments – Composited grab samples of surface sediments were collected using a decontaminated stainless steel sampling spoon or a ponar dredge. Composites were formed by mixing samples from three to five sub-locations in a stainless steel pan using a spoon. Sediments were not sieved; however, attempts were made to collect only fine textured material and avoid sediments with a high prevalence of sand or coarser material. The mixed sediments were transferred to three 250 ml labeled chemically clean glass jars with Teflon® lined lids or sealable polyethylene bags if the samples were to be analyzed for inorganic elements only. A desired minimum sample mass was 200 g. Samples were transported on wet or dry ice to the Utah Field Office field lab in Salt Lake City, Utah where they were stored in commercial freezers (-12° C) until shipped on dry ice to the Geochemical and Environmental Research Group (GERG) at Texas A&M, College Station, Texas for analysis.

Invertebrates – Invertebrate samples were collected at riverine, palustrine and lacustrine sites. Preferred taxa included midge larvae (Chironomidae) and mixed benthic invertebrates, including damselfly and dragonfly larvae (Ondonata), plankton (e.g., *Daphnia* spp) and waterboatman beetles (Corixidae). The majority of samples were collected with kick-nets and transferred using forcepsto chemically clean glass jars with Teflon® lined lids. Sealable polyethylene bags were also used for samples to be analyzed for inorganic elements only. Desired minimum sample mass was 10 grams. Light traps (Espinosa and Clark 1972) were used at several sites to collect aquatic invertebrates when kick-nets proved non-productive. Brine shrimp adults and cysts were collected on the South Arm of the GSL from the top 20-30 cm of water surface by towing kick-nets or plankton nets from a boat. Samples of brine shrimp cysts were separated from adults with 500 and 106 micrometer stainless steel sieves. Flying invertebrates were collected at the Bear River MBR and Ogden Bay WMA using sweep nets from moving vehicles along the dike roads. All samples were transported on wet or dry ice to the Utah Field Office lab in Salt Lake City, Utah and stored frozen in commercial freezers (-12° C) until shipped on dry ice to GERG for analysis.

Fish – Fish were collected at major source-waters close to the Great Salt Lake or in wetlands using gill nets, Fyke nets, minnow traps or angling. Three composite, whole-body samples of five adult fish (generally common carp, *Cyprinus carpio*) were collected at most sites, though composite samples of Utah chub (*Gila atraria*) and mosquitofish (*Gambusia affinis*) were also collected. Fish were often held in live wells until processed and samples of similar-sized fish were composited. Total length, weight, sex and body condition were recorded in the field. Large whole-body fish collected for organochlorine analysis were double wrapped in aluminum foil then placed in plastic bags. Samples were stored under dry ice in the field, transported to the Utah Field Office lab and stored in commercial freezers (-12° C)

until shipped to GERG for analysis. Individual fish were collected and tissues dissected for biomarker analysis at selected sites. These included:

AChE Inhibition –Up to six head from each site were individually wrapped in aluminum foil, frozen using dry ice and shipped to the Patuxent Wildlife Research Center (PACF) in Laurel, Maryland for analysis of brain AChE activity. Brains were dissected out of the craniums at the laboratory and prepared for quantification of AChE enzyme activity by spectrophotometry (Ellman et al. 1961).

EROD Activity – Six carp livers from most sites were necropsied in the field using chemically clean or single-use instruments, visually inspected for gross pathological lesions, and weighed to the nearest 0.1 g. Approximately 5 grams of tissue was stored in plastic cryovials and immediately frozen using dry ice. Samples were stored in liquid nitrogen at the Utah Field Office lab until shipped to PACF where they were subsequently prepared and analyzed for EROD activity according to standard methods described in Kennedy and Jones (1994) and Melancon (1996).

PAH Metabolites – Three bile samples were collected from three separate gall bladders from each of eight pre-selected sites using pre-chilled syringes and glass serum collection tubes. Samples were immediately frozen using dry ice and remained frozen until shipped to GERG for analysis of PAH metabolites benzo(a)pyrene, naphthalene, and phenanthrene.

Endocrine Disruption – 20 individual caudal vein blood samples (preferably ten male and ten female) were collected from each site using 25-28 gauge needles and stored in 5 cubic centimeter (cc) heparinized Vacutainer tubes on wet ice prior to transport to the Utah Field Office lab. Plasma was collected using disposable plastic pipettes and frozen at -12º C in polyethylene cryovials after each blood sample was centrifuged at 10,000 rpm (± 10% rpm) for 10 minutes. Samples were shipped frozen to the Florida Caribbean Science Center (FCSC) in Gainesville, Florida. Gonads from these fish were removed and weighed, and approximately 5 grams of gonadal tissue placed in Bouin's preservative solution and also shipped to FCSC for histopathological evaluation and determination of reproductive status.

Bird Eggs – Three to five eggs of wetland-dependent bird species were collected at each of 19 reconnaissance sites during 1996 and 1997, where possible. Black-necked stilt (*Hymantopus mexicanus*) and American coot (*Fulica americana*) were the primary species of choice; however, if these species were not available, secondary choices for egg collections were American avocet (*Recurvirostra americana*) and pied-billed grebe (*Podilymbus podiceps*), followed by other shorebirds or ducks. The two species approach (i.e., shorebirds and "ducks") permitted the evaluation of shoreline/mudflat/playa habitats and open water habitats within one sample site. One randomly selected egg was collected per nest, preferably at a late stage of development to allow for evaluation of viability and deformities in embryos. Eggs were candled (Klett et al 1986) or floated (Westerskov 1950) in the field to determine approximate age. Eggs were held at ambient temperature for a maximum of eight hours and transported to the lab where standard measurements were made, stage of development determined using the method described in Caldwell and Snart (1974) and embryos examined for viability and gross abnormalities. Following measurements, egg contents were then transferred to chemically cleaned containers and stored at -12°C prior to shipment to GERG. All egg samples were individually analyzed for chemical constituents.

Additional barn swallow eggs were collected in 1999 from Ogden Bay WMA and Bear River MBR for PAH analysis. Nests were monitored every two to four days to record clutch size and nesting success, and the approximate age of the eggs was calculated from nest chronology data. Two late-term eggs were collected per nest, prepared as above, and combined into a single composite sample.

Additional Forster's tern (*Sterna forsteri*) eggs were collected in 2000 from the Crystal Unit of Farmington Bay WMA for total and methylmercury analysis. Tern nests were marked during the egg

laying and early incubation stages and one eggs from each of 12 nests was collected and processed as described above approximately three weeks following the initiation of incubation.
Bird Livers – Eared grebes were collected on the South Arm of the Great Salt Lake in 1997, 1998 and 2000 using a shotgun and steel shot. Birds were sampled during spring migration (April and May) and fall migration and molt (September, October, November and December). Age class (young of year, juvenile, adult) for each bird was estimated by plumage and eye color (Jehl 1988). Birds were placed into plastic bags and transported on wet ice to the Utah Field Office lab where they were weighed and necropsied. Livers were removed and weighed using decontaminated instruments and body condition based on internal and subcutaneous fat deposits was recorded. Liver samples collected in 1998 and 2000 were analyzed individually for trace elements. Samples collected in 1997 were equal-weight composites analyzed for inorganic and organic constituents including dioxins and furans. One composite of eight livers came from south of Antelope Island, one composite of nine livers came from midway between Antelope Island and Stansbury Island, and one composite of 5 livers came from north of Stansbury Island.

3.2 Analytical Methods

Inorganic Constituents – Tissues were digested in heavy-walled, screw-cap Teflon® Bombs with concentrated high purity nitric acid and sediments are digested with aqua regia in glass beakers on a hotplate (Analytical Control Facility 2006). Chemical analysis for most inorganic constituents (aluminum, barium, beryllium, boron, cadmium, chromium, copper, iron, lead, magnesium, manganese, molybdenum, nickel, strontium, vanadium and zinc) was performed using inductively coupled plasma atomic emission spectroscopy. Arsenic was analyzed using graphite furnace atomic absorption spectrometry (AAS) while selenium was analyzed using either graphite furnace or hydride generation AAS. Mercury was analyzed by cold vapor AAS described in EPA method 245.5 with minor revisions and a modification of the method of Hatch and Ott (1968). Chemical analysis for trace elements was performed primarily by GERG though some samples were analyzed by PACF.

Organic Constituents – Tissue samples were extracted by the NOAA Status and Trends Method (MacLeod et al 1985) with minor revisions (Brooks et al. 1989; Wade et al. 1988). Sediment samples were freeze-dried and extracted in a Soxhlet extraction apparatus (Analytical Control Facility 2006). Quantitative analyses of chlorinated and non-chlorinated compounds were performed by GERG using capillary gas chromatography (CGC) with a flame ionization detector for aliphatic hydrocarbons, CGC with electron capture detector for OC pesticides and PCBs, and a mass spectrometer detector in the single ion monitoring (SIM) mode for aromatic hydrocarbons (Wade et al 1988). Endosulfan I and PCB congeners 114 and 157 co-elute with other analytes in normal CGC mode with electron capture, so in most cases samples were analyzed by CGC with a mass spectrometer detector in the SIM mode (Analytical Control Facility 2006). Aromatic hydrocarbon metabolites benzo(a)pyrene, naphthalene, and phenanthrene in bile were analyzed using high performance liquid chromatography (HPLC) and methods described in (Krahn et al 1984; Krahn et al 1986a; Krahn et al 1986b). Total petroleum hydrocarbons (TPH) were analyzed by gas chromatography-mass spectrometry. Dioxins and furans were analyzed by high-resolution gas chromatography/high-resolution mass spectrometry (HRGC/HRMS) following methods of (Tondeur 1987; USEPA 1990).

Biomarker Analyses – Brain AChE was analyzed using methods that generally followed the procedures of Ellman et al (1961). Exposure to carbamate pesticides was evaluated by incubating samples with the oxime 2-pralidoxime (2-PAM). AChE activity was quantified using a colorimetric spectrophotometer that measures the rate of production of 5,5'-dithiobis-2-nitrobenzoate produced (DTNB).
EROD enzyme activity was quantified at PACF using standard methods described in Kennedy and Jones (1994) and Melancon (1996). Blood plasma was analyzed at the FCSC for 17β-estradiol (E_2, also referenced in this report as E), 11-ketotestosterone (11-KT, also referenced in this report as T), and vitellogenin at FCSC using methods described in Goodbred et al. (1997). Histopathology of gonads was also performed at the FCSC.

Quality Assurance/Quality Control – Laboratory quality assurance/quality control was monitored by the PACF and individual labs, and also by the authors during the data analysis and reduction phase. Labs performed the required number of blanks, spikes, duplicates and use of standard reference materials according to the contract with PACF.

3.3 Data Analysis

Our objective was to determine spatial trends in contaminants in relation to wetland types or spatial trends in relation to known or suspected contaminant sources or pathways. Various methods were used depending on sample type and sample size. These included statistical comparisons between areas and sampling sites, and comparing data to accepted and relevant benchmarks (e.g., screening levels) for contaminant exposure and effects.

Statistical analysis was performed using either NCSS 2001 (Hintze 2001) or Excel (Microsoft Corp, Redland, WA). NCSS 2001 was also used to produce box plots and scatterplots while Excel was used to produce bar charts. In general, statistical comparisons were more widely used to evaluate metals concentrations due to larger sample sizes and greater detection frequency; organochlorine residues (with the exception of PCBs and DDT) were regularly below the level of detection and so were often evaluated by simple presence/absence/relative magnitude.

Assumptions of normality were tested using either the Shapiro-Wilk W test or the Martinez-Iglewicz test, data were $\log_{10}$-transformed where necessary, and critical significance value was set at $\alpha = 0.05$.

Significant differences among groups (e.g., study areas or study sites) were evaluated using analysis of variance (ANOVA) or T-tests. Differences between areas or sites were determined using the Tukey-Kramer or the Fishers Least Significant Difference tests. Linear regression was used to determine the relationship between mercury and methylmercury in tern eggs while the nonparametric Spearman Rank Correlation test was used to determine correlations between trace elements.

Data were compared to ecotoxicological screening benchmark concentrations where available, as a primary means of identifying locations where constituents could be present at levels of concern to avian species or their habitats. These are identified and discussed in the report, but in general they include (by media):

- *Sediment*- Consensus-based Threshold Effect Concentrations (TECs) and Probable Effect Concentrations (PECs) for adverse effects to fresh-water sediment-dwelling organisms, developed by MacDonald et al. (2000). These are concentrations below which adverse effects would not be expected (TECs) and above which adverse effects are probable (PECs). Although GSL wetlands are generally brackish, they are fed by fresh water, and are more ecologically similar to freshwater wetlands than they are to saline (marine) wetlands. While TECs and PECs do not directly address avian toxicity or effects, they are important to assess impacts to ecosystem and habitat resources that provide food or other services to avian species.
- *Invertebrates, Fish*- Avian dietary No Observed Adverse Effects :Levels (NOAELs) and Lowest Observed Adverse Effect Levels (LOAELS) for avian dietary exposure identified in the toxicological and/or avian resource management literature. These are cited and discussed as they are used in the report. For fish, NOAEL and LOAEL values for adverse effects in the fish themselves were also used as a measure of exposure risk to fish communities as a food source for avian species, similar to how sediment organism effects are addressed by TECs and PECs.
- *Avian eggs*- NOAEL and LOAEL values for adverse effects to avian embryonic growth, teratogenic effects, and chick hatchability and/or survivability identified in the toxicological and/or avian resource management literature. Where appropriate and available, concentrations associated with known areas where contaminants were released or were being remediated (e.g., cited in natural resource damage assessments or environmental cleanup reports) were used to compare concentrations observed in the GSL wetlands to concentrations observed at other sites.

4.0 GREAT SALT LAKE WETLANDS SYNOPTIC SURVEY (1996-1997)

A total of 480 samples of sediments, invertebrates, fish tissues and bird eggs were collected from 27 wetland locations in seven geographic areas around the GSL (**Table 2-1**) in 1996 and 1997 in an effort to systematically assess overall contaminant exposure to migratory birds that use these areas as habitat (see **Appendix Table A-1** for a summary of tissues sampled and analyses conducted at each sampling location). While the goal was to conduct the assessment synoptically—i.e., collecting all samples and all locations within the same period of time—some samples ended up being collected at different times in different locations due to logistical issues, and some sites that were sampled in 1996 were re-sampled in 1997 where preliminary results or other concerns warranted additional sample collection. Complete analytical results from all media collected at all sampling locations are in Appendix A, however the following discussion focuses on the most significant and/or noteworthy findings from the overall wetland assessment.

4.1 Sediments

A total of 34 composite sediment samples were collected from 22 of the 27 wetlands sites, in all seven of the larger geographic areas. All of these samples were split, with one portion analyzed for trace elements, and the other portion submitted for analysis of organic constituents, primarily chlorinated hydrocarbons (particularly those associated with persistent, bioaccumulative compounds such as DDTs and PCBs). Complete analytical results from these samples are presented in **Appendix Tables A-2** and **A-4**. In the following discussion, all concentrations are presented in terms of mg/kg dry weight, and all means are expressed in terms of geometric mean $\pm$ standard error (SE).

Inorganic constituents (trace elements) in Sediments

With the exception of molybdenum (Mo) and selenium (Se) most trace elements were detected in almost all samples. In general, concentrations of common elements (Al, Ba, Fe, Mg, and Mn) were within the range of background concentrations reported in (Shacklette & Boerngen 1984) for Western U.S. soils.

Table 4-1 Summary of analytical data tables contained in Appendix A, Great Salt Lake Wetlands Contaminant Assessment, 1996-1997.

Table Number	Table Title
A-1	Summary of samples collected at Great Salt Lake setlands sites, 1996-1997: Media and analytes, by site and by year
A-2	Trace elements in sediments
A-3	Organic chemicals in sediments
A-4	Trace elements in macroinvertebrates
A-5	Organic chemicals in invertebrates
A-6	Trace elements in fish
A-7	Organic chemicals in fish
A-8	Trace elements in avian eggs
A-9	Organic Chemicals in Avian Eggs
A-10	Brain acetylcholinesterase (AChE) activity in common carp
A-11	Brain ethoxyresorufin-O-deethylase (EROD) activity in common carp

Sediment threshold effect concentration (TEC) and probable effect concentrations (PEC; MacDonald et al. 2000) benchmarks (see Section 3) were exceeded in at least one location all eight of the elements most commonly associated with ecological toxicity-- arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), selenium (Se) and zinc (Zn) (**Table 4-2**). Copper and lead were most frequently present in concentrations that exceeded both TECs (> TEC in 28 of 34 samples) and PECs (Cu > PEC in 9 of 34 samples; Pb > PEC in 8 of 34 samples).

Sediment TECs, which are a more conservative, "threshold" measure of adverse effect, were frequently exceeded in many locations, such that it was difficult to make any qualitative comparisons between sites. However sediments at two sites, the Oil Drain Canal (Site IO, in the Industrially Impacted Wetlands geographic area) and the Salt Lake City Wastewater Treatment Plant (Site IS, in the same area), exceeded the TEC for each of the eight trace elements listed above. Both of these sites have a known history of contamination, with Site IO located within a canal that was historically used to transport refinery and metropolitan wastewaters to the GSL, and Site IS located in a treatment wetland (to provide tertiary treatment for wastewater) placed on land that was formerly part of an industrial site.

Sediment PECs, which are a threshold above which adverse impacts to sediment macroinvertebrates are probable, were a more useful benchmark for differentiating sites where avian populations might be impacted either directly through toxicity to the birds, or indirectly through adverse changes in the composition and abundance of invertebrate food sources. Here again, sites IO and IS had the greatest number of exceedences, with six of the eight metals (all but As and Pb) >PECs at the former and four of the eight metals (Cr, Cu, Hg, and Pb) >PECs at the latter.

Arsenic, copper and selenium- The highest overall concentrations of As and Cu were observed at the two study sites that make up the South Shore Wetland area, the C-7 Ditch (Site LC) and the Great Salt Lake State Park/Salt Aire Park (Site LS). Site LC also had the highest overall concentrations of Se observed in the GSL wetlands investigation. All (4 of 4) samples collected at Sites LC and LS exceeded the PEC for As (33 mg/kg), as did the means at these sites (47.0 $\pm$1.3 mg/kg). Copper was significantly higher at Sites LC and LS than anywhere else around the GSL (**Figure 4-1**), with the maximum observed Cu concentration in the GSL wetlands investigation (1,205 mg/kg) observed at site LC. The mean concentration for the area (914 $\pm$ 154 mg/kg) was more than six times the PEC of 149 mg/kg. Copper was also elevated at other locations around the GSL, with mean Cu concentrations > TEC in all areas except for Farmington Bay North (Figure 4-1). However, Cu was lower away from the South Shore area, with the highest Cu concentration (426 mg/kg at Site IS) lower than the lowest concentration observed at Site LS (519 mg/kg). Selenium was the least frequently detected trace element around the GSL, with observable concentrations (DL = 1.0 mg/kg) recorded in only 15 of 34 sediment samples. However, all samples collected at Sites LC and LS had detected Se; both samples from site LC exceeded the PEC[1] of 4.0 mg/kg. The Southeast Shore Industrially Impacted Wetlands, comprised of wetlands with past and/or present industrial impacts, also had Se consistently detected in sediments. However only one of the six samples collected in this area (at Site IS) had Se > PEC (**Table 4-2**).

Lead was present in all 34 sediment samples, and was present at mean concentrations that exceeded the TEC of 35.8 mg/kg in all geographic locations but Antelope Island and the wetlands in Farmington Bay North (**Table 4-2**). Lead concentrations in sediments were most elevated in the Southeast Shore Industrialized Wetlands (SE Shore Industrial area), where three of five sediment samples exceeded the PEC of 128 mg/kg, and Ogden Bay, where four of five samples were >128 mg/kg, as was the mean (163 $\pm$58.6 mg/kg). Lead in Ogden Bay sediments was significantly higher than in any other geographic area around the lake (p = 0.01).

1 The PEC for selenium (4.0 mg/kg) is an upper toxicity threshold identified by the U.S. Bureau of Reclamation's National Irrigation Water Quality Program (NIWQP, 1998), rather than a consensus-based PEC (MacDonald et al., 2000)

Table 4-2. Summary of select trace elements (mg/kg, dry weight) in Great Salt Lake wetland sediments by geographic area and exceedances of Consensus-Based toxicity thresholds; Great Salt Lake Wetlands Synoptic Survey, 1996-1997.

Trace Element		Antelope Island	South Shore	S. Shore Wetlands	SE Shore Industrial	Farmington Bay S	Farmington Bay N	Ogden Bay
# of sites		*3*	*2*	*4*	*4*	*4*	*2*	*3*
# of samples (n=)		*3*	*4*	*10*	*6*	*4*	*2*	*5*
Arsenic	*Gmean*	6.1	**<u>47.5</u>**	**16.2**	**13.2**	**10.5**	4.6	**12.2**
	Max	14.0	50.8	49.6	20.7	22.2	9.7	15.5
#>Ref [9.8 / 33.0][1]		[0 / 0]	[4 / 4]	[7 / 1]	[5 / 0]	[3 / 0]	[0 / 0]	[4 / 0]
Cadmium	*GMean*	0.29	**1.54**	0.71	**2.27**	0.87	nc	**1.74**
	Max	0.4	3.6	0.95	8.1	1.3	1.2	2.9
#>Ref [0.99 / 4.98		[0 / 0]	[3 / 0]	[0 / 0]	[6 / 1]	[3 / 0]	[1 / 0]	[4 / 0]
Chromium	*GMean*	13.7	28.1	18.5	**47.5**	29.3	18.9	19.3
	Max	22.6	46.1	25.8	183	41.8	30.0	25.2
#>Ref [43.4 / 111]		[0 / 0]	[1 / 0]	[0 / 0]	[3 / 2]	[0 / 0]	[0 / 0]	[0 / 0]
Copper	*GMean*	**49.3**	**<u>914</u>**	**82.5**	**146**	**65.6**	20.5	**41.5**
	Max	58.8	1205	356	426	124	42.2	58.1
#>Ref [31.6 / 149]		[2 / 0]	[4 / 4]	[9 / 2]	[6 / 3]	[3 / 0]	[1 / 0]	[4 / 0]
Lead	*GMean*	21.2	**65.4**	**49.7**	**127**	**70.8**	10.6	**<u>163</u>**
	Max	28	108	104	364	171	45	386
#>Ref [35.8 / 128]		[0 / 0]	[4 / 0]	[9 / 0]	[5 / 3]	[3 / 2]	[1 / 0]	[5 / 4]
Mercury	*GMean*	0.04	0.14	0.07	**0.27**	**0.21**	nc	**0.31**
	Max	0.07	0.258	0.08	1.52	0.31	0.08	0.48
#>Ref [0.18 / 1.06		[0 / 0]	[2 / 0]	[0 / 0]	[3 / 2]	[3 / 0]	[0 / 0]	[4 / 0]
Selenium	*GMean*	nc	**3.76**	nc	**1.58**	nc	nc	nc
	Max	nd	6.48	2.79	5	1.78	nd	1.43
#>Ref [1.0 / 4.0]		[0 / 0]	[4 / 2]	[3 / 0]	[5 / 1]	[1 / 0]	[0 / 0]	[1 / 0]
Zinc	*GMean*	57.5	**194**	106	**292**	**157**	67.8	**256**
	Max	65.4	407	180	611	354	113	516
#>Ref [121 / 459]		[0 / 0]	[3 / 0]	[3 / 0]	[5 / 2]	[3 / 0]	[0 / 0]	[4 / 1]

<u>KEY AND ABBREVIATIONS</u>

#>Ref [TEC / PEC]: Number of samples that exceed Threshold Effects Concentration (TEC) and Probable Effects Concentration (PEC) (MacDonald et al. 2000). For Se, TEC= Se background, PEC= Se toxicity threshold (National Irrigation Water Quality Program 1998)

Gmean: Geometric mean concentration for geographic area
Gmean: Gmean>TEC
<u>Gmean:</u> Gmean>PEC

NC: Not Calculated (geometric mean not calculated because >50% of values were less than the detection limit)

ND: Not Detected (all samples were < detection limit)

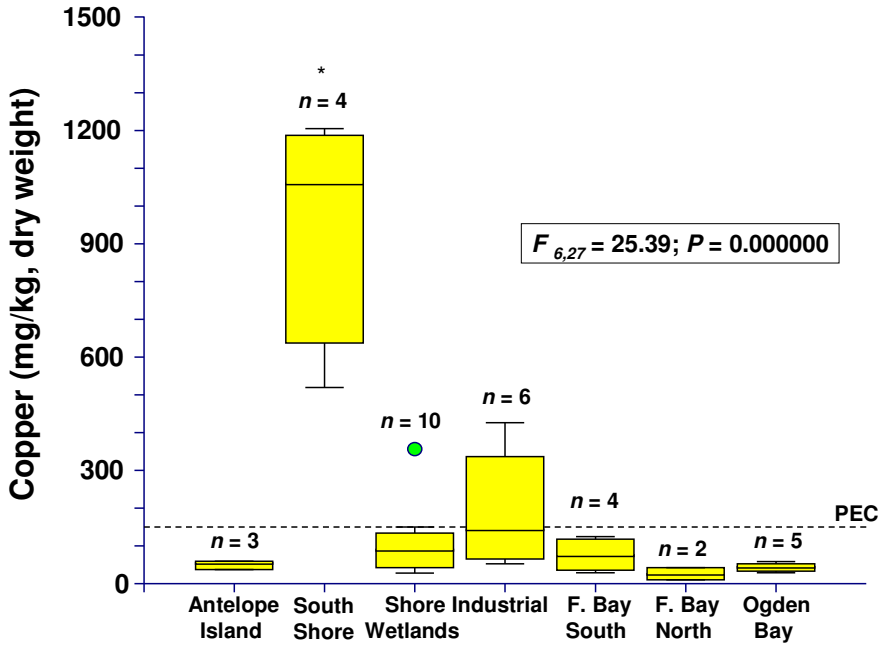

Figure 4-1 Concentrations of copper in wetland sediments by geographic area, Great Salt Lake Wetlands Synoptic Survey, 1996-1997. "*" denotes significant difference from other areas.

Cadmium, Chromium, Mercury- The TECs for at least one of these trace elements (0.99 mg/kg Cd, 43.4 mg/kg Cr and 0.18 mg/kg Hg) were exceeded in at least one sample for all geographic areas except for Antelope Island (**Table 4-2**). However, PECs for these elements (4.98 mg/kg Cd, 111 mg/kg Cr and 1.06 mg/kg Hg) were only exceeded at the SE Shore Industrial area (10 samples from two sites, IO and IS. Cadmium was significantly higher there (p = 0.04) than at the nearby South Shore Wetlands and was elevated compared to concentrations at Antelope Island, Farmington Bay South, and Farmington Bay North. Although mean concentrations of Cr were not significantly different among areas (p = 0.07), the SE Shore Industrial area was the only place where the mean concentration of Cr exceeded the TEC and where samples with Cr >PEC were observed. Mercury was detected at mean sediment concentrations > TEC in three geographic areas (SE Shore Industrial, Farmington Bay South and Ogden Bay), but again the SE Shore Industrial area was the only one where Hg was detected in concentrations > PEC. However, the highest mean Hg concentration (0.31 $\pm$ 0.07 mg/kg) was observed in Ogden Bay. Concentrations of mercury were not significantly different among areas.

Zinc- Half of the sediment samples collected around the GSL wetlands had Zn > TEC (121 mg/kg), and mean Zn concentrations exceeded the TEC at four of the seven geographic areas evaluated. The PEC (459 mg/kg) was exceeded in the SE Shore Industrial area (both Sites IO and IS) and in Ogden Bay (at Ogden Bay South, Site OS). Mean Zn concentrations in these two geographic areas were elevated compared to the other geographic areas around the lake, but not significantly so. However mean Zn concentrations at the SE Shore Industrial area were significantly elevated (p = 0.01) compared just to the nearby Antelope Island and South Shore Wetland areas.

Organic Compounds in Sediments

Complete analytical results for the 34 sediment samples submitted for analysis are presented in **Appendix Table A-3**; this table includes only organochlorine (OC) compounds that were detected in at least one sample. Many of the constituents were present in sediments in very low concentrations, and were quantified by the laboratories in µg/kg (parts per billion). Detection limits for most compounds were in the parts per trillion range (<1 µg/kg). However, to allow easier comparison with trace element results, all concentrations in sediments discussed below are expressed in terms of mg/kg dry weight.

Three of the OCs evaluated-- α-BHC, pentachloro-anisole and toxaphene—were not detected in any of the samples. Twenty three of the 26 OCs evaluated were detected in at least one sediment sample. The most frequently detected OCs in sediment were *p,p'*-DDE (28 detections), and α- and γ-chlordanes (25 detections each). Other OCs that were detected in more than 50% of the samples were *o,p'*-DDE, *p,p'*-DDT, dieldrin, and *cis*-and *trans*-nonachlors.

DDTs (ortho (o,p'-) and para (p,p'-) isomers of DDD, DDE and DDT) – Residues of DDT-based pesticides were still detectable in sediments in GSL wetlands 20 years after their use was discontinued. In all, 12 of the 23 sites, in five of the seven geographic ranges, had detectable DDT residues. The most frequently detected isomer was p,p' DDE, which was found in 28 of the 34 samples. If p,p' DDE was not present, there were no DDT residues detected at all in the sample. One of the two sediment samples collected at Site IS had the highest observed concentration of total DDT residues, 0.207 mg/kg. However, the other sample collected at this site had only 0.004 mg/kg total DDTs. This provides an example of the potential for uneven distribution of contaminants at waste-impacted sites (i.e., "hot-spots") which translates into unevenly distributed potential for exposure (and ecological risks) at these sites. No sites (including Site IS) had sediments with total-DDT > PEC (0.052 mg/kg), however the "high" sediment sample at site IS exceeded the PECs for total DDE (*o,p'*- and *p,p'*- isomers); 0.031 mg/kg) and total DDT isomers (*o,p'*- and *p,p'*-; 0.063 mg/kg). Two other wetland sites Farmington Bay South (Site FP, a single sample) and Ogden Bay (Site ON, one sample out of two) also exceeded the PEC for total DDEs.

Non-DDT Organochlorine Pesticides/Herbicides - This diverse class of OCs includes compounds that were formerly widely used, such as dieldrin, chlordane, and mirex, and their environmental breakdown products. Trace residues of at least one of these OCs were detected at all of the wetland sites surveyed (see **Appendix Table A-4** for complete analytical results). However, concentrations exceeding TECs were detected at only seven of the sites (**Table 4-4**). The more contaminated sample from Site IS (above) also had the most non-DDT OC residues detected, and detected at the highest concentrations—this was the only site at which these compounds exceeded PECs. Site IO (the Oil Drain), also in the industrially-impacted wetlands geographic area, had six non-DDT OC's detected at concentrations > TECs, but all were less than PECs. It is relevant that both of these sites have been impacted by wastewater effluents over periods of time dating back to when non-OC pesticides were routinely applied, and it is likely that the concentrations observed at both of these sites are associated with those practices.

Polychlorinated Biphenyls (PCBs) - PCBs are a large class of OCs consisting of 209 congeners that differ by the number and position of chlorine atoms substituted on a core biphenyl ring structure. They are ubiquitous in the environment, based largely on their former widespread use and their resistance to environmental degradation. Results from the GSL wetlands were consistent with this trend, with total PCBs (t-PCB, all congeners combined) detected in all sediments sampled around the GSL, including at sites with relatively little disturbance or contamination history (e.g., site AO on Antelope Island). The highest concentrations of PCBs were observed at sites at or near known former sources such as industry or waste management. The "high" sample from Site IS (with elevated concentrations of other OCs) had 4.14 mg/kg t-PCB, well above the PEC of 0.68 mg/kg. Consistent with observed concentrations of other OCs at site IS, the other of the two samples collected had much lower t-PCB (0.004 mg/kg; see **Appendix Table A-3**). Site IO was the only other site where t-PCB > PEC (**Figure 4-2**). The TEC for t-PCB (0.060 mg/kg) was exceeded at 10 additional sites.

Table 4-3 Maximum detected concentrations of DDT isomers and total DDT residues in sediments (mg/kg, dw), compared with screening threshold concentrations, Great Salt Lake Wetlands Synoptic Survey, 1996-1997

		o,p'-DDD + *p,p'*-DDD	*o,p'*-DDE + *p,p'*-DDE	*o,p'*-DDT + *p,p'*-DDT	Total DDT [b]
Threshold Effects Concentration (TEC)[a]		**0.0049**	**0.0032**	**0.0042**	**0.005**
Probable Effects Concentration (PEC)[a]		***0.028***	***0.031***	***0.063***	***0.572***
Area #2: Antelope Island:	*(n)**				
Antelope Island offshore (AO)	*1*	0.0005	0.0005	ND	0.001
Antelope Island East (AE)	*1*	0.0003	0.0004	0.0006	0.001
Antelope Island South (AS)	*1*	ND	0.0002	ND	<0.001
Area #3: GSL South Shore:					
C7 Ditch (LC)	*1*	0.0010	0.0017	0.0003	0.003
Saltair/GSL State Park (LS)	*2*	ND	ND	ND	ND
Area #4: South Shore Wetlands:					
Airport Mitigation Site (SA)	*2*	0.0016	**0.0076**	ND	**0.009**
Gillmor Sanctuary (SG)	*5*	0.0009	0.0013	ND	0.002
Goggin Drain (SD)	*1*	0.0006	0.0005	0.0002	0.001
North Point Canal (SN)	*2*	0.0007	0.0018	**0.0046**	**0.007**
Area #5: SE Shore Industrial Wetlands:					
Beck Hot Springs (IB)	*1*	0.0017	0.0014	0.0004	0.003
Oil Drain Canal (IO)	*2*	**0.0079**	**0.0168**	**0.0489**	**0.074**
Petrochem Ponds (IP)	*1*	0.0031	0.0026	ND	**0.006**
SLC Sewage Treatment Plant (IS)	*2*	**0.0213**	***0.0458***	***0.1402***	**0.207**
Area #6: Farmington Bay South:					
Bountiful Pond (FP)	*1*	**0.0049**	***0.0335***	0.0036	**0.042**
FBWMA- Crystal Unit (FC)	*1*	0.0016	0.0010	0.0004	0.003
NW Oil Drain Delta (FO)	*1*	0.0008	0.0027	ND	0.004
State Canal (FS)	*1*	**0.0164**	**0.0194**	0.0036	**0.039**
Area #7: Farmington Bay North:					
Bair Creek (FB)	*1*	ND	ND	ND	ND
Kaysville Marsh (FK)	*2*	0.0017	**0.0096**	0.0031	**0.014**
Area #8: Ogden Bay:					
Howard Slough (OH)	*1*	0.0018	**0.0047**	ND	**0.007**
Ogden Bay WMA- North (ON)	*2*	**0.0174**	***0.0359***	0.0036	**0.057**
Ogden Bay WMA- South (OS)	*1*	0.0021	**0.0033**	0.0017	**0.007**
Ogden Bay WMA- South Canal (OC)	*1*	0.0017	0.0026	0.0021	**0.006**

KEY

0.001 Value > TEC

0.001 Value > PEC

**Values given for sample with maximum "Total DDT" concentration if > 1 sample collected at a site*

NOTES & ABBREVIATIONS:

ND = Compound not detected

(n) = number of samples per site

(a) Threshold Effects Concentrations (TEC) and Probable Effects Concentrations (PEC) from MacDonald, et al., 2000

(b) sums calculated using (0.5 x DL) for isomers that were not detected. If no DDT isomers were detected in a sample, a "total DDT isomers" sum was not calculated

Table 4-4 Maximum detected concentrations of non-DDT organochlorine pesticide residues exceeding screening benchmarks in sediments (mg/kg, dw), Great Salt Lake Wetlands Synoptic Survey, 1996-1997

	dieldrin	endrin	beta BHC	gamma BHC	alpha chlordane[a]	gamma chlordane[a]	oxy chlordane[a]	Heptachlor[b]	heptachlor epoxide
Threshold Effects Concentration (TEC)	**0.0019**	**0.0022**	**0.005**	**0.003**	**0.0032**	**0.0032**	**0.0032**	**0.0025**	**0.0025**
Probable Effects Concentration (PEC)	***0.062***	***0.207***	***0.21***	***0.005***	***0.018***	***0.018***	***0.018***	***0.016***	***0.016***
Area #2: Antelope Island:									
Antelope Island offshore (AO)	0.0004	ND	ND	0.0004	**0.004**	ND	ND	ND	ND
Antelope Island East (AE)	ND	ND	ND	0.0004	0.001	0.0002	ND	ND	ND
Antelope Island South (AS)	ND	ND	ND	0.0001	0.000	ND	ND	ND	ND
Area #3: GSL South Shore:									
C7 Ditch (LC)	0.0002	ND	ND	ND	0.001	0.0005	ND	ND	ND
Saltair/GSL State Park (LS)	ND	ND	**0.009**	ND	ND	0.001	ND	ND	ND
Area #4: South Shore Wetlands:									
Airport Mitigation Site (SA)	ND	ND	ND	ND	ND	ND	ND	ND	ND
Gillmor Sanctuary (SG)	0.0002	ND	ND	0.0002	0.001	0.001	ND	ND	ND
Goggin Drain (SD)	0.0001	ND	ND	0.0001	0.000	0.0002	ND	ND	ND
North Point Canal (SN)	0.0003	ND	0.0001	0.0003	0.000	0.0003	ND	0.000	ND
Area #5: SE Shore Industrial Wetlands:									
Beck Hot Springs (IB)	0.0003	ND	0.004	0.0003	0.002	0.000	ND	ND	ND
Oil Drain Canal (IO)	**0.020**	**0.004**	ND	ND	**0.013**	**0.013**	**0.017**	**0.003**	ND
Petrochem Ponds (IP)	ND	0.0006	0.0009	ND	ND	0.001	0.0005	ND	ND
SLC Sewage Treatment Plant (IS)	***0.066***	ND	0.0004	***0.008***	***0.050***	***0.050***	ND	***0.021***	**0.008**
Area #6: Farmington Bay South:									
Bountiful Pond (FP)	0.0009	ND	ND	ND	0.001	0.001	ND	ND	ND
FBWMA- Crystal Unit (FC)	0.0002	ND	ND	ND	0.002	0.001	ND	ND	ND
NW Oil Drain Delta (FO)	0.0016	ND	ND	ND	0.002	0.003	ND	ND	ND
State Canal (FS)	**0.011**	ND	ND	ND	**0.005**	**0.007**	0.0007	ND	0.000
Area #7: Farmington Bay North:									
Bair Creek (FB)	ND	ND	ND	ND	ND	ND	ND	ND	ND
Kaysville Marsh (FK)	0.0006	ND	ND	0.0002	0.002	**0.002**	0.0002	ND	0.000
Area #8: Ogden Bay:									
Howard Slough (OH)	ND	ND	ND	ND	0.001	0.003	ND	ND	ND
Ogden Bay WMA- North (ON)	0.0008	ND	0.0008	ND	0.001	**0.002**	ND	ND	ND
Ogden Bay WMA- South (OS)	0.0005	ND	0.0002	ND	0.000	0.000	0.0002	ND	0.000
Ogden Bay WMA- South Canal (OC)	0.0004	ND	ND	ND	0.001	0.002	0.0002	ND	ND

KEY:

0.001	Maximum detected value
0.001	Maximum detected value > TEC*
0.001	Maximum detected value > PEC*
	**Ingersol,et al, 2000*

NOTES AND ABBREVIATIONS:

Max: Maximum detected concentrations shown

ND: Residue not detected in samples from site.

(a): TEC and PEC for chlordane used for evaluation

(b): TEC and PEC for heptachlor expoxide used for evaluation

While one of the explanations for the broad distribution of PCBs is their environmental persistence, atmospheric deposition is also a mechanism for their distribution. Depending on the congener and its source, PCBs can be volatilized into the upper atmosphere where they can then be transported by global air currents, evidenced by observations of PCBs in arctic and Antarctic habitats (Lemmetyinen and Rantamaki 1980). This may explain their presence in wetlands in even what are perceived as relatively pristine locations, such as Antelope Island. However, another possible, closer source of PCBs to the GSL wetlands is a magnesium processing facility on the west shore of the GSL, U.S. Magnesium. This facility separates magnesium via electrolysis from highly concentrated GSL brines which contain magnesium chloride ($MgCl_2$). A by-product of the facilities' processing of GSL brines is chlorinated hydrocarbons. In limited "stack sampling" of the facility's air emissions, the U.S. EPA and others have detected a large number of highly chlorinated hydrocarbon compounds , including hydrochlorbenzene (HCB, C_6Cl_6), dioxins and furans, and "PCB-209"(decachlorobiphenyl, or $C_{10}Cl_{10}$). PCB-209 is considered rare in the environment, but it has been consistently detected in environmental media at the U.S. Magnesium facility (U.S. EPA, unpublished data), and is considered to be a "fingerprint" compound for the facility. PCB-209 is potentially less toxic than other PCB compounds due to its large molecular size (caused by the large number of chlorines substituted onto the PCB structure), but it is evident that it is bioavailable. However its ecological toxicity has not been evaluated. The distribution of PCB-209 in the GSL ecosystem beyond the boundaries of the U.S. Magnesium facility has also not been evaluated to date.

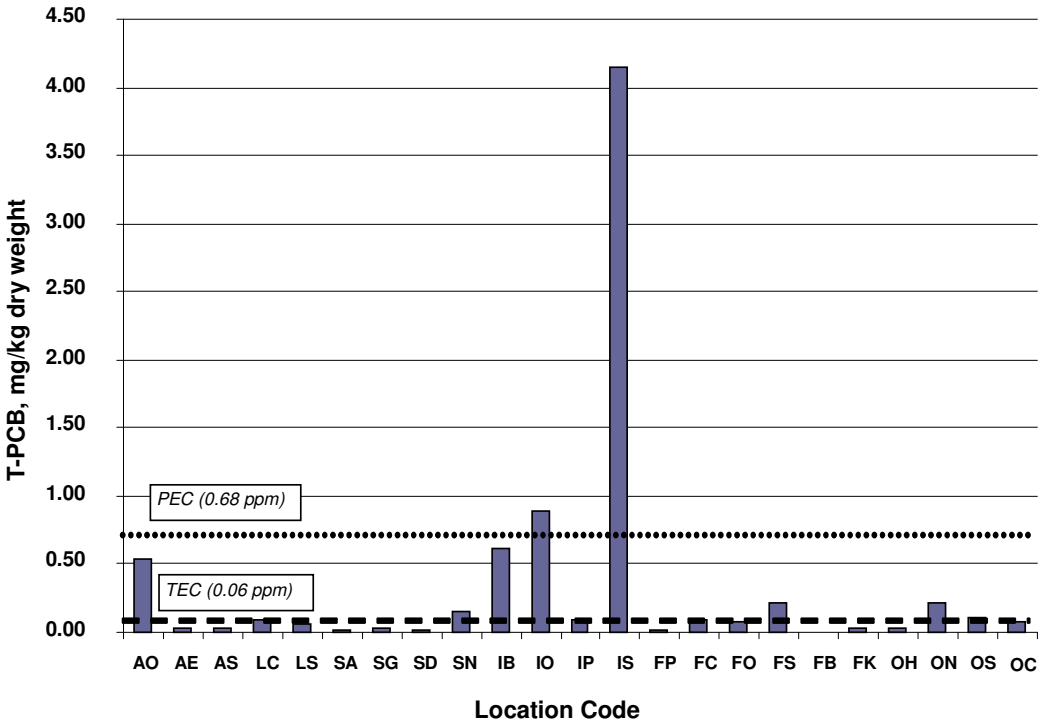

Figure 4-2 Maximum detected concentrations of total PCBs in sediments (mg/kg) compared to screening threshold concentrations, Great Salt Lake Wetlands Synoptic Survey, 1996-1997

Dioxins and Furans - Dioxins and furans can be contaminants in manufactured organochlorine compounds, such as the combination of the herbicides 2,4-D and 2,4,5-T ("agent orange"), but they are also spontaneously formed as products of incomplete combustion in the presence of chlorine. Sediment samples were collected at four locations (one each) chosen on the basis of proximity to suspected dioxin sources, including the east side of Antelope Island (Site GA, facing US Magnesium); the C-7 Ditch site on the south shore of the GSL (Site LC); a wetland mitigation site on the southeast shore of the GSL (the "Airport Mitigation" site, SA); and the State Canal (Site FS) in Farmington Bay. Seven of 17 dioxin/furans analyzed were detected in at least one sample (see **Appendix Table A-3**), at concentrations slightly above detection limits (about 1-3 parts per trillion). When these compounds were converted to toxicity-equivalent concentrations of TCDD (the most toxic of the compounds) using TCDD toxicity equivalence factors (TEFs) (Van Leeuwen 2003) and summed, the resultant total TCDD-TEF concentrations fell well below sediment benchmark concentrations (CCME 1999).

Total Petroleum Hydrocarbons (TPH) - Sediments from 31 of the wetland sites were selected for TPH analysis based on past land use at the site and/or proximity to potential sources of hydrocarbon spills and releases. All 31 had detectable concentrations of TPH ranging from 28 mg/kg at Bair Creek (Site FB) in the Farmington Bay South area to 96,560 mg/kg at Site IS (**Appendix Table A-3**). While TPH is typically used as a screening tool to identify hydrocarbon contamination, this "analyte" is actually the sum of total extractable petroleum hydrocarbons present in a sample, and consists of several hundred individual aliphatic and aromatic hydrocarbon compounds with widely varying individual toxicity characteristics. There are no ecologically derived screening benchmarks for TPH, but benchmark values ranging from 50 to 1,000 mg/kg are used by various state environmental agencies to guide cleanup of petroleum contaminated sites. The highest overall TPH concentrations in the GSL wetlands were detected in areas with a history of petroleum management operations in the upstream watershed, most notably the industrially-impacted wetlands on the southeast shore of the GSL, including site IS (with the maximum detected concentration of TPH), and Site IO, with 13,792 – 28,906 mg/kg TPH, respectively. Four of the five sediment samples collected at the industrially impacted wetlands sites had TPH >1,000 mg/kg, with far higher concentrations observed at Site IS (the sediment sample with elevated concentrations of other OCs), and Site IO (**Table 4-5**). While present at much lower concentrations than in the industrially impacted wetlands, TPH was higher than expected at the Antelope Island sites (**Table 4-5**). This may be due to spills and releases from nearby marinas.

Table 4-5. Total petroleum hydrocarbons (TPH) > 1,000 mg/kg in sediments, Great Salt Lake Wetlands Synoptic Survey, 1996-1997

Sample Site Description	TPH, mg/kg
Area #2: Antelope Island (3 sites)	
Antelope Island offshore (GA)	**2,412**
Antelope Island East (AE)	**1,173**
Area #3: GSL South Shore (2 sites)	
C7 Ditch (LC)	**1,204**
Area #4: South Shore Wetlands (4 sites)	
North Point Canal (SN)	**1,221**
Area #5: South Shore Industrially Impacted Wetlands (4 sites)	
Beck Hot Springs (IB)	**1,564**
Oil Drain Canal (IO)	**28906**
SLC Sewage Treatment Plant (IS)	**96560**
Area #6: Farmington Bay South (4 sites)	
State Canal (FS)	**6042**
Area #7: Farmington BayNorth (2 sites)	
Kaysville Marsh (FK)	**1240**
Area #8: Ogden Bay (4 sites)	
Ogden Bay WMA- North (ON)	**1305**
Ogden Bay WMA- North (ON)	**3280**
Ogden Bay WMA- South (OS)	**1058**

4.2 Invertebrates

Twenty-eight composite invertebrate samples were collected from twenty-two wetland sites within seven areas during 1996 and 1997 and evaluated for trace elements; complete analytical results are presented in **Appendix Table A-4**. At sixteen of these sites, samples were split and a representative sub-sample was submitted for analysis of OCs (typically one sample per wetland location); two OC samples were submitted for sites IS and FK. Complete results of OC analyses are presented in **Appendix Table A-5**. Where practical and achievable, invertebrate samples were collected from the same sample locations as sediment samples. Metals results were reported by the laboratory in mg/kg dry weight, and are presented here in those units. As was the case with sediments, invertebrate organochlorine analyses were reported by the laboratory in µg/kg (ppb) dry weight, but have been converted to mg/kg (dry weight) here both for comparison with metals concentrations, and also for comparison with avian dietary benchmarks, which are typically reported in mg/kg. Concentrations of constituents in invertebrates were compared with literature-based no observed adverse effects levels (NOAELs) and lowest observed adverse effects levels (LOAELs) in the diet of birds, and are identified as they are discussed below.

Invertebrate groups collected within the GSL wetlands included chironomids (midge larvae), Odonates (dragonfly and damselfly larvae), *Ephydra* sp. (brine fly larvae), and Corixids (water boatman). One sample of midge larvae from the Audubon Gilmore Sanctuary site (Site SA) was only analyzed for selenium due to limited sample mass; therefore, there are only twenty-seven data points for the remaining metals. Because sediments were not depurated from the invertebrates prior to sampling, species in direct contact with sediments (i.e., chironomid larvae) were more influenced by sediment concentrations than other taxa. This was a significant factor in the comparison of metals concentrations between taxa (see

below); although it was not evaluated for OC residues because of overall low detection rates, it is most likely a factor in those results as well.

Inorganic Constituents (trace elements) in Invertebrates

Most of the trace elements analyzed were detected in invertebrates, with the "essential elements" (e.g., Ca, Cu, Fe, Mg, Mn, and Zn) occurring in all samples. Trace elements associated with contamination occurred less frequently, including Hg (in 54% of samples), Be (25%), V (11%), Cd, Pb, Se (7%), As and Ni (4%). Chironomid larvae had significantly higher concentrations of a number of elements (Al, Ba, Be, Cr, Fe, Mg, Ni, Pb, and V) than other taxa ($P = 0.05$), but invertebrate type did not significantly influence trace element concentrations between areas ($P < 0.001$). With the exception of Mn, there were no significant differences in metals concentrations between geographic areas using pooled data for each element. However, concentrations of several trace elements exceeded avian dietary thresholds at specific locations, as did geometric mean concentrations at several of the geographic areas evaluated (**Table 4-6**). The discussion below highlights the trace elements observed to be at the highest concentrations or most frequently exceeding avian dietary levels of concern (LOCs). Means discussed below are geographic means; results are discussed in terms of mg/kg dry weight.

Lead- Mean concentrations of Pb exceeded the avian dietary LOC of 5 mg/kg (2000) in five of the seven geographic areas evaluated, including wetlands managed primarily for hunted waterfowl in Farmington Bay South and Ogden Bay, with the highest concentration (17.4 mg/kg) occurring in the Ogden Bay area. Mean lead > LOC was also observed in the South Shore Wetlands area and the Industrially-Impacted wetlands, with the maximum concentration (74.2 mg/kg) observed in the South Shore Wetlands. Overall, 17 of 28 invertebrate samples analyzed had Pb > LOC. Ten of these samples were of chironomid larvae, including the five highest concentrations. Most GSL wetland areas have been used by waterfowl hunters since at least the early 20th century, so lead shot is a likely source of the lead observed in both sediments and invertebrates, particularly in waterfowl management areas. Like most metals, lead compounds (i.e., lead salts) in soil are less bioavailable in neutral to alkaline soil or water environments. However, metallic lead, either in the form of shot pellets or pellet fragments, can be highly bioavailable and toxic in the digestive system, where it can be solubilized by stomach acids and immediately taken up in blood. Given that the areas where high Pb was identified are managed for waterfowl productivity and hunting, further investigation of the distribution and magnitude of lead contamination in sediments (e.g., in historically heavily hunted and/or highly productive areas) may be warranted.

Chromium- Chromium was the only other trace element for which mean concentrations greater than the avian LOC (10 mg/kg; (2000)) were observed. In all, nine of the 28 invertebrate samples exceeded the LOC. The highest concentration of Cr (31.9 mg/kg) occurred at the OH (Howard Slough) site within the Ogden Bay area; contributing to a mean concentration of 11.0 mg/kg for the Ogden Bay geographic area. Farmington Bay North also exceeded the LOC, with a mean Cr concentration of 11.6 mg/kg. Although the LOC was exceeded in these two areas, they were not significantly higher than any of the other geographic areas ($F_{6,20} = 0.74$; $P = 0.62$).

Aluminum- Geometric mean concentrations of Al were less than the avian dietary NOAEL of 5,000 mg/kg (Sparling 1990) in all seven of the GSL geographic areas evaluated (Table 4-6). However, five samples (all chironomids) exceeded this NOAEL, including at Site SI (the Inland Sea Shorebird Reserve, a wetland mitigation within the GSL South Shore wetlands area) which had the maximum observed concentration (10,707 mg/kg). Although Al is not a contaminant of concern for GSL wetlands based on past industrial activities, it may be elevated in some areas (particularly those containing GSL lakebed sediments) because of the evaporitic nature of the GSL and its sediments. This is likely the cause of elevated concentrations of other evaporates such as boron and zinc as well. High concentrations of Al

Table 4-6. Geometric mean and maximum detected concentrations of selected trace elements (mg/kg, dry weight) in invertebrates by geographic area, compared with available avian dietary effect thresholds, Great Salt Lake Wetlands Synoptic Survey, 1996-1997.

Trace Element		Antelope Island	South Shore	S. Shore Wetlands	SE Shore Industrial	Farmington Bay S	Farmington Bay N	Ogden Bay
	n=	*3*	*6*	*5**	*4*	*4*	*2*	*3*
Aluminum	Gmean	265	665	2624	958	2656	4749	2831
	Max	1348	8262	10707	2822	6009	9888	8312
[#>Ref]	[5000][1]	[0]	[1]	[2]	[0]	[1]	[1]	[2]
Arsenic	GMean	3.9	11.8	2.1	1.7	2.9	4.3	5.0
	Max	10.5	51.1	9.3	2.7	4.4	8.4	5.6
[#>Ref]	[30]	[0]	[1]	[0]	[0]	[0]	[0]	[0]
Boron	GMean	15.2	15.9	11.4	18.9	5.8	5.3	8.3
	Max	49.0	36.3	53.0	35.6	15.2	13.7	20.7
[#>Ref]	[30]	[1]	[3]	[1]	[1]	[0]	[0]	[0]
Cadmium	GMean	0.14	0.3	0.8	0.49	0.53	0.57	0.3
	Max	0.3	1.6	1.14	0.85	1.3	1.5	0.5
[#>Ref]	[20]	[0]	[0]	[0]	[0]	[0]	[0]	[0]
Chromium	GMean	1.76	5.55	6.70	8.0	9.15	**11.6**	**11.0**
	Max	3.59	23.6	14.9	28.1	19.5	16.9	31.9
[#>Ref]	[10]	[0]	[1]	[2]	[2]	[2]	[1]	[1]
Copper	GMean	13.2	81.8	30.5	44.4	27.8	21.4	22.0
	Max	17.9	377	60.4	73.4	41.4	26.6	53.1
[#>Ref]	[200]	[0]	[2]	[0]	[0]	[0]	[0]	[0]
Lead	GMean	1.6	4.9	**8.5**	**10.7**	**10.9**	**8.4**	**17.4**
	Max	10.1	26.5	74.2	53.6	33.9	22.6	49.3
[#>Ref]	[5]	[1]	[3]	[3]	[2]	[3]	[1]	[3]
Mercury	GMean	0.14	NC	NC	NC	NC	NC	0.10
	Max	0.19	0.09	0.07	0.11	1.13	0.09	0.23
[#>Ref]	[0.4]	[0]	[0]	[0]	[0]	[1]	[0]	[0]
Selenium*	GMean	1.08	2.17	2.51	1.66	2.78	1.42	2.20
	Max	1.40	5.99	5.13	6.46	4.31	1.83	6.35
[#>Ref]	[3]	[0]	[3]	[1]	[2]	[3]	[0]	[1]
Zinc	GMean	59.9	105	108	130	128	112	112
	Max	74.8	282	169	156	175	134	150
[#>Ref]	[178]	[0]	[1]	[0]	[0]	[0]	[0]	[0]

KEY AND ABBREVIATIONS

Gmean: Geometric mean concentration for geographic area

Gmean: Gmean>referenced toxicity value

Max: Maximum detected value (among samples in geographic area)

[#>Ref]: number of individual (composite) samples per geographic area exceeding the referenced threshold (citations given in discussion in text).

NC: geometric mean not calculated (more than 50% of values <detection limit)

(e.g., above the NOAEL) can interfere with phosphate metabolism, which in turn interferes with calcium deposition into bones and eggshells. However, this effect has been seen primarily in areas with low acidic buffering capability (e.g., lakes with pH in the range of 4.0 – 4.6), which may also be limited in the amount of dietary calcium and phosphorous available (Miles et al. 1993). In an estuarine environment with mean dietary Al concentrations of 2,384 mg/kg, no differences could be seen in the mechanical properties of bones in American coot (*Fulica americana*) foraging in the area, which was also very enriched in calcium (> 70,000 mg/kg; (Hui & O. Ellers 1998).

Arsenic and Copper- The maximum detected concentrations of both of these elements (51 mg/kg and 377 mg/kg, respectively) were observed at site LS; exceeding their respective levels of concern: 30 mg/kg for As (Camardese et al. 1990) and 200 mg/kg for Cu (2000). The LOC for Cu was also exceeded at site LC (377 mg/kg). The geometric mean concentration of Cu at the GSL South Shore area (81.8 mg/kg) was substantially higher than at the other geographic areas (though < LOC), but this difference was not statistically significant ($P = 0.18$). These two sites are either in or adjacent to mining-impacted areas associated with the copper smelter and refinery located on the south shore of the GSL. No other locations sampled exceeded LOC concentrations for either As or Cu.

Mercury and Selenium- Mercury was only detected in 12 of 27 invertebrate samples (DL = > 0.2 mg/kg). Because of the low detection rate, geometric mean concentrations were not calculated for the geographic areas. Where it was detected, Hg was < 0.3 mg/kg in invertebrates from all locations except for site FC (the Crystal Unit within FBWMA, in the Farmington Bay South geographic area) which had a sample with 1.13 mg/kg Hg, exceeding the LOC of 0.4 mg/kg. Selenium was detected more frequently, in 26 of 28 samples, with 10 samples exceeding the LOC of 3.0 mg/kg (Lemly 1996) The highest concentration of Se (6.46 mg/kg) occurred at site IS within the SE Shore Industrial area, followed closely by a sample at site OH within the Ogden Bay area with 6.35 mg/kg Se. The greatest frequency of exceedances of the avian dietary LOC for Se occurred at the Farmington Bay South area (75%) and at the GSL South Shore and SE Shore Industrial areas (50%). Geometric means did not exceed the LOC at any of the geographic areas, however this level was approached at the Farmington Bay South area (geometric mean Se = 2.78 mg/kg).

Organic Compounds in Invertebrates

Nineteen invertebrate samples from 16 locations around the GSL were evaluated for OCs (DDT isomers and non-DDT OCs) and PCBs. A single sample was collected in most locations; two samples each were collected at sites IS and FK. Complete analytical results (compounds identified in at least one invertebrate sample) are presented in **Appendix Table A-5**. As with OC results in sediment samples, concentrations were reported by the laboratories in µg/kg (parts per billion) but have been converted to mg/kg (dry weight) for presentation below.

Nineteen OCs were detected in GSL invertebrate samples, compared to 23 OCs detected in sediments. This included 13 non-DDT compounds, five of the six DDT isomers, and t-PCB. Only t-PCB and *p,p'*-DDE were detected in > 50% of the samples. Oxychlordane and *p,p'*-DDT were detected in 47% of the samples. At least one OC was detected in all invertebrate samples, with the exception of sites AS (Antelope Island South) and IP (the "Petrochem Ponds") where no OCs were detected. Sites IO, FS and FK had both the greatest number of OCs detected (12 OCs at all three sites) and the highest total OC concentrations (summed concentrations of detected OCs) ranging from 0.072 mg/kg at Site FK to 0.112 mg/kg at Site IO. These sites also had a large number of OCs detected in sediment samples, and relatively high total OC and PCB concentrations compared to other sites in the GSL study. Overall OC concentrations in invertebrates, including t-PCBs which were present in the highest concentrations, were low compared to published data from contaminated sites. The maximum detected concentration of t-PCB (0.091 mg/kg at site IO) was low compared to the avian dietary NOAEL of 0.5 mg/kg (Barron et al. 1995).

Concentrations of DDTs, including "total DDTs" (t-DDT, the summed concentration of detected DDT isomers) were also relatively low, but exceeded avian LOCs at several locations. Total DDT exceeded the avian dietary NOAEL of 0.004 mg/kg (Sample et al. 1996) at nine sites (Table 4-7), with *p,p'*-DDE, being the largest contributor. The maximum detected concentration of *p,p'*-DDE (0.027 mg/kg) occurred at Site ON, contributing to the maximum detected concentration of t-DDT (0.0484 mg/kg). This concentration also exceeded the avian dietary LOAEL of 0.04 mg/kg.

Table 4-7 Comparison of total DDT residues in wetland invertebrates (mg/kg wet weight) with calculated risk-based dietary thresholds for insectivorous birds, Great Salt Lake Wetlands Synoptic Survey, 1996-1997

		Sum DDTs [(b)]
	NOAEL, Woodcock[(a)]	***0.004***
	LOAEL, Woodcock[(a)]	**0.04**
Geographic Area and Study Site	**Invertebrate Type**	
Antelope Island:		
Antelope Island offshore (GA)	Brine Fly Larvae	0.0016
Antelope Island East (AE)	Brine Fly Larvae	ND
Antelope Island South (AS)	Odonates	ND
GSL South Shore		
C7 Ditch (LC)	Chironomids	***0.0076***
Saltair/GSL State Park (LS)	Benthic Macroinvertebrates	ND
South Shore Wetlands		
Goggin Drain (SD)	Benthic Macroinvertebrates	0.01
Inland Sea Shorebird Reserve (SI)	Chironomids	***0.0043***
South Shore Industrially Impacted Wetlands		
Beck Hot Springs (IB)	Corixids	0.0013
Oil Drain Canal (IO)	Chironomids	0.0101
Petrochem Ponds (IP)	Chironomid	ND
SLC Sewage Treatment Plant (IS)	Chironomid	ND
SLC Sewage Treatment Plant (IS)	Benthic Macroinvertebrates	***0.0077***
Farmington Bay South		
FBWMA- Crystal Unit (FC)	Benthic Macroinvertebrates	0.0011
State Canal (FS)	Benthic Macroinvertebrates	***0.0173***
Farmington Bay North		
Kaysville Marsh (FK)	Chironomid	***0.00685***
Kaysville Marsh (FK)	Chironomid,Leech	***0.0205***
Ogden Bay		
Howard Slough (OH)	Chironomid	***0.00564***
Ogden Bay WMA- North (ON)	Chironomids	**0.0484**
Ogden Bay WMA- South (OS)	Benthic Macroinvertebrates	***0.0089***

KEY: ***VALUE***: ≥ No Observed Adverse Effect Level (NOAEL)
VALUE: ≥ Lowest Observed Adverse Effect Level (LOAEL)

(a) (Sample et al. 1996). Calculated avian toxicity reference value assuming diet consists 100% of invertebrates
(b) Sum of measured concentrations of *ortho-* and *para-* isomers of DDD, DDE and DDT

Biomagnification of OCs from sediments to invertebrates was not quantitatively evaluated because of low detection rates for most OCs in invertebrates. However, a qualitative comparison of sediment and invertebrate OC concentrations indicates minimal uptake, except possibly at Site ON, which had relatively high DDT concentrations in both sediments (Table 4-2) and invertebrates (Table 4-7). There is also some correspondence between total PCBs in invertebrates at site IO, and sediment PCBs which were elevated (>PEC) at that site.

4.3 Fish

Whole-body composite samples of fish were collected from GSL estuarine wetland locations that are supplied by freshwater inflows. Fish were not collected at the Antelope Island sites or Site LS due to l habitat. Concentrations of inorganic and organic constituents in fish were compared to two sets of endpoints to evaluate risks to birds: first as a contributor to avian diets (i.e., for piscivorous birds), and the health of the fish themselves, as a component of the foraging habitat (i.e., the food source) of piscivorous birds. Avian dietary levels of concern (NOAELs, LOAELs, etc) were used for the first comparison, and fish health indicators were used for the latter. Common carp (*Cyprinus carpio)* were most frequently collected; Utah chub (*Gila atraria*) and western mosquitofish (*Gambusia affinis*) were collected in locations where carp could not be found. In most cases, sampling crews attempted to collect fish from the same locations as sediment and macroinvertebrate samples, but there was less linkage between these media due to logistics issues involved with sampling fish as compared to other media. However, because fish are not sessile in the same way as invertebrates, and also because their diet is not as intimately linked to a single location, there was less need for this level of correspondence in sampling. A total of 30 fish samples were collected from 12 wetland locations for evaluation of trace metals. Twenty three samples from 11 locations were analyzed for organic compounds. The number of samples collected at each site ranged from one (at sites FC, FU and ON) to four (Site LC).

Trace Elements in Fish

As was the case for sediments and macroinvertebrates, concentrations of trace elements in fish are reported here in mg/kg dry weight, both in the following discussion and in **Appendix Table A-6**, which contains complete analytical results. In cases where benchmarks were presented in the literature in terms of wet weight, they have been converted to dry weight using 75% moisture content for a conversion factor. The mean percent moisture of all fish collected at GSL sites was 74.3%.

Trace element concentrations in fish were generally low and rarely exceeded concentrations of concern either for adverse effects to piscivorous birds or to the fish themselves. The concentrations of selected elements (As, Cd, Cr, Cu, Hg, Pb, Se, and Zn) in fish are summarized by geographic area in **Table 4-8**, along with exceedences of effect thresholds identified in peer-reviewed scientific literature.

Copper - Copper was the only element in which concentrations in fish exceeded the benchmark for fish health (13.3 mg/kg; (Eisler 2000). This occurred only at the GSL South Shore area (represented by Site LC), where three of six samples slightly exceeded this concentration, with a maximum observed concentration of 16.3 mg/kg, and a mean of 11.2 mg/kg. However, these concentrations were significantly and more than two times higher than any other area evaluated (**Figure 4-3**).

Selenium - Se was detected in >50% of fish samples from all geographic areas except the Farmington Bay North area. However, the GSL South Shore area (Site LC) was the only one where Se was present in concentrations exceeding both the avian dietary LOC of 3 mg/kg and the fish effects benchmark of 4 mg/kg (National Irrigation Water Quality Program 1998). All six samples collected at Site LC exceeded 3 mg/kg Se, with a geometric mean concentration of 6.36 mg/kg, which was 2-3 times higher than the maximum detected concentrations from other geographic areas (Table 4-8). Concentrations of

Table 4-8 Summary of selected trace elements in whole body fish (mg/kg, dry weight) by geographic area, and exceedences of levels of concern, Great Salt Lake Wetlands Synoptic Survey, 1996-1997.

Trace Element		GSL South Shore	S. Shore Wetlands	SE Shore Industrial	Farmington Bay S	Farmington Bay N	Ogden Bay
	n=	6	6	3	12	1	7
Arsenic	GMean	NC	NC	NC	NC	NC	NC
	Max	1.3	0.7	ND	ND	1	0.5
#>Ref	[12 / 30][1]	[0]	[0]	[0]	[0]	[0]	[0]
Cadmium	GMean	0.17	NC	NC	NC	NC	NC
	Max	0.23	ND	ND	ND	0.1	ND
#>Ref	[NA/20]	[-- / 0]	[-- / 0]	[-- / 0]	[-- / 0]	[-- / 0]	[-- / 0]
Chromium	GMean	1.43	1.49	0.84	1.97	NC	2.27
	Max	4.26	5.51	1.49	4.75	7.08	3.61
#>Ref	[NA/10]	[-- / 0]	[-- / 0]	[-- / 0]	[-- / 0]	[-- / 0]	[-- / 0]
Copper	GMean	11.2	3.14	4.47	3.09	NC	2.87
	Max	16.3	4.89	5.51	5.98	4.83	3.79
#>Ref	[13.3/200]	[3 / 0]	[0 / 0]	[0 / 0]	[0 / 0]	[0 / 0]	[0 / 0]
Lead	GMean	0.81	NC	NC	0.59	NC	0.91
	Max	2.13	1.5	1.5	1.43	1.5	3.2
#>Ref	[NA/5]	[-- / 0]	[-- / 0]	[-- / 0]	[-- / 0]	[-- / 0]	[-- / 0]
Mercury	GMean	NC	0.14	0.07	NC	NC	NC
	Max	0.34	0.26	0.08	0.26	0.14	0.37
#>Ref	[0.8/1.2]	[0]	[0]	[0]	[0]	[0]	[0]
Selenium	GMean	**6.36**	1.68	2.4	1.77	NC	1.41
	Max	9.1	2.1	3.3	2.7	1.7	1.91
#>Ref	[4/3]	[5 / 6]	[0]	[0 / 1]	[0]	[0]	[0]
Zinc	GMean	**239**	**213**	164	**199**	NC	**225**
	Max	360	262	199	247	151	512
#>Ref	[NA/178]	[-- / 5]	[-- / 4]	[-- / 1]	[-- / 10]	[0]	[-- / 5]

KEY AND ABBREVIATIONS

Gmean: Geometric mean concentration for geographic area
Gmean: Gmean> referenced toxicity value
NC: geometric mean not calculated (i.e., more than 50% of values <detection limit)
ND: all samples were less than the detection limit
#>Ref: number of samples > referenced threshold value
[X / Y]: [effects to fish / avian dietary threshold];
NA: referenced value not identified in literature

Threshold values not referenced in text:

As: Fish- toxicity threshold (Sandhu 1977) / Avian dietary- Reduced weight in mallard ducklings, (Camardese et al. 1990)
Cd: Fish health- NA / Avian dietary- Level of concern (Cain et al. 1983)
Cr: Fish health- NA / Avian dietary- Level of concern (Eisler, 2000)
Cu: Fish Health-(National Irrigation Water Quality Program 1998) / Avian dietary- Level of concern (Eisler, 2000)
Pb: Fish health- NA / Avian dietary- Level of concern (Eisler, 2000)
Hg: Fish Health- Sublethal endpoints for adult and juvenile fish (Beckvar et al. 2005) / Avian dietary- Behavioral and reproductive effects in loons (Barr 1986)
Se: Fish health- Lower effects threshold (National Irrigation Water Quality Program 1998) / Avian dietary- Lower effects threshold (National Irrigation Water Quality Program 1998)
Zn: Fish health- NA; Avian dietary Level of concern (2000)

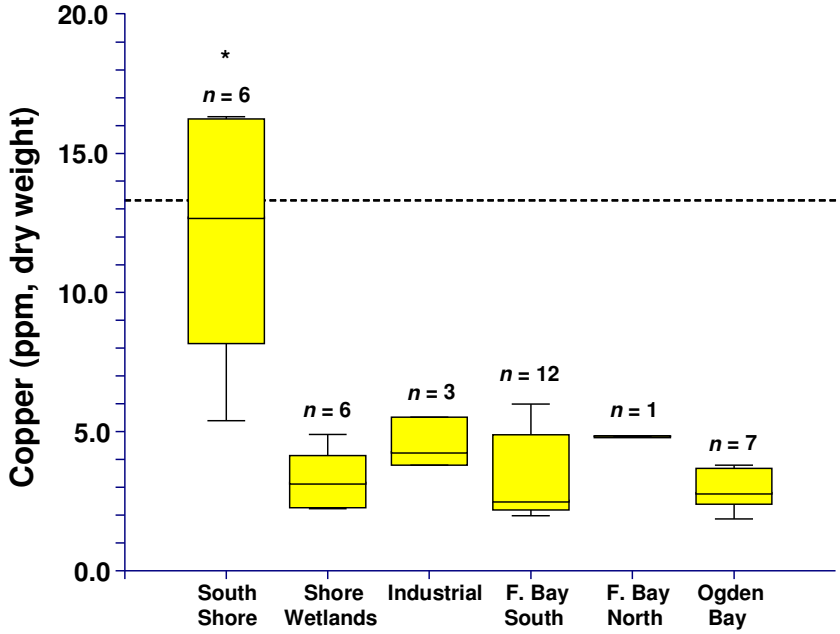

Figure 4-3. Copper in whole-body fish by geographic area, Great Salt Lake Wetlands Synoptic Survey, 1996-1997. Dashed line represents level of concern for fish health; "*" denotes significant difference ($P < 0.001$).

Se at Site LC were significantly elevated in fish compared to the other five areas ($P < 0.001$; **Figure 4-4**). The only other location where Se exceeded either the fish or avian benchmark was Site IO in the Southeast Shore Industrial Area, where one of three samples exceeded 3 mg/kg.

Mercury - Hg was detected in 20 of 35 samples but was detected in > 50% of samples in only two geographic areas: the GSL South Shore wetlands, and the SE Shore Industrial area. The highest concentration of Hg was observed in the Ogden Bay area (0.37 mg/kg). No fish samples exceeded Hg effects thresholds for either fish health (0.8 mg/kg, converted from 0.2 mg/kg wet weight; (Beckvar et al. 2005)) or avian dietary exposure for fish-eating birds (1.2 mg/kg, converted from 0.3 mg/kg wet weight;(Barr 1986)). As a point of comparison for human health, maximum detected concentrations of mercury in fish at all GSL wetland sites were well below 1.2 mg/kg dry weight, equivalent to EPA's fish consumption screening level of 0.3 mg/kg wet weight (assuming 75% moisture).

Zinc - Zinc was detected in all 35 fish samples, and exceeded the avian dietary threshold, 178 mg/kg, an avian dietary threshold concentration associated with possible immune suppression in young birds (Stahl et al. 1989), in 25 of the 35. The maximum detected concentration of Zn (512 mg/kg) was observed at Site OS in Ogden Bay. In all, zinc concentrations in 25 of the 35 fish samples exceeded this threshold, yielding geometric mean Zn concentrations that exceeded the LOC for avian dietary exposure in four of the six geographic areas (**Table 4-8**). Notably, the lowest Zn concentrations were observed in the three non-carp samples collected (two mosquito fish and one Utah chub); however, data were insufficient to evaluate whether there were species differences in Zn concentrations.

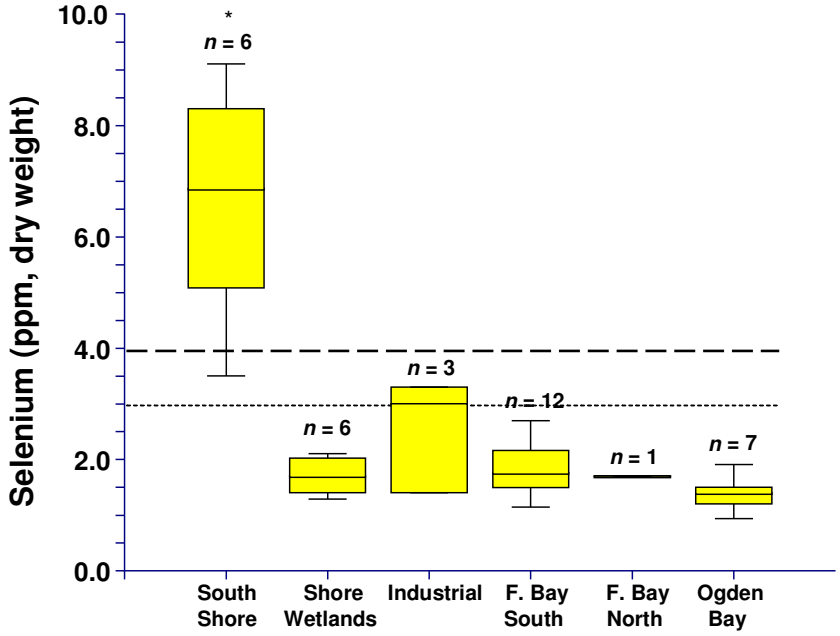

Figure 4-4. Selenium in whole-body fish by geographic area, Great Salt Lake Wetlands Synoptic Survey, 1996-1997. The dotted and dashed lines represent avian and fish health effects levels, respectively; "*" denotes significant difference ($P < 0.001$)

The concentration of zinc in carp may be proportional to age (and therefore body mass), but this could not be evaluated (i.e., through correlation analysis) because samples were composited. However, in a study of 24 species of fish and invertebrates commonly consumed in Asia, including common carp, Zn concentrations in carp were dramatically higher than any other species evaluated (Lian-Ten Sun and Sen-Shyong Jeng 1998). This study evaluated ten different tissues (e.g., muscle and skeletal tissues, organs, gonads and digestive tract tissues) of fish and invertebrates from fresh water, brackish water and marine habitats. While most of the tissues from most of the species evaluated had on the order of 13-130 mg/kg dry weight Zn, common carp had slightly elevated Zn concentrations in muscle tissue (mean ± SD 248 ± 144 mg/kg). Concentrations in digestive tract tissues (mean 941 ± 382 mg/kg) were generally an order of magnitude greater than observed in other species. This suggests that the Zn concentrations observed in carp from the GSL may be a species characteristic, rather than an indication of Zn contamination within the ecosystem.

Arsenic, Cadmium, Chromium and Lead - Concentrations of As, Cd, Cr, and Pb were infrequently detected in whole-body fish tissues. Arsenic was detected in < 50% of samples from all geographic areas. Cadmium was not detected at all in four of the six geographic areas sampled, but was detected in > 50% of samples from the GSL South Shore area. Lead was detected in all six geographic areas, but in < 50% of samples in only three of them. Chromium was detected in all geographic areas, and in > 50% of samples at five of them. None of these metals were present in any fish samples in concentrations exceeding either fish or avian effects levels.

Organic Compounds in Fish
Complete datasets regarding the number of samples collected at each location and OC residues observed in samples are presented in **Appendix Table A-7**. In contrast to analytical results for OCs in sediments and invertebrates, residues for fish are presented as mg/kg **wet weight**. This was done as an aid for comparison with toxicity benchmarks for these compounds, which are most often presented in the literature in these terms.

All of the OC residues detected in GSL wetland sediments were detected in at least one fish sample, with the exception of aldrin and endrin. Total PCBs, *p, p'*-DDD, and *trans*-nonachlor were detected in all 23 samples. Ten other OCs (*p,p'*-DDE, *o,p'*-DDD, and *o,p'*-DDT; HCB, *cis*-nonachlor, α, γ, and oxy-chlordane isomers, heptachlor epoxide, and γ-BHC) were detected in ≥ 70% of the samples. When grouped by categories of related OC pesticides (e.g., parent compounds and metabolic or environmental break-down products), t-PCB, t-DDT, and total chlordanes were present in the highest concentrations (**Table 4-9**). None of the OCs evaluated exceeded protective benchmarks for fish health. However concentrations of t-DDT and t-PCB exceeded avian dietary NOAELs (cited in (Hinck et al. 2006) at several locations (**Figure 4-5**). The highest concentrations of t-DDT were observed in Ogden Bay, where the sample from site ON (0.238 mg/kg) exceeded the avian NOAEL (0.15 mg/kg). Fish sampled at Site OS were slightly under the NOAEL, with 0.105 mg/kg t-DDT. This was consistent with the results in sediments and invertebrates, where Site ON was one of three sites that had elevated DDTs in sediments (Table 4-3) and was the only site where DDTs in invertebrates exceeded the risk-based avian dietary NOAEL for insectivorous birds (Table 4-7). Total DDTs were also slightly elevated in portions of Farmington Bay, with 0.014 mg/kg at Site FS (the State Canal, a point where water from the Jordan River enters the GSL) and 0.101 mg/kg at Site FP (a ponded wetland complex located down-gradient from a former municipal landfill. However, t-DDT in fish at Sites FC and FU, both located within Farmington Bay Waterfowl Management Area (FBWMA) was lower, with a mean concentration of 0.025 mg/kg. The predominant isomer of DDT in fish from most sites was DDE (*o,p'*- and *p,p'*- isomers), except at Site FP where DDD predominated (but where DDD made up the smallest proportion of total DDTs in sediments; Table 4-3).

Total PCBs exceeded the avian dietary NOAEL of 0.11 mg/kg (cited in (Hinck et al. 2006) at several locations, with the highest mean concentration (0.524 mg/kg) at Ogden Bay, where fish collected from site ON had 0.640 mg/kg total PCBs (Figure 4-5). Other sites with elevated total PCBs in fish had included Sites IO, LC and SD; which all have more obvious potential than Ogden Bay for exposure to PCBs based on proximity to past or current sources. Sites IO and LC are located in industrial drainage canals and Site SD (the Goggin Drain) is located in another drainage canal that historically carried wastes from the industrialized northwest quadrant of Salt Lake City to the south shore of the GSL.

4.4 Avian Eggs

Eighty eight avian eggs from seven different species of bird were randomly collected during 1996-1997 for evaluation of trace elements and organic compounds. Eggs were collected at 19 wetland locations, within all seven of the geographic areas surveyed. In most cases, only one egg was collected from each nest. At least one egg was collected from each location, with up to five eggs collected at some locations. All eggs (n=88) were analyzed for trace elements. The contents of a subset of eggs (n=36) were split, with half of the contents submitted for analysis of trace elements and the other half submitted for th analysis of organic constituents. Egg collections were focused on species that are abundant and important in the generally brackish and shallow habitats that characterize the GSL wetlands, including American avocet (*Recurvirostra americana*; species code AMAV), black-necked stilt (*Himantopus mexicanus*; BNST) and snowy plover (*Charadrius alexandrinus*; SNPL). Four additional species collected, American coot (*Fulica americana*; AMCO), cinnamon teal (*Anas cyanoptera*; CITE), double-crested cormorant (*Phalacrocorax auritus*; DCCO) and mallard (*Anas platyrhynchos*; MALL) generally forage in and nest around freshwater environments such as palustrine wetlands.

Table 4-9 Summary of organochlorine residues in whole body fish (mg/kg, WET weight) by geographic area, and exceedences of levels of concern, Great Salt Lake Wetlands Synoptic Survey, 1996-1997.

Location Description		Total PCB	Total DDTs (a)	Total Chlordane(b)	HCB	dieldrin	gamma BHC
Detection Frequency, All Sites		100%	NA	NA	91%	87%	70%
Geometric Mean, All sites		*0.1477*	0.0565	0.0258	0.001	0.004	0.0005
LC (C7 Ditch)	*Detect. Freq*	4/4	NA	NA	4/4	4/4	4/4
	Geomean	*0.150*	0.056	0.016	0.001	0.003	0.0004
	Max	*0.202*	0.068	0.024	0.002	0.005	0.001
SA (Airport Mitigation)	*Detect. Freq*	2/2	NA	NA		ND	ND
	Geomean	0.033	0.010	NC	0.001	---	---
	Max	0.033	0.011	0.001	0.001	---	---
SG (Goggin Drain)	*Detect. Freq*	3/3	NA	NA	3/3	3/3	3/3
	Geomean	*0.182*	0.051	0.017	0.001	0.006	0.001
	Max	*0.189*	0.053	0.017	0.002	0.006	0.001
IO (Oil Drain Canal)	*Detect. Freq*	2/2	NA	NA	2/2	2/2	2/2
	Geomean	*0.195*	0.024	0.013	0.002	0.009	0.001
	Max	*0.281*	0.038	0.018	0.006	0.012	0.002
FB (Bountiful Pond)	*Detect. Freq*	2/2	NA	NA	2/2	2/2	2/2
	Geomean	*0.131*	0.100	0.049	0.003	0.013	0.001
	Max	*0.158*	0.101	0.054	0.003	0.013	0.002
FC (FBWMA- Crystal Unit)	*n=1*	0.051	0.006	NC	ND	ND	ND
FU (FBWMA- Unit 1)	*n=1*	*0.253*	0.097	0.022	ND	0.004	ND
FS (State Canal)	*Detect. Freq*	3/3	NA	NA	3/3	3/3	3/3
	Geomean	*0.140*	0.126	0.041	0.001	0.018	0.0005
	Max	*0.177*	0.141	0.053	0.002	0.023	0.0006
OH (Howard Slough)	*Detect. Freq*	2/2	NA	NA	2/2	2/2	ND
	Geomean	0.083	0.074	0.035	0.002	0.002	---
	Max	0.090	0.078	0.036	0.002	0.002	---
ON (Ogden Bay WMA-North)	*n=1*	*0.640*	*0.238*	0.053	0.002	0.004	ND
OS (Ogden Bay WMA-South Canal)	*Detect. Freq*	2/2	NA	NA	2/2	2/2	2/2
	Geomean	*0.474*	0.097	0.038	0.001	0.005	0.0002
	Max	*0.550*	0.105	0.040	0.002	0.005	0.0003
Protective level for fish health[(c)]		*5.0*	*0.6*	*0.3*	*0.33*		
Dietary threshold for piscivorous birds-low [(c)]		*0.11*	*0.15*	*0.300*	*0.1*	*0.081*	
Dietary threshold for piscivorous birds-high[(c)]		**5.0**[(d)]	**1.00**	**4.200**	**0.330**	**0.120**	

LEGEND:

Value ≥ lower level of concern, piscivorous bird dietary exposure
Value ≥ upper level of concern, piscivorous bird dietary exposure
Value maximum detected value in 1996-1997 fish samples

NOTES:

(a) sum of detected concentrations of *o,p'*- and *p,p'*- forms of DDT, DDD and DDE
(b) sum of detected concentrations of chlordane and related compounds *cis*-nonachlor, α, γ, and oxy-chlordane isomers, heptachlor epoxide
(c) cited in (Hinck et al. 2006).
(d) cited in (Kubiak et al. 1989)

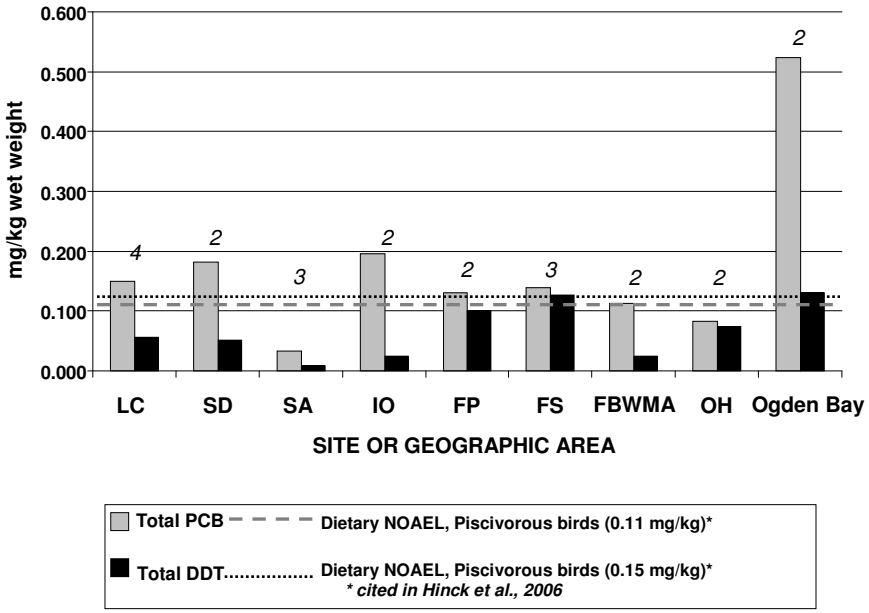

Figure 4-5 Geometric mean concentrations of total PCBs and total DDTs in whole-body fish tissues at sites and geographic locations around the Great Salt Lake, compared to avian dietary no observed adverse effect levels (NOAELs); Great Salt Lake Wetlands Synoptic Survey, 1996-1997

When both habitat types occurred within a site, eggs were collected from both groups of species if possible. The most frequently collected species were black-necked stilt (n = 41) and American coot (n = 32), and the greatest number of eggs was collected in the Farmington Bay South geographic area (**Table 4-10**).

Inorganic Constituents (Trace Elements) in Avian Eggs

Six trace elements (Cu, Fe, Mg, Se, Sr, and Zn) were found in all 88 eggs; Ba, Hg and Mn were found in >90% of all eggs (See **Appendix Table A-8** for complete analytical results). The least frequently detected elements (in < 5% of eggs) were B, Be, Cd, Mo and Pb. In general, trace element concentrations in eggs were low (**Table 4-11**). Of the constituents of concern for avian toxicity (As, Cd, Cu, Hg, Pb, Se, and Zn) only copper, selenium, mercury and zinc were present in concentrations that exceeded the screening benchmarks used for this evaluation (National Irrigation Water Quality Program 1998); these are discussed further below.

Copper - Copper was detected in all of the eggs sampled, which was expected because Cu is a trace nutrient. However, Cu was present at significantly higher concentrations ($P < 0.001$) at Site LS (mean Cu = 4.11 mg/kg) than at any other location around the GSL (**Figure 4-6**). This was driven by eggs collected in 1997 (n = 9) which ranged from 3.24 – 7.30 mg/kg, including three eggs that exceeded the screening value of 5.5 mg/kg. These were the only eggs out of the 88 collected that exceeded this benchmark, and represented three different species (BNST, AMCO and MALL) with different foraging preferences, indicating that Cu is available for uptake in a variety of food sources at the site.

Table 4-10 Numbers and species of avian eggs collected, for GSL Wetlands Synoptic Contaminants Survey, 1996-1997.

Geographic Area	Site Loc. Code[a]	Total # eggs	*Shorebird Species[b]* AMAV	BNST	SNPL	*Waterfowl Species[b]* AMCO	MALL	DCCO	CITE
Antelope Island n = 4 (2) [c]									
	AS	1				1*(1)*			
	AE	3		3*(1)*					
GSL South Shore n = 12 (1)									
	LS	12		9 *(1)*		1	2		
South Shore Wetlands n = 8 (5)									
	SA	6		3 *(1)*			2 *(1)*	1 *(1)*	
	SG	1	1 *(1)*						
	SI	1			1 *(1)*				
SE Shore Industrial n = 11 (7)									
	IB	3	3 *(1)*						
	IS	6				5 *(3)*	1 *(1)*		
	IP	2				1*(1)*	1 *(1)*		
Farmington Bay South n = 29 (11)									
	FN	5		3 *(1)*		2 *(1)*			
	FP	3		3 *(1)*					
	FS	7		3 *(1)*		3 *(1)*			1
	FC	12		6*(3)*		6 *(2)*			
	FO	2		2 *(1)*					
Farmington Bay North n = 7 (5)									
	FK	7		3*(3)*		4*(2)*			
Ogden Bay n = 17 (5)									
	OH	6		3*(1)*		3*(1)*			
	OS	6		3*(1)*		3*(1)*			
	ON	5				3*(1)*	2		
	TOTALS	*88 (36)*	*4 (2)*	*41 (15)*	*1 (1)*	*32 (14)*	*8 (3)*	*1 (1)*	*1*

NOTES:

(a) See Table 2-1 in text for key to Site Location Codes

(b) Species Abbreviation Codes:

AMAV: American avocet (*Recurvirostra americana*
AMCO: American coot (*Fulica americana*)
BNST: black-necked stilt (*Himantopus mexicanus*)
CITE: cinnamon teal (*Anas cyanoptera*)
DCCO: double-crested cormorant (*Phalacrocorax auritus*)
MALL: mallard (*Anas platyrhynchos*)
SNPL: snowy plover (*Charadrius alexandrinus)*

(c) All eggs analyzed for trace elements. Numbers in parentheses indicate number of eggs also analyzed for organic constituents.

Table 4-11 Summary of selected trace elements in avian eggs (mg/kg, dry weight) by geographic area, and exceedences of levels of concern, Great Salt Lake Wetlands Synoptic Survey, 1996-1997.

Trace Element		Antelope Island	GSL South Shore	S. Shore Wetlands	SE Shore Industrial	Farmington Bay S	Farmington Bay N	Ogden Bay
# Sites Evaluated		*2*	*1*	*3*	*3*	*5*	*1*	*3*
# eggs (n)		*4*	*12*	*8*	*11*	*29*	*7*	*17*
# AMCO eggs		*1*	*1*	*0*	*6*	*11*	*4*	*9*
Arsenic	*Gmean*	NC	NC	NC	NC	NC	NC	NC
	Max	ND	1.1	ND	0.7	1.38	ND	0.84
#>Ref	[2.8]	--	[0]	--	[0]	[0]	--	[0]
Barium	*GMean*	1.19	2.3	2.97	1.74	3.29	4.38	5.88
	Max	1.69	5.87	17.3	3.33	11.5	5.99	17.2
#>Ref	[NA]	[--]	[--]	[--]	[--]	[--]	[--]	[--]
Cadmium	*GMean*	NC	NC	NC	NC	NC	NC	NC
	Max	ND	ND	ND	0.23	0.48	ND	ND
#>Ref	[0.15]	--	--	--	[1]	[2]	--	--
Copper	*GMean*	2.35	4.11	3.18	3.18	2.78	2.30	2.78
	Max	2.99	7.30	4.16	4.23	3.83	2.95	4.97
#>Ref	[5.5]	[0]	[3]	[0]	[0]	[0]	[0]	[0]
Lead	*GMean*	NC	NC	NC	NC	NC	NC	NC
	Max	ND	ND	ND	0.55	0.6	ND	ND
#>Ref	[NA]	--	--	--	[--]	[--]	--	--
Mercury	*GMean*	0.68	0.39	0.37	0.15	0.66	0.33	0.36
	Max	1.11	1.19	1.13	0.30	5.99	1.47	1.49
#>Ref	[3]	[0]	[0]	[0]	[0]	[3]	[0]	[0]
Selenium	*GMean*	2.6	4.8	3.6	3.2	3.1	2.0	1.6
	Max	3.6	7.5	5.3	4.4	4.6	3.1	3.2
#>Ref	[6]	[0]	[2]	[0]	[0]	[0]	[0]	[0]
Strontium	*GMean*	14.9	25.7	14.3	14.0	10.2	5.84	6.23
	Max	23.8	50.2	35.5	26.2	29.3	8.46	20.3
#>Ref	[NA]	[--]	[--]	[--]	[--]	[--]	[--]	[--]
Zinc	*GMean*	42.8	**52.4**	46.5	49.6	**51.2**	49.3	**51.4**
	Max	46.5	82.1	59.7	57.8	78.4	53.8	65.8
#>Ref	[50]	[0]	[7]	[3]	[5]	[14]	[2]	[10]

KEY AND ABBREVIATIONS

Gmean: Geometric mean concentration for geographic area

Gmean: Gmean> referenced toxicity value

NC: geometric mean not calculated (i.e., more than 50% of values <detection limit)

ND: all samples were less than the detection limit

#>Ref: number of samples > referenced threshold value it

[value]: Level of concern

As, Cu, Hg, Se, Zn: (National Irrigation Water Quality Program 1998))

Cd: background from Seiler (2003)

NA: referenced value not identified in literature

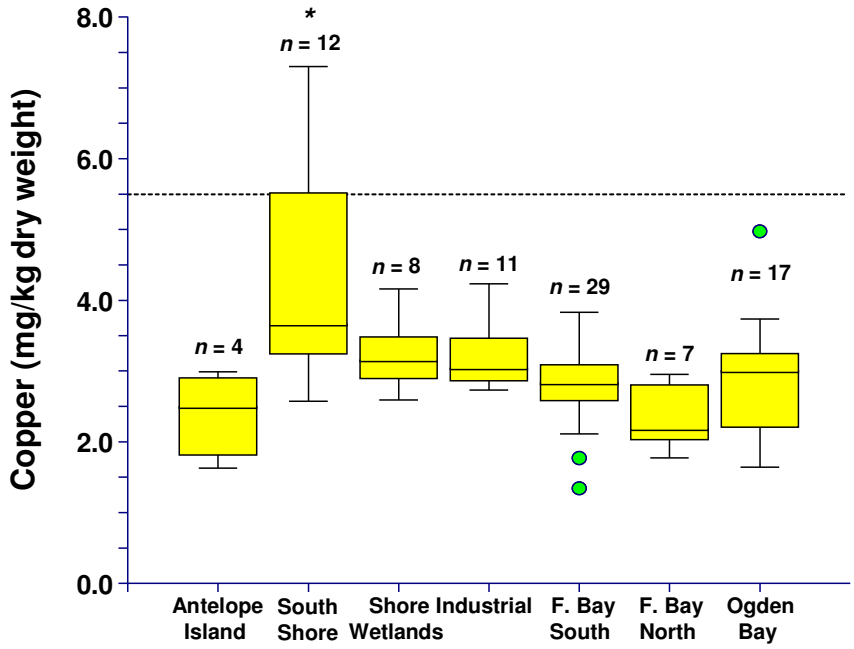

Figure 4-6 Concentrations of copper in avian eggs by geographic area, Great Salt Lake Wetlands Synoptic Survey, 1996-1997. "*" denotes significant difference from other areas.

Selenium - Three eggs from Site LS (two BNST, one AMAV; one collected in 1996, two in 1997) exceeded the toxicity threshold for Se identified by DOI (6 mg/kg). This area had the highest geometric mean (4.8 mg/kg) and was significantly elevated ($P < 0.001$) compared to the other geographic areas (**Figure 4-7**). This was consistent with observed sediment Se concentrations (Table 4-2) and with Se uptake observed in fish (Figure 4-4) from these two sites on the GSL south shore, which are adjacent to each other and near a metals smelting and refining facility (operated by Kennecott Utah Copper Corporation, KUCC) located upgradient from the GSL. At the time that eggs were collected for this study, a preliminary investigation of contamination on and around the KUCC facility was being conducted under the auspices of the U.S. EPA and the Utah Department of Environmental Quality (UDEQ). Releases of concern included a permitted wastewater discharge to the GSL located east of Site LS (the C7 Ditch, location of Site LC), selenium-contaminated groundwater which had impacted wetlands immediately to the south of Site LS (the "I-80 Wetlands"), and wind-blown tailings originating from large (ca. 8 mi^2) tailings piles 1 mile (2km) from Sites LS and LC. The samples collected by the Service for the GSL wetlands assessment, along with more focused sampling at the I-80 wetlands in the mid 2000's eventually led to the lodging and settlement (in 2008) of a Natural Resource Damages (NRD) claim by the DOI for impacts to migratory birds from these releases.

Mercury - Mercury was detected in all 88 eggs and the maximum detected concentration was 5.99 mg/kg dry weight at site FC in the Farmington Bay South area, which is double the LOC (3 mg/kg) identified by the DOI (National Irrigation Water Quality Program 1998). While the highest mean for a geographic area occurred at the Antelope Island area (0.68 mg/kg, n = 4), the highest individual egg concentrations and the occurred at Site FC (mean = 1.86 mg/kg, n = 12). Of six eggs collected at Site FC in 1996 (two AMCO, one BNST), three exceeded 3 mg/kg. Based on these results, additional samples were collected at Site FC in 1997.

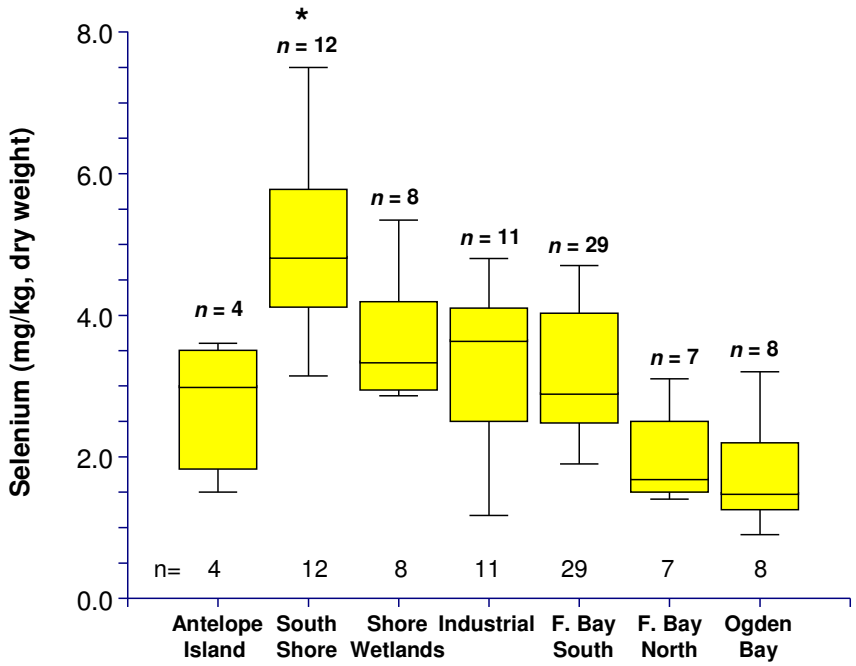

Figure 4-7. Selenium in avian eggs by geographic area, Great Salt Lake Wetlands Synoptic Survey, 1996-1997. "*" indicates that area (GSL South Shore Wetlands) is significantly different than other areas ($P < 0.001$)

Mercury concentrations in 1997 were significantly lower than in 1996 ($P = 0.018$), but all eggs from both years at site FC had significantly higher Hg concentrations ($P = 0.005$) than at other sites within the Farmington Bay South geographic area (**Figure 4-8**). Interestingly, Hg was not elevated in eggs from sites in the SE Shore Industrial area (Sites IB, IS and IP) , which have had a long history of metals-associated activities; in fact this geographic area had the lowest mean Hg concentration of any of the geographic areas.

The Crystal Unit of Farmington Bay Waterfowl Management Area (Site FC) is immediately adjacent to the point where the Oil Drain Canal enters the waters of the GSL in Farmington Bay (see Figure 2-1). The accumulated sediments from the canal (many of which originated from refineries and other industrial facilities at the head of the canal) form a broad, shallowly inundated delta that is intensively used by birds for foraging. Based on the observed Hg concentrations and concerns for avian exposure, a follow-up study was conducted at Site FC in 2000 to further evaluate the potential for Hg uptake in piscivorous birds, which are typically subject to higher mercury exposure through food chain bioaccumulation mercury (see Section 6).

Zinc- By far the greatest number of exceedences of avian toxicity benchmarks for metals was observed with Zn, in which 41 of 88 eggs exceeded the toxicity threshold of 50 mg/kg identified by the DOI (National Irrigation Water Quality Program 1998). The only area where this benchmark was not exceeded was Antelope Island, where three BNST eggs and one AMCO egg were collected. The mean Zn concentration exceeded 50 mg/kg in three areas: the GSL South Shore, Farmington Bay South, and Ogden Bay (Table 4-10).

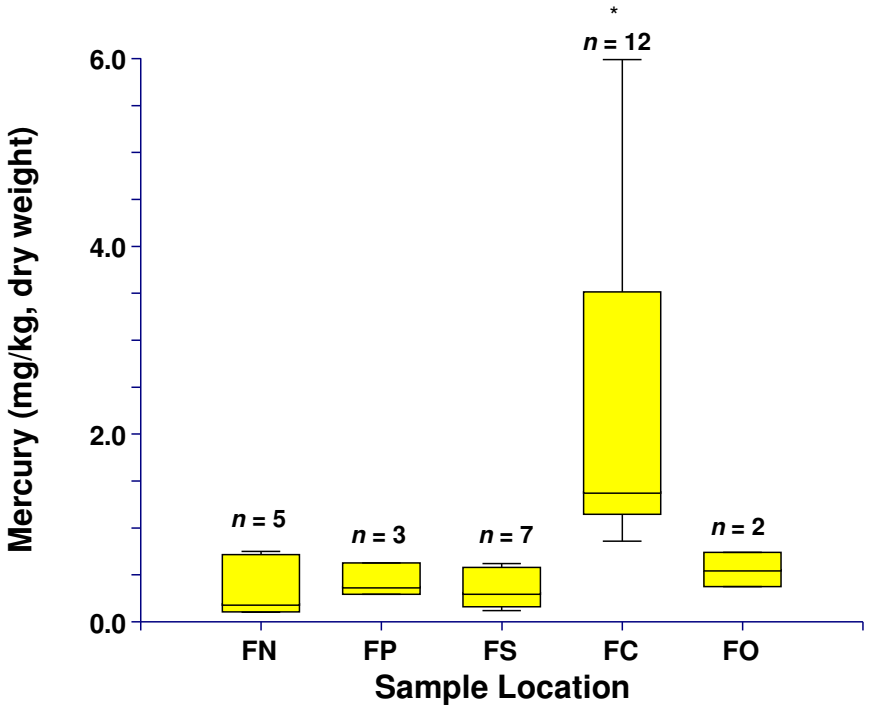

Figure 4-8. Concentrations of mercury in avian eggs from individual sites within the Farmington Bay South area, Great Salt Lake Wetlands Synoptic Survey, 1996-1997. "*" denotes significant difference from other locations.

Zinc is a primary nutrient that is typically very well regulated, and there is almost as much literature available regarding the adverse effects of zinc deficiency as there is regarding Zn toxicity. While 50 mg/kg is identified in one reference as a no-effect level (NOAEL), there is little information regarding the effect of excess Zn in either adult or developing birds, particularly data that are linked with Zn concentrations in eggs. However, an evaluation of data retrieved from the Service's Environmental Contaminants Data Management System (ECDMS) database (accessed April 5, 2009) for the Service's "Mountain-Prairie" Region (Region 6: Utah, Colorado, Wyoming, North Dakota, South Dakota, Nebraska) indicates 1) that for any given area, American coot eggs have higher concentrations of Zn than other species evaluated around the GSL and in R6; and that 2) Zn in eggs from any given species within the GSL ecosystem is similar Zn concentrations in other states within R6 (**Figure 4-9**). Additionally, the likelihood that mean Zn concentrations for a given GSL ecosystem area exceed 50 mg/kg appears to be a function of the proportion of American coot eggs represented in the mean (see **Appendix Table A-8**). These observations indicate that 50 mg/kg is likely an overly conservative screening benchmark.

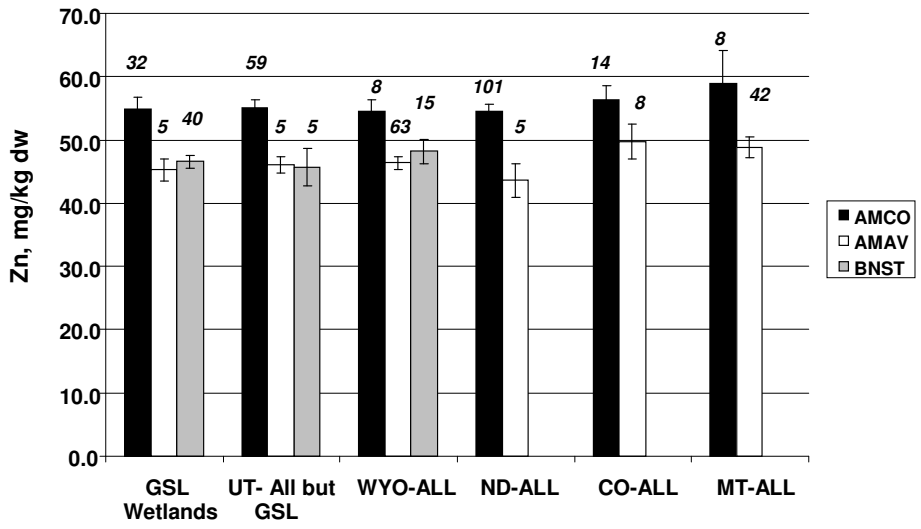

Figure 4-9 Zinc concentrations in three species, American coot (AMCO), American avocet (AMAV) and black-necked stilt (BNST) from GSL Wetlands and other locations in the western United States, 1991-2008. Data from U.S. Fish and Wildlife Service Environmental Contaminants Data Management System (ECDMS), 2009. Error bars indicate standard error; numbers above bars indicate sample size.

Organic Compounds in Avian Eggs

Similar to the results in fish, most of the OCs analyzed (23 of 26) were detected in at least one egg collected around the GSL (see complete analytical results for detected OCs in **Appendix Table A-9**). As was the case for OC concentrations in fish; all OC concentrations in eggs are presented below in terms of mg/kg wet weight. Total PCBs and DDT (at least one isomer) were observed in all eggs sampled. The predominant DDT isomer in eggs was *p,p'* DDE (observed in all eggs) versus *p, p'*-DDD which was the most frequently detected isomer in fish. However, p,p'- DDE was also frequently detected (in 65% of eggs), as were several non-DDT OCs including oxychlordane (89%), HCB (78%), and dieldrin (67%). Total DDTs (summed isomers) and t-PCB made up 80% or more of all OCs by weight in eggs (**Figure 4-10**).

Total PCBs- Although t-PCB was detected in all eggs, concentrations were generally low (**Figure 4-10**). The highest total PCB concentration measured in an individual egg was 1.39 mg/kg (ww) in a BNST egg at site FK; this was the only egg that exceeded the NOAEL (1.3 mg/kg) identified by (Wiemeyer et al. 1984). None of the eggs sampled exceeded the LOAEL of 3.5-5.0 mg/kg (Giesy et al. 1994) derived for avian eggs in the Great Lakes region.

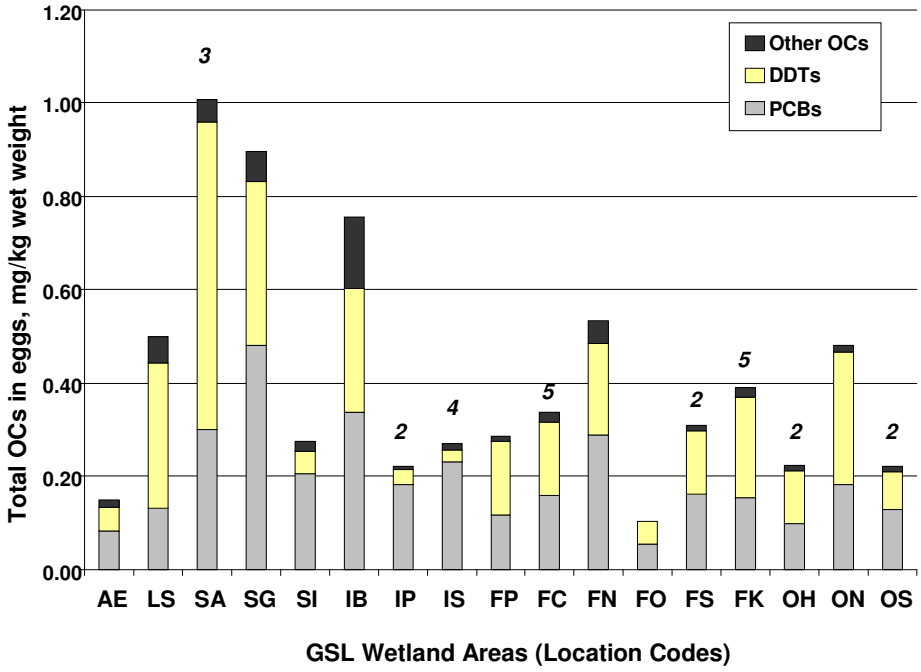

Figure 4-10 Relative contribution of total PCBs, total DDTs, and other organochlorine (OC) residues (mg/kg, ww) in avian eggs, Great Salt Lake Wetlands Synoptic Survey, 1996-1997. Mean concentrations are presented where n>1; *n*=1 unless otherwise indicated.

Total DDTs and DDT metabolites- Summed DDT residues in eggs around the GSL ranged from 0.008 mg/kg in an AMCO egg from site IP, to 1.87 mg/kg, in a BNST from site SA collected in 1997 (**Appendix Table A-9**). This latter egg, and a BNST egg from site FK with 1.457 mg/kg total DDT, were the only two individual eggs that exceeded the lowest avian effects level found in the literature (1.0 mg/kg, (Blus 2003). Mean concentrations at sample sites (with sample numbers ranging from 1 – 5) were also < 1.0 mg/kg (**Figure 4-11**).

Despite elevated concentrations of DDTs and PCBs in a few individual eggs collected around the GSL, there were no significant concentration trends between-geographic areas (**Figure 4-12**). This was at least in part due to high within-site variability and small and uneven sample sizes. However, is interesting to note that some of the highest concentrations of both t-PCB and total DDTs in individual eggs were observed in the GSL South Shore Wetlands (i.e., Sites SA, SG and SI; see data in Appendix Table A-9). This is somewhat surprising because these sites are distant from industrial sources, and of some concern because they are wetlands being managed as conservation areas and/or wetland mitigation banks. However, these sites are all at the "bottom of the watershed" and receive water (and sediments) from industrial effluents upstream., and/or may have been previously under agricultural management or subject to mosquito abatement activities (e.g., in the case of DDT residues). As discussed above (Section 4.1), PCBs in eggs from this area may also be due to exposure to air emissions containing PCBs created by incomplete combustion of hydrocarbons from large industrial sources such as U.S. Magnesium (located approximately 30 miles (50 km) to the west-northwest of the South Shore Wetlands). Analysis of individual PCB congeners would be required to support this hypothesis.

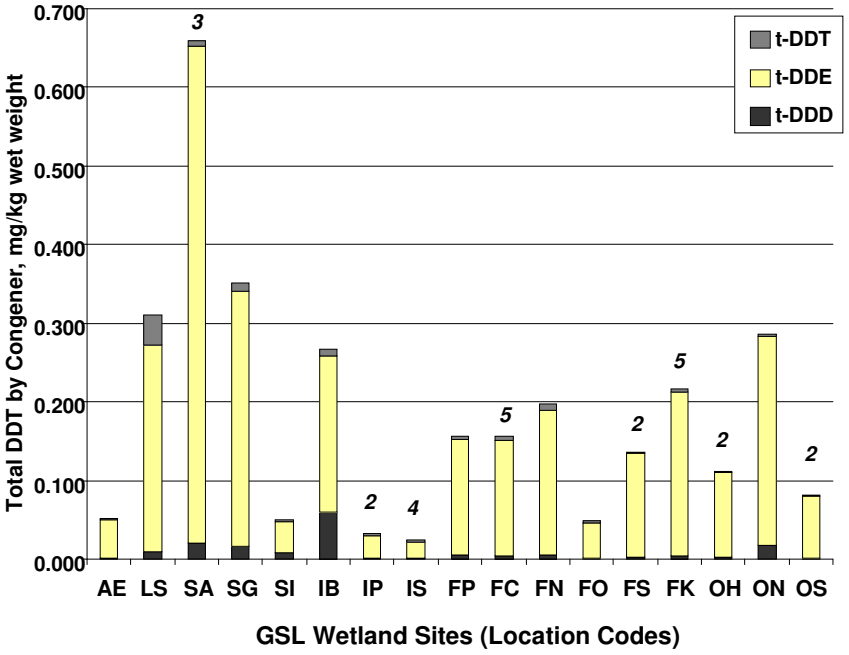

Figure 4-11. Total DDT residues (summed *o,p'*- and *p,p'*- isomers of DDD, DDE and DDT) in avian eggs, Great Salt Lake Wetlands Synoptic Survey, 1996-1997. Mean concentrations are presented where n>1; *n*=1 unless otherwise indicated.

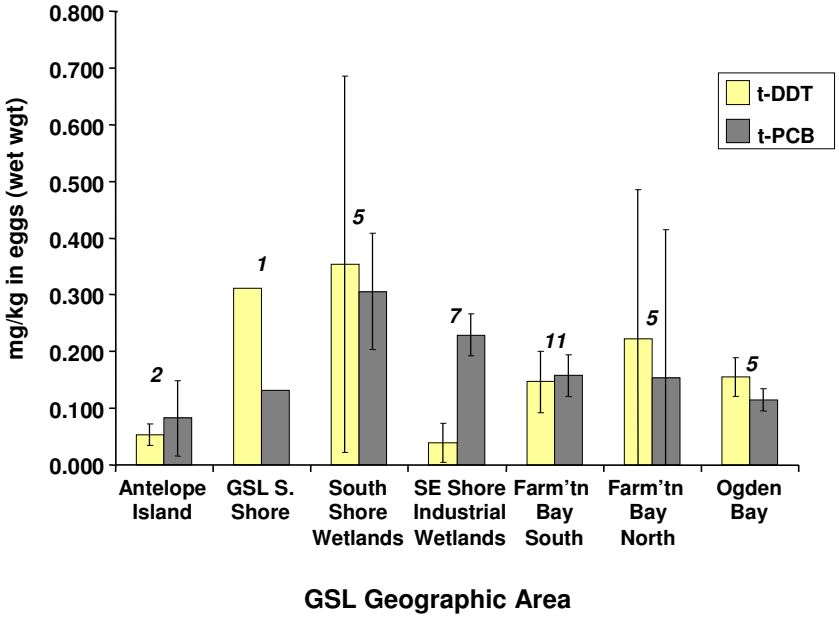

Figure 4-12. Mean concentrations of total PCBs and total DDTs in avian eggs by geographic area (mg/kg wet weight), Great Salt Lake Wetlands Synoptic Survey, 1996-1997. Sample size (*n*) presented above bars; error bars represent standard error (±SE), .

4.5 Fish Reproductive Biomarkers and PAHs in Bile

Biomarkers of contaminant exposure in fish were included in the 1996-1997 Great Salt Lake wetlands synoptic survey because analysis of these endpoints can help to either identify specific compounds to which wildlife may be exposed, or can provide additional information that can be used in conjunction with conventional chemical analyses to interpret the effects of contaminants detected in environmental media or biological tissues. Biomarkers can range from highly specific indicators of exposure to certain compounds (e.g., depression of acetylcholinesterase (AChE) activity as an indicator of exposure to organophosphate compounds), or they can be more general measures of physiological response that can indicate a biochemical or physiological response to a less specific group of chemical that may be present. An example of this type of biomarker is the measurement of ethoxyresorufin-*O*-deethylase (EROD) activity, which is a measure of the activity of a class of metabolic enzymes (cytochrome P450) that are induced in tissues such as liver in the presence of several classes of organic chemicals, which are in turn metabolized with the aid of these enzymes. Biomarker endpoints alone will not generally indicate that a contaminant is present, but will instead, paired with accompanying chemical analytical data, indicate that chemical contaminants in the environment are present in a quantity and form that elicits a biological response from the test organism. In this respect, biomarker analyses are screening tools that are most useful to identify sites where further evaluation of possible chemical contamination might be appropriate.

A broad suite of biomarkers was assessed in fish as part of the GSL Wetlands survey. These data were evaluated as an estimator of contaminant exposure to piscivorous birds, but direct exposure to fish was also considered because fish health is a basic ecosystem indicator in aquatic habitats. Biomarker-derived evidence of contaminant exposure in fish was also considered to be a screening predictor of exposure in aquatic-dependent bird species that could be evaluated without applying the generally lethal assessment methods (e.g., collection of liver or brain tissues) to the birds themselves. Samples for biomarker analysis were generally collected at the same time that samples for chemical analysis were collected. In this section, we report results from endocrine system responses in male and female common carp and polynuclear aromatic hydrocarbon (PAH) metabolites in common carp. Results on AChE activity in common carp brain tissue and EROD activity in carp liver tissue are reported in **Appendix Tables A-10 and A-11**, respectively.

Endocrine Hormones in Common Carp

Blood serum samples from 79 male and 80 female adult common carp (*Cyprinus carpio*) collected between July 31 - August 27, 1996 and from July 23 - August 28, 1997 were analyzed for the sex steroid hormones 17β-estradiol (E_2) and 11-ketotestosterone (11-KT) and for vitellogenin (VTG), an egg yolk precursor found in female non-mammalian vertebrates. The ratio of E_2 to 11-KT (estrogen:testosterone ratio or E/T ratio) was also calculated and evaluated. The reproductive status of each fish was determined through histologic evaluation of gonadal tissue samples. The gonadosomatic index (GSI) was calculated by dividing (field-measured) gonad mass by the fish mass. Complete data from these evaluations are presented in (**Appendix Table A-12**). Four sites were sampled in 1996 and eight sites were sampled in 1997; two sites (LC and FS) were sampled in both years. Males and females were analyzed separately due to natural differences in sex steroid hormones between the sexes.

Endocrine Hormones in Male Carp - In male carp, significant differences exist between sites for concentrations of E_2, 11-KT and the E/T ratio (**Table 4-12**). A summary of key differences for E_2 include: concentrations from site OS were significantly higher than at all sites except SD, while the lowest geometric mean concentrations of E_2 occurred at FC, FU, and OH. Concentrations of testosterone in male carp were similar across all locations except site OH which had the lowest geometric mean concentration and was significantly lower than all other sites. The E/T ratio at OS was significantly higher than at FP, FC, FU, while the E/T ratios at FC and FU were significantly lower than most other sites (FP, OH, SD, LC, SA, and FS) (**Figure 4-13).** Ratios of E/T in male fish are generally expected to be less than one as concentrations of 11-KT should be greater than E_2 (Goodbred et al. 1997). Sites

where ratios in male fish were >1 might suggest an unusual endocrine response and included LC (14% of male fish), SD (20%), FP (20%), FS (25%) and OS (75%). Vitellogenin was detected in one male carp at each of sites FP, LC, FS, and FU. Mean GSI (ratio of gonad mass to fish mass) was lowest at site FP (3.4%); this was significantly lower than the GSI at sites OH (8.1%) and ON (7.8%) which were the sites with the highest GSI means. The mean GSI at site OH was also significantly greater than at sites, OS, SA, and FS. GSI was significantly, but poorly correlated with weight ($r = 0.36$), length ($r = 0.34$), relative body condition ($r = 0.34$), concentrations of E_2 ($r = -0.34$), and collection date ($r = 0.38$) and not correlated with 11-KT ($r = 0.07$). Length and weight were highly correlated with each other ($r = 0.96$).

Table 4-12. Geometric mean concentrations (pg/ml) of 17β-estradiol (estrogen) and 11-keto-testosterone (testosterone), arithmetic mean E/T ratios, arithmetic mean gonadosomatic index (GSI), and detection of vitellogenin (VTG) in male common carp, Great Salt Lake Wetlands Synoptic Survey, 1996-1997.

Location (and Code)	*n*	Estrogen, pg/ml[a]	Testosterone pg/ml[a]	E/T Ratio (pg/ml)[a]	GSI[a]	VTG[b]
P-Value[c]		*(< 0.001)*	*(<0.001)*	*(<0.001)*	*(<0.001)*	
C7 Ditch (LC)	7	473 c,d,e	954 b	0.47 b,c,d	5.4% a,b,c	*
Goggin Drain (SD)	5	909 e,f	2,095 b	0.44 b,c,d	6.2% a,b,c	
Airport Mitigation (SA)	10	434 b,c,d,e	815 b	0.53 c,d	4.9% a,b	
Bountiful Pond (FP)	10	383 b,c,d	963 b	0.40 b,c	3.4% a	*
State Canal (FS)	20	516 d,e	876 b	0.59 c,d	5.0% a,b	*
Crystal Unit (FC)	2	124 a,b	1,775 b	0.07 a	6.5% a,b,c	
Unit 1 (FU)	8	111 a	948 b	0.12 a	5.0% a,b,c	*
Howard Slough (OH)	8	118 a	260 a	0.43 b,c,d	8.1% c	
Ogden Bay South (OS)	4	2,485 f	1,527 b	1.62 d	4.5% a,b	
Ogden Bay North (ON)	5	182 a,b,c	1,330 b	0.14 a,b	7.8% b,c	

NOTES AND ABBREVIATIONS:

pg/ml = picogram per milliliter

(a) For each endpoint (e.g., Estrogen), means similarity (Tukey-Kramer LSD, $P \geq 0.05$) noted with letters (e.g., means noted with "a" are similar to each other)

(b) Detection of VTG noted with "*"

(c) *P* values are for ANOVA comparison between sites (1996 and 1997) with pooled data

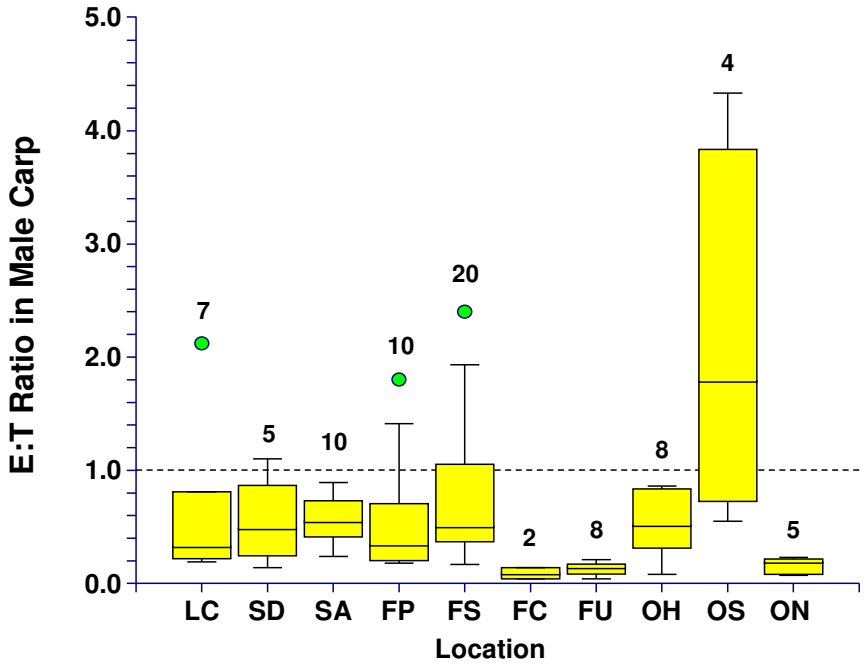

Figure 4-13. Ratio of 17β-estradiol (E) to 11-ketotestosterone (T) in male common carp, Great Salt Lake Wetlands Synoptic Survey, 1996-1997. Dashed line indicates one-to-one E/T ratio. Sample sizes are shown above box plots.

Endocrine Hormones in Female Carp - A total of 80 female common carp were collected from four locations in 1996 and eight locations in 1997, with fish being collected from sites LS and FS in both years. Data for E_2, 11-KT, E/T ratio and VTG were log-transformed prior to statistical analyses, while data for GSI met the assumption for parametric statistics.

The reproductive status of the female fish collected ranged from "undeveloped oocytes" to "late vitellogenic" based on gonad histopathology (**Table 4-13**), but the majority (72.5%) were classified as mid (n = 20) and late (n = 38) vitellogenic. Concentrations of E_2 and VTG were significantly lower in the "undeveloped oocytes" (n = 2), and "early pre-vitellogenic" (n = 6) reproductive status classes; therefore these fish were removed from further statistical analysis of hormone levels (**Table 4-13**). This eliminated site FU from further analysis (which had two fish in "undeveloped oocytes" and the remaining four fish in "early pre-vitellogenic"). Sites FP and FC were also removed from further analysis due to the reduction of sample size to n=1 by removing three fish due to sexual status (2 from FP and 1 from FC). Fish in the "pre-vitellogenic" class (n = 6) were also removed from the analysis of vitellogenin, but were included in other analyses.

Table 4-13. Influence of sexual status on geometric mean concentrations of 17β-estradiol (estrogen), 11-keto-testosterone (testosterone), mean estrogen to testosterone (E/T) ratio, vitellogenin (VTG), and mean gonadosomatic index (GSI) in female common carp, Great Salt Lake Wetlands Synoptic Survey, 1996-1997. *P*-values are shown in parentheses. Means with similar letters are similar to each other. Sexual status was not determined for one fish.

Status	*N*	Estrogen[(a)] (pg/ml)		Testosterone[(a)] (pg/ml)		E/T Ratio[(a)]		VTG[(a)] (mg/ml)		GSI	
P-Values[(b)]		*(< 0.001)*		*(0.10)*		*(0.09)*		*(<0.001)*		*(<0.001)*	
Undeveloped Oocytes	2	193	a	418	--	0.46	--	0.52	a	0.0%	a
Early Pre-Vitellogenic	6	254	a	501	--	0.52	--	0.32	a	0.7%	a
Pre-Vitellogenic	6	742	b	598	--	1.24	--	0.18[(c)]	a	1.5%	a
Early Vitellogenic	7	1,037	b	724	--	1.43	--	2.02	b	3.7%	a,b
Mid Vitellogenic	20	512	b	305	--	1.62	--	3.13	b	6.2%	b
Late Vitellogenic	38	702	b	524	--	1.31	--	2.77[(d)]	b	10.3%	c

NOTES AND ABBREVIATIONS:

pg/ml = picogram per milliliter

(a) For each endpoint (e.g., Estrogen), means similarity (Tukey-Kramer LSD, $P \geq 0.05$) noted with letters (e.g., means noted with "a" are similar to each other). "--" = no significant difference observed

(b) *P* values are for ANOVA comparison between sites (1996 and 1997) with pooled data

(c) n = 5 for VTG in females in pre-vitellogenic state

(d) n = 37 for VTG in females in late-vitellogenic state

As with male carp, data for female carp from both 1996 and 1997 at site FS were evaluated for between-year differences; 1996 and 1997 data from site LC were also evaluated because sample sizes were sufficient. At both sites, concentrations of E_2 and VTG did not differ between years; however, 11-KT was significantly higher in 1997 compared to 1996 at both sites (**Table 4-14**). There were significant differences between study sites and years for concentrations of E_2, 11-KT and E/T ratio in female fish, but there was not a significant difference in VTG concentrations (**Table 4-14**). The geometric mean concentration of E_2 at site OS (1996) was significantly higher than all sites except site SD (also 1996); the lowest geometric mean occurred at site FS in 1997. Geometric mean concentrations of 11-KT at sites ON and LC (1996) were significantly higher than at sites SA and FS (1997) which had the lowest geometric mean concentrations of 11-KT for all sites and years evaluated. The higher concentrations of 11-KT observed at ON and LC (1996) also had an impact on the E/T ratio by lowering it to less than 1.0 (i.e., 11-KT > E_2) at these sites. Site ON (1996) had the lowest mean observed E/T ratio (0.44) and was significantly lower than at the other sites and years; the E/T ratio was also < 1 at sites LC (1996) and FS (1996) (**Table 4-14**). Concentrations of VTG were not significantly different among sites, but the highest and lowest means occurred at sites OH (1997) and OS (1996), respectively.

Table 4-14. Geometric mean concentrations of 17β-estradiol (estrogen), and 11-keto-testosterone (testosterone), and arithmetic mean estrogen to testosterone (E/T) ratio, vitellogenin (VTG) concentration, and gonadosomatic index (GSI) in female common carp, Great Salt Lake Wetlands Synoptic Survey, 1996-1997.

Location (Code)	*n*	Estrogen[a] (pg/ml)		Testo-sterone[a] (pg/ml)		E/T Ratio[a]		VTG[a, c] (mg/ml)		GSI[c]	
P-Values[(b)]		*(< 0.001)*		*(< 0.001)*		*(< 0.001)*		*(0.206)*		*(0.001)*	
C7 Ditch (LC-96)	8	726	a,b	1,110	c	0.65	a,b	1.59	--	7.9%	a,b
State Canal (FS-96)	10	583	a,b	728	b,c	0.78	a,b	2.85	--	8.6%	a,b
Goggin Drain (SD-96)	6	1,166	b,c	660	b,c	1.82	b,c	2.48	--	11.3%	a,b
Ogden B South (OS-96)	5	2,436	c	565	a,b,c	4.20	c	1.47	--	6.5%	a,b
C7 Ditch (LC-97)	5	580	a,b	481	a,b,c	1.21	a,b	2.46	--	10.3%	a,b
Airport Mitigation (SA-97)	9	535	a,b	222	a	2.40	c	3.10	--	5.7%	a
State Canal (FS-97)	10	424	a	241	a	1.73	b,c	2.69	--	5.3%	a
Howard Slough (OH-97)	9	776	a,b	314	a,b	2.44	c	4.51	--	13.1%	b
Ogden B North (ON-97)	7	512	a,b	1,180	c	0.44	a	3.08	--	7.6%	a,b

NOTES AND ABBREVIATIONS:

pg/ml = pictogram per milliliter

(a) For each endpoint (e.g., Estrogen), means similarity (Tukey-Kramer LSD, $P > 0.05$) noted with letters (e.g., means noted with "a" are similar to each other). "--" = no significant difference observed

(b) *P*- values are for ANOVA comparison between sites (1996 and 1997) with pooled data

(c) Fish in pre-vitellogenic sexual status were not used to calculate means for VTG or GSI. Sample numbers for data used to calculate means are: LC 96 = 7; LC 97 = 4; FS 96 = 9; FS 97 = 8; OS = 4; ON = 6

The mean GSI for female fish among sites and years ranged from 5.3% (site FS, 1997) to 13.1% (site OH, 1997), and differed significantly among sites, with GSI at site OH (1997) significantly higher than at sites SA and FS (both 1997). Length and weight of female fish were highly correlated with each other (r = 0.97) but both were only weakly correlated with GSI (r = 0.49 for both length and weight). GSI in female fish was even less correlated with concentrations of E_2 (r =0.12) and collection date (r =0.07) than in male fish, suggesting that GSI in female fish could not be predicted by hormone levels or that spawning (related to GSI) could not be predicted by collection date. The correlation between 11-KT and E/T ratio was relatively high (r =0.71), while the correlation between E_2 and the E/T ratio was considerably lower (r = 0.44), suggesting that 11-KT in female fish had a greater influence on the E/T ratio than E_2.

Despite between- and among-site significant differences in reproductive endpoints for both male and female carp, the impact of contaminant stressors on reproductive anatomy and physiology remains unclear. While some fish serum hormone concentrations appear abnormal and vitellogenin protein was detected in male fish populations from some locations, more data, including fish contaminant concentrations and occurrence of intersex, with higher sample sizes (allowing for more complex statistical analyses) would be required to elucidate if environmental stressors are disrupting endocrine function in GSL wetland fish.

Relative Body Condition (Male and Female Fish)- Relationships between length and weight in fish are well documented and commonly used to assess the health of fish populations; however, relative body condition *(Rn)* may be a more useful indicator because of the potential for seasonal variation in the length-weight relationship due to factors such as spawning and nutritional deficits (Osmundson et al. 1997). Relative body condition is defined as:

$$Rn = \frac{M_O}{M_E}$$

where M_O is the observed mass of an individual fish, and M_E is the "expected" mass, which has been determined by a linear regression of the log-transformed length-to-weight relationship for a given population. A relative body condition of 1.0 indicates the fish's observed mass equals the expected mass of that population.

For the population of 79 male carp collected in 1996 and 1997, the mean *Rn* was 1.00 with a range of 0.964 to 1.056 ($R^2 = 0.95$). The results from ANOVA indicate that *Rn* was significantly different between locations ($F_{9,69} = 6.87$; $P < 0.001$), and paired t-tests of observed and expected mass for each site showed observed mass was significantly higher than the expected mass at FU and OH, while at LC and ON observed mass was significantly lower than the expected.

Analysis of *Rn* for 80 female carp yielded results similar to those of the males. The mean *Rn* was 1.00 with a range of 0.957 to 1.048 ($R^2 = 0.97$). Relative body condition was significantly different between locations ($F_{9,70} = 2.79$; $P = 0.007$), and paired t-tests of observed and expected mass showed observed mass was significantly higher than the expected mass at FU and OH and significantly lower than the expected mass at LC and OS. These results are almost identical to the males.

If the *Rn* was similar across all sites, fish within each site would be equally above and below an *Rn* of 1.0. That, however, was not the case. Relative body condition in both males and females was higher than expected at sites FU and OH, possibly suggesting heavier and healthier fish, and was lower in males and females at site LC, suggesting thinner fish. The one disparity between the sexes was *Rn* was lower in males at site ON but lower at site OS for females.

Polynuclear Aromatic Hydrocarbon Metabolites in Fish Bile

Bile from three individual fish at each of eight different locations was analyzed for the polynuclear aromatic hydrocarbon (PAH) metabolites of benzo(a)pyrene, naphthalene and phenanthrene parent compounds. Metabolites of all three of these compounds were detected in every sample (**Table 4-15**, with complete data in **Appendix Table A-13**).

The highest mean concentrations of all three metabolites occurred at site FS in Farmington Bay, followed closely by sites ON in Ogden Bay and LC at the mouth of the C7 canal on the south shore of the GSL. Site FU, also in Farmington Bay (and near the mouth of the Oil Drain canal), had elevated concentrations of phenanthrene and moderately elevated levels of benzo(a)pyrene.

Concentrations of benzo(a)pyrene at C7 Ditch, State Canal and Ogden North are indicative of a highly PAH contaminated environment (Krahn et al. 1986; Pinkney et al. 2001), and only Airport Mitigation and Crystal Unit had consistent concentrations that might be considered background (Suzanne McDonald, Geochemical and Environmental Research Group, personal communication) (**Figure 4-14**). Similar trends appear for naphthalene (**Figure 4-15**) and for phenanthrene (**Figure 4-16**), except that phenanthrene appears to be elevated across every site. Regarding the relatively high concentrations of PAHs at C7 Ditch, this may be explained by the proximity of site LC to an interstate freeway and to KUCC's copper smelter and refining facility, both of which are likely sources of PAH emissions that can be deposited in nearby waters. Potential sources of PAHs in Ogden Bay include the Ogden Rail Yard, motor boat traffic, roadways upstream and spills.

Table 4-15. Mean concentrations (mg/kg ww) of PAH metabolites in bile from common carp, Great Salt Lake Wetlands Synoptic Survey, 1996-1997.

Location	*Sex (M,F)*	*Benzo(a)pyrene*[(a)]		*Naphthalene*[(a)]		*Phenanthrene*[(a)]	
		P-Values[(b)]					
		(<0.001)		*(< 0.001)*		*(< 0.001)*	
C7Ditch (LC)	(1,2)	***1.060***	a	***549***	a,b	***123.5***	a
Airport Mitigation (SA)	(2,1)	0.126	b	68	c,d	44.1	b
Bountiful Pond (FP)	(3,0)	0.288	b	135	c	43.2	b
Crystal Unit (FC)	(1,2)	0.159	b	74	c,d	14.7	b,c
State Canal (FS)	(1,2)	***1.366***	a	***650***	a,b	***188.6***	a,d
Unit 1 (FU)	(1,2)	0.262	b	129	c	***125.1***	a
Howard Slough (OH)	(0,3)	0.288	b	100	c	38.2	b
Ogden North (ON)	(0,3)	***1.155***	a	298	b	***76.4***	a
Means, all sites		0.405		176		***62.7***	

KEY AND NOTES:

Value: "low" level

Value: "moderate" level

Value: "high" level (see text for discussion and reference)

(a) For each endpoint (e.g., benzo(a)pyrene), means similarity (Tukey-Kramer LSD, $P > 0.05$) noted with letters (e.g., means noted with "a" are similar to each other).

(b) *P* values are for ANOVA comparison between sites

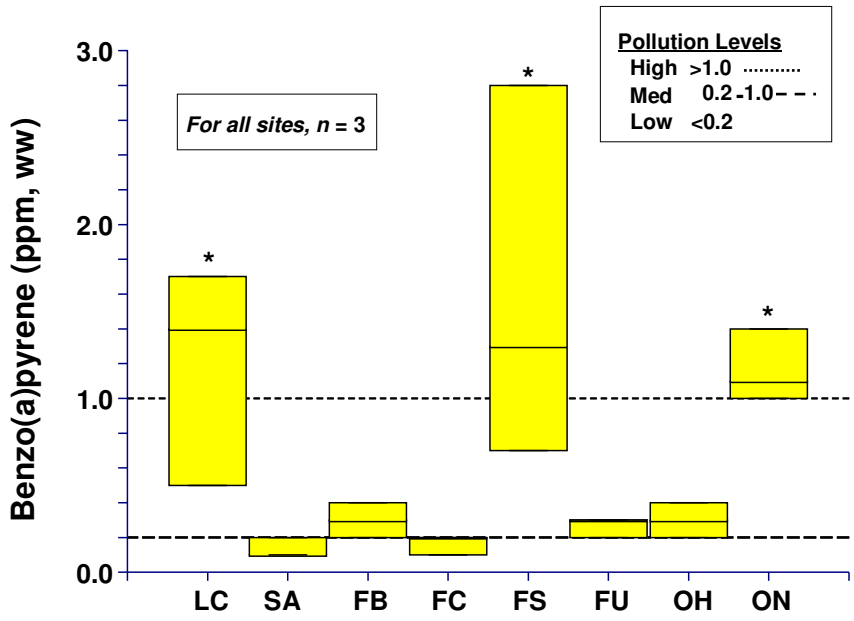

Figure 4-14. Concentrations of benzo(a)pyrene in bile from common carp (*Cyprinus carpio*) Great Salt Lake Wetlands Synoptic Survey, 1996-1997. Sites marked with (*) are significantly elevated compared to other sites; references for threshold levels given in text.

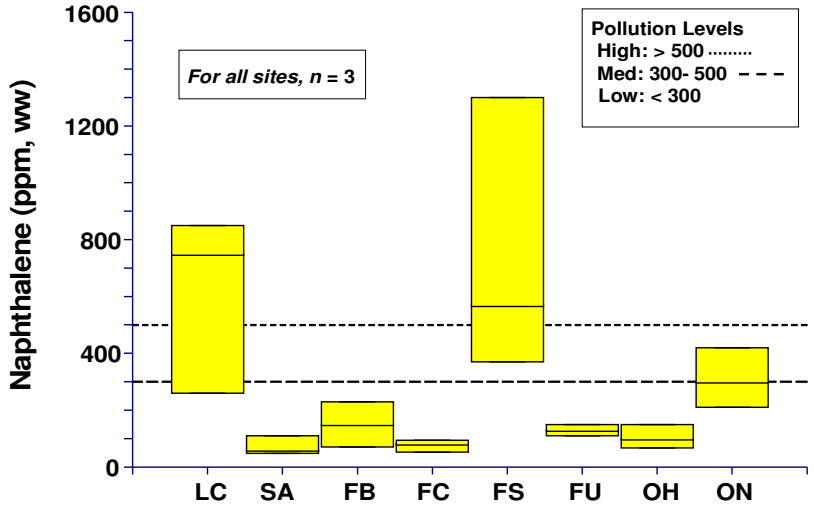

Figure 4-15. Concentrations of naphthalene in bile from common carp (*Cyprinus carpio*) Great Salt Lake Wetlands Synoptic Survey, 1996-1997. See Table 4.1-13 for results of means testing between sites (Tukey's Least Significant Difference); references for threshold levels given in text.

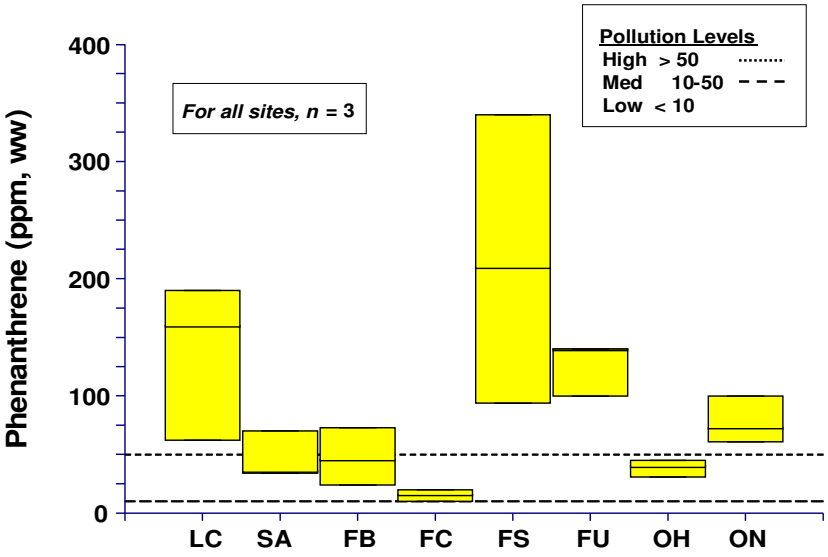

Figure 4-16. Concentrations of phenanthrene in bile from common carp (*Cyprinus carpio*) Great Salt Lake Wetlands Synoptic Survey, 1996-1997. See Table 4.1-13 for results of means testing between sites (Tukey's Least Significant Difference); references for threshold levels given in text.

Weight of evidence Analysis, Fish endocrine and body condition indicators

Table 4-16 provides a summary of responses observed within the suite of biomarkers evaluated at the GSL wetland sites, including enzyme biomarkers (AChE and EROD), endocrine hormone concentrations and ratios, and detections of elevated concentrations of PAH metabolites in bile. Because of high sample variability due to uneven sample sizes and different collection times, it was difficult to observe trends in this data; but nevertheless, three of the seven geographic areas evaluated had consistent "positive" responses (i.e., responses indicative of potential contaminant exposure) for these endpoints. Within the GSL south shore area, Site LC was the only site with aquatic habitat suitable for fish. While Farmington Bay South and Ogden Bay each contained multiple sample sites, all may be relatively homogenous with respect to fish populations, making it difficult to tie potential exposure to any particular site without further investigation. Carp at site LC had positive indications of contaminant exposure along several lines: E/T ratios were altered in female fish, vitellogenin was observed in male fish, body condition was adversely impacted in both sexes, and relatively high concentrations of PAH metabolites were observed in the subset of fish evaluated for this endpoint. However, increased EROD activity was not observed. Looking at contaminant data in fish from Site LC (Section 4.3) these findings are consistent with Cu and

Table 4-16. Weight of Evidence Summary: Responses of common carp endocrine sex hormones, vitellogenin, body condition, and enzyme biomarkers and detection of elevated concentrations of PAH compounds for the GSL South Shore, Farmington Bay South, and Ogden Bay. All data were collected from 1996-1997.

	Sites with Responses*					
	GSL South Shore		Farmington Bay South		Ogden Bay	
Endocrine:	**F**	**M**	**F**	**M**	**F**	**M**
Estrogen	--	--	FS	--	--	OS
Testosterone	--	**--**	--	--	ON	**--**
E/T Ratio	LC	--	FS	--	ON	OS
Vitellogenin	--	LC	--	FP, FS, FU	--	--
Body Condition	LC	LC	FU	FU	OS	ON
Enzyme Biomarkers:						
EROD	--	--	FU	--	--	--
AChE	LC	LC	--	--	--	--
PAH Compounds:						
Benzo(a)pyrene	LC		FS		ON	
Naphthalene	LC		FS		**--**	
Phenanthrene	LC		FS, FU		ON	

KEY and NOTES:

--	No response
Endocrine:	Site code indicates a response above or below expected at site
Enzyme Biomarkers:	Site code indicates activation of enzyme at site
PAH:	Site code indicates elevated concentrations of a PAH at site

* Biomarkers and presence of PAH compounds were not evaluated in the GSL Open Water, SE Industrialized Area Wetlands, Antelope Island, and Farmington Bay North. Responses were not detected in the GSL South Shore Wetlands.

Se concentrations that exceeded fish health levels of concern (**Table 4-8**) although concentrations of chlorinated organic compounds that are implicated in endocrine disruption were generally below levels of concern for fish (**Table 4-9**). An additional factor in fish health at LC, particularly regarding general indicators such as relative body condition, is overall habitat condition, which is generally impaired at the site. These factors, including high sediment and nutrient loads, occasional high biological oxygen demand and consequent low dissolved oxygen, and high summer temperatures may have as great or greater cumulative effect on fish health as contaminant-driven factors. However, these data also correspond with observations of elevated Cu (**Figure 4-6**) and Se (**Figure 4-7**) in avian eggs, indicating that these metals are both elevated and biologically available throughout the site. In total, it can be concluded that avian health and productivity may be adversely impacted by exposure at Site LC.

Within Farmington Bay South, Sites FS and FU were the most impacted with respect to fish biomarkers. Female fish from Site FS had altered estrogen levels and E:T ratios, while male fish from both sites FS and FU exhibited vitellogenin expression, and body condition of both sexes was altered at site FU. However, fish from site FU had relatively low concentrations of bile PAH metabolites with the exception of phenanthrene, while fish from Site FS had high concentrations of all three PAH metabolites. Site FS is located at the outlet of the State Canal, which contains water originating from the Jordan River. Jordan River meets water quality standards, and all environmental media collected at the site had relatively low concentrations of contaminants, with only slightly elevated concentrations of OCs in sediments and macroinvertebrates. Site FU also had relatively low concentrations of observed contaminants despite its proximity to the NWOD delta. Again, habitat quality and other biotic factors may also play a role in the observed endocrine responses, which may overshadow contaminant responses.

At Ogden Bay, female fish at Site ON had increased testosterone levels and male fish had increased estrogen levels, leading to altered E:T ratios for the respective sexes at the respective sites. However, relative body condition findings were reversed, with females from Site OS and males from Site ON having decreased relative body condition. Fish from site ON had elevated bile PAHs. Site ON was among the sites where DDT and its metabolites appeared to still be present in the food-chain, with elevated concentrations observed in sediments (**Table 4-3**), macroinvertebrates (**Table 4-7**), and fish (**Figure 4-5**), indicating that DDT was still bioavailable throughout the aquatic food chain at Site ON at the time of sampling. This was somewhat borne out in the avian egg results, where DDT concentrations at site ON were also slightly elevated, with only other sites with a history of intensive mosquito abatement activity such as Sites LS, SA and SG having higher concentrations (**Figure 4-11**).