Chapter 7: Bioaccumulation of Contaminants in Fish Tissues

INTRODUCTION

Bottom dwelling (i.e., demersal) fishes are collected as part of the Point Loma Ocean Outfall (PLOO) monitoring program to assess the accumulation of contaminants in their tissues. Bioaccumulation of contaminants in fish occurs through the biological uptake and retention of chemical contaminants derived via various exposure pathways (U.S. EPA 2000). The main exposure routes for demersal fishes include uptake of dissolved chemicals in seawater and the ingestion and assimilation of pollutants contained in different food sources (Rand 1995). Because of their proximity to seafloor sediments, these fish may also accumulate contaminants through ingestion of suspended particulates or sediments that contain pollutants. For this reason, the levels of many contaminants in the tissues of demersal fish are often related to those found in the environment (Schiff and Allen 1997), thus making these types of assessments useful in biomonitoring programs.

The bioaccumulation portion of the Point Loma ocean monitoring program consists of two components: (1) liver tissues are analyzed for trawl-caught fishes; (2) muscle tissues are analyzed for fishes collected by hook and line (rig fishing). Species of fish collected by trawling activities (see Chapter 6) are representative of the general demersal fish community, and certain species are targeted based on their prevalence in the community and therefore ecological significance. The chemical analysis of liver tissues in these fish is especially important for assessing population effects since this is the organ where contaminants typically concentrate (i.e., bioaccumulate). In contrast, fishes targeted for capture by rig fishing represent species that are characteristic of a typical sport fisher's catch, and are therefore considered of recreational and commercial importance and more directly relevant to human health issues. Consequently, muscle tissue is analyzed from these fishes because it is the tissue most often consumed by humans, and therefore the results may have implications related to public health concerns and policy.

This chapter presents the results of all tissue analyses that were performed on fishes collected in the PLOO region during 2008. All liver and muscle samples were analyzed for contaminants as specified in the NPDES discharge permits that govern the PLOO monitoring program (see Chapter 1). Most of these contaminants are also sampled for the National Oceanic and Atmospheric Administration (NOAA) National Status and Trends Program. NOAA initiated this program to detect and monitor changes in the environmental quality of the nation's estuarine and coastal waters by tracking contaminants thought to be of environmental concern (Lauenstein and Cantillo 1993).

MATERIALS AND METHODS

Field Collection

Fishes were collected during October of 2008 from four trawl zones (see below) and two rig fishing stations (Figure 7.1). Pacific sanddabs (*Citharichthys sordidus*) and English sole (*Parophrys vetulus*) were collected for analysis of liver tissues from the trawling zones, while several species of rockfish (*Sebastes* spp) were collected for analysis of muscle tissues at the two rig fishing stations (see Table 7.1). The rockfish species analyzed included copper rockfish (*S. caurinus*), greenblotched rockfish (*S. rosenblatti*), and vermilion rockfish (*S. miniatus*), although the mixed rockfish samples may have included additional species of *Sebastes*.

Each trawl zone represents an area centered on a specific site or sites. Zone 1 includes the two 1-km areas surrounding nearfield stations SD10 and SD12, which are located just south and north of the PLOO, respectively. Zone 2 includes the two 1-km areas surrounding the two northern farfield stations, SD13 and SD14. Zone 3 represents the 1-km area surrounding station SD8, which is located south of the outfall near the LA-5 dredged materials disposal site. Zone 4 is the 1-km area surrounding station SD7, which is located several kilometers south of the outfall and near the old (non-active) LA-4 disposal site. All trawl-caught fishes

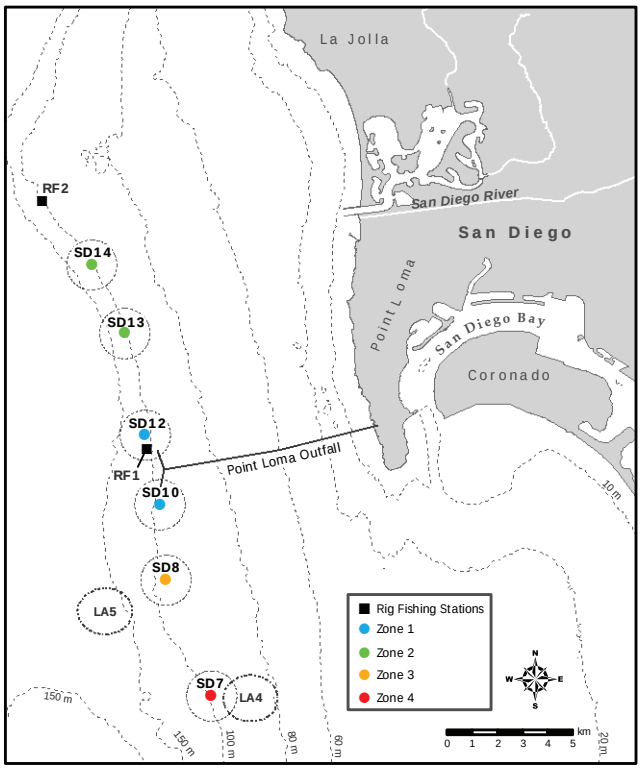

Figure 7.1
Otter trawl stations/zones and rig fishing stations for the Point Loma Ocean Outfall Monitoring Program. See text for description of zones.

were collected following City of San Diego guidelines (see Chapter 6 for a description of collection methods). Efforts to collect the targeted species at the trawl stations were limited to five 10-minute (bottom time) trawls per site. Fishes collected at the two rig fishing stations were caught within 1 km of the station location using standard rod and reel procedures; fishing effort was limited to 5 hours at each of these stations.

In order to facilitate the collection of sufficient tissue for subsequent chemical analysis, only fish ≥13 cm in standard length were retained. These fish were sorted into no more than three composite samples per station, each containing a minimum of three individuals. Composite samples were typically made up of a single species; the only exceptions were samples that consisted of mixed species of rockfish. All fish collected were wrapped in aluminum foil, labeled, sealed in re-sealable plastic bags, placed on dry ice, and then transported to the City's Marine Biology Laboratory where they were held in the freezer at -80°C until dissection and tissue processing.

Table 7.1
Species of fish collected from each PLOO trawl zone or rig fishing station (RF1–RF2) during October 2008. Comp=composite; Pacific sanddab=PS; English sole=ES; copper rockfish=CRF; vermilion rockfish=VRF; greenblotched rockfish=GBRF; mixed rockfish=MRF.

Station/Zone	Comp 1	Comp 2	Comp 3
Zone 1	PS	PS	ES
Zone 2	PS	PS	PS
Zone 3	PS	PS	PS
Zone 4	PS	PS	PS
RF1	CRF	MRF	GBRF
RF2	VRF	VRF	MRF

Tissue Processing and Chemical Analyses

All dissections were performed according to standard techniques for tissue analysis. A brief summary follows, but see City of San Diego (2004) for additional details. Prior to dissection, each fish was partially defrosted and then cleaned with a paper towel to remove loose scales and excess mucus. The standard length (cm) and weight (g) of each fish were recorded (Appendix F.1). Dissections were carried out on Teflon® pads that were cleaned between samples. The tissues (liver or muscle) from each dissected fish were then placed in separate glass jars for each composite sample, sealed, labeled, and stored in a freezer at -20°C prior to chemical analyses. All samples were subsequently delivered to the City's Wastewater Chemistry Services Laboratory for analysis within 10 days of dissection.

The chemical constituents analyzed for each tissue sample were measured on a wet weight basis, and included trace metals, chlorinated pesticides, and polychlorinated biphenyl compounds (PCBs) (see Appendix F.2). Metals were measured in units of mg/kg and are expressed herein as parts per million (ppm), while pesticides and PCBs were measured as µg/kg and expressed as parts per billion (ppb). Totals for PCBs, PAHs, and the pesticides DDT, BHC (=lindane and derivatives), and chlordane were calculated as the sum of the detected constituents (i.e., total PCB=sum of all congeners detected); detected values for each individual constituent are listed in Appendix F.3. This report includes estimated values for some

Table 7.2

Summary of metals, pesticides, total PCBs, and lipids in liver tissues of fishes collected at PLOO trawl zones during 2008. Data include the number of detected values (n), as well as minimum (Min), maximum (Max), and mean detected concentrations for each species.The number of samples per species is indicated in parentheses; nd=not detected.

	English sole (1)		Pacific sanddab (11)					
Parameter	**n**	**Min/Max**	**n**	**Min**	**Max**	**Mean**	**% Detected**	**Max**
Metals (*ppm*)								
Aluminum	nd	—	7	3	22	16	58	22
Antimony	nd	—	10	0.2	0.6	0.4	83	0.6
Arsenic	1	6.79	11	1.19	3.40	2.50	100	6.79
Barium	1	0.12	11	0.17	0.48	0.29	100	0.48
Beryllium	nd	—	1	0.104	0.104	0.104	8	0.104
Cadmium	1	0.71	11	2.58	11.80	6.17	100	11.80
Chromium	1	0.2	11	0.2	0.4	0.3	100	0.4
Copper	1	4.8	11	5.0	9.6	6.9	100	9.6
Iron	1	115	11	45	157	88	100	157
Lead	1	2.6	7	0.2	0.3	0.3	67	2.6
Manganese	1	1.0	11	0.7	1.2	0.9	100	1.2
Mercury	1	0.06	11	0.04	0.22	0.10	100	0.22
Nickel	1	0.2	6	0.2	0.4	0.3	58	0.4
Selenium	1	2.15	11	0.48	1.10	0.77	100	2.15
Silver	1	0.15	3	0.06	0.20	0.11	33	0.20
Thallium	nd	—	6	0.6	0.7	0.6	50	0.7
Tin	1	2.7	11	4.1	4.9	4.5	100	4.9
Zinc	1	65.40	11	24.50	39.20	31.37	100	65.40
Pesticides (*ppb*)								
HCB	nd	—	10	4.5	6.6	5.5	83	6.6
Total Chlordane	nd	—	2	10	14	12	17	14
Total DDT	1	82.0	11	115.0	830.3	455.9	100	830.3
Total PCB (*ppb*)	1	69.4	11	64.3	606.0	254.0	100	606.0
Lipids (*% wt*)	1	10.1	11	37.0	45.2	42.4	100	45.2

parameters determined to be present in a sample with high confidence (i.e., peaks confirmed by mass-spectrometry), but that otherwise occurred at levels below the method detection limit (MDL). A detailed description of the protocols for chemical analyses is available in City of San Diego (2009).

Results and Discussion

Contaminants in Trawl-Caught Fishes

Metals

Eleven metals occurred in 100% of the liver samples analyzed from trawl-caught fishes in 2008, including arsenic, barium, cadmium, chromium, copper, iron, manganese, mercury, selenium, tin, and zinc (Table 7.2). Another seven metals (i.e., aluminum, antimony, beryllium, lead, nickel, silver, thallium) were also detected, but less frequently at rates between 8–83%. Concentrations of most metals were <15 ppm. Exceptions occurred for aluminum, iron, and zinc, which all had concentrations >20 ppm in at least one sample. Of all the metals detected, iron was present in the highest concentrations in both species of fish that were analyzed (i.e., Pacific sanddabs and English sole). Comparisons of the frequently detected metals from sanddab samples collected from zone 1 located nearest the discharge site to those located farther away (i.e., zones 2–4) suggest

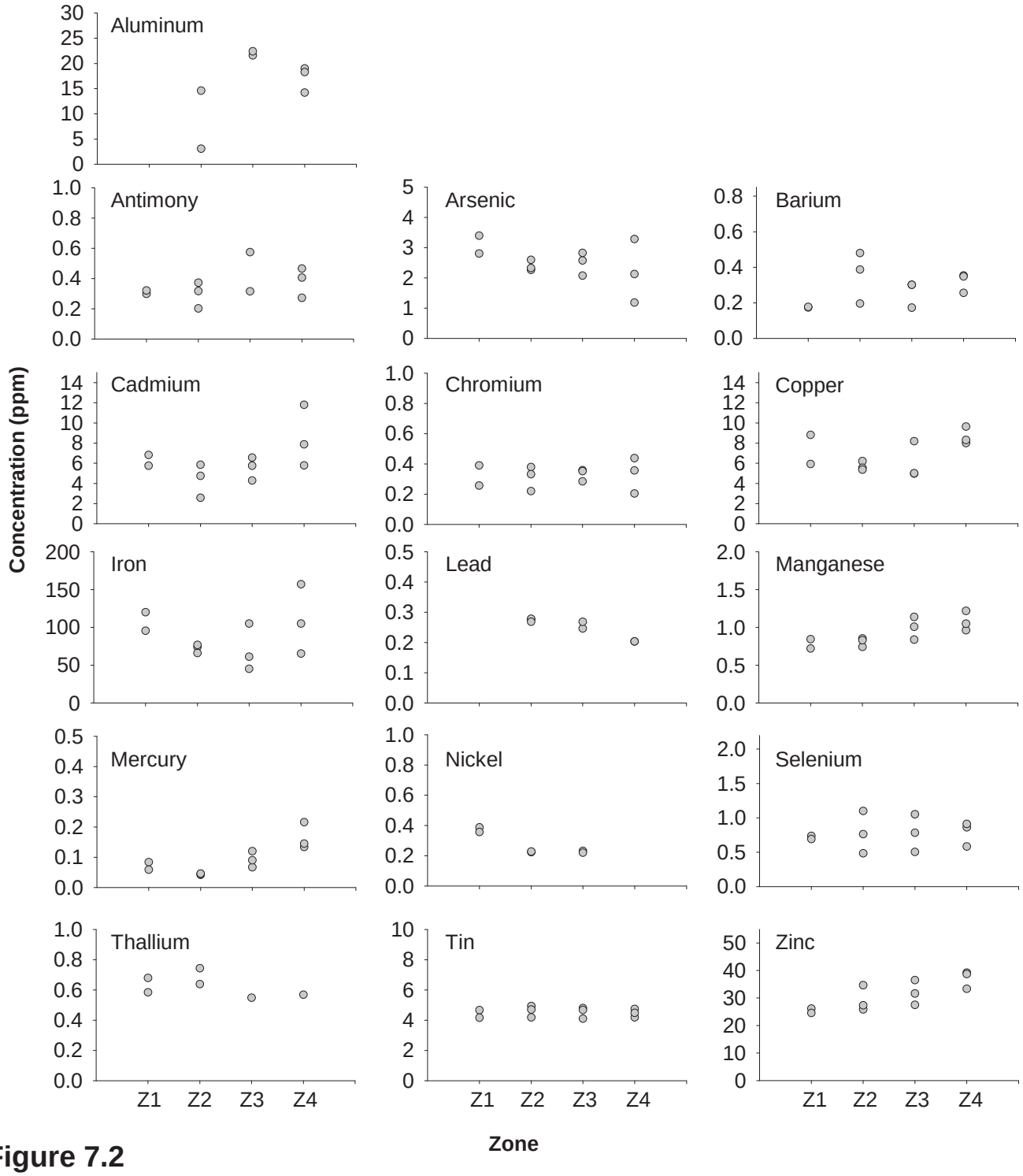

Figure 7.2

Concentrations of frequently detected metals in liver tissues of Pacific sanddabs collected from each PLOO trawl zone (Z1–Z4) during 2008. Only two Pacific sanddabs samples were collected from zone 1; otherwise missing values=non-detects.

no clear relationship between contaminant loads in fish tissues and proximity to the outfall (Figure 7.2). Only nickel concentrations appeared to be higher in sanddab samples collected near the outfall than at the other monitoring sites. However, all tissue samples had very low nickel concentrations compared to those reported previously for the PLOO region (see City of San Diego 2007a).

Pesticides

Only three chlorinated pesticides were detected in trawl-caught fishes during 2008 (Table 7.2), each

at concentrations substantially less than historical highs (see City of San Diego 2007a). Individual components of total chlordane and total DDT are listed in Appendix F.2, while detected values are included in Appendix F.3. DDT was detected in all tissue samples with concentrations ranging between 82 and 830 ppb. Hexachlorobenzene (HCB) was also detected frequently (83% of samples), but at much lower concentrations (i.e., <7 ppb). Chlordane, which consisted solely of trans-nonachlor, was also found in relatively low concentrations (≤14 ppb), and in only two sanddab samples. As with metals, there was no clear relationship between concentrations of these pesticides and proximity to the outfall (Figure 7.3).

PCBs

Polychlorinated biphenyl compounds occurred in every liver tissue sample analyzed during the year. All PCB congeners that were detected are summarized in Appendix F.3. Overall, total PCB concentrations were highly variable in fish livers, ranging from 64 to 606 ppb (Table 7.2). These values were an order of magnitude less than reported previously for the region (e.g., see City of San Diego 2007a), and there was no clear relationship between PCB accumulation in fish livers and proximity to the outfall (Figure 7.3). Instead, the highest PCB concentration was detected in a sanddab sample from zone 3, a location where PCB concentrations have historically been higher in several species of fish (e.g., see City of San Diego 2003, 2007a); these elevated PCBs have been found to be most likely associated with sediment deposition targeted for the LA-5 dredge materials dumpsite (Parnell et al. 2008).

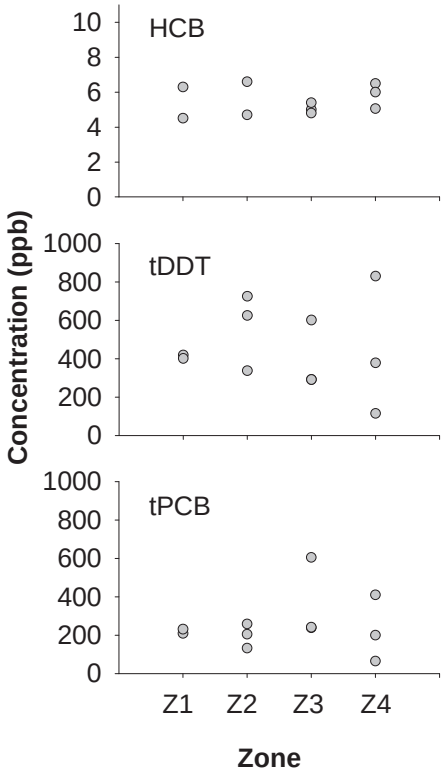

Figure 7.3
Concentrations of hexachlorobenzene (HCB), total DDT (tDDT), and total PCB (tPCB) in liver tissues of Pacific sanddabs collected from each PLOO trawl zone (Z1–Z4) during 2008. Only two Pacific sanddabs samples were collected from zone 1; otherwise missing values=non-detects.

Contaminants in Fishes Collected by Rig Fishing

Arsenic, barium, chromium, copper, iron, manganese, mercury, selenium, tin, and zinc occurred in 100% of the muscle tissue samples collected from various species of rockfish at the two rig fishing stations in 2008 (Table 7.3). In addition to these 10 metals, aluminum, antimony, beryllium, cadmium, silver, and thallium were also detected, but less frequently at detection rates of 17–83%. The metals present in the highest concentrations were aluminum (up to 3.11 ppm), arsenic (up to 5.75 ppm), iron (up to 6.76 ppm), and zinc (up to 5.72 ppm). The pesticide DDT was detected in 100% of the muscle samples, while hexachlorobenzene (HCB) and PCB were detected in 50 and 67% of the samples, respectively (Table 7.4). Each of these contaminants was detected in relatively low concentrations (i.e., <15 ppb).

To address human health concerns, contaminant concentrations found in the muscle tissues of fishes collected as part of the PLOO monitoring program were compared to state, national, and international limits and standards (see Table 7.3,7.4). These include: 1) the California Office of Environmental Health Hazard Assessment (OEHHA), which has developed fish contaminant goals for chlordane, DDT, methylmercury, PCBs, and selenium (Klasing and Brodberg 2008); 2) the United States Food and Drug Administration (U.S. FDA), which has set limits on the amount of mercury, total DDT, and chlordane in seafood that is to be sold for human

Table 7.3

Summary of metals in muscle tissues of fishes collected at PLOO rig fishing stations during 2008. Data include the number of detected values (n), as well as minimum (Min), maximum (Max), and mean detected concentrations for each species. Concentrations are expressed as parts per million (ppm); the number of samples per species is indicated in parentheses; nd=not detected. Data are compared to OEHHA fish contaminant goals (OEHHA), U.S. FDA action limits (AL), and median international standards (IS) for parameters where these exist. Bold values meet or exceed these standards. See Appendix F.2 for names of each metal represented by periodic table symbol.

	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Mn	Hg	Se	Ag	Tl	Sn	Zn
Copper rockfish (1)																
n	nd	1	1	1	nd	nd	1	1	1	1	1	1	nd	nd	1	1
Min/Max	—	0.2	**1.42**	0.08	—	—	0.1	0.6	3	0.1	0.18	**0.57**	—	—	1.8	4.93
Greenblotched rockfish (1)																
n	nd	1	1	1	1	1	1	1	1	1	1	1	nd	nd	1	1
Min/Max	—	0.3	**5.75**	0.13	0.042	0.08	0.2	0.8	5	0.2	**0.28**	**0.34**	—	—	2.0	4.46
Mixed rockfish (2)																
n	1	1	2	2	nd	nd	2	2	2	2	2	2	nd	2	2	2
Min	2	0.2	**1.42**	0.09	—	—	0.2	1.1	5	0.1	0.13	**0.39**	—	0.4	1.7	3.01
Max	2	0.2	**2.44**	0.11	—	—	0.2	1.1	5	0.2	**0.29**	**0.50**	—	0.6	2.0	5.72
Mean	2	0.2	**1.93**	0.10	—	—	0.2	1.1	5	0.1	0.21	**0.45**	—	0.5	1.8	4.36
Vermilion rockfish (2)																
n	2	2	2	2	nd	nd	2	2	2	2	2	2	2	2	2	2
Min	3	0.2	1.04	0.09	—	—	0.1	0.7	6	0.2	0.12	0.27	0.05	0.7	2.0	3.32
Max	3	0.2	**1.74**	0.10	—	—	0.2	0.9	7	0.3	0.13	**0.31**	0.05	0.8	2.1	3.83
Mean	3	0.2	1.39	0.10	—	—	0.2	0.8	7	0.3	0.12	0.29	0.05	0.8	2.1	3.57
All species:																
% Detected	50	83	100	100	17	17	100	100	100	100	100	100	33	67	100	100
Max	3	0.3	**5.75**	0.13	0.042	0.08	0.2	1.1	7	0.3	**0.29**	**0.57**	0.05	0.8	2.1	5.72
OEHHA											0.22	7.4				
AL*											1.0					
IS*			1.4			1	1	20			0.5	0.3			175	70

*From Mearns et al. 1991. U.S. FDA action limits for mercury and all international standards are for shellfish, but are often applied to fish.

consumption (see Mearns et al. 1991); 3) international standards for acceptable concentrations of various metals and DDT (see Mearns et al. 1991). Of the contaminants detected in muscle tissues of fishes collected off Point Loma during 2008, the metals arsenic and selenium occurred in concentrations slightly higher than median international standards, while mercury (as a proxy for methylmercury) exceeded the OEHHA fish contaminant goal. Exceedences for arsenic and selenium occurred in every species of fish, while the exceedance for mercury occurred only in greenblotched and vermilion rockfish samples.

In addition to addressing public health issues, spatial patterns were analyzed for HCB, DDT, and total PCB concentrations, as well as for all metals that occurred frequently in fish muscle tissues (Figure 7.4). Overall, concentrations of HCB, DDT, PCB, and various metals in the muscles of fishes captured at the two rig fishing stations were fairly similar, which suggests that there was no relationship to the outfall discharge site. However, comparisons of contaminant loads in fishes from these stations should be considered with caution since different species were collected at the two sites, and the bioaccumulation of contaminants may differ between species because

Table 7.4

Summary of chlorinated pesticides, total PCB, and lipids in muscle tissues of fishes collected at PLOO rig fishing stations during 2008. Data include the number of detected values (n), as well as minimum (Min), maximum (Max), and mean detected concentrations for each species. HCB=hexachlorobenzene; tDDT=total DDT; tPCB=total PCB. The number of samples per species is indicated in parentheses. Data are compared to OEHHA fish contaminant goals (OEHHA), U.S. FDA action limits (AL), and median international standards (IS) for parameters where these exist. Bold values meet or exceed these standards.

	HCB (ppb)	tDDT (ppb)	tPCB (ppb)	Lipids (% wt)
Copper rockfish (1)				
n	nd	1	1	1
Min/Max	—	6.3	1.5	0.5
Greenblotched rockfish (1)				
n	1	1	1	1
Min/Max	15.0	9.7	1.3	0.3
Mixed rockfish (2)				
n	1	2	1	2
Min	0.4	0.9	0.5	0.2
Max	0.4	7.5	0.5	0.5
Mean	0.4	4.2	0.5	0.3
Vermilion rockfish (2)				
n	1	2	1	2
Min	0.4	5.0	1.3	0.1
Max	0.4	8.2	1.3	0.7
Mean	0.4	6.6	1.3	0.4
All species:				
% Detected	50	100	67	100
Max	15.0	9.7	1.5	0.7
OEHHA		21	3.6	
AL*		5000		
IS*		5000		

* From Mearns et al. 1991. U.S. FDA action limits and all international standards are for shellfish, but are often applied to fish.

of differences in physiology, diet, and exposure to contaminant sources associated with migration habits and/or other large scale movements. This potential problem may be minimal in the Point Loma region as all fish specimens sampled in 2008 belong to the same family (Scorpaenidae), have similar life histories (i.e., bottom dwelling tertiary carnivores), and are therefore likely to have similar mechanisms of exposure to and uptake of contaminants (e.g., direct contact with sediments, similar food sources). However, species such as those reported herein are known to traverse large areas (M. Love, pers. comm.), and therefore may be exposed to contaminants present instead in other locations.

Summary and Conclusions

Several trace metals, the pesticides DDT, HCB, and chlordane, and a combination of PCB congeners were detected in liver tissue samples collected from two different species of flatfish (i.e., Pacific sanddabs, English sole) in the PLOO region during 2008. Many of the same contaminants were also detected in muscle tissues of several species of rockfish (*Sebastes* spp) sampled during the year, although often less frequently and/or in lower concentrations. Tissue contaminant values ranged widely in fishes collected within and among stations. However, all contaminant concentrations were within the range of values reported previously for the Southern California Bight (SCB) (e.g., Mearns et al. 1991, Allen et al. 1998). In addition, concentrations of these contaminants were generally similar to those reported previously by the City of San Diego for the Point Loma region (e.g., City of San Diego 2003, 2007a), as well as for other long-term monitoring sites for the South Bay Ocean Outfall monitoring area (e.g., City of San Diego 2007b). Further, while some muscle tissue samples from sport fish collected off Point Loma had arsenic and selenium concentrations above the median international standard for shellfish, and some had mercury levels that exceeded OEHHA fish contaminant goals, concentrations of mercury and DDT were still below FDA human consumption limits.

The frequent occurrence of metals and chlorinated hydrocarbons in the tissues of fish captured off Point Loma may be due to multiple factors. Mearns et al. (1991) described the distribution of several contaminants, including arsenic, mercury, DDT, and PCBs as being ubiquitous in the SCB. In fact, many metals occur naturally in the environment, although little information is available on background levels in fish tissues. In addition, Brown et al. (1986) determined that no areas of the SCB are sufficiently free of chemical contaminants

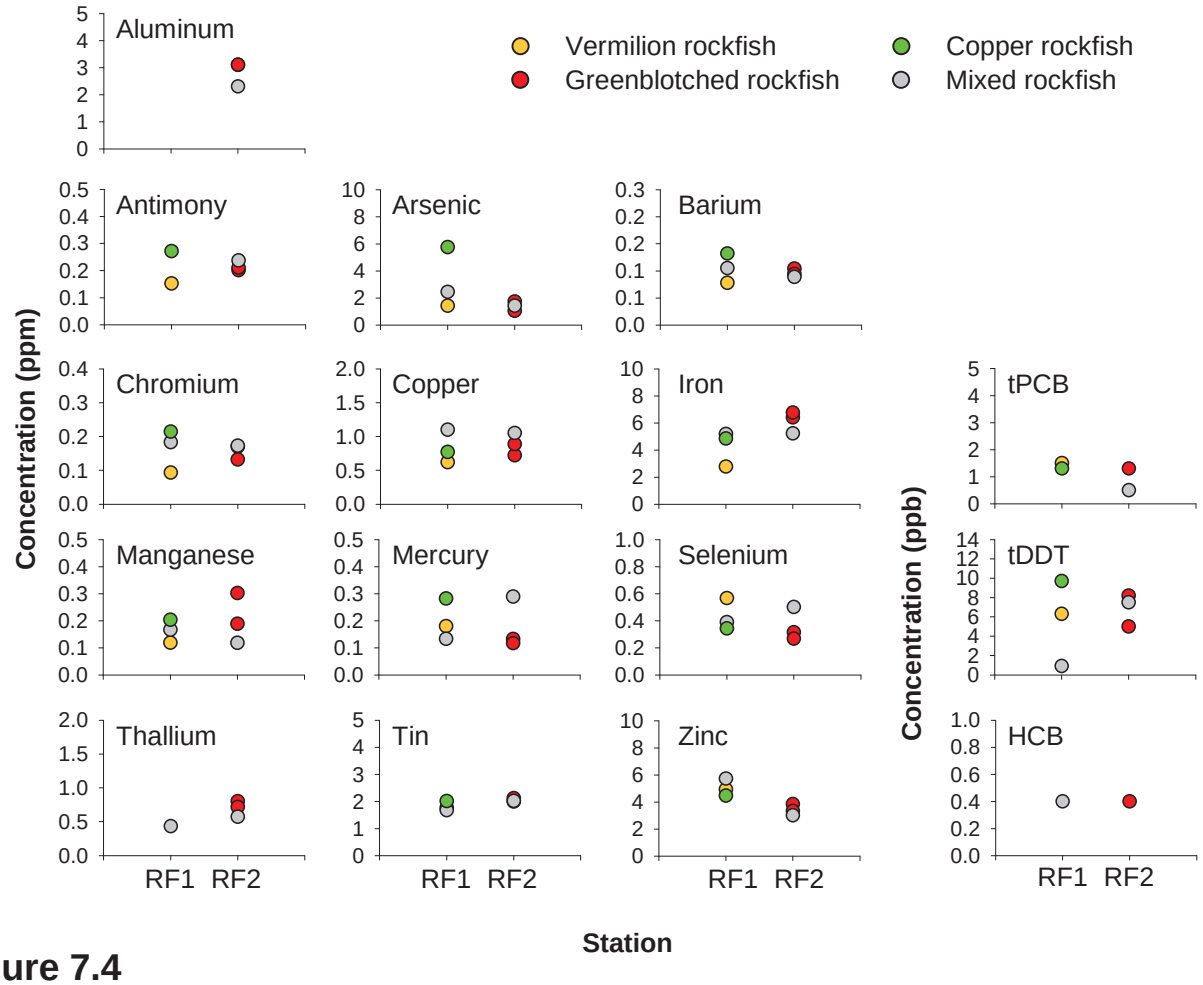

Figure 7.4

Concentrations of frequently detected metals, total PCB (tPCB), total DDT (tDDT), and hexachlorobenzene (HCB) in muscle tissues of fishes collected from each PLOO rig fishing station during 2008. All missing values=non-detects.

to be considered reference sites. This conclusion has been supported by more recent work regarding PCBs and DDTs (e.g., Allen et al. 1998, 2002).

Other factors that affect the accumulation and distribution of contaminants include the physiology and life history of different fish species. Exposure to contaminants can vary greatly between different species and among individuals of the same species depending on migration habits (Otway 1991). Fishes may also be exposed to contaminants in an area that is highly contaminated and then move into an area that is not. In addition, intra-specific differences in feeding habits, age, reproductive status, and gender can affect the amount of contaminants a fish will retain in its tissues (e.g., Connell 1987, Evans et al. 1993).

Overall, there was no evidence that fishes collected in 2008 were contaminated by the discharge of wastewater from the PLOO. Concentrations of most contaminants were similar across zones/stations, and no clear relationship with proximity to the outfall was evident. These results are supported by the findings of two recent assessments of bioaccumulation in fishes off San Diego (City of San Diego 2007a, Parnell et al. 2008). Finally, there was no other indication of adverse fish health in the region, such as the presence of fin rot, other indicators of disease, or any physical anomalies (see Chapter 6).

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