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. Anthropogenic inputs to coastal waters (including municipal wastewater outfalls) can lead to increased concentrations of chemical contaminants within the local marine environment, which can in turn bioaccumulate in the tissues of fishes and their prey. This is because the accumulation of contaminants in most fishes occurs through the biological uptake of dissolved chemicals from seawater and the ingestion and assimilation of pollutants contained in different food sources (Rand 1995, USEPA 2000). In addition, demersal fishes may accumulate contaminants through ingestion of suspended particulates or sediments that contain pollutants because of their proximity to seafloor sediments. For this reason, the levels of many contaminants in the tissues of demersal fishes 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 analyzed for trawl-caught fishes; (2) muscle tissues analyzed for fishes collected by hook and line (rig fishing). Species of fish collected by trawling activities (see Chapter 6) are considered representative of the general demersal fish community, with certain species targeted (e.g., Pacific sanddabs) based on their overall prevalence and ecological significance. The chemical analysis of liver tissues in these trawl-caught fishes is especially important for assessing population effects because this organ is 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 (e.g., various species of rockfish), and are therefore considered of recreational and commercial importance and more directly relevant to human health concerns. Consequently, muscle tissue is analyzed from these fishes because it is the tissue most often consumed by humans, and therefore the results may have public health implications. All liver and muscle tissue samples collected are chemically 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 Status and Trends Program, which was initiated by the National Oceanic and Atmospheric Administration (NOAA) 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).

This chapter presents the results of all chemical analyses that were performed on the tissues of fishes collected in the PLOO region during 2010. The goals of the chapter are to: (1) assess the level of contaminant loading in fishes throughout the region, (2) identify possible effects of wastewater discharge on contaminant accumulation in fishes collected near the discharge site, and (3) identify any spatial or temporal trends in contaminant loading.

Materials and Methods

Field Collection

Fishes were collected during October 2010 from four trawl zones and two rig fishing stations (Figure 7.1). Each trawl zone represents an area centered around one or two specific trawl stations as specified in Chapter 6. Zone 1 includes the nearfield area within a 1-km radius of stations SD10 and SD12 located just south and north of the PLOO, respectively. Zone 2 includes the area within a 1-km radius surrounding northern farfield stations SD13 and SD14. Zone 3 represents the area within a 1-km radius surrounding farfield station

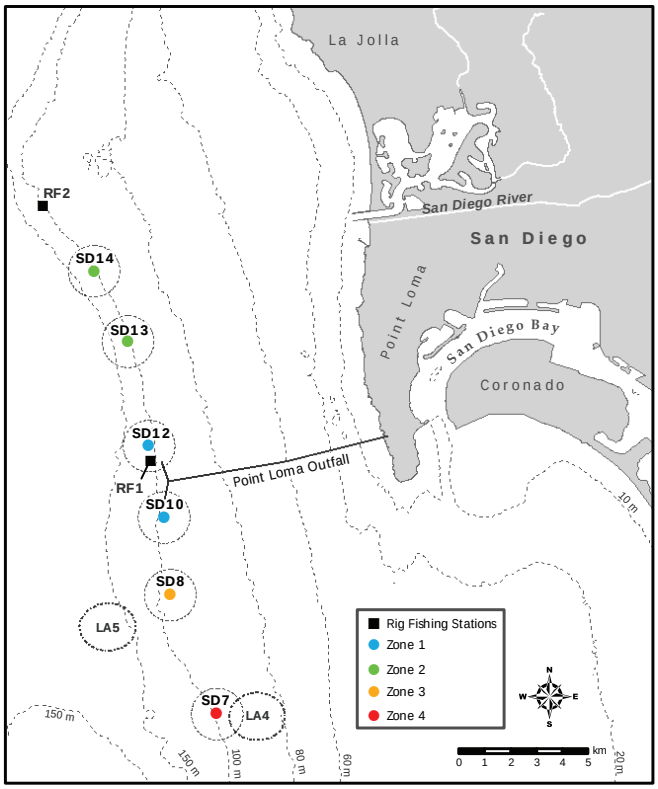

Figure 7.1
Otter trawl stations/zones and rig fishing stations for the Point Loma Ocean Outfall Monitoring Program. See text for description of zones.

SD8, which is located south of the outfall near the LA-5 dredged material disposal site. Zone 4 is the area within a 1-km radius surrounding farfield station SD7 located several kilometers south of the outfall near the non-active LA-4 disposal site. All trawl-caught fishes were collected following City of San Diego guidelines (see Chapter 6 for a description of collection methods). Efforts to collect targeted fish species at the trawl stations were limited to five 10-minute (bottom time) trawls per zone. Fishes collected at the two rig fishing stations were caught within 1 km of the station coordinates using standard rod and reel procedures. Station RF1 is located within 1 km of the outfall and is considered the nearfield site. In contrast, station RF2 is located about 11 km northwest of the outfall and is considered farfield for the analyses herein. Fishing effort was limited to 5 hours at each station.

Pacific sanddabs (*Citharichthys sordidus*) were collected for analysis of liver tissues from the trawling zones, while California scorpionfish (*Scorpaena guttata*), and several different species of rockfish (*Sebastes*) were collected for analysis of muscle tissues at the rig fishing stations (Table 7.1). Five different species of rockfish were analyzed, including copper rockfish (*S. caurinus*), chilipepper rockfish (*S. goodei*), flag rockfish (*S. rubrivinctus*), greenspotted rockfish (*S. chlorostictus*), and vermilion rockfish (*S. miniatus*).

In order to facilitate collection of sufficient amounts of tissue for subsequent chemical analysis, only fishes $\geq$13 cm in standard length were retained. These fishes were sorted into three composite samples per zone/station, with each composite containing a minimum of three individuals. Composite samples were typically made up of tissues from a single species; the only exceptions were two samples that consisted of mixed species of rockfish from station RF2 (Table 7.1). All fishes collected were wrapped in aluminum foil, labeled, sealed in re-sealable plastic bags, placed on dry ice, and transported to the City's Marine Biology Laboratory where they were held in the freezer at -80°C until dissection and tissue processing.

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 liver or muscle tissues 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.

Chemical constituents were measured on a wet weight basis, and included trace metals, DDT and other chlorinated pesticides, and polychlorinated

Table 7.1
Species of fish collected from each PLOO trawl zone or rig fishing station (RF1–RF2) during October 2010. Comp = composite; PS = Pacific sanddab; CSF = California scorpionfish; VRF = vermilion rockfish; MRF = mixed rockfish.

Station/Zone	Comp 1	Comp 2	Comp3
Zone 1	PS	PS	PS
Zone 2	PS	PS	PS
Zone 3	PS	PS	PS
Zone 4	PS	PS	PS
RF1	CSF	CSF	CSF
RF2	VRF	MRF[a]	MRF[b]

[a] Includes copper, chillipepper, and greenspotted rockfish
[b] Includes vermilion and flag rockfish

biphenyl compounds (PCBs) (see Appendix F.2 for full listing and chemical abbreviations). Metal concentrations 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). The data for each parameter reported herein were generally limited to values above method detection limits (MDL). However, concentrations below MDLs were included as estimated values if the presence of the specific constituent was verified by mass-spectrometry (i.e., spectral peaks confirmed). A more detailed description of the analytical protocols is provided by the Wastewater Chemistry Services Laboratory (City of San Diego 2011a).

Data Analyses

Data summaries for each contaminant include detection rates (i.e., number of reported values/ number of samples), and the minimum, maximum, and mean detected values of each parameter by species. Totals for DDT and PCBs were calculated for each sample as the sum of the detected constituents. For example, total DDT (tDDT) equals the sum of all DDT derivatives, while total PCB (tPCB) equals the sum of all individual congeners. The detected values for each of these individual constituents are listed in Appendix F.3. In addition, the distribution of frequently detected contaminants in fishes collected in the PLOO region was assessed by comparing concentrations in fishes collected at the "nearfield" zone and station (zone 1, RF1) to those from "farfield" stations located farther away to the south (zones 3 and 4) and north (zone 2, RF2). Because concentrations of contaminants can vary so much among different species of fish, only intra-species comparisons were used for these evaluations. Finally, in order to address seafood safety and public health issues, the concentrations of contaminants found in fish muscle tissue samples collected in 2010 were compared to state, national, and international limits and standards. These include: (1) the California Office of Environmental Health Hazard Assessment (OEHHA), which has developed fish contaminant goals for chlordane, DDT, methylmercury, selenium, and PCBs (Klasing and Brodberg 2008); (2) the United States Food and Drug Administration (USFDA), which has set limits on the amount of mercury, total DDT, and chlordane in seafood that is to be sold for human consumption (Mearns et al. 1991); (3) international standards for acceptable concentrations of various metals and DDT (Mearns et al. 1991).

Results

Contaminants in Trawl-Caught Fishes

Metals

Eight metals were detected in 100% of the liver tissue samples analyzed from trawl-caught Pacific sanddabs in the PLOO region during 2010, including arsenic, cadmium, copper, iron, manganese, mercury, selenium and zinc (Table 7.2). Another seven metals were detected less frequently in fewer than 83% of the samples. These included aluminum, barium, chromium, nickel, silver, thallium and tin. Antimony, beryllium and lead were not detected in any of the liver samples collected during the year. Most metals occurred at concentrations $\leq$20 ppm. Exceptions included higher levels up to about 83 ppm for iron and 35 ppm for zinc. Comparisons of metal concentrations in tissue samples collected from fish at the nearfield (zone 1) stations to those located farther away in zones 2–4 revealed no clear pattern between contaminant loads in local fishes and proximity to

the PLOO (Figure 7.2). Only concentrations of tin appeared to be higher in sanddab livers collected near the outfall than at the other monitoring sites, although even these higher levels were very low when compared to values reported previously for the region (City of San Diego 2009).

Pesticides

Only three chlorinated pesticides (i.e., heptachlor, HCB, and DDT) were detected in trawl-caught Pacific sanddabs during 2010 (Table 7.2). Heptachlor was detected in a single liver sample from zone 2 at a concentration of 25 ppb. Both HCB and DDT were detected in most or all tissue samples (≥92%) but at concentrations substantially lower than historical maxima (City of San Diego 2007). For example, tDDT was present in fish tissues at levels ranging between 90.1–177.5 ppb, while HCB concentrations were lower with a maximum of 8 ppb. Total DDT was composed primarily of p,p-DDE, which accounted for up to 81% of this pesticide in each sample (Appendix F.3). Another two DDT derivatives, p,p-DDMU and p,p-DDT, occurred in every sanddab liver sample in 2010, whereas p,p-DDD and o,p-DDE were detected less frequently. All four of these DDT derivatives were found at concentrations ≤42 ppb. Concentrations of HCB and DDT in fish tissues were similar between the nearfield zone and farfield zones (Figure 7.3).

PCBs

PCBs occurred in all liver tissue samples analyzed during 2010 (Table 7.2). Seven of the nineteen PCB congeners that were detected occurred in 100% of the samples; these included PCB 99, PCB 110, PCB 118, PCB 138, PCB 153/168, PCB 180, and PCB 187 (Appendix F.3). Of these, PCB 153/168 and PCB 138 occurred at the highest concentrations, with values ranging up to 63 and 34 ppb, respectively. Total PCB concentrations were variable, ranging between about 47–280 ppb (Table 7.2). The highest PCB concentrations occurred in fish from nearfield zone 1 and farfield zones 3 (near LA-5) and 4 (near LA-4) (Figure 7.3). Overall, concentrations of tPCB in samples from all zones were an order of magnitude less than reported previously for the region (City of San Diego 2007).

Table 7.2

Summary of metals, pesticides, total PCBs, and lipids in liver tissues of Pacific sanddabs collected at PLOO trawl zones during 2010. Data include detection rate (DR), minimum, maximum, and mean* detected concentrations ($n \leq 12$). See Appendix F.2 for MDLs and Appendix F.3 for values of individual constituents summed for total DDT and total PCB.

Parameter	DR (%)	Min	Max	Mean
Metals (ppm)				
Aluminum	58	nd	16.50	7.88
Antimony	0	nd	nd	—
Arsenic	100	2.18	4.08	2.95
Barium	75	nd	0.06	0.05
Beryllium	0	nd	nd	—
Cadmium	100	3.61	10.90	7.05
Chromium	83	nd	0.40	0.20
Copper	100	1.66	6.28	3.15
Iron	100	49.00	82.80	63.16
Lead	0	nd	nd	—
Mangenese	100	0.93	2.14	1.35
Mercury	100	0.04	0.12	0.06
Nickel	17	nd	0.28	0.25
Selenium	100	0.50	1.07	0.81
Silver	42	nd	0.19	0.11
Thallium	75	nd	0.96	0.60
Tin	50	nd	0.42	0.26
Zinc	100	17.60	35.10	24.72
Pesticides (ppb)				
HCB	92	nd	8.00	5.80
Heptachlor	8	nd	25.00	25.00
Total DDT	100	90.10	177.50	128.35
Total PCB (ppb)	100	46.70	280.30	194.86
Lipids (% weight)	100	9.26	39.70	28.39

nd = not detected

* Minimum and maximum values were calculated based on all samples, whereas means were calculated on detected values only.

Contaminants in Fishes Collected by Rig Fishing

Arsenic, copper, mercury, selenium and zinc occurred in 100% of the muscle tissue samples from fishes collected at the two rig fishing stations

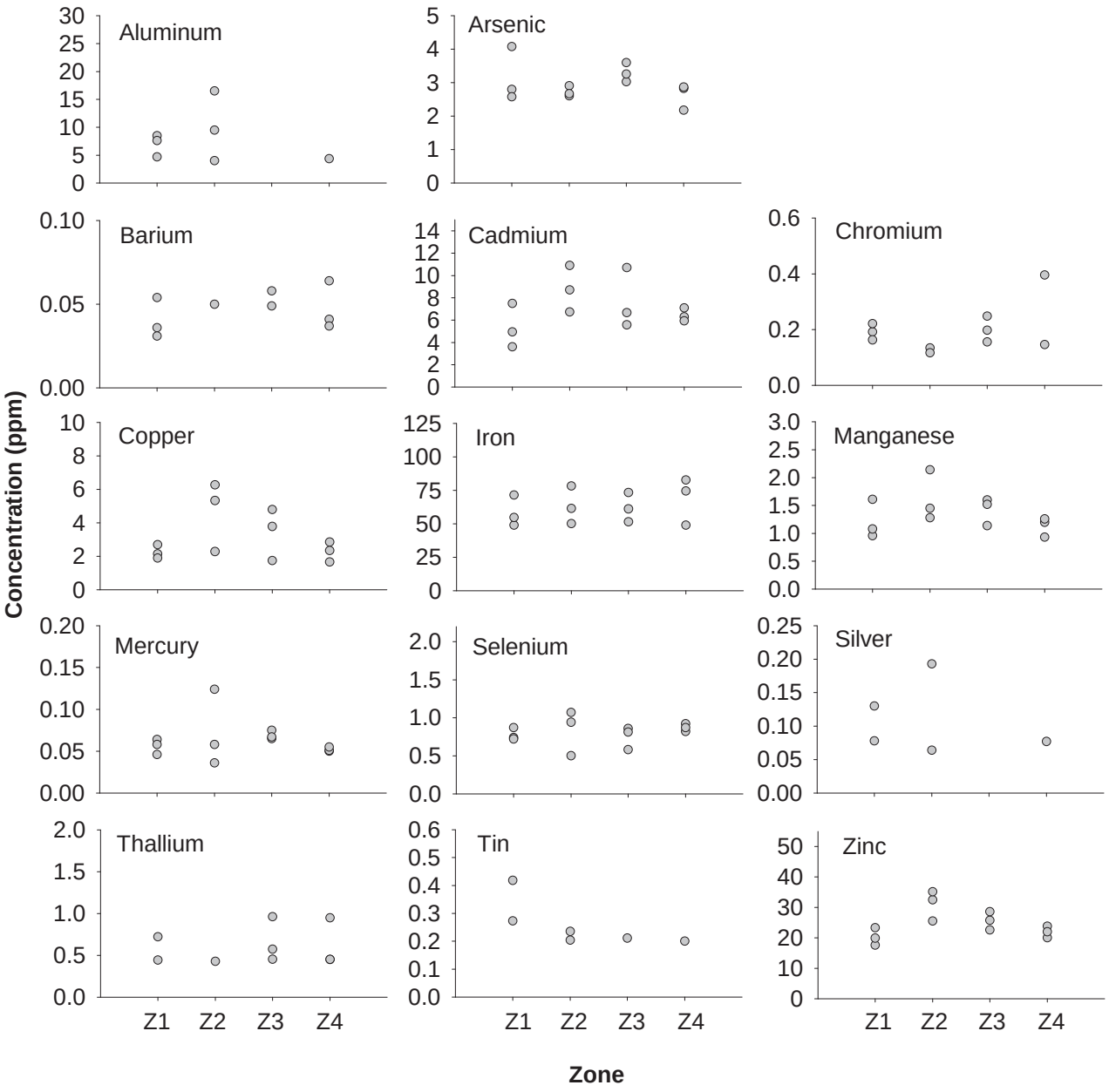

Figure 7.2

Concentrations of metals detected in at least 20% of liver tissue samples from Pacific sanddabs collected from each trawl zone (Z1–Z4) off Point Loma during 2010. Missing values = non-detects. Zone 1 is considered "nearfield".

in 2010 (Table 7.3). In addition to these five metals, aluminum, chromium, iron and thallium were detected, but in ≤50% of samples. The metals present in the highest concentrations were aluminum (up to about 3 ppm), arsenic (up to about 2 ppm), iron (up to about 4 ppm), and zinc (up to about 4 ppm). Concentrations of the remaining metals in fish muscle tissues were all less than 1 ppm. The highest concentrations of arsenic, chromium, mercury, thallium and zinc occurred in muscle tissues of California scorpionfish. In contrast, rockfish muscle tissues contained the highest concentrations of aluminum, copper, iron and selenium.

DDT and HCB were the only pesticides detected in rockfish muscle tissues collected in the Point Loma region during 2010 (Table 7.4). Total DDT (mostly p,p-DDE) was detected in 100% of the samples but at relatively low concentrations ≤10.3 ppb (Appendix F.3). The highest tDDT concentrations were detected in muscle tissue from a California scorpionfish. HCB was detected in 50% of the

samples, including muscle tissues collected from California scorpionfish and rockfish, at low concentrations (0.3–0.4 ppb).

PCBs were detected in every muscle tissue sample collected at the two rig fishing stations in 2010, with tPCB concentrations ranging from 0.3 to 9.0 ppb (Table 7.4). PCB 153/168 was the most frequently detected congener, occurring in 100% of the samples (Appendix F.3). Other common congeners that were detected in at least 50% of the samples were PCB 118, PCB 138 and PCB 149. The highest concentration of PCBs was detected in muscle tissue from a California scorpionfish.

State, national, and/or international limits and standards exist for several metal (i.e., arsenic, chromium, copper, iron, mercury, selenium, thallium, zinc), DDT, and PCB concentrations in fish tissues (Tables 7.3, 7.4). Of those contaminants detected in fish muscle tissues off Point Loma during 2010, only arsenic and selenium occurred at concentrations higher than median international standards, while mercury (as a proxy for methylmercury) and tPCB exceeded state OEHHA fish contaminant goals. Levels of tDDT did not exceed either of these standards, and none of the contaminants evaluated exceeded USFDA action limits. Exceedances for mercury and selenium occurred in California scorpionfish and mixed rockfish samples, while exceedances for arsenic and tPCB occurred only in California scorpionfish samples.

In addition to addressing seafood safety and public health issues, spatial patterns were analyzed for tDDT and tPCB, as well as for all metals that occurred frequently in scorpionfish and rockfish muscle tissues (Figure 7.4). Overall, concentrations of tDDT, tPCB, 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 with proximity to the outfall. 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

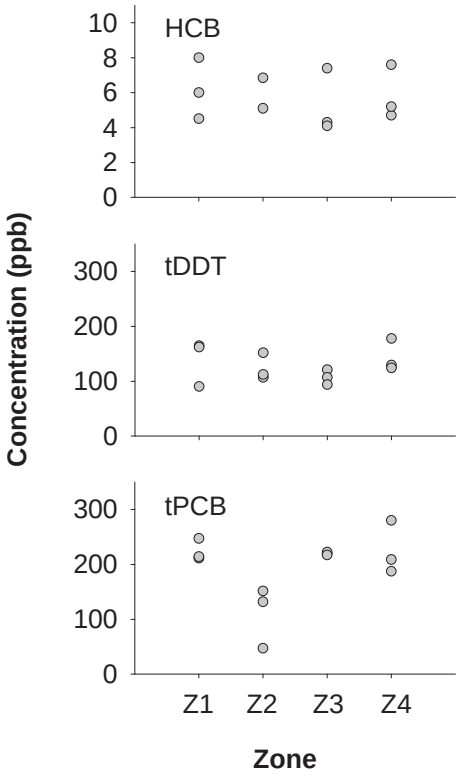

Figure 7.3
Concentrations of the most frequently detected pesticides (≥20% of samples) and tPCB in liver tissues of Pacific sanddabs collected from each PLOO trawl zone (Z1–Z4) during 2010. Missing values = non-detects. Zone 1 is considered "nearfield".

may differ between species because of differences in physiology, diet, migration habits, and/or other large scale movements that affect contaminant exposure and uptake. This problem may be minimal in the Point Loma region since all fish sampled in 2010 are bottom dwelling tertiary carnivores with similar life history characteristics.

Discussion

Fishes are often highly mobile depending on species or life-history stage, and the area in which an individual is caught may only represent a tiny fraction of the geographic area in which it lives. For example, it has been previously reported that California scorpionfish tagged in Santa Monica Bay near Los Angeles have been recaptured as far south as the Coronado Islands in Mexico (Hartmann 1987, Love et al. 1987). Therefore, even though an individual fish may have

Table 7.3

Summary of metals in muscle tissues of fishes collected at PLOO rig fishing stations during 2010. Data include the number of detected values (*n*), minimum, maximum, and mean* detected concentrations per species, and the detection rate and maximum value for all species. Concentrations are expressed as parts per million (ppm). The number of samples per species is indicated in parentheses. Bold values meet or exceed OEHHA fish contaminant goals, USFDA action limits (AL), or median international standards (IS). See Appendix F.2 for names of each metal represented by periodic table symbol.

	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
California scorpionfish																		
n (out of 3)	0	0	3	0	0	0	1	3	1	0	0	3	0	3	0	1	0	3
Min	nd	nd	1.06	nd	nd	nd	nd	0.21	nd	nd	nd	0.10	nd	0.27	nd	nd	nd	3.51
Max	nd	nd	**2.17**	nd	nd	nd	0.14	0.36	2.22	nd	nd	**0.34**	nd	**0.33**	nd	0.60	nd	3.92
Mean	–	–	**1.70**	–	–	–	0.14	0.29	2.22	–	–	0.18	–	**0.30**	–	0.60	–	3.78
Mixed rockfish																		
n (out of 2)	0	0	2	0	0	0	0	2	1	0	0	2	0	2	0	1	0	2
Min	nd	nd	0.74	nd	nd	nd	nd	0.35	nd	nd	nd	0.11	nd	0.29	nd	nd	nd	2.63
Max	nd	nd	1.18	nd	nd	nd	nd	0.42	3.64	nd	nd	**0.23**	nd	**0.46**	nd	0.47	nd	3.50
Mean	–	–	0.96	–	–	–	–	0.39	3.64	–	–	0.17	–	**0.37**	–	0.47	–	3.06
Vermilion rockfish																		
n (out of 1)	1	0	1	0	0	0	0	1	1	0	0	1	0	1	0	0	0	1
Min	3.1	nd	1.25	nd	nd	nd	nd	0.42	2.56	nd	nd	0.09	nd	0.23	nd	nd	nd	3.55
Max	3.1	nd	1.25	nd	nd	nd	nd	0.42	2.56	nd	nd	0.09	nd	0.23	nd	nd	nd	3.55
Mean	3.1	–	1.25	–	–	–	–	0.42	2.56	–	–	0.09	–	0.23	–	–	–	3.55
All Species:																		
Detection Rate (%)	17	0	100	0	0	0	17	100	50	0	0	100	0	100	0	33	0	100
Max	3.1	nd	**2.17**	nd	nd	nd	0.14	0.42	3.64	nd	nd	0.34	nd	0.46	nd	0.60	nd	3.92
OEHHA**	na	na	na	na	na	na	na	na	na	na	na	0.22	na	7.4	na	na	na	na
AL***	na	na	na	na	na	na	na	na	na	na	na	1.0	na	na	na	na	na	na
IS***	na	na	1.4	na	na	na	1	20	na	na	na	0.5	na	0.3	na	na	na	70

na = not available; nd = not detected

* Minimum and maximum values were calculated based on all samples, whereas means were calculated on detected values only.

** From the California OEHHA (Klasing and Brodberg 2008).

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

Table 7.4

Summary of pesticides, tPCB, and lipids in muscle tissues of fishes collected at PLOO rig fishing stations during 2010. Data include number of detected values (*n*), minimum, maximum, and mean* detected concentrations per species, and the detection rate (DR) and maximum value for all species. The number of samples per species is indicated in parentheses. Bold values meet or exceed OEHHA fish contaminant goals, USFDA action limits (AL), or median international standards (IS). See Appendix F.2 for MDLs and Appendix F.3 for values of individual constituents summed for tDDT and tPCB.

	Pesticides			
	HCB (ppb)	**tDDT (ppb)**	**tPCB (ppb)**	**Lipids (% weight)**
California scorpionfish				
n (out of 3)	1	3	3	3
Min	nd	1.6	1.0	0.4
Max	0.4	10.3	**9.0**	0.6
Mean	0.4	4.5	**4.9**	0.5
Mixed rockfish				
n (out of 2)	1	2	2	2
Min	nd	1.8	0.3	0.9
Max	0.3	5.0	2.5	1.0
Mean	0.3	3.4	1.4	1.0
Vermilion rockfish				
n (out of 1)	1	1	1	1
Min	0.3	5.6	1.7	0.7
Max	0.3	5.6	1.7	0.7
Mean	0.3	5.6	1.7	0.7
All Species:				
DR (%)	50	100	100	100
Max	0.4	10.3	**9.0**	1.0
OEHHA**	na	21	3.6	na
AL***	na	5000	na	na
IS***	na	5000	na	na

na = not available; nd = not detected

* Minimum and maximum values were calculated based on all samples, whereas means were calculated on detected values only.

** From the California OEHHA (Klasing and Brodberg 2008).

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

been caught near the Point Loma outfall or other areas off San Diego, any tissue contaminants it contains are likely bioaccumulated over a broad geographic area. It is therefore difficult to attribute the contaminant loading in liver or muscle tissues of fishes collected in the PLOO region to the discharge of wastewater from the outfall.

During 2010, several trace metals, pesticides and PCBs were detected in Pacific sanddab liver tissues samples collected in the PLOO region. Many of these contaminants were also detected in muscle tissues of California scorpionfish and several species of rockfish (*Sebastes*) sampled via rig fishing techniques, although often less frequently and/or in lower concentrations. Tissue contaminant loads varied widely in fishes collected within and among stations. However, all contaminant levels were within the range of values reported previously for Southern California Bight (SBC) fishes (Mearns et al. 1991, Allen et al. 1998). In addition, concentrations of these contaminants were generally similar to those reported previously for the Point Loma region (City of San Diego 2003, 2007), as well as for other long-term monitoring sites for the South Bay Ocean Outfall monitoring area (City of San Diego 2011b). Further, while some muscle tissue samples from sport fishes collected off Point Loma had arsenic and selenium concentrations above the median international standard for shellfish, and some exhibited mercury and PCB levels that exceeded OEHHA fish contaminant goals, concentrations of all contaminants were still below the USFDA consumption limits for humans.

The frequent occurrence of metals and chlorinated hydrocarbons in PLOO fish tissues are likely due to multiple factors. For instance, Mearns et al. (1991) described the distribution of several contaminants, including arsenic, mercury, DDT, and PCBs as being ubiquitous in southern California waters, and not unique to the PLOO region. In fact, many metals occur naturally in the environment, although little information is available on background levels in fish tissues. Brown et al. (1986) determined that no areas of the SBC are sufficiently free of chemical contaminants to be considered reference sites. This has been supported by more recent work examining PCBs and DDTs (Allen et al. 1998, 2002).

In addition to distributional differences of contaminants in the environment, physiological accumulation of these contaminants differ among

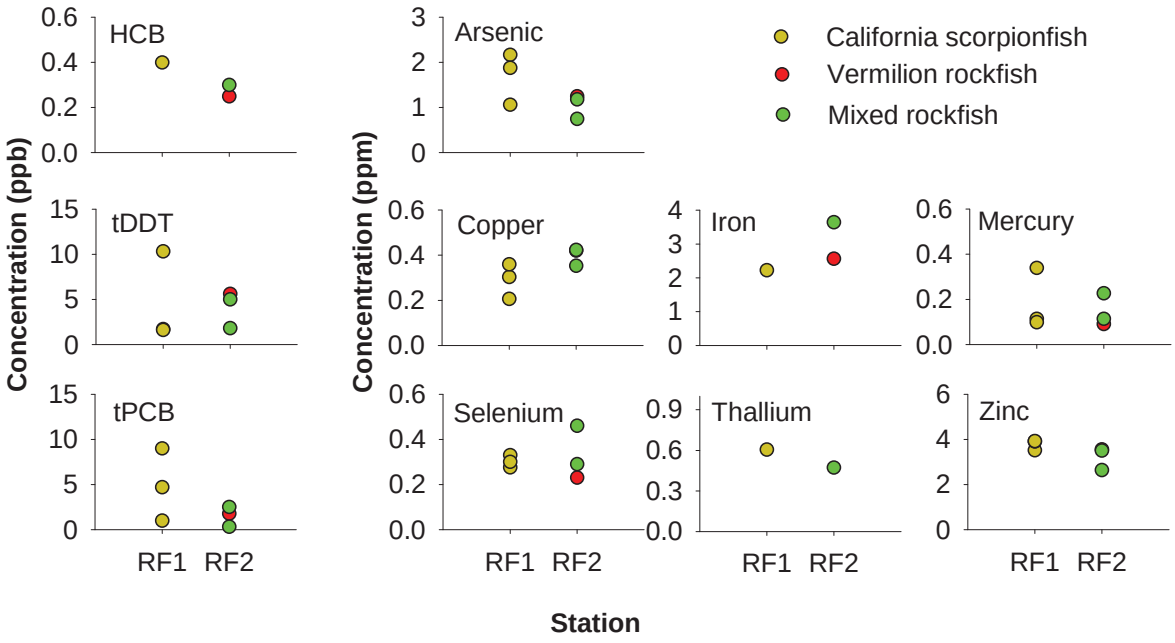

Figure 7.4
Concentrations of pesticides, tPCB, and metals detected in at least 20% of muscle tissue samples from fishes collected from each PLOO rig fishing station during 2010. Missing values = non-detects. Station RF1 is considered "nearfield".

species or even among individuals from different life history stages of a single species (see Groce 2002 and references therein). For example, different species exposed to the same concentrations of a contaminant often differ in the amount of the contaminant that ends up in their tissues. Finally, exposure to contaminants can vary greatly between different species and among individuals of the same species depending on migration habits (Otway 1991). For example, fishes may be exposed to contaminants in an area that is highly contaminated and then migrate into an area that is not.

Overall, there was no evidence that fishes collected in 2010 were contaminated by the discharge of wastewater from the PLOO. Concentrations of most contaminants were similar across zones or stations, and no relationship relevant to the outfall was evident. These results are consistent with findings of two recent assessments of bioaccumulation in fishes off San Diego (City of San Diego 2007, Parnell et al. 2008). Finally, there were no other indications of adverse fish health in the region, such as the presence of fin rot, other indicators of disease, or physical anomalies (see Chapter 6).

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