Chapter 7. Bioaccumulation of Contaminants in Fish Tissues

Introduction

Bottom dwelling (i.e., demersal) fishes are collected as part of the City of San Diego's (City) Ocean Monitoring Program to evaluate if contaminants in wastewater discharged from the Point Loma and South Bay Ocean Outfalls (PLOO and SBOO, respectively) are bioaccumulating in their tissues. Anthropogenic inputs to coastal waters can result in increased concentrations of pollutants within the local marine environment, and subsequently in the tissues of fishes and their prey. This accumulation occurs through the biological uptake and retention of chemicals derived via various exposure pathways like the absorption of dissolved chemicals directly from seawater and the ingestion and assimilation of pollutants contained in different food sources (Connell 1988, Cardwell 1991, Rand 1995, USEPA 2000). In addition, demersal fishes may accumulate contaminants through the ingestion of suspended particulates or sediments because of their proximity to the seafloor. For this reason, contaminant levels in the tissues of these 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 City's 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 collected by trawling activities (see Chapter 6) are representative of the general demersal fish community, and are targeted based on their overall prevalence and ecological significance. The chemical analysis of liver tissues in these fish is especially important for assessing population effects because 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 concerns. Consequently, muscle tissues are analyzed from these fishes because it is the tissue most often consumed by humans. All liver and muscle samples collected during the year are analyzed for contaminants as specified in the NPDES permit that governs the PLOO monitoring program (see Chapter 1). Most of these contaminants are also sampled for NOAA's National Status and Trends Program, which was initiated to detect and monitor changes in the environmental quality of the nation's estuarine and coastal waters by tracking contaminants of environmental concern (Lauenstein and Cantillo 1993).

This chapter presents summaries and interpretations of all chemical analyses that were performed on the tissues of fishes collected in the PLOO region during 2011. The primary goals are to: (1) document levels of contaminant loading in local demersal fishes, (2) identify possible effects of wastewater discharge on contaminant bioaccumulation in fishes from the PLOO region, and (3) identify other potential natural and anthropogenic sources of pollutants to the local marine ecosystem.

Materials and Methods

Field Collection

Fishes were collected during October 2011 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

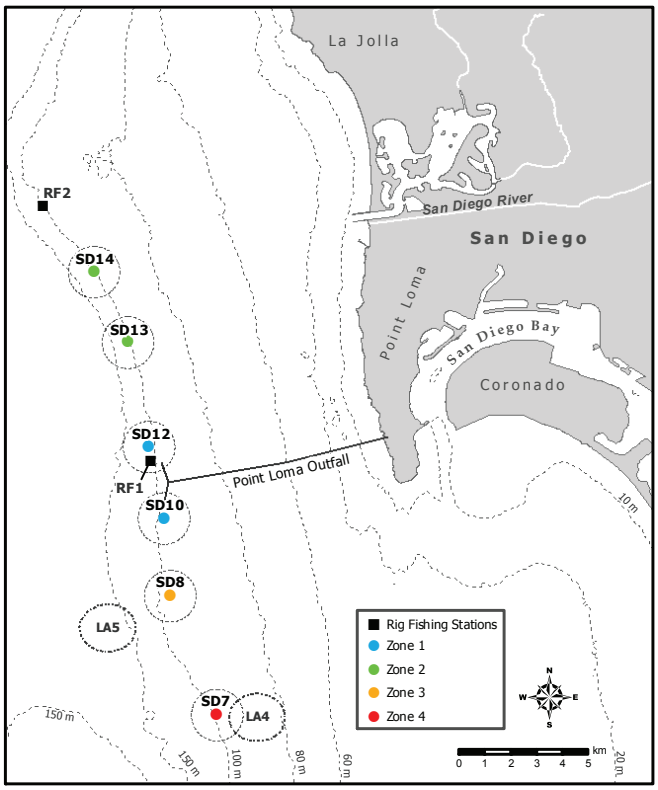

Figure 7.1
Otter trawl and rig fishing station locations sampled around the Point Loma Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

station SD8, which is located south of the outfall near the LA5 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 LA4 disposal site. All trawl-caught fishes were collected following City of San Diego guidelines (see Chapter 6 for 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 three species of rockfish were collected for analysis of muscle tissues at the rig fishing stations, including chilipepper rockfish (*Sebastes goodei*), flag rockfish (*Sebastes rubrivinctus*), and vermilion rockfish (*Sebastes miniatus*) (Table 7.1).

In order to facilitate collection of sufficient tissue for chemical analysis, only fish ≥13 cm in standard length were retained. These fish were sorted into three composite samples per station, with a minimum of three individuals in each composite. All fish 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 stored 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 (in prep) for additional details. Prior to dissection, each fish was partially defrosted and 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 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, chlorinated pesticides (e.g., DDT), and polychlorinated biphenyl compounds (PCBs). Data were generally limited to values above the method detection limit (MDL) for each parameter (see Appendix F.2). However, concentrations below MDLs were included as estimated values if presence of the specific constituent was verified by mass-spectrometry. A more detailed description of the analytical protocols is provided by the

Table 7.1
Species of fish collected from each PLOO trawl zone and rig fishing station during October 2011. Comp = composite; PS = Pacific sanddab; CRF = chilipepper rockfish; VRF = vermilion rockfish; FRF = flag 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	VRF	VRF	VRF
RF2	CRF	CRF	FRF

Wastewater Chemistry Services Laboratory (City of San Diego 2012a).

Data Analyses

Data summaries for each contaminant include detection rates, minimum, maximum, and mean detected values of each parameter by species. Total chlordane, total DDT (tDDT), and total PCB (tPCB) were calculated for each sample as the sum of all constituents with reported values (see Appendix F.3 for individual constituent values). In addition, the distribution of contaminants with detection rates ≥20% was assessed by comparing concentrations in fishes collected from "nearfield" zone/stations (zone 1, station RF1) to those from "farfield" stations located farther away to the north (zone 2, station RF2) and south (zones 3–4).

Contaminant levels in muscle tissue samples collected in 2011 were compared to state, national, and international limits and standards in order to address seafood safety and public health issues, including: (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).

In order to examine spatial and temporal patterns in contaminant loading of fishes collected from the PLOO region, multivariate analyses were performed using a 3-year data matrix composed of the main chemical parameters analyzed for each tissue sample (i.e., trace metals, pesticides, total PCBs). This analysis was conducted for all data collected between 2009 and 2011 using PRIMER software (see Clarke and Warwick 2001, Clarke and Gorley 2006). Data were limited to these three years to limit the influence of differing MDLs (Appendix F.2). Any non-detects (i.e., analyte concentrations <MDL) were first converted to "0" values to avoid data deletion issues with the clustering program, after which the data were normalized and two Euclidean distance matrices created: one for liver tissue and one for muscle tissue. For liver tissue analyses, a two-way crossed ANOSIM was conducted to determine if significant differences occurred among survey period or lipid content. For muscle tissue analyses, a two-way crossed ANOSIM was conducted to determine if significant differences occurred among survey period or species (lipids not tested since all values fell within same lipid bin; see Appendix F.4 for species list). Similarity percentages (SIMPER) analyses were used to determine which parameters accounted for significant differences identified through ANOSIM.

Results

Contaminants in Trawl-Caught Fishes

Trace Metals

Eleven trace metals occurred in 100% of the liver tissue samples analyzed from trawl-caught Pacific sanddabs during 2011, including arsenic, cadmium, chromium, copper, iron, manganese, mercury, selenium, thallium, tin and zinc (Table 7.2). Another five metals (Al, Ba, Pb, Ni, Ag) were also detected, but less frequently, at rates between 8–92%. Neither antimony nor beryllium was detected in

any of liver sample collected during the year. Most metals occurred at concentrations ≤19.2 ppm. Exceptions included higher levels up to ~29 ppm for aluminum, ~37 ppm for zinc and 101 ppm for iron. Comparisons of metals in sanddab livers from the nearfield zone (zone 1) to those from zones 2–4 revealed no clear relationship between contaminant loads and proximity to the outfall (Figure 7.2).

Pesticides

Only three chlorinated pesticides were detected in fish liver tissues during 2011 (Table 7.2). Hexachlorobenzene (HCB) and DDT were detected in all tissue samples at concentrations up to about 6 and 299 ppb, respectively. The DDT derivative p,p-DDE was found in 100% of these samples, while p,pDDMU, p,p-DDD, o,p-DDE, and p,p-DDT occurred in at least 60% (Appendix F.3). Chlordane occurred in 92% of the liver samples, at concentrations up to about 17 ppb. This pesticide consisted of one or more of the following constituents: alpha (cis) chlordane, cis-nonachlor, gamma (trans) chlordane, and trans-nonachlor. Overall, there were no clear relationships between pesticide concentrations in fish livers and proximity to the outfall (Figure 7.3).

PCBs

PCBs occurred in all liver tissue samples analyzed during 2011 at concentrations up to 317 ppb (Table 7.2). Eleven of the 31 detected congeners occurred in 100% of the samples, including PCB 99, PCB 101, PCB 110, PCB 118, PCB 138, PCB 149, PCB 151, PCB 153/168, PCB 180, PCB 183, and PCB 187 (Appendix F.3). All other congeners were found in anywhere from 8 to 92% of the samples. Overall, there was no clear relationship between total PCB and proximity to the outfall (Figure 7.3).

Table 7.2

Summary of metals, pesticides, total PCBs, and lipids in liver tissues of Pacific sanddabs collected from PLOO trawl zones during 2011. Data include detection rate (DR), minimum, maximum, and mean[a] detected concentrations ($n = 12$). See Appendix F.2 for MDLs and Appendix F.3 for values of individual constituents summed for total DDT, total chlordane and total PCB.

Parameter	DR (%)	Min	Max	Mean
Metals (*ppm*)				
Aluminum	92	nd	29.1	9.4
Antimony	0	—	—	—
Arsenic	100	3.1	4.5	3.7
Barium	83	nd	0.150	0.068
Beryllium	0	—	—	—
Cadmium	100	3.96	19.20	9.82
Chromium	100	0.16	0.33	0.23
Copper	100	2.7	10.5	4.7
Iron	100	35.3	101.0	67.2
Lead	8	nd	0.362	0.362
Mangenese	100	0.68	1.3	1.0
Mercury	100	0.037	0.473	0.110
Nickel	8	nd	0.206	0.206
Selenium	100	0.56	1.19	0.87
Silver	33	nd	0.107	0.077
Thallium	100	0.45	1.17	0.78
Tin	100	0.222	0.762	0.421
Zinc	100	19.1	36.7	24.8
Pesticides (*ppb*)				
HCB	100	1.7	5.7	3.7
Total chlordane	92	nd	16.7	8.8
Total DDT	100	44.8	298.6	212.0
Total PCB (*ppb*)	100	35.2	317.4	189.2
Lipids (*% weight*)	100	19.4	51.8	35.2

nd = not detected

[a] 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 in 2011

Arsenic, mercury, selenium and zinc occurred in 100% of the muscle tissue samples from rockfish collected at the two rig fishing stations in 2011 (Table 7.3). Another five metals (aluminum, copper, iron, thallium, tin) were also detected, but less frequently at rates between 33–83%. Antimony, barium, beryllium, cadmium, chromium, lead, manganese, nickel and silver went undetected during the year. The metals present in the highest concentrations were zinc (≤4.4 ppm), aluminum (≤4.2 ppm), iron (≤2.5 ppm), and arsenic (≤1.5 ppm). Concentrations of the remaining metals in muscle tissues were all less than 1 ppm.

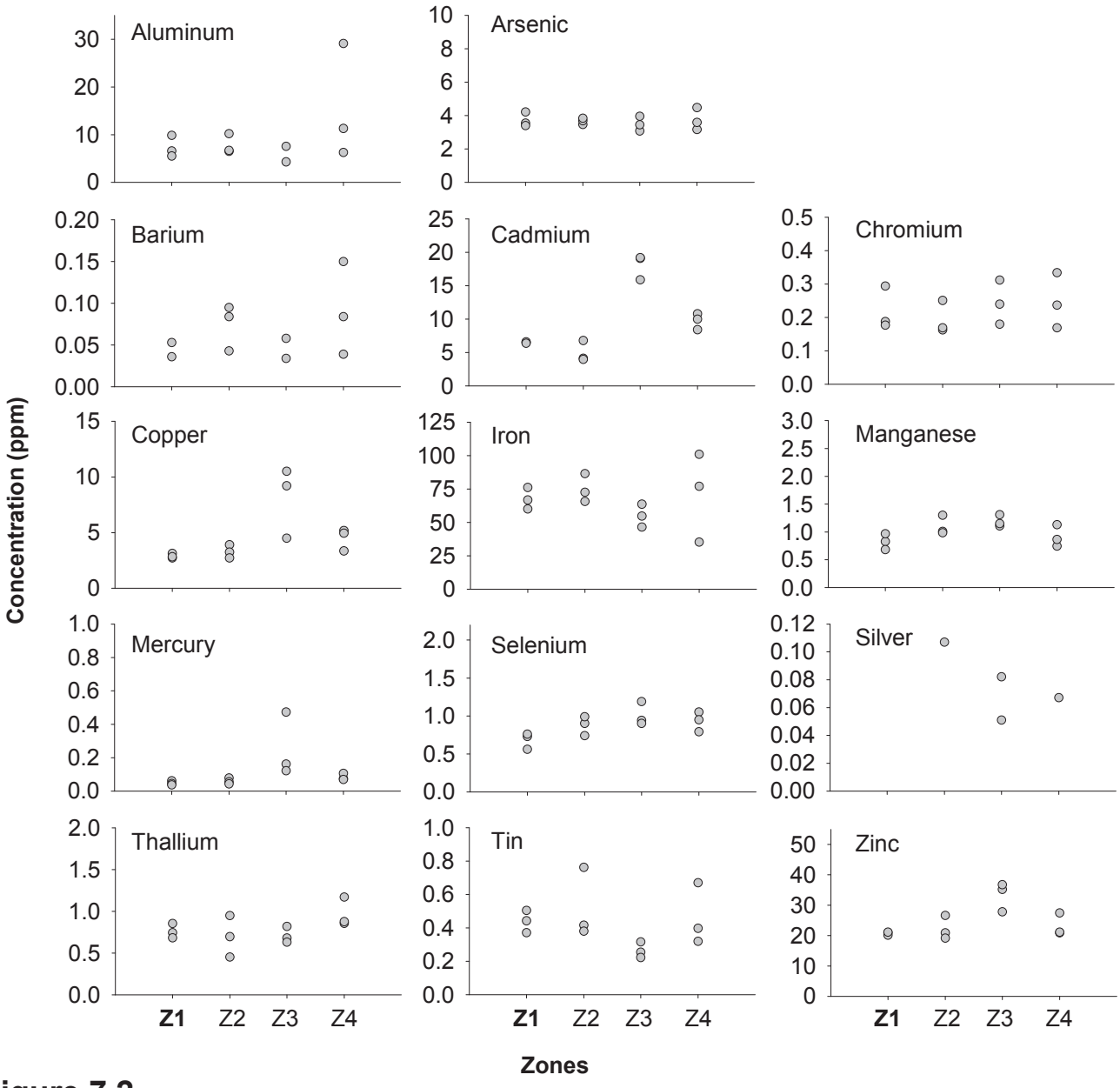

Figure 7.2
Concentrations of metals detection rates ≥20% of liver tissue of Pacific sanddabs collected from each trawl zone (Z1–Z4) off Point Loma during 2011. Missing values = non-detects. Zone 1 is considered "nearfield" (bold; see text).

Overall, metal values were fairly similar between fish collected at each rig fishing station (Figure 7.4).

Two pesticides (DDT and HCB) and PCBs were detected in every muscle tissue sample collected at the two rig fishing stations in 2011 (Table 7.4). Concentrations of all three contaminants were ≤7 ppb and none demonstrated a clear relationship with proximity to the outfall (Figure 7.4). The DDT derivative p,p-DDE and the PCB congener PCB 187 were found in all samples (Appendix F.3). An additional eight PCB congeners were detected at least 50% of the time.

Most of the contaminants detected in fish muscle tissues occurred at concentrations below state, national, and international limits or standards (Tables 7.3, 7.4). Only arsenic and selenium occurred at levels higher than median international standards, while total PCB exceeded state OEHHA fish contaminant goals. Neither mercury nor total DDT exceeded USFDA action limits, OEHHA fish

contaminant goals, or international standards. All three rockfish species had elevated concentrations (i.e., higher than threshold values) of selenium, whereas elevated arsenic levels occurred solely in vermilion rockfish, and elevated values of PCB occurred only in chilipepper rockfish.

Historical Assessment of Contaminants in Fish Tissues

ANOSIM results revealed significantly different contaminant levels in fish liver tissues based on survey period, but not by lipid content (Appendix F.5). Of the three pairwise comparisons possible for survey period, all were significant. SIMPER demonstrated that although concentrations of contaminants varied significantly among Pacific sanddabs collected during different periods, temporal trends of decreasing or increasing concentrations were not evident for any of the parameters tested (Table 7.5, Figure 7.5). Instead, concentrations of select metals, pesticides or PCBs appeared to spike randomly (e.g., aluminum in October 2009) and drove observed differences among contaminant levels in fishes collected at various times.

ANOSIM results revealed significantly different contaminant levels in fish muscle tissues based on survey period, but not among species (Appendix F.6). Pairwise comparisons revealed 2009 samples to be significantly different from 2011 samples, whereas 2010 samples were *almost* significantly different from 2011 samples, and 2010 and 2011 samples did not differ. As with liver tissues, no temporal trend of decreasing or increasing concentration was evident for any contaminant tested (Table 7.6, Figure 7.6). It is interesting to note that when high aluminum concentrations were reported from liver tissues in October 2009, concentrations were also high in muscle tissue.

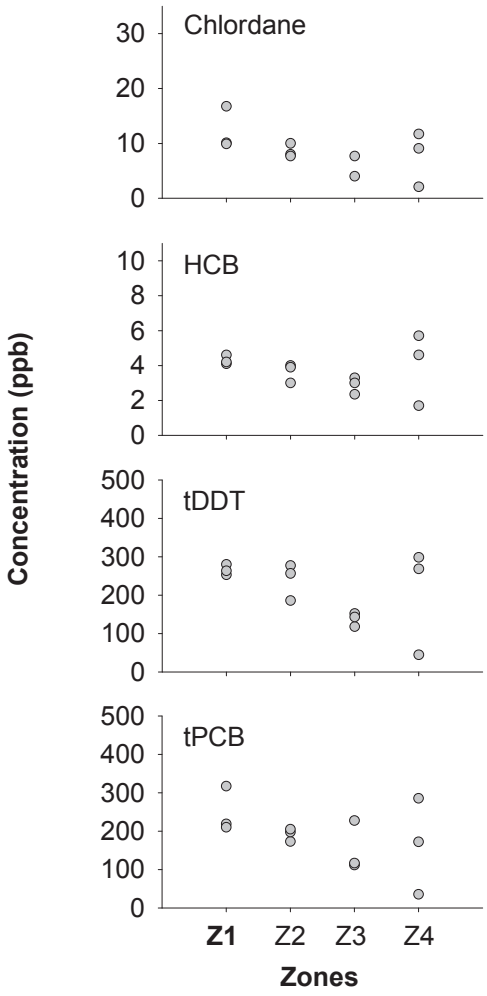

Figure 7.3
Concentrations of total chlordane, HCB, tDDT, and tPCB in liver tissues of Pacific sanddabs collected from each PLOO trawl zone (Z1–Z4) during 2011. All missing values = non-detects. Zone 1 is considered "nearfield" (bold; see text).

Discussion

Several trace metals, pesticides (e.g., DDT, HCB, chlordane) and PCB congeners were detected in liver tissue samples from Pacific sanddab liver tissues collected in the PLOO region during 2011. Many of the same metals, DDT, HCB and PCBs were also detected in rockfish muscle tissues during the year, although often less frequently and/or in lower concentrations. Although tissue contaminant concentrations varied between the four different species and stations, all values were within ranges reported previously for Southern California Bight (SCB) fishes (see Mearns et al. 1991, Allen et al. 1998, City of San Diego 2000, City of San Diego 2007). Additionally, all muscle tissue samples from rockfish collected in the area had mercury and DDT concentrations below USFDA action limits, OEHHA fish contaminant goals, and

Table 7.3

Summary of metals in muscle tissues of fishes collected from PLOO rig fishing stations during 2011. Data include the number of detected values (*n*), minimum, maximum, and mean[a] 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
Chilipepper rockfish																		
n (out of 2)	0	0	2	0	0	0	0	2	2	0	0	2	0	2	0	1	1	2
Min	—	—	0.7	—	—	—	—	0.3	2.1	—	—	0.061	—	**0.43**	—	nd	0.241	3.67
Max	—	—	0.9	—	—	—	—	0.4	2.5	—	—	0.093	—	**0.53**	—	0.53	0.241	3.72
Mean	—	—	0.8	—	—	—	—	0.3	2.3	—	—	0.077	—	**0.48**	—	0.53	0.241	3.69
Flag rockfish																		
n (out of 1)	1	0	1	0	0	0	0	1	0	0	0	1	0	1	0	1	1	1
Min	3.4	—	0.7	—	—	—	—	0.3	—	—	—	0.125	—	**0.54**	—	0.40	0.284	4.38
Max	3.4	—	0.7	—	—	—	—	0.3	—	—	—	0.125	—	**0.54**	—	0.40	0.284	4.38
Mean	3.4	—	0.7	—	—	—	—	0.3	—	—	—	0.125	—	**0.54**	—	0.40	0.284	4.38
Vermilion rockfish																		
n (out of 3)	1	0	3	0	0	0	0	2	0	0	0	3	0	3	0	1	2	3
Min	nd	—	1.0	—	—	—	—	nd	—	—	—	0.039	—	**0.33**	—	nd	0.212	3.56
Max	4.2	—	**1.5**	—	—	—	—	0.5	—	—	—	0.052	—	**0.38**	—	0.49	0.234	4.04
Mean	4.2	—	1.3	—	—	—	—	0.4	—	—	—	0.045	—	**0.36**	—	0.49	0.223	3.74
All Species:																		
Detection Rate (%)	33	0	100	0	0	0	0	83	33	0	0	100	0	100	0	50	67	100
Max	4.2	—	**1.5**	—	—	—	—	0.5	2.5	—	—	0.125	—	**0.54**	—	0.53	0.284	4.38
OEHHA[b]	na	na	na	na	na	na	na	na	na	na	na	0.22	na	7.4	na	na	na	na
AL[c]	na	na	na	na	na	na	na	na	na	na	na	1.00	na	na	na	na	na	na
IS[c]	na	na	1.4	na	na	na	1	20	na	na	na	0.50	na	0.3	na	na	na	70

na = not available; nd = not detected

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

[b] From the California OEHHA (Klasing and Brodberg 2008).

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

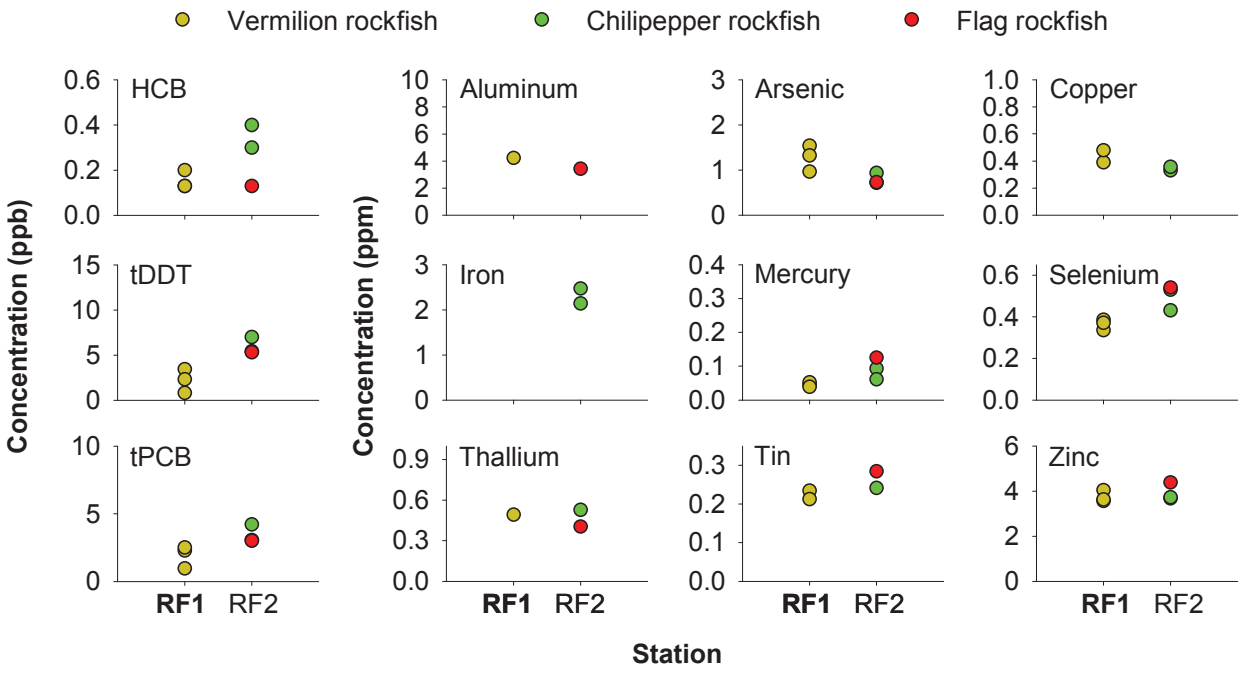

Figure 7.4
Concentrations of contaminants with detection rates ≥20% in muscle tissues of fishes collected from each PLOO rig fishing station during 2011. Missing values = non-detects. Station RF1 is considered "nearfield" (bold; see text).

international standards. However, some muscle tissues had concentrations of arsenic and selenium above the median international standards for human consumption, and some had PCB concentrations that exceeded OEHHA fish contaminant goals. Elevated levels of these contaminants are not uncommon in sportfish from the PLOO survey area (City of San Diego 2007–2011) or from the rest of the San Diego region (see City of San Diego 2012b and references therein). For example, muscle tissue samples from fishes collected over the years in the South Bay outfall survey area, including the Coronado Islands, have also had concentrations of metals such as arsenic, selenium and mercury that exceeded consumption limits.

The frequent occurrence of metals and chlorinated hydrocarbons in PLOO fish tissues 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. Brown et al. (1986) determined that no areas of the SCB are sufficiently free of chemical contaminants to be considered reference sites. This has been supported by more recent work regarding PCBs and DDTs (e.g., Allen et al. 1998, 2002).

Other factors that affect contaminant loading in fish tissues include the physiology and life history of different species (see Groce 2002 and references therein). Exposure to contaminants can also vary greatly between different species of fish and among individuals of the same species depending on migration habits (Otway 1991). Fishes may be exposed to contaminants in a highly polluted area and then move into an area that is not. For example, California scorpionfish tagged in Santa Monica Bay have been recaptured as far south as the Coronado Islands (Hartmann 1987, Love et al. 1987). This is of particular concern for fishes collected in the PLOO region, as there are many point and non-point sources that may contribute to local contamination such as the San Diego River, San Diego Bay, and dredged materials disposal sites (see Chapters 2–4; Parnell et al. 2008). In contrast, assessments of contaminant loading in sediments surrounding the PLOO reveal no evidence that the outfall is a major source of pollutants to the area (Chapter 4; Parnell et al. 2008).

Table 7.4

Summary of pesticides, tPCB, and lipids in muscle tissues of fishes collected from PLOO rig fishing stations during 2011. Data include number of detected values (*n*), minimum, maximum, and mean[a] 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)**
Chilipepper rockfish				
n (out of 2)	2	2	2	2
Min	0.3	5.4	3.0	1.6
Max	0.4	7.0	**4.2**	2.9
Mean	0.3	6.2	**3.6**	2.2
Flag rockfish				
n (out of 1)	1	1	1	1
Min	0.1	5.3	3.0	0.5
Max	0.1	5.3	3.0	0.5
Mean	0.1	5.3	3.0	0.5
Vermilion rockfish				
n (out of 3)	3	3	3	3
Min	0.1	0.8	1.0	0.3
Max	0.2	3.4	2.5	0.7
Mean	0.2	2.2	1.9	0.4
All Species:				
DR%	100	100	100	100
Max	0.4	7.0	**4.2**	2.9
OEHHA[b]	na	21	3.6	na
AL[c]	na	5000	na	na
IS[c]	na	5000	na	na

na = not available; nd = not detected

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

[b] From the California OEHHA (Klasing and Brodberg 2008).

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

There was no evidence of contaminant bioaccumulation in Point Loma fishes during 2011 that could be associated with wastewater discharge from the outfall. Concentrations of most contaminants were similar across zones or stations, and no relationship relevant to the PLOO 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). Additionally, the results of multivariate analyses confirmed that although there have been significant fluctuations in fish tissue contaminant levels over time, no relevant spatial or temporal trends are apparent. Instead, occasional spikes in tissue contaminants appear random and may be due to original exposure in other areas. Finally, there were no other indications of poor 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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Table 7.5

Summary of contaminant loads in liver tissues of Pacific sanddabs collected from the PLOO region between 2009 and 2011. Data are expressed as mean values overall samples collected during each survey. Bold indicates parameters that were considered most defining for each group according to SIMPER analysis.

	Year		
Parameter	**2009**	**2010**	**2011**
Trace Metals (*ppm*)			
Aluminum	12.20	4.60	8.65
Antimony	**0.02**	0.00	0.00
Arsenic	3.24	2.95	3.66
Barium	0.09	0.04	0.06
Beryllium	**0.002**	0.000	0.000
Cadmium	6.07	7.05	**9.82**
Chromium	**0.113**	0.164	0.226
Copper	5.580	3.150	4.690
Iron	**62.20**	63.20	67.20
Lead	0.00	0.00	**0.03**
Manganese	0.869	**1.350**	1.010
Mercury	0.106	0.062	**0.110**
Nickel	0.02	**0.04**	0.02
Selenium	1.040	0.808	0.875
Silver	0.01	**0.05**	0.03
Thallium	0.299	0.452	0.783
Tin	0.145	0.128	0.421
Zinc	23.30	24.70	**24.80**
Chlorinated Pesticides (*ppb*)			
HCB	6.280	**5.310**	3.700
Total chlordane	0.00	**2.08**	8.09
Total DDT	**406**	128	212
Total PCB (*ppb*)	209	195	**189**

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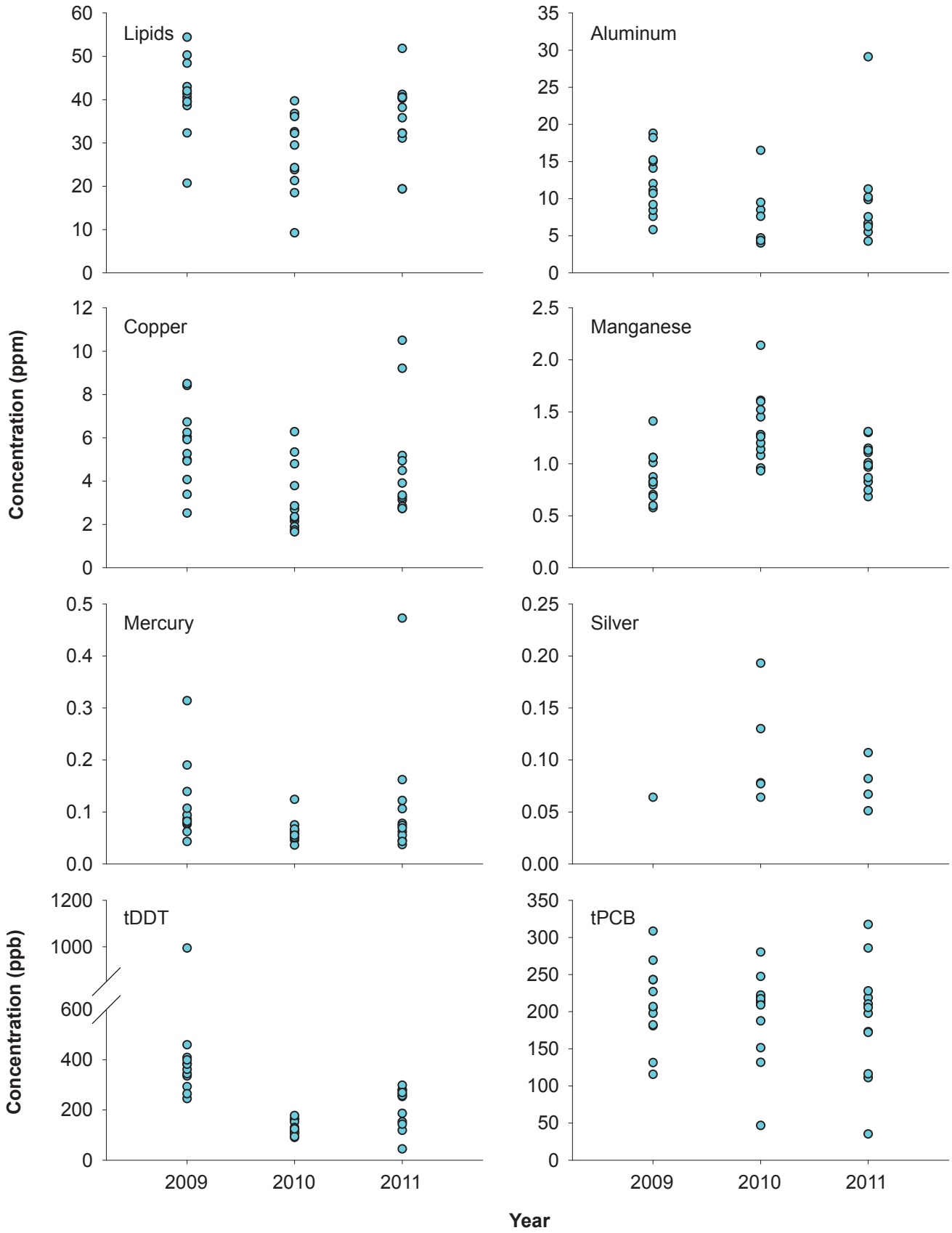

Figure 7.5
Concentrations of select parameters in liver tissues of Pacific sanddabs collected in the PLOO region between 2009 and 2011.

Table 7.6

Summary of contaminant loads in muscle tissues of fishes collected from the PLOO region between 2009 and 2011. Data are expressed as mean values overall samples collected during each survey. Bold indicates parameters that were considered most defining for each group according to SIMPER analysis.

	Year		
Parameter	**2009**	**2010**	**2011**
Trace Metals (*ppm*)			
Aluminum	5.45	0.52	1.27
Arsenic	**1.68**	1.38	1.03
Barium	0.04	0.00	0.00
Chromium	0.13	0.02	0.00
Copper	0.428	0.344	**0.316**
Iron	**1.81**	**1.40**	**0.77**
Mercury	0.191	**0.164**	0.069
Selenium	**0.456**	0.314	0.432
Silver	**0.04**	0.00	0.00
Thallium	0.000	**0.179**	**0.237**
Tin	0.000	0.000	**0.162**
Zinc	3.19	3.50	3.83
Chlorinated Pesticides (*ppb*)			
HCB	0.000	**0.158**	0.215
Total chlordane	0.00	0.00	**0.08**
Total DDT	6.50	**4.33**	4.04
Total PCB (*ppb*)	**4.02**	3.21	2.67

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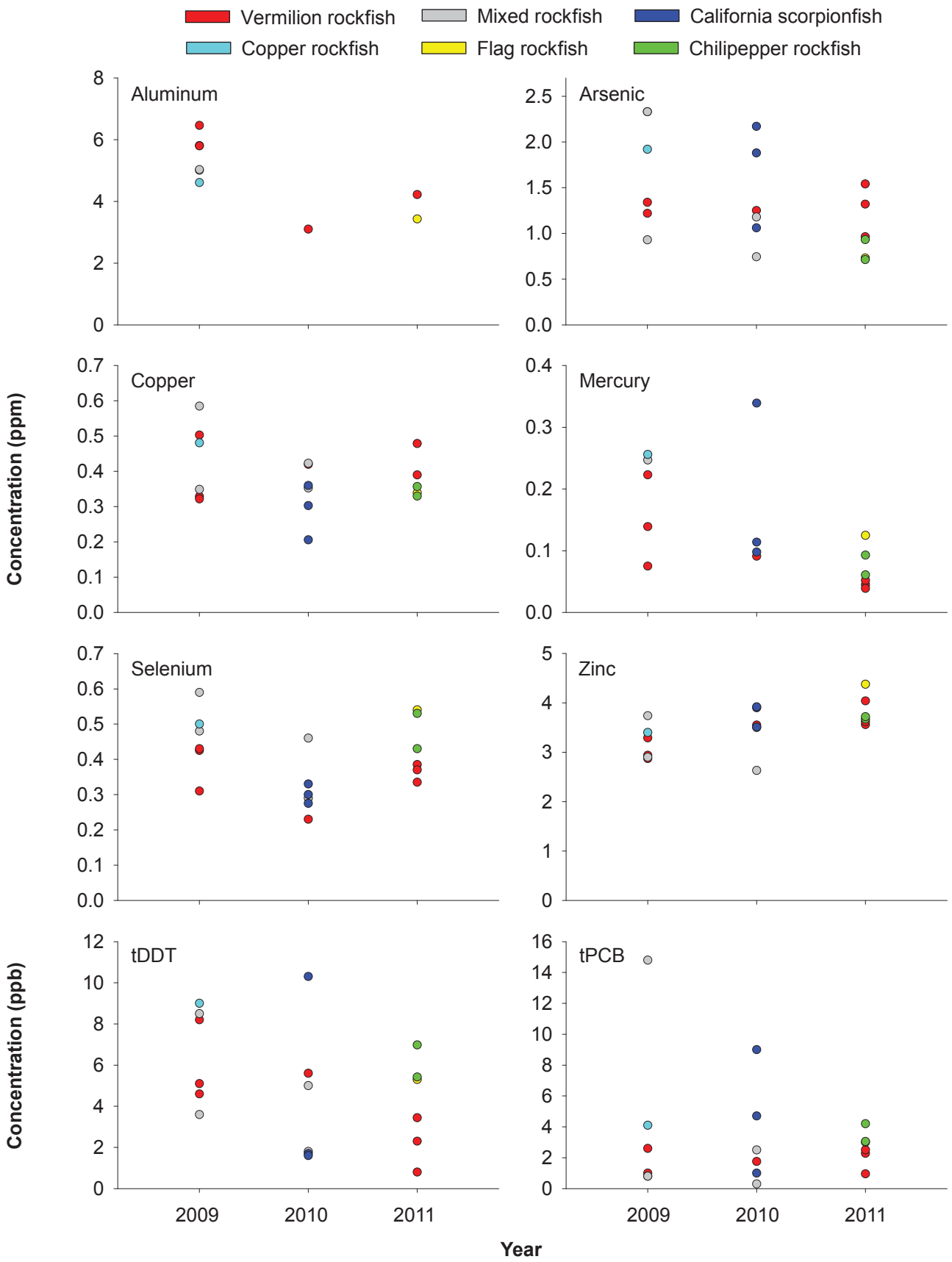

Figure 7.6
Concentrations of select parameters in muscle tissues of fishes collected in the PLOO region between 2009 and 2011.

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