Chapter 7. Bioaccumulation of Contaminants in Fish Tissues

Introduction

Fish tissue samples are analyzed 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 impacting bottom-dwelling (demersal) fish communities, and to determine if fishes collected for human consumption contain levels of contaminants that are harmful to human health. Anthropogenic inputs to the marine ecosystem (including municipal wastewater outfalls) can lead to increased concentrations of pollutants within the local 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 prevalence in the community and therefore 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 tissue is 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 discharge permits that govern the City's 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).

This chapter presents summaries and interpretations of all chemical analyses that were performed on the tissues of fishes collected in the SBOO 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 SBOO 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 April and October of 2011 at seven trawl and two rig fishing stations (Figure 7.1). English sole (*Parophrys vetulus*),

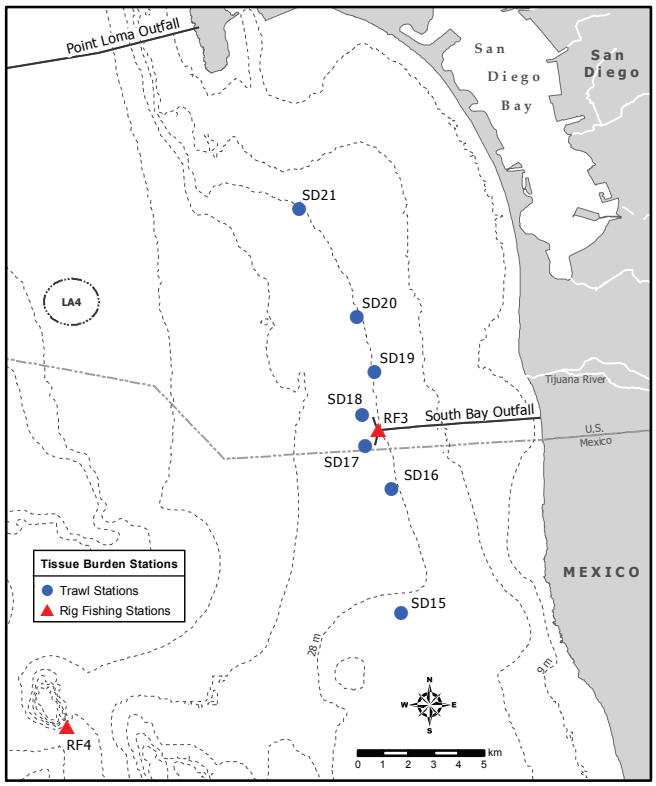

Figure 7.1
Otter trawl and rig fishing station locations sampled around the South Bay Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

hornyhead turbot (*Pleuronichthys verticalis*), longfin sanddab (*Citharichthys xanthostigma*), and Pacific sanddab (*Citharichthys sordidus*) were collected for analysis of liver tissues from the trawling stations, while California scorpionfish (*Scorpaena guttata*), brown rockfish (*Sebastes auriculatus*), bocaccio (*Sebastes paucispinis*) and vermilion rockfish (*Sebastes miniatus*) were collected for analysis of muscle tissues at the two rig fishing stations (Table 7.1). All trawl-caught fishes were collected following City of San Diego guidelines (see Chapter 6 for collection methods). Efforts to collect target 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 station. Occasionally, insufficient numbers of the target species were obtained despite this effort, which resulted in a reduced number of composite samples at a particular station, or inadequate amounts of tissue to complete the full suite of chemical analyses.

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 each composite 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 (Table 7.1). All fishes 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 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.

Each tissue sample was chemically analyzed to determine concentrations of trace metals, chlorinated pesticides (e.g., DDT), polychlorinated biphenyl compounds (PCBs), and polycyclic aromatic hydrocarbons (PAHs) on a wet weight basis. Reported values were generally limited to values above the method detection limit (MDL) for each parameter (see Appendix F.2). However,

Table 7.1

Species of fish collected from each SBOO trawl and rig fishing station during April and October 2011.

Survey	Station	Composite 1	Composite 2	Composite 3
April 2011	RF3	Brown rockfish	Brown rockfish	Vermilion rockfish
	RF4	California scorpionfish	California scorpionfish	California scorpionfish
	SD15	Hornyhead turbot [a,c]	English sole [a,b]	No sample [d]
	SD16	Hornyhead turbot	Longfin sanddab	No sample [d]
	SD17	Longfin sanddab	English sole	Hornyhead turbot
	SD18	Longfin sanddab	Hornyhead turbot	English sole
	SD19	Longfin sanddab	English sole	Hornyhead turbot
	SD20	English sole	Longfin sanddab	Longfin sanddab
	SD21	Longfin sanddab	Hornyhead turbot	No sample [d]
October 2011	RF3	Brown rockfish	Vermilion rockfish	Mixed rockfish [e]
	RF4	California scorpionfish	California scorpionfish	California scorpionfish
	SD15	Hornyhead turbot	Hornyhead turbot	Pacific sanddab
	SD16	Hornyhead turbot	Hornyhead turbot	Longfin sanddab
	SD17	Longfin sanddab	Longfin sanddab	Longfin sanddab
	SD18	Hornyhead turbot	Hornyhead turbot	Hornyhead turbot
	SD19	Longfin sanddab	Longfin sanddab	Longfin sanddab
	SD20	Longfin sanddab	Longfin sanddab	Longfin sanddab
	SD21	Hornyhead turbot	Longfin sanddab	Longfin sanddab

[a] no PAHs analyzed for these samples; [b] no metals analyzed for this sample;
[c] only metal analyzed for this sample was mercury; [d] insufficient fish collected (see text);
[e] includes vermillion rockfish and bocaccio

concentrations below MDLs were included as estimated values if the presence of the specific constituent was verified by mass-spectrometry. A more detailed description of the analytical protocols is provided by the Wastewater Chemical 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, DDT (tDDT), PCB (tPCB), and PAH (tPAH) 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 values in fishes collected from "nearfield" stations located within 1000 m of the outfall wye or diffuser legs (SD17, SD18, RF3) to those from "farfield" stations located farther away to the south (SD15, SD16), north (SD19–SD21), and west (RF4). Concentrations were also compared to maximum values reported during the pre-discharge period if available. Because contaminant levels can vary so much among different species of fish, only intra-species comparisons were used for these evaluations.

Contaminant levels in fish 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 SBOO region, multivariate analyses were performed using a 3-year data matrix comprised of the main chemical parameters analyzed for each tissue sample (i.e., trace metals, pesticides, total PCBs, total PAHs). 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 3-way PERMANOVA was conducted to determine if significant differences occurred among survey period, species, or lipid content. For muscle tissue analyses, a two-way crossed analysis of similarity (ANOSIM; maximum number of permutations = 9999) was conducted to determine if significant differences occurred among survey period or species (lipids not tested since all values fell within same lipid bin). 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 ≥78% of the liver tissue samples from trawl-caught fishes in 2011, including arsenic, cadmium, chromium, copper, iron, manganese, mercury, selenium, silver, tin, and zinc (Table 7.2). Another six metals (aluminum, antimony, barium, lead, nickel, thallium) were also detected, but less frequently at rates between 3–59%. Beryllium was not detected in any of the liver samples collected during the year. Several metals were found at levels that exceeded pre-discharge values (Figure 7.2). These included arsenic, cadmium, manganese and mercury, which exceeded pre-discharge values in 14–43% of the samples, and aluminum, copper, selenium and zinc, which exceeded pre-discharge values in ≤8% of the samples. However, intra-species comparisons between nearfield and farfield stations suggest that there was no clear relationship between metal concentrations in fish liver tissues and proximity to the outfall. For example, most of the pre-discharge exceedances occurred in samples of English sole and hornyhead turbot that were collected throughout the region.

Pesticides

Four chlorinated pesticides were detected in fish liver tissues during 2011 (Table 7.3). DDT was found in every tissue sample with tDDT concentrations ranging from 8 to 575 ppb. The DDT derivative p,p-DDE was found in 100% of the samples, whereas p,pDDMU, p,p-DDD, o,p-DDE, and p,p-DDT were detected in at least 40% (Appendix F.3). Hexachlorobenzene (HCB) occurred at a rate of 92%, while chlordane and Mirex occurred at rates of 23% and 3%, respectively. Concentrations of these three pesticides tended to be much lower than tDDT; HCB was found at levels ≤41 ppb, chlordane was ≤36 ppb, and Mirex = 1.5 ppb. Total chlordane consisted of one or more of the following constituents: alpha (cis) chlordane, cis-nonachlor, heptachlor, and trans-nonachlor.

During the past year, all values of total DDT and total chlordane were below the maximum levels detected in the same species prior to wastewater discharge (Figure 7.3). This evaluation could not be made for HCB, as this pesticide was not detected during the pre-discharge period. Overall, there were no clear relationships between pesticide concentrations in fish tissues and proximity to the outfal1.

PAHs and PCBs

PAHs were not detected in fish liver tissues during 2011. In contrast, PCBs occurred in

Table 7.2

Summary of metals in liver tissues of fishes collected from SBOO trawl 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 max value for all species. Concentrations are expressed as parts per million (ppm); the number of samples per species is indicated in parentheses. See Appendix F.2 for MDLs and names for 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
English sole																		
n (out of 4)	1	0	4	1	0	4	4	4	4	4	4	4	3	4	3	0	4	4
Min	nd	—	12.7	nd	—	0.94	0.24	4.6	151.0	0.27	1.7	0.051	nd	1.05	nd	—	0.354	28.6
Max	3.5	—	18.9	0.032	—	1.44	0.37	20.0	235.0	1.53	2.4	0.095	0.297	6.06	0.413	—	0.769	40.4
Mean	3.5	—	16.0	0.032	—	1.18	0.31	9.4	191.5	0.71	2.0	0.078	0.254	2.49	0.214	—	0.520	33.4
Hornyhead turbot																		
n (out of 13)[b]	6	0	13	4	0	13	12	13	13	0	13	14	2	13	13	5	7	13
Min	nd	—	3.2	nd	—	1.70	nd	5.7	27.3	—	0.9	0.040	nd	0.49	0.072	nd	nd	40.5
Max	8.1	—	8.9	0.043	—	11.50	0.29	16.5	74.0	—	2.1	0.176	0.285	1.20	0.255	0.75	0.547	58.9
Mean	5.0	—	4.8	0.038	—	5.73	0.20	9.9	40.5	—	1.5	0.107	0.245	0.82	0.126	0.60	0.418	48.1
Longfin sanddab																		
n (out of 19)	15	0	19	10	0	19	17	19	19	1	19	19	6	19	18	10	17	19
Min	nd	—	3.8	nd	—	0.67	nd	6.9	57.7	nd	0.6	0.060	nd	0.80	nd	nd	nd	21.7
Max	24.2	—	10.5	0.105	—	7.86	0.31	12.5	108.0	0.36	1.9	0.160	0.300	1.61	0.258	1.36	1.270	33.9
Mean	8.2	—	5.8	0.062	—	3.19	0.23	8.5	75.8	0.36	1.2	0.116	0.243	1.12	0.133	0.72	0.634	27.6
Pacific sanddab																		
n (out of 1)	0	1	1	1	0	1	1	1	1	0	1	1	0	1	0	1	1	1
Min	—	0.256	2.4	0.036	—	1.28	0.18	3.4	32.4	—	1.1	0.041	—	0.54	—	0.70	0.436	19.7
Max	—	0.256	2.4	0.036	—	1.28	0.18	3.4	32.4	—	1.1	0.041	—	0.54	—	0.70	0.436	19.7
Mean	—	0.256	2.4	0.036	—	1.28	0.18	3.4	32.4	—	1.1	0.041	—	0.54	—	0.70	0.436	19.7
All Species:																		
Detection Rate (%)	59	3	100	43	0	100	92	100	100	14	100	100	30	100	92	43	78	100
Max Value	24.2	0.256	18.9	0.105	—	11.5	0.371	20	235.0	1.5	2.4	0.176	0.300	6.06	0.413	1.36	1.27	58.9

[a] Minimum and maximum values were calculated based on all samples, whereas means were calculated on detected values only.
[b] 14 hornyhead turbot samples analyzed for mercury
nd = not detected

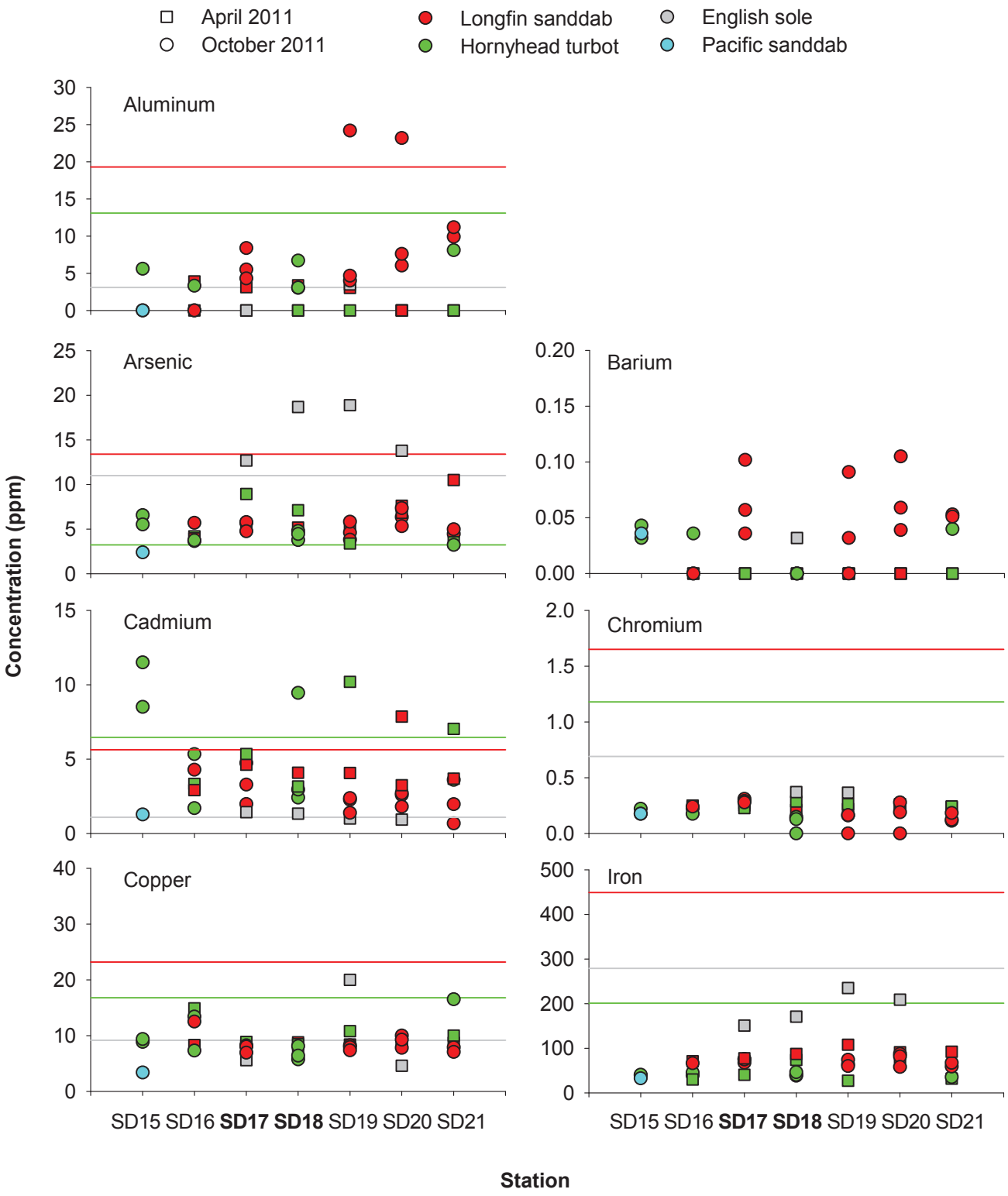

Figure 7.2

Concentrations of metals with detected rates ≥20% in liver tissues of fishes collected from each SBOO trawl station during 2011. Reference lines are maximum values detected during the pre-discharge period (1995–1998) for each species; missing lines indicate metals were not detected in that species pre-discharge. To differentiate between missing values (i.e., samples that were not collected; see Table 7.1) and non-detects, zeros were added as placeholders for non-detected values. Stations SD17 and SD18 are considered "nearfield" (bold; see text).

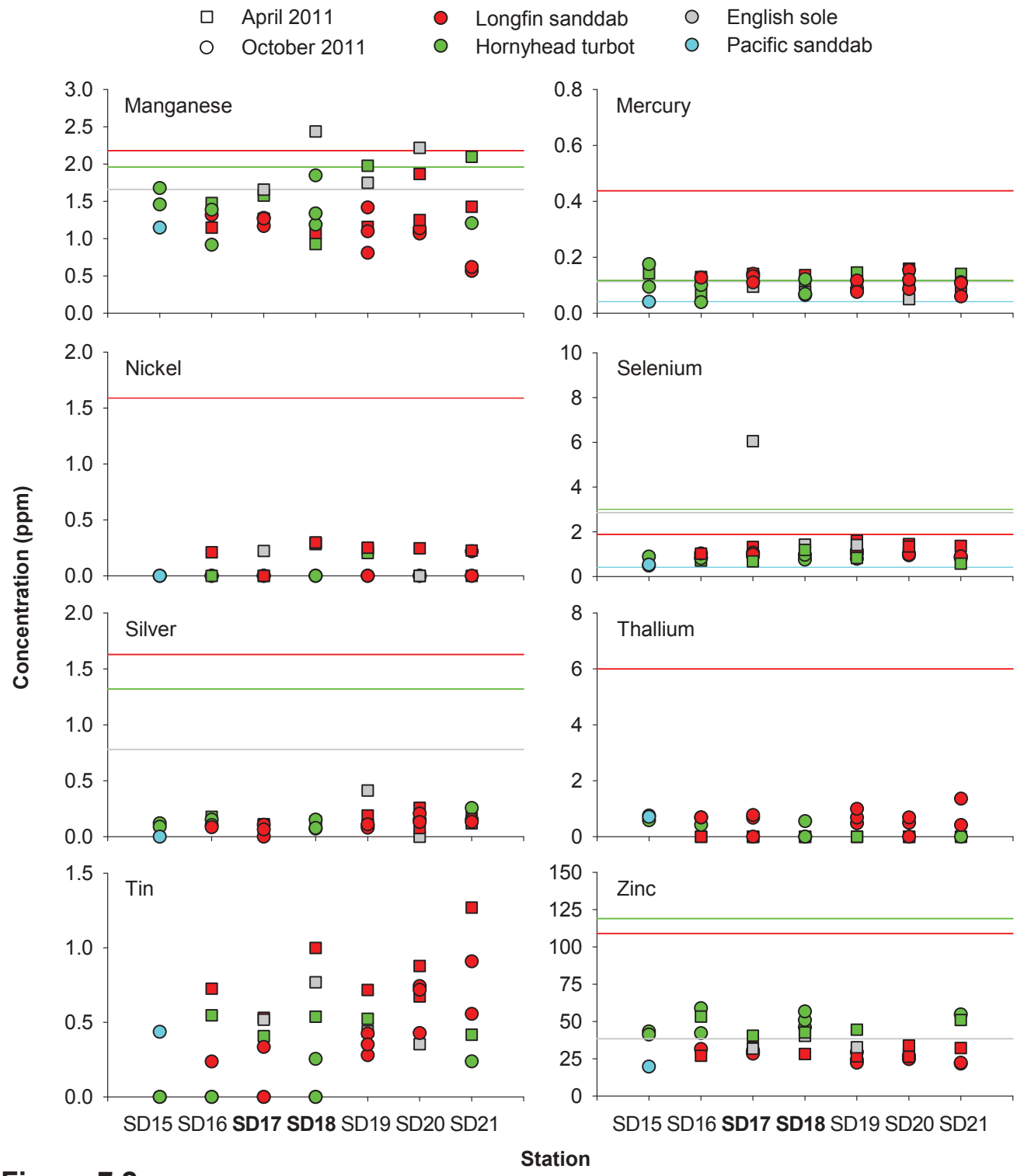

Figure 7.2 *continued*

every liver sample (Table 7.3). Total PCB concentrations were highly variable, ranging from 8.1 to 412.1 ppb. The congeners PCB 180, PCB 187 and PCB 153/168 occurred in all samples, while another 15 congeners were detected ≥41% of the time (Appendix F.3). Almost all PCB concentrations were less than pre-discharge values, with no clear relationship with proximity to the outfall (Figure 7.3). The only exception was the single Pacific sanddab sample from station SD15, which just barely exceeded the predischarge value of 38 ppb.

Table 7.3

Summary of pesticides, tPCB, and lipids in liver tissues of fishes collected from SBOO trawl stations during 2011. Data include the number of detected values (*n*), minimum, maximum, and mean[a] detected concentrations for each species, and the detection rate (DR) and max value for all species. Data are expressed in ppb for all parameters except lipids, which are presented as % weight; the number of samples per species is indicated in parentheses. See Appendix F.2 for MDLs and Appendix F.3 for values of individual constituents summed for total DDT, chlordane (tChlor), and PCB.

	Pesticides					
	HCB	**tDDT**	**tChlor**	**Mirex**	**tPCB**	**Lipids**
English sole						
n (out of 5)	5	5	1	0	5	5
Min	1.0	12.0	nd	—	52.3	3.8
Max	3.8	490.8	12.0	—	99.3	8.2
Mean	2.0	134.3	12.0	—	73.3	6.0
Hornyhead turbot						
n (out of 14)	12	14	1	0	14	14
Min	nd	8.1	nd	—	8.1	0.1
Max	41.0	79.3	13.0	—	45.9	12.1
Mean	5.7	34.1	13.0	—	22.1	6.3
Longfin sanddab						
n (out of 19)	18	19	7	1	19	19
Min	nd	47.6	nd	nd	42.3	6.8
Max	6.5	575.4	35.8	1.5	412.1	47.8
Mean	2.7	219.7	9.8	1.5	177.3	23.7
Pacific sanddab						
n (out of 1)	1	1	0	0	1	1
Min	4.8	82.0	—	—	64.8	32.3
Max	4.8	82.0	—	—	64.8	32.3
Mean	4.8	82.0	—	—	64.8	32.3
All Species:						
DR (%)	92	100	23	3	100	100
Max Value	41.0	575.4	35.8	1.5	412.1	47.8

[a] Minimum and maximum values were calculated based on all samples, whereas means were calculated on detected values only.
nd = not detected

Contaminants in Fishes Collected by Rig Fishing

Eight trace metals occurred in ≥67% of the muscle tissue samples from fishes collected at the two rig fishing stations in 2011, including arsenic, chromium, copper, iron, mercury, selenium, tin, and zinc (Table 7.4). Another eight metals (aluminum, antimony, barium, beryllium, manganese, nickel, silver, thallium) were also detected, but less frequently at rates between 8–42%. Cadmium and lead went undetected. Overall, metal values were fairly similar between the two stations and mostly occurred at concentrations less than those measured prior to discharge (Figure 7.4). Exceptions to this included arsenic, mercury, and zinc, each of which exceeded pre-discharge maxima in one or two samples (out of 12 total), primarily at station RF4.

Detection rates for DDT, HCB, and PCBs were very in high muscle tissues during 2011. Total DDT and PCB were both detected in 100% of the samples, while the pesticide HCB was detected in 92% (Table 7.5). Concentrations of all three contaminants were below 5 ppb. Neither tDDT nor tPCB exceeded pre-discharge values, whereas HCB was undetected during that period. None of the parameters demonstrated a clear relationship with proximity to the outfall (Figure 7.4). Total DDT was composed primarily of p,p-DDE (Appendix F.3). PCB 153/168 was detected in all samples, while another nine congeners were detected at rates ≥25%. As with liver tissues, no PAHs were detected in muscle tissues during 2011.

Most of the contaminants detected in fish muscle tissues occurred at concentrations below state, national, and international limits and standards (Tables 7.4, 7.5). Only arsenic and selenium were detected in concentrations higher than median international standards, while mercury (as a proxy for methylmercury) exceeded OEHHA fish contaminant goals. Vermilion rockfish had elevated concentrations (i.e., higher than threshold values) of arsenic and selenium, brown rockfish had elevated concentrations of selenium, and California scorpionfish had elevated concentrations of arsenic, selenium and mercury.

Historical Assessment of Contaminants in Fish Tissues

PERMANOVA results revealed significantly different contaminant levels in fish liver tissues based on survey period and lipid content, but not

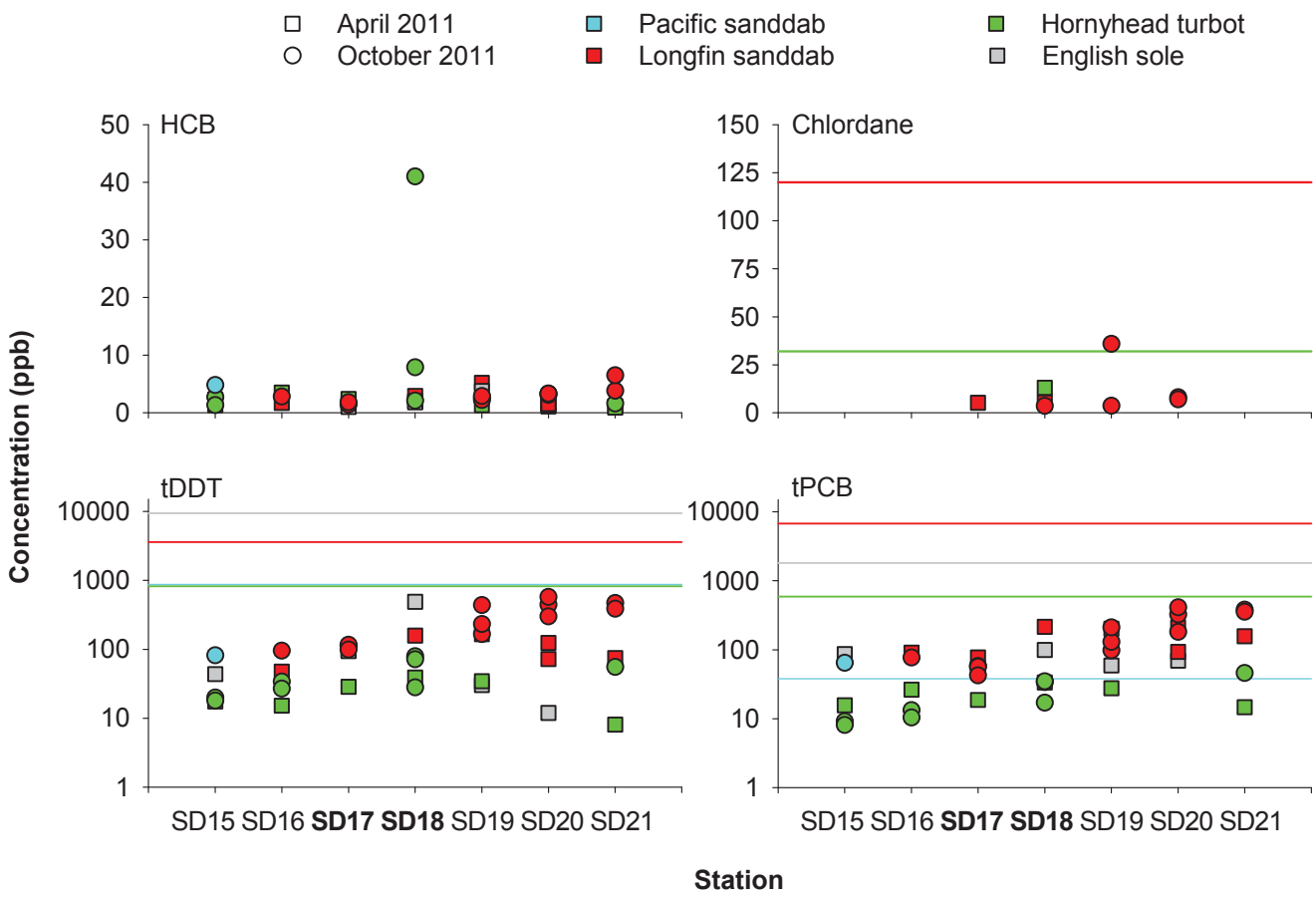

Figure 7.3
Concentrations of HCB, total chlordane, tDDT, and tPCBs in liver tissues of fishes collected from each SBOO trawl station during 2011. Reference lines are maximum values detected during the pre-discharge period (1995–1998) for each species; missing lines indicate parameters were not detected in that species pre-discharge. All missing values = non-detects. Stations SD17 and SD18 are considered "nearfield" (bold; see text).

among species (Appendix F.5). Interactions among factors were not significant. SIMPER demonstrated that although concentrations of contaminants varied significantly among fishes collected during different sampling periods, temporal trends of decreasing or increasing concentrations were not evident for any of the parameters tested (Table 7.6, Figure 7.5). Instead, high concentrations of select metals, pesticides, PAHs, or PCBs appeared to spike randomly (e.g., iron in April 2010, zinc in October 2009, tPCB in April 2009) and drove observed differences among contaminant levels in fishes collected at various times. Alternatively, contaminant concentrations in liver tissues were related to lipid content. For example, many metals including arsenic, cadmium, iron, lead, manganese, mercury, selenium and zinc tended to decrease in concentration with increasing lipid content, while pesticides such as HCB, DDT and PCBs increased in concentration with increasing lipid content. Although there were no significant differences among chemical concentrations in liver tissues based on species, the data suggest that English sole had differing levels of contaminants than all other species tested except for Pacific sanddab (Figure 7.5). Similarly, California scorpionfish appeared to have differing levels of contaminants than longfin sanddab, hornyhead turbot, and English sole.

ANOSIM results revealed significantly different contaminant levels in fish muscle tissues based on survey period, but not among species (Appendix F.6). As with liver tissues, no temporal trend of decreasing or increasing concentration was evident for any contaminant tested (Table 7.7, Figure 7.6). Based on pairwise comparisons, almost all survey periods

Table 7.4

Summary of metals in muscle tissues of fishes collected from SBOO rig fishing stations during 2011. Data include the number of detected values (*n*), minimum, maximum, and mean[a] detected concentrations for each 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, or median international standards (IS). See Appendix F.2 for MDLs and names for 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
Brown rockfish																		
n (out of 3)	0	1	3	2	0	0	3	3	2	0	1	3	2	3	1	0	2	3
Min	—	nd	0.4	nd	—	—	0.14	0.4	nd	—	nd	0.108	nd	0.27	nd	—	nd	3.8
Max	—	0.496	1.3	0.072	—	—	0.39	1.1	3.3	—	0.1	0.149	0.250	**0.39**	0.098	—	0.698	4.5
Mean	—	0.496	0.7	0.062	—	—	0.25	0.8	3.2	—	0.1	0.128	0.235	**0.33**	0.098	—	0.614	4.2
California scorpionfish																		
n (out of 6)	1	0	6	0	1	0	4	5	4	0	2	6	2	6	0	2	6	6
Min	nd	—	**1.6**	—	nd	—	nd	nd	nd	—	nd	0.129	nd	0.25	—	nd	0.222	3.5
Max	3.5	—	**3.9**	—	0.01	—	0.25	0.6	4.3	—	0.1	**0.251**	0.400	**0.34**	—	0.57	0.495	5.2
Mean	3.5	—	**2.7**	—	0.01	—	0.21	0.5	3.5	—	0.1	0.171	0.303	0.29	—	0.50	0.369	4.1
Mixed rockfish																		
n (out of 1)	0	0	1	1	0	0	nd	1	0	0	0	1	0	1	0	1	1	1
Min	—	—	1.1	0.037	—	—	0.15	0.3	—	—	—	0.041	—	0.25	—	0.60	0.248	4.2
Max	—	—	1.1	0.037	—	—	0.15	0.3	—	—	—	0.041	—	0.25	—	0.60	0.248	4.2
Mean	—	—	1.1	0.037	—	—	0.15	0.3	—	—	—	0.041	—	0.25	—	0.60	0.248	4.2
Vermilion rockfish																		
n (out of 2)	1	0	2	1	0	0	2	2	2	0	2	2	0	2	0	1	2	2
Min	nd	—	**1.5**	nd	—	—	0.13	0.4	2.5	—	0.1	0.045	—	0.26	—	nd	0.280	4.2
Max	3.2	—	**1.5**	0.032	—	—	0.21	0.6	3.3	—	0.1	0.081	—	**0.32**	—	0.53	0.427	4.7
Mean	3.2	—	**1.5**	0.032	—	—	0.17	0.5	2.9	—	0.1	0.063	—	0.29	—	0.53	0.353	4.4
All Species:																		
Detection Rate (%)	17	8	100	33	8	0	83	92	67	0	42	100	33	100	8	33	92	100
Max Value	3.5	0.496	**3.9**	0.072	0.01	—	0.39	1.1	4.3	—	0.1	**0.251**	0.400	**0.39**	0.098	0.60	0.698	5.2
OEHHA[b]	na	na	na	na	na	na	na	na	na	na	na	0.22	na	7.4	na	na	na	na
USFDA Action Limit[c]	na	na	na	na	na	na	na	na	na	na	na	1	na	na	na	na	na	na
Median IS[c]	na	na	1.4	na	na	na	1	20	na	na	na	0.5	na	0.3	na	na	175	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 mercury action limits and all international standards (IS) are for shellfish, but are often applied to fish.

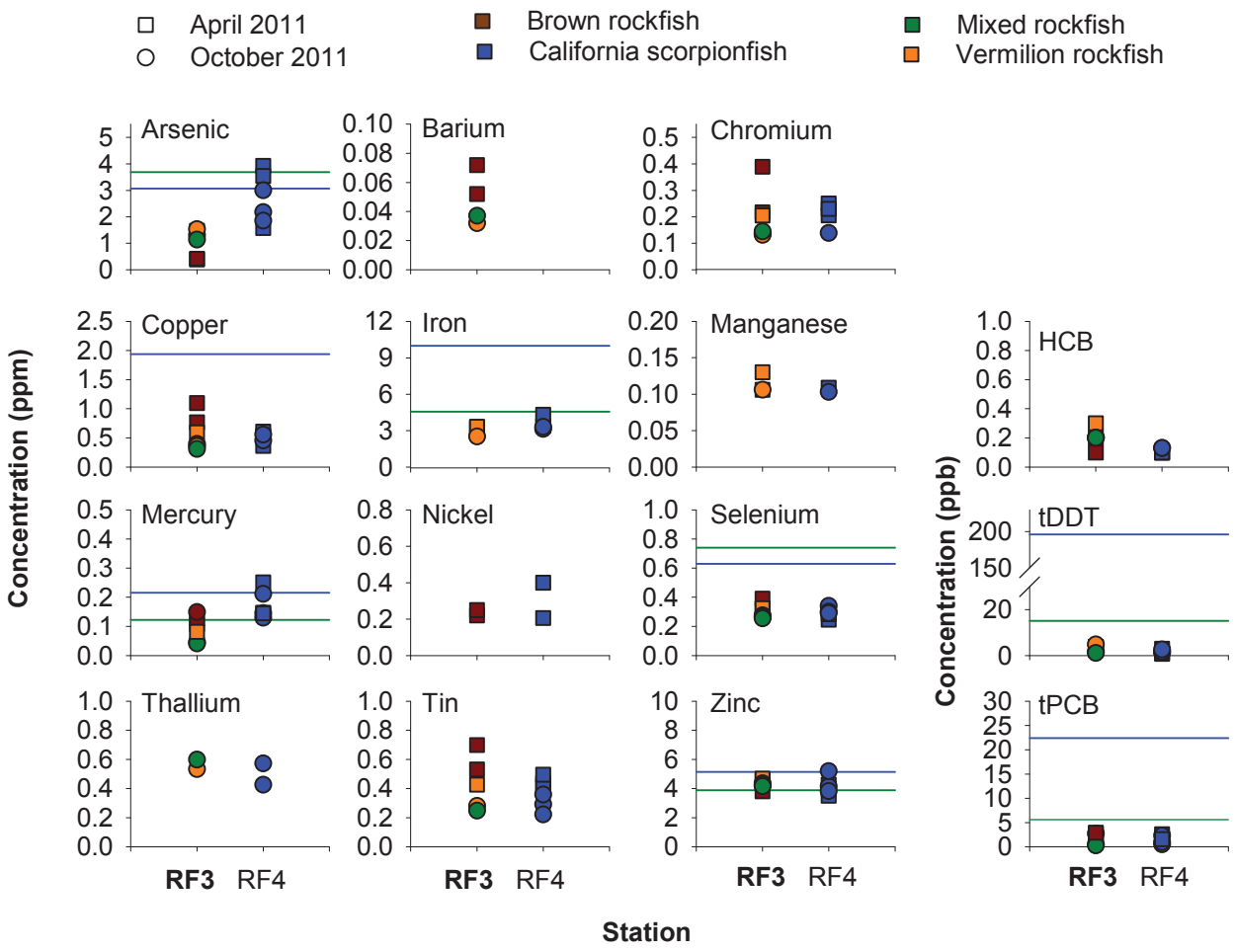

Figure 7.4
Concentrations of contaminants with detection rates ≥20% in muscle tissues of fishes collected from each SBOO rig fishing station during 2011. Reference lines are maximum values detected during the pre-discharge period (1995–1998) for each species; missing lines indicate parameters were not detected in that species prior to discharge, or the species was not collected during those surveys. All missing values = non-detects. Station RF3 is considered "nearfield" (bold; see text).

differed from each other, the only exceptions being October 2009 versus October 2011 and April 2011 versus October 2011.

Discussion

Several trace metals, pesticides (e.g., DDT, HCB, chlordane, Mirex) and PCB congeners were detected in liver tissue samples from four different species of fish collected in the SBOO region during 2011. Many of the same metals, DDT, HCB, and PCBs were also detected in muscle tissues during the year, although often less frequently and/or in lower concentrations. Although tissue contaminant concentrations varied among different fish 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 2007a). Additionally, all muscle tissue samples from sport fish collected in the area had concentrations of mercury and DDT below FDA human consumption limits. However, some muscle tissues had concentrations of arsenic and selenium above the median international standards for human consumption, and some had concentrations of mercury that exceeded OEHHA fish contaminant goals. Elevated levels of these contaminants are not uncommon in sport fish from

Table 7.5

Summary of pesticides, tPCB, and lipids in muscle tissues of fishes collected from SBOO 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 max 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, or median international standards (IS). See Appendix F.2 for MDLs and Appendix F.3 for values of individual constituents summed for total DDT and PCB.

	Pesticides			
	HCB (ppb)	**tDDT (ppb)**	**tPCB (ppb)**	**Lipids (% wt)**
Brown rockfish				
n (out of 3)	3	3	3	3
Min	0.1	1.7	0.5	0.3
Max	0.2	3.8	2.9	2.8
Mean	0.2	3.1	2.0	1.7
California scorpionfish				
n (out of 6)	5	6	6	6
Min	nd	0.7	0.5	0.3
Max	0.1	2.9	2.6	1.9
Mean	0.1	1.7	1.6	1.0
Mixed rockfish				
n (out of 1)	1	1	1	1
Min	0.2	1.0	0.3	0.6
Max	0.2	1.0	0.3	0.6
Mean	0.2	1.0	0.3	0.6
Vermilion rockfish				
n (out of 2)	2	2	2	2
Min	0.2	2.4	2.1	1.0
Max	0.3	4.7	2.7	1.6
Mean	0.2	3.6	2.4	1.3
All Species:				
Detection Rate (%)	92	100	100	100
Max Value	0.3	4.7	2.9	2.8
OEHHA[b]	na	21	3.6	na
U.S. FDA Action Limit[c]	na	5000	na	na
Median 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 and all international standards (IS) are for shellfish, but are often applied to fish.

the SBOO survey area (City of San Diego 2000–2011) 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 in the Point Loma outfall survey area over the years have also had concentrations of contaminants such as selenium, mercury, and PCB that exceeded different consumption limits.

The frequent occurrence of metals and chlorinated hydrocarbons in SBOO 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). The lack of contaminant-free reference areas in the SCB clearly pertains to the South Bay outfall region, as demonstrated by the presence of many contaminants in fish tissues prior to the initiation of wastewater discharge in 1999 (see City of San Diego 2000).

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 and among individuals of the same species depending on migration habits (Otway 1991). Fishes may be exposed to contaminants in an area that is highly polluted and then move into an area that is not. For example, California scorpionfish tagged in contaminant-laden 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 vicinity of the SBOO, as there are many point and non-point sources that may contribute to contamination in the region, including at some monitoring stations, such as the Tijuana River,

Table 7.6

Summary of contaminant loads in liver tissues of fishes collected from the SBOO 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-Quarter					
Parameter	**2009-2**	**2009-4**	**2010-2**	**2010-4**	**2011-2**	**2011-4**
Trace Metals (ppm)						
Aluminum	24.50	5.67	**27.10**	5.26	1.06	6.62
Antimony	**0.19**	0.00	0.00	**0.12**	0.00	0.01
Arsenic	**10.90**	3.94	**12.30**	5.26	8.51	4.90
Barium	**0.35**	0.04	**0.02**	0.02	0.00	0.04
Beryllium	0.000	**0.001**	0.001	0.000	0.000	0.000
Cadmium	3.31	3.56	4.60	**3.02**	**4.02**	**3.66**
Chromium	0.289	0.074	0.138	0.085	0.262	0.171
Copper	8.60	7.79	7.87	7.65	**9.43**	8.58
Iron	126.00	85.90	**147.00**	72.50	**98.50**	56.60
Lead	0.33	0.03	**0.57**	0.00	0.18	0.02
Manganese	1.890	0.961	1.690	1.110	1.580	1.190
Mercury	0.099	**0.146**	0.139	0.080	0.111	0.102
Nickel	0.00	0.00	0.00	**0.07**	**0.16**	0.01
Selenium	1.310	1.060	1.910	0.988	**1.470**	0.898
Silver	0.05	0.15	0.24	0.21	0.15	0.11
Thallium	0.000	0.093	0.101	0.447	0.000	**0.520**
Tin	2.500	0.332	0.198	0.175	0.644	0.281
Zinc	31.80	**52.80**	37.20	**36.90**	35.80	34.80
Chlorinated Pesticides (ppb)						
Endrin	**17.50**	0.00	0.00	0.00	0.00	0.00
HCB	2.03	2.24	1.52	2.84	2.07	**4.53**
Mirex	0.00	0.00	0.00	0.00	0.00	**0.07**
Total chlordane	0.00	**2.90**	0.00	0.00	2.23	**2.75**
Total DDT	590	**523**	120	118	93	183
Total PCB (ppb)	**415**	236	68	174	90	122
Total PAH (ppb)	0.00	0.00	0.00	**2.09**	0.00	0.00

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 outfall reveal no evidence that the SBOO is a major source of pollutants to the area (Chapter 4).

There was no evidence of contaminant bioaccumulation in SBOO fishes during 2011 that could be associated with wastewater discharge from the outfall. Although several tissue samples had concentrations of some trace metals that exceeded pre-discharge maxima, concentrations of most contaminants were generally similar to or below pre-discharge levels (see City of San Diego 2000). In addition, most tissue samples that did exceed pre-discharge values were widely distributed among stations and showed no outfall-related patterns. 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 were apparent. Instead, the occasional spikes in tissue contaminants appear random and may be due to

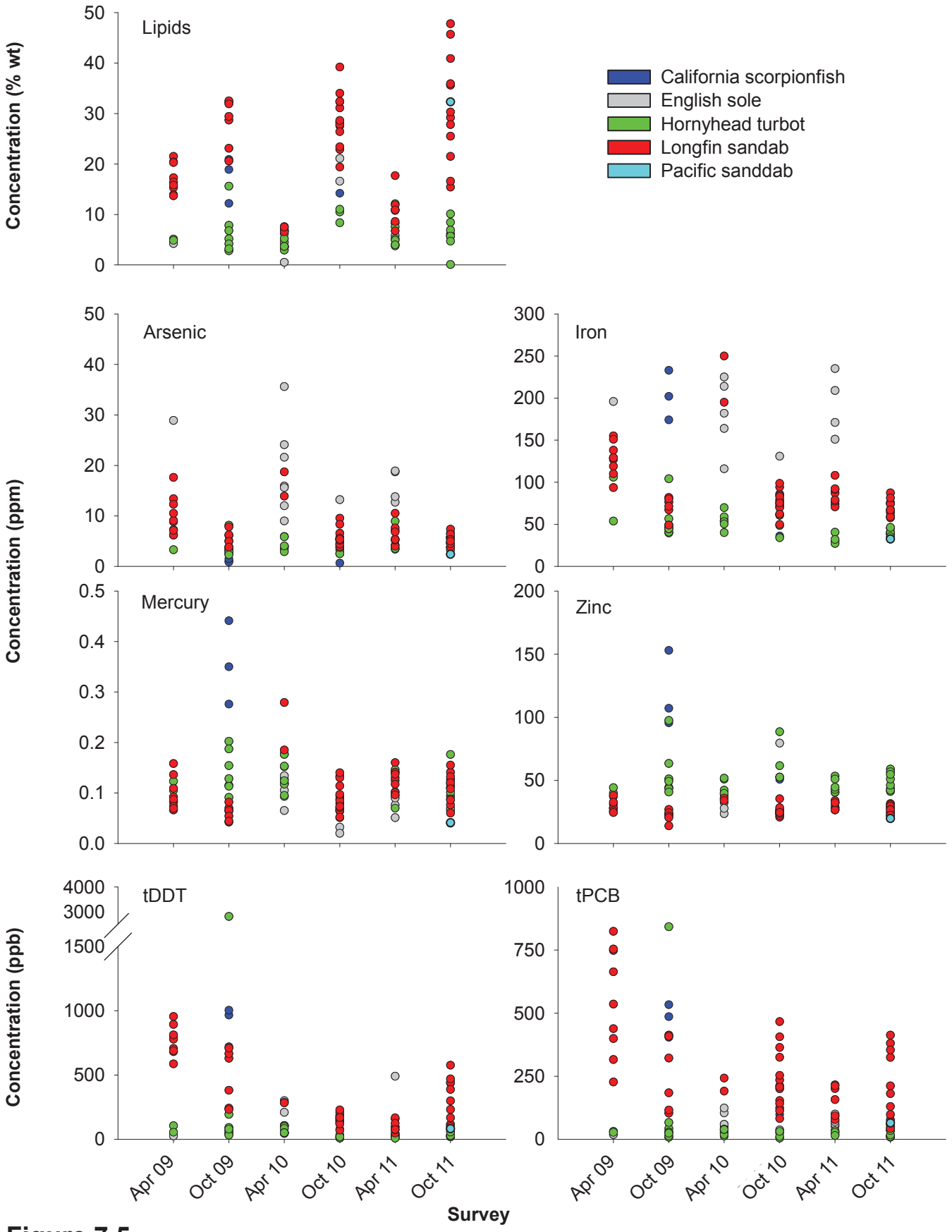

Figure 7.5
Concentrations of select parameters in liver tissues of fishes collected in the SBOO region between 2009 and 2011.

Table 7.7

Summary of contaminant loads in muscle tissues of fishes collected from the SBOO 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-Quarter					
Parameter	**2009-2**	**2009-4**	**2010-2**	**2010-4**	**2011-2**	**2011-4**
Trace Metals (ppm)						
Aluminum	14.10	5.44	7.80	0.00	0.53	0.58
Antimony	0.05	0.02	0.00	0.00	**0.08**	0.00
Arsenic	**2.01**	1.45	1.75	**1.72**	**1.89**	**1.83**
Barium	**0.11**	0.06	0.01	0.00	0.02	0.01
Beryllium	0.00	**0.01**	0.00	0.00	0.00	0.00
Cadmium	**0.01**	0.00	0.00	0.00	0.00	0.00
Chromium	0.178	**0.225**	0.023	**0.065**	0.249	0.092
Copper	**1.150**	0.390	0.432	0.322	0.661	0.345
Iron	4.52	1.29	1.24	0.00	2.91	**1.49**
Lead	0.00	0.00	**0.04**	0.00	0.00	0.00
Manganese	0.153	0.000	0.000	0.000	**0.058**	**0.035**
Mercury	0.150	**0.170**	0.172	**0.194**	0.143	**0.120**
Nickel	0.00	0.02	0.00	0.00	**0.18**	0.00
Selenium	0.233	0.278	**0.388**	0.204	0.312	0.287
Silver	0.00	**0.06**	0.00	0.00	**0.02**	0.00
Thallium	0.000	**0.203**	0.083	0.500	0.000	**0.355**
Tin	1.450	0.000	0.172	0.000	0.500	0.233
Zinc	5.44	3.13	3.97	**3.54**	4.13	4.31
Chlorinated Pesticides (ppb)						
HCB	**0.050**	0.000	**0.175**	0.000	0.150	0.143
Total DDT	3.29	3.58	**5.58**	**2.37**	2.44	2.12
Total PCB (ppb)	0.46	1.13	**4.97**	0.50	2.28	1.20

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).

Literature Cited

Allen, M.J., S.L. Moore, K.C. Schiff, D. Diener, S.B. Weisburg, J.K. Stull, A. Groce, E. Zeng, J. Mubarak, C.L. Tang, R. Gartman, and C.I. Haydock. (1998). Assessment of demersal fish and megabenthic invertebrate assemblages on the mainland shelf of Southern California in 1994. Southern California Coastal Water Research Project, Westminster, CA.

Allen, M.J., A.K. Groce, D. Diener, J. Brown, S.A. Steinert, G. Deets, J.A. Noblet, S.L. Moore, D. Diehl, E.T. Jarvis, V. Raco-Rands, C. Thomas, Y. Ralph, R. Gartman, D. Cadien, S.B. Weisberg, and T. Mikel. (2002). Southern California Bight 1998 Regional Monitoring Program: V. Demersal Fishes and Megabenthic Invertebrates. Southern California Coastal Water Research Project, Westminster, CA.

Brown, D.A., R.W. Gossett, G.P. Hershelman, C.G. Word, A.M. Westcott, and J.N. Cross. (1986). Municipal wastewater contamination in the Southern California Bight: Part I–metal and organic contaminants in sediments and organisms. Marine Environmental Research, 18: 291–310.

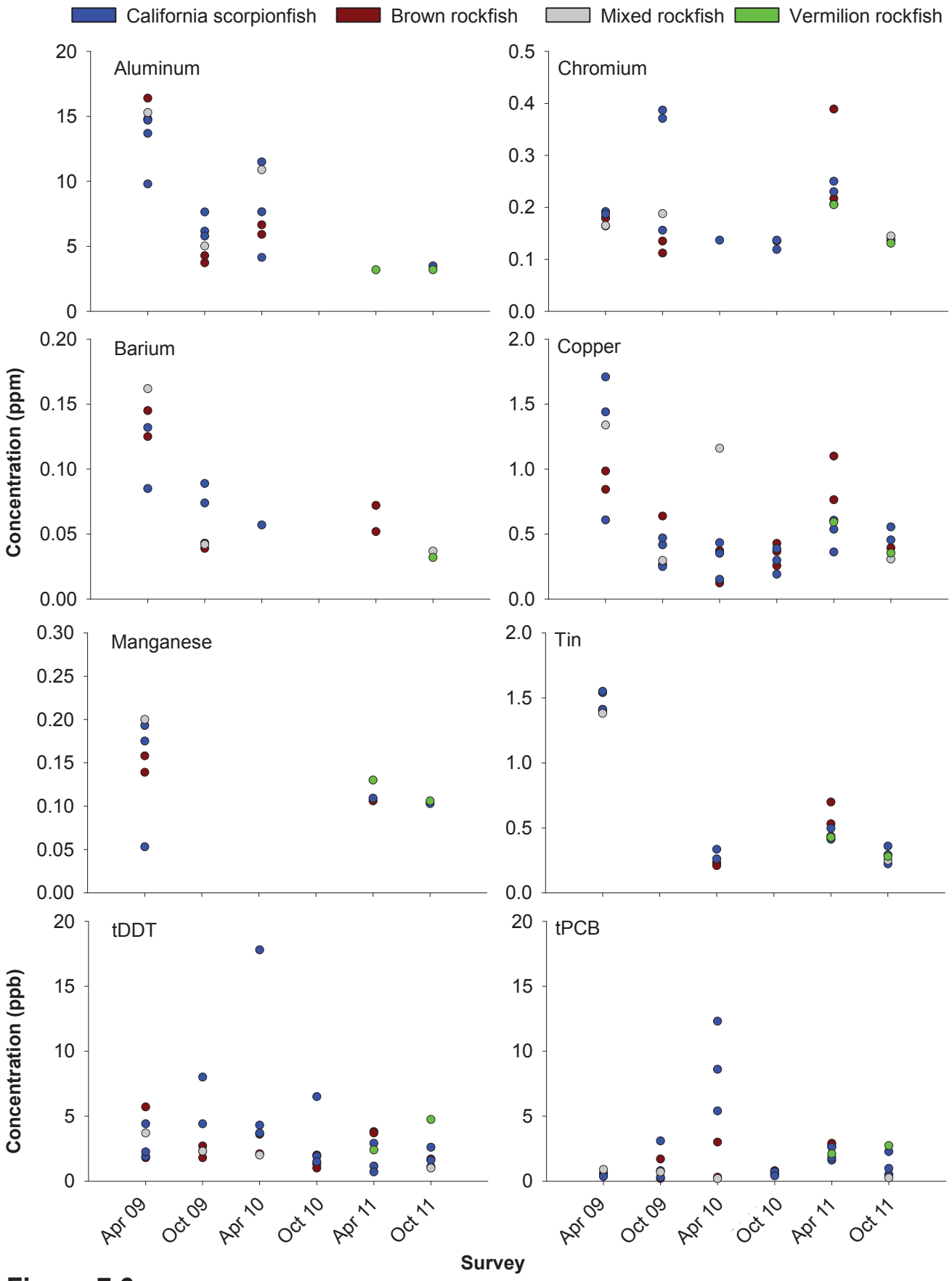

Figure 7.6
Concentrations of select parameters in muscle tissues of fishes collected in the SBOO region between 2009 and 2011.

Cardwell, R. D. (1991). Methods for evaluating risks to aquatic life and human health from exposure to marine discharges of municipal wastewaters. Pages 253–252 in A. G. Miskiewicz, editor. Proceedings of a Bioaccumulation Workshop: Assessment of the Distribution, Impacts, and Bioaccumulation of Contaminants in Aquatic Environments. Australian Marine Science Association, Inc./WaterBoard.

City of San Diego. (2000). International Wastewater Treatment Plant Final Baseline Ocean Monitoring Report for the South Bay Ocean Outfall (1995–1998). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2001). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (2000). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2002). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall, 2001. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2003). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall, 2002. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2004). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2003. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2005). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2004. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2006). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2005. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2007a). Appendix F. Bioaccumulation Assessment. In: Application for Renewal of NPDES CA0107409 and 301(h) Modified Secondary Treatment Requirements, Point Loma Ocean Outfall. Volume IV, Appendices A thru F. Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2007b). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2006. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2008). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2007. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2009). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2008. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2010). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2009. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2011). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2010. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2012a). 2011 Annual Reports and Summary for the South Bay Wastewater Reclamation Plant and Ocean Outfall. City of San Diego, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2012b). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2011. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (in prep). Quality Assurance Project Plan for Coastal Receiving Waters Montiroing. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Clarke, K.R. and R.N. Gorley. (2006). PRIMER v6: User Manual/Tutorial. PRIMER-E, Plymouth.

Clarke, K.R. and R.M. Warwick. (2001). Change in marine communities: an approach to statistical analysis and interpretation. 2nd edition. PRIMER-E, Plymouth.

Connell, D. W. (1988). Bioaccumulation behavior of persistent organic chemicals with aquatic organisms. Review of Environmental Contamination and Toxicology, 101:117-154.

Groce, A.K. (2002). Influence of life history and lipids on the bioaccumulation of organo-chlorines in demersal fishes. Master's thesis. San Diego State University. San Diego, CA.

Hartmann, A.R. (1987). Movement of scorpionfishes (Scorpaenidae: *Sebastes* and *Scorpaena*) in the Southern California Bight. California Fish and Game, 73: 68–79.

Klasing, S. and R. Brodberg (2008). Development of Fish Contaminant Goals and Advisory Tissue Levels for Common Contaminants in California Sport Fish: Chlordane, DDTs, Dieldrin, Methylmercury, PCBs, Selenium, and Toxaphene. California Environmental Protection Agency, Office of Environmental Health Hazard Assessment, Sacramento, CA.

Lauenstein, G.G. and A.Y. Cantillo, eds. (1993). Sampling and Analytical Methods of the NOAA National Status and Trends Program National Benthic Surveillance and Mussel Watch Projects 1984–1992: Vol. I–IV. Technical Memorandum NOS ORCA 71. NOAA/NOS/ORCA, Silver Spring, MD.

Love, M.S., B. Axell, P. Morris, R. Collins, and A. Brooks. (1987). Life history and fishery of the California scorpionfish, *Scorpaena guttata*, within the Southern California Bight. Fisheries Bulletin, 85: 99–116.

Mearns, A.J., M. Matta, G. Shigenaka, D. MacDonald, M. Buchman, H. Harris, J. Golas, and G. Lauenstein. (1991). Contaminant Trends in the Southern California Bight:

Inventory and Assessment. NOAA Technical Memorandum NOS ORCA 62. Seattle, WA.

Otway, N. (1991). Bioaccumulation studies on fish: choice of species, sampling designs, problems and implications for environmental management. In: A.G. Miskiewicz (ed.). Proceedings of a Bioaccumulation Workshop: Assessment of the Distribution, Impacts, and Bioaccumulation of Contaminants in Aquatic Environments. Australian Marine Science Association, Inc./Water Board.

Parnell, P.E., A.K. Groce, T.D. Stebbins, and P.K. Dayton. (2008). Discriminating sources of PCB contamination in fish on the coastal shelf off San Diego, California (USA). Marine Pollution Bulletin, 56: 1992–2002.

Rand, G.M., ed. (1995). Fundamentals of Aquatic Toxicology: Effects, Environmental Fate, and Risk Assessment. 2nd ed. Taylor and Francis, Washington, D.C.

Schiff, K. and M.J. Allen. (1997). Bioaccumulation of chlorinated hydrocarbons in livers of flatfishes from the Southern California Bight. In: S.B. Weisberg, C. Francisco, and D. Hallock (eds.). Southern California Coastal Water Research Project Annual Report 1995–1996. Southern California Coastal Water Research Project, Westminster, CA.

[USEPA] United States Environmental Protection Agency. (2000). Bioaccumulation Testing and Interpretation for the Purpose of Sediment Quality Assessment. Status and Needs. EPA-823-R-00-001. U.S. Environmental Protection Agency.

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