

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. The bioaccumulation of contaminants in a fish occurs through biological uptake and retention of chemical contaminants derived from various exposure pathways (Tetra Tech 1985). Exposure routes for demersal fishes include the uptake of dissolved chemical constituents from the water and the ingestion and assimilation of pollutants from food sources. Because of their proximity to benthic sediments, these fish can also accumulate contaminants by ingesting suspended particulate matter or sediment particles that contain pollutants. For this reason, contaminant levels in the tissues of demersal fish are often related to that found in the environment (Schiff and Allen 1997), thus making these types of assessments useful in biomonitoring programs.

The bioaccumulation portion of the PLOO monitoring program consists of two components: (1) liver tissues are analyzed for trawl-caught fishes; (2) muscle tissues are analyzed for fishes collected by hook and line (rig fishing). Species of fish collected from trawls are considered representative of the general demersal fish community, and certain species are targeted based on their ecological significance (i.e., prevalence in the community). Chemical analysis of liver tissues is important because this is the organ where contaminants typically concentrate (i.e., bioaccumulate). In contrast, fishes targeted for rig fishing represent species characteristic of a typical sport fisher's catch, and are therefore considered of recreational and commercial importance. 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 samples were analyzed for contaminants as specified in the NPDES discharge

permit that governs the PLOO monitoring program. 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 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 tissue analyses that were performed on fish collected in the PLOO region during 2007.

MATERIALS AND METHODS

Field Collection

Pacific sanddabs (*Citharichthys sordidus*) and English sole (*Parophrys vetulus*) were collected from four trawling zones, while several species of rockfish (*Sebastes* spp) were collected at the two rig fishing stations in October 2007 (**Table 7.1**, **Figure 7.1**). Rockfish species included copper rockfish (*S. caurinus*), greenblotched rockfish (*S. rosenblatti*), and vermilion rockfish (*S. miniatus*). Mixed rockfish samples may have included additional species of *Sebastes*.

Each trawl zone represents an area of one kilometer in diameter centered around a specific site or sites.

Table 7.1

Species of fish collected from each PLOO trawl zone or rig fishing station (RF1–RF2) during October 2007. Pacific sanddab=PS; English sole=ES; copper rockfish=CRF; vermilion rockfish=VRF; greenblotched rockfish=GBRF; mixed rockfish=MRF.

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

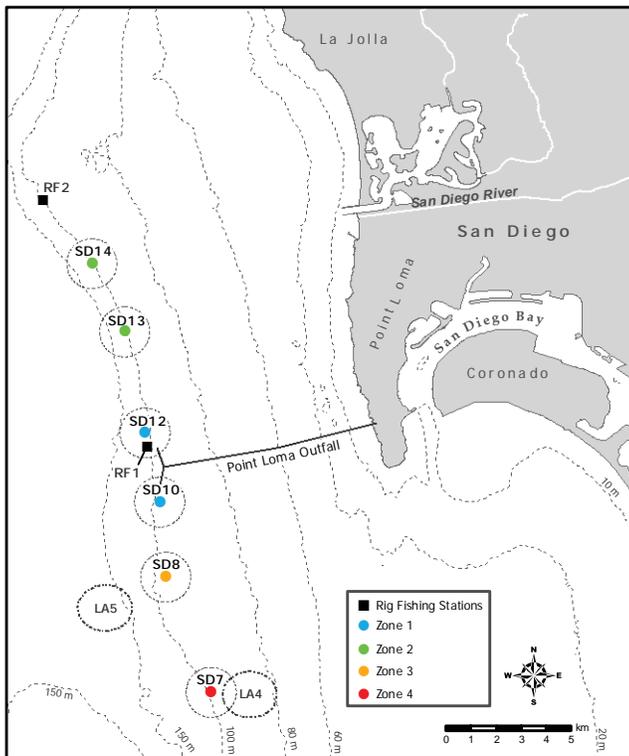


Figure 7.1

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

Zone 1 includes the two 1-km areas surrounding nearfield stations SD10 and SD12, located just south and just north of the PLOO, respectively. Zone 2 includes the two 1-km areas surrounding northern farfield stations SD13 and SD14. Zone 3 is the 1-km area surrounding station SD8, located relatively near the LA-5 dredged materials disposal site. Zone 4 is the 1-km area surrounding station SD7, located several kilometers to the south of the outfall near the old (non-active) LA-4 disposal site. All trawl-caught fishes were collected, measured, and weighed following City of San Diego guidelines (see Chapter 6 for a description of collection methods).

Fishes targeted for collection at the rig fishing sites were caught using rod and reel fishing tackle, and then measured and weighed. The effort to collect targeted fishes was limited to five 10-minute trawls (bottom time) at each trawl station. Only fish ≥ 13 cm in standard length were retained for tissue analyses. These fish were sorted into no more than three composite samples per station,

each containing a minimum of three individuals. Composite samples are made up of a single species except for samples that consist of mixed species of rockfish. The samples of fish were then wrapped in aluminum foil, labeled, sealed in re-sealable plastic bags, placed on dry ice, and then transported to the City's Marine Biology Laboratory where they were held in the freezer at -80°C until dissection and tissue processing.

Tissue Processing and Chemical Analyses

All dissections were performed according to the following standard techniques for tissue analysis. Each fish was partially defrosted and then cleaned with a paper towel to remove loose scales and excess mucus prior to dissection. The standard length (cm) and weight (g) of each fish were recorded (**Appendix D.1**). Dissections were carried out on Teflon[®] pads that were cleaned between samples. Tissue samples were then placed in glass jars, sealed, labeled, and stored in a freezer at -20°C prior to chemical analyses. All samples were subsequently delivered to the City of San Diego Wastewater Chemistry Services Laboratory within 10 days of dissection.

The chemical constituents analyzed for each tissue sample included trace metals, chlorinated pesticides, and polychlorinated biphenyl compounds (PCBs) (see **Appendix D.2**). Metals were measured as mg/kg or parts per million (ppm), while pesticides and PCBs were measured as $\mu\text{g}/\text{kg}$ or parts per billion (ppb). Totals for DDT, PCB, BHC (=lindane and derivatives) and chlordane were calculated as the sum of detected constituents (i.e., total PCB = sum of all detected congeners). Values for each individual constituent are listed in **Appendix D.3**. This report includes estimated values for some parameters determined to be present in a sample with high confidence (i.e., peaks confirmed by mass-spectrometry), but at levels below the method detection limit (MDL). A detailed description of the analytical protocols may be obtained from the City of San Diego Wastewater Chemistry Services Laboratory (City of San Diego 2008).

Table 7.2

Summary of metals, pesticides, and total PCBs detected in liver tissues from fishes collected from PLOO trawl zones during 2007. The number of samples per species is indicated in parentheses; n=number of detected values; nd=not detected.

Parameter	English sole (1)		Pacific sanddab (11)					Overall
	n	Min/max	n	Min	Max	Mean	% Detected	Max
<i>Metals (ppm)</i>								
Aluminum	1	15.4	11	13.5	23.3	17.5	100	23.3
Antimony	1	0.77	11	0.59	1.91	1.43	100	1.91
Arsenic	1	5.7	11	0.5	2.6	1.7	100	5.7
Barium	1	0.314	11	0.225	0.548	0.437	100	0.548
Beryllium	nd	—	nd	—	—	—	—	—
Cadmium	1	0.79	11	3.10	7.43	4.51	100	7.43
Chromium	1	0.348	11	0.132	0.952	0.561	100	0.952
Copper	1	3.7	11	2.3	4.8	3.4	100	4.8
Iron	1	180	11	49	121	77	100	180
Lead	1	1.42	1	0.31	0.31	0.31	17	1.42
Manganese	1	0.82	11	0.803	1.17	0.99	100	1.17
Mercury	1	0.048	11	0.038	0.143	0.080	100	0.143
Nickel	1	0.237	11	0.190	0.753	0.457	100	0.753
Selenium	1	2.3	11	0.6	1.4	0.8	100	2.3
Silver	1	0.072	nd	—	—	—	8	0.072
Thallium	nd	—	9	1.1	2.9	1.9	75	2.9
Tin	1	1.8	11	1.9	2.9	2.6	100	2.9
Zinc	1	46.5	11	19.6	39.7	31.8	100	46.5
<i>Pesticides (ppb)</i>								
Total Chlordane	1	3.2	11	3.2	23.2	14.0	100	23.2
Total DDT	1	130	11	143	472	341	100	472
Total BHC	nd	—	2	3.3	4.4	3.8	17	4.4
HCB	1	5.2	11	1.1	8.3	4.7	100	8.300
Total PCB (ppb)	1	135	11	108	866	256	100	866
Lipids (%wt)	1	13	11	18	59	46	100	59

RESULTS AND DISCUSSION

Contaminants in Trawl-Caught Fishes

Metals

Fourteen metals, including aluminum, antimony, arsenic, barium, cadmium, chromium, copper, iron, manganese, mercury, nickel, selenium, tin and zinc occurred in 100% of the liver samples analyzed from trawl-caught fishes in 2007 (Table 7.2). Lead, silver and thallium were also detected, but less frequently (i.e., detection rates of 8-75%), while beryllium was not detected at all. Concentrations of most metals were <10 ppm.

Exceptions occurred for aluminum, iron and zinc, which all had concentrations >20 ppm in at least one sample. Of all the metals detected, iron was present in the highest concentrations in both species of fish that were analyzed. Comparisons of the frequently detected metals from Pacific sanddab samples collected closest to the discharge site (i.e., Zone 1) to those located farther away (Zones 2–4) suggest that there was no clear relationship between contaminant loads and proximity to the outfall (Figure 7.2).

Pesticides

Several chlorinated pesticides were detected in trawl-caught fishes during 2007 (Table 7.2).

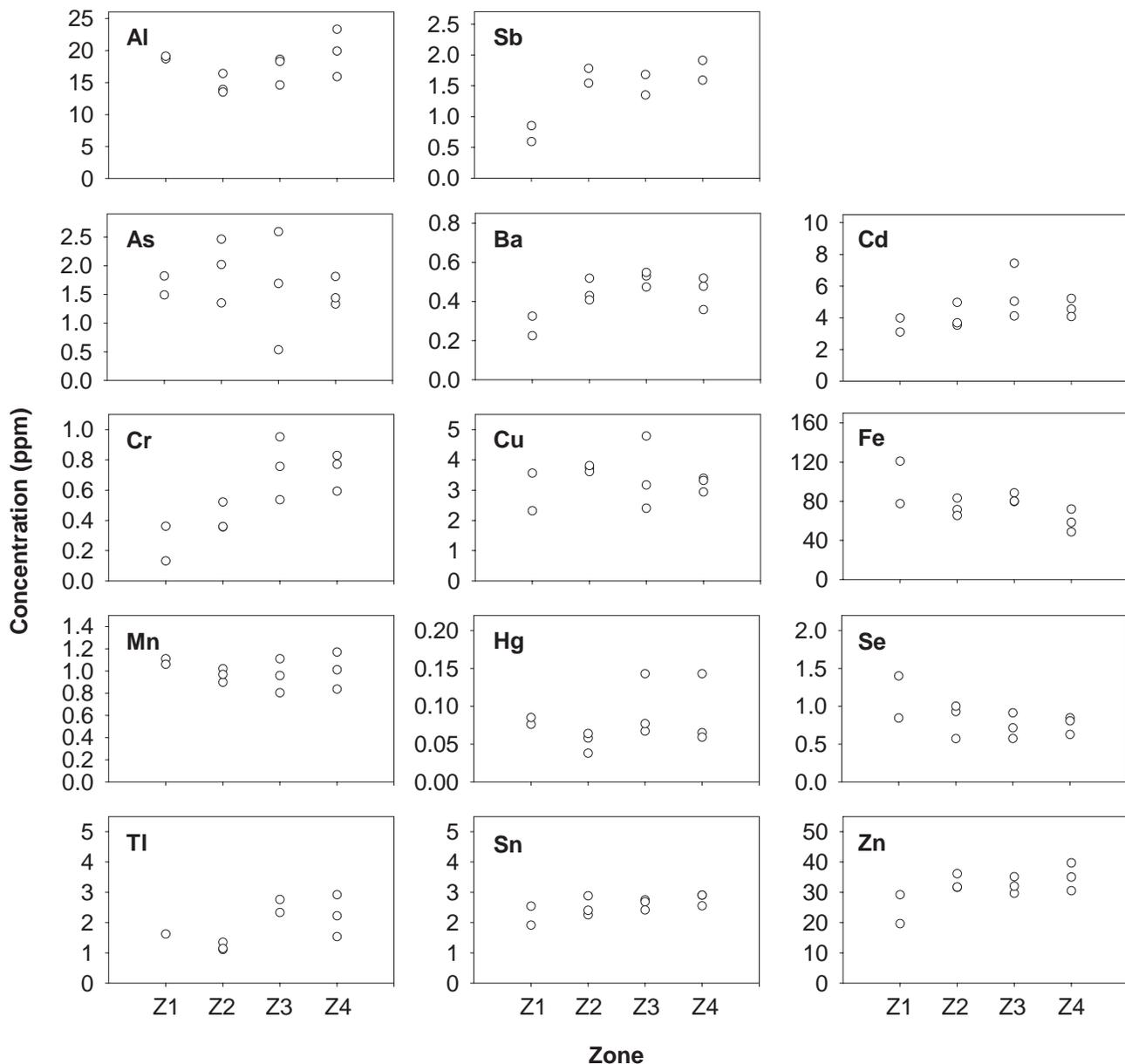


Figure 7.2

Concentrations of frequently detected metals in liver tissues of Pacific sanddabs collected from each PLOO trawl zone (Z1–Z4) during 2007. Only two Pacific sanddabs samples were collected from Zone 1; otherwise missing values = non-detects.

Individual components of total chlordane, total DDT, and total BHC are listed in Appendix D.2, while detected values of all pesticides are included in Appendix D.3. Chlordane, DDT, and HCB were detected in all samples; concentrations of total chlordane ranged from 3.2 to 23.2 ppb, total DDT ranged from 130 to 472 ppb, and HCB ranged from 1.1 to 8.3 ppb. The pesticide BHC (lindane) was also detected at concentrations up to 4.4 ppb in 17% of the samples. As with metals, there was no

clear relationship between concentrations of these pesticides and proximity to the outfall (**Figure 7.3**).

PCBs

PCBs occurred in every tissue sample. All detected PCB congeners are summarized in Appendix D.3. Total PCB concentrations were highly variable overall, ranging from 108 to 866 ppb (Table 7.2). There was no clear relationship between PCB concentrations in fish livers and proximity to the outfall (Figure 7.3).

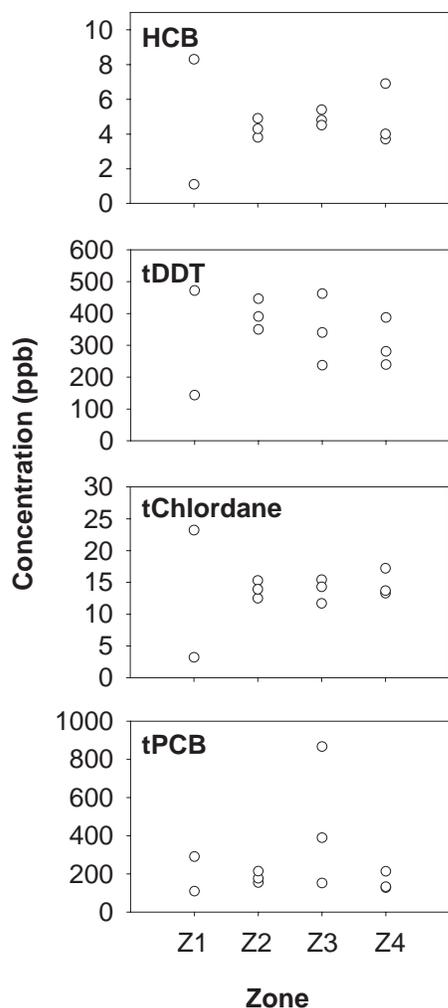


Figure 7.3
Concentrations of frequently detected chlorinated pesticides, total DDT, total Chlordane, and total PCB in liver tissues of Pacific sanddabs collected from each PLOO trawl zone (Z1–Z4) during 2007. Only two Pacific sanddabs samples were collected from Zone 1; otherwise missing values = non-detects.

Contaminants in Fishes Collected by Rig Fishing

Aluminum, arsenic, barium, cadmium, chromium, copper, iron, manganese, mercury, nickel, selenium, tin and zinc occurred in 100% of the muscle tissue samples collected from various species of rockfish at the two rig fishing stations in 2007 (Table 7.3). Antimony was only detected in 17% of the samples, while beryllium, lead, thallium and silver were not detected at all. The

metals present in the highest concentrations were aluminum (17.8 ppm), iron (7.7 ppm), zinc (5.2 ppm) and arsenic (2.13 ppm). DDT and PCBs were detected in 100% of the muscle samples, while the pesticides HCB and BHC were detected in 67 and 17%, respectively (Table 7.4). Each of these contaminants was detected in relatively low concentrations ranging from 0.1 ppb for HCB to 9.2 ppb for total DDT.

To address public health concerns, contaminant concentrations found in rockfish muscle tissues were compared to national and international limits and standards (Tables 7.3 and 7.4). The United States Food and Drug Administration (FDA) has set limits on the amount of mercury, total DDT, and chlordane for seafood that is to be sold for human consumption, while there are also international standards for acceptable concentrations of various metals (see Mearns et al. 1991). Of the contaminants detected in fish muscle tissues sampled as part of the PLOO monitoring program, only arsenic and selenium occurred in concentrations equal to or slightly higher than median international standards (see Table 7.3).

In addition to addressing the above concerns, spatial patterns were analyzed for HCB, total DDT, total PCB, and for all metals that occurred frequently in muscle tissues (Figure 7.4). Overall, concentrations of DDT, PCB and various metals were fairly similar in the muscles of fishes captured at both rig fishing stations, which suggests that there is no relationship with proximity to the outfall. However, comparisons of contaminant loads in fishes from stations RF1 and RF2 should be considered with caution since different species of fish were collected at the two sites, and the bioaccumulation of contaminants may differ between species due to differences in their physiology and diet. This potential problem may be minimal for the fish analyzed herein as all specimens belong to the same family (Scorpaenidae), have similar life histories (i.e., bottom dwelling tertiary carnivores), and are therefore likely to have similar mechanisms of exposure to and uptake of contaminants (e.g., direct contact with sediments, similar food sources).

Table 7.3

Summary of metals detected in muscle tissues from fishes collected at PLOO rig fishing stations during October 2007. Values are expressed as parts per million (ppm). The number of samples per species is indicated in parentheses; n=number of detected values, nd=not detected. Data are compared to U.S. FDA action limits (A.L) and median international standards (I.S.) where these exist. Bold values meet or exceed these standards. See Appendix D.1 for names and periodic table symbols.

	Al	As	Ba	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Sb	Se	Sn	Zn
Copper rockfish (1)														
n	1	1	1	1	1	1	1	1	1	1	nd	1	1	1
Min/max	17.8	1.71	0.132	0.063	0.304	0.572	7.7	0.085	0.157	0.192	—	0.67	1.5	4.8
Greenblotched rockfish (2)														
n	2	2	2	2	2	2	2	2	2	2	nd	2	2	2
Min	13.6	1.41	0.114	0.049	0.291	0.514	5.2	0.114	0.179	0.116	—	0.33	1.3	4.6
Max	15.2	1.78	0.185	0.063	0.306	0.591	7.6	0.190	0.181	0.150	—	0.38	1.6	5.1
Mean	14.4	1.59	0.149	0.056	0.298	0.552	6.4	0.152	0.180	0.133	—	0.36	1.4	4.8
Mixed rockfish (1)														
n	1	1	1	1	1	1	1	1	1	1	nd	1	1	1
Min/max	12.5	1.23	0.096	0.055	0.292	0.583	6.7	0.183	0.139	0.132	—	0.41	1.6	4.7
Vermilion rockfish (2)														
n	2	2	2	2	2	2	2	2	2	2	1	2	2	2
Min	15.0	1.60	0.098	0.038	0.264	0.469	4.5	0.045	0.166	0.164	0.49	0.37	1.4	5.2
Max	15.5	2.13	0.112	0.050	0.294	0.469	5.6	0.047	1.010	0.167	0.49	0.40	1.6	5.2
Mean	15.3	1.86	0.105	0.044	0.279	0.469	5.0	0.046	0.588	0.165	0.49	0.39	1.5	5.2
% Detected	100	100	100	100	100	100	100	100	100	100	17	100	100	100
Max	17.8	2.13	0.18	0.06	0.31	0.59	7.7	0.19	1.010	0.190	0.49	0.67	1.6	5.2
A.L.*								1.00						
I.S.*		1.4		1	1	20		0.5				0.3	175	70

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

SUMMARY AND CONCLUSIONS

Fourteen trace metals, DDT, and a combination of PCB congeners were detected in 100% of the liver tissue samples collected from two species of fish (Pacific sanddabs and English Sole) around the PLOO in 2007. All contaminant values were within the range of those reported previously for the Southern California Bight (SCB) (see Mearns et al. 1991, Allen et al. 1998). In addition, concentrations of these contaminants were generally similar to those reported previously by the City of San Diego for this survey area (e.g., City of San Diego 2007a), as well as the South Bay outfall monitoring area (e.g., City of San Diego 2007b). Concentrations of most parameters were similar across zones/stations,

and no clear relationship with proximity to the outfall was evident. These results are supported by a recent special study (Parnell et al. MS, 2008).

The frequent occurrence of metals and chlorinated hydrocarbons in the tissues of fish captured off Point Loma may be due to multiple factors. Mearns et al. (1991) described the distribution of several contaminants, including arsenic, mercury, DDT and PCBs as being ubiquitous in the SCB. In fact, many metals occur naturally in the environment (see Chapter 4), although little information is available on background levels in fish tissues. In addition, Brown et al. (1986) determined that no areas of the SCB are sufficiently free of chemical contaminants to be considered reference sites. This conclusion has been supported by more recent work regarding PCBs and DDTs (e.g., Allen et al. 1998, 2002).

Table 7.4

Summary of chlorinated pesticides, total PCB, and lipids detected in muscle tissues from fishes collected at PLOO rig fishing stations during October 2007. tBHC=total BHC (lindane); HCB=hexachlorobenzene; tDDT=total DDT; tPCB=total PCB. Values are expressed in parts per billion (ppb) for all parameters except lipids, which are presented as percent weight (% wt). The number of samples per species is indicated in parentheses; n=number of detected values, nd=not detected. Data are compared to U.S. FDA action limits (A.L.) and median international standards (I.S.) for parameters where these exist.

	tBHC	HCB	tDDT	tPCB	Lipids
Copper rockfish (1)					
n	nd	nd	1	1	1
Min/max	—	—	5.4	2.3	1.8
Greenblotched rockfish (2)					
n	1	1	2	2	2
Min	0.7	0.5	4.2	1.1	0.3
Max	0.7	0.5	9.2	1.2	0.5
Mean	0.7	0.5	6.7	1.2	0.4
Mixed rockfish (1)					
n	nd	1	1	1	1
Min/max	—	0.1	6.1	2.3	0.5
Vermilion rockfish (2)					
n	nd	2	2	2	2
Min	—	0.1	3.6	2.0	0.5
Max	—	0.5	5.9	3.9	0.7
Mean	—	0.3	4.7	2.9	0.6
% Detected	17	67	100	100	100
Max	0.7	0.5	9.2	3.9	1.8
A.L.*		300	5000		
I.S.*		100	5000		

*From Table 2.3 in Mearns et al. 1991. FDA action limits for total DDT and chlordane are for fish muscle tissues and all international standards are for shellfish, but are often applied to fish.

Other factors that affect the accumulation and distribution of contaminants include the physiology and life history of different fish species. Exposure to contaminants can vary greatly between different species and among individuals of the same species depending on migration habits (Otway 1991). Fishes may also be exposed to contaminants in an area that is highly contaminated and then move into an area that is not. This may explain why many of the pesticides and PCBs detected in fish collected off Point Loma in 2007 were detected

in low concentrations or not at all in sediments surrounding the outfall (see Chapter 4). In addition, intra-specific differences in feeding habits, age, reproductive status, and gender can affect the amount of contaminants a fish will retain in its tissues (e.g., Connell 1987, Evans et al. 1993).

Overall, there was no evidence that fishes collected in 2007 were contaminated by the discharge of wastewater from the PLOO. While some muscle tissue samples from sport fish collected in the region had concentrations of arsenic and selenium above the median international standard for shellfish, concentrations of mercury and DDT were below the FDA action limits for human consumption. Finally, there was no other indication 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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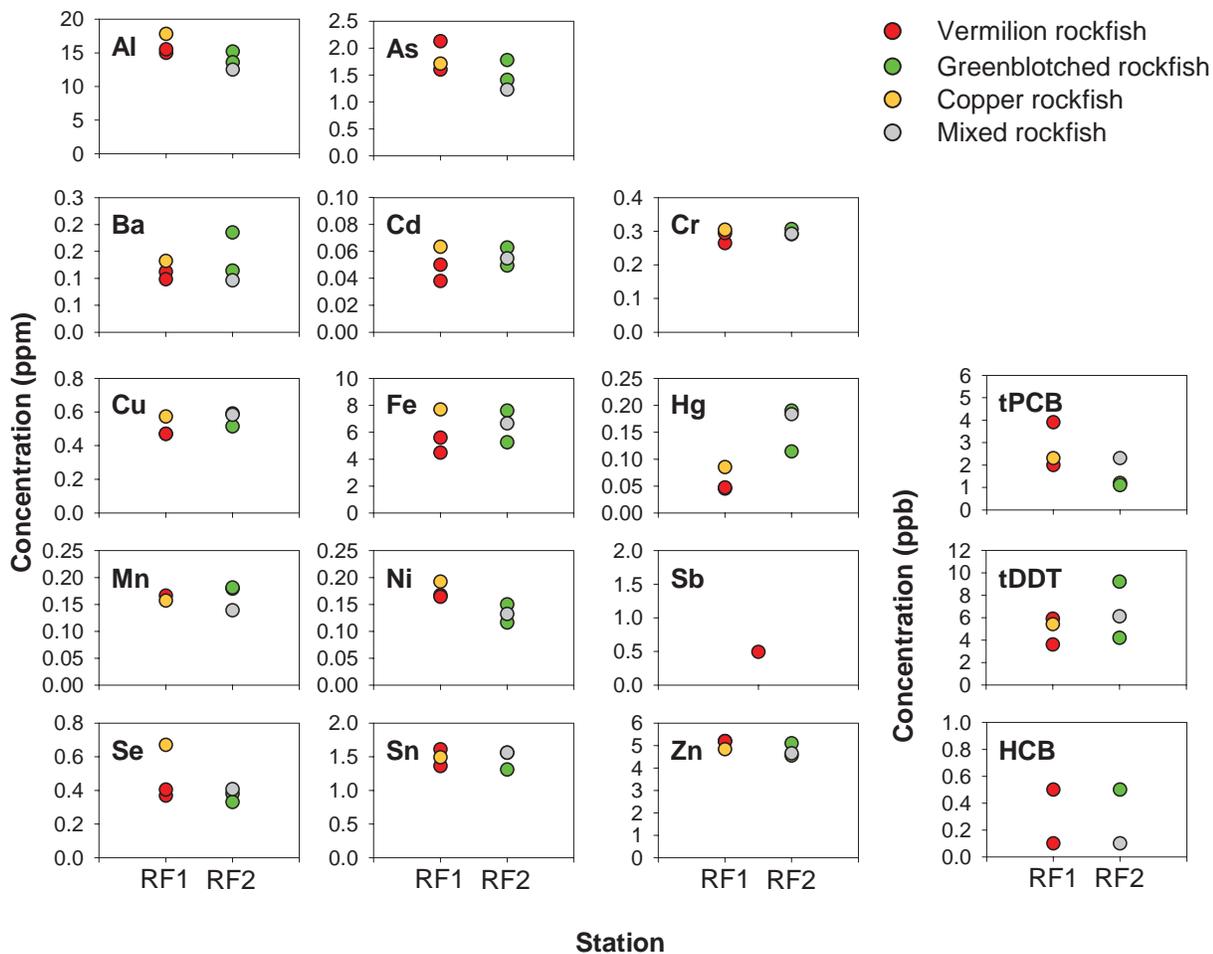


Figure 7.4

Concentrations of frequently detected metals, HCB, total DDT, and total PCB in muscle tissues of fishes collected from each PLOO rig fishing station during 2007.

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