Bioaccumulation of Chlorinated Hydrocarbons in Livers of Flatfishes from the Southern California Bight

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ABSTRACT

Although inputs of chlorinated hydrocarbon compounds to the Southern California Bight (SCB) are presently low, historical deposits represent a source of bioaccumulation potential to sediment-associated fauna. To assess this bioaccumulation potential, 14 chlorinated hydrocarbon classes (13 pesticides and PCB) were measured in livers of three species of flatfish collected from 63 randomly selected sites on the coastal shelf between Point Conception and the United States/Mexico international border.

Tissue contamination was widespread throughout the SCB, but was limited to just two chlorinated organic compound classes. Virtually 100% of Pacific sanddab (*Citharichthys sordidus*) and longfin sanddab (*Citharichthys xanthostigma*) populations were contaminated with total DDT and total PCB. Total DDT also contaminated the majority (64%) of the Dover sole (*Microstomus pacificus*) population in the SCB. The other 12 pesticides and their metabolites were consistently not detected in all of the target species. Total PCB measurements in tissues of SCB flatfish were dominated by 12 congeners (52, 66, 87, 101, 105, 118, 128, 138, 153, 170, 180, and 187), which averaged 95% of the combined mass of the 27 congeners analyzed. Sediment concentrations (normalized by total organic carbon content) accounted for most of the variability observed in tissue concentrations (normalized by lipid content) for 8 of these 12 congeners and total PCB. Normalized sediment concentrations were also significantly correlated to normalized tissue concentrations for total DDT and p,p’-DDE.

Tissue concentrations measured in this study from reference areas of the SCB were compared to tissue concentrations measured from reference areas in studies conducted in 1977 and 1985. It was found that total DDT and total PCB liver concentrations decreased one to two orders of magnitude in Pacific and longfin sanddabs between 1985 and 1994. Total DDT and total PCB liver concentrations decreased five- to 35-fold in Dover sole between 1977 and 1994. These comparisons are potentially confounded by differences in sample design and analytical methods, as well as the variability inherent in fish catch, size class, and life history. The reductions in tissue concentrations appear to transcend these technical differences, however, since they occurred over several depths, species, and locations.

INTRODUCTION

Historical inputs of the chlorinated hydrocarbons total DDT and total PCB have been a regional concern in the SCB for over 25 years. When the manufacture and use of these compounds were banned in 1971, an estimated 19 metric tons of DDTs and 10 metric tons of PCBs were discharged into the SCB through municipal wastewater outfalls (SCCWRP 1973). Discharges of these lipophilic compounds have accumulated in offshore sediments (Stull *et al.* 1986), where they have altered marine communities and bioaccumulated in tissues of benthic invertebrates and demersal fishes (Young *et al.* 1976, Swartz *et al.* 1986). Ongoing monitoring programs for DDT and PCB burdens in demersal fishes of the SCB are localized and centered near outfalls of large municipal wastewater dischargers. These monitoring programs are useful for assessing point source impacts and historical trends near specific wastewater outfalls (Stull 1995), but they lack regional perspective. The existing programs do not measure tissue contaminant levels in remote areas, contamination arising from other potential sources, or population-wide accumulation throughout the SCB. These factors are important in understanding whether bioaccumulation patterns are localized or widespread, and whether they affect a few individuals or the entire species.

Attempts to achieve regional assessment of tissue contamination by integrating local studies have been limited by incongruous data. For example, the local monitoring programs typically target different species and constituents, have dissimilar sampling periods or frequencies, and utilize various catch criteria and tissue compositing techniques. Special studies on demersal fish bioaccumulation have been inadequate to fill the data needs since they most often focus on “hot spots” or attempt to assess reference areas with a limited number of samples. Integrating special studies becomes especially troublesome when attempting to synthesize results that apply different analytical methods and/or parameters for accuracy, precision, and limits of detection. All too frequently, sediments and tissues are not sampled synoptically to assess exposure. Moreover, the resulting data are often difficult to access and evaluate.

In an effort to understand Bight-wide distributions of chlorinated hydrocarbon accumulation in demersal fishes, a regional survey of contamination in flatfishes was conducted in 1994. This survey addressed the following issues:

--What is the extent of fish tissue contamination throughout the entire SCB?

--What is the spatial distribution of fish tissue contaminants?

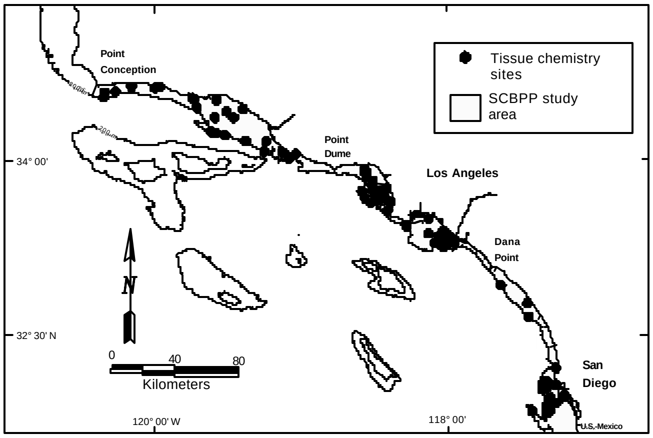
--What is the relationship between sediment and tissue contamination levels?

The primary goal (i.e., determining the extent of demersal fish tissue contamination) was explored using two distinct approaches: (1) what percent of the fish range contains contaminated fish, and (2) what percent of the fish population has been contaminated?

METHODS

Seventy-eight stations in the SCB were targeted for synoptic sediment and tissue measurements to assess demersal fish bioaccumulation (Figure 1). Stations were selected using a stratified random design; additional details are provided by Bergen (1996) and Stevens (in press). Stations were located from Point Conception to the United States/Mexico international border in depths ranging from 13 to 208 m. Samples were collected between July 12 and August 22, 1994.

FIGURE 1. Stations targeted for fish liver samples on the mainland shelf of Southern California at depths of 10 to 200 m, July and August 1994.



Selection of Target Species, Contaminants, and Tissues

Three species of flatfish were selected for chemical analysis including the Pacific sanddab (*Citharichthys sordidus*), longfin sanddab (*Citharichthys xanthostigma*), and Dover sole (*Microstomus pacificus*). The rationale for targeting these species included: (1) these species occupy a broad geographic coverage, providing the opportunity to assess Bight-wide distributions of contaminants; (2) all three species live and feed primarily in the benthos, thereby increasing sediment-organism interaction and routes of contaminant exposure; and (3) these species have been evaluated for bioaccumulation in historical studies.

Chlorinated hydrocarbons were measured due to their inherent bioaccumulation potential (SCCWRP 1982) and historical importance in the SCB. Since chlorinated hydrocarbons are more concentrated in liver tissue than muscle tissue or whole fish, only the livers were examined.

Sampling and Tissue Compositing Techniques

Demersal fishes were collected using 7.6-m head-rope semiballoon otter trawls with 1.25-cm cod-end mesh. Trawls were towed for 10 min (bottom time) at 0.8 to 1.2 m/sec (1.5 to 2.4 knots). If no target species were collected in the first trawl, sampling was considered to be complete, and field crews moved on to the next station. If target species were taken in the first trawl, additional trawls were conducted until sufficient quantities of specimens were collected for compositing. Once on board, all species were processed for taxonomic identification, abundance, individual length and weight, and the presence of anomalies. Target species were then removed from the rest of the catch. Each target species was placed in separate Ziplock bags and immediately frozen for transport to the landside processing facility.

Approximately 5 to 10 g of liver tissue were required for analytical processing. Therefore, multiple fish of the same species were composited into a single sample for each site to obtain sufficient tissue mass. On the average, 10 individual Dover sole specimens greater than 12 cm standard length (SL) were dissected. All Dover sole specimens were sexually immature. For each of the smaller sanddab species, approximately 15 individuals greater than 8 cm SL were dissected and composited to obtain sufficient tissue mass for each site. Over 95% of the sanddab specimens were immature; the few specimens with gonads were females.

Sediment samples were collected using a 0.1 m^2 modified Van Veen grab. The top 2 cm were removed using a Teflon or polyethylene spoon, taking care to avoid sediments in contact with the wall of the grab, and placed in 500 mL borosilicate glass containers with Teflon liners. Samples were placed on ice while transported to the laboratory, where samples were frozen until analysis.

Laboratory Methods

Sediments and tissues were analyzed for 13 separate pesticides or metabolites and 27 PCB congeners (Table 1). Sediments were thawed and homogenized at room temperature, then solvent-extracted using a Soxhlet apparatus (SW-846, Method 3540). Tissue composites were thawed and homogenized using stainless steel polytrons and extracted using chloroform and methanol (Bligh and Dyer 1959). Extracts were dried with anhydrous sodium sulfate, then cleaned up by removing sulfur with copper or mercury, and passing the extract through Florisil- and/or alumina-packed columns. Each extract was concentrated prior to instrumental analysis using a gas chromatograph equipped with electron capture detectors (GC-ECD) for quantifying analytes. For sediments, typically DB-5 and DB-17/608/1701 columns were used for analyte identification and confirmation, respectively. For tissues, confirmation of target compounds for most samples was accomplished using gas chromatography/mass spectrometry (GC/MS).

TABLE 1. Chlorinated hydrocarbons analyzed from sediments and livers of demersal fishes in 1994[a].

Pesticides	Polychlorinated Biphenyls	
Aldrin	PCB	8
alpha-Chlordane	PCB	18
Dieldrin	PCB	28
Endosulfan I	PCB	29
Endosulfan II	PCB	44
Endrin	PCB	50
Heptachlor	PCB	52[c]
Heptachlor epoxide	PCB	66[c]
Hexachlorobenzene	PCB	77
Lindane	PCB	87[c]
Mirex	PCB	101[c]
o,p' - DDT[b]	PCB	104
o,p' - DDE[b]	PCB	105[c]
o,p' - DDD[b]	PCB	118[c]
p,p' - DDT[b]	PCB	126
p,p' - DDE[b]	PCB	128[c]
p,p' - DDD[b]	PCB	138[c]
trans-Nonachlor	PCB	153[c]
	PCB	154
	PCB	170[c]
	PCB	180[c]
	PCB	187[c]
	PCB	188
	PCB	195
	PCB	201
	PCB	206
	PCB	209

[a] Minimum detection limit in sediment = 1 ng/dry g; in tissues = 4.2 ng/wet g.

[b] Sum for total DDT.

[c] Sum for total PCB.

Of the 6 isomers and metabolites summed for total DDT, over 95% was p,p'-DDE. Of the 27 PCB congeners measured, 12 were consistently detected (Congeners 52, 66, 87, 101, 105, 118, 128, 138, 153, 170, 180, and 187); 7 were occasionally detected (Congeners 28, 44, 104, 126, 195, 200, and 206); and 7 were never detected (Congeners 8, 18, 29, 50, 77, 154, and 188). The 12 consistently detected PCB congeners comprised, on average, approximately 95% of all 27 PCB congeners analyzed (Table 1).

Data Analysis

Data analysis focused on estimating the percent of area where contaminated fish were found and the percent of each fish population that had been contaminated. In addition, comparing mean concentrations of contaminants in fish tissues within the SCB was of particular interest. For these comparisons, mean concentrations were restricted to species, depth, and area. Areas near large wastewater outfalls and distant from outfall areas were particularly important since most historical chlorinated hydrocarbon emissions were discharged through publicly owned treatment works (POTWs). In addition, mean concentrations from this study were compared to historical data.

To compare contaminant concentrations among or within fish ranges, weighted summary statistics were used. Weighting factors were determined from probability distributions and sampling grid intensities. These techniques for trawling have been detailed by Allen and Moore (SCCWRP 1996). Area-weighted means were calculated following Equation 1:

Equation 1:

$$\mathrm{Mean}_{\mathrm{area}} = \frac{\sum_{i=1}^{n} (\mathrm{uobs}_i * \text{area weight}_i)}{\sum_{i=1}^{n} \text{area weight}_i}$$

Where,

area weight$_i$ = the area weight for station *i*;
n = number of stations in region of interest (e.g., fish range);
uobs$_i$ = concentration at station *i*.

To compare mean contaminant concentrations among or within fish populations, fish density weighting was required. Fish densities were determined from trawl area and target species abundance following Equation 2:

Equation 2:

$$\text{Mean}_{\text{population}} = \frac{\sum_{i=1}^{n} [\text{uobs}_i * (\text{area weight}_i) * (\text{abundance}_i / \text{trawl area}_i)]}{\sum_{i=1}^{n} [(\text{area weight}_i) * (\text{abundance}_i / \text{trawl area}_i)]}$$

Where,

area weight$_i$ = the area weight for station i;
abundance$_i$ = abundance of target species at station i;
trawl area$_i$ = area trawled at station i;
n = number of stations for species (e.g., Pacific sanddab);
uobs$_i$ = concentration at station i.

Fish density weighting requires several assumptions (Heimbuch *et al.* 1995), the greatest of which is the probability of individual fish capture being independent of area or the presence of other fish. Secondarily, it is assumed that tissue composite samples represent the site mean.

For comparisons to historical data, area-weighted mean concentrations were used for individual species. Historical data were not weighted, but arithmetic means were calculated from the same general areas used in this study. No adjustment was made for differences in size, sex, or reproductive maturity for historical data, although the previous studies did sample at the same time of the year (i.e., summer).

For deciphering sediment-tissue relationships, correlations and linear regressions were calculated that used normalized tissues (by lipid content) and normalized sediments (by TOC). In the case of DDTs, only p,p'-DDE was used because this metabolite represented over 95% of this pesticide in tissues. For PCBs, the 12 most prevalent congeners were used for calculating correlation coefficients.

RESULTS

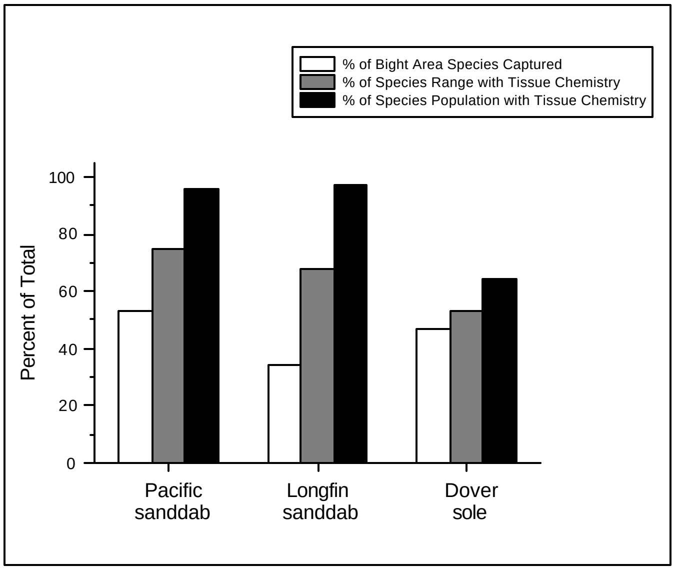
Trawling and Compositing Success

Trawl samples were collected from 63 (81%) of the 78 proposed stations. Eight stations were abandoned due to unsuitable bottom conditions (i.e., rocks or kelp); five stations were abandoned due to fouled nets on high relief bottom features (nets hung or torn); and two stations were unacceptable due to improper trawl sampling (duration or positioning). Since most of the unsampled stations were the result of unsuitable bottom conditions and not improper trawling, and since the target species do not reside in these unsampled environments, it is assumed that most of the missed samples do not represent unsampled fish.

Of the 63 trawlable stations, 52 provided sufficient catch for tissue analysis. Figure 2 shows the differences between the percent of Bight area where a target species was caught (i.e., the fish range), the percent of that species' range represented by a composite sample, and the percent of the fish population represented by a composite sample. For example, Pacific sanddabs were collected at 45 stations or approximately 53% of the SCB area. Of those stations, 34 provided sufficient tissue for chemical analysis. However, those 34 stations represented nearly 80% of the Pacific sanddab range and 96% of the Pacific sanddab population in the SCB. Similarly, adequate numbers of longfin sanddab were obtained for composite samples at 27 of 38 stations (32% of the Bight area). However, those stations represented over 70% of the longfin sanddab range and 97% of the longfin sanddab population in the SCB. Dover sole occurred in 47% of the SCB area. Sufficient numbers of Dover sole were obtained for tissue composites in 53% of the Dover sole range, representing only 64% of the Dover sole population in the Bight.

Extent and Spatial Distribution of Tissue Contamination

FIGURE 2. Percent area of Southern California Bight where Pacific sanddab (*Citharichthys sordidus*), longfin sanddab (*Citharichthys xanthostigma*), and Dover sole (*Microstomus pacificus*) were captured and the percent of each species range and population represented with bioaccumulation samples, July and August, 1994.



Twelve of 14 chlorinated organic compound classes analyzed were not detected in flatfish livers from the SCB. Total DDT and total PCB, however, were detected consistently in fish tissues throughout the Bight (Table 2, Appendix 1). Virtually 100% of the Pacific sanddab and longfin sanddab populations were contaminated with total DDT and/or total PCB. Similarly, every Dover sole measured was contaminated with total DDT. The incidence of total PCB contamination in Dover sole, however, was much lower (approximately 17% of the population).

On a Bight-wide scale, Pacific and longfin sanddab livers generally had higher DDT and PCB levels than did Dover sole livers (Table 2, Appendix 1). When weighted by area, the concentrations of lipids, total DDT, and total PCB in the livers of Dover sole were lower by a factor of 3 to 4 compared to Pacific or longfin sanddabs. When weighted by fish density, the concentrations of lipids, total DDT, and total PCB in the livers of Dover sole were lower by a factor of 4 to 5 compared to the other two species. Interspecies similarities and differences can vary due to lipid content (exposure and fugacity), location of catch (area weight), species abundance (fish density weight), and other factors.

In all three species of flatfish, the highest total DDT concentrations were located on or near the Palos Verdes Shelf, an area of historical discharge (Figures 3a through 3c). Liver tissue concentration maxima in Pacific sanddab (43,000 ng/wet g) and longfin sanddab (22,600 ng/wet g) were measured near Whites Point, the location of the County Sanitation Districts of Los Angeles County (CSDLAC) wastewater outfall. Total DDT tissue concentrations in both of these species gradually declined moving to the north through Santa Monica Bay towards Point Dume. Total DDT in Pacific and longfin sanddab liver tissue remained uniformly lower in areas to the south.

The spatial distribution of total PCB in liver tissues of flatfish was similar to total DDT (Figures 4a through 4c). The highest total PCB concentrations in Pacific sanddab (1,100 ng/wet g) and longfin sanddab (1,100 ng/wet g) were located on the Palos Verdes Shelf near Whites Point. Once again, tissue PCB levels generally declined moving to the north through Santa Monica Bay while levels remained uniformly lower in areas to the south. Unlike the DDT measurements, however, noticeably higher total PCB concentrations were observed near the wastewater outfalls of Orange County and the City of San Diego, particularly in longfin sanddab livers (Figure 4b).

When assessed cumulatively, Pacific and longfin sanddabs from outfall areas had significantly higher total DDT and total PCB concentrations than did those of other middle depth (25 to 100 m) areas of the SCB shelf (Figure 5). Area-weighted mean concentrations of total DDT were an order of magnitude higher in livers of fish captured near outfalls compared to fish captured distant from outfalls (2,000 versus 200 ng/wet g for Pacific sanddab, 2,500 versus 150 ng/wet g for longfin sanddab, and 60 versus < 4 ng/wet g for Dover sole). The differences in area-weighted mean total PCB concentrations between outfall and nonoutfall areas were less extreme for liver tissues from Pacific sanddabs, but were still significant for longfin sanddabs. The sample size for Dover sole at nonoutfall areas was small (n=2), but concentrations were below detection limits for both total DDT and total PCB.

Tissue Contamination Relative To Sediments

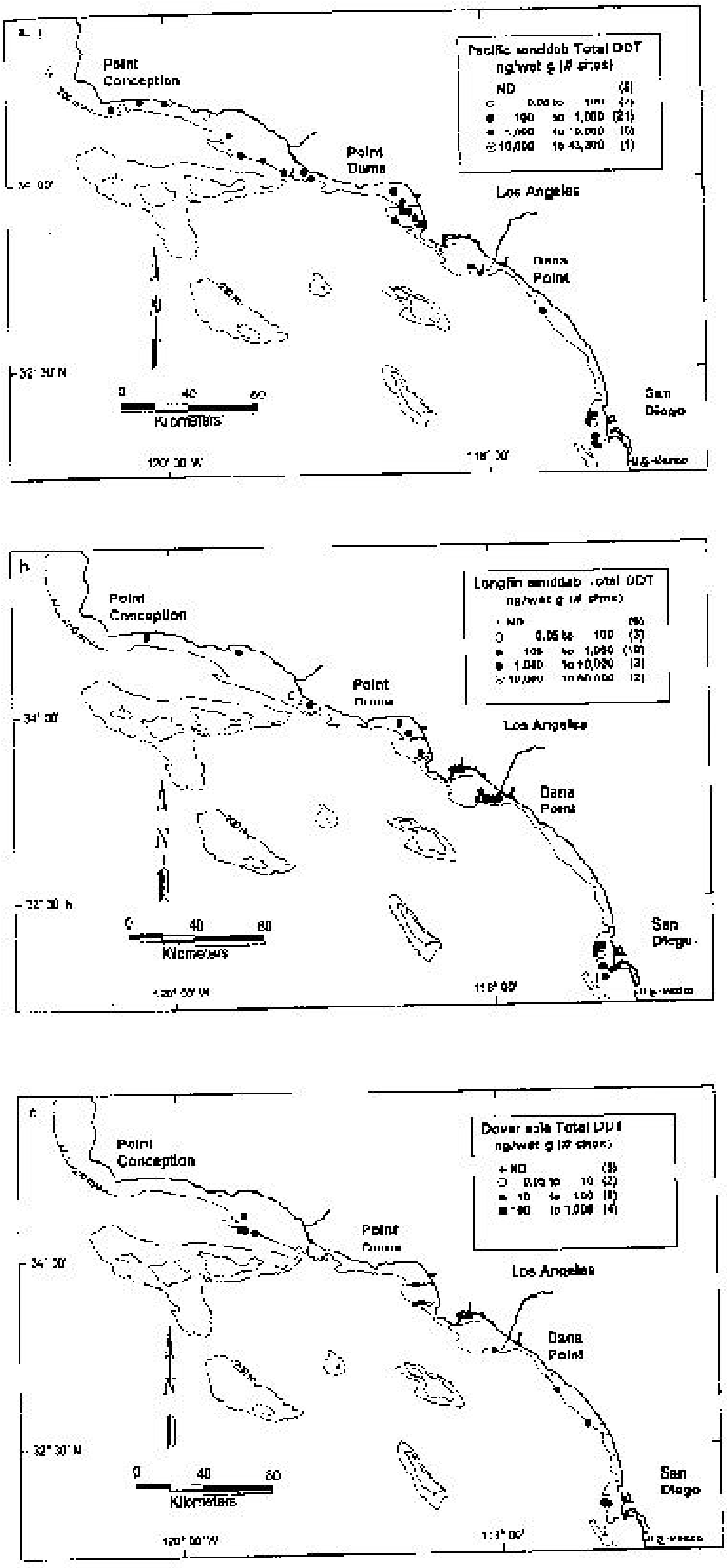
The p,p'-DDE concentrations measured in the liver tissues of flatfishes significantly covaried with concentrations measured in the sediments (Figures 6a through 6c). Normalization of sediment and biological data to the organic content of their matrix (i.e., TOC or lipid) significantly increased the correlation between the two accumulation compartments. The normalized concentrations in sediments accounted for 65, 79, and 53% of the variability observed in normalized tissue concentrations from livers of Pacific sanddab, longfin sanddab, and Dover sole, respectively.

Normalized concentrations of total PCB also significantly covaried with normalized liver tissue concentrations

TABLE 2. Mean concentrations of lipids, DDT, and PCB in livers of Pacific sanddab (*Citharichthys sordidus*), longfin sanddab (*Citharichthys xanthostigma*), and Dover sole (*Microstomus pacificus*) from the southern California Bight in 1994 weighted by area and fish density.

	Percent of Range Contaminated	Mean Weighted by Area			Percent of Population Contaminated	Mean Weighted by Fish Density		
		Lipid (%ww)	Total DDT (ng/wet g)	Total PCB (ng/wet g)		Lipid (%ww)	Total DDT (ng/wet g)	Total PCB (ng/wet g)
Pacific sanddab	75	15.9	654	74	96	18.1	1003	152
Longfin sanddab	68	12.7	1011	122	97	18.8	1815	166
Dover sole	53	3.9	158	25	64	4.1	214	38

FIGURE 3. Distribution of DDT in flatfish livers of the Southern California Bight, July and August 1994: (a) Pacific sanddab (*Citharichthys sordidus*); (b) longfin sanddab (*Citharichthys xanthostigma*); and (c) Dover sole (*Microstomus pacificus*). ND = below detection limit; ng/wet g = parts per billion (ppb) wet weight basis.



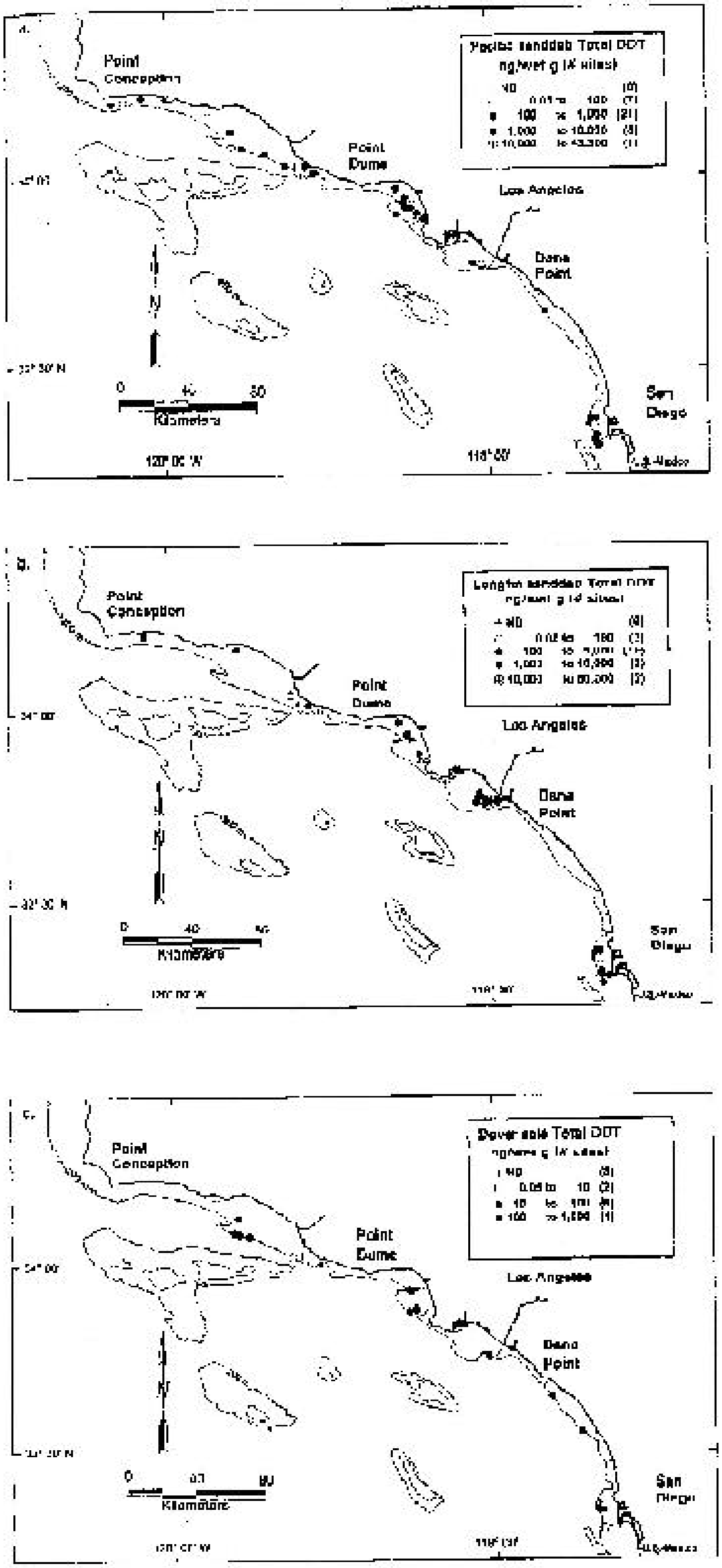
in flatfishes of the SCB (Table 3). Interestingly, the covariance of sediment and tissues differed by PCB congener. PCB congeners 118, 138, and 153 were found most frequently in sediments and tissues and also derived the greatest correlation between the two bioaccumulation compartments. PCB congeners 66, 101, and 187 also showed a high degree of covariance between organic phases in sediments and liver tissues. For these two groups of congeners, sediments accounted for 63 to 82% of the variability in tissue concentrations measured.

DISCUSSION

This study demonstrated that tissue contamination in flatfishes was widespread, but limited to just two chlorinated organic compound classes. Virtually 100% of Pacific sanddab and longfin sanddab fish populations were contaminated with total DDT and total PCB. The other 12 pesticides were 100% nondetectable. Additionally, the total DDT and total PCB contamination was distributed throughout much of these species' range in the Bight. The Pacific sanddab is, in fact, the most commonly occurring flatfish species in the SCB (SCCWRP 1996). Therefore, these results represent the most comprehensive region-wide understanding of flatfish contamination.

Not surprisingly, the spatial distribution of total DDT and total PCB concentrations in the liver tissues of flatfishes indicated that the highest levels were found near historical discharges of these compounds on the Palos Verdes Shelf. Large reservoirs of these pesticides still exist there (Stull *et al.* 1986), even though emissions are now extremely low or nondetectable in treated wastewater effluents (SCCWRP 1996). The spatial trend in tissue concentrations decreased moving northward, the net direction of the dominant oceanic currents in the region (Hickey 1993). At a limited number of locations in the SCB, others have made this observation while investigating liver and muscle tissue of these same species (Young *et al.* 1991, Mearns *et al.* 1991); and muscle tissue or whole body burdens from other fish species (MacGregor 1974, SCCWRP 1982, and SMBRP 1992) and invertebrates (SCCWRP 1975, CSWRCB 1987). In this study, the magnitude of tissue contamination significantly covaried with in-place sediment concentrations. In-place sediments as a bioaccumulation source of DDT (p,p'-DDE) or PCB (Aroclor 1254) for demersal fish of the SCB

FIGURE 4. Distribution of PCB in flatfish livers of the Southern California Bight, July and August 1994: (a) Pacific sanddab (*Citharichthys sordidus*); (b) longfin sanddab (*Citharichthys xanthostigma*); and (c) Dover sole (*Microstomus pacificus*). ND = below detection limit; ng/ wet g = parts per billion (ppb) wet weight basis.



has also been established by Young *et al.* (1991), assuming a fugacity-based model. By comparing fish with different feeding habits, Smokler *et al.* (1979) demonstrated that the sediment reservoir of total DDT on the Palos Verdes Shelf was an ongoing route of exposure to demersal fishes. Our study not only verifies these earlier findings, but provides greater empirical data as a result of our extended study area. Furthermore, we established relationships between specific PCB congeners in sediments and tissues, which had not been attempted previously. Our results showed that the most environmentally abundant congeners were most frequently accumulated in tissues.

Although this study was able to assess the extent of flatfish bioaccumulation, it was not capable of assessing the impact of these contaminants. Both DDT and PCB have the potential to induce harm in individual fish (Spies *et al.* 1994). Also, DDT and PCB have been implicated in reproductive impairment of white croaker (*Genyonemus lineatus*) and kelp bass (*Paralabrax clathratus*) from the SCB (Hose *et al.* 1989). Unfortunately, similar ecotoxicological benchmarks have not been reported for the target species in this study. Additionally, such benchmarks are most appropriately measured in other target tissues (e.g., gonads). Once a candidate benchmark is established, however, it can be quickly and easily used to assess the extent of Bight-wide impacts by applying the criterion to a cumulative distribution function of the data (Appendix 1). While an assessment of human health impacts was considered, comparisons were determined to be inappropriate because: (1) the target species were rarely caught by recreational anglers (Allen *et al.* 1996) and generally were not part of a large commercial market; and (2) human health risk analyses focus on muscle rather than liver tissue for assessing exposure to seafood consumers (USEPA 1995).

While this study was not designed for trend analysis, some limited temporal comparisons can be provided for total DDT and total PCB. Reference areas were specifically chosen for this comparison because: (1) substantially less temporal information exists for areas distant from Palos Verdes; (2) these areas represent the greatest proportion of the fish population; and (3) these areas are potential feeding grounds for predatory fish, birds, and mammals. Two previous studies, one conducted in

FIGURE 5. Mean (area weighted) total DDT and total PCB levels in Pacific sanddab (*Citharichthys sordidus*), longfin sanddab (*Citharichthys xanthostigma*), and Dover sole (*Microstomus pacificus*) livers in outfall and nonoutfall areas, Southern California Bight, July and August 1994. ND = nondetectable.

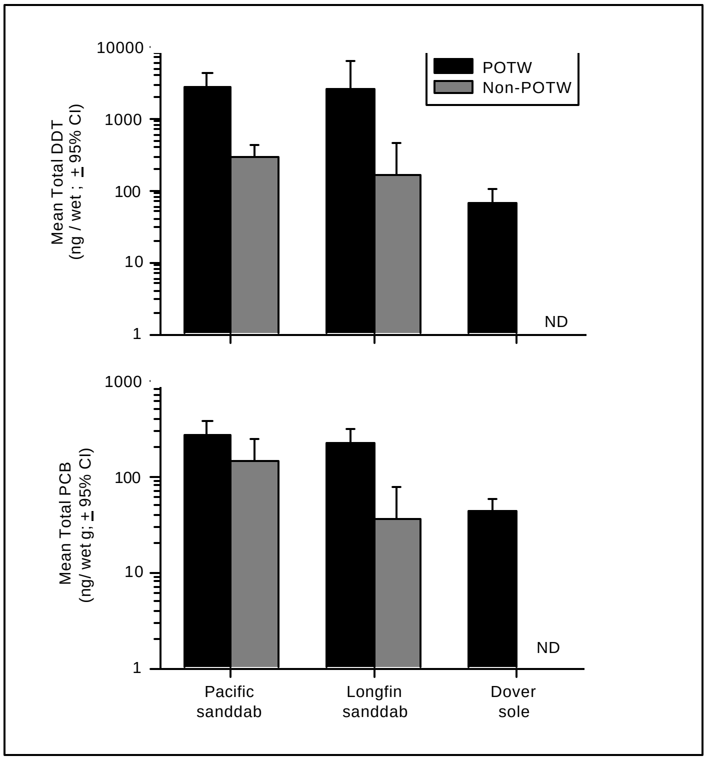
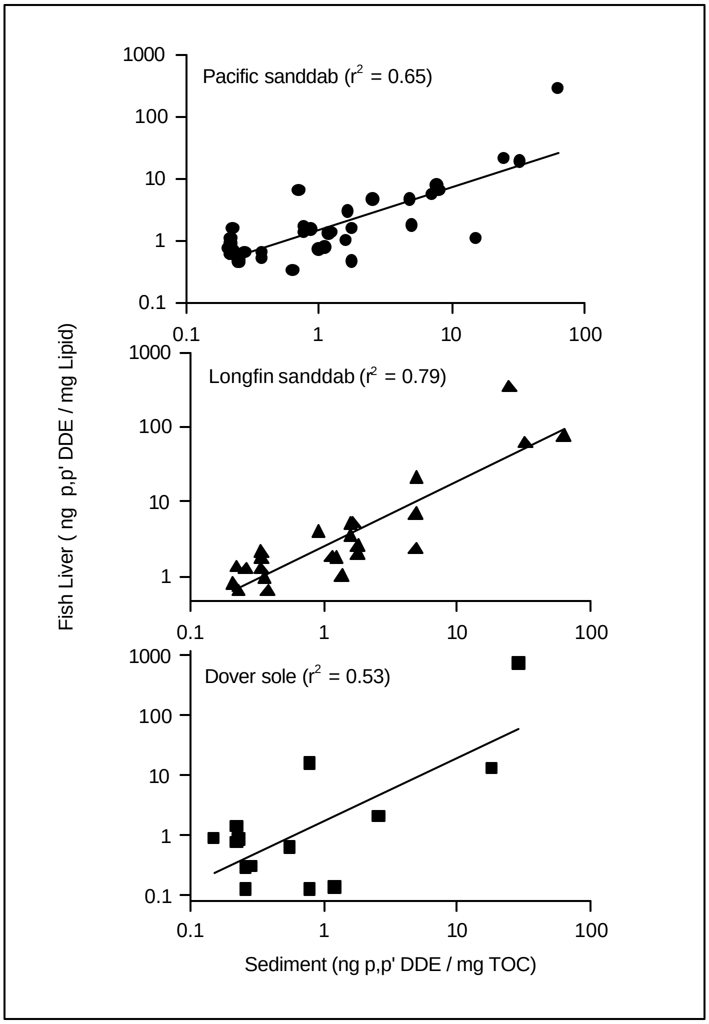


FIGURE 6. Biological-sediment accumulation factors for p,p'-DDE in Pacific sanddab (*Citharichthys sordidus*), longfin sanddab (*Citharichthys xanthostigma*), and Dover sole (*Microstomus pacificus*) livers in the Southern California Bight, July-August 1994.



1977 (Mearns *et al.* 1991, SCCWRP unpublished data) and the other in 1985 (Thompson *et al.* 1987), measured pesticide and PCB concentrations in liver tissues of sanddabs and Dover sole. The comparisons in this study were stratified to discriminate any depth-related bias, which significantly reduced sample sizes. Therefore, the comparisons are qualitative in nature.

For every species at each depth, substantial decreases in total DDT and total PCB concentrations have occurred in demersal fish livers from reference areas over the last 10 to 20 years (Table 4). Mean contaminant levels in Pacific sanddabs and longfin sanddabs in 1994 decreased by one to two orders of magnitude compared to 1985. At 60 m depth, mean total DDT and total PCB levels in Dover sole in 1994 decreased 5- to 35-fold compared to 1977. Attempts to assess temporal trends in PCB tissue burdens are complicated by the substantially different technology used in 1994 compared to the previous surveys (i.e., Aroclor versus Congener PCB analysis). Even with potential analytical bias, not to mention the variability inherent to fish catch, size class, location, and exposure, these temporal differences are considerable. Although relatively few reference sites were actually assessed over time, the reductions universally occurred over different species, depths, and locations.

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TABLE 3. Spearman rank correlation coefficients (r_s) between PCB in sediments (normalized by TOC) and liver tissue (normalized by lipid content) for two species of flatfish from the Southern California Bight in 1994. For coefficients in bold, p< 0.01; "-" indicates p>0.05. Sample size (n) represents number of sites with co-occurring sediment-tissue PCB congeners.

PCB Congener	Pacific sanddab	(n)	Longfin sanddab	(n)
52	0.742	13	-	4
66	0.604	14	0.673	11
87	-	9	-	3
101	0.547	17	0.601	11
105	-	11	**0.673**	10
118	**0.720**	19	**0.800**	18
128	-	10	-	7
138	**0.780**	21	**0.700**	19
153	**0.750**	22	**0.632**	21
170	-	9	-	7
180	-	13	**0.681**	17
187	0.615	12	**0.820**	13
Total PCB	**0.790**	23	**0.780**	21

TABLE 4. Comparison of mean total DDT and total PCB concentrations (ug / wet g) in livers of Pacific sanddab (*Citharichthys sordidus*), longfin sanddab (*Citharichthys xanthostigma*), and Dover sole (*Microstomus pacificus*) in reference areas at various depths from 1977 to 1994.

Year	Depth	Pacific sanddab			Longfin sanddab			Dover sole		
		Total DDT	Total PCB	(n)	Total DDT	Total PCB	(n)	Total DDT	Total PCB	(n)
1977[a]	60 m	-	-		-	-		0.76	1.44	(2)
1985[b]	60 m	4.33	5.82	(2)	6.21	7.81	(6)	0.42	0.35	(2)
	150 m	5.57	5.50	(8)	2.83	3.02	(1)	0.47	0.39	(2)
1994[c]	50-70 m	0.14	< 0.01	(6)	0.22	0.07	(3)	< 0.01	< 0.01	(2)
	130-170 m	0.16	0.03	(4)	-	-	(0)	0.13	0.04	(7)

[a] Mearns *et al.* (1991) and SCCWRP unpublished data: Total PCB = Aroclor 1242+1254.
[b] Thompson *et al.* (1987); Total PCB = Aroclor 1242+1254.
[c] This study; mean weighted by area, Total PCB = sum of 12 congeners.

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ACKNOWLEDGMENTS

The authors thank Jeffrey N. Cross (NMFS); Stephen B. Weisberg and Mary Bergen (both of SCCWRP); the Southern California Bight Pilot Project Steering Committee, Analytical Chemistry and Trawl Quality Assurance Working Groups; and David R. Young (U.S. EPA) and Alan J. Mearns (NOAA) for advice in the planning and analysis of this report. We also thank the field teams of the City of San Diego, County Sanitation Districts of Orange County, County Sanitation Districts of Los Angeles County, City of Los Angeles, SCCWRP, MEC Analytical Systems, and MBC Applied Environmental Sciences. We thank Valerie E. Raco-Rands and David Tsukada (both of SCCWRP) for processing the samples following collection and Pace Laboratories for fish dissections. Chemical analysis was conducted by Pace Laboratories, Rich Gossett (CRG Marine Laboratories), Lori McKinley (CSDOC), and Eddy Zeng, Charlie Yu, Cherrie Vista, and Azra Hussain(all of SCCWRP). We appreciate the improve-

ments suggested by anonymous critical external reviewers.

APPENDIX 1.

Cumulative distribution functions (CDFs) for tissue concentrations in livers of three species of flatfish from the Southern California Bight (SCB): Pacific sanddab (*Citharichthys sordidus*), longfin sanddab (*Citharichthys xanthostigma*), and Dover sole (*Microstomus pacificus*).