Distribution of contamination above predator-risk guidelines in flatfishes on the southern California shelf in 1998

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ABSTRACT - Most studies of fish contamination in southern California have focused on human health-risk concerns, health- risks to individual fish, or assessment of changes in contaminant levels over time. These studies have not been able to assess the extent of fish on the southern California shelf with contamination levels of concern because of limited distributions of individual species and/or lack of appropriate contaminant-risk guidelines. By shifting focus to a foraging guild of species with a broader distribution and to predator-risk concerns, such an assessment becomes possible. The objective of this study was to determine the spatial extent of fish on the southern California shelf with contamination levels of potential risk to bird and mammal predators. We used the sanddab guild rather than individual species to get better spatial coverage. Members of this guild have been shown to have similar contaminant uptake with similar contaminant exposure. Sanddab-guild species were collected at 225 sites on the southern California shelf (depth 2-202 m) in summer 1998. Sites were selected from a stratified-random sampling design, which provided a basis for assessing spatial extent of variables of concern. Whole fish composites of sanddab-guild species were analyzed for DDTs, PCBs, and chlordane. Levels of contaminants in these composites were compared to predator-risk guidelines of Environment Canada (for DDT, PCB) and the National Academy of Sciences (for chlordane). The spatial extent of contamination was determined for the shelf as a whole and for subpopulations of interest (e.g., wastewater discharge areas, harbors, etc.). DDT in sanddab guild species exceeded the predator-risk guideline (14 μg/kg ww) in 71% of the area on the southern California shelf. PCB exceeded the guideline (0.79 ng TEQ/kg) in 8% (mammals) and 5% (birds) of the area. Chlordane was below the guideline (50 ppb) at all sites sampled. Percent area above the guideline for DDT were was highest on the southeastern Channel Islands and mainland ports. Tissue concentrations in fish were correlated with sediment concentrations. Historically deposited sediments are the presumed source of most DDT and PCB contamination on the southern California shelf, as discharge of both were banned three decades ago. Previous studies have shown that contaminant levels in these fishes have decreased more than an order of magnitude during that period, and presumably effects on birds and mammals also decreased during this period. Nevertheless, results of this study suggest that potential risks to upper food-chain predators still exist and should be a focus of future fish contamination assessments of the southern California shelf.

INTRODUCTION

For more than 65 years, chemical contaminants have been discharged into coastal waters of the Southern California Bight via numerous point and nonpoint sources. These contaminants are dispersed into the water column in a dissolved state or on particulates, and are accumulated by fishes via contact with water, sediment, or food sources. High levels of contaminants (particularly chlorinated hydrocarbons such as DDT and PCBs) have been found in many southern California fishes for more than three decades (Mearns *et al*. 1991). Levels near Los Angeles (particularly on the Palos Verdes Shelf) have long been known to be particularly high (SCCWRP 1973, Mearns *et al*. 1991, Allen and Cross 1994). Most studies of fish contamination in southern California have focused on human health-risk concerns (Pollock *et al*. 1991), health-risks to

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individual fish (Cross and Hose 1988, Hose *et al*. 1989), or assessment of changes in contaminant levels over time (Allen and Cross 1994). These studies have not been able to assess the spatial extent of fish on the southern California shelf with contamination levels of concern because of limited distributions of individual species and/or lack of appropriate contaminant-risk guidelines. The first assessment of the areal extent of contaminated fishes on the mainland shelf of southern California was made in 1994 (Allen *et al*. 1998, Schiff and Allen 2000). Although this study provided substantial information on the distribution of contamination in flatfishes on the southern California mainland shelf (10-202 m depth), it was not able to assess the extent of area with fish with contamination levels of concern because 1) no single species occurred across the entire shelf; and 2) no threshold of concern had been established for fish liver contamination for the species examined in that survey. Since the 1994 survey, Allen *et al*. (2002b) showed that sanddab-guild species (Allen 1982) had similar uptake of DDT when exposed to the same sediments, and these, in combination, occurred across the entire shelf. In addition, by examining contamination in whole fish composites of the guild species, contaminant levels could be compared to predator-risk (e.g., wildlife protection) guidelines or thresholds (NAS 1974; Environment Canada 1997, 1998).

The objective of this study was to determine the extent of area on the southern California shelf with contaminant levels of concern. Sanddab-guild fishes were targeted to achieve better areal coverage while whole fish composites and predator-risk guidelines were used to assess risk to predators. Chemical analysis focused on DDT, PCBs, and chlordane, all of which have predator-risk guidelines.

Methods

Field Sampling

The survey study area was the southern California shelf, including bays and harbors, the mainland, and selected islands (Figure 1a). Sampling sites were selected using a stratified random design (see Stevens 1997). Subpopulations were defined for region, bays/shelf zones, and human influence categories. Regions included the northern mainland (Point Conception to Point Dume); central mainland (Point Dume to Dana Point); southern mainland (Dana Point to United States-Mexico international border); northwest Channel Islands shelf (San Miguel Island to western Santa Cruz Island); southeast Channel Islands shelf (eastern Santa Cruz Island, Anacapa Island, and Santa Barbara Island); and Santa Catalina Island shelf. Bays/shelf zones included bays and harbors (5-30 m), inner shelf (5-30 m), middle shelf (31-120 m), and outer shelf (121-200 m), with bay and harbor areas being partitioned into ports, marinas, and other bay areas. Human influence subpopulations included large

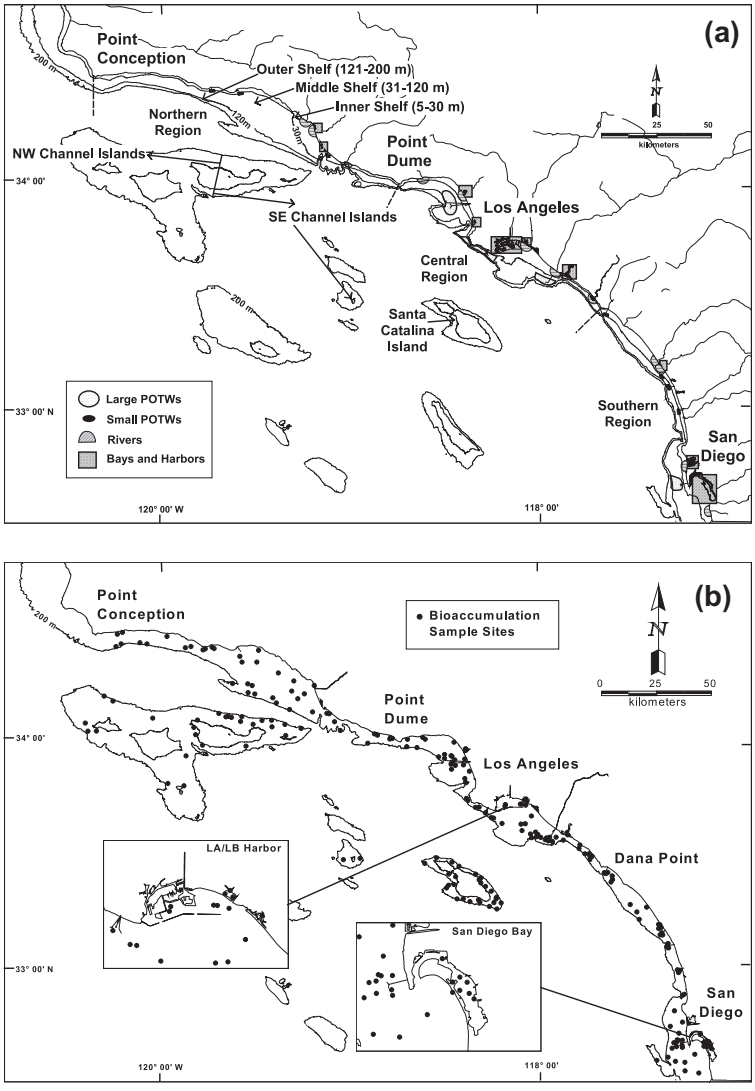


Figure 1. Distribution of (a) sampling subpopulations for regions, depth/habitat zones, and human influence areas; and (b) bioaccumulation stations sampled by trawl in the Southern California Bight 1998 Regional Survey, July-September 1998.

POTW, small POTW, non-POTW, and river mouth areas.

Primary target species for this study included seven species of the sanddab guild (Table 1). This list was slightly expanded from Allen (1982), which described the guild. The five species in the sanddab guild of Allen (1982) were speckled sanddab (*Citharichthys stigmaeus*), longfin sanddab (*Citharichthys xanthostigma*), Pacific sanddab (*Citharichthys sordidus*), gulf sanddab (*Citharichthys fragilis*), and slender sole (*Lyopsetta exilis*). In the present study (Table 1), small (< 21 cm SL) California halibut (*Paralichthys californicus*) and petrale sole (*Eopsetta jordani*) have been added to this guild. The primary sanddab guild species (as well as small petrale sole) are benthic generalists and feed, at least partly, on the benthos. Small California halibut are the most likely ecological counterpart of sanddab species in bays, whereas the other flatfish species in southern California bays feed on infaunal polychaetes and clam siphons. The sanddab guild was chosen as a primary target because 1) component species show similar levels of contamination with similar levels of exposure to sediment contaminants (Allen *et al.* 2002b), and 2) the guild occurred in 96% of the area of the southern California shelf and was generally abundant in 1994 (Allen *et al.* 1998).

Fish samples for bioaccumulation analysis were collected at 225 stations (Figure 1b) using a 7.6-m (headrope) otter trawl with 1.3 cm cod-end mesh. A sample composite consisted of six fish of an age class (Table 1). At each station, composites were made for each age class for all sanddab guild species collected. Composites of each species were placed in separate Ziploc® bags and immediately frozen for transport to the processing facility on land.

Laboratory Methods

Target Analytes and Guidelines

Chlorinated hydrocarbons were measured due to their inherent bioaccumulation potential (Gossett *et al.* 1982), historical importance in the Southern California Bight (SCB), and role in human and environmental health concerns. The DDT and polychlorinated biphenyls (PCBs) were the only chlorinated hydrocarbons found in flatfishes on the mainland shelf of southern California in 1994, and both were found in virtually all fish examined (Allen *et al.* 1998, Schiff and Allen 2000). Because of this, DDT and PCBs were chosen for analysis in this study. Chlordane was also chosen because it was a pesticide of concern in bay and harbor areas.

Whole fish samples were analyzed for two isomers of chlordane, two isomers of DDT and their four common metabolites, and 41 PCB congeners (Table 2). Congener-specific analysis was performed because the transport, persistence, bioavailability, and toxicity varies substantially among different PCB congeners. The list of 41 PCB target analytes was developed based upon their presence in four common Aroclor mixtures (i.e., 1242, 1248, 1254, 1260), their occurrence in environmental samples,

Table 1. Sanddab-guild species[1] targeted for bioaccumulation study on the southern California shelf in July-September 1998.

		Standard Length Ranges (cm)			
		Age Class[2]			
Common Name	Scientific Name	0	1	2	Other
speckled sanddab	*Citharichthys stigmaeus*	5-7	8-10	11-16	--
longfin sanddab	*Citharichthys xanthostigma*	5-8	9-13	14-16	--
Pacific sanddab	*Citharichthys sordidus*	5-8	9-13	14-16	--
gulf sanddab	*Citharichthys fragilis*	5-7	8-10	11-14	--
slender sole	*Lyopsetta exilis*	5-8	9-10	11-12	--
petrale sole	*Eopsetta jordani*	5-7	8-14	15-20	--
California halibut	*Paralichthys californicus*	5-9	10-20	NT	--

[1] Sanddab guild species, slightly expanded from Allen (1982); scientific and common names based on Nelson *et al*.(2004).

[2] Age classes of primary sanddab guild species from Allen *et al*. (2002b).

NT = Not targeted.

Table 2. Chlorinated hydrocarbons analyzed.

Pesticides	Polychlorinated Biphenyl (PCB) Congeners		
DDT and Metabolites	Predator-risk Congeners	Other PCB Congeners	
p,p'-DDT	PCB-77	PCB-18	PCB-138
p,p'-DDD	PCB-81	PCB-28	PCB-149
p,p'-DDE	PCB-105	PCB-37	PCB-151
o,p'-DDT	PCB-114	PCB-44	PCB-153
o,p'-DDD	PCB-118	PCB-49	PCB-158
o,p'-DDE	PCB-123	PCB-52	PCB-168
	PCB-126	PCB-66	PCB-170
Chlordanes	PCB-156	PCB-70	PCB-177
	PCB-157	PCB-74	PCB-180
Chlordane-a	PCB-167	PCB-87	PCB-183
Chlordane-g	PCB-169	PCB-99	PCB-187
	PCB-189	PCB-101	PCB-194
		PCB-110	PCB-201
		PCB-119	PCB-206
		PCB-128	

and their potential toxicity as identified by McFarland and Clarke (1989).

Processing of Fish Samples

Five species of the sanddab guild were selected in the laboratory for chemical analysis: small California halibut, speckled sanddab, longfin sanddab, Pacific sanddab, and slender sole. Gulf sanddab and small petrale sole did not occur frequently in this survey. Selection of composites for analysis emphasized the most frequent age classes and the most frequent species to increase the comparability of the samples.

As the focus of this study was on predator-risk assessment and as predators consume whole fish rather than fish fillets or livers, we processed whole fish composites for chemical analysis following methods given in Allen *et al*. (2002a,b). After thawing frozen composites, individual fish in a composite were measured (cm SL) and weighed, and individual weights were summed to give a composite weight in grams. Composite samples were homogenized in a blender, with 0.5 or 1.0 L stainless steel or glass containers with silicone or BUNA rubber gaskets with Teflon® (or aluminum foil-lined) lids. The composite fish and an equal weight of deionized water (to facilitate blending) were combined and blended for 2-5 min to obtain a smooth homogenate. Two equal-sized aliquots of homogenate were used to fill two wide-mouthed glass jars with Teflon®-lined lids (and external labels) to three-fourths full or less; the remainder of the sample was discarded. Blenders were washed with nonionic soap and water, rinsed several times with deionized water, dried, and then rinsed with an appropriate solvent (e.g., methanol, ethanol, acetone) and dried. Samples were kept at -20°C (± 2°C) for up to six months.

Chemical Analysis

Prior to analysis, sample aliquots were thawed and thoroughly mixed to ensure a uniform homogenate and then subsequently solvent extracted. Extraction methods included soxhlet extraction, accelerated solvent extraction (ASE), microwave-assisted solvent extraction (MASE), and homogenization solvent extraction. The extracts were subjected to appropriate clean-up procedures and analyzed by gas chromatography with either electron capture detection (GC-ECD) or mass selective detection (GC-MS). Following analysis, the measured concentration was doubled to correct for the equal weight of water added to the sample during homogenization.

Whole fish samples were analyzed through the collaborative efforts of five participating laboratories. The quality assurance/quality control requirements for this study were performance based. The particular analytical methods used for the analysis were left to the discretion of the individual laboratory with the requirement that each demonstrate acceptable analyte recoveries and detection limits, and meet the general data quality objectives (DQOs) specified in B'98,SC (1998). All laboratories were required to evaluate and monitor their analytical performance through the use of method blanks, certified reference materials (CRMs), matrix spikes, and sample duplicate analyses.

Method blanks were used to assess any laboratory contamination introduced during all stages of the sample preparation and analysis. Certified reference materials were used to assess the accuracy of the analytical results. The recommended CRM for the fish tissue analysis was the CARP-1, available from the Research Council of Canada. The CARP-1 CRM is a ground whole common carp (*Cyprinus carpio*) sample with certified values for 14 PCB congeners.

In addition, an inter-laboratory calibration study was performed to derive consensus values for DDT and it metabolites. Each laboratory was required to obtain comparable results in relation to both the certified values and the consensus values. Matrix spike samples were used to evaluate recoveries and analytical performance for low concentrations of target analytes. A sample of orange roughy (*Hoplostethus atlanticus*) was spiked with target analytes at concentrations near the reporting limit and subjected to the entire analytical procedure to determine the accuracy of the results for analytes in the lower region of the calibration range. In contrast to CRMs, blanks, and duplicates, there was no specific frequency or data quality objective stated for matrix spikes. Finally, duplicate analyses were performed on approximately 5% of the samples (i.e., one per batch) to estimate the precision of the analytical results.

Data Analysis

Percent Above Threshold

The objective of this study was to answer the question, "What is the extent of fish with contamination levels of concern?" Hence, data analysis focused on estimating the percent of area where contaminated fish were found and the percent of each fish population with contamination levels above a threshold of concern. As the species in the sanddab guild have similar uptake under similar conditions (Allen *et al.* 2002b), the component species in combination were regarded as being functionally equivalent and the guild was treated as a 'superspecies.' Hence, contaminant concentrations from a site were likely to be about the same no matter which sanddab guild species were present. In this study, we chose the species/age class composite that was the priority composite for chemical analysis for use in data analysis; hence, a single composite represented a station.

The thresholds of concern were predator-risk guidelines for aquatic and/or marine wildlife from the National Academy of Science (NAS 1974) and Environment Canada (1997, 1998). The guideline for chlordane was 50 µg/kg ww (NAS 1974). The guideline for total DDT was 14.0 µg/kg ww (Environment Canada 1997) and that for PCB was 0.79 ng (TEQ)/kg ww (Environment Canada 1998). The PCB guideline was based on the toxicity equivalent quotient (TEQ) of the products of the summed PCB congeners and their toxicity equivalency factors (TEFs). These TEFs were used to estimate the relative toxicity of PCBs based on their similarity to dioxin. Specifically, the TEFs are assigned to the congeners based on their ability to produce a response in the cytochrome system relative to the most potent inducer, 2,3,7,8-TCDD [a dioxin; TCDD = tetrachlorodibenzo-p-dioxin] (Environment Canada 1998). Thus, the TEQ is the total TCDD toxic equivalents concentration and is calculated as follows:

$$TEQ = \Sigma (PCBi \times TEFi)$$

where PCBi = Individual PCB congener.
TEFi = Toxicity of PCB congener relative to TCCD dioxin.

The TEFs used in this study were those recommended by the World Health Organization (Van den Berg *et al*. 1998). The TEFs were available for 12 PCB congeners found in this study, with TEFs differing for mammals and birds (Table 3).

Population Summary Statistics

Trawl data were expressed as values per standard trawl haul. In this survey, the area sampled in this trawl haul was approximately 3,014 m^2. Because a stratified random survey design was used, different weighting factors were assigned to stations in some subpopulations (Appendix A2 in Allen *et al*. 2002a). These weighting factors were used in percent of area

Table 3. Summary of congener-specific toxicity equivalent factors (TEFs) for mammals and birds used to assess predator risk.

	WHO Congener-specific TEFs[1]	
Congener	Mammals	Birds
PCB 77	0.00010	0.05000
PCB 81	0.00010	0.10000
PCB 105	0.00010	0.00010
PCB 114	0.00050	0.00010
PCB 118	0.00010	0.00001
PCB 123	0.00010	0.00001
PCB 126	0.10000	0.10000
PCB 156	0.00050	0.00010
PCB 157	0.00050	0.00010
PCB 167	0.00001	0.00001
PCB 169	0.01000	0.00100
PCB 189	0.00010	0.00001

WHO = World Health Organization.
[1] Van den Berg, *et al*. (1998).

calculations (including medians) and in adjustment of mean values, standard deviations, and confidence limits. If it is stated that *x* percent of the area had a particular attribute value, this should be interpreted as meaning that the value is likely to occur in a standard trawl haul from *x* percent of the area.

Population data were analyzed in two ways: 1) calculation of medians, means, and 95% confidence intervals for population attributes in the SCB and in various subpopulations, and 2) assessment of the percent of area within each subpopulation above the SCB median.

Mean parameter values were calculated using a ratio estimator (Thompson 1992):

$$m = \frac{\sum_{i=1}^{n} (p_i * w_i)}{\sum_{i=1}^{n} w_i} \quad (1)$$

where

m = Mean parameter value for population *j*.
p_i = Parameter value at station *i*.
w_i = Weighting factor for station *i*, equal to the inverse of the inclusion probability for the site.
n = Number of stations sampled in population *j*.

Weighting factors for each station are provided in (Allen *et al*. 2002a). The ratio estimator was used in lieu of a stratified mean because an unknown fraction of each stratum could not be sampled (e.g., hard bottom). Thus, the estimated area was used as a divisor in place of the unknown true area. The standard deviation of the mean response was calculated as follows:

$$\text{Standard Deviation} = \sqrt{\frac{\sum_{i=1}^{n} (p_i - m)^2 * w_i}{\sum_{i=1}^{n} w_i}} \quad (2)$$

The standard error of the mean response was calculated as follows:

$$\text{Standard Error} = \sqrt{\frac{\sum_{i=1}^{n} ((p_i - m) * w_i)^2}{(\sum_{i=1}^{n} w_i)^2}} \quad (3)$$

The 95% confidence intervals were calculated as 1.96 times the standard error. The ratio estimator for the standard error approximates joint inclusion probabilities among samples and assumes a negligible spatial covariance, an assumption that appears warranted. However, the assumption is conservative because its violation would lead to overestimation of the confidence interval (Stevens and Kincaid 1997).

Percent of Area and Medians

As with the 1994 survey, the 1998 survey was designed specifically to address questions regarding the spatial distribution of the data. These issues included the determination of cumulative frequency distributions (CDFs) (Stevens and Olsen 1991). The CDFs provide graphical information on the percent of the survey area that lies below a given indicator value. A population attribute (e.g., abundance) value from a station has an associated weighting factor (Allen *et al.* 2002a). To calculate a CDF, indicator values were ranked from low to high. The weighting factors for stations with a given indicator value were then accumulated, giving a cumulative sum of weight at each ranked indicator value. Then each cumulative sum of weight was divided by the total area weight to give a cumulative frequency distribution (with proportions adding up to 1.0)**.** Medians can be determined from CDFs and compared among subpopulations and to those of the SCB as a whole. The median was the value of an attribute at which 50% of the area of a subpopulation lies above or below. This median thus differs from observation medians, defined as the value at which 50% of the observations lie above or below. Confidence limits of medians for population attribute data were determined by calculating 95% confidence limits of means on log-transformed data and back-transforming.

Population Means

In addition, comparing mean and median concentrations of contaminants in fish tissues within the SCB was of interest. For these comparisons, mean and median concentrations, as well as percent of the area above threshold, were determined for subpopulations and for the SCB as a whole.

To compare contaminant concentrations in the sanddab guild, stratified summary statistics were used. Weighting factors were determined from probability distributions and sampling grid intensities. Mean values were calculated following Equation 6. To compare mean contaminant concentrations among

or within fish populations, fish density weighting was required. Fish density weighting requires several assumptions (Heimbuch *et al.* 1995), the most important 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.

Fish densities were determined from trawl area and target species abundance as follows:

$$m = \frac{\sum_{i=1}^{n} (p_i * w_i)^* (\text{abundance}_i / \text{trawl area}_i)}{\sum_{i=1}^{n} w_i * (\text{abundance}_i / \text{trawl area}_i)} \quad (4)$$

where

m = Mean parameter value for population j.
p_i = Parameter value (concentration) at station i.
w_i = Weighting factor for station i, equal to the inverse of the inclusion probability for the site.
n = Number of stations for species (e.g., Pacific sanddab).
abundance_i = Abundance of target species at station I.
trawl area_i = Area trawled at station i.

Correlation/Regression Analysis

For deciphering sediment-tissue relationships, wet-weight tissue and lipid-normalized tissue concentrations were correlated with sediment concentrations normalized by TOC.

Results

Distribution of Contamination in Fish

DDT

Total DDT was analyzed in sanddab guild composites from 225 stations. Of these, 99% had detectable levels of tDDT, with concentrations ranging from 0.0 (nondetect) to 10,462.4 µg/kg (ppb) (Table 4). Concentrations of *p,p*-DDE were higher than the other five DDT isomers and metabolites analyzed in all composites. All composites from the central and southern mainland regions, and from the southeast Channel Islands, had detectable concentrations. The highest values occurred on the Palos Verdes Shelf (Figure 2a) and hence occurred in the central mainland region within the middle shelf large POTW subpopulation (Table 4). The lowest values occurred in the northern mainland region within the inner shelf "other mainland" subpopulation and at Santa Catalina Island in the middle shelf zone (Table 4, Figure 2a).

Median and mean concentrations of tDDT differed substantially. Overall, the median concentration was 21.8 µg/kg and the mean concentration was 96.6 µg/kg (Table 4). Median concentrations ranged from 3.8 µg/kg for the inner shelf small POTW subpopulation to 160.2 µg/kg for the middle shelf large POTW subpopulation. Mean concentrations ranged from 6.0–1,415.0 µg/kg, with low and high values occurring in the same subpopulations as the median. The greatest difference between these parameters occurred in the middle shelf large POTW subpopulation (160.2 µg/kg median, 1,415.0 µg/kg mean).

Total DDT concentrations were above the predator-risk guideline of 14 µg/kg in 66% of the sanddab guild population (= fish) on the southern California shelf (Table 5). By region, 76% of the fish of this guild in the mainland region and 59% in the island region were above this guideline. In the mainland region, the percent of fish above the threshold increased from north to south (60 to 96%) (Table 5). In the island region, 100% of the fish in the southeast Channel Islands had tDDT levels above the threshold, whereas only 45% were above the threshold at the northwest Channel Islands. By depth, the percent of fish above the threshold was highest in the bays and harbors (92%) and lowest on the middle shelf (59%). Within the human influence subpopulations, the percent of fish above the threshold was highest in the port and "other bays" (100%), and lowest on the island inner shelf zone (0%) and middle shelf small POTW subpopulation (3%).

Total DDT levels were also above the predator-risk guideline in 71% of the area of the southern California shelf (Table 5). Stations below the guideline were largely concentrated largely along the northern and southern mainland shelf areas, around Santa Rosa Island, and on the central Santa Catalina Island shelf (Figure 2b). The percent of area over the threshold was similar for the mainland (70%) and island regions (74%) (Table 5, Figure 3). In the mainland region, the percent of area above the threshold was highest (95%) in the central region and lowest (77%) in the northern region. At the islands, 100% of the southeast Channel Islands area, 69% of the Santa Catalina Island area, and 65% of the northwest Channel Islands area were above the threshold. By depth, the percent of area above the threshold was highest (91%) in the bays and harbors, and lowest (35%) on the inner shelf, with the outer

Table 4. Summary of tDDT (µg/kg) concentrations in sanddab-guild composites by subpopulation.

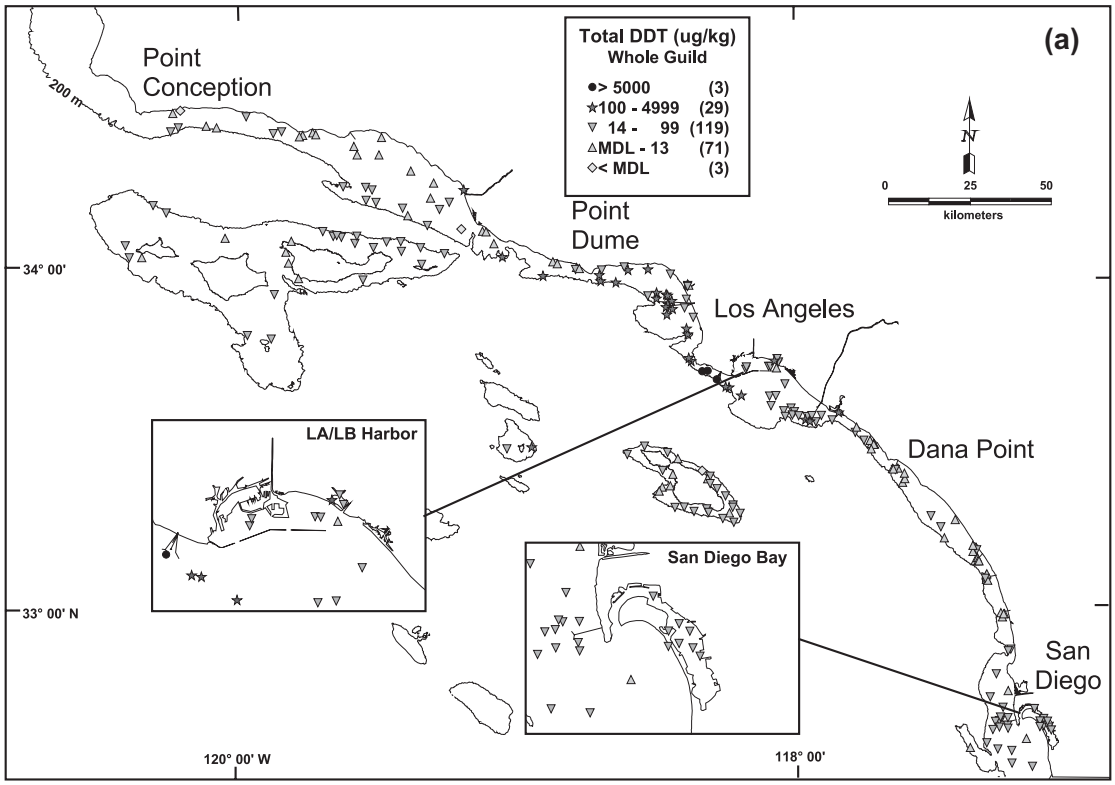
Subpopulation	No. of Stations	% Det.	Range Min.	Range Max.	Area-Weighted Values Median	Mean	95% CI
Region							
Mainland	170	99	0.0	10,462.4	20.5	146.6	72.0
North	42	95	0.0	202.9	10.5	20.3	8.1
Central	71	100	2.8	10,462.4	42.9	361.6	184.3
South	57	100	2.1	70.0	16.2	17.4	3.0
Island	55	98	0.0	160.2	22.1	25.4	7.9
Cool (NW Channel Islands)	14	100	5.2	35.7	18.7	19.1	6.1
Warm	41	98	0.0	160.2	27.5	37.1	16.7
SE Channel Islands	15	100	15.1	160.2	29.1	43.0	23.2
Santa Catalina Island	26	96	0.0	65.7	19.2	23.1	6.4
Shelf Zone							
Bays and Harbors (2-30 m)	18	100	7.4	234.7	30.4	54.7	27.0
Ports	3	100	18.1	42.0	18.5	26.4	12.5
Marinas	9	100	7.4	234.7	48.4	83.0	51.8
Other Bay	6	100	26.0	70.0	27.5	34.4	9.6
Inner Shelf (2-30 m)	46	96	0.0	184.3	9.7	22.3	14.1
Small POTWs	9	100	2.6	19.2	3.8	6.0	3.2
River Mouths	8	100	3.0	48.2	9.2	21.1	10.8
Other Mainland	25	92	0.0	184.3	9.8	23.4	15.3
Island	4	100	6.8	11.6	7.0	9.0	2.2
Middle Shelf (31-120 m)	119	99	0.0	10,462.4	22.0	129.0	67.7
Small POTWs	14	100	2.1	30.6	5.5	7.3	3.4
Large POTWs	32	100	13.5	10,462.4	160.2	1,415.0	910.2
Mainland non-LPOTW	42	100	4.2	1,061.4	21.6	115.4	89.9
Island	31	97	0.0	160.2	19.3	24.3	10.3
Outer Shelf (121-202 m)	42	100	2.0	217.6	29.3	38.2	12.6
Mainland	22	100	4.2	217.6	29.5	48.3	26.8
Island	20	100	2.0	63.0	28.5	30.3	4.1
Total (all stations)	225	99	0.0	10,462.4	21.8	96.6	44.3

* Threshold = 14 µg/kg, Environment Canada (1997).
No. = Number; Det = detected; Min. = Minimum; Max. = Maximum; CI = Confidence interval;
POTW = Publicly owned treatment work monitoring areas.

shelf (86%) and middle shelf (76%) being intermediate. For human influence subpopulations, the percent of area above the threshold was highest (100%) in ports and "other bays," and lowest on the island inner shelf (0%) and the middle shelf small POTWs (7%) (Figure 3). The distribution of DDT above the guideline was centered around the central and southern mainland regions, southeast Channel Islands, and Santa Catalina Island (Figures 2b, 3). Within the area above threshold, highest DDT concentrations (>5,000 µg/kg) were on the Palos Verdes Shelf (Figure 2a). DDT concentrations above 100 µg/kg occurred primarily on the Palos Verdes Shelf and Santa Monica Bay, with some on the San Pedro Shelf (Figure 2a).

Chlordane

Total chlordane was analyzed in sanddab guild composites from 225 stations. Of these, 8% had detectable levels of chlordane, with concentrations



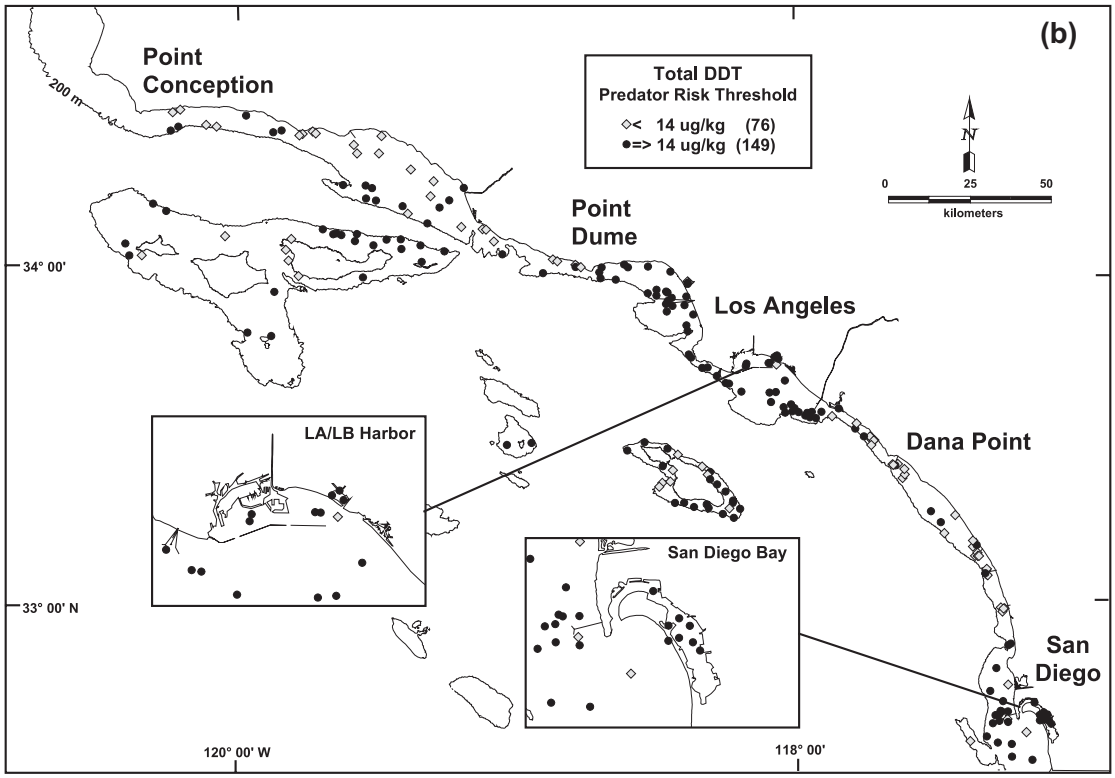


Figure 2. Distribution of (a) tDDT concentrations and (b) concentrations of tDDT greater than predator-risk guideline in sanddab-guild fishes on the southern California shelf, July-September 1998. Predator-risk guideline = 14 mg/kg (Environment Canada 1997).

Table 5. Percent of fish and percent of area by subpopulation on the southern California shelf with tDDT, mPCB, and bPCB concentrations in sanddab-guild fishes above predator-risk guidelines.

	Percent above Guideline					
	tDDT		mPCB		bPCB	
Subpopulation	Fish[1]	Area	Fish[1]	Area	Fish[1]	Area
Region						
Mainland	76	70	8	10	3	3
Northern	60	42	0	0	0	0
Central	92	95	38	27	12	10
Southern	96	77	< 1	1	0	0
Island	59	74	6	6	6	7
Cool (NW Channel Islands)	45	65	0	0	0	0
Warm	93	91	22	23	21	21
SE Channel Islands	100	100	34	21	33	28
Santa Catalina Island	82	69	3	4	3	4
Shelf Zone						
Bays and Harbors (2-30 m)	92	91	26	38	0	0
Ports	100	100	25	67	0	0
Marinas	83	79	23	23	0	0
Other Bay	100	100	31	42	0	0
Inner Shelf (2-30 m)	81	35	0	0	< 1	< 1
Small POTWs	22	10	0	0	0	0
River Mouths	47	50	0	0	22	13
Other Mainland	23	37	0	0	0	0
Island	0	0	0	0	0	0
Middle Shelf (31-120 m)	59	76	8	12	4	6
Small POTWs	3	7	0	0	0	0
Large POTWs	98	97	37	44	34	31
Mainland non-LPOTW	82	83	12	14	1	3
Island	45	68	5	7	4	7
Outer Shelf (121-202 m)	87	86	5	2	5	6
Mainland	77	70	0	0	0	0
Island	97	98	10	3	11	10
Total (all stations)	66	71	7	8	5	5

Fish[1] = used here to indicate "fish in guild".
DDT guideline = 14 µg/kg, Environment Canada (1997).
PCB guideline = 0.79 ng TEQ/kg, Environment Canada (1998).
TEQ = toxicity equivalent quotient, which differs between birds and mammals.
mPCB = PCB predator-risk guideline for mammals.
bPCB = PCB predator-risk guideline for birds.
POTW = publicly owned treatment work monitoring areas.

ranging from 0.0 (nondetect) to 14.6 µg/kg (Table 6). The two isomers, α—chlordane and γ—chlordane (chlordane-a and chlordane-g), did not occur together in the same composite; α—chlordane was detected more frequently than γ—chlordane. All samples had concentrations below the NAS threshold of 50 µg/kg (NAS 1974). The highest values occurred near the Los Angeles County outfall (central mainland region, middle shelf, large POTW subpopulation) and on the west side of Santa Cruz Island (northwest

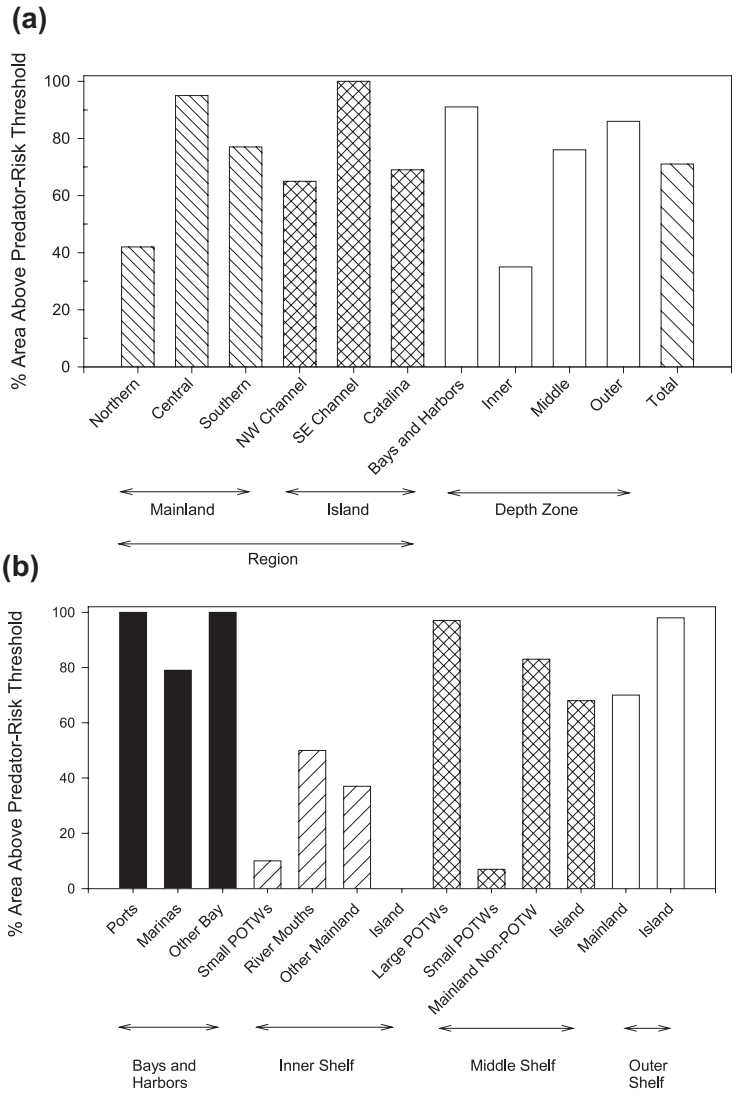


Figure 3. Percent of area with sanddab-guild fish above predator-risk guideline for tDDT by subpopulation in (a) region and depth zone subpopulations and (b) subpopulations within depth zones.

Channel Islands). The median concentration of chlordane was 0 µg/kg for all subpopulations and the overall mean concentration was 0.2 µg/kg (Table 6). Detection rates for individual species were similar to those for the guild, with values ranging from 6-12%.

Total Polychlorinated Biphenyls (PCBs)

PCBs were analyzed in sanddab-guild composites from 225 stations. Of these, 44% had detectable levels of PCBs, with concentrations of total PCB ranging from 0.0 (nondetect) to 710.3 (µg/kg) (Table 7). The overall median and mean concentrations were 0.0 and 10.3 µg/kg, respectively. The highest values occurred in the central mainland region middle shelf large POTW subpopulation on the shelf off of Los Angeles (including the Palos Verdes Shelf), as well as in the bays and harbors (including LA/LB Harbor and San Diego Bay) (Table 7, Figure 4). These "ports" had a 100% detection rate. The lowest values occurred among the northern and southern mainland subpopulations and most of the Channel Islands. Most of the species had detection rates similar to that for the feeding guild, with values between 31% and 49%. However, California halibut had a higher detection rate of 68%, which reflects occurrence of this species primarily in bays and harbors, where PCB contamination was found to be high.

Mammal PCB/Toxicity Equivalency Quotients (TEQs)

Nine of the PCB congeners detected in this study had potential toxicity factors (TEFs) assigned to their concentrations (Table 3). These congeners included PCB77, PCB81, PCB105, PCB114, PCB118, PCB123, PCB156, PCB167, and PCB169. Of the 225 samples collected, 26% had detectable levels of the PCB congeners that are toxic to marine mammals (Table 8). The PCBmTEQ concentrations toxic to mammals ranged from 0.0 (nondetect) to 30.9 ng/kg (pptr). The overall median concentration was 0.0 ng/kg; the overall mean concentration was 0.5 ng/kg. The samples with potential risk to mammals occurred in the central mainland region middle shelf large POTW subpopulation off of Los Angeles, including off Palos Verdes, near the Los Angeles County ocean outfall, and in bays and harbors, primarily San Diego Bay (Table 8, Figure 5).

For the Bight as a whole, 7% of the sanddab-guild fish were estimated to be above the mammal predator-risk guideline for PCBmTEQs of 0.79 ng/kg TEQ (Table 5). By region, 8% of the fish of this guild in the mainland region and 6% in the island region were above this guideline. The largest percentage of fish with PCBmTEQ levels above the guideline were from the central mainland region middle shelf large POTW subpopulation (37%) and in the bays and harbors (26%) (Table 8, Figure 6). These subpopulations were also the ones with the highest levels of total PCB.

Table 6. Summary of chlordane (µg/kg) concentrations in sanddab-guild composites by subpopulation on the southern California shelf.

Subpopulation	No. of Stations	% Det.	Range Min.	Range Max.	Area-Weighted Values Median	Area-Weighted Values Mean	Area-Weighted Values 95% CI
Region							
Mainland	170	8	0.0	14.6	0.0	0.2	0.2
Northern	42	2	0.0	1.5	0.0	0.0	0.1
Central	71	18	0.0	14.6	0.0	0.6	0.4
Southern	57	0	0.0	0.0	0.0	0.0	0.0
Island	55	5	0.0	11.4	0.0	0.1	0.1
Cool (NW Channel Islands)	14	7	0.0	11.4	0.0	0.1	0.2
Warm	41	5	0.0	1.0	0.0	0.1	0.1
SE Channel Islands	15	7	0.0	0.6	0.0	0.1	0.1
Catalina Island	26	4	0.0	1.0	0.0	0.0	0.1
Shelf Zone							
Bays and Harbors (2-30 m)	18	17	0.0	5.2	0.0	0.6	0.7
Ports	3	0	0.0	0.0	0.0	0.0	0.0
Marinas	9	33	0.0	5.2	0.0	1.4	1.4
Other Bay	6	0	0.0	0.0	0.0	0.0	0.0
Inner Shelf (2-30 m)	46	2	0.0	11.4	0.0	0.2	0.3
Small POTWs	9	0	0.0	0.0	0.0	0.0	0.0
River Mouths	8	0	0.0	0.0	0.0	0.0	0.0
Other Mainland	25	0	0.0	0.0	0.0	0.0	0.0
Island	4	25	0.0	11.4	0.0	3.0	5.0
Middle Shelf (31-120 m)	119	8	0.0	14.6	0.0	0.2	0.2
Small POTWs	14	0	0.0	0.0	0.0	0.0	0.0
Large POTWs	32	19	0.0	14.6	0.0	1.5	1.2
Mainland Non-LPOTW	42	7	0.0	3.3	0.0	0.2	0.3
Island	31	3	0.0	0.6	0.0	0.0	0.0
Outer Shelf (121-202 m)	42	7	0.0	2.0	0.0	0.1	0.1
Mainland	22	9	0.0	2.0	0.0	0.2	0.2
Island	20	5	0.0	1.0	0.0	0.0	0.0
Total (all stations)	225	8	0.0	14.6	0.0	0.2	0.1

No. = Number; Det = detected; Min. = Minimum; Max. = Maximum; CI = Confidence interval; POTW = publicly owned treatment work monitoring areas.

Similarly, 8% of the area of the southern California shelf had fish with PCBmTEQ levels above the mammal predator-risk guideline (Table 5). The percent of area over the threshold was similar for the mainland (10%) and island regions (6%) (Table 5, Figure 6). In the mainland region, the area above the threshold was primarily in the central region and in the bays and harbors. At the islands, the area above the threshold for mammals was primarily the southeast Channel Islands subpopulation. For human-influence subpopulations, the percent of area above threshold was highest in the ports (67%), large POTWs (44%), and "other bays" (42%).

Bird PCB/TEQs

The same nine potentially toxic PCB congeners found in mammals (above) had TEFs assigned to their concentrations. However, the TEFs for birds were different from those of mammals (Table 3). Of the 225 samples collected, 26% had detectable levels of the PCB congeners that are toxic to birds (Table 9). The PCBbTEQ concentrations toxic to birds

Table 7. Summary of tPCB (µg/kg) concentrations in sanddab-guild composites by subpopulation on the southern California shelf.

Subpopulation	No. of Stations	% Det.	Range Min.	Range Max.	Area-Weighted Values Median	Area-Weighted Values Mean	Area-Weighted Values 95% CI
Region							
Mainland	170	43	0.0	710.3	0.0	15.1	6.9
Northern	42	21	0.0	19.4	0.0	1.8	1.9
Central	71	76	0.0	710.3	7.1	37.2	16.5
Southern	57	18	0.0	323.0	0.0	3.0	2.4
Island	55	49	0.0	69.8	0.0	3.3	3.2
Cool (NW Channel Islands)	14	36	0.0	9.3	0.0	0.6	0.8
Warm	41	54	0.0	69.8	3.0	8.2	8.2
SE Channel Islands	15	67	0.0	69.8	3.4	10.3	11.5
Santa Catalina Island	26	46	0.0	27.7	0.0	3.1	2.3
Shelf Zone							
Bays and Harbors (2-30 m)	18	78	0.0	323.0	19.9	86.7	50.4
Ports	3	100	62.8	254.0	155.6	188.4	100.5
Marinas	9	67	0.0	103.3	8.8	25.4	21.2
Other Bay	6	83	0.0	323.0	12.1	114.2	107.3
Inner Shelf (2-30 m)	46	26	0.0	36.6	0.0	3.4	3.7
Small POTWs	9	11	0.0	13.8	0.0	1.4	2.7
River Mouths	8	50	0.0	18.4	0.0	4.4	4.4
Other Mainland	25	20	0.0	36.6	0.0	3.4	4.0
Island	4	50	0.0	9.3	0.2	2.9	3.9
Middle Shelf (31-120 m)	119	46	0.0	710.3	0.0	13.0	6.7
Small POTWs	14	0	0.0	0.0	0.0	0.0	0.0
Large POTWs	32	72	0.0	710.3	28.4	114.9	58.2
Mainland non-LPOTW	42	40	0.0	105.4	0.5	13.1	10.3
Island	31	48	0.0	69.8	0.0	3.5	4.3
Outer Shelf (121-202 m)	42	45	0.0	48.4	0.0	3.6	2.5
Mainland	22	41	0.0	48.4	0.0	5.1	4.7
Island	20	50	0.0	27.7	0.0	2.4	2.0
Total (all stations)	225	44	0.0	710.3	0.0	10.3	4.5

No. = Number; Det = detected; Min. = Minimum; Max. = Maximum; CI = Confidence interval; POTW = Publicly owned treatment work monitoring areas.

ranged from 0.0 (nondetect) to 466.7 ng/kg. The overall median concentration was 0.0 ng/kg; the overall mean concentration was 7.7 ng/kg. The majority of the samples with potential risk to birds occurred in the central mainland region middle shelf large POTW subpopulation off of Los Angeles, including Palos Verdes and near the Los Angeles County ocean outfall (Table 9, Figure 7). A few samples with levels higher than the threshold for birds were taken from the southeast Channel Islands and Santa Catalina Island. Note that samples from the bays and harbors subpopulation that had been over the threshold for mammals were not over the threshold for birds.

Overall, 5% of the sanddab guild fish in the SCB were above the bird predator-risk guideline of 0.79 ng/kg TEQ (Table 5). By region, 3% of the fish of this guild on the mainland and 6% at the islands were above this guideline. The largest percentages of fish with PCBbTEQ levels over the threshold were from the central mainland region middle shelf large POTW subpopulation (34%) and in the inner shelf river mouth subpopulation (22%) (Table 5).

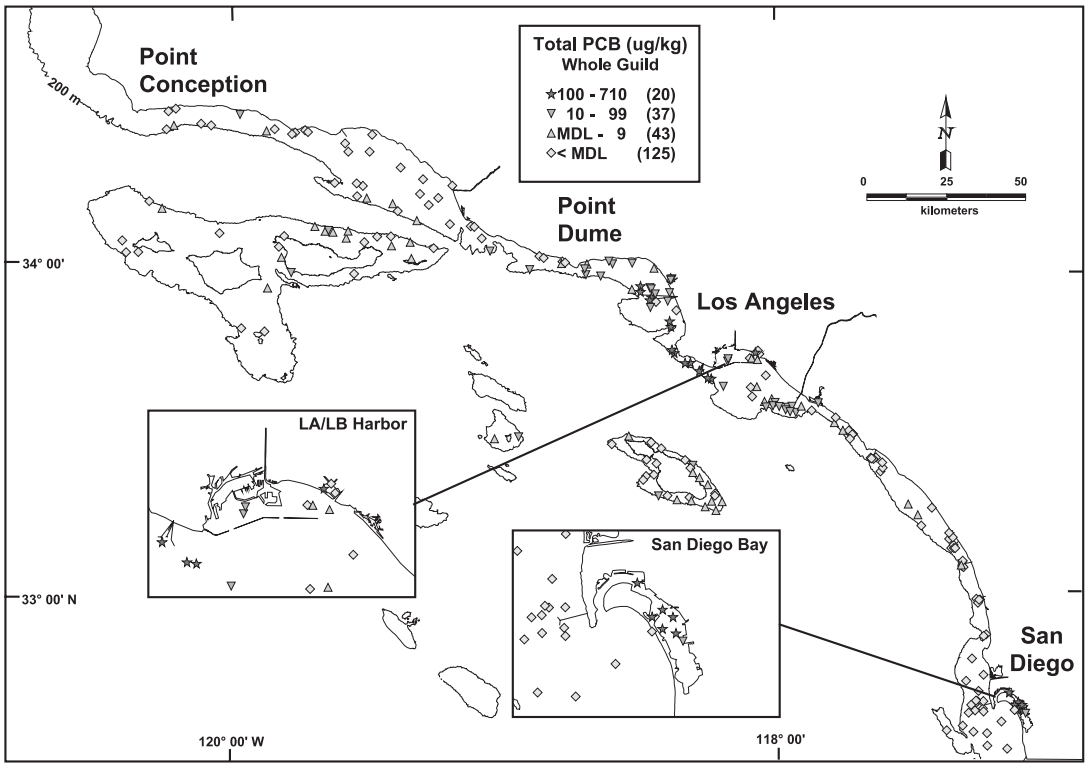


Figure 4. Distribution of tPCB concentrations in sanddab-guild fishes.

Similarly, 5% of the southern California shelf had fish with PCBbTEQ levels above the bird predator-risk guideline of 0.79 ng/kg TEQ (Table 5). By region, 3% of the area was above the threshold for the mainland region and 10% for the island region. In the mainland region, the area above the threshold was primarily in the central region (Table 5, Figure 8). At the islands, the area above the threshold for birds was primarily the southeast Channel Islands subpopulation. For subpopulations categorized by human influence, the percent of area above the threshold was highest in the middle shelf large POTW subpopulation (31%) and in the inner shelf river mouth subpopulation (13%).

Tissue Contamination Relative to Sediments

The relationship between contaminant concentrations in whole fish samples of the feeding guild was compared to sediment contaminant concentrations taken at the same station for both total DDT and total PCBs. A strong, positive linear relationship was evident between fish and sediment concentrations for total DDT ($r^2 = 0.63$) (Figure 9). The relationship for PCBs ($r^2 = 0.40$) was also strongly positive, but weaker than for total PCB (Figure 9). Normalizing to lipid content did not improve the relationship between the whole fish and sediment concentrations ($r^2 = 0.59$ for tDDT, $r^2 = 0.40$ for tPCB).

Discussion

Extent of Contamination of Concern

The primary objective of this study was to determine the extent of area on the southern California shelf with contaminant levels of concern because this was the unanswered question from the 1994 survey (Allen *et al*. 1998). The study focused on whole fish composites of sanddab guild species and on DDT, PCBs, and chlordane. In addition to the primary objective of this study, secondary results were to describe the general distribution of fish tissue contamination in these species by region, shelf zone, and human influence subpopulations on the southern California mainland and island shelf, and in bays and harbors. The results of this study showed that fish with DDT concentrations above the predator-risk guideline used in this study (i.e., Environment Canada 1997) occurred in 71% of the area of the southern California shelf. In contrast, the area above the PCB predator risk guideline (Environment Canada 1998) was 8% for mammals and 5% for birds. None of the fish samples had chlordane con-

Table 8. Summary of PCB mTEQ (ng/kg) concentrations in sanddab-guild composites by subpopulation on the southern California shelf. mTEQ = toxicity equivalent quotient for mammals.

Subpopulation	No. of Stations	% Det.	Range Min.	Range Max.	Area-Weighted Values Median	Area-Weighted Values Mean	Area-Weighted Values 95% CI
Region							
Mainland	170	28	0.00	30.89	0.00	0.83	1.10
Northern	42	7	0.00	0.22	0.00	0.00	0.00
Central	71	53	0.00	30.89	0.07	2.20	3.00
Southern	57	11	0.00	3.00	0.00	0.02	0.02
Island	55	22	0.00	1.80	0.00	0.10	0.09
Cool (NW Channel Islands)	14	14	0.00	0.16	0.00	0.01	0.02
Warm	41	24	0.00	1.80	0.00	0.26	0.22
SE Channel Islands	15	47	0.00	1.80	0.04	0.35	0.31
Santa Catalina Island	26	12	0.00	1.08	0.00	0.06	0.08
Shelf Zone							
Bays and Harbors (2-30 m)	18	72	0.00	3.00	0.19	1.00	0.55
Ports	3	67	0.00	2.80	1.20	1.70	1.40
Marinas	9	67	0.00	2.90	0.14	0.64	0.63
Other Bay	6	83	0.00	3.00	0.15	1.10	1.00
Inner Shelf (2-30 m)	46	13	0.00	0.74	0.00	0.03	0.03
Small POTWs	9	11	0.00	0.16	0.00	0.02	0.03
River Mouths	8	25	0.00	0.74	0.00	0.12	0.16
Other Mainland	25	8	0.00	0.37	0.00	0.03	0.04
Island	4	25	0.00	0.16	0.00	0.04	0.07
Middle Shelf (31-120 m)	119	28	0.00	30.89	0.00	0.76	1.00
Small POTWs	14	0	0.00	0.00	0.00	0.00	0.00
Large POTWs	32	50	0.00	12.70	0.00	2.20	1.40
Mainland non-LPOTW	42	21	0.00	30.90	0.00	1.30	2.00
Island	31	26	0.00	1.80	0.00	0.10	0.12
Outer Shelf (121-202 m)	42	17	0.00	0.82	0.00	0.07	0.06
Mainland	22	18	0.00	0.51	0.00	0.04	0.05
Island	20	15	0.00	0.82	0.00	0.09	0.09
Total (all stations)	225	26	0.00	30.89	0.00	0.53	0.69

* Threshold = 0.79 ng/kg, Environment Canada (1998).
No. = Number; Det = detected; Min. = Minimum; Max. = Maximum; CI = Confidence interval; POTW = Publicly owned treatment work monitoring areas.

centrations above the predator-risk guideline of 50 µg/kg (NAS 1974). Although these guidelines have identified areas of potential concern, further studies are needed to determine concentrations that cause specific levels of impact.

DDT

The distribution of DDT above the predator-risk guideline was centered around the central and southern mainland regions, southeast Channel Islands, and Santa Catalina Island (Figure 2b), with the highest levels (>1,400 µg/kg) in the large POTW area on the Palos Verdes Shelf, followed by the large POTW areas in Santa Monica Bay and San Pedro Bay, with the remaining areas above threshold (e.g., San Diego Shelf, Santa Catalina Island, southeast Channel

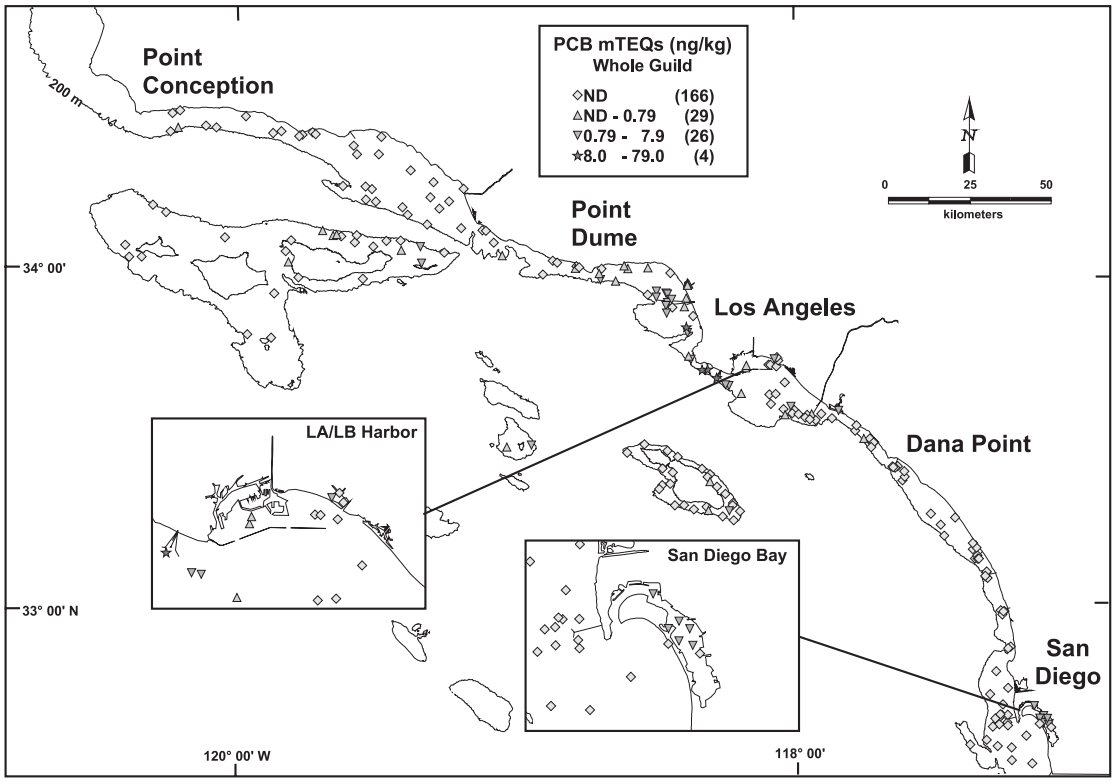


Figure 5. Distribution of PCB mTEQ concentrations in sanddab-guild fishes. mTEQ is for mammals. Predator-risk guideline = 0.79 ng/kg TEQ (Environment Canada 1998).

Islands) with levels of 15-140 μg/kg. The decreasing gradient, from the Palos Verdes Shelf sediments to the southeast Channel Islands in the north and to San Diego to the south, suggests that the source of this DDT is historical sediments on the Palos Verdes Shelf. Schiff and Gossett (1998) found a similar decrease in DDT levels extending north of the Palos Verdes Shelf in 1994. Another possible path is suggested by a series of above-guideline sites from the Santa Clara River to the southeast Channel Islands (Figure 2b). In 1998, satellite imagery of the SCB showed a sediment plume of Santa Clara River runoff extending from the mouth of that river to Anacapa Island (Burt Jones, University of Southern California, Los Angeles, CA, personal communication). It is noteworthy that the only area around Santa Cruz Island with DDT levels below the predator-risk guideline was on the western end of the island, which is sheltered from west-flowing currents from both the central mainland and the Santa Barbara Channel (Figure 2b).

Since discharge of DDT was banned in 1972, most DDT in the southern California environment is assumed to originate from widespread historically deposited sediments, particularly on the Palos Verdes Shelf and in the Santa Monica Bay area (Mearns *et al*. 1991, Schiff and Gossett 1998), and perhaps from agricultural areas upstream of some rivers. During the past three decades, DDT levels have decreased more than an order of magnitude in fish muscle tissue at highly contaminated discharge sites (Allen and Cross 1994) and in liver tissue at reference sites (Allen *et al*. 1998, Schiff and Allen 2000). It is likely that predator risk has declined, as have tissue DDT levels over the past three decades, although no earlier whole fish data exist. Food web accumulation of DDT in southern California populations of brown pelican, bald eagle, and peregrine falcon in the 1970s and 1980s is well documented (Anderson and Hickey 1970, Risebrough *et al*. 1971, Andersen and Gress 1983, MBC 1993), as well as possible DDT effects on parturition in pinnipeds at the northwest Channel Islands (Hydroqual 1994). It is not known to what degree the levels found in whole sanddab-guild samples actually pose a risk to southern California birds and mammals. Most of the sanddab guild species occur in relatively deep water and are generally cryptic (and difficult to see) or buried in the sediments. Nevertheless, as they are among the most common and abundant soft-bottom species,

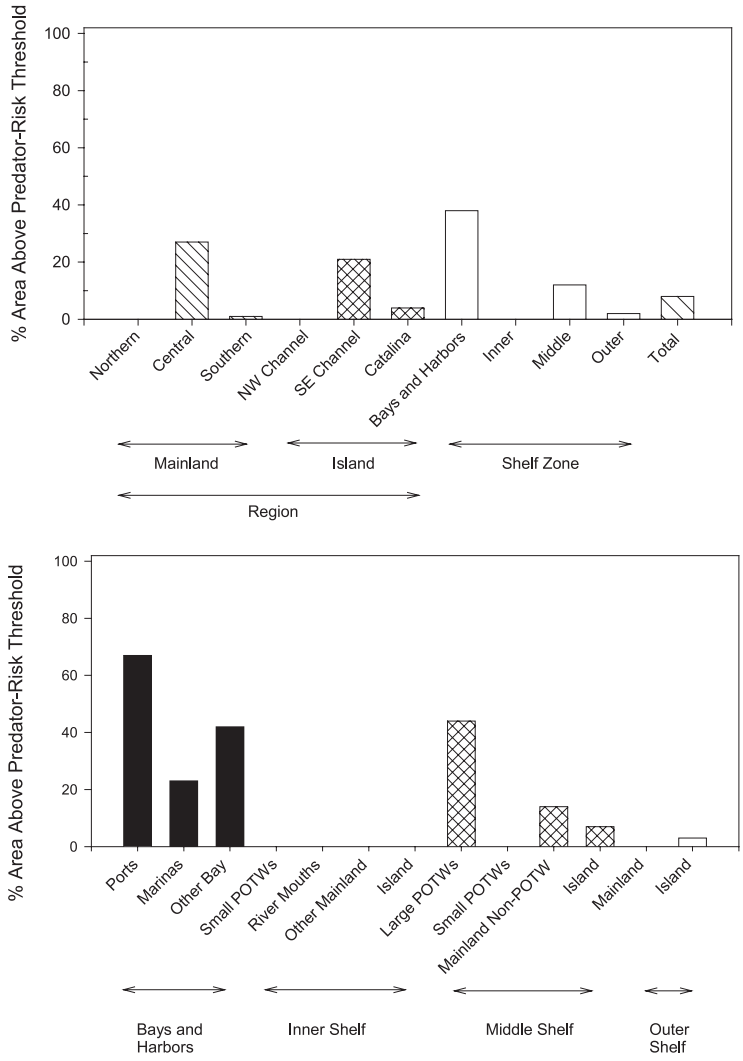


Figure 6. Percent of area with sanddab-guild composites above predator-risk guideline for PCB mTEQ (ng/kg) for mammals by subpopulation in (a) region and depth zone subpopulations and (b) subpopulations within depth zones on the southern California shelf.

they may be eaten by pinnipeds, dolphins, diving birds, sharks and rays, and are likely eaten by larger predatory fishes.

Most previous studies in southern California have focused on contaminant levels in fish liver or muscle, with levels in whole fish seldom being determined (Mearns *et al*. 1991). Allen *et al*. (2002b) found whole fish tDDT concentrations in sanddab guild species in southern California in 1997 ranging from nondetect to 18,160 µg/kg (in Pacific sanddab from the Palos Verdes Shelf). In 1998, values ranged from 0.0 - 10,462 µg/kg.

Chlordane

Chlordane was not widespread in sanddab-guild fishes in 1998, and none of the chlordane detected in sanddab-guild tissue was above the predator-risk guideline (Table 6). Although ∝-chlordane, trans-nonachlor, and heptachlor (all chlordane isomers or congeners) were examined in flatfish livers in the 1994 regional survey, none was detected (Allen *et al.* 1998, Schiff and Allen 2000). Chlordane was included in the 1998 survey because it was thought to be of potential concern to fishes living in bays and harbors. It did occur in a number of bays (e.g., Newport Bay, Alamitos Bay, Marina del Rey), as well as occasionally on islands (western Santa Cruz Island, Santa Barbara Island, and Santa Catalina Island); these

Table 9. Summary of PCB bTEQ (ng/kg) concentrations in sanddab-guild composites by subpopulation. bTEQ = toxicity equivalent quotient for birds.

Subpopulation	No. of Stations	% Det.	Range Min.	Range Max.	Area-Weighted Values Median	Mean	95% CI
Region							
Mainland	170	28	0.00	466.66	0.00	1.31	1.65
Northern	42	7	0.00	0.02	0.00	0.00	0.00
Central	71	54	0.00	466.66	0.12	3.53	4.53
Southern	57	11	0.00	0.30	0.00	0.00	0.00
Island	55	22	0.00	437.38	0.00	17.00	22.00
Cool (NW Channel Islands)	14	14	0.00	0.02	0.00	0.00	0.00
Warm	41	24	0.00	437.38	0.00	48.90	56.50
SE Channel Islands	15	47	0.00	437.38	0.00	68.30	78.40
Santa Catalina Island	26	12	0.00	74.09	0.00	2.85	5.50
Shelf Zone							
Bays and Harbors (2-30 m)	18	72	0.00	0.58	0.02	0.14	0.08
Ports	3	67	0.00	0.28	0.12	0.17	0.14
Marinas	9	67	0.00	0.58	0.01	0.15	0.13
Other Bay	6	83	0.00	0.30	0.01	0.11	0.10
Inner Shelf (2-30 m)	46	13	0.00	111.05	0.00	0.16	0.31
Small POTWs	9	11	0.00	0.02	0.00	0.00	0.00
River Mouths	8	25	0.00	111.05	0.00	13.90	25.40
Other Mainland	25	8	0.00	0.04	0.00	0.00	0.00
Island	4	25	0.00	0.02	0.00	0.00	0.00
Middle Shelf (31-120 m)	119	28	0.00	466.66	0.00	8.70	12.30
Small POTWs	14	0	0.00	0.00	0.00	0.00	0.00
Large POTWs	32	50	0.00	466.66	0.00	24.00	32.30
Mainland non-LPOTW	42	21	0.00	3.46	0.00	0.17	0.23
Island	31	26	0.00	437.38	0.00	16.60	26.90
Outer Shelf (121-202 m)	42	17	0.00	203.00	0.00	11.30	21.30
Mainland	22	18	0.00	0.05	0.00	0.00	0.00
Island	20	15	0.00	203.00	0.00	20.17	37.60
Total (all stations)	225	26	0.00	466.66	0.00	7.70	9.00

*Threshold = 0.79 ng/kg, Environment Canada (1998).
No. = Number; Det = detected; Min. = Minimum; Max. = Maximum; CI = Confidence interval;
POTW = Publicly owned treatment work monitoring areas.

areas were not surveyed in 1994. However, while chlordane was not detected in flatfish livers from the mainland shelf in 1994, it did occur there in whole sanddab-guild tissue in 1998, particularly at a number of stations on the Palos Verdes Shelf, and in Santa Monica Bay (particularly near the Hyperion Treatment Plant outfall).

Although historical records of chlordane in whole fish samples from the SCB are not available, chlordane has been measured in muscle and liver tissue (Mearns *et al*. 1991). In these tissues, chlordane was historically (1971-1985) high in Marina Del Rey, Long Beach Harbor (Seal Beach), and southern San Diego Harbor (Mearns *et al*. 1991). Chlordane in muscle and liver tissue from kelp bass (*Paralabrax clathratus*) collected on the Palos Verdes Shelf was 19 µg/kg and 386 µg/kg, respectively, in 1985 (Risebrough 1987, Mearns *et al.* 1991). Whole fish samples of sanddab-guild fishes from this area in 1998 had 14.6 µg/kg (Table 6), which is comparable to 1985 levels in kelp bass muscle tissue. Chlordane was also found in kelp bass at the southeast Channel

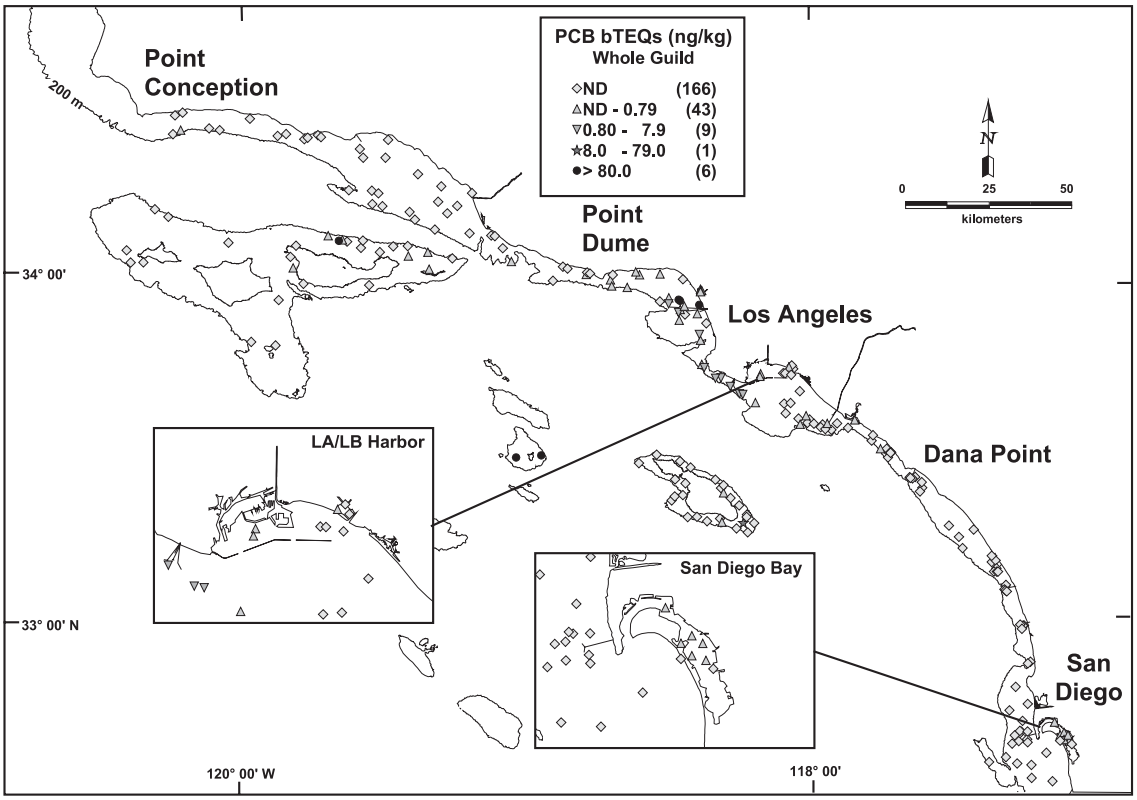


Figure 7. Distribution of PCB bTEQ concentrations in sanddab-guild fishes. bTEQ is for birds. Predator-risk guideline = 0.79 ng/kg TEQ (Environment Canada 1998).

Islands (Anacapa Island), Santa Barbara Island, and Santa Catalina Island in 1985, and was found there in sanddab-guild fishes in 1998.

PCBs

The distribution of PCB TEQs above mammal and bird guidelines showed a different pattern, with risks to mammals being highest near large POTW outfalls (particularly at Palos Verdes and in Santa Monica Bay) and in San Diego Bay (Figure 5). A similar pattern follows for tPCB in sanddab guild composites (Figure 4). Although both PCB and DDT levels in fish have typically been high on the Palos Verdes Shelf, PCB levels have historically been high in San Diego Bay whereas DDT levels have not (Mearns *et al.* 1991). In contrast to values for mammals, PCB TEQs for birds were highest at locations in Santa Monica Bay, at both sites on Santa Barbara Island, and at a site north of Santa Cruz Island (Figure 7). This pattern differs greatly from that of tPCBs in fish samples. The differences between PCB TEQs for birds and for mammals were associated with differences in bird and mammal TEFs for different PCB congeners (Table 3) and the relative concentration of these congeners.

Relationship of Tissue and Sediment Contaminant Levels

High levels of fish contamination are generally associated with high levels of sediment contamination (Smokler *et al*. 1979, Mearns *et al*. 1991, Allen and Cross 1994, Schiff and Allen 2000). In the 1994 survey (Allen *et al*. 1998), DDT and PCB levels in fish livers were highly correlated with sediment concentrations (Schiff and Allen 2000). In that study, lipid normalized DDT concentrations were highly correlated with organic carbon (OC) normalized sediment concentrations for longfin sanddab, Pacific sanddab, and Dover sole, and for lipid normalized PCBs for Pacific sanddab and longfin sanddab. Similarly in this study, whole fish composites of Pacific sanddab and longfin sanddab also were also highly correlated with sediment contamination for tDDT and tPCB. Lipid normalization did not improve the correlations. As this study focused on predator-risk assessment, wet weight whole fish samples were used rather than lipid-normalized samples because predators eat whole fish.

Most studies of fish contamination in southern California have focused on either muscle or liver tissue, with fewer measurements of whole fish concen-

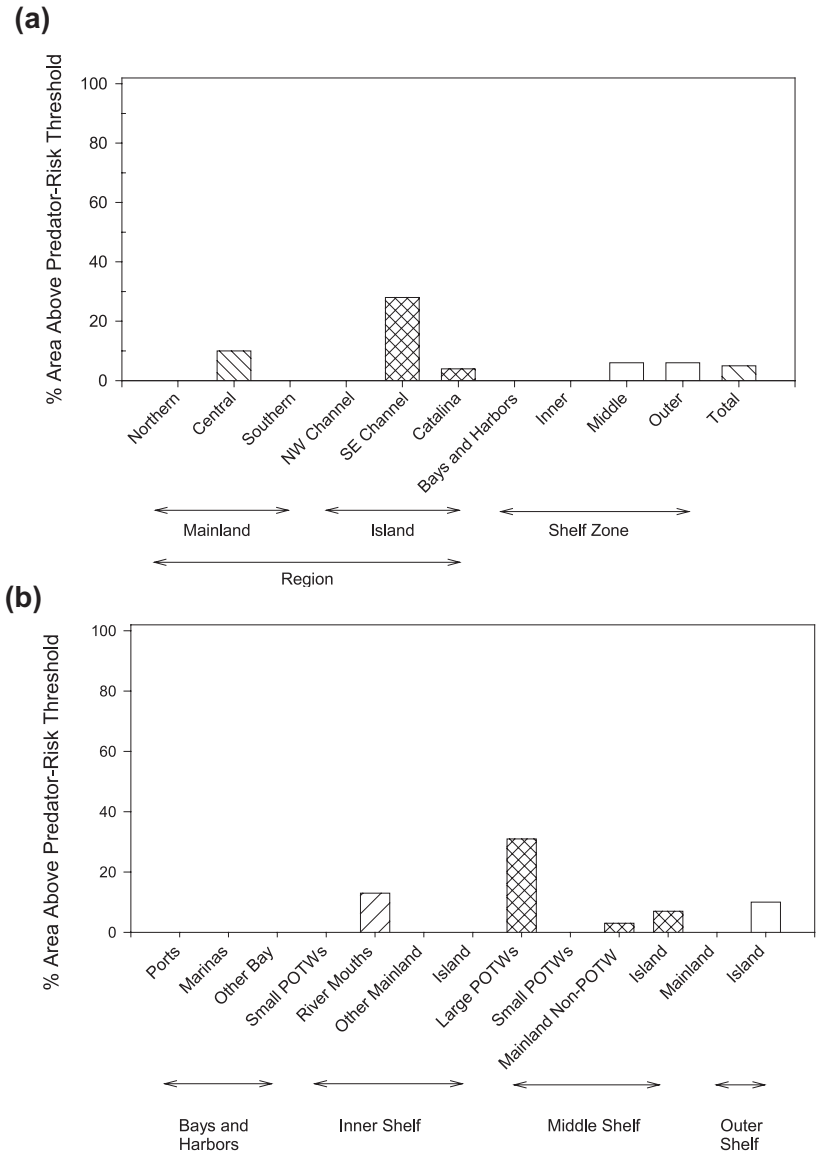


Figure 8. Percent of area above predator-risk guideline for PCB bTEQ (ng/kg) for birds by subpopulation in (a) region and depth zone subpopulations and (b) subpopulations within depth zones on the southern California shelf.

trations have been (Mearns *et al*. 1991). The historical use of three different tissues has made comparison with previous samples difficult. However, some relationships are known. For sanddabs, liver concentrations of tDDT in longfin sanddabs were 100 times higher than in muscle tissue of the same fish (Groce 2002). Studies are currently underway to better define relative concentrations of contaminants in whole fish, muscle, and liver. When these become available, a reevaluation of historical samples may provide estimates of the extent of fish contamination above predator-risk guidelines in the past. In addition, the relationship of whole fish tissue concentrations to sediment concentrations of total DDT (Figure 9) raises the possibility that a threshold sediment concentration might be defined, above which sanddab-guild species are likely to have DDT concentrations of potential risk to marine predators.

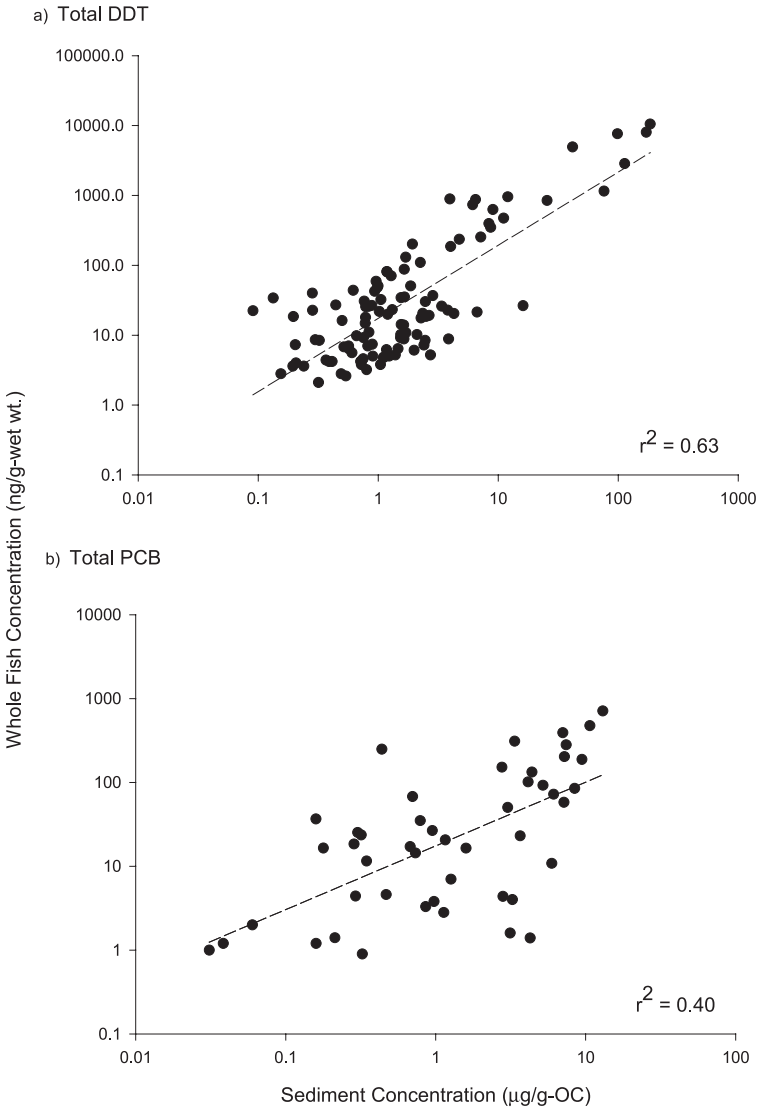


Figure 9. Relationships between (a) total DDT and (b) total PCB concentrations in whole fish composites of sanddab-guild species and in sediments. Dashed lines are best fit to the data from linear regression.

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