Chlorinated Hydrocarbon Levels in Fishes and Shellfishes of the Northeastern Pacific Ocean, Including the Hawaiian Islands

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*ABSTRACT—We analyzed 39 species of fishes, 6 species of shellfishes, a sea cucumber (*Parastichopus californicus*), and an euphausid, from marine waters off California, Oregon, Washington, British Columbia, Alaska, and Hawaii for ΣDDT (1,1,1-trichloro-2,2-bis(*p*-chlorophenyl)ethane, DDT, and its metabolites 1,1-dichloro-2,2-bis(*p*-chlorophenyl)ethylene, DDE, and 1,1-dichloro-2,2-bis(*p*-chlorophenyl)ethane, TDE) and PCB (polychlorinated biphenyls). We also analyzed a few samples of fish eggs, liver, oil, and meal. Finfishes from the northeastern Pacific Ocean rarely contained chlorinated hydrocarbons in excess of 1 ppm; shellfishes never exceeded 0.5 ppm. Often samples did not contain quantifiable amounts of TDE, DDT, or PCB. Chlorinated hydrocarbon levels increased gradually going southward from Alaska to southern California, but the highest levels were associated with point sources of pollution, such as ΣDDT around the Los Angeles County sewer outfalls and PCB from the Duwamish River in the Elliott Bay section of the Seattle, Wash., harbor. The southward geographical gradient was especially steep in sablefish, *Anoplopoma fimbria*, *which contained noticeably higher levels of ΣDDT than other species of fishes collected in the same area. Except for sablefish, ΣDDT levels in edible tissue exceeded the U.S. Food and Drug Administration (FDA) guideline of 5 ppm only in certain fishes taken in the vicinity of Los Angeles. Only in goatfish,* Mulloidichthys auriflamma, *from Hawaii did the mean level of PCB exceed the proposed FDA guideline of 2 ppm, but not the current one, 5 ppm. In a few cases length, weight, age, or lipid correlated with chlorinated hydrocarbon content, but frequently contaminant levels had no relationship to physical measurements. In contrast, correlations were often significant between chlorinated hydrocarbons, such as DDE and ΣDDT or ΣDDT and PCB (*$P = 0.05$*).*

Introduction

Reports of excessive amounts of chlorinated hydrocarbons in fishery products have threatened the utilization by humans of the vast protein resources in the sea. Chlorinated hydrocarbons from both agricultural and industrial chemicals have been found repeatedly in marine organisms throughout the world (Risebrough et al., 1968, 1976; Bowes and Jonkel, 1975). Insecticides, such as DDT[1] and dieldrin, were the subject of earlier reports on estuarine and marine animals from the northeastern Pacific Ocean (Modin, 1969; Earnest and Benville, 1971; Duke and Wilson, 1971). Levels of ΣDDT exceeding the U.S. Food and Drug Administration action level (5 ppm) were found in fish from central California (Shaw, 1972).

Although the obvious source of pollution would have been agricultural runoff, the principal source was industrial waste disposal. In March 1970, Montrose Chemical Corporation[2] was dumping 290 kg/day of ΣDDT into the Los Angeles (Calif.) County sewer system (Burnett, 1971). As a point of comparison, the San Francisco Bay Delta system, which drains the vast agricultural regions of the Sacramento and San Joaquin River valleys, in 1965 released 8 kg/day ΣDDT into the Pacific Ocean.[3] In the same period before DDT usage declined, the Mississippi River, which receives the run-off from 40 percent of the land mass of the conterminous United States, introduced less than 25 kg/day ΣDDT into the Gulf of Mexico (Butler, 1969). The effluent from the Montrose plant by 1971 had produced a 300 t reservoir of ΣDDT, which extended over an area of 911 nmi^2 surrounding the Los Angeles County sewer outfalls at Whites Point (MacGregor, 1976). After dumping stopped in March 1970, levels of ΣDDT in the marine environment off southern California decreased in areas more removed from the Whites Point sewer outfalls (Anderson et al., 1975), but did not disappear entirely (Anderson et al., 1977). In the vicinity of the outfalls, however, ΣDDT levels in Dover sole did not change in the interval between 1971-72 and 1974-75 (Young et al., 1977; McDermott-Ehrlich et al., 1978).

More recently, a second type of chlorinated hydrocarbon, PCB, surfaced as a contaminant in the aquatic environment. PCB's are industrial chemicals formerly used in electrical equipment, protective coatings, and carbonless carbon paper. Although mainly a problem in freshwater fisher-

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[1] Abbreviations used in this manuscript: DDE = 1,1-dichloro-2,2-bis(*p*-chlorophenyl)ethylene; DDT = 1,1,1-trichloro-2,2-bis(*p*-chlorophenyl) ethane; PCB = polychlorinated biphenyls; ΣDDT = DDT and its metabolites DDE and TDE; TDE = 1,1-dichloro-2,2-bis(*p*-chlorophenyl)ethane.

[2] Mention of trade names, products, or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

[3] Southern California Coastal Water Research Project. 1973. Chlorinated hydrocarbons in intertidal organisms of the bight. *In* The ecology of the Southern California Bight: Implications for water quality management, section 8.5.2, p. 307-309. Southern California Coastal Water Research Project, El Segundo, CA 90245.

ies, PCB's are also a concern in species such as striped bass in the eastern United States, Dover sole from around Los Angeles (McDermott-Ehrlich et al., 1978), fishes from areas of unusual PCB pollution, such as the Duwamish River in Seattle, Wash.,[4] juvenile estuarine fishes (Butler and Schutzmann, 1978), and fish livers.[5]

Most previously published data dealing with chlorinated hydrocarbons in marine life of the northeastern Pacific have come from southern California, an area unrepresentative of the northeastern Pacific Ocean as a whole. Not only were the amounts of contaminants entering that environment unusually large, but the means of removing them were unusually small. Because of the very low rainfall, the sewers in the area represent the major "rivers." The sewer effluent provides only a limited source of water for dilution and silt for burial. Under more favorable circumstances, dispersion of both PCB and ΣDDT does occur. In spite of the intensive agricultural activity of the Sacramento and San Joaquin valleys, marine organisms from around San Francisco Bay contained much lower ΣDDT levels than those from the Los Angeles area (Modin, 1969), apparently because of tidal flushing and the continuous deposition of silt. Farther north along the coast, marine animals in the Strait of Georgia contained much lower levels of chlorinated hydrocarbons than those caught near the urban environment of Vancouver, British Columbia (Albright et al., 1975). Fishes and shellfishes from marine waters of Oregon, Washington, and British Columbia contained very low levels of ΣDDT (Stout, 1968).

Although the data in the literature included mainly atypical samples, the safety of marine fishery products to consumers was questioned. Information about typical commercial and sport fisheries was unavailable. Data on chlorinated hydrocarbons in the edible tissues of marine animals of the northeastern Pacific Ocean were needed. To provide that information, we have determined the concentration of ΣDDT and PCB in 45 species of fishes and shellfishes of both sport and commercial importance from marine waters of California, Oregon, Washington, British Columbia, Alaska, and Hawaii. We have included samples of the same species from several geographical areas and from highly polluted as well as relatively clean sites. In most cases, the edible portion (flesh) was analyzed and in a few cases eggs, liver, meal, and oil, in order to expand our information about these fishery products.

Table 1.—Marine animals analyzed for chlorinated hydrocarbons, northeastern Pacific Ocean.

Common name	Scientific name
Finfish	
Albacore	*Thunnus alalunga*
Anchovy, northern	*Engraulis mordax*
Bass, striped	*Morone saxatilis*
Bocaccio	*Sebastes paucispinis*
Bonito, Pacific	*Sarda chiliensis*
Cod, Pacific	*Gadus macrocephalus*
Croaker, white	*Genyonemus lineatus*
Goatfish	*Mulloidichthys auriflamma*
Halibut, Pacific	*Hippoglossus stenolepis*
Herring, Pacific	*Clupea harengus pallasi*
Lingcod	*Ophiodon elongatus*
Mackerel, jack	*Trachurus symmetricus*
Marlin, blue	*Makaira nigricans*
Moano	*Parupeneus multifasciatus*
Rockfish, blue	*Sebastes mystinus*
Rockfish, rosy	*Sebastes rosaceus*
Rockfish, species unknown	*Sebastes* spp.
Rockfish, starry	*Sebastes constellatus*
Rockfish, vermilion	*Sebastes miniatus*
Sablefish	*Anoplopoma fimbria*
Salmon, chinook	*Oncorhynchus tshawytscha*
Salmon, chum	*Oncorhynchus keta*
Salmon, coho	*Oncorhynchus kisutch*
Salmon, pink	*Oncorhynchus gorbuscha*
Salmon, sockeye	*Oncorhynchus nerka*
Sardine, Pacific	*Sardinops sagax*
Saury, Pacific	*Cololabis saira*
Scad, bigeye	*Selar crumenophthalmus*
Scad, mackerel	*Decapterus pinnulatus*
Scorpionfish, California	*Scorpaena guttata*
Sole, Dover	*Microstomus pacificus*
Sole, English	*Parophrys vetulus*
Sole, rex	*Glyptocephalus zachirus*
Sole, sand	*Psettichthys melanostictus*
Treefish	*Sebastes serriceps*
Tuna, bigeye	*Thunnus obesus*
Tuna, yellowfin	*Thunnus albacares*
Wahoo	*Acanthocybium solanderi*
Whiting, Pacific[1]	*Merluccius productus*
Shellfish, Plankton, and Sea Cucumber	
Euphausid (plankton)	Euphausiacea
Mussel	*Mytilus edulis*
Oyster, Pacific	*Crassostrea gigas*
Sea cucumber	*Parastichopus californicus*
Shrimp, Alaska pink	*Pandalus borealis*
Shrimp, Oregon pink	*Pandalus jordani*
Shrimp, spot	*Pandalus platyceros*
Squid	*Loligo opalescens*

[1] Formerly known as Pacific hake.

Methods

Marine animals (Table 1) were obtained from a variety of sources including research vessels, commercial fishermen, and fish processors. To prevent contamination, specimens were immediately wrapped in new aluminum foil. Unless they could be processed within a day of receipt, specimens were frozen immediately and held at −18°C. Unless specified, samples consisted of the edible portion of the animal: Whole, skinless fillets of fish; drained, shucked oysters and mussels; peeled shrimp (tail meat); and whole squid including beak. Only small portions of halibut, salmon, and tuna were supplied in some cases: A steak, flesh from the nape of the neck, a portion of the light flesh. When available, whole salmon steaks were analyzed (i.e., flesh with skin, fat, and bones) because the skin and fat are often consumed. The choice of species and sites sometimes depended on the availability of specimens from other projects rather than the specific design of this study. Samples of fish liver, eggs, meal, and oil, as well as all shellfish, were analyzed as composites. Many of the samples of edible tissue of finfish were also analyzed as composites of equal-weight portions of ground flesh of individual fish. Shrimp were cooked in order to expedite removal from the shell; all other samples were raw. The tissues were ground and mixed thoroughly to obtain homogeneous samples, which were stored in aluminum or glass containers at −18°C until analysis.

Chlorinated hydrocarbon analysis was evolving during the course of these analyses. For a few of the earlier samples, the AOAC method for determination of chlorinated pesticides in nonfatty foods (Horowitz, 1970) was used; the sample size was adjusted to limit the oil content to 2 g, and water was added to make a total water volume

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[4] Stout, V. F., and L. G. Lewis. 1977. Appendix B: Role of disposal of PCB-contaminated sediment in the accumulation of PCB's by marine animals. Aquatic disposal field investigations, Duwamish Waterway disposal site, Puget Sound, Wash. Environmental Effects Laboratory, U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Miss.

[5] P. A. Butler. EPA-NOAA Fish Monitoring Program: Pacific Coast, Gulf Breeze, Fla., private commun. March 1975

of 80 ml. In most cases, however, extracts were prepared by the procedure of Reinert (1970), because it gave cleaner extracts of marine fishery samples (Stout and Beezhold, 1979). Samples were extracted with propanol-2/benzene (1:1), and the extracted materials transferred to hexane by repeated codistillation of the propanol-2, benzene, and water with hexane. One aliquot of the hexane extract was evaporated to minimum weight for determination of the lipid content. Another aliquot was cleaned up on Florisil. PCB's were separated from TDE, DDT, and most of the DDE on activated silica gel (Snyder and Reinert, 1971), which also separates the interfering hydrocarbons, phenanthrene, fluoranthrene, and pyrene from the PCB (Zitko, 1978). At least 90 percent of the PCB was contained in the pentane fraction, which also contained part of the DDE. The rest of the DDE and all of the TDE and DDT were eluted in the benzene fraction. DDE was quantified by summing the amount in both fractions. In earlier samples, PCB's were not separated from DDT and its metabolites. The details of our procedures were published previously (Stout and Beezhold, 1979). Blanks carried through the whole procedures showed no chromatographic peaks which interfered with quantitation of the chlorinated hydrocarbons.

Extracts were quantitated by electron-capture gas chromatography. A Varian 600 C gas chromatograph with a titanium tritide detector was fitted with a 1.5 m (5 foot) × 0.32 cm (0.125 inch) outside diameter glass column containing a mixture of equal parts of 15 percent QF-1 on 800-100 mesh Gas-Chrom Q and 10 percent DC-200 on the same support (Burke and Holswade, 1966). Reference standards of *p,p'*-DDE, *p,p'*-TDE, and *p,p'*-DDT were obtained from the U.S. Environmental Protection Agency, Health Effects Research Laboratory, Research Triangle Park, N.C. They were at least 99 percent pure. Aroclor 1254 obtained from the Monsanto Company, St. Louis, Mo., was the standard for the PCB, because the residues in the fish matched this Aroclor most closely. Standard curves of peak height versus concentration were used to determine the concentrations of components in the extracts. The sensitivity throughout each run was assured by frequent injections of standard solutions.

In most samples, the PCB's were quantitated by summing the peak heights corresponding to the five major peaks in Aroclor 1254 after omitting the peak with a retention time similar to that of *p,p'*-DDE (Stout, 1980). The PCB in a few samples were quantified by including the contribution of four additional peaks following the major peaks of Aroclor 1254. In those cases, standard curves also included the sum of the heights of those peaks. This method was used for samples in a study of the accumulation of PCB from dumped dredge spoils (footnote 4) to compensate for the presence of PCB similar to Aroclor 1260. This simplified method accounted for approximately 90 percent of the PCB indicated by a mixed standard of Aroclors 1254 and 1260. The presence of the more highly chlorinated PCB is indicated in the tables and text. The ΣDDT content of these samples was quite low; to improve the accuracy of PCB analysis, DDT/PCB separation was omitted. Consequently, only the major component, DDE, was quantified. The very small amounts of TDE and DDT were obscured by PCB peaks and were not measurable. In every sample, a correction to the DDE concentration in the pentane fraction was made to compensate for the component of PCB which overlapped with the DDE peak. The correction was based on the concentration of PCB in the same pentane fraction, as described by Stout (1980).

The quantifiable limit was 0.01 ppm for DDE, TDE, and DDT, and about 0.05 ppm for PCB depending on daily sensitivity. When the limit differed from specified, it was indicated in the tables. The mean coefficient of variation for samples analyzed in duplicate was 11 percent. The average recovery of spiked standards was 85 percent. The values reported were not corrected for recovery. Residue values were calculated on the basis of micrograms chlorinated hydrocarbon per gram wet tissue or parts per million (ppm).

Results and Discussion

Continental United States and British Columbia

Shellfishes, Plankton, and Sea Cucumbers

Mollusks have been used as indicators of chlorinated hydrocarbon pollution (Butler, 1973; Goldberg et al., 1978), because they accumulate and depurate these substances readily in response to changing concentration in the environment. Our data for shellfishes present a clear picture of the low levels of these pollutants in several coastal areas of the northeastern Pacific Ocean. In most cases, the values were below the quantifiable limit, 0.01 ppm ΣDDT and 0.05 ppm PCB. Butler (1973), in his massive study of oysters, rarely found quantifiable amounts of chlorinated hydrocarbons in the marine waters of Washington. Even in southern California where previous workers found elevated levels of ΣDDT and PCB in fishes, the levels in squid were low, 0.018 ppm ΣDDT and <0.1 ppm PCB (Table 2).

Limited dilution of pollutant-laden run-off may account for the low but measurable levels of PCB in marine animals from Puget Sound and Hood Canal. The land mass of the Olympic Peninsula restricts the full impact of oceanic tidal flushing in these inland waters. Sea cucumbers from Agate Passage, Wash., away from concentrated urban development but popular for small boats (sources of PCB contamination), contained the lowest quantifiable level of PCB, 0.05 ppm. Mussels from Manchester, Wash., contained 0.09 ppm PCB. The water in that area comes from upwellings from the depths of Puget Sound, and it is thought to be unusually free from human pollution. The mussels, however, were collected from piers which had been treated with antifouling material which may have contained PCB. Euphausids, zooplankton common in Puget Sound, contained 0.20 ppm PCB. Whole spot shrimp from Whitney Point, Wash., on Hood Canal contained 0.17 ppm PCB. That elevated level may result from the inclusion

Table 2.—Σ DDT and polychlorinated biphenyls in shellfishes, plankton, and sea cucumbers from the northeastern Pacific Ocean.

Species	Date of collection (mo/yr)	Location	No. of animals[1]	Lipid content (%)	Mean total length (cm)	Mean weight (g)	Chlorinated hydrocarbon content (ppm)				
							DDE ppm	TDE ppm	DDT ppm	Σ DDT ppm	PCB[2] ppm
Euphausids[3]	2/72	Kayak Pt., Wash.	[4]				0.009	0.007	0.014	0.030	0.20
Mussel	3/76	Mukilteo, Wash.	120	0.9	4.3	6.3	0.008	n.a.	n.a.		[5]0.12
	9/70	Manchester, Wash.	75	1.41	5.8	18.9	n.d.	n.d.	n.d.	n.d.	n.a.
	9/72	Manchester, Wash.	12		5.6	15.7	n.d.	n.d.	n.d.	n.d.	0.09
Oysters	8/75	Liberty Bay, Wash.	6		13.1	39.0	n.d.	n.d.	n.d.	n.d.	<0.11
Sea cucumbers[3]	3/76	Agate Passage, Wash.	12	0.5		342	n.d.	n.d.	n.d.	n.d.	0.05
Shrimp, Alaska pink[3]	2/76	Seattle harbor, Wash.[6]	84	1.5		6.2	n.d.	n.a.	n.a.		[5]0.39
Shrimp, Oregon pink	5/70	Westport, Wash.	50			4.9	n.d.	n.d.	n.d.	n.d.	n.a.
[3]	4-12/76	Seattle harbor, Wash.	98	1.7		4.0	n.d.	n.a.	n.a.		[5]0.43
	7/70	Astoria Canyon, Oreg.	50	1.0		5.6	n.d.	n.d.	n.d.	n.d.	n.a.
	5/70	Garibaldi Pt., Oreg.	50	1.4		4.1	n.d.	n.d.	n.d.	n.d.	n.a.
	7/70	Tillamook Head, Oreg.	50	0.7		5.7	n.d.	n.d.	n.d.	n.d.	n.a.
Shrimp, spot[3]	2/76	Whitney Point, Wash.	40	1.5		23.1	n.d.	n.a.	n.a.		[5]0.17
Squid[3]	7/72	Monterey Bay, Calif.	10	1.9	14.8	78.2	n.d.	n.d.	n.d.	n.d.	<0.1
[3]	3/71	San Pedro, Calif.	11		12.7	36.4	0.018	n.d.	n.d.	0.018	n.a.

Note: n.a. = not analyzed; n.d. = not detected.

[1] Edible tissue analyzed as a composite.

[2] Aroclor 1254 used as standard.

[3] Whole, raw.

[4] Two 10-g samples.

[5] Aroclor 1254 and 1260.

[6] Elliott Bay. The Duwamish River, known to be heavily polluted with PCB (Butler and Schutzmann, 1978), flows into Elliott Bay.

of the nonedible parts of the animal, especially the hepatopancreas, in the sample.

The highest levels of PCB were found in Elliott Bay, the main deep-water harbor area of Seattle, Wash. Alaska pink shrimp contained 0.39 ppm PCB and Oregon pink shrimp, 0.43 ppm PCB (Table 2). The Duwamish River, which flows into Elliott Bay, was known to be polluted with PCB at least as early as 1972 (Butler and Schutzmann, 1978). Sources of this pollution have not been identified, but both distributors and users of these chemicals have facilities along the river.

Fishes

General Distribution of ΣDDT and PCB. Early work focused on acquiring a broad spectrum of data, to obtain an overview of the chlorinated hydrocarbon picture in marine fishes of the northeastern Pacific Ocean. Many samples were analyzed as composites of several animals. Later on, more individual fish were tested. In all, about 40 percent of the data on fishes was derived from analyses of individual fish.

Instead of the anticipated normal distribution, the chlorinated hydrocarbon levels varied widely between individual fish in a single catch. Often one or two fish had markedly higher levels than the others. Frequently the range of concentrations of pollutants was extremely wide. The ratio of highest to lowest concentration among fish in a single sample reached 92 for ΣDDT and 24 for PCB (Fig. 1). This variability was not related just to size of fish nor simultaneous exposure to both pollutants, as illustrated by a catch of 10 striped bass from the Sacramento River at Clarksberg, Calif. (The striped bass is anadromous.) The heaviest fish, 20.5

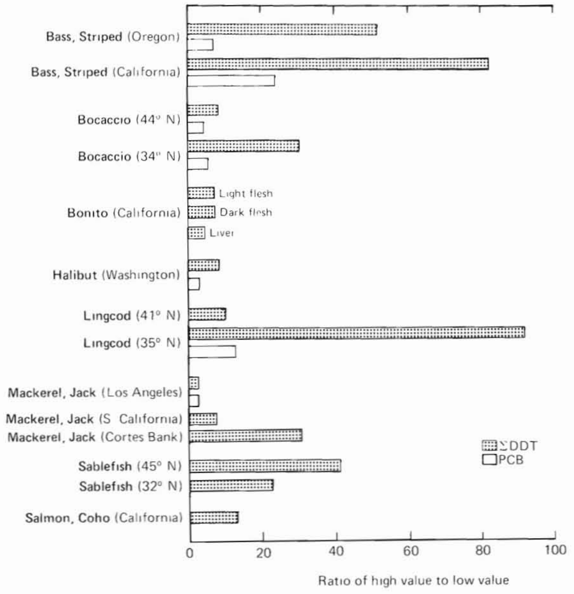

Figure 1.—Variability in chlorinated hydrocarbon level among individual northeastern Pacific fishes in a single catch: ratio of highest value to lowest value.

kg, ranked highest in both ΣDDT and PCB content. The lightest fish, 1.5 kg, ranked second highest in PCB content, but only sixth in ΣDDT content. The heaviest fish ranked seventh in lipid content, the lightest fish, fifth. The two lightest fish were males; they ranked second and third in PCB content, third and sixth in ΣDDT content, fifth and eighth in lipid content, and fifth and tenth in length. The fish with the lowest lipid content, 0.6 percent, contained the least ΣDDT and PCB, but the fish with the highest lipid content, 7.4 percent, ranked near the middle in chlorinated hydrocarbon content. The fish with the greatest amounts of ΣDDT and PCB ranked seventh in lipid content (Fig. 2).

How did the fluctuations of all these parameters rank in fishes analyzed individually? Size variations were smallest, variations in PCB and lipid content intermediate, and variations in ΣDDT content highest of all. The means of the coefficients of variation were 14.7 ± 8.5 percent for length, 41.5 ± 24.9 percent for weight, 58.7 ± 27.4 percent for PCB, 62.1 ± 33.6 percent for lipid, 95.3 ± 55.8 percent for DDE, and 104 ± 57.5 percent for ΣDDT (Table 3). The standard errors of the means of DDE, ΣDDT, and PCB are shown in Table 4.

The method for summarizing data was an important issue, because of this great variability in size, lipid, and chlorinated hydrocarbon levels among individual specimens within samples. Some authors (e.g., Butler and Schutzmann, 1978) have reported data on marine organisms in terms of percent positive samples, highest residue level, and mean of positive samples. We felt that this system emphasized positive data, because data for samples without quantifiable residues tended to be obscured. Instead we reported means which included all specimens. Geometric means or medians would have reduced the skew from high outliers and better reflected the contaminant picture in the marine environment. Arithmetic means, on the other hand, could be compared directly with the many data on composite samples, which perforce included high outliers.

Table 3.—Coefficients of variation of the physical data, ΣDDT and polychlorinated biphenyls in fish analyzed individually, northeastern Pacific Ocean.

Species[1]	Location	Lipid	Length	Weight	DDE	TDE	DDT	ΣDDT	PCB
		Coefficient of variation (%)							
Albacore	Northern Calif.	49.3	8.5	23.9	58.8	n.c.	n.c.	[2]	n.c.
	33°00′N 135°00′W	45.0	13.6	29.7	38.5	n.c.	n.c.	[2]	n.c.
Bass, striped	Umpqua River, Oreg.	58.6	23.5	75.2	86.2	86.4	82.1	86.1	65.2
	Clarksberg, Calif.	81.8	24.7	72.9	220	166	127	200	86.6
Bocaccio	44°42′N 124°24′W	53.2	6.8	20.9	65.5	82.4	75.9	67.6	62.8
	34°06′N 119°24′W	38.1	22.0	56.6	118	110	126	118	69.8
Bonito	Ventura, Calif.	37.3	3.3	7.1	87.6	85.5	85.7	86.1	n.a.
Halibut, Pacific	Kodiak, Alaska	86.5	32.6	92.6	75.0	n.c.	n.c.	[2]	53.1
	British Columbia	68.8	14.1	43.0	88.9	n.c.	n.c.	[2]	n.c.
	S. of Willapa Bay, Wash.	120	23.1	63.2	55.6	42.9	90.0	66.3	36.2
Lingcod	41°20′N 124°10′W	87.7	18.1	54.6	77.3	n.c.	n.c.	[2]	n.c.
	35°35′N 121°16′W	148	16.9	53.3	219	177	247	220	105
Mackerel, jack	Near Los Angeles Harbor, Calif.	27.5	5.4	13.5	34.3	34.3	40.3	33.3	31.7
	Southern Calif.[3]	45.7	n.a.	23.3	67.9	95.0	109	74.9	n.a.
	Cortes Bank, Calif.	29.0	3.9	10.6	54.8	39.5	27.4	53.2	18.2
Sablefish[4]	45°23′N 124°45′W	n.a.	13.5	31.5	178	131	115	169	n.a.
[4]	32°26′N 117°33′W	27.6	6.1	21.4	77.8	84.7	82.0	76.2	n.a.
Salmon, coho	Point Reyes, Calif.	51.3	13.5	53.2	113	103	53.1	107	n.c.
Mean		62.1	14.7	41.5	95.3	95.2	97.0	104.4	58.7
Standard deviation		33.6	8.5	24.9	55.8	44.0	54.6	57.5	27.4

Note: n.c. = not calculable because substance not detected in most specimens; n.a. = not analyzed.

[1] For further details about date of catch, number of fish, etc., see Table 5.

[2] Only quantifiable for DDE.

[3] Catch date 1/70.

[4] Listed in Table 5.

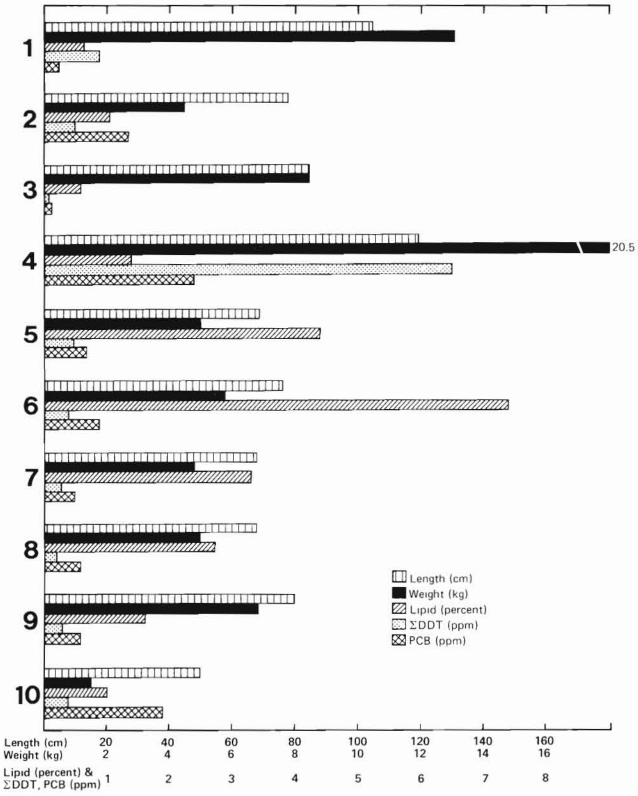

Figure 2.—Variability in length, weight, lipid, ΣDDT, and PCB among 10 striped bass collected near Clarksberg, Calif. (These anadromous fish spawn in the Sacramento River.)

Table 4.—ΣDDT and polychlorinated biphenyls in marine fishes from the northeastern Pacific Ocean.

Species	Date of collection (mo/yr)	Location	No. of animals[1]	Lipid content (%)	Mean fork length (cm)	Mean weight (g)	Chlorinated hydrocarbon content (ppm)				
							DDE(SEM)	TDE	DDT	ΣDDT(SEM)	PCB[2](SEM)
Albacore	9/70	Off Grays Harbor, Wash.	7	9.8	66	5,833	0.032	n.d.	0.020	0.052	n.a.
	8/73	Northern Calif.	[3]10	6.8	61	4,849	0.017 (0.003)	n.d.	n.d.	0.017 (0.003)	<0.05(0.003)
	6/73	33°00′N 135°00′W	[3]10	3.4	61	3,946	0.013 (0.002)	n.d.	n.d.	0.013 (0.002)	<0.05(0.002)
Anchovy, northern	7/69	Camano Island, Wash.	[4]19		13	15	0.018	0.020	0.012	0.050	n.a.
	9/72	San Pedro Harbor, Calif.	[4]25	11.4	12	15	1.64	0.456	0.074	2.18	0.83
Bass, striped	6/73	Umpqua River, Oreg.	[3]10	2.6	84	9,645	0.058 (0.016)	0.022	0.028	0.108 (0.029)	0.19(0.039)
	6/73	Clarksberg, Calif.	[3]10	2.8	80	7,517	0.742 (0.515)	0.206	0.093	1.04 (0.658)	0.99(0.270)
Bocaccio	6/75	44°42′N 124°24′W	[3]10	1.9	73	4,772	0.139 (0.029)	0.017	0.029	0.185 (0.040)	0.14(0.029)
	4/74	34°06′N 119°24′W	[3]10	1.2	50	1,519	0.735 (0.274)	0.020	0.042	0.797 (0.298)	0.16(0.035)
	5/70	Santa Monica Bay, Calif.	[5]9	1.4	31	282	9.38	1.02	1.24	11.6	n.a.
	9/70	Santa Monica Bay, Calif.	[5]4	3.8	33	249	6.38	0.76	0.84	7.97	n.a.
	9/70	Santa Monica Bay, Calif.	[5]3	3.0	44	643	25.2	1.61	2.12	28.9	n.a.
Bonito, Pacific	3/71	Ventura, Calif.	[3]10	8.0	60	3,030	6.19 (1.71)	1.01	0.889	8.08 (2.20)	n.a.
Cod, Pacific	9/70	Vancouver Island, B.C.	10	0.5	49	1,349	n.d.	n.d.	n.d.	n.d.	n.a.
Croaker, white	5/70	Oceanside, Calif.	16	0.7	23	161	0.583	<0.04	0.058	0.641	n.a.
Halibut, Pacific	7/71	Kodiak, Alaska	[3]10	2.8	132	42,350	0.008 (0.002)	n.d.	n.d.	0.008 (0.002)	0.05(0.008)
	8/71	British Columbia	[3]10	3.1	101	13,870	0.018 (0.005)	n.d.	n.d.	0.018 (0.005)	<0.08(0.005)
	4/72	S. of Willapa Bay, Wash.	[3]10	4.0	117	24,730	0.072 (0.013)	0.007	0.010	0.089 (0.019)	0.09(0.011)
Herring, Pacific	12/68	Bellingham, Wash.	[4]50				0.043	0.012	0.041	0.097	n.a.
Lingcod	7/73	41°20′N 124°10′W	[3]10	1.2	78	5,821	0.088 (0.022)	n.d.	n.d.	0.088 (0.022)	<0.06(0.004)
	4/74	35°35′N 121°16′W	[3]10	0.9	69	3,741	0.886 (0.613)	0.044	0.073	0.999 (0.696)	0.20(0.068)
Mackerel, jack	10/69	Long Beach, Calif.	[5]13		29	224	2.34	0.62	0.24	3.21	n.a.
	7/73	Near Los Angeles Harbor, Calif.	[3,5]10	9.9	31	374	2.57 (0.279)	0.394	0.159	3.12 (0.329)	0.92(0.092)
	12/69	Southern Calif.	[5]52			106	0.364	0.049	0.097	0.510	n.a.
	1/70	Southern Calif.	[3,5]25	2.9		248	4.46 (0.606)	0.624	0.618	5.70 (0.854)	n.a.
	6/73	Cortes Bank, Calif.	[3,5]10	4.7	24	163	0.062 (0.011)	0.008	0.007	0.077 (0.013)	<0.08(0.004)
Rockfish, blue	5/70	Farnsworth Bank, Calif.	5	1.8	22	170	0.440	<0.02	0.055	0.495	n.a.
Rockfish, rosy	5/70	Farnsworth Bank, Calif	6	0.7	16	87	0.283	<0.05	<0.05	0.283	n.a.
Rockfish, unknown	1/70	Cortes Bank, Calif.	10	0.9	24	245	0.123	<0.02	<0.02	0.123	n.a.
Rockfish, starry	5/70	Santa Monica Bay, Calif.	5	1.8	25	294	50.5	3.14	3.64	57.2	n.a.
	9/70	Santa Monica Bay, Calif.	2	2.1	22	148	67.4	3.26	5.58	76.3	n.a.
	5/70	Farnsworth Bank, Calif.	13	0.9	19	104	0.283	<0.04	<0.04	0.283	n.a.
Rockfish, vermilion	5/70	Santa Monica Bay, Calif.	10	2.2	31	533	14.9	[6]	1.12	16.0	n.a.
	9/70	Santa Monica Bay, Calif.	2	3.5	24	297	39.6	3.20	3.68	46.5	n.a.
	9/70	Santa Monica Bay, Calif.	1	4.2	34	621	59.5	4.85	4.72	69.1	n.a.
Sablefish[7]											
Salmon, chinook	7/70	Manchester, Wash.[8]	[5]25	3.4	11	16	0.075	0.007	0.037	0.118	n.a.
	9/70	Manchester, Wash.[8]	[5]25	2.4	13	34	0.078	<0.015	0.037	0.115	n.a.
	9/74	Westport, Wash.	[9]1				0.075	<0.02	<0.02	0.075	0.24
	5/73	Columbia River, Oreg.	[3]2	11.8	74	10,669	0.189	0.047	0.033	0.270	0.26
	8/69	Jones Beach, Oreg.	[5]25		[10]	[10]	0.054	0.038	0.043	0.134	n.a.
	8/74	Pt. Reyes, Calif.	[3]2	6.8	67	4,953	0.069	0.013	0.009	0.091	0.09
Salmon, chum	6/73	Puget Sound, Wash.	[3]2	7.4	56	2,156	0.006	n.d.	n.d.	0.006	<0.04
Salmon, coho	7/70	Manchester, Wash.[8]	[5]1	8.2	43	1,150	0.090	0.015	0.040	0.144	n.a.
	9/70	Manchester, Wash.[8]	[5]15	2.9	23		0.060	n.d.	0.038	0.098	n.a.
	11/75	Auburn, Wash.	[9]10	3.1	60	2,565	0.023	0.006	0.005	0.034	0.24
	5/73	Columbia River, Oreg.	[3]2	6.1	54	3,100	0.027	n.d.	n.d.	0.027	<0.06
	8/74	Pt. Reyes, Calif.	[3]5	5.4	61	4,067	0.046 (0.023)	0.009	0.006	0.061 (0.030)	<0.09(0.018)
Salmon, pink	6/73	Puget Sound, Wash.	[3]2	9.6	55	2,270	0.009	n.d.	n.d.	0.009	<0.05
Salmon, sockeye	8/70	Seattle, Wash.[11]	[9]9	9.5			0.015	0.010	0.015	0.039	n.a.
	6/73	Puget Sound, Wash.	[3]2	9.4	56	2,384	0.007	n.d.	n.d.	0.007	<0.04
Saury, Pacific	8/70	Off Grays Harbor, Wash.	[5]75	6.3	50		0.020	0.004	0.006	0.030	n.a.
	67	La Jolla, Calif.	[4]30				n.d.	n.d.	n.d.	n.d.	n.a.
Scorpionfish, California	7/70	Farnsworth Bank, Calif.	10	0.9		378	0.258	<0.015	<0.015	0.258	n.a.
Sole, Dover	7/70	Astoria Canyon, Oreg.	10	0.5	42	688	n.d.	n.d.	n.d.	n.d.	n.a.
	9/70	Astoria, Oreg.	10	0.8	32		n.d.	n.d.	n.d.	n.d.	n.a.
	5/70	Santa Monica Bay, Calif.	13	3.6	24	141	11.6	0.82	0.93	13.3	n.a.
Sole, English	76	Seattle Harbor, Wash.[12]	[4]80	4.0	26	141	0.016	n.a.	n.a.		[13]1.71
	9/70	Astoria, Oreg.	10	1.9	29		0.023	n.d.	n.d.	0.023	n.a.
	5/70	Pt. Loma, Calif.	14	0.8	22		0.653	0.051	0.077	0.781	n.a.
Sole, rex	7/70	Astoria Canyon, Oreg.	10	0.5	30	154	n.d.	n.d.	n.d.	n.d.	n.a.
	9/70	Astoria, Oreg.	10	0.6	28		n.d.	n.d.	n.d.	n.d.	n.a.
Sole, sand	7/70	Astoria, Oreg.	10	0.5	38	608	0.008	n.d.	n.d.	0.008	n.a.
Treefish	5/70	Farnsworth Bank, Calif.	7	0.9	20	146	0.229	<0.04	<0.04	0.229	n.a.
Whiting, Pacific[14]	9/70	Astoria, Oreg.	[4]10	5.2	45		0.070	0.007	0.022	0.100	n.a.

Note: n.d. = not detected; n.a. = not analyzed.
SEM = standard error of the mean (relevant to specimens analyzed individually only).

[1] Fillets analyzed as a composite, except as noted.
[2] Aroclor 1254 used as standard.
[3] Analyzed individually.
[4] Whole.
[5] Whole fish, less head, tail, and viscera.
[6] Interference.
[7] Tabulated separately in Table 5.
[8] Hatchery reared.
[9] Steak.
[10] Fingerlings.
[11] Chittenden Locks.
[12] Elliott Bay. The Duwamish River, known to be heavily polluted with PCB, flows into Elliott Bay.
[13] Aroclor 1254 and 1260.
[14] Formerly known as Pacific hake.

For this reason, arithmetic means were calculated for all parameters in fish analyzed individually.

Marine fishes from the northeastern Pacific Ocean rarely contained chlorinated hydrocarbons in excess of 1 ppm. Samples of fishes often did not contain quantifiable amounts of TDE, DDT, and PCB. A few examples will describe the general picture. Thus, halibut from Alaska, British Columbia, and Washington contained less than 0.1 ppm ΣDDT or PCB. Albacore from Washington and northern California contained similar low levels of these contaminants. No ΣDDT was found in Dover, English, rex, or sand soles from the mouth of the Columbia River. In five species of salmon from Washington, Oregon, and California, the chlorinated hydrocarbon levels were 0.007-0.270 ppm ΣDDT and <0.04-0.26 ppm PCB (Table 4).

The amounts of chlorinated hydrocarbons in marine animals generally reflect the extent to which these compounds occur in marine waters and in the air above. The levels in fishes reflect long-term exposure, since fishes lose these compounds slowly, if at all (Lieb et al., 1974). Our data for both shellfishes and finfishes indicate that in most places north of California, only limited amounts of chlorinated hydrocarbons were ever released into the marine environment of the northeastern Pacific Ocean. These findings are similar to those for the northwestern Atlantic Ocean (Sims et al., 1977; Stout, 1980).

Point Sources of ΣDDT and PCB. Within a single species, chlorinated hydrocarbon levels increased gradually going southward from Alaska to southern California and dramatically from offshore southern California to Los Angeles (Table 4). Burnett (1971) found a similar ΣDDT gradient in the mole crab, *Emerita analoga*, from sites between San Francisco and the U.S.-Mexico border. The maximum levels of chlorinated hydrocarbons were associated with the Whites Point sewer outfalls in Los Angeles County, Calif. Starry rockfish from Santa Monica Bay contained up to 76 ppm ΣDDT in the flesh. Besides living in a heavily contaminated area, rockfish live longer than most fish. The specimens examined in our study were more than 10 years old. The high ΣDDT levels in the fishes of this one specific area indicated that the reservoir of ΣDDT in the marine sediments off Los Angeles contributed much more ΣDDT to marine fishes than past agricultural and domestic applications of the insecticide DDT. Furthermore, anchovies and jack mackerel from the Los Angeles area contained nearly 1 ppm PCB in addition to high levels of ΣDDT (Table 4). The ΣDDT around the sewer outfalls apparently travels a long distance. The Southern California Coastal Water Research Project (footnote 3) reported elevated levels of ΣDDT in the coastal mussel, *Mytilus californianus*, up to 100 km away. In our study, lingcod collected about 270 km to the north at lat. 35°35′N, long. 121°16′W (near Morro Bay, Calif.) contained 1 ppm ΣDDT but substantially less PCB, 0.20 ppm.

Outside of southern California, the areas of notable chlorinated hydrocarbon concentration were the Sacramento River and the Elliott Bay area of Seattle harbor. The Sacramento River receives widespread run-off from urban development and agricultural activities in the Sacramento valley and indirectly via tidal wash, from the region drained by the San Joaquin River. Both ΣDDT and PCB were elevated, 1 ppm each, in striped bass from the Sacramento River. Elliott Bay, as is typical for marine waters of Washington (Butler, 1973), contained little ΣDDT. The maximum concentration in English sole was 0.070 ppm DDE. PCB levels, however, were distinctly elevated. The mean for 80 English sole was 1.71 ppm. Four of 16 composites, each containing 5 fish, had PCB levels above 3 ppm. These data were completely consistent with the known PCB pollution of the Duwamish River, which flows into Elliott Bay. In spite of the PCB reservoir in the Duwamish River (Butler and Schutzmann, 1978; footnote 4), coho salmon, which had migrated upstream through the area to a hatchery at Auburn, Wash., contained only 0.24 ppm PCB compared with <0.06 ppm in fish caught off the Columbia River, an area without known PCB pollution.

The Los Angeles sewer outfalls, Sacramento River, and Elliott Bay represented the exceptions in chlorinated hydrocarbon pollution of marine waters of the northeastern Pacific. All these areas attract sport fisheries, but little commercial fishing. Although localized problems may have existed in other areas, the effects of these sources on marine fishes were detectable only in a few fish.

Sablefish. Outside of the fallout area of point sources of chlorinated hydrocarbon pollution, marine fishes generally did not contain more than 1 ppm ΣDDT. A preliminary analysis of a single sablefish from northern Oregon foretold that sablefish was a unique species in the northeastern Pacific Ocean. That one fish contained 2.92 ppm ΣDDT. Subsequent analyses of 22 individual specimens and 26 composite samples of sablefish, 582 fish in all, showed that they contained unusually high levels of ΣDDT compared with all other species tested. Sablefish from the Bering Sea contained the same amount of ΣDDT, 0.01 ppm, as halibut from Kodiak Island, but five other samples from southeastern Alaska showed consistently higher levels up to a maximum of 0.22 ppm ΣDDT. The geographical ΣDDT gradient was particularly evident in sablefish. Three samples from Washington waters contained a mean of 0.66 ppm ΣDDT, and five samples from Oregon, 0.75 ppm. The highest levels in individual fish from Oregon were 13.4, 12.7, 2.92, and 1.65 ppm. Most samples from California contained more than 1 ppm ΣDDT (Table 5). From Santa Cruz southward, the mean ΣDDT level generally exceeded 5 ppm, a level found in other species only near Los Angeles. In individual sablefish from southern California, the highest concentrations were 20.2, 11.7, 11.5, and 10.1 ppm.

Alongside the steeper southward gradient in ΣDDT levels in sablefish was a similar geographic disparity in the relative contributions of DDT and

Table 5.—DDT and its metabolites in sablefish, *Anoplopoma fimbria*, from the northeastern Pacific Ocean.

Date of collection (mo/yr)	Location	No. of animals[1]	Lipid content (%)	Mean length[2] (cm)	Mean weight[2] (g)	Chlorinated hydrocarbon content (ppm)			
						DDE(SEM)	TDE	DDT	ΣDDT(SEM)
9/71	Bering Sea, Alaska	9	3.4	33	916	0.010	n.d.	n.d.	0.010
3/71	Lisianski Inlet, Alaska	8	5.0	52	1,375	0.030	n.d.	n.d.	0.030
5/72	Betton Island, Alaska	23	18.8	42	2,015	0.133	0.029	0.053	0.215
5/72	Betton Island, Alaska	12	17.6	50	3,610	0.082	0.018	0.042	0.142
3/72	Southeast Alaska	46	11.7	42	1,917	0.061	0.014	0.032	0.107
3/71	Unknown, Alaska	10	21.0	64	3,625	0.074	<0.04	0.049	0.123
3/71	48°21′N 126°01′W	23	18.0	59	2,485	0.454	0.058	0.109	0.621
6/71	48°08′N 126°13′W	21	12.7	57	2,658	0.349	0.061	0.129	0.539
3/71	S. of Willapa Harbor, Wash.	10	19.0	67	3,086	0.582	0.093	0.159	0.834
3/71	Unknown, Wash.	30	17.7	58	2,535	0.209	0.036	0.089	0.334
10/71	S.W. of Columbia River, Oreg.	60	13.5	40	1,881	0.723	0.068	0.146	0.937
5/71	46°01′N 124°44′W	22	11.6	37	1,522	0.362	0.049	0.078	0.489
5/71	46°00′N 124°48′W	8	12.5	44	2,311	0.336	0.043	0.086	0.465
4/71	46°00′N 124°45′W	1	9.4	37	1,160	2.63	<0.25	0.29	2.92
6/71	45°54′N 124°51′W	20	7.4	37	1,280	0.462	0.040	0.076	0.578
6/71	45°23′N 124°45′W	[3]10		40	1,695	2.70 (1.52)	0.150	0.269	3.11 (1.66)
6/71	45°23′N 124°30′W	29		40	1,867	0.471	0.045	0.100	0.616
10/71	Eureka, Calif.	34	12.9	56	2,335	1.50	0.13	0.23	1.86
10/71	Eureka, Calif.	2	1.6	32	1,270	0.03	n.d.	n.d.	0.03
12/71	Eureka, Calif.	30	6.2	32	849	0.211	0.020	0.026	0.257
12/71	Fort Bragg, Calif.	24	9.8	34	946	0.505	0.051	0.082	0.638
10/71	Santa Cruz, Calif.	19	15.2	40	1,756	3.08	0.39	0.61	4.08
10/71	Santa Cruz, Calif.	11	16.0	50	4,001	7.25	0.57	1.04	8.86
2/72	Pt. Sal, Calif.	10		27	455	0.194	n.d.	n.d.	0.194
5/70	Santa Monica Bay, Calif.	10	6.0	48	831	19.0	2.36	2.05	23.4
11/71	32°26′N 117°33′W	[3]12	14.2	38	1,366	5.77 (1.30)	0.45	1.28	7.50 (1.64)
11/71	32°26′N 117°33′W	25	13.6	38	1,352	7.13	0.56	1.64	9.33
12/71	32°26′N 117°31′W	30	14.3	39	1,406	5.70	0.54	1.33	7.57
4/71	32°25′N 117°22′W	34	10.7	38	1,517	4.79	0.30	0.90	5.99

Note: n.d. = not detected.
SEM = Standard error of the mean (relevant to specimens analyzed individually only).
[1] Fillets analyzed as a composite.
[2] Measured eviscerated and with head off.
[3] Analyzed individually.

Table 6.—Proportions of ΣDDT present as *p,p′*-DDE, *p,p′*-TDE, and *p,p′*-DDT and ratio of polychlorinated biphenyls to ΣDDT in finfishes by state, northeastern Pacific Ocean.

	All species except sablefish				Sablefish		
	% of ΣDDT present as			PCB (ppm)	% of ΣDDT present as		
State	DDE	TDE	DDT	ΣDDT (ppm)	DDE	TDE	DDT
Alaska	n.c.	n.c.	n.c.	n.c.	59.2	9.8	31.2
Washington	59.7	18.2	25.0	7.1	67.8	10.5	22.0
Oregon	66.3	12.0	21.3	1.26	79.3	6.5	14.0
California except Los Angeles	80.1	10.5	9.4	0.54	78.8	7.1	14.0
Los Angeles	85.7	7.4	7.6	—	81.2	10.1	8.8

Note: n.c. = not calculable because chlorinated hydrocarbon values below quantifiable level;
— = no data because PCB not analyzed.

its metabolites to ΣDDT. In the State of Washington for all species except sablefish, 59.7 percent of the ΣDDT was DDE. Nearly the same proportion of DDE (59.2 percent) was found in sablefish from Alaskan waters. The proportion of DDE increased going southward in all species with a more rapid increase in sablefish. The maximum proportion in that species, 81.2 percent, was nearly achieved as far north as Oregon, 79.3 percent (Table 6). In other species, the increase was more gradual and reached a higher level in Los Angeles, 85.7 percent, perhaps because those species lived closer to the Los Angeles County sewer outfalls. This geographic gradient masked any possible decline with time, which might have been expected, especially in southern California, after DDT dumping ceased in 1970. Similarly, no temporal trend for PCB in Elliott Bay developed in the years following restriction of PCB usage in 1971 (Pavlou and Dexter, 1979).

The reason for the distinctive pattern of ΣDDT accumulation in sablefish is not known. Although a few individuals of this species migrate vast distances, most sablefish remain within a rather limited area after migrating to deep water at the end of their juvenile stages of development[6]. The elevated ΣDDT levels may be associated with the early life in contaminated bays and inlets, the higher lipid content of this species, or both. Alternatively, the deep layers of the ocean may be more polluted than the surface. Chlorinated hydrocarbons, nearly insoluble in water and highly soluble in lipids, partition readily into organic-rich particulate matter and fatty tissues of living organisms. Air and waterborne residues of chlorinated hydrocarbons concentrate in organic material on or in the water column. How demersal sablefish, living in deep water, accumulate higher concentrations of chlorinated hydrocarbons than other fatty species, such as herring, salmon, and saury, which live higher up in the water column, is not yet understood.

Liver, Eggs, Meal, and Oil. The presence of chlorinated hydrocarbons in the edible tissue of fishes and shellfishes raised a question about the levels in other tissues and in fishery products. Chlorinated hydrocarbons are hydrophobic and lipophilic. It seemed possible that they might accumulate to a greater extent in liver, eggs, and other nonedible portions of fishes than in the edible portion. Also the levels in fishery products of this region were unknown.

Early on we examined 16 samples of fish liver in an effort to discover any relationship between the level of ΣDDT in the flesh and in the liver. No clear pattern developed. In three samples of saltwater, hatchery-reared salmon, the liver-to-flesh ΣDDT ratio

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[6] Low, L. L., G. K. Tanonaka, and H. H. Shippen. 1976. Sablefish of the northeastern Pacific Ocean and Bering Sea. Processed rep., 115 p. Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, Seattle, WA 98112.

was always below 1. Salmonids may be unique in containing less chlorinated hydrocarbon in the liver than in the flesh. Lieb et al. (1974) emphasized the same unusual finding in a PCB feeding study with rainbow trout, *Salmo gairdneri*. For wild fishes, the values ranged from 1.3 to 106. In general terms, fishes from California had lower liver-to-flesh ratios than those from Oregon and Washington. Hatchery-reared fishes had the lowest values of all, even though the tissue ΣDDT levels were distinctly lower in the hatchery-reared fishes than in wild fishes from California (Table 7).

Two samples of fish eggs were also analyzed. Coho salmon eggs from Skykomish, Wash., in 1970 contained 0.068 ppm ΣDDT and those from Auburn, Wash., in 1975, 0.018 ppm ΣDDT and 0.15 ppm PCB. The difference in ΣDDT level may reflect the decrease in ΣDDT in the environment after DDT usage in the United States was banned in 1973. Alternatively, the difference may be insignificant because ΣDDT was not separated from PCB in the earlier sample. Of interest to both biologist and consumer is the low level of PCB in the eggs and flesh of salmon from Auburn, Wash. These animals traveled through the highly polluted Duwamish River (see above) without accumulating high levels of PCB.

Since fish meal and fish oil, the industrial products of fish reduction, compose significant components of poultry rations, the concentrations of ΣDDT and PCB in these products are important factors in utilization of marine resources. Few data have been published related to fisheries in the northeastern Pacific Ocean. Thus, the limited analyses reported here provide a brief description of an aspect of fisheries seldom reported in the literature. A sample of herring meal from Puget Sound contained 0.049 ppm ΣDDT; the associated oil contained 0.577 ppm ΣDDT. These values can be compared with 0.097 ppm ΣDDT in whole herring caught nearby in Bellingham, Wash. (Table 4). The chlorinated hydrocarbon content of fish meal and oil is related to the amount of oil in each component. Thus, fish meal, which is mainly protein, contains a relatively low level of chlorinated hydrocarbons. In fact, as shown previously (Stout, 1978), when the protein fraction of fish was converted to fish protein concentrate, which is essentially free of oil, the chlorinated hydrocarbons partitioned with the oil. The fish protein concentrate contained less than 0.01 ppm ΣDDT. At a first glance, the level of chlorinated hydrocarbons in herring oil from Puget Sound seemed high (0.577 ppm ΣDDT). Fish oil, however, contains the chlorinated hydrocarbons undiluted by protein or water, so it is logical that the oil contained higher levels of these substances than either the fish from which it originated or the meal produced from the same lot of fish. The levels of chlorinated hydrocarbons in oils from salmon and anchovy correspond with the levels found in the flesh of the same species of fishes from similar geographical areas. Salmon oil from Alaska and Washington contained less than 0.2 ppm ΣDDT, but anchovy oil from California contained 10 ppm DDE (Table 8). The high level of ΣDDT found in a 1955 sample of sardine oil from southern California, 34 ppm, was consistent with the unusual reservoir of ΣDDT located off the Los Angeles County sewer outfalls.

Table 7.—ΣDDT in livers of fishes from the northeastern Pacific Ocean.

Species	Date of collection[1] (mo/yr)	Liver lipid content (%)	Chlorinated hydrocarbon content (ppm)				Liver-to-flesh ratio	
			DDE	TDE	DDT	ΣDDT	Lipid	ΣDDT
Albacore	9/70	19.9	0.046	0.101	0.034	0.182	2.0	3.5
Bocaccio[2]	9/70	26.9	46.8	7.37	5.30	59.4	7.1	7.5
[3]	9/70	25.1	168	10.0	13.2	192	8.4	6.6
Bonito	3/71	11.7	8.44	1.46	1.01	10.9	1.5	1.3
Cod, Pacific	9/70	35.7	0.299	<0.015	0.088	0.388	71	>38.8
Rockfish, starry	9/70	31.8	1,170	51.8	73.5	1,300	15.1	17.0
Rockfish, vermilion[2]	9/70	23.8	257	22.8	15.2	295	6.8	6.3
[3]	9/70	27.3	397	5.5	23.9	426	6.5	6.2
Salmon, chinook[4]	9/70	3.0	0.059	n.d.	0.027	0.086	1.2	0.75
Salmon, coho[4]	7/70	3.9	0.019	0.005	n.d.	0.024	0.5	0.17
[4]	9/70	2.9	0.021	n.d.	n.d.	0.021	1.0	0.21
Scad, bigeye	12/70	2.7	n.d.	n.d.	n.d.	n.d.	3.9	n.d.
Scad, mackerel	12/70	2.6	n.d.	n.d.	n.d.	n.d.	3.7	n.d.
Sole, Dover	7/70	9.3	0.135	[5]	0.025	0.160	18.6	>16
Sole, rex	7/70	8.3	0.106	[5]	0.020	0.126	16.6	>12.6
Sole, sand	7/70	18.4	0.517	0.102	0.232	0.851	36.8	106

Note: n.d. = not detected.

[1] All livers analyzed as composites. Location, number of fish, and size data in Tables 4 and 13.

[2] Smaller fish.

[3] Larger fish.

[4] Hatchery reared.

[5] Interference.

Table 8.—ΣDDT and polychlorinated biphenyls in eggs, meal, and oil of fishes from the northeastern Pacific Ocean.

Species	Date of collection (mo/yr)	Location	Type of sample[1]	Lipid content (%)	Chlorinated hydrocarbon content (ppm)				
					DDE	TDE	DDT	ΣDDT	PCB[2]
Anchovy, northern	6/69	California	Oil		10.1	n.a.	n.a.		n.a.
Herring, Pacific	11/68	Puget Sound, Wash.	Meal		0.025	n.d.	0.024	0.049	n.a.
	11/68	Puget Sound, Wash.	Oil		0.283	[3]	0.294	0.577	n.a.
Salmon, coho	11/70	Skykomish, Wash.[4]	Eggs	9.0	0.052	n.d.	0.016	0.068	n.a.
	11/75	Auburn, Wash.[4]	Eggs	6.2	0.016	n.d.	0.002	0.018	0.15
Salmon, sockeye	3/71	Alaska	Oil		0.091	0.064	<0.04	0.155	n.a.
	3/71	Puget Sound, Wash.	Oil		0.070	0.045	<0.03	0.115	n.a.
Salmon, unknown	11/68	Washington	Oil		0.146	<0.08	<0.10	0.146	n.a.
Sardine, Pacific	12/55	Terminal Isl., Calif.	Oil		17.5	9.03	7.44	34.0	n.a.

Note: n.a. = not analyzed; n.d. = not detected.

[1] One composite sample each.

[2] Aroclor 1254 used as standard.

[3] Interference.

[4] Sea-run fish returning to the hatchery.

Statistical Analyses

The 18 samples of 5 or more fish

analyzed individually (Table 3) provided a pool of data for studying the relationships between physical measurements and chlorinated hydrocarbon content. Because of the variability in data discussed previously, a nonparametric statistical test, Kendall's τ, was considered most appropriate. In lingcod from Oregon, correlations were found between length, weight, or age and DDE ($P = 0.05$). For striped bass from Oregon, there were correlations ($P = 0.05$) for length, weight, or age and TDE or DDT, for weight and ΣDDT, and for length or weight and PCB. In albacore from northern California, there was a relationship between length, weight, or lipid and DDE ($P = 0.05$). In bocaccio from southern California length, weight, age, or lipid correlated ($P = 0.05$) with DDE, DDT, or ΣDDT and length, weight, or lipid with PCB. In a set of 25 jack mackerel from southern California, there was a relationship between weight or lipid and DDE, TDE, DDT, or ΣDDT ($P = 0.05$). Length, age, and PCB measurements were not obtained. Kendall's τ was rarely significant for these parameters in the other sets of fish analyzed individually (Tables 9-12). Because of the large variability among individual fish, it was not surprising that correlations between physical measurements and chlorinated hydrocarbon content existed in so few cases, even though such relationships do exist in freshwater fishes (Bache et al., 1972).

Nonetheless, relationships did exist between the chlorinated hydrocarbons present in marine fish. DDT and its metabolites remained in the marine environment to the same extent without preferential loss of DDT, DDE, or TDE. In all 11 samples where TDE and DDT were quantifiable, Kendall's τ for DDE vs. ΣDDT was significant at the 0.05 level (Table 9). Furthermore, ΣDDT and PCB accumulation were also related (Table 12). Both DDE vs. PCB and ΣDDT vs. PCB were significant at the 0.05 level in five of the seven cases in which ΣDDT and PCB were quantifiable.

The frequent correlation between chlorinated hydrocarbons in marine fishes suggested that dispersion of DDT and PCB was linked in some way. PCB was, in fact, proposed as a carrier for DDT to decrease its volatility and thereby increase its persistence. Even so, there is no record that the insecticide DDT and the solvent and electrical insulator PCB were ever intentionally used in combination. Just how agricultural and domestic applications of DDT could balance with dissipation of PCB from electrical equipment and coatings to produce related concentrations of these substances in the marine environment is not clear. Only the ill-defined variable "population density" links these two chlorinated hydrocarbons, i.e., the more people the more insecticides and the more industrial chemicals used and released into the environment.

Hawaii

Eight species of fishes from the northeastern Pacific Ocean within 150

Table 9.—Kendall's τ between DDE and length, weight, age, lipid, or ΣDDT in fishes from the northeastern Pacific Ocean.

Species	Location[1]	DDE (ppm) vs. fork length	DDE (ppm) vs. weight	DDE (ppm) vs. age	DDE (ppm) vs. lipid	DDE (ppm) vs. ΣDDT (ppm)
Albacore	Northern California	0.511*	0.578*	n.	0.533*	n.
	33°N 135°W	−0.089	−0.178	n.	0.489	n.
Bass, striped	Oregon	0.378	0.422	0.400	0.422	0.911*
	California	0.400	0.178	n.	−0.200	0.956*
Bocaccio	44°N 124°W	0.200	0.111	0.089	0.689*	0.933*
	34°N 119°W	0.711*	0.689*	0.600*	0.689*	1.000*
Bonito	California	−0.222	0.200	n.	0.200	0.867*
Halibut, Pacific	Alaska	0.044	0.044	0.200	0.022	n.
	British Columbia	0.378	0.378	0.489	0.422	n.
	Washington	0.444	0.444	0.356	0.133	0.956*
Lingcod	41°N 124°W	0.622*	0.556*	0.533*	0.156	n.
	35°N 121°W	0.378	0.444	[2]0.306	0.200	1.000*
Mackerel, jack[3]	Los Angeles Harbor	−0.044	−0.2	n.	0.378	0.911*
	Southern California	n.	0.600*	n.	0.507*	0.860*
	Cortes Bank	0.111	0.267	n.	0.444	n.
Sablefish	45°N 124°W	[4]0.089	[4]0.111	n.	n.	0.911*
[5]	32°N 117°W	[4]0.167	[4]0.273	0.333	0.076	0.970*
Salmon, coho[6]	California	0.100	0.200	n.	0.800	n.

Note: Ten fish per sample; * = Kendall's τ significant at the 0.05 level; n. = no data, at least one parameter either unavailable or not quantifiable.

[1] See Table 4 for details except for sablefish, which are listed in Table 5.

[2] One fish omitted, because age not obtained.

[3] Twenty-five fish.

[4] Measured eviscerated and with head off.

[5] Twelve fish.

[6] Five fish.

Table 10.—Kendall's τ between TDE or DDT and length, weight, age, or lipid in fishes from the northeastern Pacific Ocean.

Species	Location[1]	TDE (ppm) vs. fork length	TDE (ppm) vs. weight	TDE (ppm) vs. age	TDE (ppm) vs. lipid	DDT (ppm) vs. length	DDT (ppm) vs. weight	DDT (ppm) vs. age	DDT (ppm) vs. lipid
Bass, striped	Oregon	0.533*	0.667*	0.511*	0.311	0.578*	0.533*	0.600*	0.444
	California	0.089	0.044	n.	0.022	0.333	0.111	n.	−0.044
Bocaccio	44°N 124°W	0.133	0.089	0.200	0.444	0.067	0.067	0.200	0.555*
	34°N 119°W	0.378	0.356	0.378	0.422	0.600*	0.578*	0.556*	0.600*
Bonito	Calif.	−0.178	−0.022	n.	0.511*	−0.244	−0.044	n.	0.444
Lingcod	35°N 121°W	0.356	0.422	[2]0.167	0.311	0.489	0.511*	[2]0.361	0.178
Mackerel, jack[3]	Los Angeles Harbor	0.044	−0.111	n.	0.467	0.200	−0.044	n.	−0.089
	S. Calif.	n.	0.607*	n.	0.480*	n.	0.680*	n.	0.473*
Sablefish	45°N 124°W	[4]0.200	[4]0.222	n.	n.	0.089	0.022	n.	n.
[5]	32°N 117°W	[4]0.348	[4]0.333	0.333	−0.167	0.439	0.364	0.424	−0.258

Note: Ten fish per sample; * = Kendall's τ significant at the 0.05 level; n. = no data, at least one parameter either unavailable or not quantifiable.

[1] See Table 4 for details except for sablefish, which are listed in Table 5.

[2] One fish omitted, because age not obtained.

[3] Twenty-five fish.

[4] Measured eviscerated and with head off.

[5] Twelve fish.

Table 11.—Kendall's τ between ΣDDT and length, weight, age, or lipid in fishes from the northeastern Pacific Ocean.

Species	Location[1]	ΣDDT (ppm) vs. fork length	ΣDDT (ppm) vs. weight	ΣDDT (ppm) vs. age	ΣDDT (ppm) vs. lipid
Bass, striped	Oregon	0.467	0.511*	0.444	0.333
	California	0.356	0.133	n.	−0.156
Bocaccio	44°N 124°W	0.133	0.044	0.156	0.622*
	34°N 119°W	0.711*	0.689*	0.600*	0.689*
Bonito	California	−0.267	0.156	n.	0.333
Lingcod	35°N 121°W	0.378	0.444	[2]0.306	0.200
Mackerel, jack[3]	Los Angeles Harbor	0.044	−0.111	n.	0.378
	Southern California	n.	0.660*	n.	0.487*
Sablefish	45°N 124°W	[4]0.088	[4]0.022	n.	n.
[5]	32°N 117°W	[4]0.197	[4]0.242	0.303	0.045

Note: Ten fish per sample; * = Kendall's τ significant at the 0.05 level; n. = no data, at least one parameter either unavailable or not quantifiable.

[1] See Table 4 for details except for sablefish, which are listed in Table 5.

[2] One fish omitted, because age not obtained.

[3] Twenty-five fish.

[4] Measured eviscerated and with head off.

[5] Twelve fish.

Table 12.—Kendall's τ between PCB and length, weight, age, lipid, DDE, or ΣDDT in fishes from the northeastern Pacific Ocean.

Species	Location[1]	PCB (ppm) vs. fork length	PCB (ppm) vs. weight	PCB (ppm) vs. age	PCB (ppm) vs. lipid	PCB (ppm) vs. DDE (ppm)	PCB (ppm) vs. ΣDDT (ppm)
Bass, striped	Oregon	0.511*	0.556*	0.489	0.556*	0.867*	0.778*
	California	−0.044	−0.222	n.	0.200	0.422	0.467
Bocaccio	44°N 124°W	0.089	0.	0.156	0.622*	0.800*	0.822*
	34°N 119°W	0.644*	0.622*	0.489	0.689*	0.889*	0.889*
Halibut, Pacific	Alaska	0.022	0.022	0.222	0.222	0.356	n.
	Washington	0.400	0.400	0.133	0.444	0.644*	0.622*
Lingcod	35°N 121°W	−0.067	0	[2]0.028	0.644*	0.378	0.378
Mackerel, jack	Los Angeles Harbor	−0.022	−0.089	n.	0.356	0.800*	0.711*

Note: Ten fish per sample; * = Kendall's τ significant at the 0.05 level; n. = no data, at least one parameter either unavailable or not quantifiable.

[1] See Table 4 for details except for sablefish, which are listed in Table 5.

[2] One fish omitted, because age not obtained.

Table 13.—ΣDDT and polychlorinated biphenyls in Hawaiian marine fishes.

Species	Date of collection (mo/yr)	Location	No. of animals[1]	Lipid content (%)	Mean fork length (cm)	Mean weight (g)	Chlorinated hydrocarbon content (ppm)				
							DDE	TDE	DDT	ΣDDT	PCB[2]
Goatfish	12/70	Koko Head	[3]12	7.9	23.9	283	0.107	0.089	0.089	0.285	[4]2.24
Marlin, blue	7/72	18°28′N 156°35′W	10		249	101,287	0.008	n.d.	0.006	0.014	<0.05
Moano	12/70	Mokuleia	[3]16	2.3	16.8	106	n.d.	n.d.	n.d.	n.d.	n.a.
Scad, bigeye	12/70	Pokai Bay	[3]14	0.8	20.6	129	n.d.	n.d.	n.d.	n.d.	n.a.
Scad, mackerel	12/70	Barbers Pt.	[3]14	0.7	24.7	169	n.d.	n.d.	n.d.	n.d.	n.a.
Tuna, bigeye	6/72	16°44′N 158°25′W	10	1.0	133	50,500	0.018	0.015	n.d.	0.033	<0.08
Tuna, yellowfin	6/72	20°34′N 158°18′W	10	2.6	148	68,080	n.d.	n.d.	n.d.	n.d.	1.02
Wahoo	6/72	21°05′N 159°08′W	10			16,420	n.d.	n.d.	n.d.	n.d.	0.48

Note: n.d. = not detected; n.a. = not analyzed.

[1] Fillets analyzed as a composite.

[2] Aroclor 1254 used as standard.

[3] Fillets with skin.

[4] Aroclor 1260.

km of the Hawaiian Islands were analyzed. No ΣDDT was detectable in five samples (Table 13). The highest level was associated with onshore pollution. Goatfish, collected on a reef at Koko Head, 16 km from the center of Honolulu, contained 0.285 ppm ΣDDT. Formerly, much DDT was used for insect control in urban areas. The same goatfish also contained 2.24 ppm PCB, which may have come from a nearby harbor; in the past, PCB found widespread use in marine paints and lubricants. How far PCB from this source dispersed is not known, but a composite of 10 yellowfin tuna caught nearly 100 km southwest of Honolulu, contained 1.02 ppm PCB. Since tuna range over vast areas, it was not clear whether this level reflected PCB pollution emanating from the Hawaiian Islands or from distant sites. Wahoo caught about 130 km west of Honolulu contained half as much PCB, 0.48 ppm. In bigeye tuna and blue marlin caught farther south, PCB were below the quantifiable limit.

Conclusions

Chlorinated hydrocarbon levels in the edible tissue of marine animals were generally quite low. A geographical gradient developed going southward from Alaska to southern California. It could be attributed to agriculture, industrial activity, and urbanization. Distinctly elevated levels of ΣDDT and PCB, however, were associated with point sources of contamination, such as the Los Angeles County sewer outfalls and the Duwamish River. Except for sablefish, ΣDDT levels in edible tissue exceeded the Food and Drug Administration guideline of 5 ppm only in fishes taken in the vicinity of the Los Angeles County sewer outfalls, where commercial fishing is restricted to bait fishing. Only in goatfish from Hawaii did the mean level of PCB exceed the proposed Food and Drug Administration guideline of 2 ppm. In no sample did the mean PCB level exceed the current guideline of 5 ppm.

In contrast to what has been found in other research on freshwater fishes, significant positive associations between physical measurements and chlorinated hydrocarbon content existed only in lingcod and striped bass from Oregon, in albacore from northern California, and in bocaccio and one set of 25 jack mackerel from southern California. Between chlorinated hydrocarbons, however, significant positive associations often existed ($P = 0.05$).

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