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PCB CONTAMINATION OF SOUTHERN
CALIFORNIA MARINE ORGANISMS

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ABSTRACT

In the past, the submarine discharge of municipal wastewater has been the dominant source of PCB to the marine environment off southern California. However, the level of input from this source has steadily decreased during the period 1972 ($>19,000$ kg/yr) to 1975 (2,600 kg/yr). Despite the significant decrease in this input, no significant decrease was observed over the 3 year period 1971-72 to 1974-75 in the level of PCB in muscle tissue of Dover sole, Microstomus pacificus, collected from the major municipal wastewater discharge sites. In contrast, similar surveys of the intertidal mussel, Mytilus californianus, indicated that the PCB levels in this marine organism had significantly decreased over the same time period.

Bight wide surveys of M. californianus and the yellow rock crab, Cancer anthonyi, indicate that PCB contamination of these marine animals is low but widespread. Levels of PCB in the harbor mussel, M. edulis, were highest in specimens collected from areas of intense vessel activity. A convenient and effective system for continuously monitoring PCB levels in the marine environment is described.

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INTRODUCTION

Over the last 4 years, the Southern California Coastal Water Research Project has been studying the inputs of PCB's to the Southern California Bight. A number of sources of PCB's (most closely resembling Aroclors 1242 and 1254) to the marine environment off southern California have been identified and their inputs quantified. The submarine discharge of municipal wastewater has been the dominant source of PCB to the marine environment off southern California. However, the level of input from this source has steadily decreased during the period 1972 ($>19,000$ kg/yr) to 1975 (2,600 kg/yr). Dry aerial fallout also appears to be an important source, and if wastewater inputs continue to decrease, fallout may become the dominant input mode of the future. PCB inputs from surface runoff are of secondary importance, and those from direct industrial discharges and vessel antifouling

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Contribution 53 of the Southern California Coastal Water Research Project.

paints are insignificant. Detailed results of our inputs studies are presented elsewhere in these proceedings (ref. 1) and a background paper (ref. 2).

Other workers have studied PCB contamination off California and elsewhere in the U.S. in the past decade. During the summer of 1975, several reports of high PCB levels in fish collected from Lake Michigan and the Hudson River caused public concern about PCB residues in commercial fish and sport fish (refs. 3-6). Munson's work in California (ref. 7) indicated that, in 1972, concentrations of these chlorinated hydrocarbons were low but widespread in the southern California marine community

The work of Allen and his colleagues (ref. 8) with rhesus monkeys attests to the toxic effects of short-term, low-level (25 ppm) exposures to PCB's on nonhuman primates. Later results of their experiments on the monkeys showed that exposure to PCB's at the 2.5- and 5-ppm levels was related to spontaneous abortions and the birth of undersized infants (ref. 9). Also, de Long et al. (ref. 10) found PCB's to be associated with premature births in the California sea lion.

In conjunction with our studies of PCB sources, we undertook research into the fates and effects of PCB's in marine animals. Our research involved several organisms common locally (the Dover sole, Microstomus pacificus, a benthic flatfish; the yellow rock crab, Cancer anthonyi; and an open coast and a harbor mussel, Mytilus californianus and M. edulis, respectively), and three distinct programs:

- Regional surveys of PCB levels in the flatfish, the crab,

and the mussels. Specimens from stations throughout the Southern California Bight (fig.1) were analyzed to determine the levels of PCB's present in their tissues and plot the distribution of the substances in the Bight. Changes over time were noted, as were relationships between the concentration levels and man's centers of activity along the coast (wastewater discharge, major harbors). We also sought to identify the dominant PCB present by determining if the PCB's found most closely resembled Aroclor 1242 or Aroclor 1254¹. Finally, we investigated the PCB levels in specimens of the flatfish afflicted with a fin erosion disease prevalent around several southern California wastewater outfalls.

- A study of the relative amounts of PCB's in the various tissues of the flatfish and the crab.
- The design of a convenient and effective system for continuously monitoring PCB levels in the marine environment.

This paper presents a brief summary of the results of these studies.

SAMPLING PROCEDURE AND

CHEMICAL ANALYSIS

McDermott et al. (ref. 11) report in detail the procedures used for the collection and preparation of biological samples as well as the subsequent PCB analyses by electron-capture gas chromatography for all research programs discussed in this paper.

¹Throughout the text, 1242 PCB and 1254 PCB have been used to distinguish between substances most closely resembling Aroclor 1242 and Aroclor 1254, respectively.

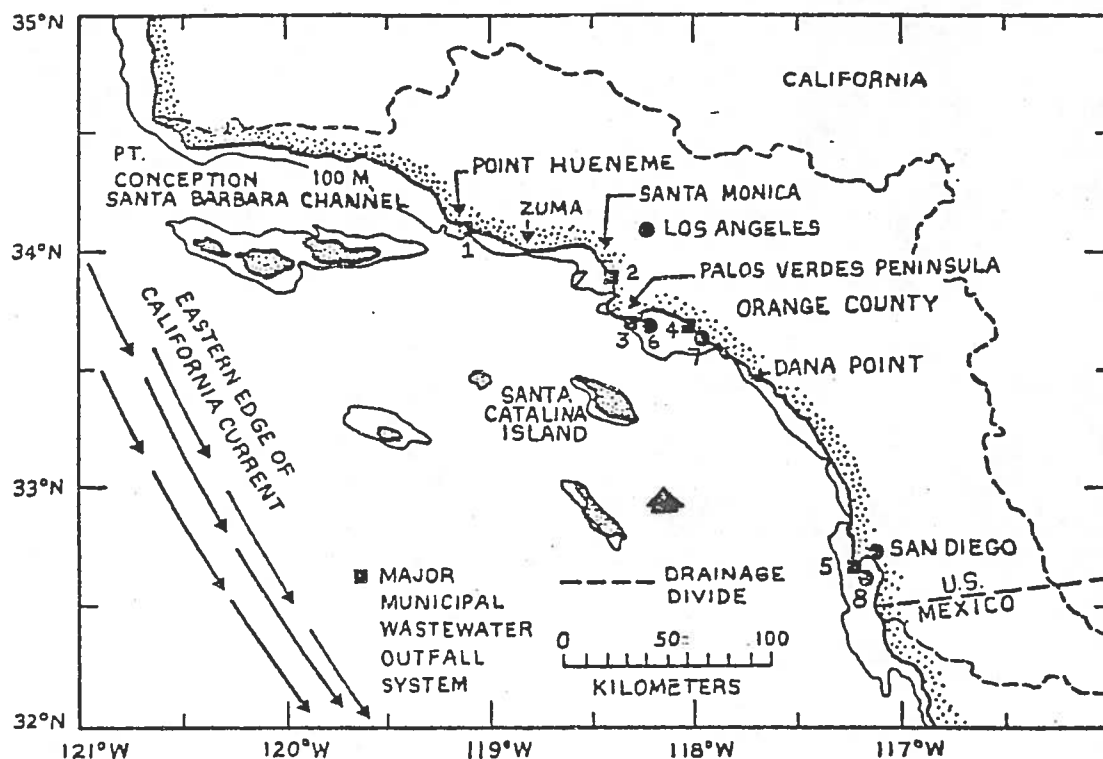


Figure 1. The Southern California Bight. Outfall systems are (1) Oxnard City, (2) Hyperion, Los Angeles City, (3) Whites Point, Los Angeles County, (4) Orange County, and (5) San Diego City. Major harbors are (6) San Pedro, (7) Newport, and (8) San Diego.

RESULTS AND DISCUSSION

Regional Surveys of PCB's in Marine Animals

Two Bight-wide surveys of PCB contamination in the benthic flatfish, Dover sole, were conducted during 1971-72 and 1974-75 (ref. 11). The results of these regional surveys (table 1) revealed that PCB levels in specimens collected near the three largest municipal wastewater discharge sites off Palos Verdes, Santa Monica, and Orange County were significantly higher than levels found in specimens from regions with little or no wastewater discharge. Despite the high levels of PCB in the fish from the outfall areas, less than 2 percent of all Dover sole taken in the two surveys had muscle tissue PCB concentrations that exceeded the Federal Food and Drug Administration's tolerance of 5 mg/wet kg in the edible portion of fish intended for interstate commerce.

Over the 3-year study period, municipal wastewater emissions of total PCB decreased (ref. 1). Yet we observed no statistically significant decrease in the levels of total PCB in the Dover sole. This finding indicates that other factors or inputs of these chlorinated hydrocarbons are involved in maintaining the total PCB levels in this fish.

During 1971 and 1974, Bight-wide surveys of the open coast mussel were also conducted (refs. 11, 12). The results are shown in table 2. A regional survey of the yellow rock crab was also conducted during 1971 (ref. 11). Table 3 presents the median concentration of total PCB in the muscle tissue of the crabs collected in each region. These surveys indicate that the PCB

TABLE 1. Total PCB concentrations (mg/wet kg)
in muscle tissue of Dover sole.^a

<u>Region</u>	<u>1971-72</u> <u>(n^b = 110)</u>		<u>1974-75</u> <u>(n^c = 165)</u>	
	<u>Region</u> <u>Median</u>	<u>Station</u> <u>Range</u>	<u>Region</u> <u>Median</u>	<u>Station</u> <u>Range</u>
Point Hueneme	0.1	0.1	0.06	0.05-0.07
Santa Monica	1.5	0.4-2.8	2.0	1.0 -2.3
Palos Verdes	1.9	1.1-6.3	1.3	0.06-2.5
Orange County	0.7	0.1-1.2	0.6	0.3 -2.8
Dana Point	0.06	0.03-0.09	0.7	0.03-0.14
San Diego	-	-	0.2	0.09-0.6
Santa Catalina				
Island	0.04	0.03-0.04	0.05	0.03-0.07

^a After ref. 3. There is no statistically significant difference between the 1971-72 and the 1974-75 levels.

^b Composite samples of Dover sole muscle tissue.

^c Individual samples of Dover sole muscle tissue.

TABLE 2. Concentrations (mg/wet kg) of the PCB most closely resembling Aroclor 1254 in the whole soft tissues of Mytilus californianus.*

<u>Station</u>	<u>1971</u>	<u>1974</u>
Coastal		
Gaviota	0.05	0.01
Santa Barbara	0.03	0.02
Port Hueneme	0.12	0.37
Point Dume	0.08	0.04
Palos Verdes Peninsula		
Point Vicente	0.38	0.10
Royal Palm	0.52	0.14
San Clemente	0.05	0.02
Point Loma	0.12	0.06
Island		
Anacapa	0.01	0.01
Santa Barbara	0.07	0.02
Santa Catalina	0.02	0.01
San Nicolas	0.02	0.01
San Clemente	0.02	0.02

* After refs. 11, 12.

TABLE 3. Regional survey of total PCB concentrations (mg/wet kg) in the muscle tissue of individual yellow rock crabs, 1971-72.^a

<u>Region</u>	<u>No. of Samples</u>	<u>Region Median</u>	<u>Station Range</u>
Santa Monica	12	0.68	0.13 -2.2
Palos Verdes	16	0.82	0.30 -1.8
Outside San Pedro Harbor	5	0.49	0.32 -0.83
Orange County	9	0.32	0.23 -0.54
Ensenada ^b	3	0.014	0.012-0.018

^a After ref. 11.

^b Three chelae (Cancer species) purchased in fish market.

contamination levels in these animals are low but widespread. Levels of total PCB in specimens near the major outfall systems were generally 10 to 100 times higher than levels in specimens collected from coastal or island control sites; however, the Federal tolerance level for PCB compounds was not exceeded in the edible portion of any specimens of these two species. The two surveys of M. californianus indicate that the level of PCB contamination in these mussels had decreased significantly over the 3-year interval, 1971-74, with a median percent decrease of 54 percent.

The dominant PCB observed in the three species surveyed was 1254 PCB; the other PCB identified was 1242 PCB. The percent composition of total PCB in the muscle tissue samples from the crab and mussel specimens was similar to that in the Dover sole muscle samples. The median 1974-75 composition of total PCB in muscle tissue of Dover sole taken near the five major discharge sites was 67 percent 1254 PCB and 33 percent 1242 PCB. This contrasted with the median 1974 composition of municipal wastewater emission of PCB: 29 percent 1254 PCB and 71 percent 1242 PCB. These data, along with a comparison of total PCB levels in Dover sole muscle tissue, surface sediments, and municipal wastewater emissions (table 4), indicate that the PCB levels in Dover sole are not dependent only upon the level of PCB discharged in wastewaters and that other factors, such as the solubility, volatility, the sediment load, or the relative biological uptake and retention rate of a given PCB are involved in the resulting levels of PCB's in this marine animal.

TABLE 4. Comparison of total PCB levels in muscle tissue of Dover sole and bottom surface sediments and PCB mass emission rates in municipal wastewater.*

Region	1971-72			1974-75	
	Dover Sole (mg/wet kg)	Sedi- ments (mg/dry kg)	Muni- cipal Waste (kg/yr)	Dover Sole (mg/wet kg)	Muni- cipal Waste (kg/yr)
Palos Verdes	1.9	3.6	11,600	1.3	1,270
Santa Monica	1.5	0.53	1,920	2.0	956
Orange County	0.7	0.02	5,800	0.6	2,100
San Diego	-	0.01	118	0.2	1,050
Point Hueneme	0.1	0.004	3	0.1	5

* After refs. 1, 2, 11.

Distribution of PCB's in Tissues
of a Benthic Flatfish and Crab

In February 1975, special collections of Dover sole were made off Palos Verdes and Orange County for the analysis of PCB's in the muscle, liver, gonad, heart and kidney tissues (ref. 11). The results are presented in table 5. The level of PCB in the liver tissue was 10 to 20 times higher than the levels observed in the other tissues analyzed. To determine the liver and muscle tissue burdens of the two sets of fish, the median concentrations of PCB in the specific tissue was applied to the average wet weight of that tissue:

	<u>Liver Burden</u>	<u>Muscle Burden</u>	<u>Ratio, Liver to Muscle</u>
Palos Verdes	0.04 mg	0.02 mg	2
Orange County	0.02 mg	0.03 mg	0.7

The liver-to-muscle tissue burden ratio for PCB in Palos Verdes Dover sole was 2; for Orange County specimens, the ratio was 0.7. There are two possible explanations for the high liver-to-muscle tissue burden ratio in the Palos Verdes fish. A review of the literature indicates that (1) in metabolic disturbances, the lipid (fat) content in liver tissue may significantly increase, and (2) chlorinated hydrocarbons, which are hepatic poisons, induce fatty livers. As chlorinated hydrocarbons are associated with lipids, if either one or both of these situations had occurred in the Palos Verdes Dover sole, it would have resulted in an increase in the total PCB levels in the liver and a higher liver-to-muscle tissue burden ratio. The lipid content of these tissues is being studied, and further

TABLE 5. Total PCB concentrations (mg/wet kg)
in composite samples of tissues of
Dover sole, 1975.*

<u>Tissue</u>	<u>Palos Verdes</u>		<u>Orange County</u>	
	<u>Median</u>	<u>Range</u>	<u>Median</u>	<u>Range</u>
Muscle	0.7	0.1-1.1	1.1	0.6-1.4
Liver	15	11-18	8.3	4.8-13
Gonads	1.4	0.8-5.2	0.8	0.7-4.6
Heart	1.8	1.5-3.2	0.5	0.4-0.8
Kidney	0.8	0.6-1.1	0.6	0.6-0.8

* After ref. 11.

work on the physiological and ecological implications of these tissue burdens is underway.

Analysis of the PCB concentrations in the reproductive organs of C. anthonyi indicate that the gonadal tissues generally contain PCB levels five to ten times higher than the muscle tissue levels (ref. 11). Also, in females, the gonad had an absolute tissue burden of PCB that was 25 percent higher than the muscle tissue burden:

	<u>Male</u>	<u>Female</u>
Percent of combined gonad/muscle tissue weight		
Gonad	7	27
Muscle	93	73
Tissue burden (mg)		
Gonad	0.009	0.031
Muscle	0.025	0.025

As the reproductive organs of this crustacean are exposed to considerably higher levels of this synthetic organic than is the muscle, spawning may represent a significant distribution mechanism of these contaminants in the marine environment, and a significant factor in the elimination of a large percentage of the body burden of these materials from the crab. The long-term effects of PCB concentrations on reproduction or other biological processes in this crustacean are unknown.

Fin Erosion and PCB Levels in a Benthic Flatfish

The Dover sole collected off Palos Verdes are frequently affected by fin erosion; the disease has recently also become prevalent off Orange County. Data on specimens with eroded fins and those with healthy fins taken in 1974 in single trawls were

paired. Utilizing the Wilcoxon signed-rank test, the levels of PCB in the muscle tissue of the unaffected fish and the diseased fish were found to be different at the 90 percent confidence level ($p = 0.10$). Although this level is not considered to be statistically significant, it shows a strong tendency for the total PCB levels to be higher in the diseased fish. The median values for the diseased and unaffected groups were 2 and 1 mg/wet kg, respectively (refs. 11, 13).

If this association was dependent upon the input level of PCB, one would expect fin erosion to be dominant off Orange County where the input level of PCB is the greatest. One would also expect to find it off Santa Monica and San Diego where the level of input is similar to Palos Verdes. However, this is not the case. There are several possible reasons for the association between high PCB levels and fin erosion. The disease is predominantly found in the Palos Verdes region: Palos Verdes sediments have the highest levels of PCB in the Bight, thus contaminated sediments could be the dominant factor. Also, PCB--in combination with other constituents present in this region (DDT, hydrogen sulfide, trace metals)-- could be involved in the development of the disease. It is also possible that PCB uptake is enhanced in diseased fish; hence the higher levels could be the result of the disease rather than a cause. These relationships are being studied further.

Surveys of PCB's in Harbor Mussel

Composite samples of the whole soft tissues of Mytilus edulis collected from three major southern California harbors

(San Pedro, Newport, and San Diego) were analyzed for PCB's (ref. 11).

The survey showed that the harbor mussels had contamination levels up to 20 times those found in specimens of the same species collected from nearby coastal sites. Highest levels were found in mussels taken near regions of heavy vessel activity. Figure 2 shows the data for San Diego Bay, where the range of total PCB values near the commercial docks and navy moorings (0.80 to 1.3 mg/wet kg) is three to four times higher than the values observed at other inner harbor sites, and ten times greater than levels in nearby coastal mussels.

The levels of 1254 PCB in seawater at the mouths of the harbors were generally on the order of 1 part per trillion (ref. 1, 2). The values of 1254 PCB in the whole soft tissues of the harbor mussels were 100,000 times these seawater levels.

Although most antifouling paints presently applied to vessel bottoms in southern California contain PCB concentrations of less than 1 mg/dry kg, a few samples of pre-1970 paint chips averaged about 10 percent PCB or 100,000 mg/dry kg (ref. 14). Thus it is possible that thousands of kilograms of this synthetic material could have been released annually to the harbor and coastal marine ecosystems, before the widespread use of nonrecoverable PCB's was discontinued in the U.S. in the early 1970's.

Bouy Mussels: An Offshore Biomonitoring System

In June 1974, 4- to 6-cm long specimens of M. californianus were collected from Point Sal, an area known to be relatively

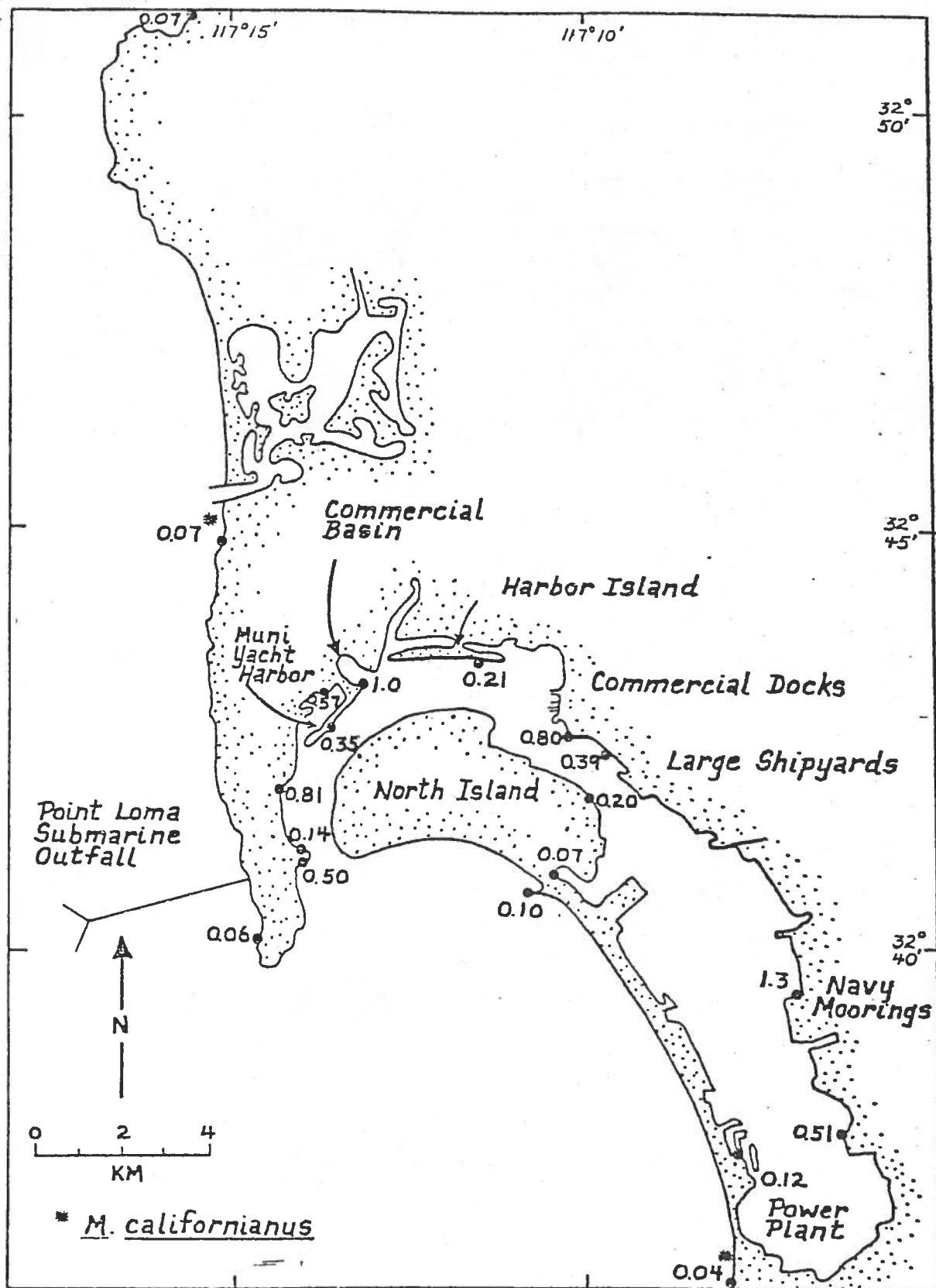


FIGURE 2. Total PCB concentrations (mg/wet kg) in whole soft tissues of *Mytilus edulis* in San Diego Bay, January 1974. (After ref. 11).

free of PCB contamination. Within 1 day of collection, these mussels were transported to a taut-line bouy anchored off Whites Point, where wastewaters from Los Angeles County's Joint Water Pollution Control Plant discharged (ref. 11). The mussels were placed in net bags fastened at five levels between the sea surface (0.5 m) and the bottom sediments (35 m), which are highly contaminated with trace metals and chlorinated hydrocarbons at this site (refs. 15-17).

The mussels transported to the buoy system off Palos Verdes appeared to survive well under the test conditions: Less than 10 percent mortality was observed at any of the five levels (0.5 to 35 m) at which the mussels were suspended during the 3-month study.

On the average, mussels living at Royal Palm Beach, inshore of the buoy, contained 17 times as much PCB as the control specimens at the time of their transfer to the buoy northwest of the outfalls. Thus, exposure of these mussels to PCB was greatly increased upon their transfer to the discharge region.

The results indicated that there was a direct relationship between uptake of PCB and proximity of the bioindicator to the contaminated bottom sediments and to the wastewater plume, which is trapped beneath the thermocline. The bottom specimens became approximately 10 times as contaminated as did the surface specimens.

At the end of the 13-week period, the 1254 PCB concentrations in the whole soft tissues of specimens collected from Level 5 (closest to the bottom sediments) were approaching 0.4 mg/wet kg; those specimens from Level 1 (at the surface)

were at 0.04 mg/wet kg. To date, the highest 1254 PCB concentration measured in the water above the outfalls is 4 ng/l (ref. 12). This suggests a concentration factor on the order of 100,000 for 1254 PCB in the whole soft tissues of M. californianus, a number in good agreement with the estimate for M. edulis in the harbors.

SUMMARY

1. No statistically significant decrease in the Bight-wide levels of PCB in the muscle tissue of Dover sole was observed over the 3-year period 1971-72 to 1974-75.

2. The level of PCB contamination of the open coast mussel decreased significantly over the 3-year interval, 1971-74, with a median percent decrease of 54 percent.

3. Regional surveys of the yellow rock crab and open coast mussel indicate that PCB contamination levels in these animals are low but widespread.

4. For all three species surveyed, PCB levels in specimens collected near major outfall systems were generally 10 to 100 times higher than levels in specimens collected from coastal or island control sites.

5. The dominant PCB observed in the three species surveyed most closely resembled Aroclor 1254; the other PCB identified most closely resembled Aroclor 1242. In contrast, the dominant PCB discharged via municipal wastewaters most closely resembled Aroclor 1242.

6. The liver tissue of Dover sole generally had concentrations of PCB's 10 to 20 times greater than the levels found in the muscle, gonad, heart and kidney tissues.

7. The liver-to-muscle tissue burden ratio for total PCB

in Palos Verdes Dover sole was three times higher than the ratio for Orange County specimens.

8. The reproductive organs of the yellow rock crab generally contain PCB levels five to ten times higher than the muscle tissue levels.

9. PCB's were found to be associated with the fin erosion disease prevalent in Dover sole collected around major municipal wastewater discharge sites at the 90 percent confidence level ($p = 0.10$).

10. Harbor mussels had PCB contamination levels up to 20 times those found in specimens of the same species collected from nearby coastal sites. Highest levels were found in mussels taken near regions of heavy vessel activity.

11. Although the mussel used in the buoy system was an intertidal organism, less than 10 percent mortality was observed at depths to 35 m. This mussel's hardiness, its ubiquitous distribution along many coastlines around the world, its very high ability for concentrating chlorinated hydrocarbons above seawater values, and its apparent ability to rapidly respond to changes in environmental levels of such contaminants make it a very useful bioindicator, both in natural intertidal communities and on offshore substrates.

The widespread use of nonrecoverable PCB's was curtailed in the U.S. during the early 1970's. However, the inputs of these persistent substances are still diffuse and difficult to control. There is a need for more knowledge of the effects of these materials in the marine environment; in particular, uptake rates, persistence, and biological effects should be studied.

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