POLYCHLORINATED BIPHENYLS OFF SOUTHERN CALIFORNIA

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Summary

Polychlorinated biphenyls are ubiquitous contaminants of the marine ecosystem off southern California. The greatest known source is the submarine discharge of municipal wastewaters; aerial fallout also appears to be an important input route. In contrast, surface runoff is only of secondary importance, and direct industrial discharge appears to be completely insignificant.

Maximum concentrations of 1254 PCB found in bottom sediments off Palos Verdes Peninsula were 10 ppm, with values falling 100 fold to baseline values over a depth of 20 cm. Muscle tissue from benthic crabs (Cancer anthonyi) and flatfish (Microstomus pacificus) collected from discharge regions also exhibited 100 fold increases in 1254 PCB levels over control values. It appears that the numerous harbors in the Bight also have relatively high levels of PCB contamination. Intertidal bay mussels (Mytilus edulis) contained up to 20 times more 1254 PCB than corresponding specimens collected nearby along the open coast.

Finally, an offshore biomonitoring system has been developed, utilizing the intertidal coastal mussel (M. californianus), which appears to offer good potential for indicating zones of greatest biological availability of synthetic pollutants released from submarine outfalls.

Introduction

Chlorinated hydrocarbons are among the most important pollutants yet identified in the Southern California Bight.[1-6] The coastal plain adjacent to this marine ecosystem (Figure 1) is inhabited by approximately 11 million persons (approximately 5 percent of the U.S. population), and large quantities of waste materials are introduced both directly and indirectly into the waters of the Bight. Potentially significant sources and transport routes include submarines discharges of municipal wastewaters, direct industrial discharges, antifouling paints and other vessel related materials, surface runoff, aerial fallout, and ocean current advection.[7]

Here we summarize our findings from studies into the industrially important polychlorinated biphenyls (PCB) conducted over the last several years while investigating the inputs and distributions of chlorinated hydrocarbons off southern California.

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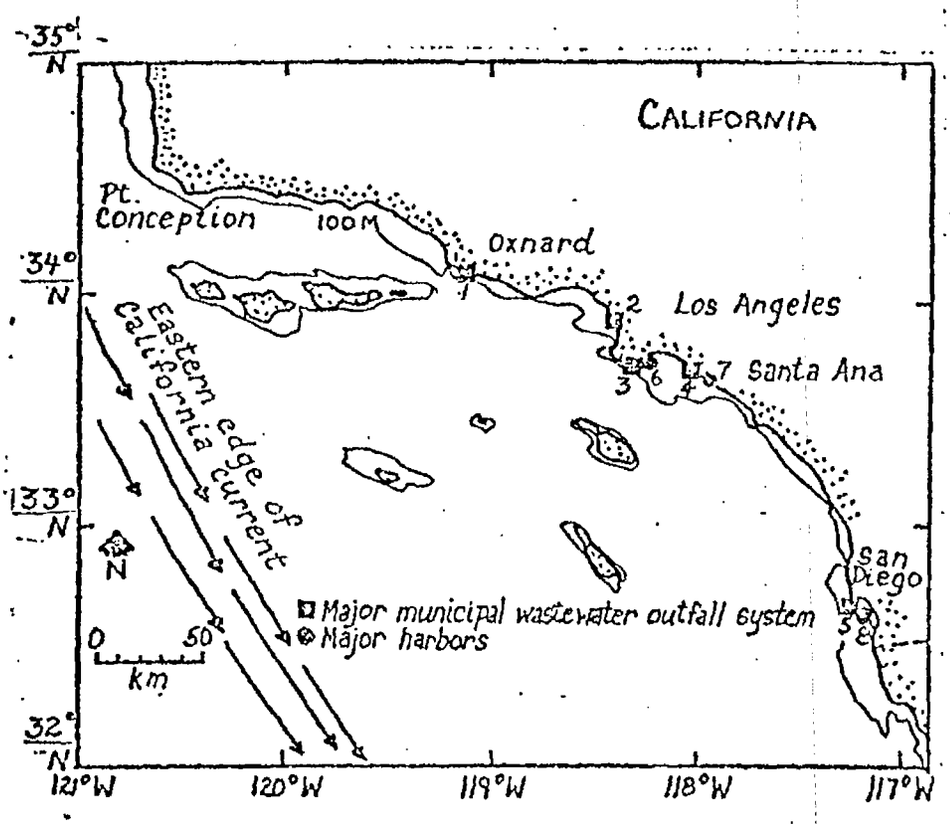

Figure 1. The Southern California Bight. Major outfall systems are (1) Oxnard City, (2) Hyperion, Los Angeles City, (3) JWPCP, Los Angeles County, (4) OCSD, Orange County, and (5) Point Loma, San Diego City. Major harbors are (6) San Pedro, (7) Newport, and (8) San Diego.

Sampling

Five major treatment plants* located along the southern California coast contribute more than 95 percent of the 4×10^9 liters of municipal wastewater discharged daily into the Bight. In order to obtain an estimate of the importance of this input route, we analyzed one-week composites (usually collected twice a year) of the final effluents obtained from each of these plants since 1972.

In southern California, most industrial effluents discharged directly into marine waters (excluding power plant cooling waters) flow into San Pedro Harbor or San Diego Bay.

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* Joint Water Pollution Control Plant (JWPCP), Los Angeles County; Hyperion Treatment Plant, City of Los Angeles; Orange County Sanitation District Treatment Plant (OCSD), Orange County; Point Loma Treatment Plant, City of San Diego; Oxnard Treatment Plant City of Oxnard.

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Therefore, to estimate the level of PCB input from this source during 1973 and 1974, half-day effluent composites obtained for each of the major types of industries discharging into both areas were analyzed. In addition, during 1973 we conducted an intensive survey to determine the composition and quantities of major brands of antifouling paints used on recreational, commercial, and naval vessles in the 14 harbors and marinas in southern California.[8]

We estimated the contribution of surface runoff by sampling major channels along the southern California coast during both storm and dry weather conditions between 1971 and 1973. To measure aerial inputs, replicate 1 week collections of dry aerial fallout were analyzed from 13 coastal and 5 island stations throughout the Bight during two 13 week periods in 1973 and 1974. Finally, to estimate the magnitude of ocean current advection inputs during 1973, we analyzed results of PCB measurements for replicate samples of surface seawater which we had collected in the Santa Barbara Channel at the edge of the Bight.

During 1971, we collected ocean bottom sediments near the JWPCP outfalls off Palos Verdes Peninsula using a deliberate box corer. Utilizing traps and benthic trawls, samples of the benthic crab (Cancer anthonyi) and a flatfish, the Dover sole (Microstomus pacificus) were collected from around the Hyperion, JWPCP and OCSD outfalls during 1971 and 1972; the Dover sole was subsequently resampled in these regions in 1974 and 1975. In addition, during 1974 we sampled the intertidal bay mussel (Mytilus edulis) from throughout San Pedro, Newport and San Diego Harbors. Later that year, to estimate uptake rates and steady state concentrations, we transferred 2,000 specimen of the intertidal mussel (M. californianus) from an uncontaminated control station to net bags suspended from a taut line buoy system situated above highly contaminated sediments near the JWPCP outfalls.

Methodology

Most of the various categories of samples were processed and analyzed utilizing well established laboratory techniques in conjunction with electron capture gas chromatography. The aerial fallout samples were analyzed using a procedure developed by Dr. Vance McClure (National Marine Fisheries Service, La Jolla, California), and the seawater samples were

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analyzed in collaboration with Brock de Lappe and Dr. Robert Risebrough, utilizing a technique they developed at the University of California at Berkeley.

Results and Discussion

Sources and Transport Routes

Table 1 summarizes the estimated annual mass emission rates of 1242 PCB and 1254 PCB (42 and 54 percent chlorination, respectively) to the Bight via six modes of input, and Table 2 presents the breakdown of 1974 inputs from major municipal submarine discharges. Approximately equal concentrations of 1242 and 1254 PCB were measured in surface runoff; thus, although reliable measurements of 1242 PCB in dry aerial fallout have not yet been made, we estimated an upper limit for this input assuming a 1 to 1 ratio of 1242 and 1254 PCB in fallout.

Table 1. Estimated annual mass emission rates (kg/yr) of polychlorinated biphenyls to the Southern California Bight.

Route	Year	1242 PCB	1254 PCB
Municipal Wastewater	1974	4300	1100
Direct Industrial	1973-74	-	60
Antifouling Paints	1973	<1	<1
Surface Runoff	1973	≤500	300
Aerial Fallout	1973-74	≤1500*	1500
Total (Land)		4500-6000*	3000
Ocean Currents	1973	-	4000

* Assuming a 1 to 1 ratio between 1242 and 1254 PCB in aerial fallout.

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Table 2. Estimated 1974 mass emission rates (kg/yr) of polychlorinated biphenyls to the Bight via major municipal wastewaters.

Treatment Plant	Flow (mgd)	1242 PCB	1254 PCB
JWPCP	350	910	360
Hyperion (5-mi)	330	50	110
Hyperion (7-mi)	5	470	320
OCSD	150	1890	210
Pt. Loma	95	950	110
Oxnard	10	1	3
Total	940	4270	1110

These results indicate that municipal wastewater is the dominant mode of input for PCB to the coastal waters, followed by dry aerial fallout. Surface runoff contributions are an order of magnitude lower, while estimated coastal inputs from direct industrial discharges and antifouling paint application are relatively insignificant.

In view of the fact that the quantity of 1254 PCB (1,100 kg) introduced during 1974 was more than one-fourth the estimated quantity (4,000 kg) carried annually by surface layer (0-50 m) currents flowing through the entire Bight, one would expect that local contamination of nearshore sediments and organisms by this synthetic material would be clearly evident.

Marine Sediments

Figure 2 presents vertical profiles of 1254 PCB concentrations in bottom sediment layers from box cores collected at three sites within the monitoring zone and down current of the JWPCP outfalls off Palos Verdes Peninsula.*

* Distance downcurrent: Station B18, 7 km; Station B21, 1.5 km; and Station B20, between the legs of the wye of the outfall.

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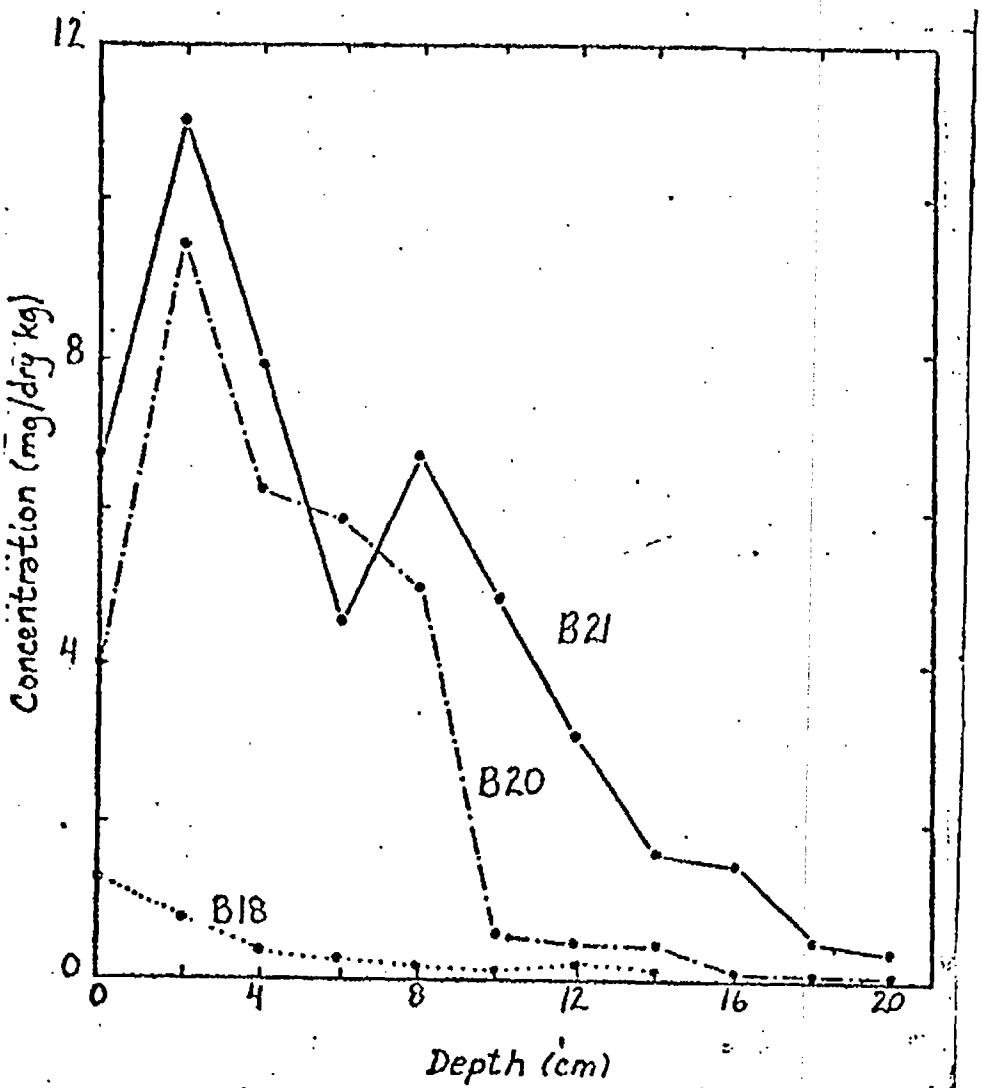

Figure 2. Vertical profiles of 1254 PCB concentrations in sediments collected northwest of the JWPCP outfalls, box cores, July 1971.

concentrations of 1254 PCB in nearsurface sediments (10 ppm, mg/dry kg) collected at Station B21, located 1.5 km from the nearest outfall diffuser, exceeded the lowest levels measured at the bottom of the three cores (0.1 ppm) by a factor of 100. Surface sediments from the Santa Barbara Basin (180 km to the northwest) also contain about 0.1 ppm 1254 PCB.[9]

We previously calculated that, in 1972, the upper 30 cm of bottom sediments in a 50 sq km area of this discharge zone contained approximately 200 metric tons of DDT and its residues[6]; we believe this estimate to be accurate within 25 percent of the actual value. Although we have much fewer data on the distribution of PCB in these sediments, extrapolation of our present information using observed PCB to DDT ratios suggests that the corresponding load of 1254 PCB in these sediments is on the order of 6 metric tons.

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Marine Animals

Benthic Organisms. Samples of muscle tissue from crabs (C. anthonyi) and Dover sole (M. pacificus) collected in these discharge regions also exhibited significant levels of PCB contamination above baseline concentrations (Figures 3 and 4, respectively). Levels

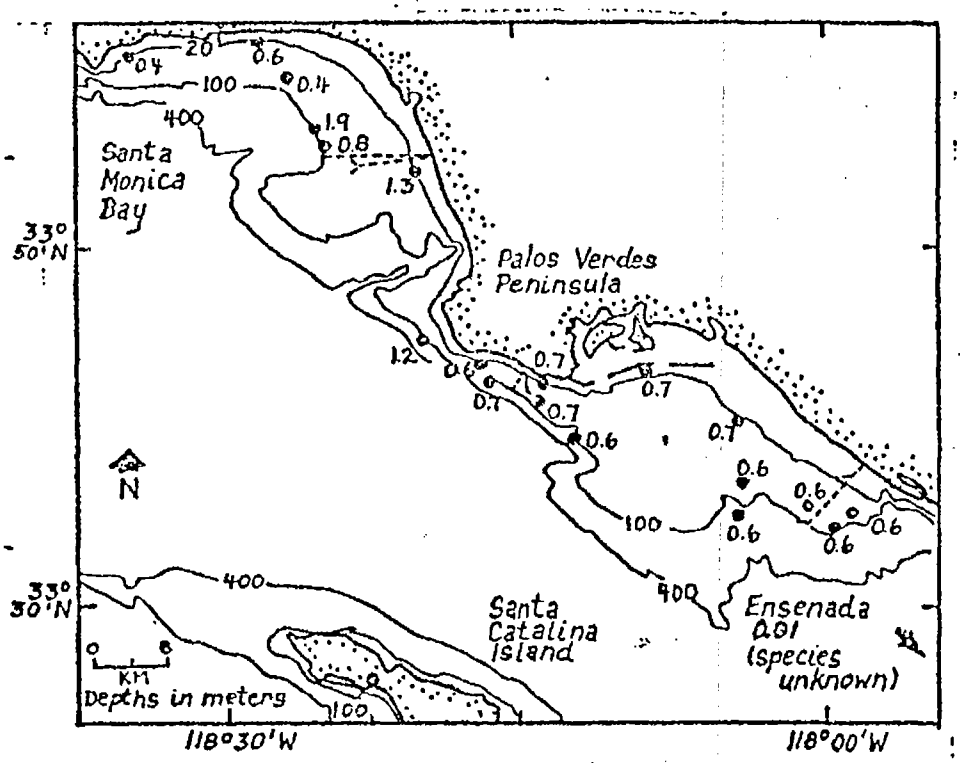

Figure 3. 1254 PCB concentrations (mg/wet kg) in muscle tissue of the crab, Cancer anthonyi, collected off southern California, 1971-72.

in both species from around major outfall sites were generally 100 times greater than those observed at island or coastal control stations. In addition, there has not been any significant change in PCB levels during the three years interval between 1971-72 and 1974-75; median 1254 PCB concentrations in Dover sole collected from off Palos Verdes Peninsula during the two periods were 1.9 and 1.3 ppm (mg/wet kg), respectively. Corresponding values for the Santa Monica Bay stations around the Hyperion outfalls were 1.5 and 2.0 ppm; off the Orange County outfalls, the median values were 0.8 and 0.6 ppm respectively.

a fall-off?

2 declined
1 went up.

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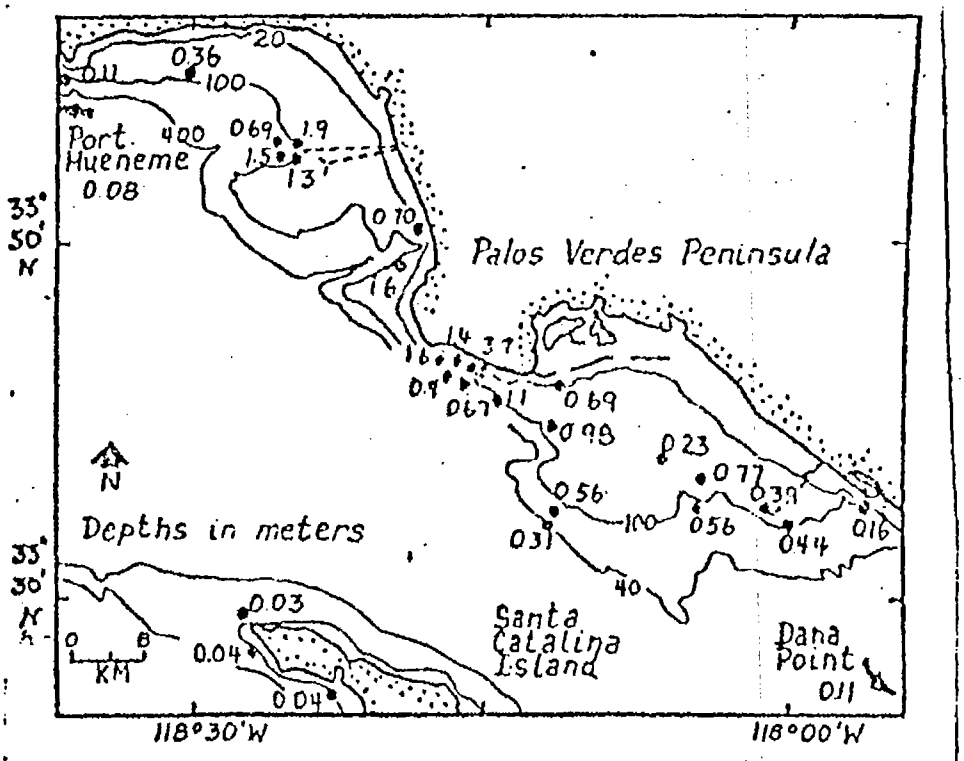

Figure 4. 1254 PCB concentrations (mg/wet kg) in muscle tissue of the Dover sole, Microstomus pacificus, collected off southern California, 1971-72.

Bay Mussels. Our surveys of 5 cm bay mussels (M. edulis) from three of the largest southern California harbors revealed contamination levels up to 20 times those found in specimens of the same species collected from nearby coastal sites.[10] Highest levels were found near regions of greatest vessel activity as illustrated by the results for San Diego Bay presented in Figure 5. Comparison of seawater levels (generally on the order of one

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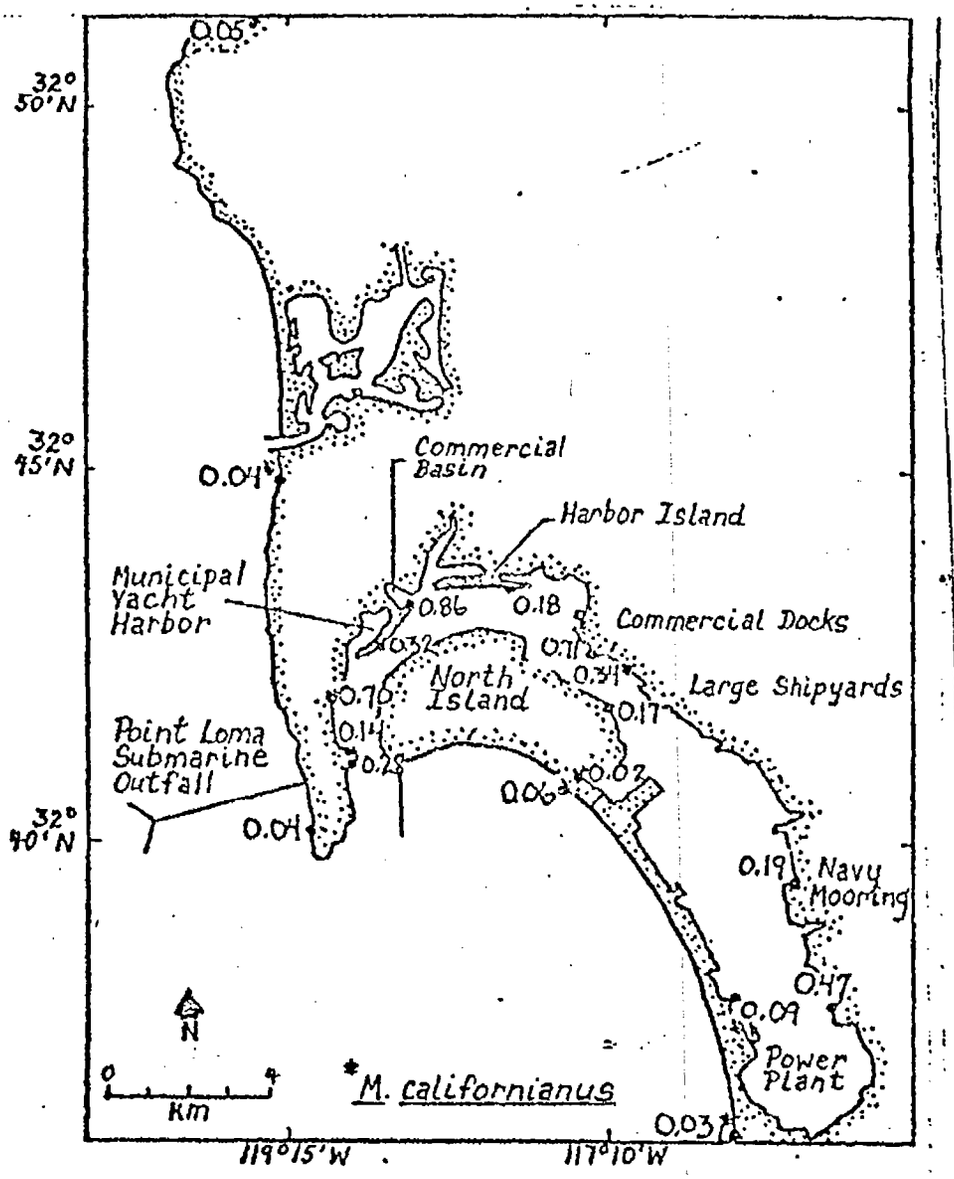

Figure 5. 1254 PCB concentrations (mg/wet kg) in whole soft tissues of the bay mussel, Mytilus edulis, collected in San Diego Bay, January 1974.

part per trillion, ng/l) and mussel concentrations of 1254 PCB found in San Diego and the other harbors suggests that the whole soft tissues of M. edulis accumulate PCB on the order of 100,000 times above seawater values.

Although antifouling paints presently applied to vessel bottoms in southern California generally contain PCB concentrations of less than 1 ppm (mg/dry kg), a few samples of old paint chips averaged about 10 percent PCB (100,000 ppm).[8] 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 non-recoverable PCB was discontinued in the United States during the early 1970's.

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Offshore Biomonitoring System

In June 1974, uncontaminated specimens of open coast, intertidal mussels (M. californianus), 5 cm in length, were transferred to net bags fastened at five different levels between the sea surface and bottom (35 m) on a taut line buoy system installed over the highly contaminated sediments near the JWPCP outfalls. The rate and extent of PCB uptake was then monitored for 3 months in specimens collected at 1 to 2 week intervals. The mussels appeared to survive well under these conditions; less than 10 percent mortality at any level was observed over the study period.

On the average, mussels living at Royal Palm Beach inshore of the buoy contained 20 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.

Resultant uptake of 1254 PCB with time in male specimens is presented in Figure 6; similar results were observed for female specimens, and application of the Wilcoxon signed-rank test revealed no significant effect of sex on PCB uptake. These data show that there is 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. Projected "steady state" concentrations for the two levels of suspension appear to be on the order of 0.4 and 0.04 ppm (mg/wet kg). To date, the highest 1254 PCB concentrations measured in the water above the JWPCP outfalls is 4 parts per trillion. This suggests a concentration factor on the order of 100,000 for 1254 PCB in the whole soft tissues of M. californianus, in good agreement with the estimate for M. edulis in the harbors.

Conclusions

Municipal wastewaters and aerial fallout dominate the known inputs of PCB to the Southern California Bight. More than 5 metric tons of 1242 and 1254 PCB were discharged during 1974 from the five major southern California treatment plants. Such inputs have resulted in localized zones of relatively high bottom sediment contamination around submarine outfall systems.

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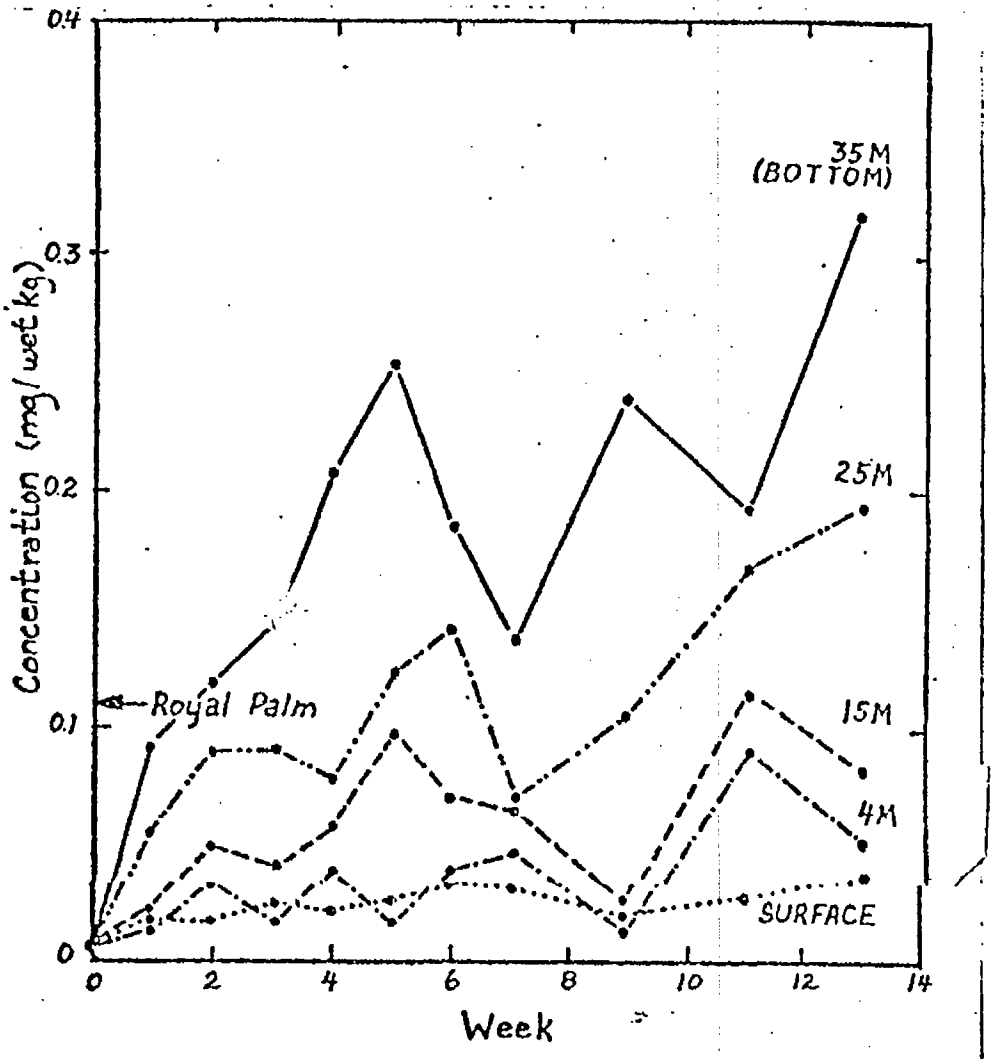

Figure 6. 1254 PCB concentrations in whole soft tissue composites of male intertidal mussels, Mytilus californianus, translocated from Point Sal to the taut line buoy system off Palos Verdes, June through September 1974.

Measured annual emissions of 1254 PCB from the three major outfall systems agreed within a factor of 2; similar agreements were observed in the 1254 PCB levels in crabs (C. anthonyi) and flatfish (M. pacificus) collected from the three discharge regions. Thus it is apparent that PCB compounds are widespread contaminants of both coastal wastewater inputs and benthic organisms in southern California.

Highest concentrations in the bay mussel (M. edulis) were measured near locations of greatest vessel activity, such as mooring and bottom repainting facilities. The contamination of harbor organisms may be the result of past usage of antifouling paints containing high levels of PCB, although inputs from other vessel-related materials (such as hydraulic fluids) could also be important.

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Although the bioindicator (M. californianus) used in the offshore biomonitoring system is an intertidal organism, less than 10 percent mortality was observed, even at a depth of 35 m, over the 3 month study period. Thus, this mussel's hardiness, its ubiquitous distribution along many coast lines around the world, its very high ability for concentrating chlorinated hydrocarbons above seawater values (approximately 100,000 fold for 1254 PCB), and its apparent ability to rapidly respond to changes in environmental levels of such contaminants makes it a very useful bioindicator both in natural intertidal communities and on offshore monitoring substrates.

Acknowledgements

Dr. Robert Risebrough and Brock de Lappe (Bodega Marine Laboratory, University of California at Berkeley) provided seawater PCB concentrations discussed in this paper, and assisted us in analyzing harbor water and municipal effluents. Dr. Vance McClure (National Marine Fisheries Service, La Jolla, California) developed the techniques used to collect and analyze dry aerial fallout. Bottom sediments and organisms were collected with the assistance of Dr. Ronald Kolpack (University of Southern California) and Douglas Hotchkiss and the crew of the Sea-S-Dee (County Sanitation Districts of Los Angeles County).

Municipal wastewaters were collected with the assistance of personnel from corresponding treatment plants. Members of this Project who contributed to this research include Willard Bascom (Director), Elliott Birkihiser, Rick Gammon, Joseph Johnson, Jack Mardesich, Dr. Alan Mearns, Michael Moore, Paul Smokler, Harold Stubbs, Ileana Szpila, and Michael Westbrook.

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