The effects of waste disposal on the coastal waters of Southern California

Deep diffuser outfalls and effective source control permit acceptable ocean disposal

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Changes in the condition of the coastal water off Southern California resulting from the disposal of large quantities of municipal wastes have long been a controversial subject. A decade ago pelicans were unable to breed on the nearby islands, the beds of giant kelp off Palos Verdes had disappeared, and the animal populations in large areas of the ocean bottom were substantially altered. These problems were attributed to the discharge of large quantities of organic solids with contaminants such as DDT attached. The extent of these and possibly other detrimental effects was not known, and there was great public concern.

Ten years of study by the Southern California Coastal Water Research Project (SCCWRP) has provided much information about the effects of wastes discharged from deep marine outfalls. In that same decade the discharge of specific pollutants has been significantly reduced. Now pelicans and kelp are back; changes in the bottom and its life have been mapped and are reasonably well understood; in most areas marine life seems to be in good condition.

The findings described here apply to the open coastal water off Southern California, especially the area extending 15 km out from the shoreline between Point Conception and the Mexican border (Figure 1). This is the region most likely to be influenced by the wastes and activities of the 12 million people who live nearby.

These coastal waters are part of the Southern California Bight, a body of water 200 km wide in some places, which covers a unique basin-and-range submarine topography and includes seven islands. The main stream of the California Current sweeps southward along the outer coast beyond Point Conception and passes outside the islands partly over the western part of this bight. Sometimes a relatively

SCCWRP

SCCWRP, for Southern California Coastal Water Research Project, is a scientific organization whose primary objective is to understand the ecology of the coastal waters of Southern California. It is concerned with all of the effects of humans on the adjacent sea but the principal effort is directed toward discovering the effects on sea life of the discharge of municipal wastes.

SCCWRP was founded in 1969 when five local government agencies (the cities of Los Angeles and San Diego and the county sanitation districts of Los Angeles, Orange, and Ventura counties) entered into a joint powers agreement to sponsor environmental studies. Their intention was to establish a sound scientific basis for any action that might be taken relative to the ocean disposal of wastewater. They agreed to contribute funds in proportion to the amount of wastewater each discharged. To keep the project free of partisan pressures, its control was delegated to a commission of local civic leaders and elected officials that reflects public concern for environmental quality.

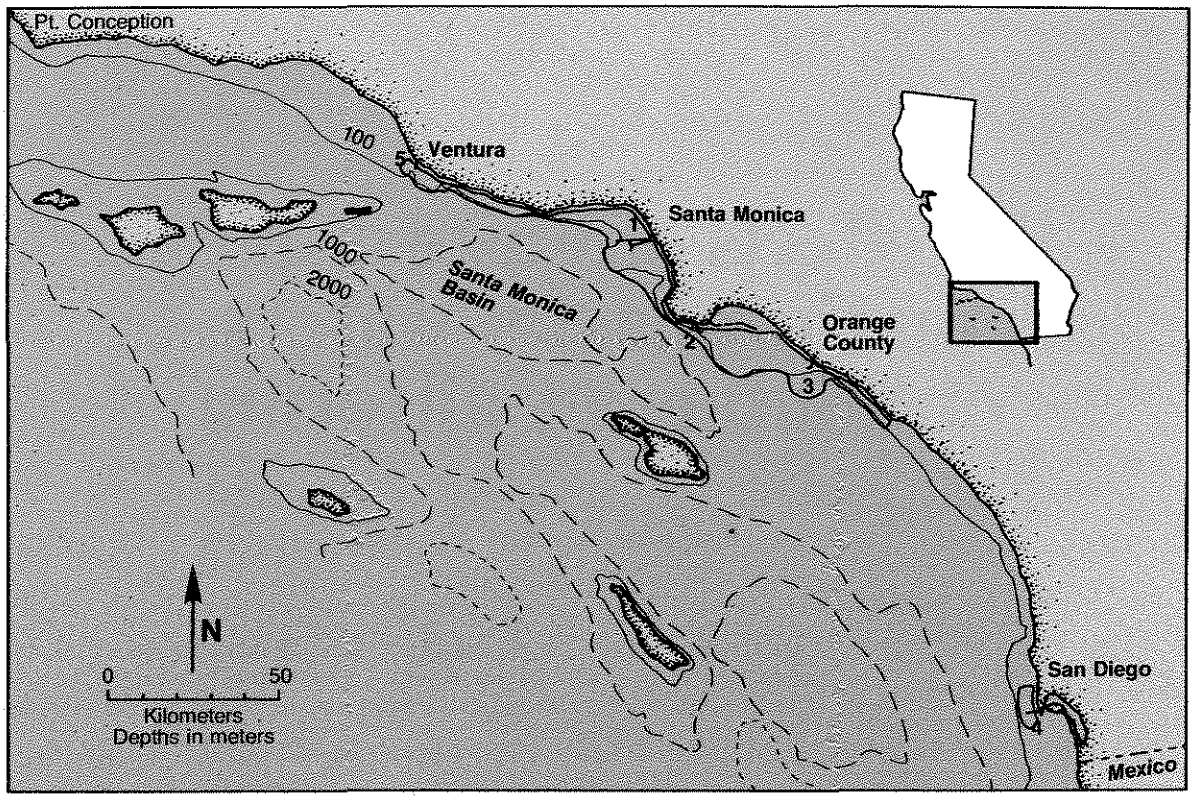
That financial support has been supplemented by a series of grants from EPA, the National Ocean and Atmospheric Agency, the National Science Foundation, the California State Water Resources Control Board, and others.

The director of the project is Willard Bascom, an oceanographer; its scientists are organized into three divisions: biology, chemistry, and engineering. The director and the scientists receive overall guidance and review from a consulting board of eminent scientists headed by Perry McCarty of Stanford University. This board (originally led by John D. Issacs of Scripps Institution of Oceanography) set the tone of the research by recommending that the project dedicate itself to "understanding the changing ecology of Southern California's inshore waters," rather than confining its work to areas near wastewater discharge points.

Scientific findings are regularly reported in biennial reports (*42*) as well as in professional papers in leading scientific journals.

The SCCWRP laboratory is in Long Beach, Calif., or in the coastal waters of California, depending on one's point of view.

FIGURE 1
The coastal area studied in the SCCWRP project[a]



[a]The Southern California coast faces a wide basin-and-range region that separates the coastal shelf from the deep ocean and influences waves and current. The large outfalls are numbered: 1. Los Angeles City, 2. Los Angeles County, 3. Orange County, 4. San Diego City, 5. Ventura County. The areas outlined in blue show the extent of SCCWRP's detailed ecological survey of the coastal shelf and slope. Grabs from 408 stations were taken and (mostly) analyzed for benthic infauna and chemistry.

warm current flows northward inside the islands bringing tropical life forms that influence the local ecology. Near the outfalls the subsurface currents are influenced by alternating tidal motions, but generally there is a net drift to the north and west that transports discharged waste constituents seaward. The surface currents are of less interest because wastes from deep outfalls rarely surface.

In this paper the following definitions apply: *Contamination* is an increase in some substance above its natural range. Contamination does not necessarily result in adverse effects and so is not synonymous with *pollution*, which means there is damaging excess of one or more contaminants. A *toxicant* is a substance that has the potential for causing harmful effects in an organism.

Man-made additions

All important sources of contaminants in the coastal waters of this region have been investigated. In approximate order of importance, the sources include municipal wastes, stream runoff, aerial fallout, harbor discharges, thermal discharges, and material from ships. The effects of the first are significant; the others are minor to negligible. Industrial wastes are subject to rigorous source-control before they go into the municipal sewage systems and are processed and discharged with the residential wastes as municipal waste.

Five entities contribute the major part of the wastewaters: Los Angeles County, Los Angeles City, Orange County, San Diego City, and Ventura County. Each of these treats sewage in different ways, mostly to a primary level but with varying percentages of secondary treatment. The treated effluents flow seaward through pipes 3–4 m in diameter and are released into the sea at a depth of about 60 m through diffusers with dozens of openings (*1*). The city of Los Angeles also discharges sludge through a 75-cm diameter pipe that opens at a depth of 100 m on the rim of a submarine canyon 10 km offshore. This last effluent contains a combination of digested primary sludge, secondary sludge, and secondary effluent; sewage solids account for less than 1% of the discharge.

Table 1 summarizes the concentrations of various materials contained in the approximately 4 billion liters of wastewater a day discharged by these five outfalls during 1979. Reports of the discharges to the the state, based on 24-hour composites of final effluent (measured daily for suspended solids, monthly for metals and chlorinated hydrocarbons) have been summarized annually by SCCWRP for the last decade. The discharge of large but unknown amounts of total DDT by a chemical company into the Los Angeles County sewer system stopped by June 1970. This was clearly the largest single cause of environmental damage. In spite of a steady increase in wastewater volume, the successful control of this source and others has resulted in a continuing decline in the amounts of all contaminants discharged except silver (*2*). The greatest decreases were achieved with DDT (now 3.5% of the 1971 value) and PCBs (now 13.6% of the 1971 value). Of the materials discharged, these two chlorinated hydrocarbons, which are most troublesome to marine organisms, are now discharged at levels from a few parts per billion to fractions thereof (*3*).

Upon discharge the wastewater immediately begins to entrain the surrounding seawater and to rise until the density of the mixture is equal to that of the surrounding water. In a matter of minutes, a dilution of 100 to 200 has been achieved. This dilute solution, which includes the bulk of the original particles, drifts off with the surrounding water and is very widely dispersed.

When the coastal water is stratified, which is the usual condition, this wasteplume is at a depth of 20 to 40 meters, and waste materials rarely reach the surface. However, during a few weeks in the winter when recreational use is minimal, wave action breaks up the thermocline/pycnocline stratification, and the coastal waters are mixed. Under these conditions the dilution is about twice as great as normal (*4*).

California state regulations contained in the most recent Ocean Plan, establish acceptable concentration standards for various possible pollutants that must be met by the dischargers (*5*). These levels are set so that when the effluent is diluted at least 100:1, the threshold of presumed toxicity to any sea animal, plus a reasonable safety margin, is not exceeded (*6*).

Because the dischargers comply with state regulations and the actual dilution is greater than required, the problem of protecting marine life is theoretically solved. However, the particles released agglomerate with each other and with those naturally present in the ocean. About 10% of the particles thus created are heavy enough to fall to the bottom near the point of release (*7*). Since most of the possible pollutants including about 90% of the metals, are attached to particles, there is a steady buildup of contaminants on the bottom near the discharge point (*8*). These are responsible for most of the biological effects observed. The sediments form patterns on the ocean bottom in accordance with the currents that determine their trajectory of fall. Usually the contaminants do not maintain their original level of potential toxicity because they are steadily altered by chemical–bacterial activity, mixed downward by bioturbation, buried by subsequent sedimentation, or stirred and dispersed by occasional violent storms. These factors, plus the reductions in discharge of contaminants that have occurred over the past decade, cause the toxicity threat to lessen with time.

FIGURE 2
Sea surface temperatures in the Southern California Bight[a]

[a]Thermal scan of sea surface temperatures made on Sept. 17, 1979 from NOAA-6 showing complex surface water motion in the Southern California Bight. The light-colored cold water of the main California current flows southward on the left side of the picture; dark relatively warm water intrudes from the south, setting up huge eddies. (Processed by the Remote Sensing Facility, Scripps Institution of Oceanography)

Sampling methods

The following is a brief summary of the equipment used in the ecological surveys. Ships about 20 m long were employed; the positions of the survey stations were determined within about 30 m using LORAN C; depths were obtained with a high-quality 50-kh echo sounder. For chemical determinations samples of the bottom were taken with a 0.1 m^2 Van Veen chain-rigged grab whose top can be opened so that smell, texture, and color can be recorded (*9*). For chemical analysis, five small cores of the undisturbed sediment surface were taken to a depth of 2 cm and composited in a glass jar. A second grab from the same location was screened for benthic infauna. Animals remaining on a 1.0-mm screen were preserved for later identification, counting, and weighing.

Bottom trawls were made with a standard net (otter boards with a 10-m headrope) and dragged along the bottom for 10 min at 1.1 m/sec. All fish were immediately identified, counted, and measured. For rocky bottoms that could not be trawled, an automatic 35-mm strobe camera was used. Alternatively, a television camera mounted on a sledlike frame was towed along the bottom to examine hard strata, sediments, and animals (*10*). Both invertebrates and fish could usually be identified at distances of 3–5 m. Trawls, cameras, hook and line, and other fishing methods each gave somewhat different but mutually supporting data.

Water samples to determine chemical concentration, plankton content, amount of solids, or toxicity were collected by means of pumps and hoses to depths of 120 m (*11*, *12*). Appropriate anticontamination procedures were used, depending on the purpose for which the samples were being taken.

All samples were brought to the laboratory for analysis, identification, dissection, and description. Of the nearly 5000 invertebrate species in these coastal waters, less than half have been adequately described in the taxonomic literature. Some animals have appeared in various reports under a dozen or more synonyms so that some of those originally thought to be missing from areas near outfalls were found to be present under another name. A taxonomic standardization program that involved over 200 local systematists led to uniformly correct identifications and resulted in two volumes of taxonomic keys describing many Southern California species (*13*).

Identifying affected areas

Environmental assessment requires that a comparison be made between an area thought to be contaminated and a similar region that has not been influenced by humans. Therefore, a control survey was made along the entire Southern California coast, a distance of some 400 km, at a depth of 60 m, the same as that of the large outfalls (*14*). At 71 stations spaced no farther apart than 10 km, samples of bottom muds and animals were taken. All locations where there was any indication that people (or natural oil seeps) had caused a disturbance were set aside. Twenty-eight control stations remained, the characteristics of which are summarized in Table 2. They show that under natural conditions there is considerable variation in the biota and chemistry. We submit that other stations in the area that fall within this range of conditions have the equivalent of control conditions.

In 1978 a new survey was begun to measure present environmental conditions on the coastal shelf off Southern California. The region covered included the area likely to have been affected by the outfalls and extended outward to control conditions. A series of transect lines were laid out perpendicular to the shoreline at intervals of about 4 km and sampling stations were located at 20-, 30-, 60-, 100-, 200-, 300-, and 500-m depths. A grid with points spaced 1 km apart was added to cover the area close to the two Los Angeles City outfalls in more detail. Now from Dana Point to Port Hueneme, a distance of about 100 km, over 350 stations blanket the shelf and slope. Figure 3 shows station locations and infaunal characteristics in the central part of the area that includes the outfalls in Santa Monica Bay and off Palos Verdes Peninsula.

Having mapped the biological situation on the bottom, the problem was to interpret its meaning in ecological terms. Three principal parameters of benthic infauna (number of species, number of individuals/m^2, and biomass/m^2) were used as the basis of Table 3 (*15*). These were arranged into groups according to Infaunal Index levels (see box). Control conditions had been identified previously.

The logic of the descriptive words in the left-hand column of that table is as follows: If all three of the principal parameters at any location are equal to or greater than control conditions, an area is "normal." This situation turned out to correspond to an Infaunal Index of 60 or above. If one of the parameters is lower than the control value, but the other two are equal or greater than controls, the situation is "changed." This applies to index values ranging from 30 to 60. Below an index of 30, the number of species is less than half of that of the average control station value, the number of individuals varies considerably, and the biomass is enhanced many times. We call a region with these conditions "degraded" be-

TABLE 1
Average concentrations in municipal waste discharges in 1979[a]

	Los Angeles County Palos Verdes	Los Angeles City Santa Monica Bay 5-miles	Los Angeles City Santa Monica Bay 7-miles	Orange County San Pedro Bay	San Diego Point Loma	Ventura County Port Hueneme
Distance of discharge offshore (km)	2.6	8	11	8	4	2
Depth of discharge (m)	60	60	100	60	60	16
Flow						
mgd	367	353	4.8	188	128	16.3
L/day × 10^6	1390	1336	18.1	712	484	62
General constituents (mg/L)						
Suspended solids	195	75	7,060	140	143	95
BOD	204	144	ND[b]	166	142	229
Oil and grease	39.9	19	400	26.0	36.7	14.5
NH_3-N	40.1	16.7	232	25.6	25.0	18.8
Cyanide (CN)	0.17	0.09	0.18	0.05	0.004	0.013
Phenols	2.6	0.06	0.53	0.06	0.18	0.12
Trace metals (mg/L)						
Silver	0.019	0.044	0.70	0.011	0.023	0.020
Arsenic	0.010	0.013	0.22	0.003	0.009	0.005
Cadmium	0.027	0.02	0.80	0.047	0.009	0.014
Chromium	0.257	0.07	5.33	0.114	0.054	0.055
Copper	0.220	0.19	8.7	0.291	0.131	0.099
Mercury	0.0010	0.0025	0.062	0.0005	0.0016	0.0015
Nickel	0.21	0.16	3.4	0.14	0.07	0.043
Lead	0.145	0.15	4.89	0.11	0.092	0.093
Selenium	0.013	0.002	0.052	ND[b]	ND[b]	ND[b]
Zinc	0.69	0.31	15.0	0.34	0.22	0.12
Chlorinated hydrocarbons (μg/L) (discharger values)						
Total DDT	1.4	0.18	0.89	Not detected	0.2	ND[b]
Total PCB	0.69	0.61	9.32	1.64	0.2	
Total identifiable chlorinated hydrocarbons	2.17	0.86	10.8	1.65	0.4	

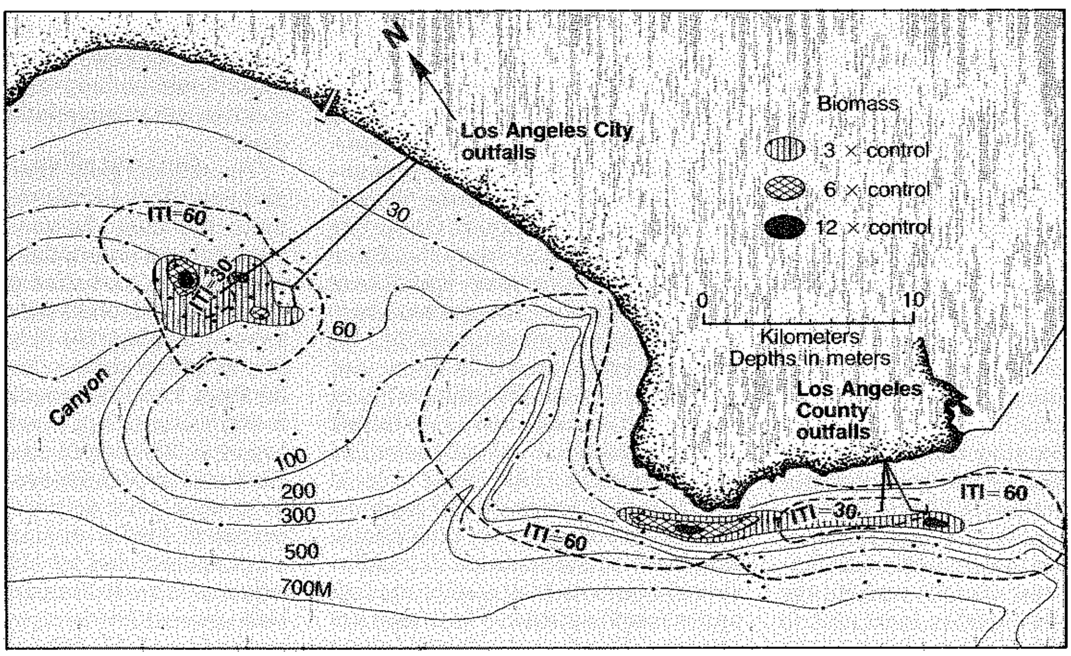
[a] Average concentrations of general constituents, trace metals, and chlorinated hydrocarbons in the final effluent of municipal waste discharges in 1979 (assembled by H. Schafer (*2*)).
[b] ND = no data.

TABLE 2
Summary of control survey data taken in pristine areas[a]

	Number of samples	Mean value	Range of values Low	High
Sediments (upper 2 cm)	28			
Sand (%)		40	7.6	83.7
Volatile solids (%)		2.8	1.8	3.8
Chemical oxygen demand		20 160	17 780	25 600
Silver (mg/dry kg)		0.38	0.06	1.7
Cadmium (mg/dry kg)		0.39	0.1	1.4
Chromium (mg/dry kg)		23.1	6.5	43
Copper (mg/dry kg)		9.1	2.8	31
Nickel (mg/dry kg)		12.2	1.6	35
Lead (mg/dry kg)		6.6	2.7	12
Zinc (mg/dry kg)		42.2	9.8	62
Benthic infauna	29			
Number of species		71	40	124
Infaunal Index		93.5	83.1	98.3
Shannon–Weaver diversity		3.05	2.19	3.98
Biomass (g/m²)		70	28	112
Fish (trawl data)	28	Median		
Number of species		14.5	12	16
Number of individuals		378	186	623
Biomass (kg)		4.7	3.2	7.9
Shannon–Weaver diversity		1.38	1.22	1.57
Invertebrates (trawl data)	28			
Number of species		10.5	7	14
Number of individuals		181	90	351
Biomass (kg)		7.4	2.5	12.5

[a] Data were taken in pristine areas at a depth of 60 m along the Southern California coast. Metals are those available in hot nitric acid digestion (from J. Q. Word and A. J. Mearns (14)).

FIGURE 3
Areas of change in the Santa Monica Bay and off the Palos Verdes peninsula[a]



[a]A section of the ecological survey shown in Figure 1 that includes Santa Monica Bay and the Palos Verdes peninsula. Locations of 150 benthic sampling stations are indicated by dots. The dashed lines are drawn through Infaunal Index values of 60 and 30 to show the area of change. The shading within the changed area shows where the biomass is greater than at controls by factors of 3, 6, and 12. These are not "monitoring" stations in the sense that word is used in California. Monitor refers to measurements or samples taken by the dischargers at specific locations and intervals around the outfalls as required by state and local governments. Each discharger makes his own measurements and reports directly. The values so obtained are in good agreement with those given here.

cause we think it may reflect toxic effects as well as feeding characteristics.

Figure 3 shows the areas around two outfalls enclosed by dashed index isolines of 60 and 30; on the same chart the regions of very high biomass are also plotted. It can be seen that substantial increases in biomass exist in the region that is "changed." The apparent causes of this increased biomass are an enhancement in the number of animals that are able to capitalize on the new food supply and the larger than average size of individual animals. Mearns and Word estimated that the increase in benthic biomass due to the four large discharges is 20 000 metric tons. The increase in each area was found to be proportional to the amount of solids released by the nearby outfall (*16*).

The only two "degraded" areas in Southern California are those shown in Figure 3 (3 km^2 at Los Angeles City and 9 km^2 at Los Angeles County). For the same two outfalls the "changed" areas, within the index isoline of 60, are 48 km^2 and 85 km^2, respectively. The size of "changed" areas around other outfalls are: San Diego, 4 km^2; Orange County, 10 km^2; Ventura is normal (*15*).

Fish and their diseases

Fisheries in Southern California are generally in good condition. Excluding the sardine, commercial landings from 1930 to 1975 increased at a rate of about 1200 m tons/year. Sport fish landings nearly doubled in the last 25 years. However, it is not known whether the increased catch is due to a change in abundance or in fishing effort. Because both the outfalls and the fishermen's operating ports are in urban areas, approximately one-third of the party-boat catches and commercial fish landings occur within 10 to 20 miles of the large waste discharges (*17*). The area most influenced by the "seven-mile sludge line" is a favorite fishing site for party boats.

Studies of demersal fish and epibenthic invertebrates were conducted using standard trawls. At the 60 m control stations on soft bottom, the average number of fish species caught in a standard trawl is 14.5, with a biomass of 4.7 kg. At the most contaminated location in Santa Monica Canyon below the sludge outfall, the number of fish species increased to 17.4 ± 5 and the biomass to 40.7 ± 30 kg. These levels are about the same as those at Redondo Canyon, which receives some of the Los Angeles County waste particulates. Both canyons have higher values than those in three roughly comparable areas where natural conditions prevail.

In the last decade over 300 000 fish representing 151 species taken in the coastal waters and near some of the offshore islands have been examined. One objective of this work was to identify the types and frequency of fish disease and to determine whether human wastes are a likely cause of disease. About 5% of these fish showed some external abnormality (*18*). The two types of disease that were most prevalent and received particular attention were external tumors and fin erosion.

In Southern California, skin tumors occur commonly in young Dover sole, but the prevalence of tumors in these fish is low in comparison with the number found in other species of cod and flatfish living far away from major sources of contamination in Alaska and British Columbia (*18*). The wide distribution of fish tumors in time and space suggests that they are not related to the discharge of municipal wastewater.

During the last decade, fin erosion has been found in 33 species of fish in the region of the Palos Verdes shelf, but it is rare in all species except Dover sole, Rex sole, calico rockfish, and green striped rockfish. These are small fish, rarely taken except in scientific trawls.

In 1977 samples taken with trawls on the Palos Verdes shelf at depths between 23 and 137 m showed that 39% of the Dover sole and 28% of the calico rockfish had fin erosion. A few kilometers to the north or south the frequency was down to one-tenth those values, and at control stations the incidence is less than 1% for Dover sole.

Dover sole with fin erosion are occasionally trawled in Santa Monica Bay and San Pedro Bay, but these fish may have migrated from the Palos Verdes shelf. Various hypotheses about the origin of this disease (bacteria, abrasion, macroparasites, fin nipping, H_2S in interstitial water, and high metal levels in the sediment) have been tested and rejected (*19*). In this region fin erosion is related to the Los Angeles outfall. The Dover sole in Southern California is far from its main range and was rarely caught there before the outfalls existed. It may be that the outfalls both attract the fish and induce the disease. Fin erosion has also been found near industrial areas of Seattle, Boston, and various foreign cities. Although a cause and effect relationship has not been established, data from various studies suggest that petroleum products and/or synthetic organic compounds such as PCBs contribute to the development of this disease (*18*, *19*, *20*).

Sardines, a very important commercial fish in California before 1950, are now relatively rare. Their population fluctuates for reasons not related to pollution. Studies of fish scales in varves in the Santa Barbara basin sediments have shown that sardines have been present in large numbers 12 times during the last 1800 years for periods of 20 to 100 years (*21*). The rest of the time there have been few in the region, as there are few at present.

Algae

The Palos Verdes peninsula has been a favorite collecting ground for phycologists for the past 100 years. As a result there are reasonably good records of the intertidal algae there in 1895–1896, 1908–1912, 1957, 1973–1976, and 1978–1980 (*22*). This relatively long time-series shows that the originally high species diversity went through a low point in the 1950s but now is higher than ever recorded. To some extent these data may reflect the level of scientific knowledge and effort that went into each of the surveys, but there is little doubt that a temporary decline was somehow connected with the Los Angeles County outfall. At White's Point, for example, the number of species recorded went from 64 in 1910, to 30 in 1957, to 53 in 1975, to 107 in 1979. Although the reasons for the changes are not known with certainty, it is probable that one or more pollutants (DDT and suspended solids), as well as oceanographic factors (warm water, storms), local construction, and trampling contributed substantially to the decline.

The subtidal giant kelp *Macrocystis pyrifera* at Palos Verdes has fared much the same. In water depths to 20 m, it forms underwater forests whose canopies are harvested for food and chemicals, and whose stipes and fronds serve as a refuge for fish. In the first quarter of this century, the canopies of the Palos Verdes kelp beds covered 600 to 800 hectares. Apparently the decline began in 1937 with the first waste discharge and continued until about 1958 when giant kelp virtually disappeared. In 1967 a restoration program was initiated, and by 1974 new beds began to form. In December 1980 the beds covered 280 hectares, about the same area as in 1948 (*23*) (Figure 4).

All kelp beds off Southern California decreased in size during the warm water years of 1957–1959, but most

TABLE 3

Relationship between the Infaunal Index and several infaunal characteristics[a]

Zone	Infaunal index	Average no. of species/0.1 m^2	Dominant feeding strategy of infauna	% in Groups I, II	% in Groups III, IV	Average biomass (g/m^2)	Average no. of individuals/m^2	Average BOD of sediments (mg/dry kg)	% Volatile solids in sediments
Normal (Control: 100–80)	90	71 ± 4 (n = 29)	Subsurface feeders	96	4	70 ± 5 (n = 29)	4230 ± 240 (n = 29)	632 ± 38 (n = 29)	2.8 ± 1 (n = 29)
Normal (100–60)	70	77 ± 7.2 (n = 23)	Subsurface feeders	79	21	81.7 ± 9.7 (n = 18)	6179 ± 720 (n = 23)	870 ± 123 (n = 18)	3.9 ± 0.7 (n = 37)
Changed (60–30)	50	69 ± 5 (n = 30)	Surface feeders	56	44	168 ± 47 (n = 30)	7725 ± 1886 (n = 30)	1,188 ± 174 (n = 10)	5.2 ± 1.3 (n = 23)
Changed (60–30)	40	48 ± 2 (n = 38)	Surface feeders	21	79	254 ± 65 (n = 21)	8935 ± 1056 (n = 38)	2,421 ± 600 (n = 22)	5.8 ± 0.8 (n = 20)
Degraded (30–0)	20	31 ± 2.4 (n = 12)	Suspension feeders	19	81	623 ± 160 (n = 12)	3480 ± 763 (n = 12)	12 893 (n = 3)	11.6 ± 4.7 n = 3)
Degraded (30–0)	10	23 ± 2 (n = 25)	Suspension feeders	7	93	223 ± 71 (n = 25)	6401 ± 1005 (n = 25)	17 021 ± 2038 (n = 9)	20.6 ± 2.7 (n = 9)

[a] The relationship between the Infaunal Index and other characteristics of the infauna that were used to establish zones of normal, changed, and degraded. From W. Bascom, A. J. Mearns and J. Q. Word (*15*).

began to increase again in the 1960s, while the Palos Verdes beds continued to decline. The special factors detrimental to the Palos Verdes beds were smothering of rock in shallow water by floc from wastewater that prevented the attachment of young plants, reduction of light by suspended particles in the water, overgrazing by sea urchins, high concentrations of potentially toxic compounds, intensive use of the area by sport fishermen and divers, and burial of the deeper rocky substrates by sediments (*24*). Although great improvement is evident and kelp now grows to depths of 13 m, recovery is not yet complete.

Contaminants in the food web

Most animals in the sea live by eating smaller animals, the larger ones taking into their guts whatever toxic materials the smaller ones possess. Thus the concentration of toxicants may increase in the muscle tissue or vital organs of animals at higher trophic levels. A much debated question is whether there is biomagnification of pollutants in the marine food web. The answer is mixed. Metals in their usual inorganic forms do not increase in muscle tissue with trophic level; organic materials do, including synthetic chemicals such as PCBs and pesticides as well as organic forms of metals, such as methyl mercury. These statements are useful generalities to which there may be exceptions caused by differences in the age or size of the animal, unusual availability of certain foods, or lipid content of the organs measured.

Table 4a presents the tissue concentrations of organic compounds and metallic trace elements in Southern California's coastal pelagic foodweb. The fish were selected to cover the widest possible range of trophic levels as determined by stomach content and cesium–potassium ratios, the latter being a chemical indicator of trophic level (*25*, *26*). Contaminants in these fish are presumed to represent background conditions.

Table 4b gives data on contaminants in the food web on the Palos Verdes shelf, a region influenced by the Los Angeles County outfall. With the possible exception of zinc (which arguably decreases with increasing trophic level), the concentrations of inorganic metals do not change much throughout the food web. Man-made organic compounds and organic mercury (the latter probably not a result of the outfall discharges) increase with trophic level (*27*). A comparison of Tables 4a and 4b shows that although metals are similar in both food webs, there is a great deal more total PCB and total DDT in the animals near the outfall.

The best known example of toxicant accumulation at a high trophic level is that of the brown pelican, whose numbers on the Anacapa Island rookery dwindled to a few hundred in the late 1960s as a result of DDT issuing from an outfall (*28*). The route by which the DDT reached the pelicans is not clear; possibly it was via anchovies that had eaten contaminated particles. A few years later the deaths at the Los Angeles Zoo of captive sea birds that had been fed on queenfish from the outfall area (also high in DDT) gave additional confirmation (*29*). The DDT discharge was stopped in 1970 as soon as it was detected, and in recent years the level of DDT in the marine environment has been relatively low. The pelicans have returned and are present in what are believed to be normal numbers; 2150 nests were reported on Anacapa Island at the end of 1980 (*30*).

Metals in the sea and from effluents are nearly all attached to particulates (*31*); only rarely do they exist in the sea in the free ionic form usually used in toxicity tests. Therefore, it does not seem reasonable to base opinions about metal toxicity in particulate-laden coastal waters on data taken under radically different conditions in clean glass tanks (*32*). Realistic toxicity values can be obtained only from tests that use or simulate the real world.

Brown has demonstrated that animals have a substantial capability for effectively detoxifying some inorganic metals (Cd, Cu, Zn, Hg, Sn, Ag, Be) with the sequestering protein metallothionein (*33*). Later work showed that Au, Bi, and Ni are also detoxified. When metals are bound to metallothionein in a cell, they are, in effect, partitioned away from enzymes, nucleic acids, and other sites of toxic action. Thus it appears probable that most metals, at levels and in forms resulting from marine outfalls, aren't a serious threat to marine animals (*34*).

Metals are often found in high concentrations in surface sediments near outfalls. Figure 5 shows the distribution of chromium in the surface sediments of Santa Monica Bay (*35*). The patterns of other metals on the bay floor are similar. However, even when there are high metal levels in the sediment, the level in interstitial water rarely exceeds 10 times the background level of that metal in seawater (which ranges from 0.01–1.0 μg/L) (*36*). Moreover, the highest levels of metals measured in invertebrates taken from very contaminated bottoms are rarely over 10 times the levels in animals from control sites (a few parts per million) (*37*).

Bacteria and viruses

Human coliform bacteria, sometimes accompanied by pathogenic bacteria, are discharged in large numbers by all outfalls. These join the numerous marine bacteria and other microorganisms that are naturally present in seawater. These harmless coliform bacteria, which are also produced by whales and sea lions, are used as a convenient indicator of the possible presence of pathogens. If the incidence of disease is small in the population on shore, as it is in most U.S. cities, pathogenic bacteria are not likely to be present in significant levels in the sea. As far as can be determined, there has never been a case of human sickness caused by bacteria or viruses from outfalls in the open coastal waters of Southern California. Samples of water at many beach and near-shore stations are monitored daily for coliform. With rare exceptions they meet the California State Ocean Plan standard, which requires (in water used for body contact sports) that a level of 1000 coliform per 100 mL be exceeded no more than 20% of the time

The Infaunal Index

The interest of many nonscientists in the ecological findings required more understandable ways to be developed for describing the relative condition of benthic animal communities. The Infaunal Index, proposed by Word (*39*, *40*), is based on an approach previously used in the Great Lakes (*41*). It makes use of 53 indicator animals that were selected on the basis of their abundance in areas near and away from outfalls. These dominant animals, which represent about 1% of the total number of species that might be encountered, are divided into four roughly equal groups according to their observed response to benthic conditions. The numbers of individuals in each group captured in a grab are inserted in a simple formula and a value between 0 and 100 is obtained, which is commonly known as the Infaunal Index. This empirical number is indicative of the overall response of a benthic community to changes in the quality of the bottom caused by the addition of organic solids. As the amount of particulate material in the water and the amount of organic detritus on the bottom increase, the benthic community shifts from dominance by predominantly suspension feeding animals of Group I toward dominance by the subsurface and detritus feeding animals of Group IV.

Because the Infaunal Index is a single number, data from a survey using this characteristic can be plotted on a chart to show how community structure shifts with the change in food supply. Thus it is especially useful for determining the extent of outfall effects.

The Infaunal Index, formerly called the Infaunal Trophic Index (ITI), is calculated by the formula:

$$ITI = 100 - \left[33\tfrac{1}{3}\left(\frac{0n_1 + 1n_2 + 2n_3 + 3n_4}{n_1 + n_2 + n_3 + n_4}\right)\right]$$

where n_1 is the number of individuals in Group I. The coefficients in the numerator of the equation (0, 1, 2, 3) are simply scaling factors. Other numbers could be used; as long as the coefficients evenly increase (or decrease), they serve to generate index values that change gradually and evenly as infaunal feeding strategies change.

The values of the Infaunal Index range from 0 to 100.

The Infaunal Index has been under constant review since its inception. During the past year we have decided to omit any reference to "trophic" in the index and make it simply reflect the empirical changes in animal assemblages along the outfall gradient. In the revised version, full scientific names (usually to species level) will be used; the number of groups will be reduced to three: control, transition, and polluted.

The 53 invertebrate taxa used in the Infaunal Index

Group I Suspended detritus feeders	**Normal**	**Active**
Passive	*Owenia* (Po)	*Nemocardium* (Pe)
Maldanidae (Po)	Sabellidae (Po)	*Crenella* (Pe)
Onuphidae (Po)	Serpulidae (Po)	*Ampelisca II* (A)
Ampharetidae (Po)	*Amphipholis* (E)	*Byblis* (A)
Terebellidae (Po)	*Amphiodia* (E)	Phoxocephalidae (A)
	Phoronis (Ph)	*Cucumaria* (E)
	Caprellida (A)	*Sthenelanella* (Pe)
	Ampelisca I (A)	
Group II Surface detritus feeders	**Mobile**	**Specialized**
Stationary	Orbiniidae (Po)	*Cistena californiensis* (Po)
Spionidae (Po)	Capitellidae (Po)	
Magelonidae (Po)	*Mediomastus*	
Cirratulidae (Po)	*Decamastus*	
Myriochele (Po)	*Nephtys* (Po)	(A) = Arthropoda
Axinopsida (Pe)	*Glycera* (Po)	(AN) = Annelid
Mysella (Pe)	*Goniada* (Po)	(E) = Echinodermata
Calyptogena (Pe)	Tanaids (A)	(G) = Gastropoda
Photis (A)	Ostracoda (A)	(Pe) = Pelecypoda
	Euphilomedes	(PH) = Phoronid
	Cumacea (A)	(Po) = Polychaeta
Group III Surface deposit feeders	**Mobile**	
Stationary	*Travisia* (Po)	
Parvilucina tenuisculpta (Pe)	*Nereis* (Po)	
Macoma carlottensis (Pe)	*Bittium* (G)	
Nuculana (Pe)	Mitrella *permodesta* (G)	
Nucula (Pe)	*Nassarius* (G)	
Yoldia (Pe)		
Group IV Subsurface deposit feeders		
Capitella capitata (Po)		
Armandia bioculata (Po)		
Ophelina acuminata (Po)		
Oligochaeta (An)		
Solemya (Pe)		
Stenothoidae (A)		
Dorveilleidae (Po)		

TABLE 4a

Open coastal pelagic food web [a]

	No. samples	Composited animals/ sample	Trophic level	Cs/K × 10^{-6}	Organic compounds mg/kg wet wt. Total PCB	Total DDT	Methyl Hg	Inorganic metals mg/kg wet wt. Hg	Cd	Cr	Cu	Ni	Zn	% Dry wt.	% Lipi
Mako shark	5	1	4.40	18	0.038	0.13	1.42	0	0.03	0.06	0.32	<0.04	3.9	26	1.4
Swordfish	5	2	3.97	11	0.017	0.10	1.20	0	0.08	0.02	0.31	<0.02	6.2	25.3	3.7
Bonito	5	10	3.80	9.6	0.026	0.20	0.20	0.02	0.01	0.04	0.34	0.08	3.5	27	1.0
Pacific mackerel	7	10	3.54	6.9	0.020	0.05	0.09	0.02	0.06	0.03	0.38	<0.08	4.4	28	1.5
Sardine	5	10	3.01	4.0	0.108	0.53	0.01	0.04	0.02	0.04	0.25	<0.08	3.6	30	3.6
Anchovy	5	30	2.82	1.5	0.005	0.004	0.02	0.01	0.16	0.07	0.34	<0.04	8.9	23	1.9
Zooplankton	5	>100	2.0	2.7	<0.004	0.01	<0.01	<0.02	0.86	0.08	0.98	0.31	9.6	12	1.1

TABLE 4b

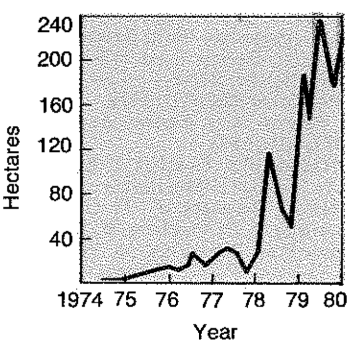
Food web off Palos Verdes, within 3 km of outfall [a]

	No. samples	Composited animals/ sample	Trophic level	Cs/K × 10^{-6}	Total PCB	Total DDT	Methyl Hg	Hg	Cd	Cr	Cu	Ni	Zn	% Dry wt.	% Lipi
Spiny dogfish	5	1	4.16	32.9	3.10	44.0	1.48	0.20	0.12	0.03	0.11	<0.02	3.8	27.3	10.5
Scorpion fish	5	2	4.53	6.5	0.048	0.22	0.22	0	<0.01	<0.02	0.18	<0.03	2.3	22	0.8
Dover sole	5	10	3.52	3.4	0.255	5.99	0.02	0.03	<0.01	<0.01	0.15	<0.02	2.7	20	1.4
Sicyonia	5	15	3.33	2.8	0.051	0.283	0.05	0.02	0.01	0.16	5.3	<0.02	11.8	24	1.1
White croaker	5	10	3.36	2.1	0.354	7.52	0.06	0.01	<0.01	<0.01	0.24	<0.02	1.9	22	1.8
Mysids & decapod shrimp	5	>100	2.78	9.7	0.031	0.39	—	0.01	0.05	0.70	2.0	0.27	15.3	12	1.2

[a] Concentrations of organic compounds and inorganic elements in the muscle tissue of animals of the coastal pelagic foodweb are compared with those from animal found near a large outfall (*27*). All concentrations are medians of the multiple samples in mg/kg wet weight. High lipid concentrations, given in percentage of wet weigh help explain the high level of PCB and DDT in large sardines that may have spent some time near an outfall. Inorganic mercury concentrations are total mercury les the benzene-extractable fraction shown in the column for organic mercury. In all cases lead was less than 0.12 mg/kg and silver was less than 0.01 mg/kg (*27*).

FIGURE 4

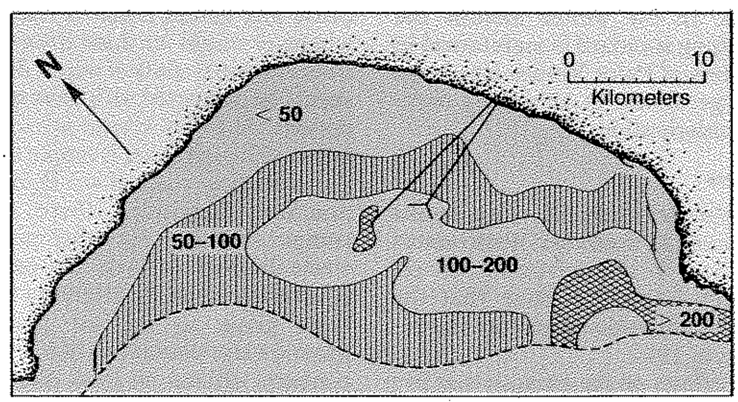
Area of the canopy of giant kelp at Palos Verdes[a]



[a]The area of the canopy of giant kelp (*Macrocystis pyrifera*) was measured at Palos Verdes from 1974 to 1980 (from Wilson et al. (*23*)).

FIGURE 5

Distribution of chromium in the upper 2 cm of Santa Monica Bay sediments[a]



[a]Other metals make similar patterns. Numbers are chromium values in mg/dry kg (*34*).

Principal foods from stomach analysis			
Pacific & jack mackerel	73%	Other fish	27%
Anchovy	43%	Hake	42%
Anchovy	98%	Other fish	1%
Anchovy	47%	Mycids	47%
Copepods	98%	Crab zoea	1%
Copepods	65%	Detritus	34%
Diatoms & dinoflag-ellates	85%	Green algae (halo-sphaera)	15%
Squid	70%	Midshipman, white croaker	8% 8%
Cancer crabs	100%		
Poly-chaetes	67%	Micro crusta-ceans	32%
Gastro-pods	75%	Micro crusta-ceans	25%
Poly-chaetes	57%	Copepods	40%
Copepods, clado-cerans		Diatoms detritus	

in any month, and for shellfish harvesting, coliform in the adjacent water may not exceed 330/mL. In recent years no swimming beaches or shellfish harvesting areas have been closed because of bacteria originating from deep outfalls. In the winter months the shellfishing standard is maintained in the waters of Palos Verdes (the large discharge closest to shore) by occasional chlorination.

Overview

Careful measurements of the results of discharging municipal wastewaters into the marine environment off Southern California show that the following situation existed at the beginning of 1982.

The effects on the animals that live in the bottom are localized in clearly identified areas where detrimental factors, such as a reduction in the number of species, are somewhat compensated for by an increase in the number of individuals and total biomass. About 3 km^2 around one outfall and 9 km^2 around another are the only areas on the coast that can be described as "degraded." Even in these regions there are an average of 26 benthic species with an average biomass five times greater than control values.

Fish and epibenthic invertebrates have increased in biomass, number of individuals, and (in some places) number of species as a result of the waste discharges. The total increase in the mass of animals caused by the outfalls has been estimated at 20 000 tons (*38*). Sport fishing appears to have improved and party boats often fish around the outfalls, but there is no hard data to support this opinion.

Near one outfall, fin erosion affects several species of fish that are rarely taken except in scientific trawls. No human sickness has ever been attributed to the discharges.

In areas where serious damage to the environment has been observed in the past, there has been notable recovery of the marine life. The once-threatened pelicans are back in force, and in a region where marine algae were in very poor condition only six years ago, there are now more species of intertidal algae than ever before noted, as well as large beds of giant kelp. This demonstrates that sea life is resilient and that environmental problems caused by waste discharge can be reversed in a few years. Improvements in treatment and source control have helped nature rectify many of the environmental wrongs of the past.

In summary, environmental conditions are not as good in all respects as one would wish, but there are no very serious problems either. In some coastal regions, the ocean is probably the most ecologically satisfactory place to dispose of municipal wastes. Because any action taken is relative to whatever might be done instead, the environmental costs of ocean disposal should be compared with those of other options that may create worse problems. Although there is ample data on the ecological costs of sea disposal in Southern California, there are no comparable data for other proposed waste disposal methods. For example, equivalent scientific attention has not been given to the air pollution, groundwater contamination, and detrimental effects on land plants and animals caused by onshore disposal.

Extensive ecological studies such as this one are undertaken to help society solve its problems by making facts available so that rational decisions can be reached. We hope these data will be so used.

Much other good scientific work, too extensive to mention here, has been done on waste effects in Southern California waters by scientists from the University of California (Scripps Institution of Oceanography, Los Angeles, Santa Barbara), University of Southern California, California Institute of Technology (Environmental Quality Laboratory), and other universities, as well as by California Fish and Game, National Marine Fisheries, and the Bureau of Land Management. Subject material included stable isotopes of C and N, Pb 210 in basin sediments, effects of wastes on plankton, algae, and kelp, fish abundance, and metals in seawater.

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