Assessment of Benthic Infauna on the Mainland Shelf of Southern California

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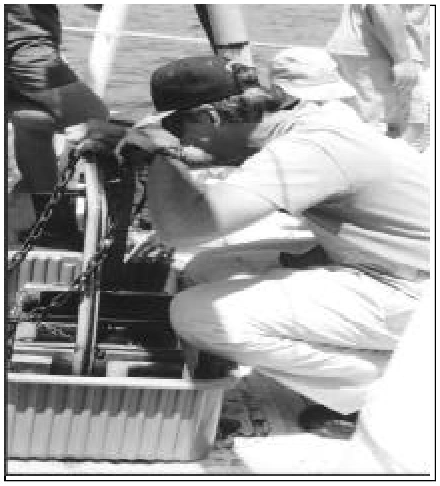

ABSTRACT

In order to assess the biological condition of the sediment, benthic infauna were sampled from 251 Southern California Bight (SCB) continental shelf sites in the summer of 1994. Sample sites were selected using a stratified random design, with the primary strata being depth zone, geography, and proximity to point and non-point discharges. Benthic infaunal condition was assessed using the Benthic Response Index (BRI), and by comparing dominant taxa and community parameters (e.g., number of taxa) of the sampling strata most likely to be influenced by point and non-point discharges with those for the SCB as a whole. Ninety-one percent of sediments in the SCB were found to contain healthy benthic communities. Most stations with altered benthos were located near river mouths, in Santa Monica Bay, or on the Palos Verdes Shelf. Deviations from reference condition, where observed, were mostly small and limited to minor changes in species composition, rather than decline in diversity or loss of abundance.

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INTRODUCTION

Benthic organisms are reliable indicators of environmental stress and are used worldwide for assessment of marine sediment condition (Pearson and Rosenberg 1978, Word and Mearns 1979, Gray *et al.* 1990, Anderlini and Wear 1992, Weisberg *et al.* 1997). In southern California, benthic organisms have been used to assess the effects of municipal wastewater outfalls (e.g., Bascom 1978, Stull *et al.* 1986, Zmarzly *et al.* 1994, Diener *et al.* 1995, Dorsey *et al.* 1995, Stull 1995); thermal and industrial discharges (e.g., Southern California Edison Company 1997); disposal of dredged material and drilling muds (U.S. EPA 1987); and stormwater runoff (Bay and Schiff 1997).

Most of the benthic monitoring in southern California is designed to evaluate the localized effects of individual sources (e.g., an outfall or disposal of dredged material), rather than to evaluate the cumulative environmental health of the region. A few studies have collected data beyond the local scale, but these studies have not focused on regional assessment. Between 1956 and 1959, scientists at the University of Southern California collected 862 benthic infaunal samples in the area between Point Arguello and 4 km south of the United States/Mexico international border. This sampling provided the foundation for our current knowledge of benthic assemblages in southern California (Allan Hancock Foundation 1959, 1965; Stevenson 1961, Barnard and Hartman 1959, Barnard and Ziesenhenne 1960, Jones 1969), but was never used for regional environmental assessment. In 1977, scientists at the Southern California Coastal Water Research Project (SCCWRP) collected benthic samples at intervals of approximately 10 km between Point Conception and the

United States/Mexico international border (Word and Mearns 1979). These data were used for environmental assessment; however, the assessment was limited to the 60 m depth contour. Surveys with fewer sites and more depths were conducted in 1985 (Thompson *et al.* 1987) and 1990 (Thompson *et al.* 1993), but the objective of these samplings was to provide information on reference conditions, not environmental assessment.

Effective management requires regional assessment (NRC 1990). Regional assessment provides the opportunity to appraise cumulative effects, particularly from episodic and non-point sources that cannot be assessed using local data alone. Regional assessment also allows managers to develop regional priorities by comparing the relative importance of different pollutant sources and different chemical groups. Recognizing the need for regional assessment, in the summer of 1994 12 agencies joined in a cooperative sampling effort, referred to as the Southern California Bight Pilot Project (SCBPP), to assess the ecological health of southern California's mainland shelf (SCBPP Steering Committee 1998). One part of that effort, which is presented here, is an assessment of the ecological health of soft-bottom habitats.

METHODS

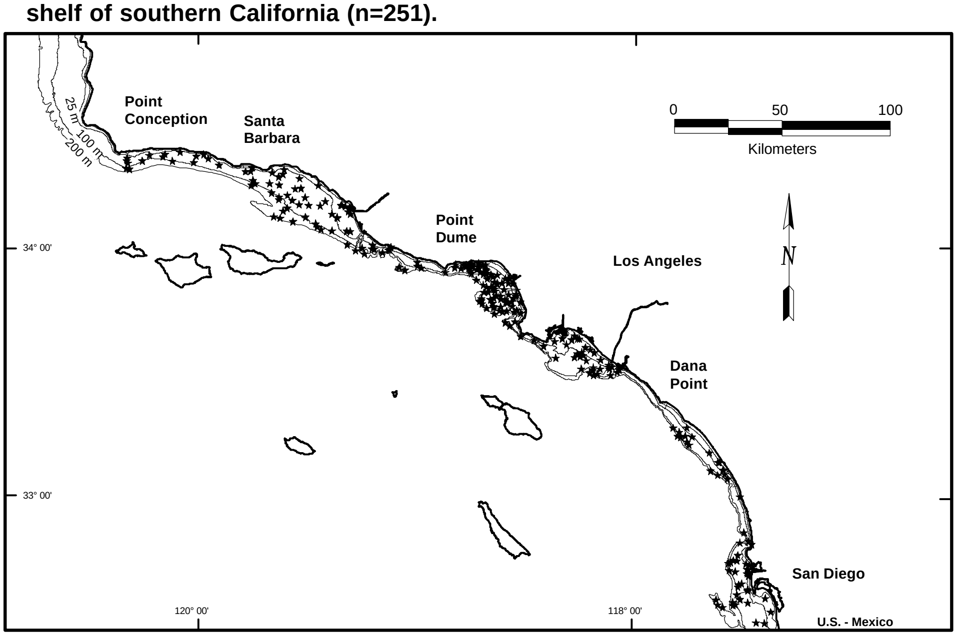
Between July 13 and August 22, 1994, 251 sites on the southern California continental shelf (defined as 10-200 m deep) from Point Conception, California, to the United States-Mexico international border (Figure 1) were sampled for benthic infauna. Sites were selected using a stratified random design, with the primary strata being depth zone (inner shelf from 10-25 m, middle shelf from 26-100 m, and outer shelf from 101-200 m); geography (Santa Monica Bay); and proximity to input sources (wastewater outfalls and river mouths) (Figure 2). Details of sample design, including site selection, are provided in Bergen (1996), Stevens (1997), and Bergen *et al.* (1998).

Sediment samples were collected using a 0.1 m^2 Van Veen grab. Only samples with a penetration depth of at least 5 cm and no evidence of disturbance (e.g. washout) were accepted for processing. Sediment for infaunal analysis was sieved through a 1 mm mesh screen. The material retained on the screen was placed in a relaxant solution of 1 kg of $MgSO_4$ per 20 L of seawater for 30 min and then preserved in 10% sodium borate buffered formalin. Sediment samples for total organic carbon (TOC), sediment grain size, trace metals, DDTs, PCBs, and PAHs were taken from a second grab sample. Sediment chemistry samples were taken from the top 2 cm of the grab (Schiff and Gossett 1998).

Infaunal samples were sorted into six major taxonomic categories (annelids, arthropods, molluscs, ophiuroids, other echinoderms, and other phyla), and the wet weight of each group was measured to the nearest 0.1 g. Specimens were then identified to the lowest practicable taxon and enumerated. Details of methods used for sample collection and processing, including evaluation of quality assurance and control procedures, are presented in Bergen *et al.* (1998).

Data were analyzed by comparing dominant taxa and mean community parameters (e.g., number of species) between strata of potential concern (Santa Monica Bay, areas around wastewater outfalls, and stormwater discharge areas) and other areas of the SCB. Community parameters included number of species, Shannon-Wiener Diversity (H'), evenness (H'/$\log_2$s), dominance (), and the percent of abundance and biomass comprised by major phyletic groups. Since community parameters and species composition are naturally affected by depth (Bergen *et al.* 1998), comparisons were made between similar depth zones.

FIGURE 1. Location of benthic infaunal stations sampled on the mainland shelf of southern California (n=251).



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

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

where m is the mean concentration for population j; p_i is the parameter value (e.g., concentration) at station i; w_i is the weighting for station i, equal to the inverse of the inclusion probability for the site; and n is the number of stations sampled in population j.

The ratio estimator was used in lieu of a stratified mean because an unknown fraction of each stratum was unsampleable (e.g., hard bottom). Thus, the estimated area, a random variable, was used as a divisor in place of the unknown true area. Standard error of the mean response was calculated as:

$$\text{Standard Error} = \sqrt{\frac{\sum_{i=1}^{n} ((pi - m)\bullet w_i)^2}{\left(\sum_{i=1}^{n} w_i\right)^2}}$$

Statistical differences between populations of interest were defined on the basis of non-overlapping confidence intervals. Use of the ratio estimator for the standard error approximates joint inclusion probabilities among samples and assumes a negligible spatial covariance, an assumption that appears warranted based upon preliminary examination of the data. This assumption, however, is conservative in that its violation would lead to an overestimation of the confidence interval (Stevens and Kincaid 1997).

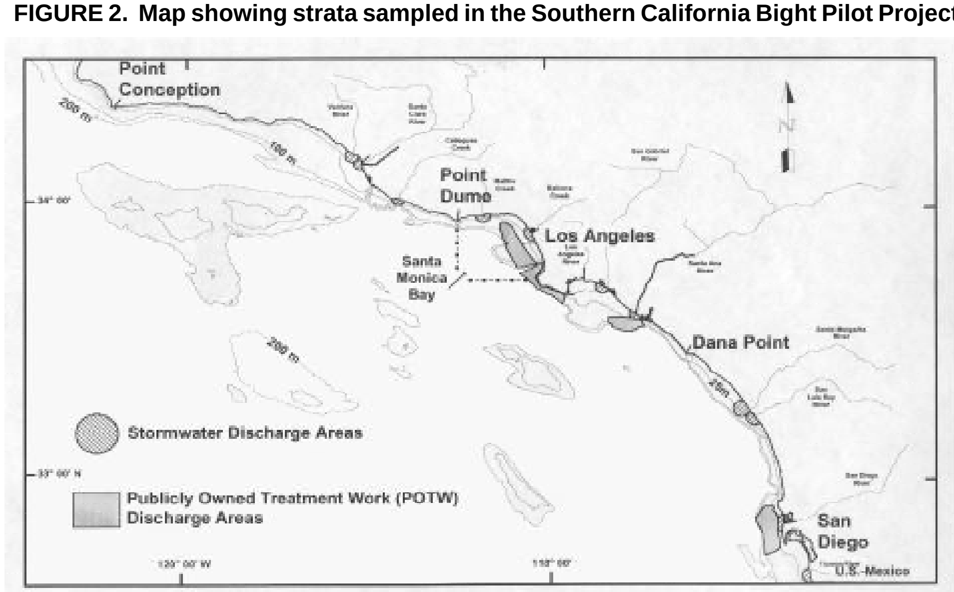
The percent of area in the SCB, as well as that in each of the strata of potential concern, exceeding thresholds of disturbance were assessed using the BRI (*See Smith et al. article in this Annual Report)*. The BRI is the abundance-weighted average pollution tolerance of species in a sample. If most of the species in a sample are typically found at reference sites, the index score for the station is low. If most of the species are pollution tolerant, the index value for the station is high. The BRI defines thresholds for four levels of response: (I) marginal deviation, the point at which minor changes occur in relative abundance of species, but most of the species occurring at reference sites are still present; (II) loss of biodiversity, the point at which some sensitive species no longer occur at the site; (III) loss of community function, the point at which large taxonomic groups, particularly arthropods and ophiuroids, are generally lost from the site; and (IV) defaunation, the point at which 90% of the species are excluded (Smith *et al.* 1998). The percent of area exceeding each of these thresholds was estimated using the same methodology used for estimating mean values, after converting the data to a binomial form. For any sample observation, p_i was 1 if it exceeded the threshold value and was 0 otherwise. The proportion of area that exceeded the selected threshold was taken as the mean of the indicator variable y_i.

RESULTS

Santa Monica Bay

The number of taxa, diversity, and total abundance of organisms were lower in Santa Monica Bay than in other areas of the SCB; however, the differences were not large (Table 1). The dominant taxa were similar in Santa

FIGURE 2. Map showing strata sampled in the Southern California Bight Pilot Project



Monica Bay and other areas of the SCB, although the bivalve molluscs *Axinopsida serricata* and *Parvulucina tenuisculpta* were more abundant and the polychaete *Mediomastus* spp. was less abundant in Santa Monica Bay than elsewhere in the Bight (Table 2).

Benthic communities were classified as reference by the BRI in 87% of Santa Monica Bay, compared to 92% of areas outside of Santa Monica Bay (Figure 3). Ten percent of Santa Monica Bay was classified in Response Level I and 2% in Response Level II.

Publicly Owned Treatment Work (POTW) Areas

While the number of taxa was similar, diversity was lower in mid-depth POTW areas than in non-POTW areas, although the difference was not large (Table 3). The proportion of the abundance comprised by annelids was higher and the proportion comprised by arthropods lower in POTW areas than in non-POTW areas. Dominant taxa in mid-depth POTW areas and non-POTW areas were, for the most part, similar (Table 4). Except for the polychaete *Mediomastus* spp., maldanid polychaetes, and the tanaid *Leptochelia dubia*, most of the dominant species were more abundant in POTW areas than in non-POTW areas.

Benthic communities were classified as reference by the BRI in 89% of POTW areas, compared to 92% of non-POTW areas (Figure 3). Eight percent of POTW areas were classified in Response Level I and 3% in Response Level II.

Stormwater Areas

Diversity, abundance, and other characteristics of communities were similar in stormwater and non-stormwater discharge areas (Table 5). The frequency of occurrence of dominant taxa in stormwater discharge areas was similar to that found in other shallow areas; however, the average abundance of most species was lower in stormwater discharge areas than in other shallow areas of the SCB (Table 6).

Benthic communities in 60% of the stormwater discharge areas were classified as reference by the BRI, compared to 87% of non-stormwater areas; 23 and 17% of the area were categorized in Response Levels I and II, respectively (Figure 3).

The Southern California Bight

Benthic communities in 91% of the mainland shelf of the SCB were classified as reference by the BRI (Figure 3). Eight percent of the area was categorized in Response Level I; less than 2% of the area was categorized in Response Level II. No areas were found with index values in Response Levels III and IV.

TABLE 1. Community characteristics in Santa Monica Bay (SMB) compared to the rest of the Southern California Bight (SCB). Values are area weighted. Values that are significantly different ($p < 0.05$) are indicated by a box. CI = Confidence interval.

	SMB n = 79		Rest of SCB n = 172	
	Mean	(95% CI)	Mean	(95% CI)
Number of taxa / sample	72.85	5.15	86.18	5.28
Shannon-Wiener Diversity Index (H')	3.42	0.1	3.59	0.07
Dominance	0.07	0.01	0.06	0.01
Evenness	0.49	0.03	0.46	0.01
Total abundance / m2	3,128.76	305.66	3,957.95	369.25
Percent abundance as:				
Annelida	45.7	3.2	51.2	2.2
Arthropoda	19.8	2	19.3	1.8
Ophiuroidea	14	3.8	12.4	2
Misc. echinodermata	0.8	0.4	0.7	0.2
Mollusca	14.6	2.9	8.9	1.2
Other phyla	5	1.1	7.2	1.1
Total biomass (gm wet weight / m^2)	57.55	7.85	57.96	7.4
Percent biomass as:				
Annelida	30.5	4.1	33.4	2.6
Arthropoda	7.2	2	6.4	1.2
Ophiuroidea	36	6.1	30.4	3.8
Misc. echinodermata	6	2.1	4.8	1.2
Mollusca	13.7	3.6	15.3	2.6
Other phyla	6.6	1.8	9.6	1.9

TABLE 2. Frequency of occurrence and average abundance of species in Santa Monica Bay (SMB) and in the rest of the Southern California Bight (SCB). Species with frequency of at least 60% and average abundance greater than 20 / m^2 are shown.

Species	Taxonomic Group	Frequency (Percent) SMB	Frequency (Percent) Non-SMB	Average Abundance (Number / m^2) SMB	Average Abundance (Number / m^2) Non-SMB
Spiophanes missionensis	Annelida	93.7	94.2	323.7	367
Paraprionospio pinnata	Annelida	89.9	83.1	63.3	60.6
Parvilucina tenuisculpta	Mollusca	81	52.9	57.2	38.4
Lumbrineris spp.	Annelida	79.7	79.7	40.2	57
Pectinaria californiensis	Annelida	75.9	70.9	55.5	62.4
Axinopsida serricata	Mollusca	70.9	32.6	102.5	14
Ampelisca brevisimulata	Arthropoda	70.9	61	52	30
Maldanidae*	Annelida	70.9	78.5	35.2	99.7
Amphiodia urtica	Ophiuroidea	69.6	64	260.9	235.8
Prionospio sp. A	Annelida	67.1	62.8	27.6	48.7
Phoronis sp.	Phoronida	65.8	59.3	30.5	48.9
Tellina carpenteri	Mollusca	64.6	36.6	36.9	15
Leptochelia dubia	Arthropoda	62	44.8	23.5	32.7
Mediomastus spp.	Annelida	59.5	72.7	23.8	97.1

* All Maldanids except 11 identified species.

DISCUSSION

The large majority of sediments in the SCB were found to contain healthy benthic communities. Deviations from reference condition, where observed, were mostly small and limited to minor changes in species composition, rather than decline in diversity or loss of abundance. This finding was consistent between analyses conducted using conventional benthic parameters (abundance, diversity, composition) and those conducted using the more recently developed BRI.

The three areas that contained the sites with the largest deviation from reference condition were the Santa Barbara Channel, central/northern Santa Monica Bay, and the Palos Verdes Shelf (Figure 4). The altered stations on the Palos Verdes Shelf are in an area known to be within the influence of the County Sanitation Districts of Los Angeles County's outfall (County Sanitation Districts of Los Angeles County 1996). While these sites were more altered than most of the sites in southern California, none of them reached Response Level III. Data from the NPDES monitoring program for the Joint Water Pollution Control Plant (JWPCP) show that, in 1973, areas within 2 km of the outfall were in Response Level IV, with only the most tolerant, specialized species surviving in the vicinity of the outfall (Figure 5). The benthic communities observed on the Palos Verdes Shelf in 1994 represent a remarkable improvement from 20 years ago. A pattern of improvement is also apparent in the more recent JWPCP data. In 1985, the area surrounding the outfall was classified in Response Level III, while marginal areas of the shelf were classified primarily in Response Level II. By 1990, most of the shelf was in Response Level II. In our 1994 data, some Level II sites remained, but most of the benthos in the Palos Verdes Shelf were in Response Level I.

The Santa Barbara Channel sites with altered benthic communities were in an area known to be subject to sediment transport from the Santa Clara and Ventura Rivers (Drake *et al.* 1972, Kolpack and Drake 1985).

FIGURE 3. Percent of area that with reference altered benthic infaunal communities in subpopulations of interest in the Southern California Bight.

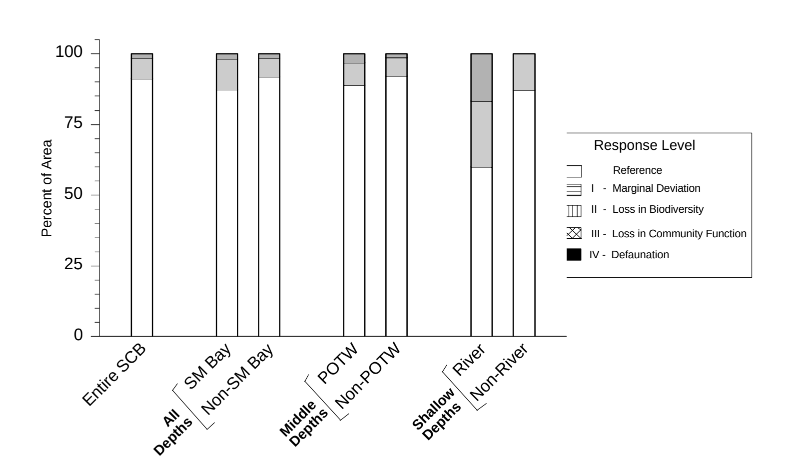


TABLE 3. Community characteristics in mid-depth (POTW) areas compared to mid-depth non-POTW areas. Values are weighted. Values that are significantly different ($p < 0.05$) are indicated by a box. CI = Confidence interval.

	POTW Mid-depth n = 45		Non-POTW Mid-depth n = 90	
	Mean	(95% CI)	Mean	(95% CI)
Number of taxa / sample	93.23	9.18	94.83	7.1
Shannon-Wiener Diversity Index (H')	3.42	0.15	3.64	0.1
Dominance	0.08	0.02	0.06	0.01
Evenness	0.49	0.03	0.46	0.02
Total abundance / m2	5,448.4	1,149.14	4,430.18	443.4
Percent Abundance as:				
Annelida	57.9	3.8	47.8	2.6
Arthropoda	13.9	2.4	18.6	1.9
Ophiuroidea	14.9	4	16.8	2.8
Misc. echinodermata	0.6	0.2	0.5	0.1
Mollusca	7.2	1.6	7.6	1.1
Other phyla	5.2	1.3	8.3	1.5
Total biomass (gm wet weight / m2)	73.63	17.11	73.83	10.68
Percent biomass as:				
Annelida	34.8	6.5	30.2	3.3
Arthropoda	4.9	1.1	4.7	0.8
Ophiuroidea	41.4	7.8	37.1	5
Misc. echinodermata	5.1	3.5	5.4	1.8
Mollusca	8.2	3	10.1	2.3
Other phyla	5.6	1.5	12.5	3.1

TABLE 4. Frequency of occurrence and average abundance of species in mid-depth publicly owned treatment work (POTW) areas and mid-depth non-POTW areas. Species with frequency greater than 60% and average abundance of at least 20 / m² in either area are included.

	Taxonomic	Frequency (Percent)		Average Abundance (Number / m²)	
Species	Group	POTW	Non-POTW	POTW	Non-POTW
Spiophanes missionensis	Annelida	100	100	652.8	454.9
Pectinaria californiensis	Annelida	91.1	82.2	109.6	64.8
Phoronis sp.	Phoronida	88.9	81.1	101.3	65.1
Amphiodia urtica	Ophiuroidea	88.9	86.7	373.2	355.5
Prionospio sp. A	Annelida	86.7	80	66.4	63.3
Lumbrineris spp.	Annelida	86.7	80	55.1	49.5
Paraprionospio pinnata	Annelida	84.4	81.1	56.4	50
Ampelisca brevisimulata	Arthropoda	80	83.3	45.2	46.1
Glycera nana	Annelida	75.6	60	28.6	19
Parvilucina tenuisculpta	Mollusca	75.6	63.3	39.8	35.8
Sthenelanella uniformis	Annelida	75.6	76.7	89.1	70.4
Maldanidae*	Annelida	73.3	83.3	56.4	98.9
Spiochaetopterus costarum	Annelida	73.3	56.7	24.7	14
Ampelisca pugetica	Arthropoda	73.3	65.6	22.9	19
Euclymeninae sp. A	Annelida	71.1	58.9	30.6	27.2
Lineidae	Annelida	68.9	60	22.5	19
Gnathia crenulatifrons	Arthropoda	64.4	72.2	37.7	23.8
Heterophoxus oculatus	Arthropoda	64.4	61.1	33.9	32.7
Axinopsida serricata	Mollusca	64.4	50	53.6	12
Mediomastus spp.	Annelida	64.4	77.8	70.4	91.8
Tellina carpenteri	Mollusca	62.2	58.9	33.8	24
Monticellina dorsobranchialis	Annelida	62.2	52.2	24	21
Ophiuroconis bispinosa	Ophiuroidea	62.2	53.3	28.2	13
Ampelisca pacifica	Arthropoda	62.2	50	20.2	16.1
Leptochelia dubia	Arthropoda	62.2	68.9	28	45.6
Tubulanus polymorphus	Nemertea	55.6	66.7	36	22.6
Euphilomedes carcharodonta	Arthropoda	48.9	66.7	54	48.8

* All Maldanids except 11 identified species.

Table 5. Community characteristics in shallow stormwater areas compared to shallow non-stormwater areas. Values are weighted. Values that are significantly different ($p < 0.05$) are indicated by a box. CI = Confidence interval.

	Stormwater Shallow n = 30		Non-Stormwater Shallow n = 31	
	Mean	(95% CI)	Mean	(95% CI)
Number of Taxa / sample	64.2	7.99	70.5	8.73
Shannon-Wiener Diversity Index (H')	3.49	0.17	3.59	0.11
Dominance	0.06	0.02	0.05	0.01
Evenness	0.46	0.04	0.48	0.03
Total Abundance / m2	2389	433.06	2761.44	611.17
Percent Abundance as:				
Annelida	46.9	4.7	50.2	4.8
Arthropoda	24.4	4.4	21.8	4.4
Mollusca	18.3	4.5	15.1	3.6
Ophiuroidea	1.6	0.6	1.3	0.5
Misc. Echinodermata	0.8	0.5	0.7	0.3
Other Phyla	8.1	1.4	10.8	1.8
Total Biomass (gm wet weight / m2)	38.37	12.18	30.91	86.93
Percent Biomass as:				
Annelida	37.1	7	33.8	5.5
Arthropoda	11.8	3.8	12.6	4.4
Mollusca	25	6.7	34.3	6.7
Ophiuroidea	7	2.9	6.7	2.7
Misc. Echinodermata	8.8	6.7	3.6	1.4
Other Phyla	10.3	3.2	8.9	2.3

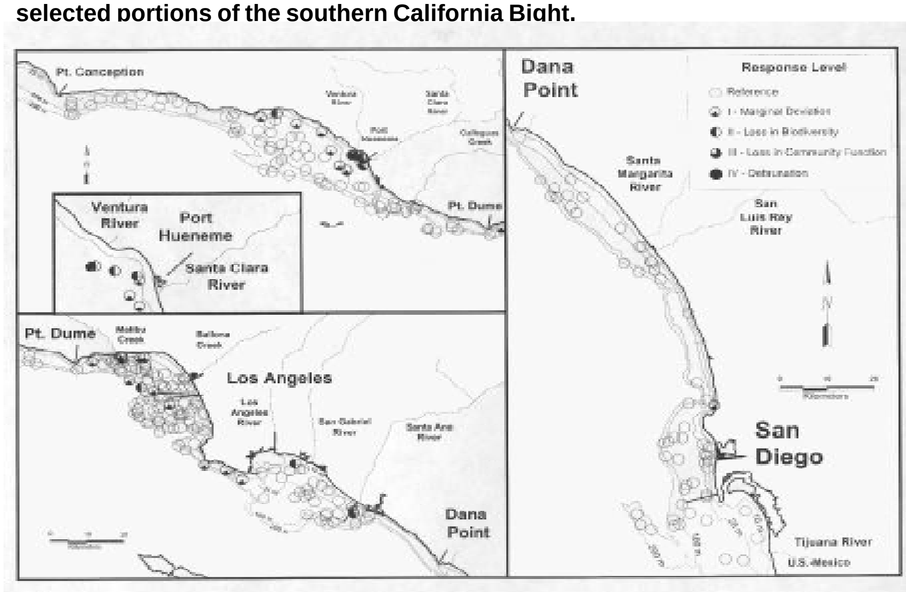
Table 6. Frequency of occurrence and average abundance of species in shallow stormwater areas and shallow non-stormwater areas. Species with frequency greater than 60% and average abundance of at least 20 / m^2 in either area are included.

		Frequency (Percent)		Average Abundance (Number / m2)	
Species	Taxonomic Group	Stormwater	Non-Stormwater	Stormwater	Non-Stormwater
Paraprionospio pinnata	Annelida	86.7	100	77.3	125.3
Spiophanes bombyx	Annelida	76.7	77.4	44	90
Spiophanes missionensis	Annelida	73.3	96.8	29.7	101.9
Ampharete labrops	Annelida	73.3	67.7	36	35
Ampelisca cristata	Arthropoda	73.3	67.7	31.3	51.5
Tellina modesta	Mollusca	73.3	87.1	42.7	62.8
Apoprionospio pygmaea	Annelida	70	83.9	43.7	64.7
Cooperella subdiaphana	Mollusca	66.7	48.4	58	16.3
Carinoma mutabilis	Nemertea	66.7	71	23.7	30.9
Lumbrineris spp.	Annelida	66.7	80.6	47.7	64.5
Macoma yoldiformis	Mollusca	63.3	74.2	47.3	70.4
Maldanidae*	Annelida	63.3	74.2	80.7	114.8
Amphideutopus oculatus	Annelida	63.3	74.2	102	91.9
Owenia collaris	Annelida	63.3	77.4	41.3	67.9
Glottidia albida	Brachiopoda	63.3	87.1	48.7	64.9
Mediomastus spp.	Annelida	60	61.3	62	85.6
Amphicteis scaphobranciata	Annelida	60	61.3	19	26.6
Chaetozone corona	Annelida	56.7	64.5	38.7	38.2
Ampelisca brevisimulata	Arthropoda	56.7	71	19	24.9
Tubulanus polymorphus	Nemertea	53.3	61.3	33	31.9
Phoronis sp.	Phoronida	46.7	64.5	13	35.4

* All Maldanids except 11 identified species.

After floods in the winter of 1969, a significant sand delta formed within 2 km of the mouths of the Ventura and Santa Clara Rivers. Sand- and clay-sized particles were also deposited in a wedge-shaped deposit, extending 2 km offshore, between Ventura and Santa Barbara. The deposit was gradually moved by wave action northward and offshore; in three years, the deposit was removed from the shelf. Since the areas that were determined to be altered in 1994 were within the area of the initial wedge-shaped deposit, it is reasonable to assume they were within the area of influence of outflow from the rivers. Other river sites, including those near the Santa Ana River, San Gabriel River, and Malibu Creek, also had altered benthic communities.

FIGURE 4. Response levels measured by the Benthic Response Index for selected portions of the southern California Bight.



Benthic communities that have index values above the reference threshold are referred to as altered rather than impacted because the BRI is a screening tool. The BRI quantifies disturbance, but does not discriminate between natural and anthropogenic disturbances. The benthic community alterations we observed near rivers may have resulted from natural disturbance. River flow can create stress by periodically altering grain size patterns, creating depositional environments under low flow conditions and erosional environments under high flow conditions. High river flow can cause rapid changes in the salinity regime, which also acts as a natural stressor. Many rivers, however, contain large amounts of chemical contamination that can be toxic to biota (Bay and Schiff 1997). Discriminating between these natural and anthropogenic alternatives requires more extensive site-specific study.

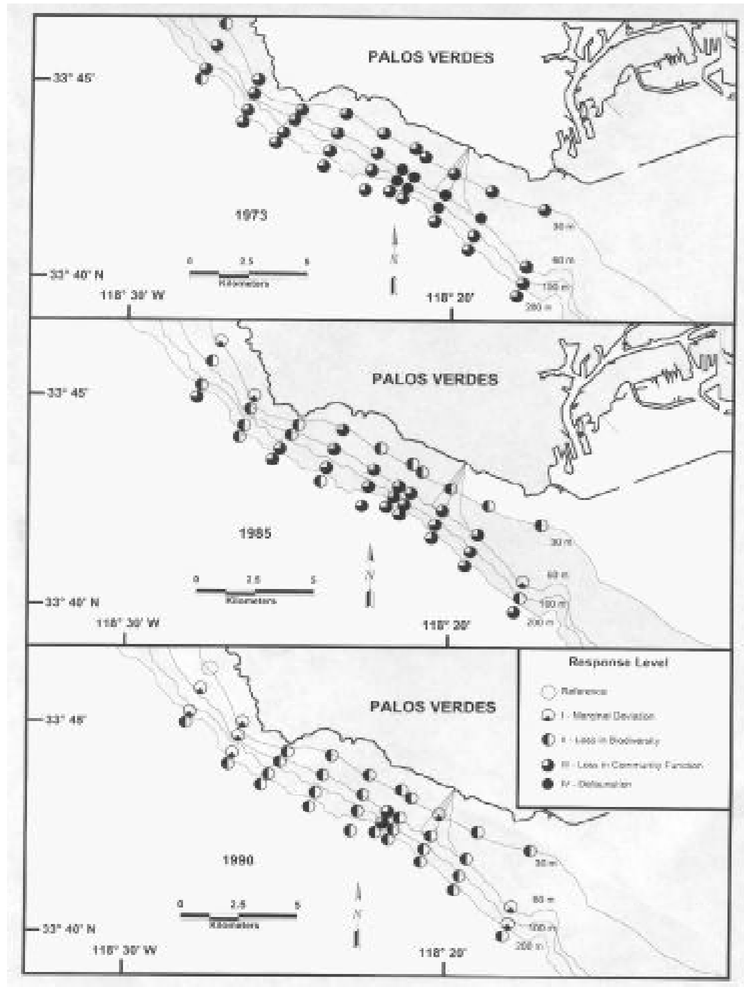
Most of the sites in Santa Monica Bay with altered benthic communities were in the vicinity of the City of Los Angeles sewage outfalls and similar to the Palos Verdes Shelf circumstance, all of the altered sites were in better condition than benthic conditions commonly encountered a decade ago (City of Los Angeles 1995). Of greater interest in Santa Monica Bay is the large number of sites at which healthy benthic assemblages were observed, since Schiff and Gossett (1998) found that more than half of the Santa Monica Bay sites exceeded Long *et al.*'s (1995) effects range median (ERM) value. The ERM value represents a concentration at which biological effects are likely to occur. This disparity between biological response and chemical exposure occurred throughout the study area, but nowhere was it as pronounced as in Santa Monica Bay.

The fact that normal benthic communities were found in sediment with high concentrations of chemicals may be attributed to any of several factors. First, the BRI may not be measuring biological response accurately. Because the BRI is a new index that has not been used extensively, it is possible that effects were underestimated. We feel this explanation is unlikely because the index was validated with independent data and consistently reproduced gradients of effect that had been documented in other published reports about southern California benthos (Smith *et al.* 1998). In addition, samples with BRI values below the reference threshold had species that are usually found in undisturbed assemblages (Jones 1969; Thompson *et al.* 1987, 1993). Samples with BRI values in Response Levels I and II had species that are not normally found in similar reference habitats. For example, the polychaetes *Cossura* sp. and *Mediomastus* sp. were dominant in disturbed shallow areas off the Santa Clara and Ventura Rivers. These polychaetes are uncommon in undisturbed shallow water areas.

A second possibility is that the Long *et al.* (1995) thresholds used to identify elevated concentrations may be inaccurate or imprecise. The three chemicals that constituted the highest percentage of ERM threshold exceedances (DDT, PCB, and nickel) were chemicals for which Long *et al.'s* database for threshold development was the smallest. This explanation also appears unlikely because Long *et al.* (1998) recently conducted a study evaluating the predictability of the thresholds using independent data from throughout the country and found that 84 to 100% of tests using more than one species showed toxicity when DDT, PCB, or nickel was higher than the ERM threshold.

Bulk sediment thresholds, such as the ERL (effects range low, or concentration at which effects should rarely be observed) and ERM values, can be confounded by binding factors in the sediment that sequester high concentrations and render the chemicals biologically unavailable. Some authors have suggested that equilibrium partitioning, in which chemical concentrations are normalized to potentially binding compounds, such as organic carbon (DiToro *et al.* 1991), is a more appropriate threshold development approach. The U.S. Environmental Protection Agency (U.S. EPA) has endorsed equilibrium partitioning in their development of national sediment quality criteria (U.S. EPA 1993a, b, c). Although EPA criteria are not yet available for DDT or PCB, MacDonald (1994), Swartz *et al.* (1994), and Chapman (1996) have developed TOC-normalized DDT thresholds. When these criteria are applied, the frequency of threshold exceedances is similar to that using the ERL threshold (Schiff and Gossett 1998).

FIGURE 5. Response levels measured by the Benthic Response Index on the Palos Verdes Shelf for the years 1973, 1985, and 1990.



A fourth possible explanation is that organisms in the SCB have become adapted to high concentrations of chemicals in the sediment. The DDT concentrations in the Palos Verdes Shelf sediments are as high as any found in the United States (NOAA 1990) and the exposure period has exceeded three decades. Adaptation to local environmental stresses, with increased tolerance to individual pollutants, has been found in other areas where high concentrations of individual pollutants persist (Weis and Weis 1989). Adaptation does not explain all of the discrepancies noted between SCB pollutant exposure and biological response, as we found high survival in amphipod toxicity tests conducted with non-native test organisms at some of the SCB high DDT sites (Bay 1996); however, it is a testable hypothesis that deserves further investigation.

We also observed a few areas with altered benthic communities and low concentrations of chemicals in the sediment. It is possible that the source of the disturbance occurs intermittently and/or is not captured in the measured sediment chemistry. Many of these sites were near river mouths, where disturbances could result from natural factors, as described above. Benthos near storm drains would be exposed to pesticides, petroleum products, and/or other contaminants during runoff events, with the material later transported offshore by wave action. Away from river mouths, both anthropogenic and natural factors may disturb benthic communities. For example, bottoms may be disturbed by storms, trawls, or boat anchors, or by the feeding activities of whales and fish (VanBlaricom 1982, Oliver *et al.* 1983). None of these disturbances would be reflected in the sediment chemistry.

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