Impacts of stormwater discharges on the nearshore benthic environment of Santa Monica Bay

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ABSTRACT - Although large loads of potentially toxic constituents are discharged from coastal urban watersheds, very little is known about the fates and eventual impacts of these stormwater inputs once they enter the ocean. The goal of this study was to examine the effects of stormwater discharges on the benthic marine environment of Santa Monica Bay. Sediment samples were collected across a gradient of stormwater impact following significantly sized storm events offshore of Ballona Creek (a predominantly developed watershed) and Malibu Creek (a predominantly undeveloped watershed). Sediments offshore of Malibu Creek had a higher proportion of fine-grained sediments, organic carbon, and naturally occurring metals (i.e., aluminum and iron), whereas sediments offshore of Ballona Creek had higher concentrations of anthropogenic metals (i.e., lead) and organic pollutants (i.e., total DDT, total PCB, total PAH). The accumulation of anthropogenic sediment contaminants offshore of Ballona Creek was evident up to 2 km downcoast and 4 km upcoast from the creek mouth, and sediment concentrations covaried with distance from the point of discharge. Although changes in sediment texture and organic content, and an increase in sediment contamination were observed, there was little or no alteration to the benthic communities offshore of either Ballona Creek or Malibu Creek. Both sites were characterized as having an abundance, species richness, biodiversity, and benthic response index similar to shallow water areas distant from creek mouths throughout the Southern California Bight. There was not a preponderance of pollution tolerant, nor a lack or pollution sensitive, species offshore of either creek mouth.

INTRODUCTION

Santa Monica Bay comprises two distinct types of watersheds. The northern half of the Bay has subwatersheds that are predominantly open lands situated within rural communities and among the largest national forests in the Los Angeles region. The southern half of the Bay (South Bay) is intensely urbanized and encompasses metropolitan Los Angeles, the largest city on the west coast of the United States. Watersheds in the northern half of the Bay (North Bay) average 5% imperviousness while watersheds in the South Bay average 20% imperviousness (Wong *et al*. 1997). While North Bay watersheds may be far from pristine, South Bay watersheds are built almost to saturation.

Due to the intense development, nearly all of the freshwater input to the Bay has been modified. This modification occurs directly, as in the case of treated municipal effluents, which comprised approximately 1.6 x 10^{12} L/yr in 1997 (Raco-Rands and Steinberger 2001). This treated effluent is piped five miles offshore and discharged at depths of 60 m. Similarly, Santa Monica Bay receives treated effluents from other direct ocean discharges including three power generating stations and an oil refinery.

This modification of freshwater inputs can also occur indirectly, as in the case of stormwater runoff. Although North Bay watersheds may run dry during the arid summers, their streambeds are in a relatively natural condition. In contrast, South Bay watersheds are almost entirely lined with concrete. While this infrastructure supports an effective mechanism for flood control, it is not designed to enhance water quality; virtually all wet-weather runoff that is discharged to the Bay is untreated. Moreover, rainstorms are relatively infrequent, enabling a longer period for pollutant build-up that is often followed by very intense rainfall, thereby increasing the efficiency of pollutant transport to the ocean (Tiefenthaler *et al*. 2001). Runoff from the Santa Monica Bay watersheds during 1991, for example (a year of median rainfall) was 1.3 x 10^{12} L, rivaling the discharge volumes of point source discharges. In the end, the loads of pollutants in stormwater runoff to Santa

Monica Bay are large, exceeding all other sources except for the City of Los Angeles municipal waste treatment plant (Schiff 1996).

Not only are pollutant inputs from Santa Monica Bay watersheds large, but they have the potential to generate impacts in the nearshore ecosystem. For example, the contaminants in both wet-weather and dry-weather flows from selected subwatersheds have elicited toxic responses in marine organisms (Bay *et al*. 1996). These organisms include local marine species such as the giant kelp (*Macrocystis pyrifera*), red abalone (*Haliotis refuscens*), and purple sea urchins (*Strongylocentrotus purpuratus*).

Although large loads of potentially toxic constituents are discharged from Santa Monica Bay watersheds, very little is known about the fates and eventual impacts of these stormwater inputs once they enter the ocean environment. Benthic environments, in particular, are at risk since they serve as an integrator of storm-discharged particulates. Accumulations of stormwater inputs may composite an entire storm, series of storms, or entire seasons. However, the accumulation of storm-discharged contaminants in offshore environments and the impact they may have on benthic communities has not been examined. The goal of this study was to examine the effects of stormwater discharges on the benthic marine environment of Santa Monica Bay.

METHODS

General Approach

This project was designed to measure the effects of stormwater impacts offshore of two watersheds in Santa Monica Bay. The first watershed, Malibu Creek, is located in the North Bay and the second watershed, Ballona Creek, is located in the South Bay (Figure 1). Both watersheds are similar in size and, when combined, encompass over half of the entire Santa Monica Bay drainage area (Wong *et al*. 1997). The Ballona Creek drainage basin is highly urbanized; 83% of the watershed is developed and comprised of predominantly residential land use. Almost the entire channel is concrete lined. Conversely, Malibu Creek is predominantly undeveloped; 88% of the watershed is open land and the channel is almost entirely earthen. These differences in watershed characteristics, in addition to localized diversity in rainfall, lead to large variations in flow and pollutant loading to the ocean, even for the same storm event (LACDPW 2000). By comparing impacts associated with each watershed type, we hoped to distinguish between effects arising from urban and non-urban stormwater runoff.

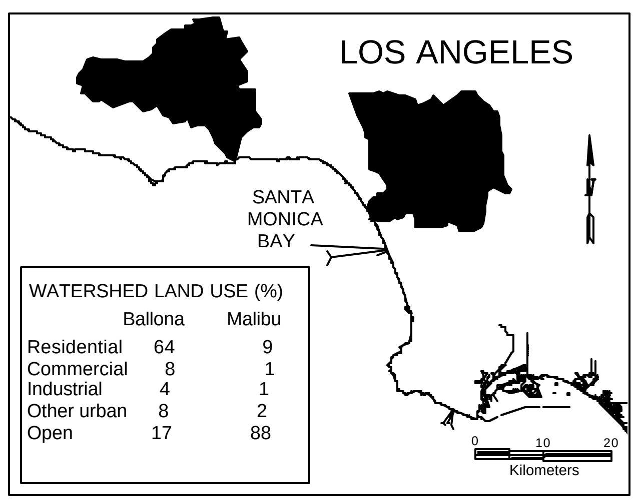
The study design had three major elements. First, a grid-based spatial survey of sediment characteristics was used to determine the best sampling locations offshore of each creek mouth. Second, sediment contamination and benthic community assemblages were measured directly offshore of each creek mouth in the area of greatest potential impact identified from the grid-based survey. Third, sediment contamination and benthic community assemblages along an isobath extending from the most impacted location (identified in the second design element) to an area outside of the stormwater plume effect were measured to evaluate the gradient of benthic impact.

Sampling

The benthic sampling was conducted following significantly sized (>0.25 in) storm events. The storm-discharged particulates were given a short amount of time (3 to 6 d, but as many as 9 d) to settle before field deployment. A total of six events were sampled offshore of Ballona Creek during the 1995/96 and 1996/97 storm seasons; five events were sampled offshore of Malibu Creek. The five storms sampled offshore of Malibu Creek were the same storms sampled offshore of Ballona Creek.

Sediment samples were obtained using a 0.1 m^2 modified Van Veen grab. For contaminant analysis, only surficial sediments (top 2 cm) from undisturbed, representative grabs were collected. Sediments not

Figure 1. Map of the Santa Monica Bay watershed including Ballona Creek and Malibu Creek. Sampling sites are indicated.



WATERSHED LAND USE (%)	Ballona	Malibu
Residential	64	9
Commercial	8	1
Industrial	4	1
Other urban	8	2
Open	17	88

in contact with the wall of the grab were placed in separate pre-cleaned containers for grain size, total organic carbon/total nitrogen (TOC/TN), trace organics, and trace metals analyses. Samples were transported on ice and then frozen (< -4ºC) prior to trace contaminant analysis, or were refrigerated (4ºC) prior to grain size analysis. For benthic invertebrate infaunal community analysis, entire sediment grab samples were gently washed through a 1.0-mm mesh stainless steel screen on the boat. The organisms retained on the screen were “relaxed” using $MgSO_4$ (Epsom salts) in seawater. After 30 min, the sample was fixed with 10% borax-buffered formalin and returned to the laboratory. After 24 h, samples were rinsed with freshwater to remove formalin, and were preserved in 70% ethanol.

Analytical Chemistry

Grain Size Analysis

Grain size analysis was performed using a Horiba Model LA-900 laser scattering particle size distribution analyzer (Dalkey and Leecaster 2001). Individual sediment samples were first homogenized at room temperature and a representative aliquot was introduced to the instrument’s sample reservoir. The sample was then dispersed and circulated through the measuring cell and the various particle sizes were determined by detection of scattered (refracted and reflected) laser light. Data were reported as frequency (%) of particles for 74 different diameters between 0.88 and 1,024 microns. Significant interferents included scratches or bubbles in the measuring cell or particles greater than 1,000 microns. During this study, no samples contained fractions greater than 1,000 microns; thus, no corrective actions were necessary.

Total Organic Carbon and Total Nitrogen

Total organic carbon and total nitrogen (TOC/TN) analysis was performed using a Carlo Erba 1108 CHN elemental analyzer equipped with an AS/23 autosampler. A detailed description of the method can be found in SCCWRP (1992). Frozen sediments were thawed and homogenized at room temperature, then dried at 60ºC overnight. After taring, an aliquot of each sample was digested with concentrated HCl vapors to remove inorganic carbon. The acidified sample was again dried and weighed, then crimped in a tin boat. The Carlo Erba CHN analyzer oxidizes each sample boat in a quartz combustion chamber and, using Poropak QS packed column, reaction products were separated and then quantified using a thermal conductivity detector. Acetanilide was used as the external standard. Acetanilide and cyclohexanone were used for QC check standards. The certified reference material was PACS-1 (3.69% C, National Research Council).

Trace Metal Analysis

Sample preparation for major and trace element analysis followed U.S. EPA Methodology (U.S. EPA 1996). Approximately 2 gm of oven-dried, fine-ground sediment were digested using 5:2, trace metal-grade nitric acid:hydrochloric acid. The acidified samples were placed in a SEMS-MS 1000 microwave oven extractor. Samples were brought to a uniform volume with reagent grade water, and the solids were removed by centrifugation or settling overnight. The supernatant with sample digest was transferred to a new polyethylene bottle prior to analysis.

Inductively coupled plasma-mass spectroscopy (ICP-MS) was used to determine concentrations of inorganic constituents (aluminum, antimony, arsenic, beryllium, cadmium, chromium, copper, iron, lead, mercury, nickel, selenium, silver, and zinc) from sample digest solutions using a Hewlett Packard Model 4500 following U.S. EPA methodology (U.S. EPA 1991). The internal standard solution included rhodium and thulium. Major interferents included argon, sodium, and magnesium. Instrument blanks were run to identify sample carry-over. A spiked sample of known concentration was used as the laboratory control material.

Pesticides (DDTs) and Polychlorinated Biphenyls (PCBs)

Chlorinated pesticide and polychlorinated biphenyl analyses were conducted using procedures established by U.S. EPA (1983, 1986). Six DDT isomers and metabolites (o,p’-DDT, p,p’-DDT, o,p’-DDE, p,p’-DDE, o,p’-DDD, p,p’-DDD) and 27 PCB congeners (Congeners 8, 18, 28, 29, 44, 50, 52, 66, 77, 87, 101, 104, 105, 118, 126, 128, 138, 153, 154, 170, 180, 187, 188, 195, 201, 206, 209) were quantified.

Specific methodological details used by the laboratory can be found in Zeng and Khan (1995). Samples for DDT and PCB analysis were first thawed and homogenized at room temperature. Twenty to 30 gm of sample were then centrifuged to remove pore water. Sediments were dried using anhydrous sodium sulfate, and then were solvent extracted in triplicate with methylene chloride utilizing a roller table that maximizes sediment-solvent contact time. Extracts were cleaned up by removing sulfur with activated copper and passed through a 2:1 alumina:silica packed column. Extracts were eluted with 1:6, hexane:methylene chloride and concentrated to 1 mL prior to instrumental analysis using a Hewlett Packard Model 5890 II gas chromatograph equipped with a 60 m x 0.25 mm ID (0.25 mm film thickness) DB-5 fused silica capillary column and a ^{63}Ni electron capture detector (GC-ECD) for quantifying analytes.

Polynuclear Aromatic Hydrocarbons

Twenty-eight polynuclear aromatic hydrocarbons (PAH) analyses were conducted using procedures established by the U.S. EPA (1983, 1986). Specific methodological details used by the laboratory can be found in Zeng and Khan (1995). Samples for PAH analysis were first thawed and homogenized at room temperature and then 20 to 30 gm of sample were centrifuged to remove pore water. Sediments were dried using anhydrous sodium sulfate, and were then solvent extracted in triplicate with methylene chloride utilizing a roller table that maximizes sediment-solvent contact time. Extracts were cleaned up by removing sulfur with activated copper and passed through a 2:1 alumina:silica packed column. Extracts were eluted with 1:6, hexane:methylene chloride and concentrated to 1 mL prior to instrumental analysis on a Hewlett Packard Model 5890 II gas chromatograph equipped with a DB-5 column (60 m x 0.25 mm ID x 0.25 mm film thickness) and a Hewlett Packard Model 5870 mass selective detector in electron impact ionization mode for quantifying analytes.

Biological Analysis

Biological sample analysis included three major steps: (1) sorting the sample under a dissection microscope into six different taxonomic groups (annelids, molluscs, arthropods, ophiuroids, miscellaneous echinoderms, and "other phyla"); (2) measuring biomass of each group of organisms; and (3) performing taxonomic identification and enumeration. A minimum of 10% of each sample was re-sorted to determine whether organisms were missed in the original sort. If sorting efficiency was less than 95%, then the entire sample was resorted. After sorting, each group was weighed to the nearest 0.01 gm and reported to the nearest 0.1 gm (wet weight). Taxonomic identification and enumeration is by far the most difficult of the three analytical steps. The goal was to identify each organism to species level (or lowest taxon possible). Ten percent of all samples were re-identified and enumerated by a second taxonomist for quality assurance. A specific procedure was established for discrepancies in identification (Bergen *et al.* 2001). A voucher collection was initiated and is maintained by the analytical laboratory.

Data Analysis

Assessment of sediment contamination consisted of examining mean concentrations of specific pollutants in samples taken offshore of each creek mouth during multiple surveys. Comparisons between watersheds were accomplished using non-parametric Mann-Whitney T-tests. Assessments of biological impairment were conducted using the following methodology. First, infauna data were examined for community condition such as abundance, biomass, and number of species. Community measures were also analyzed including diversity, evenness, and dominance. Next, the infauna results were evaluated using the benthic response index (BRI), a scale of pollutant impact using community assemblage parameters (Bergen *et al.* 2000). Finally, a species-level approach was used for examining data for "indicator" species. Indicator species included both pollution-associated taxa and taxa characteristic of reference communities (Bergen *et al.* 2001).

Benthic Response Index (BRI)

The BRI quantifies the response of benthic communities to environmental disturbances in the Southern California Bight. The BRI is an example of direct gradient analysis and, for southern California, represents a pollution gradient from reference to impact at specified depth intervals derived from ordination analysis. The BRI is calculated as the abundance-weighted average of each species position on the pollution gradient. The BRI value for each sample is:

$$BRI = \frac{\sum_{i=1}^{n} P_i\left(\sqrt[3]{N_i}\right)}{\sum_{i=1}^{n} \sqrt[3]{N_i}}$$

where: n = Number of species in the sample.
P_i = Gradient position for the ith species.
N_i = Abundance count of the ith species in the sampling unit

The BRI is scaled from 0 to 100 and thresholds were developed for reference conditions ($\leq$25) and four levels of community response. These thresholds included marginal deviation from reference (25 < BRI $\leq$ 34), loss of biodiversity (34 < BRI $\leq$ 44), loss of community function (44 < BRI $\leq$ 72), and defaunation (BRI > 72). Threshold levels are accurate to within $\pm$ three index values.

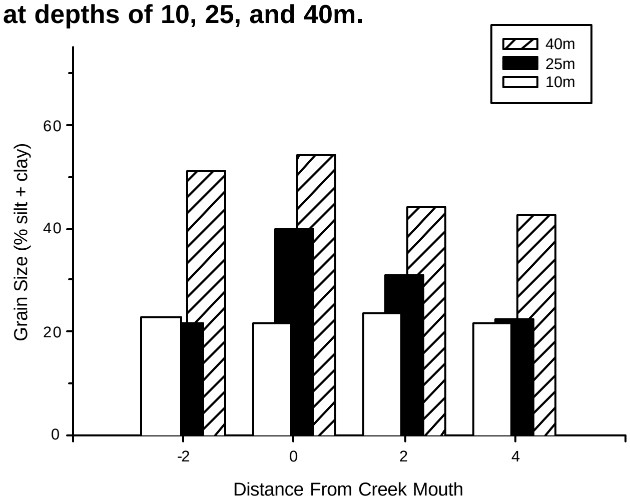
RESULTS

Spatial Survey

A discernible plume footprint, sampled prior to the rainy season, was observed offshore of Ballona Creek based upon measurements of fine-grained sediments (Figure 2). The plume footprint at Ballona Creek distinctly increased in percent of fine-grained material directly offshore of the creek mouth relative to sediments collected at similar depths either upcoast or downcoast. The footprint extended between 2 and 4 km upcoast, but less than 2 km downcoast. At 25 m depth, the proportion of sediment fines doubled in the heart of the footprint (40 *versus* 22% fines). The footprint also reached to 40 m depth roughly five km offshore. At depths of 10 m (approximately 1 km offshore), the footprint was not evident; there was no change in grain size as one moved longshore. Presumably, this is a result of increased mixing/redistribution or differential settling of runoff particles at this depth.

Although more complicated, a plume footprint was also present at Malibu Creek (data not shown). Part of this complication was that background sediments

Figure 2. Gradients in sediment grain size offshore of Ballona Creek prior to the wet-weather season. Transects extended 2 km downcoast to 4 km upcoast at depths of 10, 25, and 40m.



offshore of Malibu Creek contained much more silt and clay than offshore of Ballona Creek. Interestingly, the heart of the footprint was offset from the Malibu Creek mouth by 2 km in the downcoast direction. However, the extent of the footprint offshore of Malibu Creek remained the same as offshore of Ballona Creek; at least 2 km upcoast and 4 km downcoast from the most impacted location. In addition, the strongest sediment signal was at the 25 m depth contour, similar to that offshore of Ballona Creek. Empirical evidence also showed that watershed inputs were present since bits of terrestrial organic debris were commonly observed in the Malibu Creek sediment samples, consistent with the plume footprint.

Since relatively distinct signals in the plume footprint were evident, a transect line for future benthic sampling was established along the 25 m isobath offshore each watershed.

Sediment Quality

Sediments offshore of Malibu Creek had a higher proportion of fine-grained materials and had greater organic enrichment than sediments offshore of Ballona Creek (Table 1). The sediment from directly offshore of Malibu Creek had 68% more silt + clay, 62% more total organic carbon, and 32% more total nitrogen than sediments directly offshore of Ballona Creek.

Of the 12 trace metals measured in sediments offshore of each creek mouth, Malibu Creek had higher concentrations of naturally occurring elements such as aluminum and iron (Table 1). In contrast, Ballona Creek had higher concentrations of anthropogenic trace metals such as lead, silver, and mercury. Sediment concentrations of other trace metals, such as copper and zinc, were similar offshore of the two watersheds.

All of the organic constituents measured were more concentrated in sediments directly offshore of Ballona Creek than offshore of Malibu Creek (Table 1). The sediments directly offshore of Ballona Creek had 40% more total DDT, 86% more total PCB, and 77% more total PAH than sediments offshore of Malibu Creek. In addition, sediments directly offshore of Ballona Creek consistently detected 18 of the 27 PCB congeners measured compared to only 4 of the 27 PCB congeners measured offshore of Malibu Creek. Similarly, sediments directly offshore of Ballona Creek consistently detected 10 of the 24 PAH compounds measured compared to only 5 of the

Table 1. Mean concentrations (95% confidence intervals) of sediment characteristics and constituent concentrations directly offshore of Ballona Creek (n=6) and Malibu Creek (n=5) following storm events between 1995-1997. All samples collected at 25 m depth.

Constituent	Units	Ballona Creek		Malibu Creek	
		Mean	95% CI	Mean	95% CI
Fines	% dry	31.6	1.3	**53.1***	4.6
TOC	% dry	0.594	0.155	**0.963**	0.162
TN	% dry	0.059	0.008	**0.078**	0.008
Aluminum	µg/dry g	11492	2496	17280	5091
Arsenic	µg/dry g	5.1	0.6	5.6	1.0
Cadmium	µg/dry g	0.5	0.1	0.7	0.1
Chromium	µg/dry g	40.7	2.5	52.6	9.5
Copper	µg/dry g	12	1	13	1
Iron	µg/dry g	14997	1628	**21720**	1866
Lead	µg/dry g	**26.4**	1.3	10.3	0.6
Mercury	µg/dry g	**0.18**	0.03	0.08	0.03
Nickel	µg/dry g	14.3	0.8	27.8	2.3
Selenium	µg/dry g	0.46	0.17	0.68	0.05
Silver	µg/dry g	**0.95**	0.07	0.31	0.03
Zinc	µg/dry g	54	2	56	4
Total DDT	ng/dry g	**25.6**	3.7	15.5	3.1
Total PCB	ng/dry g	**21.5**	7.3	3.0	1.4
Total PAH	ng/dry g	**240.6**	109.2	56.2	21.9

* **Bold** indicates significantly different concentration.

24 PAH compounds measured directly offshore of Malibu Creek.

The gradient of plume influence was easily distinguished offshore of Ballona Creek (Figures 3 and 4). The sediment texture and constituent concentrations were consistently highest directly offshore of the Ballona Creek mouth and then decreased in both the upcoast and downcoast directions. For example, fine-grained materials and TOC were 65% and 85% higher, respectively, directly offshore of the Ballona Creek mouth compared to 4 km downcoast. Similarly, trace metals were between 36% (for zinc) and 136% (for lead) higher directly offshore of the creek mouth relative to 4 km upcoast. The difference among organic constituents was even more extreme, differing by a factor of 2 (for total DDT) and 10 (for total PAH).

The gradient of plume influence was less obvious for sediments offshore of Malibu Creek compared to sediments offshore of Ballona Creek (Figures 3 and 4). Fine-grained sediments and TOC differed by only 19% and 40%, respectively, between the most influenced site 2 km downcoast of the Malibu Creek mouth compared to the least influenced site 4 km upcoast. No substantial differences can be observed across the gradient of plume influence for lead, zinc, total DDT, total PCB, and total PAH. In fact, concentrations of total PCB and total PAH were nearing the limit of detection for this study.

Infaunal Communities

The benthic community directly offshore of Malibu Creek contained more organisms, more species, greater diversity, and greater biomass than the benthic community directly offshore of Ballona Creek (Table 2). Between 1995 and 1997, the average abundance directly offshore of Malibu Creek was 33% greater than directly offshore of Ballona Creek. Both Malibu Creek and Ballona Creek shared a large population density; wet-weather season abundances averaged 316 and 238 individuals per 0.1 m^2, respectively. Species richness was significantly greater offshore of Malibu Creek compared to offshore of Ballona Creek. Similarly, Malibu Creek exhibited higher diversity than Ballona Creek. Community assemblages were not dominated by a small

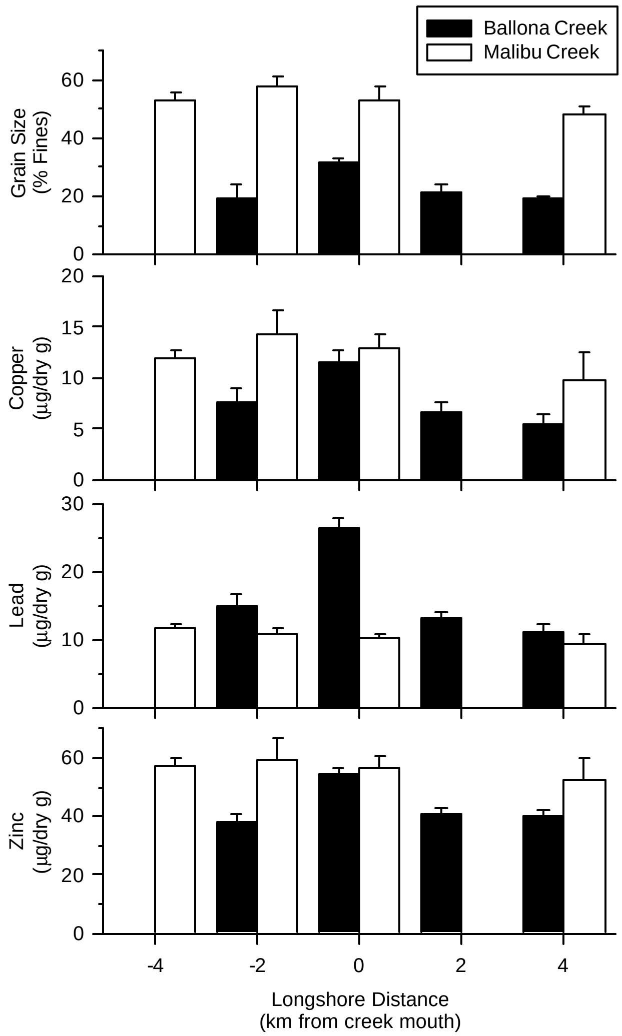


Figure 3. Grain size and trace metal concentrations (mean ± 95% confidence intervals) measured in sediments across the gradient of stormwater influence offshore of Ballona Creek and Malibu Creek. All samples were collected at 25 m depth following significantly sized storms between 1995 and 1997.

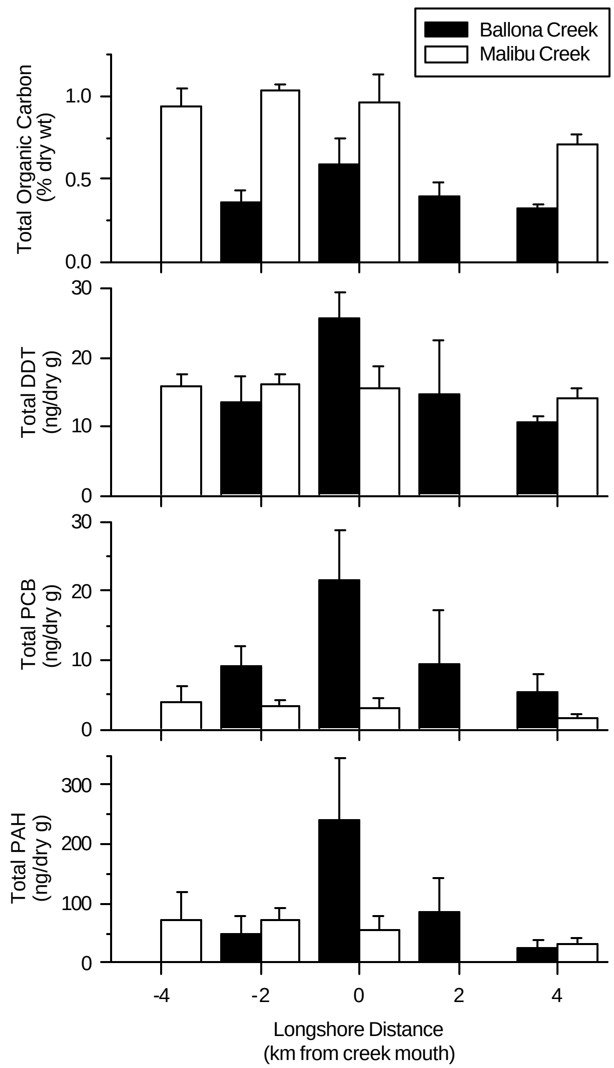


Figure 4. Total organic carbon and organic constituent concentrations (mean ± 95% confidence intervals) measured in sediments across the gradient of stormwater influence offshore of Ballona Creek and Malibu Creek. All samples were collected at 25 m depth following significantly sized storms between 1995 and 1997.

proportion of the large number of species found offshore of each watershed, however, as indicated by the relatively high evenness values at both sites.

The mean wet-weather season BRI value directly offshore of Malibu Creek was significantly higher than offshore of Ballona Creek (Table 2). The mean BRI offshore of Ballona Creek (24.0) was less than 25, indicating that this site was similar to reference conditions and within the 90^{th} percentile of other reference sites in the SCB with respect to community assemblage and relative abundance. The BRI value offshore of Malibu Creek (30.5) was greater than 25, indicating that this site marginally deviated from reference condition. It was therefore outside the 90th percentile of reference sites from the SCB, but still maintained a community that sustained at least 75% of the expected species. This indicated that there was little, or no, loss of biodiversity in communities offshore of Malibu Creek.

The community assemblages measured directly offshore of Ballona and Malibu creeks at 25 m contained taxa characteristic of shallow (10-30 m) reference communities measured throughout the SCB (Table 3). All 19 of the characteristic reference assemblage taxa that are consistently found (> 60% occurrence) and in notable abundance (average > 2

Table 2. Mean (95% confidence intervals) of biological community parameters directly offshore of Ballona Creek (n=6) and Malibu Creek (n=5) following storm events between 1995-1997. All samples collected at 25 m depth.

Biological Parameter	Units	Ballona Creek		Malibu Creek	
		Mean	95% CI	Mean	95% CI
Total Abundance	(No. / 0.1 m^2)	237.5	50.8	316.0	55.4
Species Richness	(No. / 0.1 m^2)	74.8	5.8	91.2	7.8
Diversity	(Shannon-Wiener H')	1.65	0.02	1.73	0.04
Evenness	(Pielou's J)	0.88	0.02	0.88	0.02
Benthic Response Index	(BRI)	24.0	1.7	30.5	0.7
Total Biomass*	(gm / 0.1 m^2)	2.1	0.4	6.1	2.2
Annelida		1.1	0.3	2.6	0.7
Arthropoda		0.3	0.1	0.3	0.1
Ophiuroida		0.3	0.3	2.0	1.3
Echinodermata		0.0	-	0.0	-
Mollusca		0.2	0.1	0.6	0.8
Other taxa		0.1	0.1	0.5	0.2
Abundance/Biomass Ratio	(No. Individuals/gm)	120.7	33.8	60.0	23.9

* Wet weight with outlier organisms removed (i.e., large molluscs with shells, large epifaunal echinoderms, etc.).

per 0.1 m^2) were also found directly offshore of Ballona Creek; 17 of 19 were found directly offshore of Malibu Creek. The relative abundance of these reference community taxa comprised between 30% and 43% of the total abundance offshore of Malibu and Ballona creeks, respectively, which was similar to the mean relative abundance throughout the SCB (37% of total abundance).

Except for the BRI, there was no trend in community assemblage parameters along the 25 m monitoring transect that was spatially correlated with the influence of Ballona Creek or Malibu Creek discharges (Figure 5). Total abundance, species richness, and diversity directly offshore of either creek mouth was not significantly lower (or higher) than sites upcoast or downcoast from the discharge. The BRI did show a spatial pattern that could be spatially correlated with Ballona Creek and Malibu Creek discharges. The highest BRI values from Ballona Creek were measured directly offshore of the mouth, then decreased upcoast and downcoast from the discharge. The highest BRI values offshore of Malibu Creek were 2 km downcoast from the creek mouth. Offshore of each of the respective watersheds, the lowest BRI values were at the sites farthest from the creek discharges, located 4 km upcoast. Over-interpretation is cautioned, however, since there were no statistically significant differences between sites within watersheds. Furthermore, all sites offshore of Ballona Creek were below the reference threshold.

Pollution-associated indicator taxa were relatively low in abundance along the 25 m monitoring transect offshore of Ballona and Malibu creeks (Figure 6). *Capitella capitata*, an opportunistic species indicative of degraded environs, rarely occurred offshore of either creek mouth. *Euphilomedes carcharodonta* is another species often associated with moderately impacted locations. This species abundance was also low, but showed some spatial pattern relative to discharges offshore of both Malibu and Ballona creeks. Although the greatest *E. carcharodonta* densities were observed where the highest BRI measurements were found, none of the average wet-weather season abundance measurements were statistically significantly different among Ballona

Table 3. Mean abundance (No./0.1 m2 ± 95% confidence interval) of taxa found directly offshore of Ballona Creek (n=6) and Malibu Creek (n=5), which were commonly found in reference locations of the Southern California Bight*.

Taxon	Abundance (No./0.1 m^2) Ballona 1995/97 Ave	Ballona 95% CI	Malibu 1995/97 Ave	Malibu 95% CI	SCB 1994 Ave
Amphideutopus oculatus	10.2	5.8	10.4	9.8	11.6
Paraprionospio pinnata	5.2	3.1	7.0	5.0	10.7
Spiophanes missionensis	6.5	4.1	0.0	-	10.7
Maldanidae	11.2	2.8	13.2	1.9	9.9
Spiophanes bombyx	0.2	0.3	0.0	-	9.5
Glottida albida	0.2	0.3	0.8	0.7	7.7
Mediomastus sp.	12.8	7.4	7.2	3.8	7.4
Tellina modesta	7.7	3.1	0.6	0.8	5.5
Macoma yoldiformis	1.3	1.1	2.2	1.0	5.3
Owenia collaris	3.5	3.8	0.2	0.4	5.3
Ampelisca cristata	9.0	3.9	2.4	0.5	5.2
Lumbrineris sp.	23.7	8.9	2.6	1.7	4.9
Apoprionospio pygmaea	1.8	0.5	0.6	0.8	4.8
Carinoma mutabilis	0.7	0.8	1.8	1.8	3.4
Phoronida	1.5	1.1	23.4	18.5	3.4
Ampelisca brevisimulata	6.3	2.6	7.0	5.2	3.2
Ampharete labrops	1.0	0.9	0.4	0.5	2.7
Amphicteis scaphobranchiata	0.3	0.4	0.2	0.4	2.4
Rhepoxynius menziesi	0.8	1.1	14.8	3.4	2.1
Percent of Total Station Abundance	42.6	4.5	29.8	3.6	37.3

* From Bergen *et al.* 2001.

Creek stations or among Malibu Creek stations.

Taxa characteristic of shallow reference communities were in greater abundance relative to pollution-associated indicator species along the 25 m monitoring transect offshore of Ballona and Malibu creeks (Figure 6). *Spiophanes missionensis* and *Amphideutopus oculatus* are species associated with reference communities of the SCB (Table 3). In general, stations offshore of Malibu Creek had greater densities of *S. missionensis* and *A. oculatus*. Some spatial patterns across the gradient of stormwater discharge could be observed in the relative abundance of these species, but not in the negative direction. The lowest densities of all three reference community indicator species were not observed directly offshore of the discharge, nor at the site with the highest BRI values.

Mid-depth (30-115 m) reference indicator taxa were also present in significant numbers offshore of Malibu, but not offshore of Ballona Creek (Figure 7). *Monticellina dorsobranchialis*, *Cossura* sp., and *Amphiodia* sp. are all taxa typical of mid-depth regions that normally have greater TOC and fine-grained sediments than shallow habitats. The presence of these species in depths less than 30 m is rare in the SCB. Densities of these taxa were much greater at Malibu Creek compared to Ballona Creek and also appeared to mimic the spatial pattern indicative of the stormwater gradient offshore of Malibu Creek. *Amphiodia*, in particular, is a pollution-sensitive species and is rarely found in locations of moderate anthropogenic impact in mid-depth regions.

DISCUSSION

Stormwater discharges appeared to alter the benthic habitat in Santa Monica Bay. Changes in sediment texture, organic content, and contaminant composition offshore of Ballona Creek extending 3 km offshore and up to 4 km alongshore were measured during this study. These alterations have been observed offshore of urban watersheds throughout the SCB (Schiff 2000). For example, concentrations of trace metals were enriched nearly twice as frequently near the 12 largest river and creek mouths that drain to the Bight compared to shallow water areas distant from creek mouths. Not only were

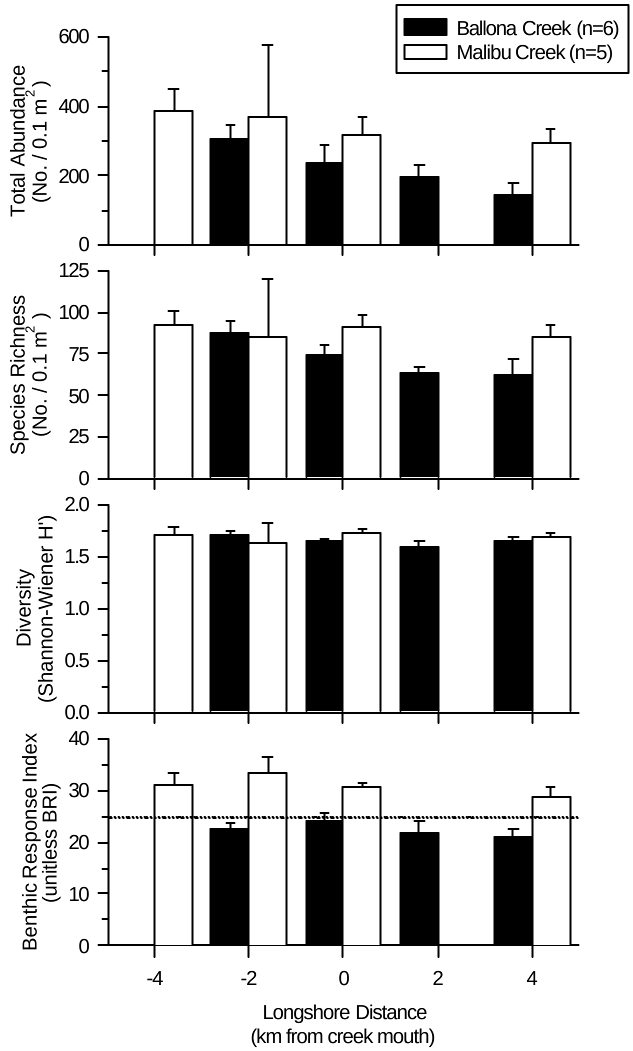


Figure 5. Infaunal biological community parameters (mean ± 95% confidence intervals) measured across the gradient of stormwater influence offshore Ballona Creek and Malibu Creek. All samples were collected at 25 m depth following significantly sized storms between 1995 and 1997.

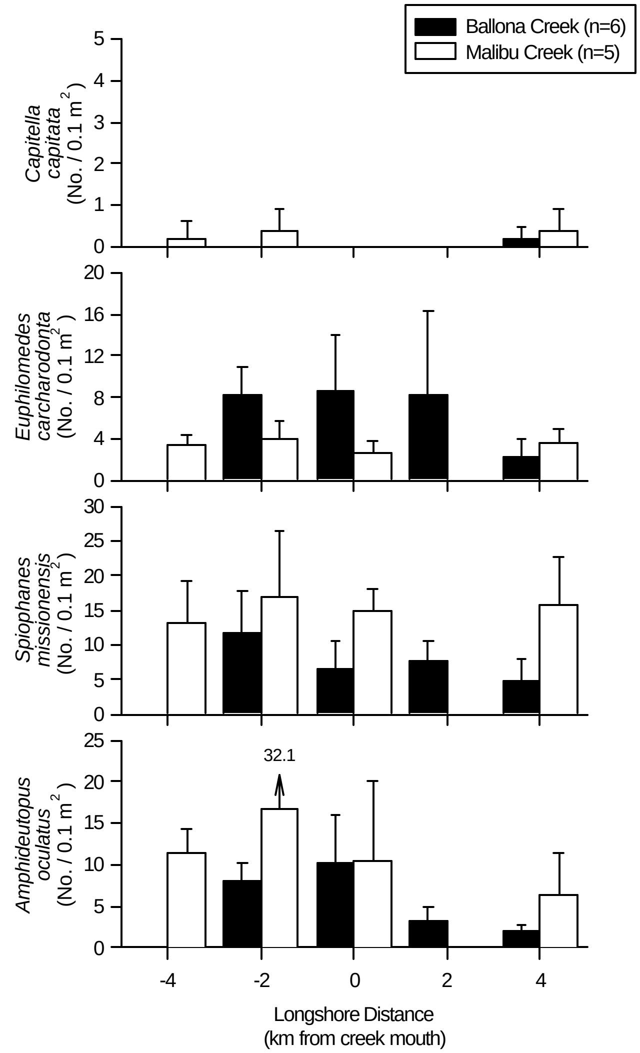


Figure 6. Abundance (mean ± 95% confidence intervals) of pollution tolerant taxa (*Capitella, Euphilomedes*) and reference community taxa (*Spiophanes, Amphideutopus*) measured across the gradient of stormwater influence offshore of Ballona Creek and Malibu Creek. All samples were collected at 25 m depth following significantly sized storms between 1995 and 1997.

sediment texture and organic content altered offshore of Ballona Creek, but changes in grain size and TOC were also observed offshore of the rural watershed of Malibu Creek. It appears that naturally derived terrestrial material also contributes organic particles to offshore areas.

Although changes in benthic habitat were observed, stormwater discharges did not appear to degrade the resident benthic community. Relatively healthy communities were measured offshore of both creeks, and they were dominated by characteristic reference site taxa. Any negative impacts observed were very subtle, such as the mild response of *Tellina modesta*, a pollution-sensitive mollusk.

This study represents one of the first applications of the BRI to stormwater-impacted areas. While stormwater areas were identified as having the potential to degrade benthic communities in the development of the BRI (Bergen *et al*. 2000), this study directly addressed the gradient of stormwater impact. Interestingly, BRI values were generally low; the rural watershed, Malibu Creek, actually had a higher BRI than the urban watershed. However, it was not the presence of shallow-water, pollution-

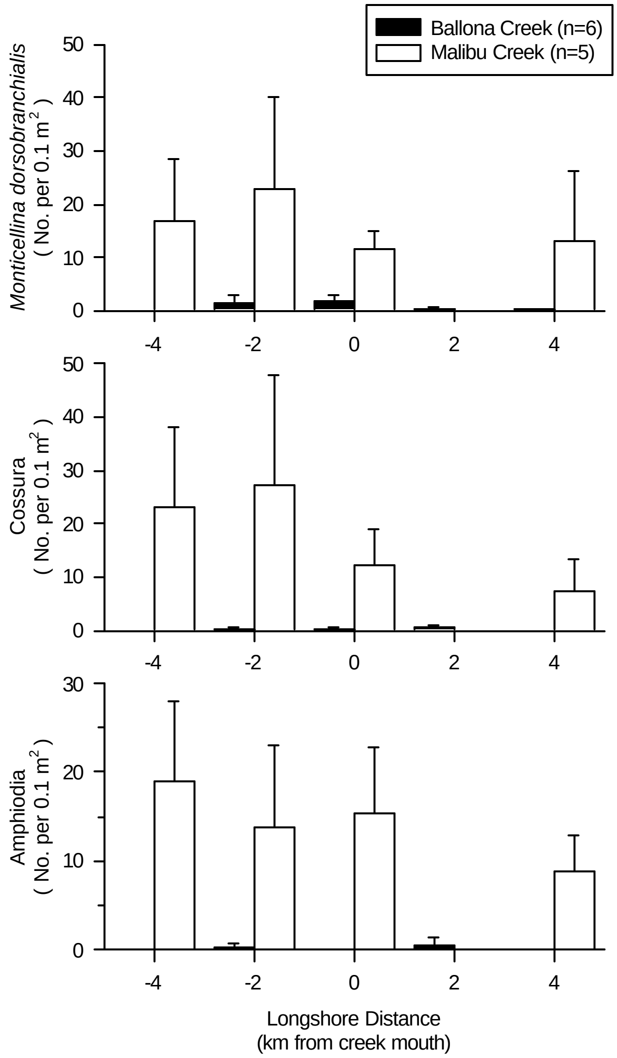


Figure 7. Abundance (mean ± 95% confidence intervals) of pollution sensitive taxa indicative of deeper depths (>30 m) measured across the gradient of stormwater influence offshore of Ballona Creek and Malibu Creek. All samples were collected at 25 m depth following significantly sized storms between 1995 and 1997.

tolerant species that altered the BRI offshore of Malibu Creek. Rather, it was the presence of mid-depth, pollution-sensitive species (e.g., *Amphiodia* sp.) in shallow water samples that altered the BRI. Species such as these are likely recruited to the fine-grained, organic-rich habitats typically found in deeper waters. It is the presence of these mid-depth species that drove the BRI higher. As the landscape in our watersheds changes, perhaps it is the lack of fine-grained, organic-rich materials that is altering the offshore benthic communities.

One explanation of why no large deleterious impact to benthic communities was observed is because the sampling sites were not in the right locations. The footprint survey conducted during the dry-weather season was designed to address this question. However, it was limited in both space and time. For example, benthic habitat quality and benthic community structure have been examined at the mouth of Ballona Creek, an area inshore of our sampling grid and one that becomes almost entirely freshwater during large storm events (Soule *et al.* 1993). The sediments contained relatively high contaminant concentrations and, episodically, were found to have nematodes in great abundance. A second location of potential impact is in deeper waters, beyond the offshore extent of our sampling grid. In these locations, storm-discharged particulates may commingle with particles from other sources, such as municipal wastewater effluents. Regardless, the fate and transport of runoff-derived materials is not well understood in the marine environment and continues to be an area where additional research is needed.

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