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SEDIMENT AND BIOLOGICAL CONDITIONS ON COASTAL SLOPES

The coastal shelf of southern California has been studied for a long time, but comparatively little is known about the biological assemblages and habitats of the coastal slope. The proposal by Orange County for future discharge of sewage sludge at a depth of about 350 m provided an immediate reason to study the slope in that area. The detection of changes caused by sludge discharge requires the investigator to sample the proposed discharge area and a similar control area before and after discharge.

The objectives of our studies were to establish the appropriate sampling design for detection of impacts of discharge and to collect predischarge data on selected sediment and biological parameters. We found that the slope areas off Newport and Point Dume were very similar to each other and represent normal slope conditions for our region.

SAMPLING SCHEDULE

Sampling began in October 1981 in the proposed discharge area off Newport, hereafter called the County Sanitation Districts of Orange County (CSDOC) area (Figure 1), where we sampled sediments and infauna on a 49-site grid (Figure 2). Analyses showed homogenous zones within the grid. Subsequently, we sampled eight of these sites, hereafter called the double-transect sites (Figure 1), semiannually (winter-summer) for 2 years (1982-1983). In 1983 we sampled a prospective control area off Point Dume, selected because of similar slope orientation, logistic ease of sampling, and the fact that previous data collected by SCCWRP revealed biological assemblages similar to those in the CSDOC area. An identical grid of eight double-transect sites was set up off Point Dume and sampled simultaneously with CSDOC

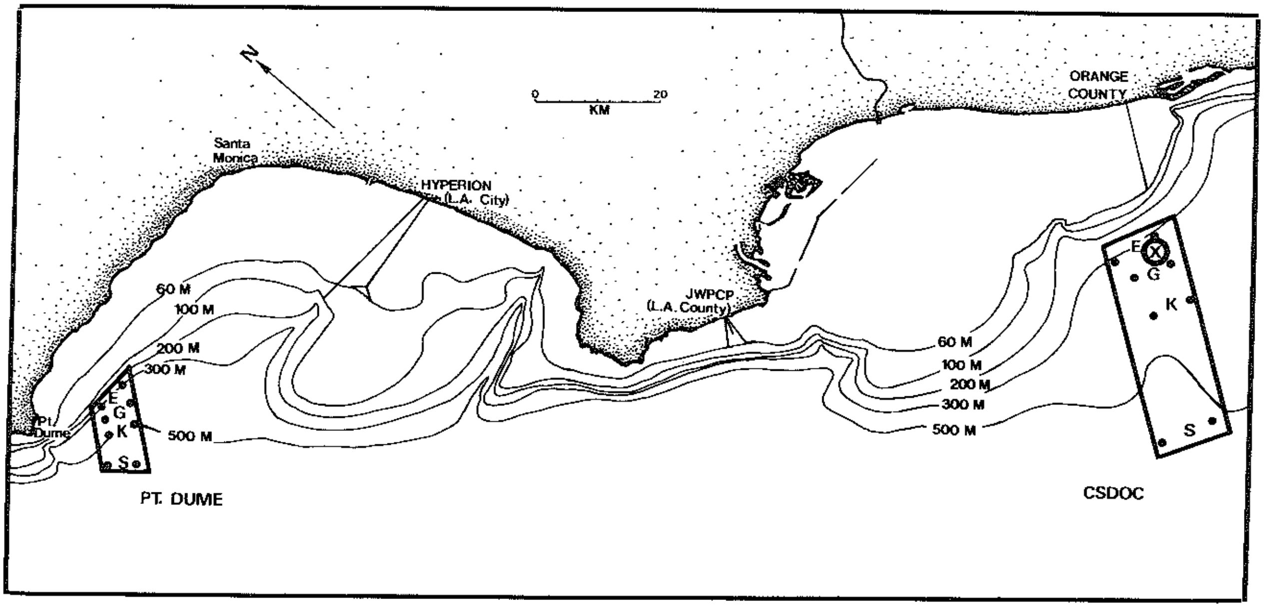

Figure 1. Chart showing locations of the study areas; E, G, K, S sites are the double-transect sites; Ⓧ in the CSDOC area shows the approximate location of the proposed deep sludge outfall.

sites. The methods of collection, measurement, and analyses and the data collected are presented below.

RESULTS

Sediments

Surface sediment samples (0-2 cm) were collected from 0.1-sq m Van Veen grab samples during three sampling periods: CSDOC, winter 1981; CSDOC, summer 1983; Point Dume, summer 1983. All of the 49-site grid stations at CSDOC (Figure 2) were sampled during the first sampling period, but only the double-transects were sampled subsequently. Measurements of grain-size, organic material, seven trace metals, and two chlorinated hydrocarbons were made using methods previously reported (Word and Mearns 1979).

Regression analyses were used to compare trends in selected sediment parameters with depth and between areas and times. Analysis of covariance was conducted to test the hypothesis of no significant differences among the regressions for CSDOC Year 1, CSDOC Year 2, and Point Dume Year 2, using the method of Zar (1974).

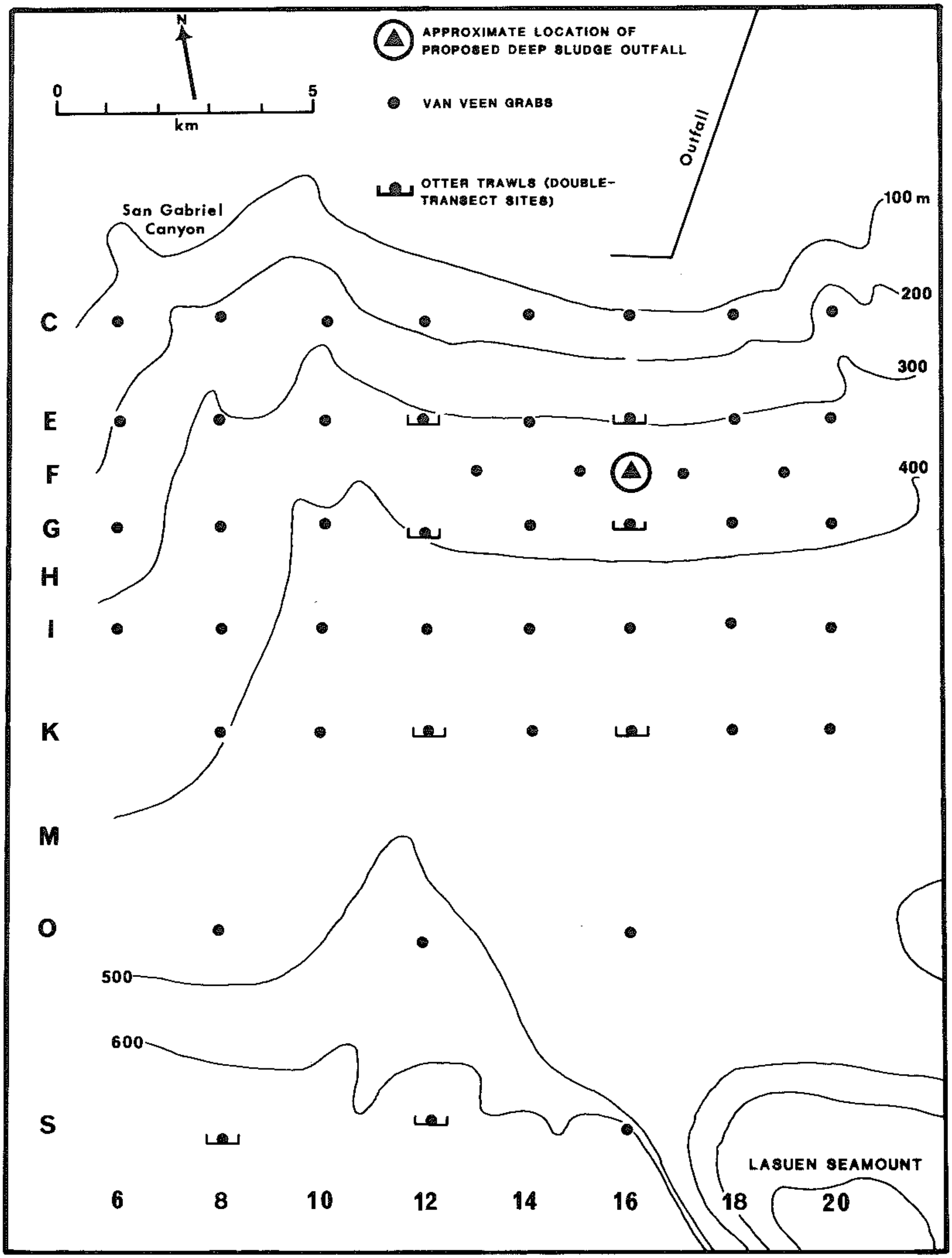

Figure 2. 49-site grid at CSDOC. These stations were all sampled during the first sampling period, winter 1981-82.

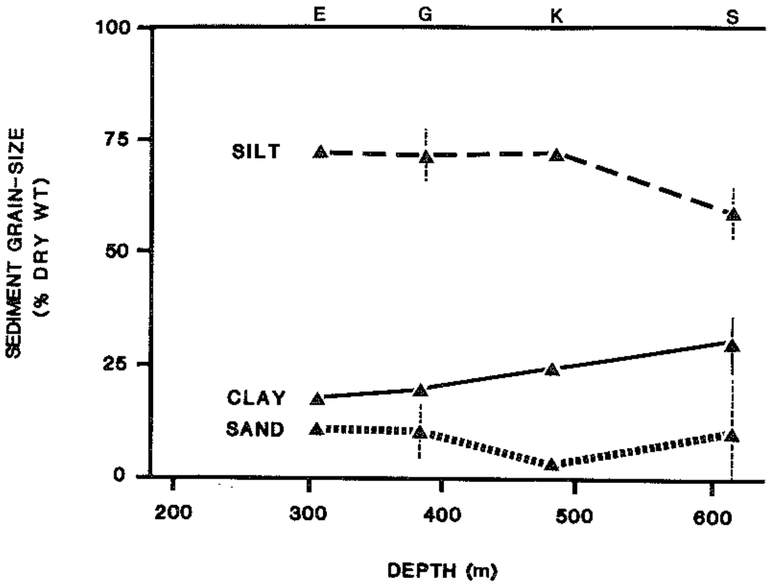

Figure 3. Plot of mean (± 1 standard deviation) sand, silt, and clay percentages in sediments at the CSDOC area double-transect sites, summer 1982.

Grain-Size and Organic Material. The sediments at the CSDOC area were predominantly silty clays; the clay fraction gradually increased with depth (Figure 3). Variation in percent of sand is due to a "canyon effect" at Stations G12 and S8 where the percent of sand was higher than at adjacent slope sites. This sandy sediment in the San Gabriel Canyon is probably derived from the San Pedro shelf (Karl et al. 1980).

The sandiest areas at CSDOC were generally the shallowest, but sandy sediment was also collected at Station F19 and at the base of Lasuen Seamount (Figure 4a). The finest grain-size sediment was collected in the upper San Gabriel Canyon and in a small depression descending into the San Diego Trough. The sediments at Point Dume were sandier than those at CSDOC. At 350 m, the proposed discharge depth, the sediments at Point Dume contained 26% sand, while the sediments at CSDOC contained 12%. The slopes of plots of sand versus depth for CSDOC and Point Dume (Figure 5) were not significantly different; the elevations were. Percents sand versus depth did not change between years at CSDOC.

Total organic material (TOM) at CSDOC generally increased over depth (Figure 4b). The outer shelf sites (shallowest) were lowest in organic material (below 5%); the deepest slope sites were usually above 10%. A canyon effect may be seen, especially at Station S8 where organic material was above 13%. Stations located in the San Gabriel Canyon generally contained more organic material than adjacent slope sites.

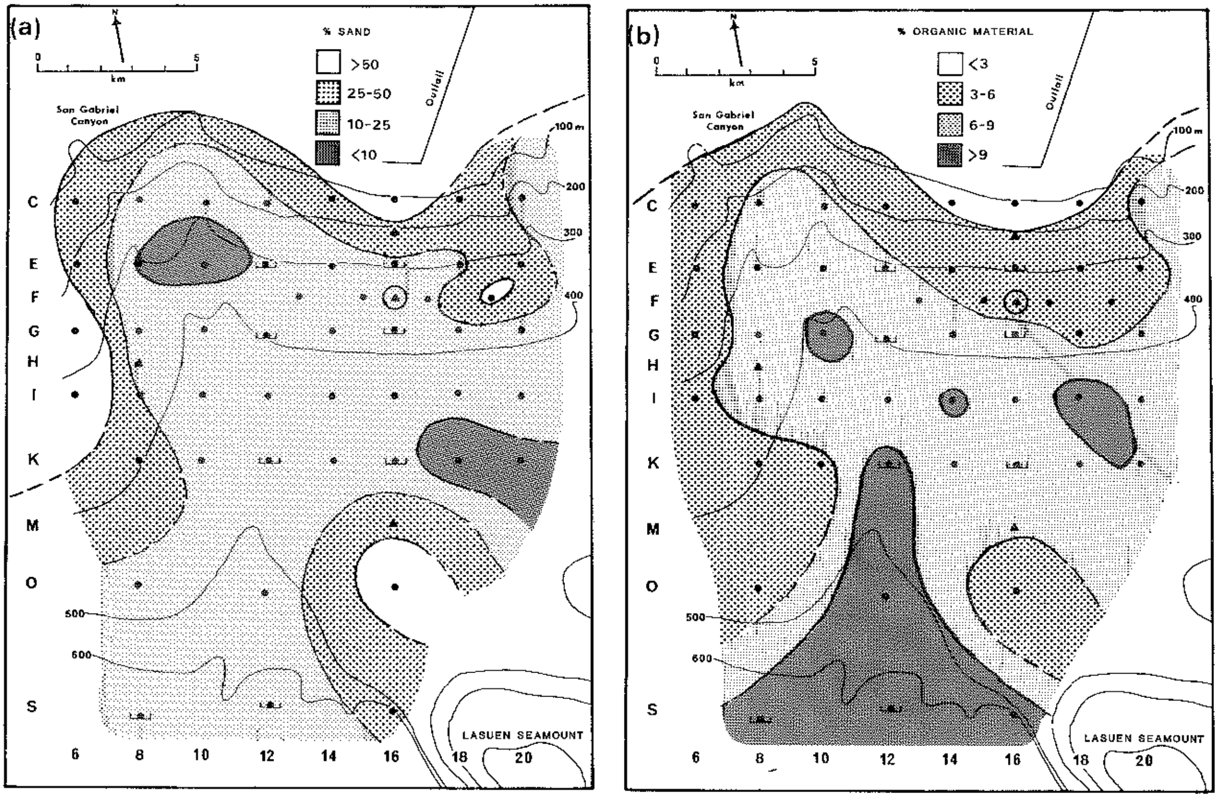

Figure 4. Surface sediment contours measured at CSDOC in October 1981; (a) shows percent sand (>63 μm) and (b) shows percent organic material (0-2 cm).

There was significantly less organic material at the deepest sites off Point Dume than at the deep CSDOC sites (Figure 5), probably because Point Dume sites contained more sand.

In studies of sludge disposal, the quality of the organic material, as well as the quantity, is important. Sludge may be composed of up to 80% organic material which is often 10% organic nitrogen (Brooks et al. 1982). The discharge of sludge into marine sediments may change existing conditions. The quality of the organic material at the proposed discharge area was measured using organic C:N ratios. Percentages of total organic carbon and nitrogen in the sediments increased with water depth, but the C:N ratio remained rather constant (Figure 6) (mean C:N = 11.5 ± 1.12 (n = 8)). These values are similar to values previously reported in the region; Emery (1960) considered 10 an average value for surface sediments and gave the San Pedro Basin a C:N of 8.0.

Contaminants in Sediments. Concentrations of seven trace metals, total DDT, and PCB were measured in the sediments at both areas.

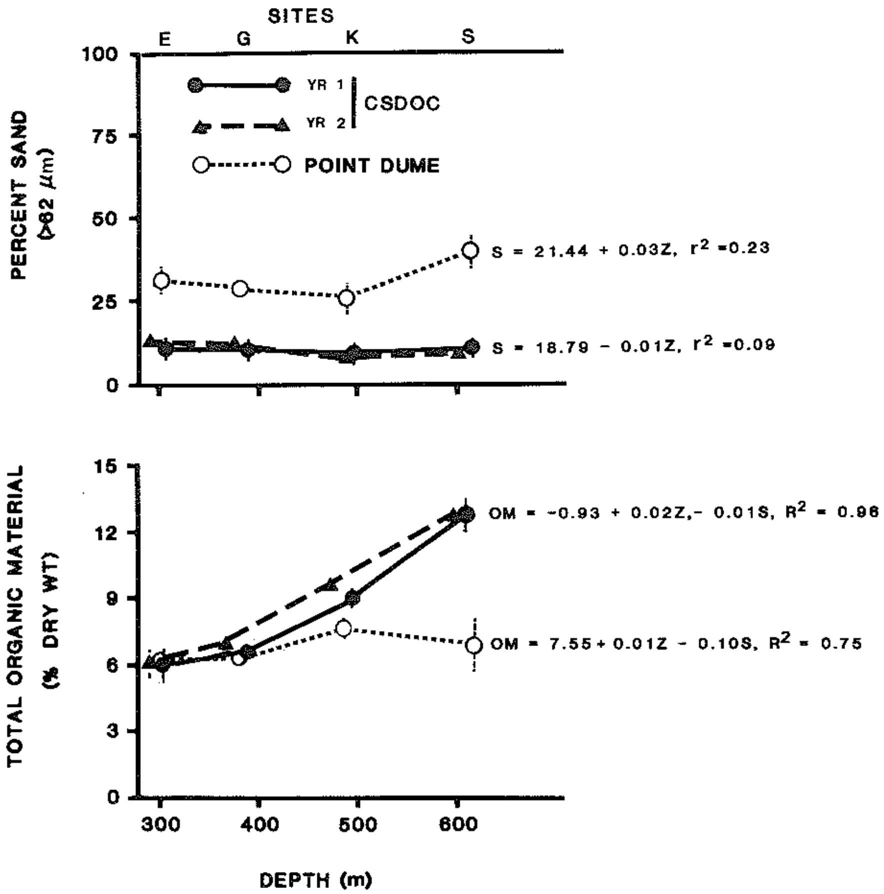

Figure 5. Plots of mean (± 1 standard deviation) percent sand and total organic material over depth in surface sediments (top 2 cm) at CSDOC and Point Dume double-transect sites. Separate regressions are given for significantly different (α = 0.05) samples (n = 4). (Z is depth (m), S is percent sand, and r^2 is the coefficient of determination.)

Hexachlorobenzene, trichlorobenzene, and dichlorobenzene were also measured but were below detection limits of 1 µg/dry kg in all samples.

Most of the metals showed no trend with change of depth, but copper showed a significant increase over depth in the CSDOC Year 2 samples; lead decreased in concentration with depth (Figure 7). Although not plotted, there were elevations of some trace metals (Cu, Hg, and Zn) at the shallowest sites (100-200 m) in the CSDOC area, probably due to the existing CSDOC outfall located shoreward in 60 m of water. Mercury concentrations in the CSDOC area were low, ranging from 0.05 to 0.1 mg/dry kg near previous measurements made on the shelf and slope in the San Pedro Channel (Chen and Lu 1974).

The levels of trace metals measured in the sediments were generally similar between CSDOC and Point Dume. Due to the higher sand

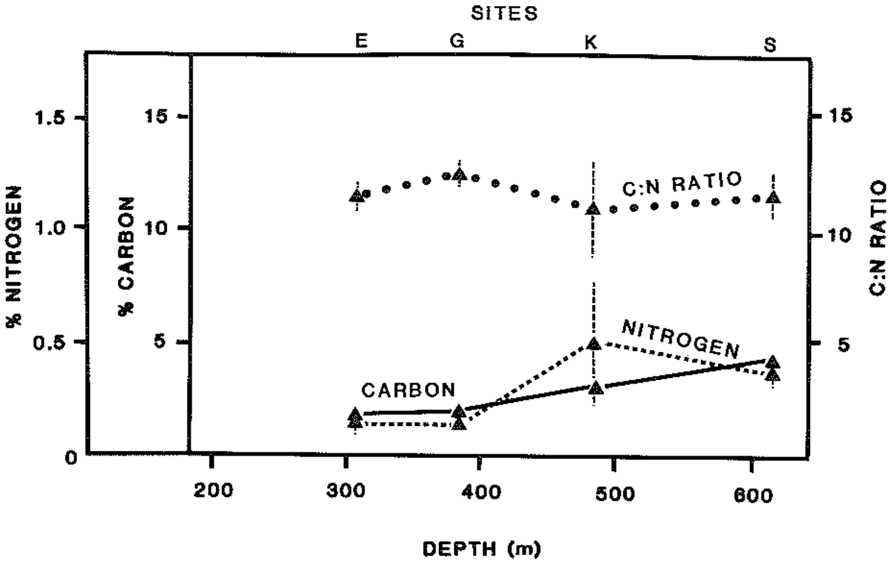

Figure 6. Percent total organic carbon and nitrogen (mean ± 1 standard deviation) in surface sediments (top 2 cm) over depth at the CSDOC double-transect sites, summer 1982. Carbon and nitrogen increased slightly over depth, but the C:N ratio remained constant.

content of the Point Dume sediments, lower trace metals values were expected. However, some metals, (such as Cd, Cr, and Pb) were higher off Point Dume than at the CSDOC area; chromium was significantly higher at Point Dume. Additionally, the chromium levels at CSDOC were significantly higher (about 20 mg/kg) in the 1983 samples than the 1981 samples. The reasons for the increase in chromium but not in other metals is unknown. The regressions for the remaining trace metals were not significantly different over time at CSDOC or between areas.

Table 1 compares these sediment parameters to those measured on the slope off Ventura County where the same sampling and analytical methods were used (Hershelman et al. 1982). The slope off Ventura County is remote from a major wastewater outfall and has been described as a "normal" or unimpacted region (Bascom et al. 1978). Sediment grain-size decreased (i.e., there was a smaller percent of sand) downslope; percent of volatile solids and trace metal concentrations increased downslope (Hershelman et al. 1982). Trace metal concentrations at CSDOC, especially from 300 to 600 m, were quite similar to those from the slope off Ventura County. Sediment trace metal concentrations at the CSDOC area were lower by at least a factor of 2 than the adjacent sediments of the San Pedro Basin (samples taken 20 km to the west of the sampling area, at 890 m (Bruland et al. 1974)).

Total DDT in the sediments showed no trends over depth at CSDOC, but at Point Dume total DDT showed a significant increase over depth (Figure 8). It is important to note that, although DDT concentrations

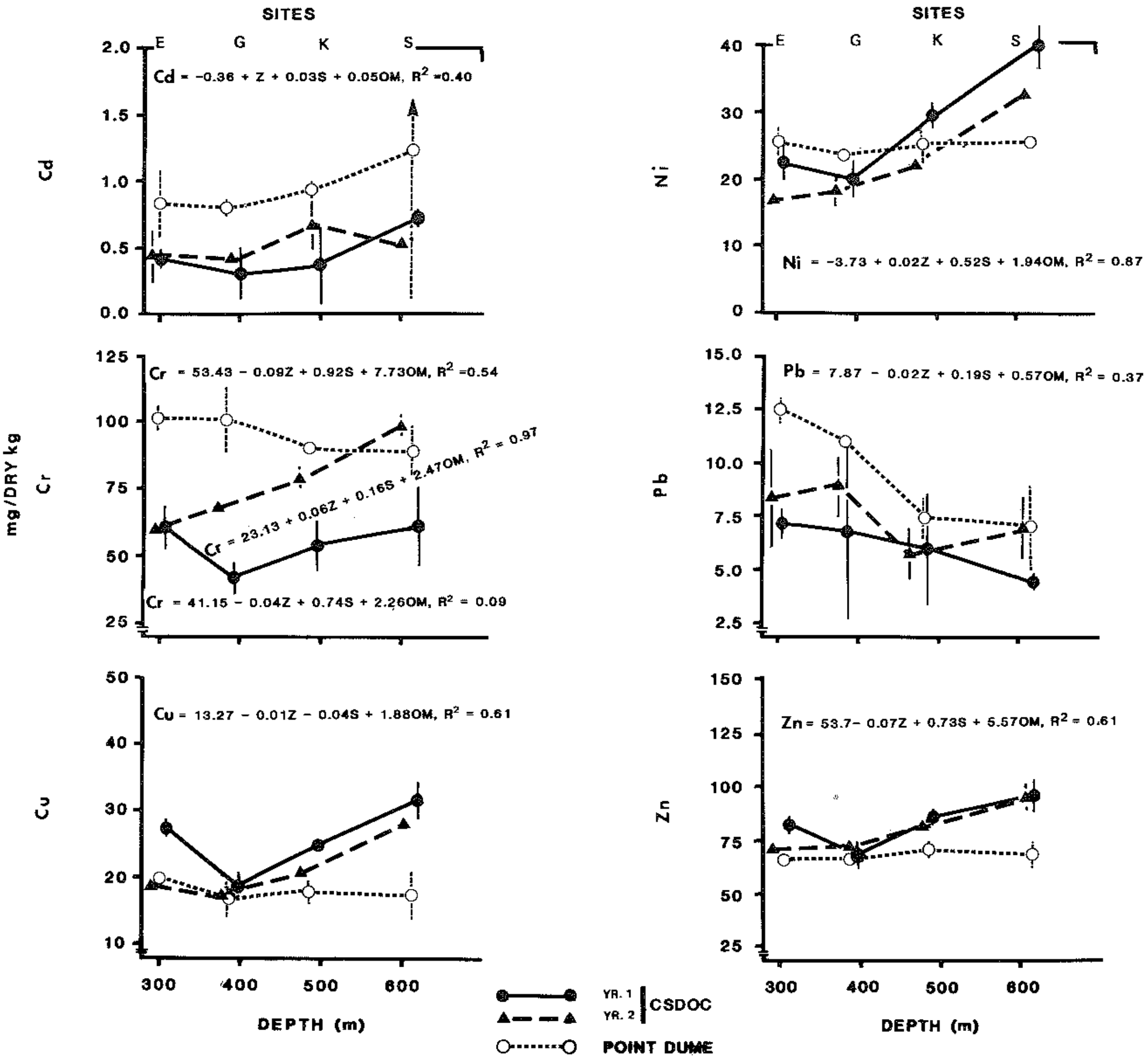

Figure 7. Variation of six mean (± 1 standard deviation) trace metal concentrations in surface sediments (top 2 cm) with depth at the CSDOC double-transect sites, summer 1982 (OM is percent of sediment which is organic material, Z is depth (m), S is percent sand, and R^2 is the coefficient of determination).

in the Point Dume sediments were elevated compared to the CSDOC sediments, due to differences in grain-size and organic material the concentrations were not significantly different between the two areas. Concentrations of DDT and PCB were elevated over concentrations measured in sediments from other clean areas; for example, concentrations of total DDT measured in sediments from the back side of Catalina Island in the same depth range were 9 µg/dry kg (Chen and Lu 1974). It is useful to note, however, that although the mean DDT

Table 1. Summary of sediment characteristics and trace metal concentrations (mg/dry kg ± 1 standard error) in surface sediments (0-2 cm) off Ventura County, the Point Dume area, and the Orange County proposed discharge area, taken from 300- to 600-m water depths.

	% Dry	%TVS	%Sand	Cd	Cr	Cu	Ni	Pb	Zn
Ventura County[a], 1982 n = 14	56 ± 1.3	5.9 ± 0.45	26 ± 4.9	1.1 ± 0.01	57 ± 3.5	19 ± 1.2	26 ± 1.7	13 ± 1.1	68 ± 3.7
Point Dume, 1983 n = 8	53 ± 1.3	6.9 ± 0.03	33 ± 2.4	0.95 ± 0.16	96 ± 3.2	18 ± 0.7	25 ± 0.6	9.4 ± 1.0	68 ± 1.3
CSDOC, 1981 n = 8	47 ± 2.0	8.7 ± 1.0	15 ± 1.2	0.46 ± 0.08	54 ± 3.8	25 ± 1.9	28 ± 3.1	6.2 ± 0.75	83 ± 4.0
CSDOC, 1983 n = 8	48 ± 2.4	9.0 ± 1.0	16 ± 1.0	0.53 ± 0.05	75 ± 5.1	21 ± 1.5	23 ± 2.4	7.6 ± 0.65	80 ± 3.9

[a] From Hershelman et al. 1982.

concentration of 27 µg/dry kg from the CSDOC area was three times larger than these clean-area concentrations, it was 150 times less than concentrations measured in 1978 from the same depth range off the Palos Verdes (White Point) outfall and 18 times less than those from the Redondo Canyon in Santa Monica Bay (SCCWRP, unpublished data).

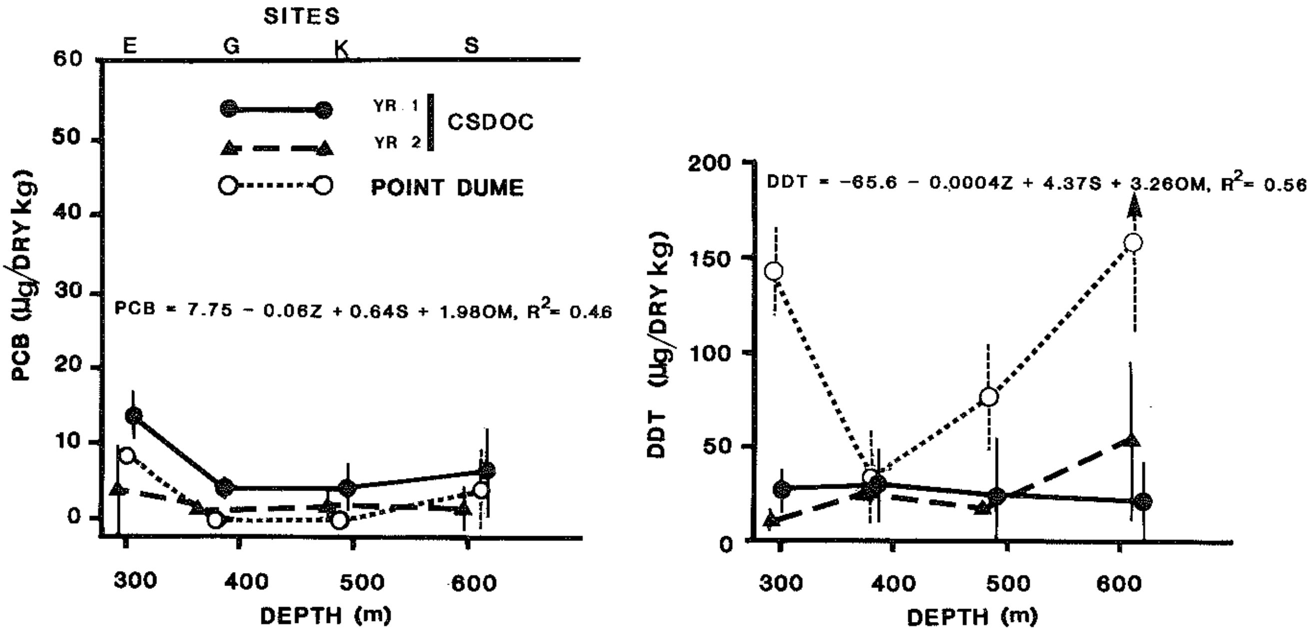

Figure 8. Variation of mean (± standard deviation) DDT and PCB concentrations with depth at the CSDOC double-transect sites, summer 1982 (OM is percent of sediment which is organic material, Z is depth (m), S is percent sand, and R^2 is the coefficient of determination).

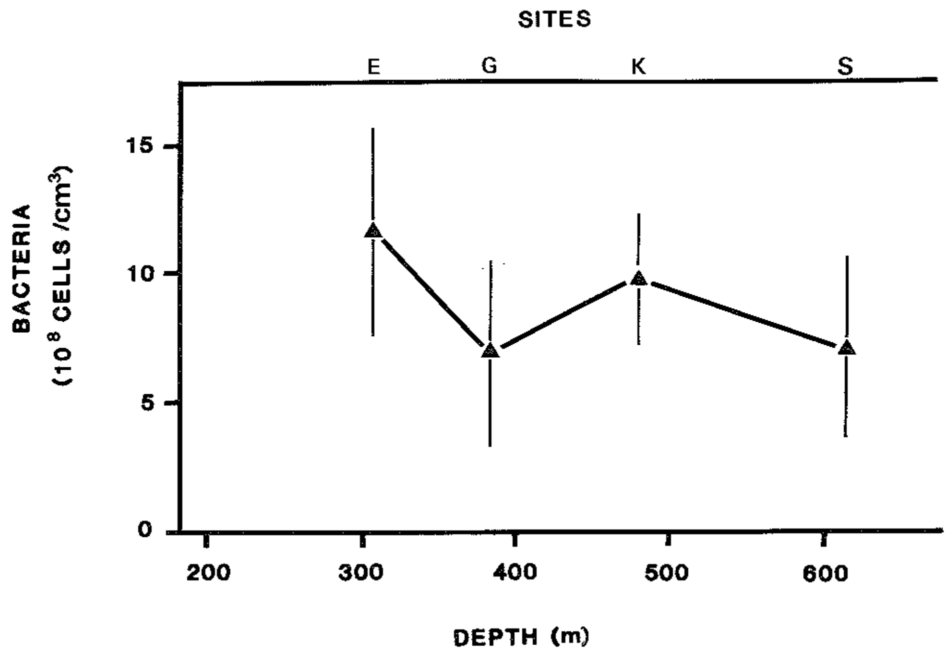

Figure 9. Variation of mean (± 1 standard deviation) number of bacterial cells over depth at the double-transect sites at CSDOC, summer 1982 (n = 2).

Microbes in Sediments. The number of bacteria in the sediment averaged 8.7×10^8 cells/cu cm at the eight double-transect sites at CSDOC and showed no trend with depth (Figure 9). Subtracting bacterial carbon estimates from total microbial biomass estimates showed that only 10 to 36% of the total microbial carbon is contributed by bacteria; it was therefore assumed that the majority of microbial carbon in the sediments was contributed by protozoans and meiofaunal metazoans.

No information on bacterial densities of slope sediments for the CSDOC region was located in the literature. For comparison, intertidal sediments were found to contain 10^8 to 10^9 cells/gm (Anderson and Meadows 1967; Dale 1974), and Hargrave (1972) and Dale (1974) calculated highly significant correlations among sediment grain-size, organic material, and bacterial counts. In our study area however, a significant correlation among these parameters was found only between grain size (mean phi) and percent of organic material (Table 2). It is possible that the elevated grain-size and amount of organic material at the canyon sites were largely responsible for the lack of significant correlations.

Benthic Infauna

Species Composition. The infauna from the CSDOC and Point Dume areas were sampled using a 0.1-sq m Van Veen grab. The samples

Table 2. Correlations between bacterial counts, organic material, and grain-size at CSDOC were significant between sediment grain-size (mean phi) and organic material, but there was no significant correlation of either grain-size or organic material to bacterial counts (r_s = Spearman's rank correlation coefficient; * = significant values; α = 0.05; n = 8).

Variable	Mean phi	TOM
Bacterial counts (cells/cm^3)	-0.17	0.07
Total organic material (%)	0.81*	-

were screened through 0.5- and 1.0-mm sieves, but only the 1.0-mm fraction is reported herein.

Species composition and abundances from the 49-site grid, October 1981, were analyzed using classification analysis (Smith 1976). The following four site groups were identified (Figure 10).

1. **Outer mainland shelf.** This group was composed of 10 sites in a depth range of 105-342 m. The two most abundant species in this group, the polychaete *Spiophanes* nr. *kroyeri* and the ophiuroid *Amphiodia urtica,* were collected at all 10 sites (Table 3). *A. urtica* and the ostracods *Euphilomedes* spp. were commonly collected at adjacent mainland shelf sites (Thompson 1982). The polychaetes *Pectinaria californiensis* and *Maldane sarsi* are common inhabitants of the southern California mainland shelf and become dominant in slope assemblage (see next site group).

2. **Upper slope.** This group was composed of 18 sites in a depth range of 282-388 m; *M. Sarsi* and *P. californiensis* were the two most abundant species. Many species in this assemblage also occurred on the mainland shelf. Only a few species, such as the echuiran *Arhynchite californicus* and the ostracod *Scleroconcha trituberculata,* were restricted to the upper slope.

3. **Transition group.** This group was composed of 15 sites at a depth range of 396-487 m. While the same two polychaete species were also the most abundant in this group, several lower slope species, such as the chaetoderms, began to appear. Generally, the upper slope organisms became less dense and more patchy.

4. **Lower slope.** This group was composed of six sites at a depth range of 422-627 m, characterized by species with very patchy distributions. Three of the five most abundant species were collected

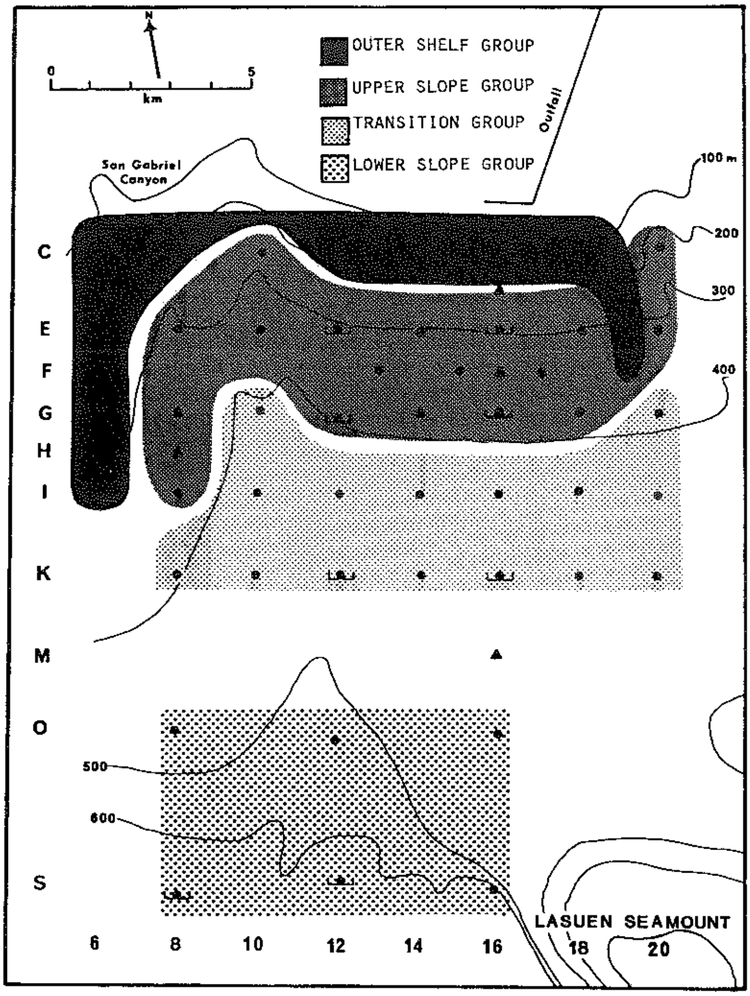

Figure 10. Benthic infaunal species at the CSDOC area. Results of classification analysis show site groupings of infaunal grab samples, October 1981; sites with same shading had similar species composition and abundances.

in only one of the six samples (Table 3). The ostrocod *Euphilomedes carcharodonta* is usually collected in shallower waters; in this site group, however, it was collected only at Station O16, a sandy site at the base of Lasuen Seamount, suggesting that bottom composition is more important than depth for this species. Of the more commonly collected invertebrates, chaetoderms and enteropneusts were most abundant. Compared to the upper slope assemblages, the lower slope assemblages were composed of many more species that are unique to these sites, for example, the clam *Tindaria californica* and the echiuran *Listriolobus hexamyotus*.

Distinct zonation on the slopes was not evident. Many outer shelf species also occurred on the upper slope, and both upper and lower slope species occurred in the transition sites. In general, the upper

Table 3. Most abundant infaunal species in each classification site group, October 1981.

Species	Taxon[a]	Mean Density (m^2)	Frequency of Collection
Outer shelf (n = 10; depth 105-342 m)			
Spiophanes nr. *kroyeri*	p	234.0	1.0
Amphiodia urtica	e	233.0	1.0
Euphilomedes producta	c	203.0	0.70
Pectinaria californiensis	p	201.0	1.0
Maldane sarsi	p	147.0	0.90
Upper slope (n = 18; depth 282-388 m)			
M. sarsi	p	138.3	0.94
P. californiensis	p	113.9	1.0
Scleroconcha trituberculata	c	27.8	0.5
Chloeia pinnata	p	25.0	0.33
Saxicavella pacifica	m	23.9	0.39
Transition (n = 15; depth 396-487 m)			
M. sarsi	p	108.0	0.67
P. californiensis	p	24.8	0.73
Prionospio lobulata	p	20.0	0.67
Chaetodermatidae	m	1.27	0.60
Brissopsis pacifica	e	11.3	0.60
Lower slope (n = 6; depth 422-627 m)			
Euphilomedes carcharodonta	c	44.0	0.17
Chaetodermatidae	m	23.3	1.0
Enteropneusta	h	16.7	0.50
Erichtonius difformis	c	16.7	0.17
Ampelisca macrocephala	c	13.3	0.17

[a] p = polychaete; c = crustacean; m = molluscan; e = echinoderm; h = hemichordate.

slope and transition sites together represent a gradation in species composition between the more distinctive outer shelf assemblage and the lower slope assemblage. No distinct canyon assemblage was identified: species composition, as well as other parameters such as species richness, were similar in canyons and on the slope proper.

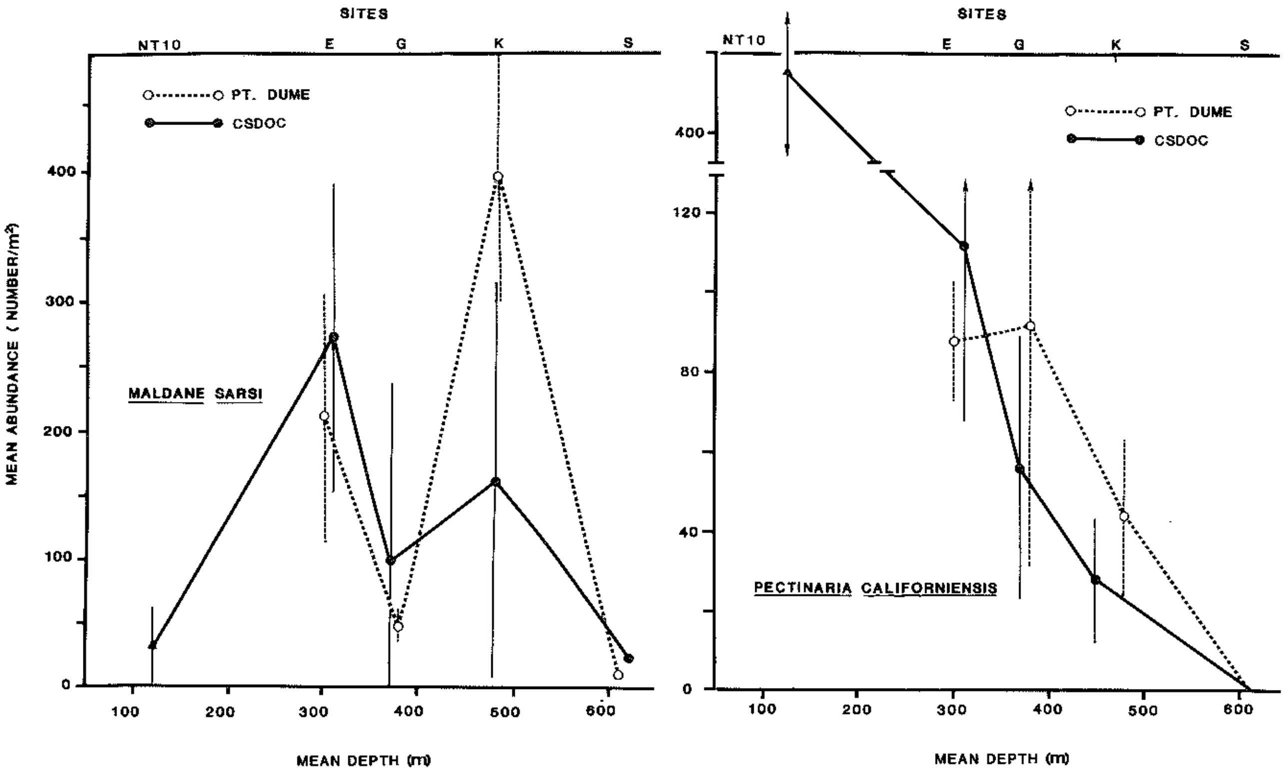

Figure 11. Variations of mean (± 1 standard deviation) densities of the two most abundant infaunal invertebrates (both polychaetes) over depth at the CSDOC and Point Dume double-transect sites. Separate curves are shown for each area, but they were not significantly different. All samples were averaged (n = 8 at CSDOC; n = 4 at Point Dume). Data point at 137 m from CSDOC monitoring station NT10 is included for comparison.

The distributions over depth of the two most abundant infaunal species, *M. sarsi* and *P. californiensis*, are shown in Figure 11. *M. sarsi* was most abundant at E sites in the CSDOC area, but at Point Dume it reached maximum densities at the K sites. The reason for this difference is not clear. *P. californiensis* was more abundant on the upper slope than the lower slope in both areas but reached its maximum densities on the mainland shelf, with average densities of 422/sq m (Thompson 1982). Analysis of variance (ANOVA) on *M. sarsi* and *P. californiensis* abundances showed no significant differences in densities between the CSDOC and Point Dume areas or between years or seasons in either area.

Species Richness, Density, and Biomass. The trends in species richness, density, and biomass in the grab samples were similar at both the CSDOC and Point Dume areas (Figure 12). Species richness and density decreased over depth, but biomass was highly variable due to the chance collection of large, widely dispersed invertebrates such as

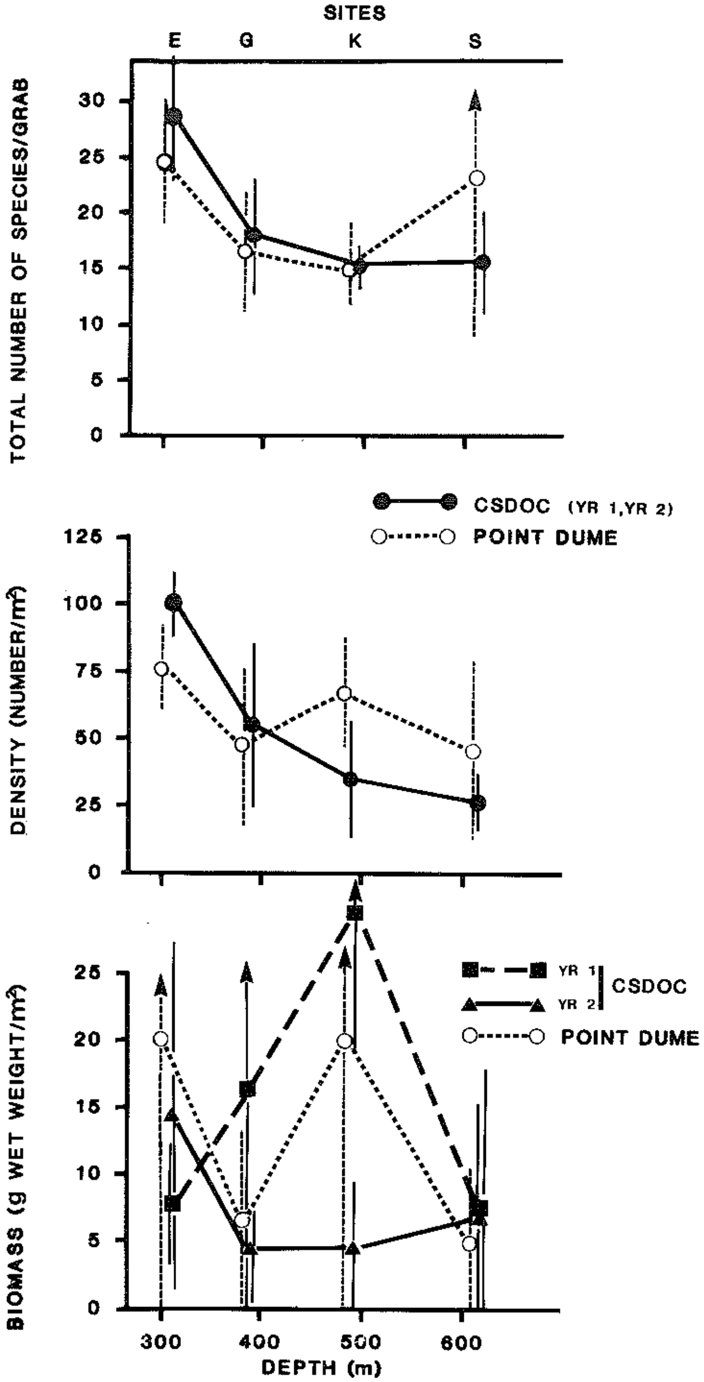

Figure 12. Trends in infaunal assemblage parameters over depth for the CSDOC and Point Dume double-transect sites. Separate curves are plotted for each area, although they are not significantly different. For biomass, the Year 1 and Year 2 CSDOC curves are plotted separately because they are significantly different.

echinoids, holothuroids, and echuirans. Analysis of variance revealed significant depth effects for species richness, density, and biomass. The shallowest sites (E) had significantly more species and higher densities than the deeper sites.

There were no significant differences in species richness or densities between Year 1 and Year 2 at CSDOC or seasonal effects within each year in either area; however, there was significantly more biomass in the Year 1 than Year 2 samples at CSDOC. This difference is probably a result of the chance collection of large invertebrates rather than a real seasonal fluctuation in biomass. Nonparametric analysis (Kruskal-Wallis test) on the data showed no significant difference in biomass between years at CSDOC.

That there was no significant difference in species richness, density, or biomass between the two areas demonstrates that infauna at the Point Dume control area were similar to infauna at the CSDOC treatment area.

Epibenthic Invertebrates

Species composition. Trawling was conducted at the double-transect sites in both areas at the same time as grab sampling. More than 108 species of invertebrates were collected by trawling. Classification analysis showed upper (E and G sites) and lower (K and S sites) slope site groupings. The five most abundant species collected at each depth from the double-transect sites are shown in Table 4. Four echinoid genera, three of them heart urchins, often were collected in the same trawl on the upper slope at CSDOC. The urchins *Allocentrotus fragilis* and *Brissopsis pacifica* comprised over 90% of trawl invertebrate catches at the upper slope sites. *A. fragilis*, a common member of the benthos along the outer shelf and upper slope throughout the southern California borderland was the second most abundant species trawled in 1977 from four areas, including insular shelves and Tanner Bank, for the Bureau of Land Management Benchmark Studies (SCCWRP, unpublished data). *Brisaster latifrons* was more abundant than *Brissopsis pacifica* at Point Dume, while the opposite was true at CSDOC. *B. pacifica* was reported from the CSDOC area (Hartman 1955), from the offshore ridges and banks, and from the slope off Oceanside (Fauchald and Jones 1979a); in contrast, *B. latifrons* was found more to the north (Nichols 1975). *Spatangus californicus* was a minor component of the trawl catches. Small epibenthic shrimp of the genus *Spirontocaris* were commonly collected at all depths, as was the clam *Cyclocardia ventricosa*. *Cyclocardia* is a common member of the mainland shelf benthos of the southern California region; Jones (1969) described it as a co-dominant with *Amphiodia urtica* from more northern mainland shelf areas.

Of the three asteroid species collected at the shallowest (E) sites, *Luidia foliolata* was the most abundant. At the deepest (S) sites, nine asteroid species were collected of which *Myxoderma platyacanthum* was the most abundant. Sponges, ophiuroids, pennatulids, and anemones

Table 4. Most abundant trawl-caught invertebrates at CSDOC and Point Dume double-transect sites, all samples averaged.

		CSDOC		Point Dume	
Site	Rank	Species[a]	Mean No./Catch	Species	Mean No./Catch
E	1	*Allocentrotus fragilis* (e)	713.5	*A. fragilis*	950.0
	2	*Brissopsis pacifica* (e)	558.3	*Brisaster latifrons* (e)	60.8
	3	*Spirontocaris holmesi* (e)	48.9	*S. holmesi*	52.0
	4	*Spatangus californicus* (e)	27.0	*B. pacifica*	35.0
	5	*Spirontocaris sp.*	13.6	*Philine alba* (op)	24.0
G	1	*B. pacifica*	2027.1	*B. latifrons*	2032.3
	2	*A. fragilis*	653.0	*B. pacifica*	1703.5
	3	*Cyclocardia ventricosa* (pe)	16.4	*A. fragilis*	787.0
	4	*Spirontocaris sica* (c)	14.4	*C. ventricosa*	107.5
	5	*Brisaster latifrons* (e)	13.8	*Laetmophilia fecundum* (h)	7.5
K	1	*B. pacifica*	6960.1	*B. pacifica*	5524.0
	2	*Myxoderma platyacanthum* (a)	293.4	*B. latifrons*	335.0
	3	*A. fragilis*	67.7	*M. platyacanthum*	223.3
	4	*C. ventricosa*	42.9	*C. ventricosa*	132.8
	5	*B. latifrons*	35.6	*L. fecundum*	62.3
S	1	*B. pacifica*	2256.9	*Asteronyx longifissus* (o)	520.8
	2	*M. platyacanthum*	935.4	*Ophiomusium jollensis* (o)	125.0
	3	Ophiactidae (o)	81.0	*Distichoptilum sp.* (p)	103.75
	4	*O. jollensis*	40.0	*Bathybenbix bairdii* (g)	93.3
	5	*S. sica* (c)	29.9	*M. platyacanthum*	92.3

[a] e = echinoid; o = ophiuroid; h = holothuroid; a = asteroid; pe = pelecypod; g = gastropod; op = opistobranch; p = pennatulid; c = crustacean.

were much more abundant at the deepest (S) than at the shallower sites. Hartman (1966) described a "glass sponge" assemblage from just above the sills of the nearshore basins from which we apparently sampled. This assemblage showed an increase of suspension-feeding organisms, suggesting an area of increased suspended particle load. The ophiuroid *Asteronyx* sp. was more abundant at the deepest (S) sites at Point Dume than at CSDOC. This ophiuroid was often collected attached to the pennatulid *Distichoptilum* from which it apparently feeds on suspended particles.

The depth distributions of the two most abundant trawl-caught invertebrates at both areas, the urchins *A. fragilis* and *B. pacifica*, are shown in Figure 13. Although their depth distributions overlapped, their maximum abundances were on the upper and lower slopes, respectively. The grab samples provided the following estimates of the densities of these urchins in each of the site groups: *A. fragilis* =

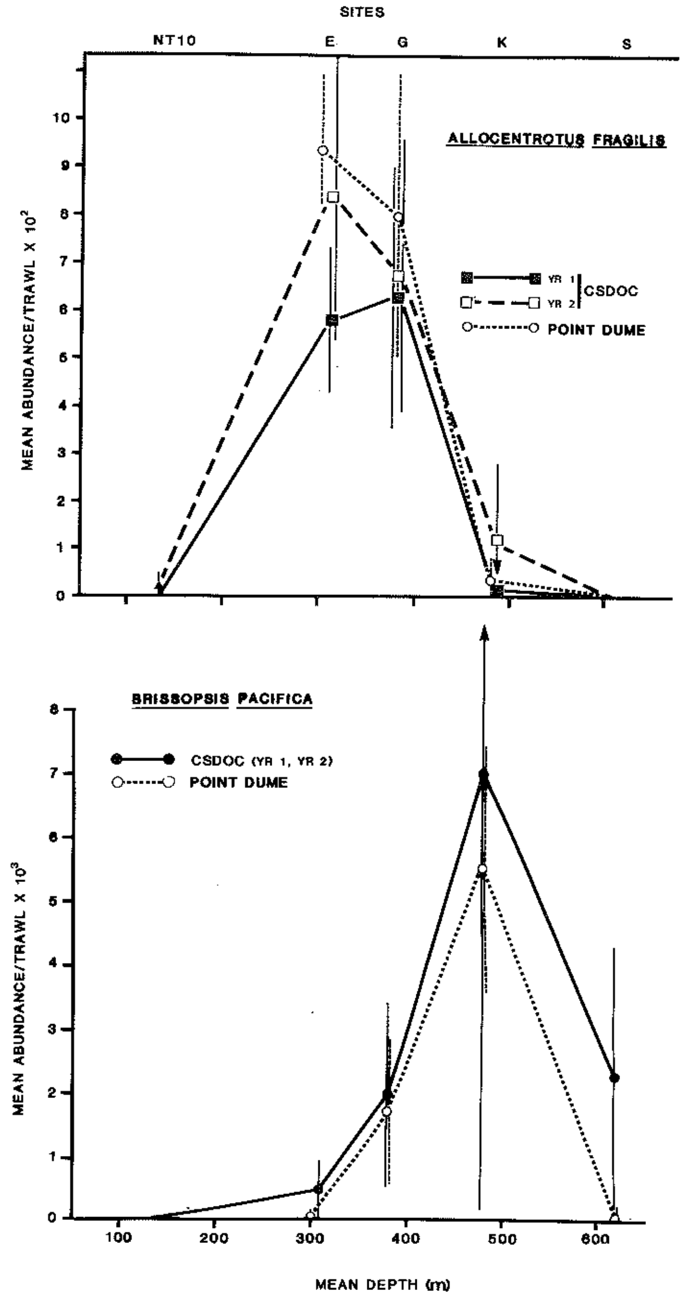

Figure 13. Depth distributions of most abundant epifaunal invertebrates (mean number per trawl ± 1 standard deviation). Separate curves are plotted for each area but were only significantly different for *A. fragilis*. These were significantly fewer during Year 1 than Year 2. CSDOC monitoring station NT10, at 137 m, is included for comparison.

1.2/sq m and *B. pacifica* = 11.6/sq m on the upper slope. On the lower slope *A. fragilis* = 0.5/sq m and *B. pacifica* = 5/sq m. ANOVA of the trawl abundance data showed significant differences in *A. fragilis* catches between the 2 years at CSDOC, but no differences between CSDOC and Point Dume. For *B. pacifica*, there were no significant temporal differences in catches, but there were significantly more

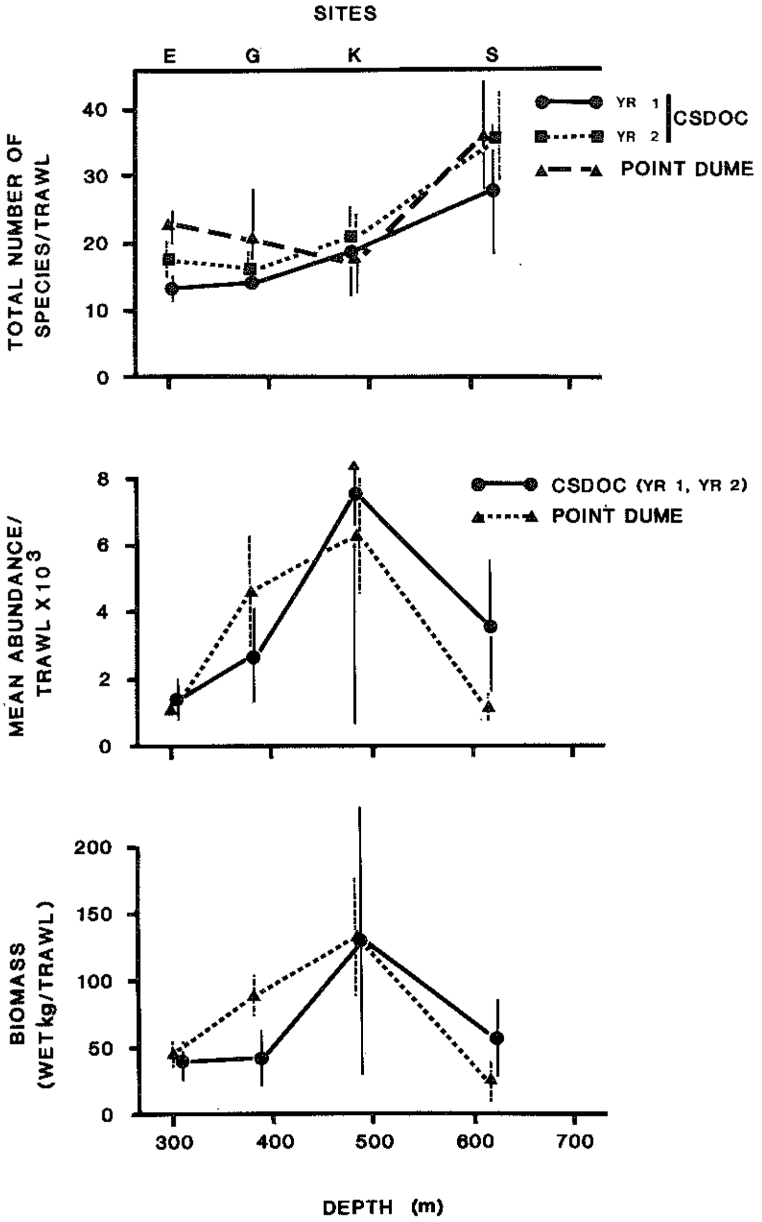

Figure 14. Trends in epibenthic invertebrates (mean catch per trawl ± 1 standard deviation) over depth for the CSDOC and Point Dume double-transect areas. Separate curves are shown for each area although they are not significantly different. Number of species was significantly different over time at CSDOC (shown separately) and seasonally at Point Dume (not shown).

caught at CSDOC than at Point Dume. Differences in the distribution of this species between areas were noted above.

Trawl Catch Parameters. The numbers of species and individuals and biomass of trawl-caught epibenthic invertebrates showed trends opposite from the infaunal grab samples (Figure 14). Epibenthic invertebrate species richness increased with slope depth. The abundance and biomass of the catches were larger at the K sites (midslope) in both areas than at the other sites. These catches were composed mostly of the echinoid *B. pacifica*. There was a significant increase in the number of species at the deepest (S) sites. These sites represent the glass sponge association discussed above, where there was a significant increase in species richness due presumably to the addition of suspension feeders. Spatial and temporal differences in trawl catches were examined by ANOVA; the only difference over time at the CSDOC area was in number of species: significantly more species were collected in the 1983 (Year 2) samples. There were no significant seasonal differences within each year, and there were no significant differences in any of these parameters between the Point Dume and CSDOC areas.

Fish

Species Composition: Upper Slope. Forty-one species of fish were collected by trawling during the study. Based on classification analysis, the trawl fish catches could be divided into upper (E and G sites) and lower (K and S sites) slope assemblages. The upper slope stations were dominated by three species of flatfish (Dover sole, *Microstomus pacificus*; rex sole, *Glyptocephalus zachirus*; and slender sole, *Lyopsetta exilis*) and two species of rockfish (splitnose rockfish, *Sebastes diplopora*, and shortspine thornyhead, *Sebastolobus alascanus*) (Table 5). Several species of small demersal and benthopelagic fishes (blackbelly eelpout, *Lycodopsis pacifica*; bearded eelpout, *Lyconema barbatum*; blackedge poacher, *Xeneretmus latifrons*; bigeye starnose, *Asterotheca pentacantha*; and black hagfish, *Eptatretus deani*) were regular but not abundant members of the upper slope fish assemblage. The dominant benthopelagic fish predators on the upper slope were Pacific whiting *(Merluccius productus)*, spiny dogfish *(Squalis acanthias)*, and, to a lesser extent sablefish *(Anoplopoma fimbria)*. One member of the upper slope assemblage, the shortspine thornyhead, also occurred on the lower slope, although in reduced abundance. Since the upper slope has no abundant indicator fish species, it can best be viewed, as it was for benthic infauna, as a transition zone between shelf and lower slope assemblages.

Species Composition: Outer Shelf. Members of the upper slope fish assemblage also occurred on the outer shelf. Upper slope fishes comprised a mean of 57% (SD = 16; n = 12) of the individuals collected at 137 m off Orange County (monitoring station NT10) between 1979 and 1982. Upper slope fishes comprised a mean of 55% (SD = 19; n = 7) of the individuals collected between 174 m and 227 m from Point Dume to Point Conception. Slender sole, Dover sole, rex sole, and blackbelly eelpout have been found to co-occur off the west coast of North America north to at least Canada (Levings 1973).

It is primarily the juveniles of the three abundant upper slope flatfishes that comprised a large portion of the catch on the outer shelf--48% (SD = 15; n = 12) of the individuals collected at CSDOC monitoring station NT10 between 1979 and 1982. Larvae of slender, Dover, and rex soles settle out of the plankton onto the shelf. As they grow, they move into deeper water. This picture is complicated by seasonal onshore-offshore movements associated with feeding and reproduction. For example, Dover sole move into shallower water to feed in the spring and summer and return to deeper water in the fall and winter to reproduce (Hagerman 1952).

Species Composition: Lower Slope. The lower slope (K and S) stations were dominated by the longspine *(Sebastolobus altivelis)* and shortspine thornyheads (Table 5). Several small demersal and benthopelagic fishes (black hagfish; purple brotula, *Oligopus diagrammus*; California rattail, *Nezumia stelgidolepis*; and blackmouth eelpout, *Lycodapus fierasfer)* are regular but not abundant members of the lower slope fish assemblage. The dominant benthopelagic fish predators on the lower slope are sablefish, brown cat shark *(Apristurus brunneus)*, filetail cat shark *(Paramaturus xaniurus)*, aurora rockfish *(Sebastes aurora)*, and blackgill rockfish *(Sebastes melanostomus)* (Cross, this volume).

Catches of the dominant species in Year 1 and Year 2 at CSDOC were compared using ANOVA. Depth distribution of three of these species are shown in Figure 15. There were significant differences over depth for all species tested except the shortspine thornyhead. Dover, rex, and slender soles and splitnose rockfish were most abundant at the E and G sites than at the K and S sites; longspine thornyheads were most abundant at the K and S sites. There was a significant difference between Year 1 and Year 2 samples for three species; more shortspine thornyheads, Dover sole, and slender sole were captured in Year 2.

Catches of the dominant species in Year 2, compared between Point Dume and CSDOC using ANOVA, showed significant differences with depth for all species. The depth distribution was similar for each dominant species between the two areas (Figure 15). There were significant depth-by-area interactions for all species, except rex sole, that were due to differences in the depth of maximum abundance in each area; for example, longspine thornyheads were more abundant at the K sites off CSDOC and at the S sites off Point Dume, while shortspine thornyheads and rex sole were more abundant at CSDOC than at Point Dume. Despite differences in abundance with depth and between areas, the distributions of the dominant species, when considered as proportions of the whole catch, were remarkably similar between areas.

Trawl Catch Parameters. There were significant depth and seasonal differences for the number of species collected per trawl at CSDOC

Table 5. Most abundant trawl-caught fish at CSDOC and Point Dume double-transect areas, all samples averaged.

		CSDOC		Point Dume	
Site	Rank	Species	Mean No./ Catch	Species	Mean No./ Catch
E	1	Shortspine thornyhead	50.6	Slender sole	96.0
	2	Slender sole	35.4	Splitnose rockfish	25.3
	3	Dover sole	29.6	Shortspine thornyhead	24.8
	4	Splitnose rockfish	20.3	Dover sole	14.5
	5	Rex sole	18.3	Stripetail rockfish	10.3
G	1	Shortspine thornyhead	41.3	Shortspine thornyhead	45.5
	2	Rex sole	15.5	Dover sole	13.5
	3	Dover sole	14.8	Rex sole	8.5
	4	Splitnose rockfish	14.3	Slender sole	4.0
	5	Slender sole	6.8	Blackbelly eelpout	3.3
K	1	Longspine thornyhead	191.0	Longspine thornyhead	64.6
	2	Shortspine thornyhead	19.1	Shortspine thornyhead	5.0
	3	Dover sole	4.4	Dover sole	3.5
	4	Splitnose rockfish	2.0	Sablefish	0.8
	5	Rex sole	1.8	Aurora rockfish	0.8
S	1	Longspine thornyhead	14.3	Longspine thornyhead	165.8
	2	Shortspine thornyhead	16.5	Shortspine thornyhead	19.0
	3	Black hagfish	7.3	Sablefish	15.0
	4	Dover sole	2.8	Dover sole	13.0
	5	Purple brotula	2.1	Purple brotula	7.5

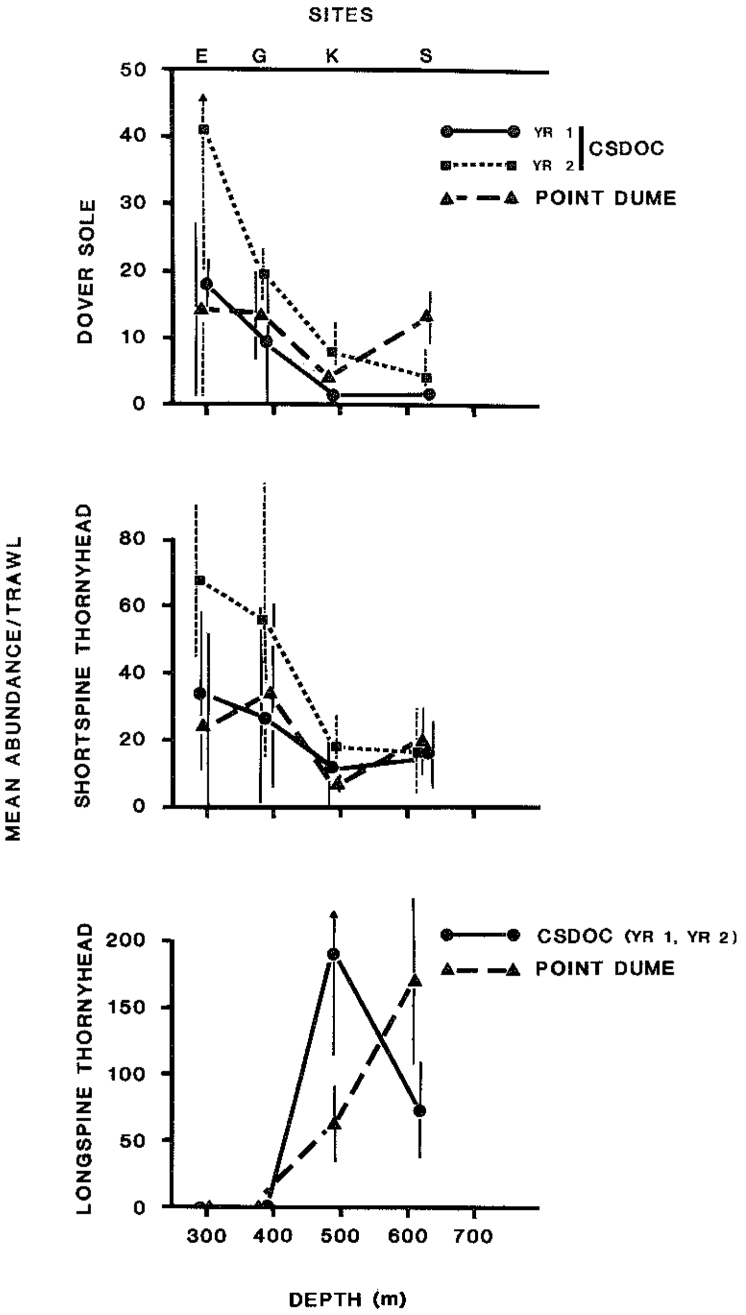

Figure 15. Trends in three dominant fish catches (mean number per trawl ± 1 standard deviation) with depth for CSDOC and Point Dume double-transect areas.

(Figure 16). Significantly more species were collected at the E sites (i.e. at 300-400 m) than at the deeper sites, and significantly more species were collected in the winter than in the summer. There were significant depth and yearly differences for the numbers of individuals collected per trawl; however, there was no consistent trend over depth. Significantly more individuals were collected in Year 2 than in Year 1.

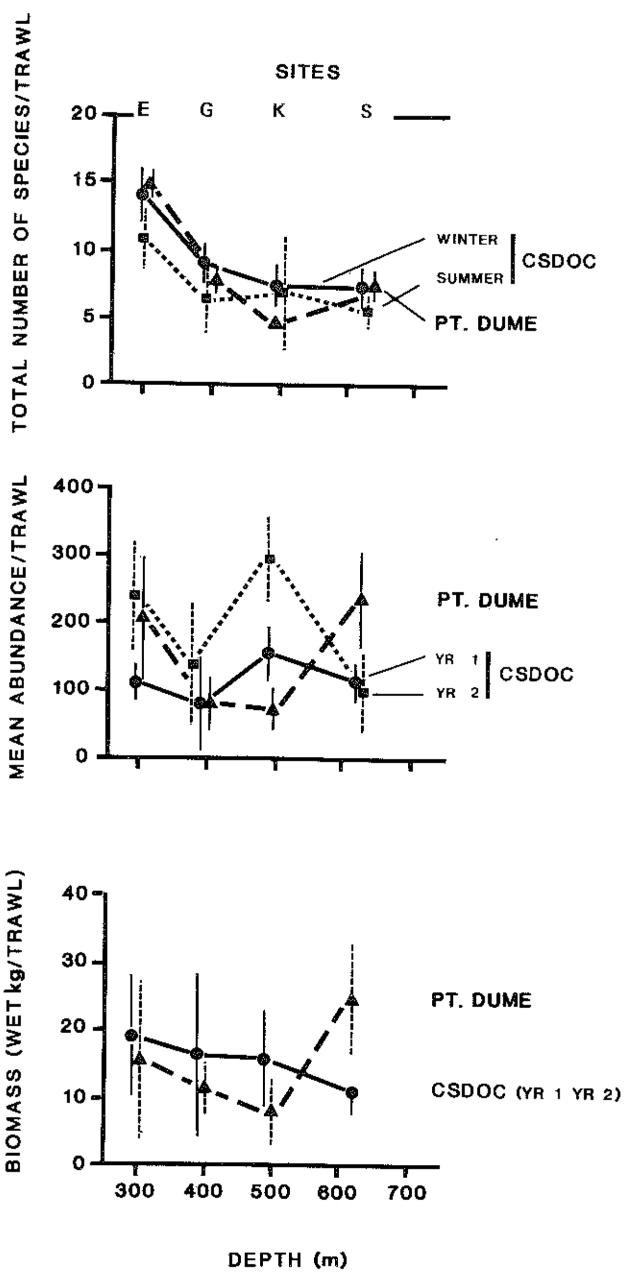

Figure 16. Trends in trawl fish catches (mean number per trawl ± 1 standard deviation) with depth for CSDOC and Point Dume double-transect areas. Although plotted separately, there were no significant differences between the two areas. Significant temporal differences are shown for number of species (seasonal) and abundances (yearly) at CSDOC.

Year 2 collections made at CSDOC and Point Dume were compared using ANOVA. There were significant differences over depth; more species were collected at the E sites in both areas (Figure 16). At CSDOC, more species were collected at the S sites than the K sites. There were no significant differences in number of species, number of individuals, or biomass collected per trawl between the two areas.

Contaminants in Fish Tissue. Silver, cadmium, chromium, copper, nickel, lead, and zinc were measured in both muscle and liver tissues of the six species of fish most sucessfully trawled from the CSDOC area (Table 6). Several (3-7) composites of two to five individual fish each were analyzed.

In muscle tissue, only zinc and copper were routinely above detection limits, with occasional positive signals for cadmium and chromium at very low levels. Silver, nickel, and lead were not measurable at detection limits of 0.004, 0.040, 0.030 mg/wet kg, respectively. The results for trace metals were in the range of concentrations previously measured in fish muscle (Schafer et al. 1982; Young et al. 1978).

All trace metals concentrations were much higher in liver tissue, although nickel and lead were below detection limits in both tissue types. High liver-to-muscle concentration ratios can be explained for some metals by the presence of metal-binding proteins, including metalloenzymes and metallothionein, at much higher levels in liver tissue than in muscle tissue (Harrison and Lam 1982). Of the metals measured in muscle tissue, copper and zinc were present at measurable levels, presumably because these are essential components of metalloenzymes present there (Brown et al. 1982). Elevated levels of copper and zinc in liver tissue are attributable not only to their presence in metalloenzymes, but because they are also bound in a nontoxic form to metallothionein. The liver also contains measurable levels of some nonessential metals such as cadmium and silver which have been shown in other studies to be sequestered by metallothionein, thus rendered nontoxic (Brown et al. 1982). Nickel and lead, which are not required for metalloenzymes, and which are not bound to metallothionein, were not detectable (<0.040 mg/wet kg) in either muscle or liver tissue. Thus, the relative distribution of metals between tissues appears to be related to their affinity for specific classes of metalloproteins.

DDT and PCB also were measured in the muscle and liver tissue of the six CSDOC species. Concentrations of the total DDT in muscle tissue ranged from 0.018 mg/wet kg in splitnose rockfish at Station E16 to 1.3 mg/wet kg in Dover sole at Station S8. Total DDT in liver tissue ranged from 0.52 mg/wet kg in sablefish from Station K12 to 21 mg/wet kg in sablefish from Station S8. Muscle tissue concentrations of total PCB ranged from 0.003 mg/wet kg in Dover sole from Station S12 to 0.28 mg/wet kg in Dover sole from Station S8. Total PCB in liver tissue ranged from 0.079 mg/wet kg in Dover sole from Station S12 to 3.5 mg/wet kg in longspine thornyheads from Station K12. Median concentrations of total DDT and PCB for all species analyzed are shown in Table 6. Results from the analysis of these samples for

Table 6. Median concentrations of trace metal and chlorinated hydrocarbon compounds in muscle and liver tissue of fish sampled from the CSDOC area, 1982 (n = number of composites (2-5 individuals) analyzed).

Species	n	Ag	Cd	Cr	Cu	Ni	Pb	Zn	Total PCB	Total DDT
Muscle Tissue (mg/wet kg)										
Dover sole	7	<0.002	<0.002	0.04	0.10	<0.02	<0.02	2.2	0.057	0.44
Pacific whiting	3	<0.002	0.003	<0.01	0.11	<0.02	<0.02	2.5	0.010	0.033
Splitnose rockfish	6	<0.002	<0.002	<0.01	0.14	<0.02	<0.02	2.6	0.008	0.026
Shortspine thornyhead	4	<0.002	<0.005	<0.01	0.04	<0.02	<0.02	2.2	0.024	0.16
Sablefish	3	<0.002	0.002	<0.01	0.03	<0.02	<0.02	1.8	0.11	0.69
Rex sole	1	<0.002	0.002	<0.01	0.12	<0.03	<0.02	2.3	0.024	0.026
Liver Tissue (mg/wet kg)										
Dover sole	7	0.15	1.1	0.23	6.9	<0.05	<0.04	32	0.42	1.5
Pacific whiting	3	0.03	0.23	<0.02	5.6	<0.06	<0.03	38	0.85	3.7
Splitnose rockfish	6	0.12	5.1	0.14	7.5	<0.05	<0.04	31	0.53	3.8
Shortspine thornyhead	4	0.02	2.5	0.06	2.4	<0.03	<0.02	18	0.66	9.4
Sablefish	3	0.03	3.0	0.19	2.0	<0.05	<0.04	21	0.25	2.0
Rex sole	1	0.01	3.8	0.18	1.2	<0.05	<0.04	19	1.4	6.7

hexachlorobenzene, trichlorobenzene, and dichlorobenzene yielded concentrations below detectable limits of 0.001 mg/wet kg in all cases.

The concentrations of the total DDT and total PCB in the muscle and liver tissue from fish samples, as in sediments, showed no trend with depth. Also, like the sediments, all the samples contained higher concentrations of DDT than PCB, suggesting an influence of these concentrations from a source other than the existing Orange County outfall.

The Pacific whiting and splitnose rockfish muscle tissue contaminant concentrations were equivalent to the lowest concentration measured in a sportfish survey conducted by SCCWRP (Gossett et al. 1982a). The Dover sole, sablefish, and longspine thornyheads showed concentrations 1) within the range of sportfish analyzed from the Los Angeles Harbor and 2) an order of magnitude lower than the highest mean concentration measured in white croaker taken from the White Point outfall area, a region known to be contaminated by DDT compounds (Gossett et al. 1982a).

The elevated liver tissue concentrations reflect the partitioning of these trace organic compounds into the lipids of the body where they are stored (Gossett et al. 1982b; Freed and Chiou 1981). These concentrations are on the same level as those measured in scorpionfish from Dana Point and San Elijo (Gossett, unpublished data) and in Dover sole from the White Point outfall (Gossett et al. 1982b).

SUMMARY AND CONCLUSIONS

The coastal slope can be divided into upper and lower slope habitats. These divisions have been recognized as sediment facies (Malouta 1978), Foraminifera assemblages (Abrams 1979), and macrofaunal assemblages (Fauchald and Jones 1978; 1979). In this report we have additionally shown that epibenthic invertebrates and fish can be so divided.

Since the sediment parameters measured in both areas corresponded to levels measured at other "normal" areas of this region and infaunal species composition was very similar to that reported by Fauchald and Jones (1978; 1979), we can consider the two areas described herein as typical southern California slope habitats. These areas also correspond well to the more generalized upper and lower archibenthal zones of transition described by Menzies et al. (1959).

This study completes the first phase in an effort to determine the effects of the proposed Orange County deepwater sludge discharge. We have documented the spatial and temporal variability within the discharge area and at a control area, because it is only by accounting for such natural variation that any changes caused by possible future sludge discharge can be detected. We have established that the control area off Point Dume is not significantly different biologically from the treatment area at CSDOC; we could find only three sediment parameters (percent sand, percent organic material, and chromium) that showed significant differences between the two areas. Nearly all significant ($p<0.05$) temporal (yearly and seasonal) differences within areas were in the biological parameters measured, but nearly all differences between the two areas were in the sediment parameters. The only biological differences between the two areas were in abundances of *Brissopsis pacifica*, shortspine thornyheads, and rex sole.

Downslope gradients of increasing sediment organic material were shown. Additionally, there was a gradient of decreasing dissolved oxygen (DO) such that the DO concentration was below 1 ml/L deeper than about 350 m, near the boundary of the upper and lower slope assemblages. The division of upper and lower slope assemblages probably reflects the existing organic material and DO gradients. We think it is likely that sludge discharge would change these two parameters the most--i.e., organic material should increase and DO should decrease--but the effects of such changes are difficult to predict. For comparison, on the San Pedro Basin floor (downslope, 878 m) the DO was found to be 0.16 ml/L, the organic material increased to 10.3%, and the mean number of infaunal species (per sample) decreased to 4 (Fauchald and Jones 1979). These circumstances suggest that, although there is adequate food (organic material), DO may limit the size of the assemblage.

The effects of sludge on the slope biological assemblages cannot be determined until discharge has begun. Following a suitable period of discharge, sampling must be conducted in both areas exactly as it was in the predischarge surveys reported herein. Analyses of variance and covariance may then be used to test for significant differences from predischarge conditions at CSDOC and Point Dume (see Bernstein et al., this volume).

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