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Impact of Sewage on the Distribution, Abundance and Community Structure of Rocky Intertidal Macro-organisms

M. M. Littler[1] **and S. N. Murray**[2]

[1] **Department of Population and Environmental Biology, University of California; Irvine, California, USA, and**
[2] **Department of Biological Science, California State University; Fullerton, California, USA**

Abstract

The biological effects of a low-volume domestic sewage discharge were studied near Wilson Cove, San Clemente Island, California (USA), from February to June, 1972. There were fewer species and less cover near the outfall (7 macro-invertebrates, 17.6%; 13 macrophytes, 91.7%) than in nearby "unpolluted" control areas (9 macro-invertebrates, 9.2%; 30 macrophytes, 103.4%). The outfall biota was less diverse than that of the controls, as shown by 5 different diversity indices. A great reduction in community stratification (spatial heterogeneity) and, hence, community complexity occurred near the outfall; this reduction in stratification was primarily due to the absence of *Egregia laevigata, Halidrys dioica, Sargassum agardhianum* and *Phyllospadix torreyi*. These were replaced in the mid-intertidal near the outfall by a low turf of blue-green algae, *Ulva californica, Gelidium pusillum* and small *Pterocladia capillacea,* and in the lower intertidal by *Serpulorbis squamigerus* covered with *Corallina officinalis* var. *chilensis*. A statistically-based determination of assemblages or groups of organisms (i.e., cluster analysis) revealed 3 discrete outfall and 3 discrete control area groups; 3 assemblages contained samples from both areas. The distributional patterns of these groups indicate that near the outfall the degree of dilution of discharged sewage is more important in regulating zonation than is tidal height. The enhancement of the suspension feeder *Serpulorbis squamigerus* and the omnivores *Ligia occidentalis, Pachygrapsus crassipes* and *Anthopleura elegantissima* in the outer fringe of the outfall plume hypothetically is due to their ability to utilize sewage as a food source. A critical effect of the outfall may be to decrease environmental stability thereby favoring rapid-colonizers and more sewage-tolerant organisms. The outfall macrophytes were characterized by relatively higher net primary productivities, smaller growth forms, simpler and shorter life histories, and most were components of early successional stages.

Introduction

The use of community parameters has become an important aspect for interpreting pollution perturbations on marine life. Among these, diversity indices have been used most extensively with varying degrees of success; for example, diversity analyses have been made for communities of benthic invertebrates (Storrs *et al.*, 1969), foraminiferans (Bandy *et al.*, 1964), fish (Bechtel and Copeland, 1970; Regier and Cowell, 1972) and seaweeds (Borowitzka, 1972). Odum (1969) developed a qualitative tabular model of characteristics and trends in ecological succession and pointed out very perceptively some of the relationships between strategies of community development and the influences of humans. Regier and Cowell (1972) emphasized the utility of community development patterns when they theorized that the effects of environmental perturbations on fisheries result in the reversal of successional trends with regard to the community features of dominance, diversity, stability and production. Their model has provided a basis for the interpretation of more rigorous and comprehensive quantitative analyses of polluted marine communities.

Some of the most important work in marine community ecology has been done in the rocky intertidal habitat, which, as pointed out by Dayton (1973), represents a relatively workable and understandable system. Although the more indirect cause-and-effect relationships are often not obvious, the manipulative approach employed in the rocky intertidal zone by such workers as Connell (1961a, b, 1970), Paine (1966, 1971), Dayton (1971, 1973) and Menge (1972) has demonstrated powerful predictive capabilities at the community level, and has added greatly to the general ecological concepts derived from more traditional descriptive approaches (see reviews by Doty, 1957; Zaneveld, 1969; Chapman, 1973).

In the heavily populated Southern California region, the coastal environment is greatly influenced by human activities, yet there is a striking lack of data concerning the effects of pollutants on rocky intertidal communities there. Of the limited published research, the most useful appears to be that concerned with marine macrophytes. Dawson (1959, 1965), in his surveys of numerous Southern California rocky intertidal stations, reported a 50 to 70% reduction in the number of algal species near sites of sewage discharge. Subsequently, a further decline in the intertidal flora near Los Angeles, attributed to human influence, has occurred (Nicholson and Cimberg, 1971; Widdowson, 1971). These alterations have not been instantaneous, and Nicholson (1972) emphasized that Southern California coastal systems have been increasingly exposed to stresses resulting from human activities since the turn of the last century. Complicated and cumulative effects, particularly during the last 10 years, have created severe problems in establishing reliable controls when attempts have been made to assess the effects of pollutants on mainland organisms. With the expansion of the human population in Southern California, even the marine communities of the sparsely populated offshore islands may soon be altered greatly.

Study Area

The Wilson Cove outfall (Fig. 1) on San Clemente Island (SCI) was selected as a simple, workable and quantifiable model for understanding the effects of domestic sewage perturbations on marine ecosystems. The marine biota of SCI, because of the ownership and control of the island by the U.S. Navy and its distant position (76 km) from the mainland, is among the least disturbed in Southern California. A 300-man naval base located at Wilson Cove produces about 95,000 l/day of sewage, consisting primarily of untreated human wastes, food scraps from the mess hall, and about 200 l/year of 90% pine-oil disinfectant which is discharged from the principal outfall at the shoreline ca. 5.3 ft (1.62 m) above mean-lower-low-water. The sewage discharge is not uniform in composition from time to time, particularly in the case of the disinfectant which was detected only sporadically in the effluent as a concentrated milky plume.

The environmental features of this outfall have been reported by Kenis *et al.*, (1972). The average concentration of dissolved O_2 is about 5.5 mg/l at the point of discharge and about 7.0 to 8.0 mg/l, a range typical for unpolluted ocean surface waters, at shoreline locations farther than 30 m from the outfall terminus (Kenis *et al.*, 1972). Measurements at the SCI outfall of biochemical oxygen demand range from 90 to 405 mgO_2/l, with a mean of 223 mgO_2/l which is typical of raw sewage. This means that SCI effluent entering the ambient seawater containing 7 to 8 mgO_2 /l would have to be diluted from several hundred to a thousand times to be beyond adverse levels for sensitive marine organisms. This level of dilution is accomplished as shown by Kenis *et al.*, (1972) within 30 m of the outfall terminus. Coliform levels in excess of California Administrative Code minimum standards (i.e., 1,000/100 ml) for public water-contact areas are restricted (Kenis *et al.*, 1972) to within 30 m to the north and south of the outfall. Mixing is adequate to keep the sewage particulates in suspension, since sedimentation was not observed either intertidally or subtidally near the study region.

The outfall has been in operation for over 10 years and discharges to the south of the southern limits of Wilson Cove (Fig. 1). The intertidal lies at the base of a bluff approximately 6 m in height that forms the terminus of a long, steeply-pitched (30° to 40°) slope located between the U.S. Navy housing units and the sea. This intertidal region is relatively uniform in character, consisting of a rocky substrate composed of large metamorphic boulders intermingled with numerous free rocks 25 to 50 cm in diameter. The intertidal extends over a horizontal distance of 10 to 15 m with a vertical differential of 2.5 m. A continuous bed of *Macrocystis pyrifera* is located 25 to 30 m seaward of the study area.

Materials and Methods

The distributions and abundances of macro-organisms were determined with reference to tidal height and distance from the outfall. A photographimetric technique (Littler, 1971) was the prin-

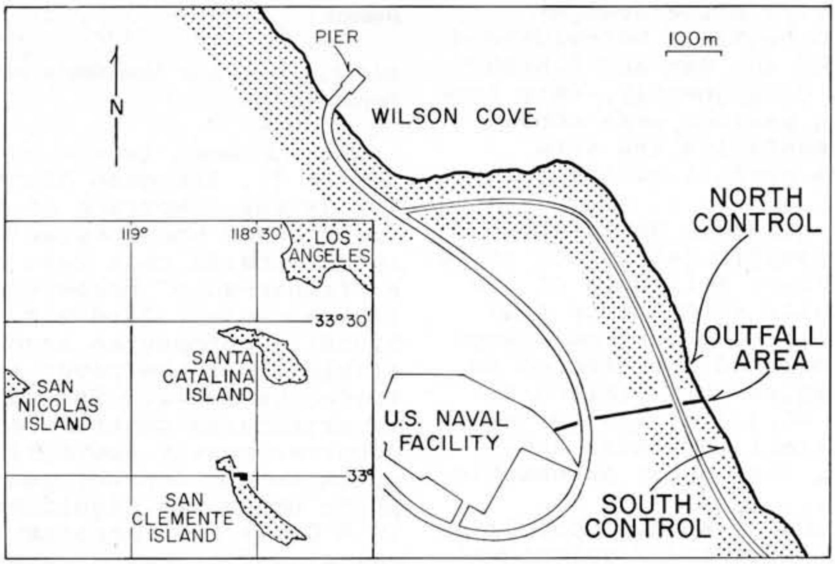

Fig. 1. Location of the San Clemente Island outfall and two control study sites

cipal method of assessing standing stocks (i.e., frequency and cover) of species populations. This method has the advantage of being fast and relatively simple and, therefore, enables a large number of samples per given time; however, as applied here it does not allow for the quantification of micro-algae, small epifauna and infauna. We acknowledge that these might be metabolically very important, but their analysis would require special techniques and expertise which comprise separate problems in themselves. For this reason, sampling was restricted to macro-epibiota that could be discerned with the unaided eye in the field or in photographs.

Five transect lines were placed at preselected angles (4°, 30°, 58°, 83°, 337°), in reference to magnetic north sighted from the outfall terminus with a liquid-filled sighting compass, and anchored just below waterline at low tide. Ring quadrats, 30 cm in diameter, were placed along transect lines at 1 or 2-m intervals, providing 0.07 m^2 stratified plots.

Photographs of the numbered ring quadrats were taken at right angles to the substrate with a Nikonos underwater camera equipped with an electronic flash. Cover was determined from the photographs by a point-intercept method. Species observed within quadrats but absent from scores were assigned a cover value of 0.05%. In many instances more than one photograph was taken per quadrat unit to measure stratification, since some samples containing algal canopies were multi-layered and yielded total cover in excess of 100%. A tape recorder, enclosed in a water-proof acrylic case, provided a rapid method of taking field notes; these minimized taxonomic problems encountered while interpreting photographs in the laboratory.

Vertical heights for each quadrat were measured from fixed reference points with a sighting level and a 7.6 m telescoping stadia rod using standard surveying techniques. Sightings of the relative tidal heights of reference points with respect to the level of mean-lower-low-water (MLLW, determined from U.S. Department of Commerce tide tables) were obtained by averaging measurements made on 3 different days. The tidal heights of individual quadrats were then calculated in respect to the calibrated reference points.

Four additional transect lines were established in control areas, 2 to the north (42 and 54 m) and 2 to the south (90 and 100 m) of the outfall pipe. These lines were positioned at randomly-selected points sufficiently remote (see Kenis *et al.*, 1972) from the influence of the outfall and with morphometry similar to the area immediately below the outfall pipe. All lines were placed perpendicular to the shoreline (i.e., 30° from magnetic north), and were sampled by the previously described techniques.

Due to difficulties in gaining access to the island and the extensive sampling program, data had to be gathered on four separate occasions. The outfall region was sampled on 14 and 26 February and 30 May, 1972; whereas the control regions were sampled on 30 May and 14 June, 1972. Assessments of the study areas, which have continued since June, 1971, showed seasonal changes in standing stock, particularly in the sewage-affected area, to be minor as evidenced by a comparison of the May and February outfall samples. Consequently, data from all four sampling periods were considered to be representative and were grouped either as outfall or control samples.

A total of 53 quadrats were taken within an area visually determined to be under the most direct influence of the outfall plume, while 46 quadrats from both of the regions removed from sewage influence were combined and treated as control data. Samples were limited to the zone between +5.3 ft (+1.62 m, the height of the outfall terminus) and -1.0 ft (-0.30 m, the lowest accessible intertidal area).

The distribution of species populations as a function of tidal height was then compared between the outfall and control areas using Wilcoxon signed-rank tests. Cover values (the percentage cover per sample plot of each species) and frequency values (the percentages of sample plots in which a given species was present) were averaged for each 0.5-ft (0.15 m) interval from -1.0 to +5.0 ft (-0.30 to +1.52 m). The total cover and total frequency values were calculated for each species as the grand mean for all 0.5-ft (0.15 m) interval averages.

The community features of species diversity, stratification and species assemblages were analyzed using the cover data. Other than simple species counts, four quantitative indices of species diversity [i.e., Shannon's Index (Shannon and Weaver, 1949), Simpson's (1949) Index, Brillouin's (1956) Index and Pielou's (1969) Evenness Index] were assessed based on total cover. Community stratification, used as a measurement of spatial heterogeneity, was determined directly from photographs taken of overstory, understory, and substrate for quadrats. To objectively determine natural assemblages or groupings of organisms, control and outfall samples were subjected to cluster analysis by the weighted-pair method, adapted in part from Sokal and Sneath (1963).

A manipulative experiment was performed to document patterns of succession and as a further means of obtaining insight into the effect of the outfall. Sixteen uniformly weathered rocks of similar size (30 to 40-cm diameter) and composition were sterilized with burning ethanol (95%), placed between +0.30 and +0.61 m (4 in each control area and 8 in the outfall plume region) on 14 June, 1972, and subsequent community development was followed for 1 year.

Results

Distribution and Abundance Patterns of Species Populations

Overall Cover. In the outfall quadrats (Table 1), the mean biotic cover of 109.3% was comprised of 91.7% evenly distributed macrophytes and 17.6% macro-invertebrates that were concentrated in a "fringe-zone" below +2.0 ft (0.61 m). In the control quadrats (112.6% cover of biota), macrophytes accounted for 103.4% (Table 1) of the cover and were concentrated below +2.0 ft; whereas, macro-invertebrates contributed 9.2% cover and occurred mostly above +2.0 ft. In respect to the control quadrats, macrophyte cover was significantly less ($P \cong 0.01$) and macro-invertebrate cover was significantly greater ($P = <0.05$) in outfall quadrats below +2.0 ft while the reverse was true ($P \cong 0.01$ and $P \cong 0.01$, respectively) above +2.0 ft (Table 1).

Outfall Cover. Blue-green algal cover (treated as a single taxonomic unit) was the greatest (43.1%) in the outfall plume area (Table 2) followed by *Ulva californica* (11.5%), *Pseudolithoderma nigra* (9.1%), *Pterocladia capillacea* (8.8%), *Corallina officinalis* var. *chilensis* (8.4%), *Gelidium pusillum* (5.7%) and *Eisenia arborea* (3.2%). *Serpulorbis squamigerus* (15.5%) provided most of the animal cover.

The distributions of outfall organisms have been plotted (Fig. 2) against tidal heights. The only algae above +4.0 ft (1.22 m) were the blue-greens, which predominated above +1.0 ft (0.30 m); they covered 58.5% of the rock surface between +1.0 and +5.0 ft (+0.30 and +1.52 m) and reached maximum cover (100%) between +4.0 and +4.5 ft (+1.22 and +1.37 m). *Pseudolithoderma nigra, Gelidium pusillum* and *Ulva californica* contributed much of the cover in the mid-intertidal zone. *P. nigra* (30%) was abundant between +2.0 and +4.0 ft (+0.61 and +1.22 m), while *G. pusillum* (11.9%) and *U. californica* (13.9%) reached maximum cover between +0.5 and +1.0 ft (+0.15 and +0.30 m). *Pterocladia capillacea* and *Corallina officinalis* var. *chilensis* were abundant between +0.5 and -0.5 ft (+0.15 and -0.15 m); *P. capillacea* averaged about 21%, and *C. officinalis* var. *chilensis* about 20% cover from -1.0 to +1.5 ft (-0.30 to +0.46 m), with maxima of both between 0.0 ft (MLLW) and +0.5 ft (+0.15 m). *Eisenia arborea* (29.5%) dominated the interval -0.5 to -1.0 ft (-0.15 to -0.30 m) and provided up to 100% cover immediately below the -1.0 ft (-0.30 m) limit of sampling.

Acmaea scabra (Fig. 2) occurred between +0.5 and +4.5 ft (+0.15 and +1.37 m) and was more abundant than either *A. limatula* or *Lottia gigantea*. *Serpulorbis squamigerus* occupied most of the primary substrate between -1.0 and +1.0 ft (-0.30 and +0.30 m), and reached a maximum of 50.6% cover between MLLW and +0.5 ft (+0.15 m). Because *S. squamigerus* was often extensively overgrown by algae, it was not easily quantified by our methods; consequently, these data represent a low estimate.

Two species of macro-invertebrates (*Anthopleura elegantissima* and *Lottia gigantea*) contributing about 0.5% cover, and two species of macrophytes (*Petalonia fascia* and *Scytosiphon lomentaria*) contributing 0.7% cover in the outfall area were absent from control samples (Table 2).

Control Cover. Blue-green algae (18.4%) provided more cover than any of the other organisms in the control areas (Table 2) followed by *Corallina officinalis* var. *chilensis* (14.1%), *Egregia laevigata* (13.8%), *Hydrolithon decipiens* (12.1%), *Gigartina canaliculata* (8.8%), *Gelidium robustum* (7.7%), *Pseudolithoderma nigra* (6.7%) and *Halidrys dioica* (5.3%); *Chthamalus fissus* (2.7%), *Tetraclita squamosa* (2.5%) and *Acmaea scabra* (1.9%) provided most of the

Table 1. Mean cover comparisons of macro-invertebrates, macrophytes, and bare rock for control area quadrats versus outfall area quadrats. Significance levels are for one-tailed Wilcoxon signed-rank test based upon paired comparisons for each 0.5-ft (0.15 m) tidal interval

Group	Mean cover (%)	
	Outfall (N = 53)	Control (N = 46)
Total intertidal cover	109.3	112.6
Combined macro-invertebrates		
Entire intertidal (-1.0 to +5.0 ft; -0.30 to +1.52 m)	17.6	9.2
Upper shore (+2.0 to +5.0 ft; +0.61 to +1.52 m)	4.1^{**}	14.7
Lower shore (-1.0 to +2.0 ft; -0.30 to +0.61 m)	30.6^{*}	3.4
Combined macrophytes		
Entire intertidal (-1.0 to +5.0 ft; +0.30 to +1.52 m)	91.7	103.4
Upper shore (+2.0 to +5.0 ft; +0.61 to +1.52 m)	87.1^{**}	55.8
Lower shore (-1.0 to +2.0 ft; -0.30 to +0.61 m)	96.4^{**}	150.3
Bare rock		
Entire intertidal (-1.0 to +5.0 ft; -0.30 to +1.52 m)	6.1^{*}	18.2
Upper shore (+2.0 to +5.0 ft; +0.61 to +1.52 m)	8.5^{**}	33.0
Lower shore (-1.0 to +2.0 ft; -0.30 to +0.61 m)	3.7	3.3

$^{*}p < 0.05$.

$^{**}p < 0.01$.

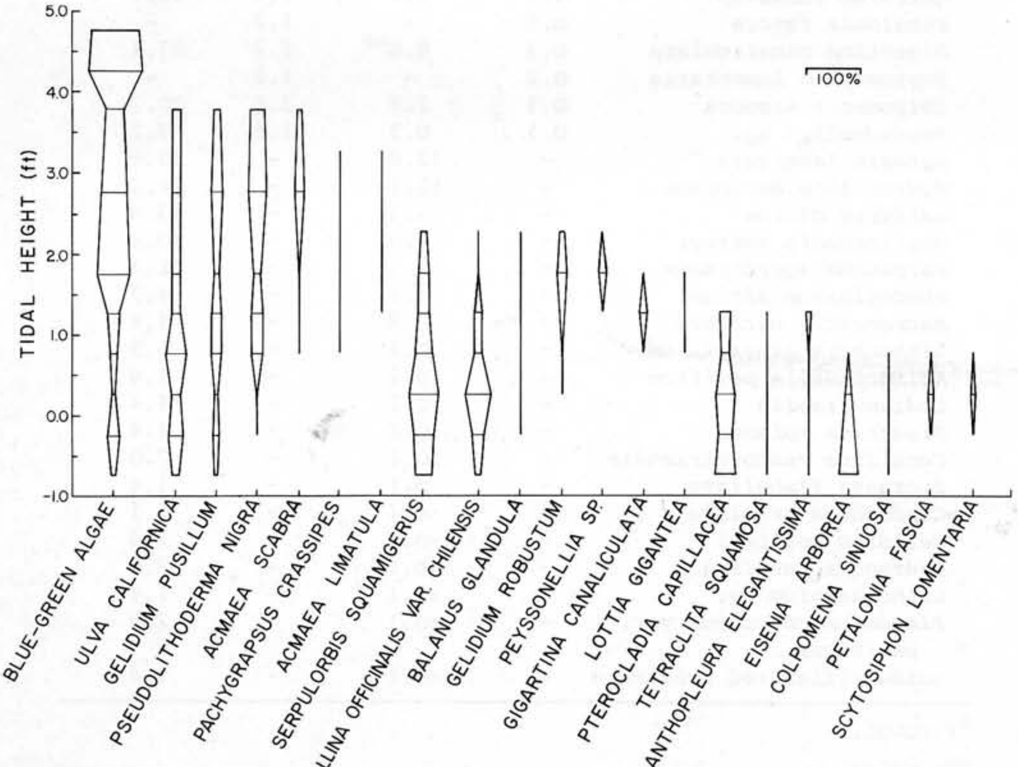

Fig. 2. Cover patterns of organisms in outfall plume area as function of tidal height. In Figs. 2-5, horizontal lines indicate the intervals with samples containing cover of a given species

Table 2. Mean cover and frequency comparisons of macro-invertebrates and macrophyte species for control areas versus outfall plume. Significance levels are for one-tailed Wilcoxon signed-rank tests based upon paired comparisons of cover for each 0.5-ft (0.15 m) tidal interval. -: species not present

Species	Mean cover (%)		Mean frequency (%)	
	Outfall (N = 53)	Control (N = 46)	Outfall (N=53)	Control (N=46)
Macro-invertebrates				
Serpulorbis squamigerus	15.5	1.0**	32.8	26.3
Acmaea scabra	1.4	1.9	30.5	56.8
Anthopleura elegantissima	0.4	-	6.3	-
Acmaea limatula	0.1	0.1	17.8	4.4
Balanus glandula	0.1	0.1	6.3	7.9
Lottia gigantea	<0.1	-	1.2	-
Tetraclita squamosa	<0.1	2.5*	4.5	36.8
Chthamalus fissus	-	2.7	-	34.8
Acmaea strigatella	-	0.6	-	31.0
Haliotis cracherodii	-	0.2	-	1.4
Littorina scutulata	-	<0.1	-	1.7
Macrophytes				
Blue-green algae	43.1	18.4**	78.8	56.7
Ulva californica	11.5	<0.1**	64.3	1.4
Pseudolithoderma nigra	9.1	6.7	38.2	52.5
Pterocladia capillacea	8.8	3.1*	25.7	10.4
Corallina officinalis var. *chilensis*	8.4	14.1	29.8	45.0
Gelidium pusillum	5.7	0.3*	51.7	10.0
Eisenia arborea	3.2	3.1	6.4	9.8
Gelidium robustum	0.7	7.7	1.8	18.1
Petalonia fascia	0.5	-	1.2	-
Gigartina canaliculata	0.3	8.8**	1.2	27.4
Scytosiphon lomentaria	0.2	-	1.2	-
Colpomenia sinuosa	0.1	2.8	3.8	20.7
Peyssonellia sp.	0.1	0.3	1.8	7.2
Egregia laevigata	-	13.8	-	20.8
Hydrolithon decipiens	-	12.1	-	54.2
Halidrys dioica	-	5.3	-	13.8
Phyllospadix torreyi	-	1.8	-	10.4
Sargassum agardhianum	-	1.7	-	11.4
Rhodoglossum affine	-	1.1	-	4.9
Macrocystis pyrifera	-	0.8	-	1.4
Lithothrix aspergillum	-	0.4	-	6.9
Anisocladella pacifica	-	0.2	-	1.4
Codium fragile	-	0.2	-	1.4
Gigartina spinosa	-	0.2	-	1.4
Corallina vancouveriensis	-	0.1	-	7.0
Dictyota flabellata	-	0.1	-	1.4
Cladophora graminea	-	<0.1	-	2.1
Gelidium coulteri	-	<0.1	-	1.4
Laurencia pacifica	-	<0.1	-	3.1
Lithothamnium sp.	-	<0.1	-	1.4
Plocamium coccineum var. *pacificum*	-	<0.1	-	2.8
Unidentified red prostrate	-	<0.1	-	1.4

*p <0.05.

**p <0.01.

animal cover in the control areas (Table 2).

The cover of control area organisms has been plotted (Fig. 3) with respect to tidal height. Blue-green algae were most abundant above +3.0 ft (+0.91 m), reaching maximum cover (67.6%) between +4.5 and +5.0 ft (+1.37 and +1.52 m). *Peyssonellia* sp. was the only other alga found above +4.5 ft (+1.37 m). The crustose forms *Hydrolithon decipiens* (12%) and *Pseudolithoderma nigra* (6%) contributed considerable cover on the sides and lower surfaces of rocks below +4.5 ft (+1.37 m). *H. decipiens* exhibited maximum cover at a slightly lower level than did *P. nigra*. *Corallina officinalis* var. *chilensis* formed a low turf on most of the rock substrate from +0.5 to +3.0 ft (+0.15 to +0.91 m) and reached maximum cover (52.2%) between +1.0 and +1.5 ft (+0.30 and +0.46 m). Much of the *C. officinalis* var. *chilensis* in the control areas served as secondary substrate for fleshy algae, e.g., *Gigartina canaliculata, Colpomenia sinuosa, Laurencia pacifica, Gelidium coulteri* and *Sargassum agardhianum.* The larger brown algae *Egregia laevigata, Halidrys dioica* and *Eisenia arborea,* the larger reds *Gelidium robustum* and *Pterocladia capillacea,* and the spermatophyte *Phyllospadix torreyi* comprised the dominant cover below +1.0 ft (+0.30 m) (Fig. 3). *Egregia laevigata* reached maximum cover (51.5%) between MLLW and +0.5 ft (+0.15 m), *H. dioica* (31.7%) between -0.5 ft (-0.15 m) and MLLW and *G. robustum* (33.4%) along with *P. torreyi* (16.3%) between +0.5 and +1.0 ft (+0.15 and +0.30 m); *Eisenia arborea* was dominant (26.5%) below -0.5 ft (-0.15 m), providing up to 100% cover immediately below the limits of sampling (-1.0 ft or -0.30 m),

Acmaea scabra and *Chthamalus fissus* (Fig. 3) were the only animals between +4.5 and +5.0 ft (+1.37 and +1.52 m). *Littorina planaxis* only occurred in samples above +5.0 ft (+1.52 m), where it was common. *A. scabra,* the most abundant limpet, reached maximum cover (4.4%) in the +3.0 to +3.5 ft (+0.91 to +1.07 m) interval. *C. fissus* was the dominant barnacle above +3.5 ft (+1.07 m), but *Tetraclita squamosa* became more abundant at lower levels. *Serpulorbis squamigerus* was distributed from -0.5 to +4.0 ft (-0.15 to +1.22 m), reaching maximum cover (4.7%) between +1.5 and +2.0 ft (+0.46 and +0.61 m). *S. squamigerus* tubes were found as isolated individuals in cracks and on lower surfaces of control rocks; only infrequently were clumps of tubes observed.

Four species of macro-invertebrates (3.6% cover) and 19 species of macrophytes (38.4% cover) were confined to control area samples (Table 2). Of these species, those most conspicuously absent from the outfall region were *Egregia laevigata, Hydrolithon decipiens, Halidrys dioica, Phyllospadix torreyi* and *Sargassum agardhianum;* in control areas these accounted for a total of about 35% of the intertidal cover.

Wilcoxon signed-rank tests of the cover data (Table 2) revealed that, of species co-occurring in both areas, the turf-forming macrophytes (blue-green algae, *Gelidium pusillum, Pterocladia capillacea* and *Ulva californica*) and *Serpulorbis squamigerus* provided significantly greater intertidal cover in the sewage-affected area, while cover of *Gigartina canaliculata* and *Tetraclita squamosa* was significantly less. It is also likely that cover of *Gelidium robustum* was significantly less in the outfall area (0.7% as compared to 7.7% in control areas). This was not revealed by the Wilcoxon statistical test since the cover of *G. robustum* was located in different tidal intervals in the outfall transects than in the control transects (Figs. 2 and 3); therefore, test comparisons resulted in a cancellation of cover differences between the two areas.

Frequency. Mean frequency values for control and outfall plume species are presented in Table 2. Mean frequency was plotted against tidal height for the most abundant (mean frequency > 5%) species in the outfall (Fig. 4) and control areas (Fig. 5). For most species, frequency data were closely parallel to cover data (Figs. 2 and 3). A noteworthy exception was revealed for bare rock, where cover data showed about three times more bare rock for controls than for the outfall area (Table 1); however, differences were negligible when frequency data were compared. This discrepancy is easily explained because small nicks and patches of bare rocks occurred in nearly all samples from both control and outfall areas, thereby resulting in similar frequency patterns.

Patterns of Community Structure

Diversity. The total number of species sampled (Table 2) was nearly twice as great in control areas (39) as in the outfall region (20). Of the two macrophyte species *(Petalonia fascia* and *Scytosiphon lomentaria)* restricted to outfall samples, only *L. gigantea* and *S. lomentaria* were observed, after careful reconnais- invertebrate species *(Anthopleura elegantissima* and *Lottia gigantea)* and two macro- sance, in low numbers in the control areas; a similar search in the sewage-affected area failed to produce addi-

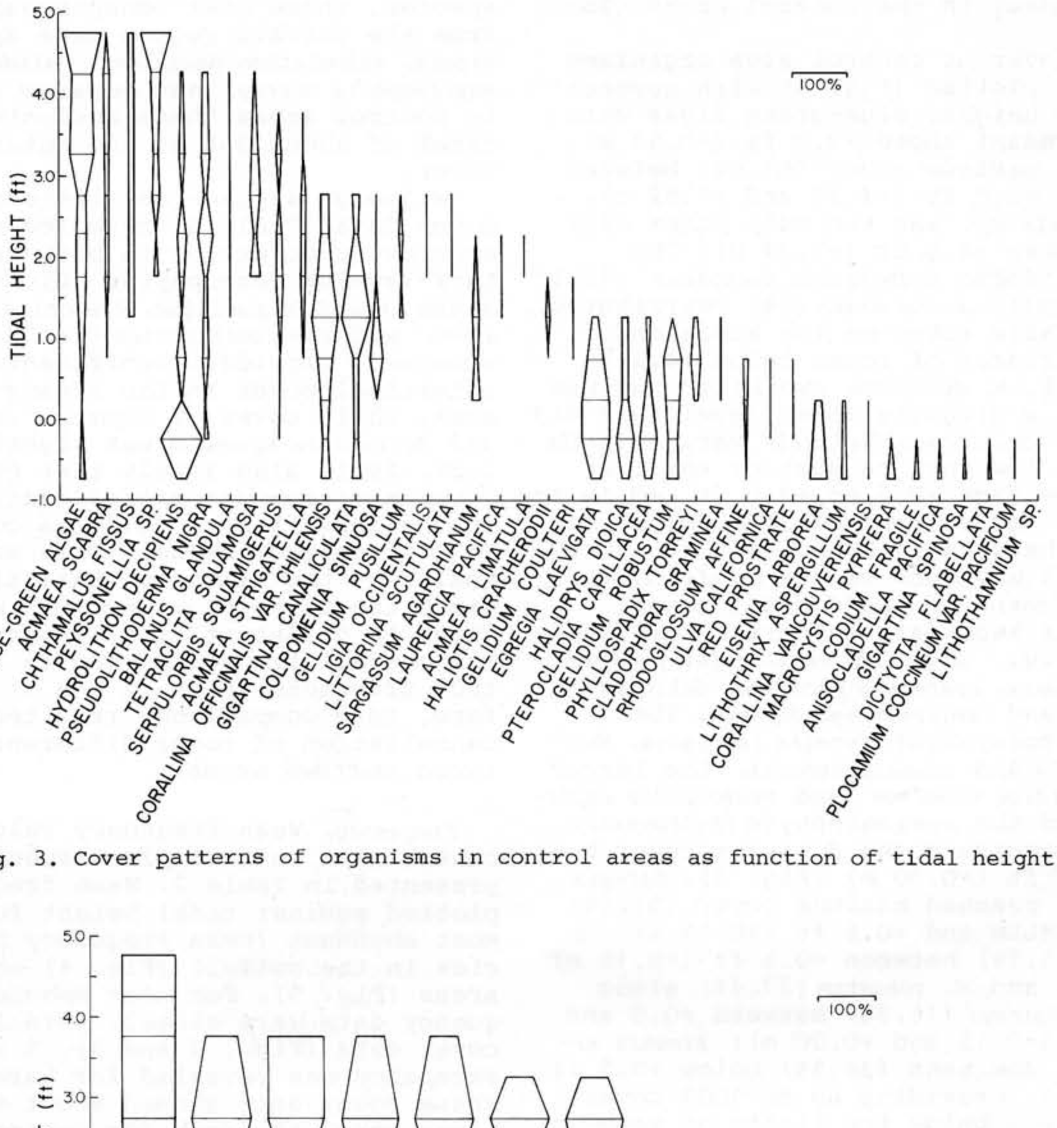

Fig. 3. Cover patterns of organisms in control areas as function of tidal height

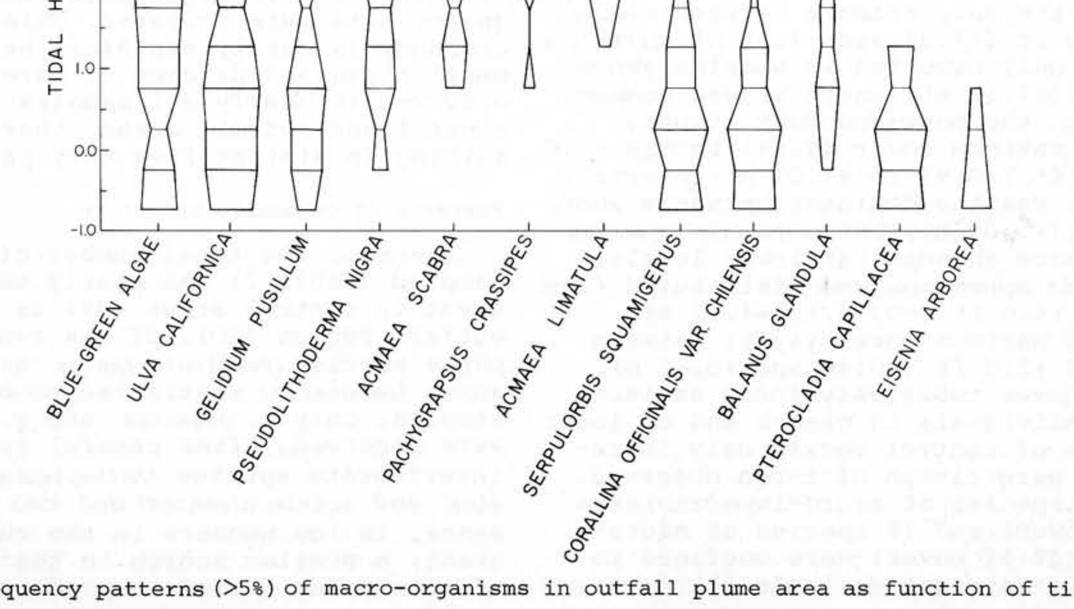

Fig. 4. Frequency patterns (>5%) of macro-organisms in outfall plume area as function of tidal height

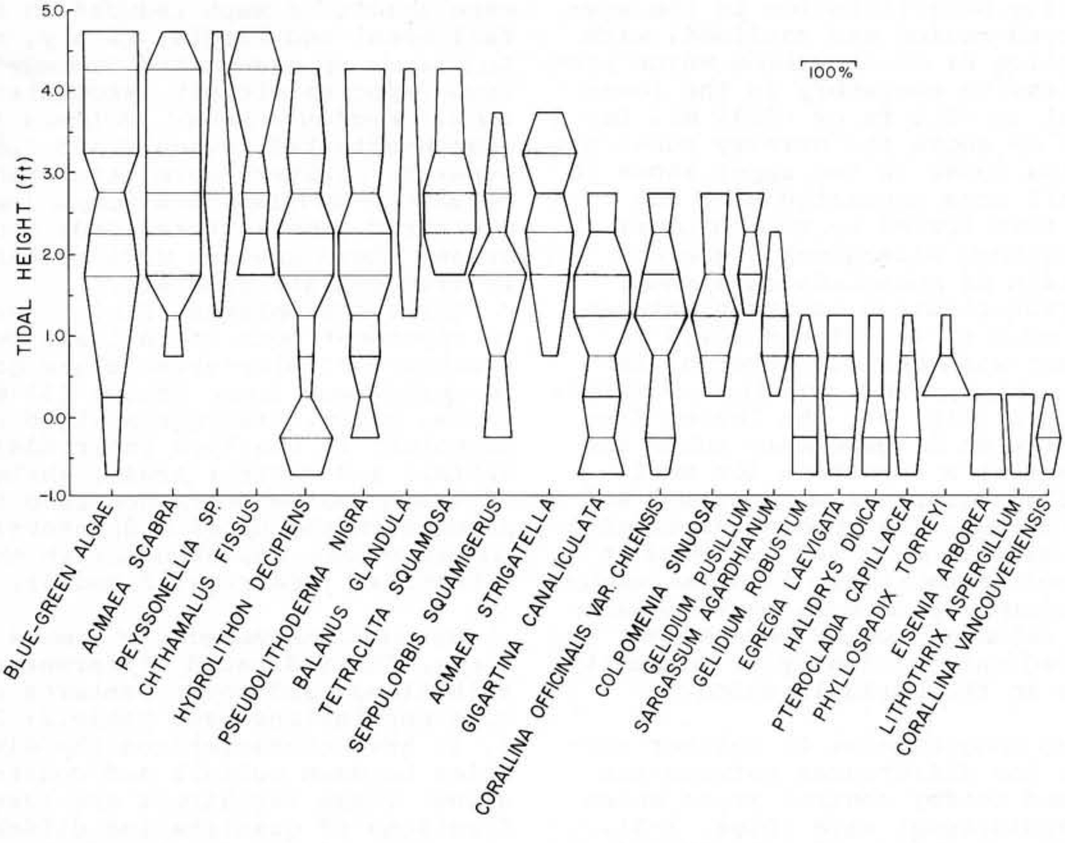

Fig. 5. Frequency patterns (>5%) of macro-organisms in control areas as function of tidal height

tional species of macro-organisms. Consequently, some 23 species were not found in the rocky intertidal area receiving discharged sewage, while only two species found in the outfall area could not be found in adjacent control sites.

To provide additional information on diversity and to avoid difficulties inherent with the use of a single index based on simple species counts, 4 quantitative indices (i.e., Brillouin's *H* Index, Shannon's *H'* Index, Simpson's λ Index, and Pielou's Evenness *J'* Index) were employed. In all comparisons the control areas revealed greater species diversity than the outfall (H=4.14 versus 2.94, H'=3.91 versus 2.80, 1-λ=0.91 versus 0.79), with differences of about 1.1 bits/individual between control and outfall communities when employing the information indices (H,H'). The evenness in abundance of individual species within each collection was also greater in control areas (J'=0.74 versus 0.63).

Stratification. Vertical layering or stratification is an important aspect of community structure because variations in habitat complexity (spatial heterogeneity) and niche diversity are involved. In intertidal communities, stratification patterns generally become more complex on the lower shore as a result of the increased abundance of the large brown algae. A clear difference between control communities (103% macrophyte cover) and outfall communities (92% macrophyte cover) was a reduction of stratification in the sewage-affected area, particularly on the lower shore (<+2.0 ft or +0.61 m), where intertidal algal cover was only 54% that of neighboring control regions (Table 1). Species comprising the principal overstory in control areas (Fig. 3) were *Egregia laevigata, Halidrys dioica, Eisenia arborea* and *Phyllospadix torreyi;* these formed an extensive canopy and dominated intertidal cover below +2.0 ft (+0.61 m), with individual thalli reaching lengths up to 3.0 m. A lower canopy (Fig. 3) of *Gigartina canaliculata, Laurencia pacifica, Gelidium robustum, Pterocladia capillacea, Gelidium coulteri, Sargassum agardhianum* and *Colpomenia sinuosa* extended up to 30 cm above the primary substrate throughout most of the mid-intertidal. Frequently, a stratum of *Corallina officinalis* var. *chilensis* with epiphytic thalli of *Gigartina canaliculata, Colpomenia sinuosa, L. pacifica* and *S. agardhianum* was the principal feature in control areas lower than +3.0 ft (+0.91 m).

Community stratification in the sewage-affected region was confined, with the exception of *Eisenia arborea* which provided extensive overstory in the lower intertidal (< -0.5 ft or -0.15 m), to within 10 cm above the primary substrate. Most of the cover on the upper shore in the outfall area consisted of a low (< 5 cm) turf formed by *Ulva californica, Gelidium pusillum,* blue-green algae and small thalli of *Pterocladia capillacea.* Marked stratification occurred between +2.0 and -0.5 ft (+0.61 and -0.15 m) concomitant with maximum cover of *Serpulorbis squamigerus* and *Corallina officinalis* var. *chilensis* (Fig. 2); the latter frequently grew on *S. squamigerus* tubes and also served as a substrate for small thalli of *U. californica, P. capillacea* and *Colpomenia sinuosa.* The common associates of *Corallina officinalis* var. *chilensis* in the control areas (i.e., *Gigartina canaliculata, Sargassum agardhianum, Laurencia pacifica* and *Gelidium coulteri*) were absent or contributed only minimally to community structure in the outfall region.

Community Classification. To further substantiate the differences between the outfall and nearby control areas shown by the populational data (Figs. 2-5), the entire assemblage of outfall and control samples (99) was subjected to statistical cluster analysis (Fig. 6). This treatment provided an objective clarification of the differences between cover of macro-organisms in the two areas.

Three groups consisting solely of outfall samples were interpreted (Fig. 6) to be distinct from control area assemblages: (1) Blue-green – *Ulva californica* group; (2) *Gelidium pusillum – Ulva californica* group; (3) *Serpulorbis squamigerus – Corallina officinalis* var. *chilensis – Pterocladia capillacea* group. The first two groups contained mostly the small turf-forming algae characteristic of much of the mid-intertidal zone in the sewage-affected area; whereas, members of the *Serpulorbis – Corallina – Pterocladia* group provided the majority of cover just below the lower margin of the *G. pusillum – Ulva* dominated turf and above the *Eisenia arborea*-dominated region.

Similarly, three clusters consisting of control area samples were interpreted as distinct: (1) *Corallina officinalis* var. *chilensis – Gigartina canaliculata* group; (2) *Hydrolithon decipiens* group; (3) *Egregia laevigata* group. Samples of the *Corallina*-dominated cluster of the control areas contained much epiphytic cover of *Gigartina canaliculata, Sargassum agardhianum, Colpomenia sinuosa, Laurencia pacifica* and *Gelidium coulteri* (species all of which were absent or much reduced in the outfall area) and little, if any, cover of *Serpulorbis squamigerus* and *Pterocladia capillacea* (species closely associated with *Corallina officinalis* var. *chilensis* in the sewage-affected region). Additionally, separate clusters were established for *Hydrolithon decipiens* and *Egregia laevigata*-dominated samples taken from control areas; these species were absent entirely from outfall quadrats.

Three assemblages (Fig. 6) were found to represent both outfall and control regions: (1) Blue-green algae group; (2) *Pseudolithoderma nigra* group; (3) *Eisenia arborea* group. Blue-green algae were prevalent in the high intertidal of both outfall and control areas, while thalli of *Pseudolithoderma nigra* occurred in patches in the upper mid-intertidal and *Eisenia arborea* was abundant in the lower intertidal (see Figs. 2 and 3).

Distributional Patterns of Species Assemblages. The indicated differences in distributional and cover patterns of species populations (see Table 2; Figs. 2, 3, 6) have characterized the dissimilarities between outfall and control regions. These variations are largely reflections of quantitative differences in cover and are displayed (Fig. 7) using the species group information derived from statistical cluster analysis. These assemblages characterize zonational patterns (Fig. 7), with the exceptions of the *Pseudolithoderma* and *Hydrolithon* groups, which have patchy distributions. Four distinct zones can be distinguished in control areas (i.e., blue-green algae, *Corallina – Gigartina, Egregia* and *Eisenia*) and these are distributed parallel to the shoreline in respect to various tidal intervals. Of these, only the *Egregia* and *Corallina – Gigartina* groups are unique (Fig. 7) to control areas; the latter impinges at the periphery of the sewage-affected area, but is completely missing across the central plume zone.

In contrast, there are 5 conspicuous zones in the outfall area (i.e., blue-green algae, blue-green – *Ulva, Gelidium – Ulva, Serpulorbis – Corallina – Pterocladia* and *Eisenia*). However, these describe a concentric pattern relative to the outfall terminus (Fig. 7) that differs appreciably from the typical distributions parallel to the shoreline characteristic of the nearby unpolluted intertidal. The *Serpulorbis – Corallina – Pterocladia* band is broader to the south, a pattern consistent with the predominant direction of sewage transport revealed by dye-drift studies (see Kenis *et al.,* 1972). Additionally, the blue-

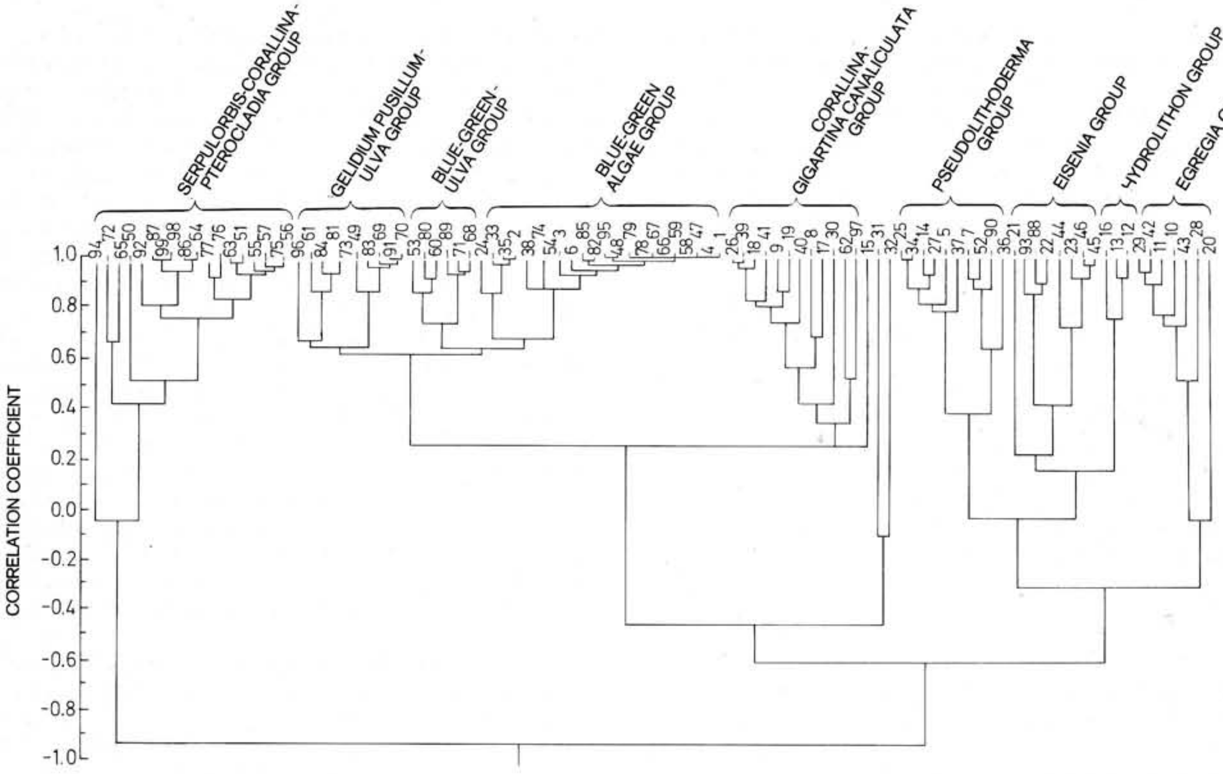

Fig. 6. Dendrogram display of differential clustering of all quadrats sampled from both control and outfall plume areas; this analysis is based upon cover data for all species within each quadrat

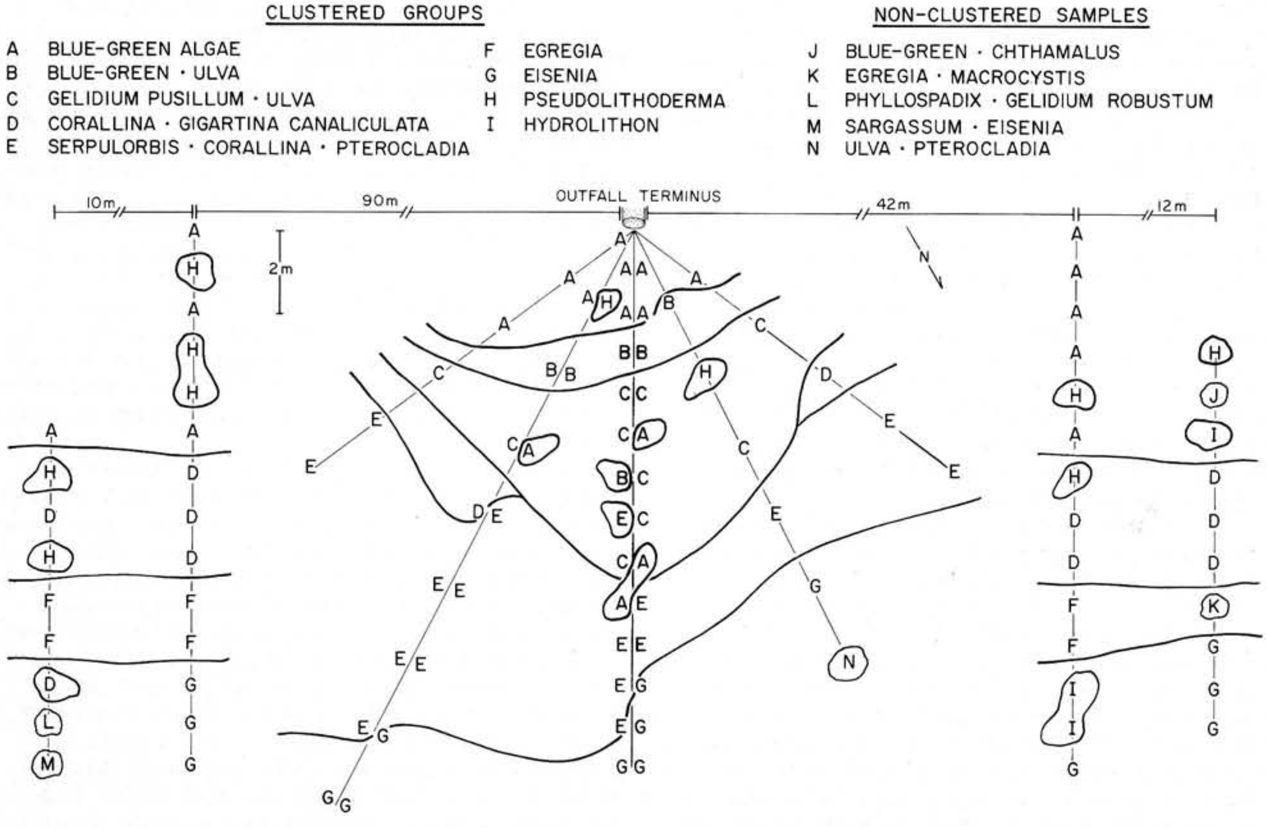

Fig. 7. Distributional patterns of species assemblages in relation to position of transects and location of quadrats in which they occurred. For full specific names see Table 2

green algae and *Eisenia* bands are displaced lower on the shoreline near the outfall (Fig. 7), toward the downstream margin of the plume.

In the case of the successional study, several of the experimental rocks were lost during storms; therefore, only qualitative results are presented at this time. Among the earliest large colonizers in both the non-polluted and polluted habitats were blue-greens, *Ulva californica* and *Gelidium pusillum* followed by *Pterocladia capillacea* and *Corallina officinalis* var. *chilensis*, species which constituted nearly 80% of the total cover in the outfall area (Table 2). In the control areas this seral stage was largely overgrown within 1 year by the larger red and brown algae, in the outfall plume it remained as an apparent disclimax community.

Discussion

The organisms most conspicuously absent from the outfall region were *Egregia laevigata, Hydrolithon decipiens, Halidrys dioica, Phyllospadix torreyi* and *Sargassum agardhianum*. These species combined to account for about 35% of the intertidal cover in the control areas (Table 2). Near Wilson Cove, *E. laevigata, H. dioica* and *S. agardhianum* were recorded growing no closer than 10 m from the sewage pipe. Reductions in the standing stocks of large brown algae, particularly subtidal kelps, near areas of sewage discharge similarly have been reported (e.g., North, 1964; State Water Quality Control Board, 1965) to be frequent for the Southern California mainland. The absence of *Halidrys dioica* parallels findings (Golubic, 1970) for the closely related genus *Cystoseira*, which decreased markedly along a gradient of increasing pollution in Yugoslavian harbors. Additionally, the complete absence of the genus *Phyllospadix*, one of the four most common intertidal macrophytes in Southern California (Dawson, 1965), from all but a few intertidal locations near the major Los Angeles County outfall at Whites Point has been reported by North (1964). *P. torreyi*, restricted in its distribution to horizontal distances greater than 25 m from the SCI outfall, is one of the most sensitive of the macro-organisms to sewage contamination.

Corallina officinalis var. *chilensis* was equally abundant in control and outfall areas (Table 2); whereas, the other articulated corallines (*C. vancouveriensis, Lithothrix aspergillum*) and crustose corallines *(Hydrolithon decipiens, Lithothamnium* sp.) were conspicuously absent from the outfall area. This contrasts with earlier reports (Dawson, 1959, 1965) where certain articulated coralline algae [i.e., *Bossiella californica* var. *californica* (as *B. insularis*), *B. orbigniana* ssp. *orbigniana* (as *B. cooperi*), *C. vancouveriensis* and *Lithothrix aspergillum*] were conspicuous components of intertidal communities adjacent to Southern Californian sites of sewage discharge. Dawson reported that *C. officinalis* var. *chilensis*, which was the dominant intertidal coralline in the sewage-affected area near Wilson Cove, was not associated with the outfalls he studied. Crustose corallines in the control areas most frequently grew on the sides and crevices of rocks or in the lower intertidal beneath large brown algae. Comparable crevices near the outfall were subjected to greater concentrations of effluent than upper surfaces, because these accumulated pools or rivulets of draining sewage during low tides. The large brown algae characteristic of the control areas were absent from the outfall region; consequently, habitats beneath an algal overstory were unavailable.

The cover of blue-green algae in the outfall region was particularly well developed on the upper shore (Fig. 2), where sewage continually splashed upon exposed rocks. Golubic (1970) recorded a similar phenomenon along the Northern Adriatic, where blue-green mats composed of several species developed maximally in the intertidal surrounding sewer outlets. These eury-tolerant algae were subjected to the most direct effects, i.e., pure sewage diluted by seawater only during high tides. The absence of *Chthamalus fissus* from this portion of the shore near Wilson Cove was notable, and was probably due to its intolerance to sewage; no "smothering" of *C. fissus* by blue-greens was noted. The enhancement of intertidal cover of the genera *Ulva* and *Pterocladia* (Table 2) in the area directly exposed to sewage coincided with the findings of Borowitzka (1972) for an Australian marine outfall.

Several species of macro-invertebrates were very prevalent in the outfall area, particularly the mobile omnivores *Pachygrapsus crassipes* and *Ligia occidentalis* and the suspension feeders *Anthopleura elegantissima, Serpulorbis squamigerus* and *Tetraclita squamosa*. Large populations of *L. occidentalis* and *P. crassipes* were observed near the sewage-affected area feeding on particulate organic matter. *A. elegantissima* probably also feeds on particulate organic matter and may be able to utilize food scraps from the effluent. No *A. elegantissima* were found, despite careful searches, in any of the control regions. *S. squamigerus* was much more abundant in the outfall (15.5% cover) than in the controls (1.0% cover) reaching greatest concentrations along the subtidal border of the sewage-affected area. *T. squamosa,* although reduced in numbers in the central portion of the outfall plume, became abundant on the periphery, reaching what appeared to be maximum concentrations in regions visually determined to border the area subjected to the most direct effects of the plume. Consequently, an enhancement of species known to utilize detritus or particulates was evident near the outfall which hypothetically has resulted from an increase in the availability of particulate organic matter. A similar trend towards the increased utilization of organic particulates in areas subjected to pollution was implicated by Jones (1973) for Northeastern Britain, where a marked shift towards suspension-feeding pathways occurred for kelp holdfast communities.

One major component of diversity is species richness or variety, a second is the evenness or equitability in the apportionment of individuals among the species sampled. The simplest measurement of species richness is the number of species in a given set of samples. Several more quantitative expressions of diversity have appeared in the literature which incorporate the abundances of populations and combine richness and evenness components. Frequently such diversity indices have been based on density data; however, other representations (e.g., cover, biomass, productivity and importance values) also have been employed. In marine intertidal communities, where density values are difficult to obtain for macrophytes and where space is an essential and frequently limiting resource, we feel that cover is perhaps the most meaningful quantitative representation of abundance.

A consistently documented effect of sewage pollution is to reduce the diversity of species of marine communities. For example, mixed domestic sewage was found (Borowitzka, 1972) to decrease algal diversity in the vicinity of an Australian marine outfall. For the Wilson Cove area, the sewage-affected region had 49% fewer species of macro-organisms than nearby controls. These data are highly comparable with those of Jones (1973), where a 45% reduction in invertebrate species was given for polluted kelp holdfast communities of the North Sea.

The spatial heterogeneity provided by large algal overstories was much reduced in the outfall area (e.g. 103% cover versus 92% cover). The mid-intertidal of the sewage-affected area was dominated by a low turf of blue-green algae, *Gelidium pusillum, Ulva californica* and small thalli of *Pterocladia capillacea.* The establishment of such algal turfs in the rocky intertidal appears to be common on shores subjected to various forms of disturbance, e.g. sand abrasion (Murray, unpublished) and trampling (Nicholson and Cimberg, 1971) or collecting (Widdowson, 1971) by humans. Along the Southern California mainland where environmental disturbances and human traffic have become more severe in recent years, an increase in the turf-forming algae (i.e., *Ulva* spp., *Gelidium coulteri* and *Pterosiphonia* spp.) has been reported to have occurred since 1959 (Widdowson, 1971).

The lower intertidal portion of the sewage-affected area (Table 1, Fig. 2) lacked the conspicuous algal overstory provided in the controls by *Egregia laevigata, Halidrys dioica, Sargassum agardhianum* and *Phyllospadix torreyi.* The marked reduction in pattern diversity resulting from decreased community stratification represents a decrease in community complexity in the outfall area and is most probably a major contributing factor to the observed reduction in species diversity. This effect, however, has been minimized along the subtidal fringe, where *Eisenia arborea* cover was very similar to that of control regions.

It was visually and quantitatively apparent (Figs. 2-7) that marked differences existed between the outfall and control macrophyte assemblages. The distributional patterns of these assemblages (Fig. 7) implicate the degree of dilution of discharged sewage to be of major importance in controlling intertidal zonation near the outfall, while zonation is correlated with tidal height in the control areas. In addition to quantification of the standing stocks, further studies were carried out in an attempt to experimentally examine the observed differences. Two possible hypotheses were considered: (1) that fluctuating concentrations of toxic sewage components such as pine oil modified species interactions and community development patterns or, alternatively, (2) that species dominances were altered by the presence of growth stimulants in the sewage (i.e., nutrients). These hypotheses were partially tested by the manipulative study of succession on cleared substrates. The results of this experiment support the first hypothesis and indicate that one of the critical effects of the outfall appears to be to increase environmental stress in the plume area which selects against all but the most tolerant and rapidly colonizing organisms (e.g. blue-green algae, *Ulva californica, Gelidium pusillum* and *Pterocladia capillacea*). Blue-green algae and ulvacean greens have been reported elsewhere (e.g. Fahey, 1953) to be among the first successional organisms on cleared intertidal transects. However, the second hypothesis is in no way refuted and may also be important (e.g. as evidenced by the enhanced abundance of suspension feeders near the outfall). In fact, the occurrence of certain algal genera (e.g. *Corallina, Gelidium* and *Ulva*) and invertebrates in polluted inshore waters has been suggested (North *et al.*, 1972) to be related to direct uptake and utilization of dissolved amino acids found in organic wastes.

The above standing-stock data and data generated in earlier studies on the primary productivity of Wilson Cove macrophytes (Littler and Murray, 1974; Littler, in press) are interpretable in the light of *r*- and *K*-selection concepts (see Pianka, 1970) derived from studies of terrestrial systems. The production rates of the seaweeds from the impacted area were considerably greater than those algae dominant in the controls, and indicate faster-growing populations; the annual form (*Ulva californica*) and the forms that propagate vegetatively (i.e., blue-greens, *Gelidium pusillum* and *Pterocladia capillacea),* in particular, have mechanisms for short and simple life histories. These potentially opportunistic species (*sensu* Connell, 1972; or *r*-selected forms *sensu* Pianka, 1970) can rapidly recolonize new surfaces that have been denuded following either random winter storms or fluctuations in levels of toxic pollutants (possibly pine-oil disinfectant in this case). These kinds of organisms, with their smaller turf-like growth habits, provide little spatial heterogeneity and this may act to reduce macro-organism diversity. Simpler life histories and greater individual production rates are also characteristic of species comprising communities classically attributed (see reviews by Margalef, 1963, 1969; Odum, 1969; Pianka, 1970) to early stages of succession. Thus, we hypothesize that a primary effect of this low-volume outfall parallels that of naturally-occurring disturbances, such as storms, creating a fluctuating environment (due to periodic lethal dosages of disinfectant) that maintains an early disclimax successional stage.

On the other hand, and in accordance with statements by Connell (1972), the relatively less-productive dominant macrophytes of the control zones indicate a relatively mature community structure. Species diversity and abundance (103% cover) is higher and perennial forms predominate with more complex life histories, relatively more structural thallus components, but fewer photosynthetic components (Littler, in press) and greater spatial heterogeneity (e.g. greater layering of canopies and more substrata levels). These macrophytes appear to be slower-growing specialists (i.e., *K*-strategists), with their populations regulated mainly by biological interactions such as intensive competition for space and light.

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Dr. M.M. Littler
Department of Population and Environmental Biology
University of California
Irvine, California 92664
USA

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