SECTION 3

ANALYSES OF STANDING STOCK AND COMMUNITY STRUCTURE OF MACRO-ORGANISMS

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INTRODUCTION

Studies of pollution effects on marine intertidal communities in the Southern California region are remarkably few in number. Of the limited information available, the most useful appears to be that (Refs. 2-5) concerned with communities of macrophytes. Dawson (Refs. 2, 3) surveyed a number of rocky intertidal stations in Southern California from 1956–1959 in an attempt to construct records of the distribution and abundance of the more conspicuous macroscopic algae. His efforts were part of a California State Water Pollution Control Board project initiated in 1954, concerned with methods and effects of the disposal of sewage into the sea. Prior to Dawson's studies, the only usable information for comparisons was contained in the collections of intertidal algae gathered between 1895 and 1912 by W. A. Setchell and N. L. Gardner from three rocky areas (Whites Point, Sunset Boulevard Beach and Pt. Fermin) in Los Angeles County. After examining these collections, Dawson (Ref. 2) concluded that approximately a 50–70% reduction in the number of species comprising the algal floras at the Whites Point and Sunset Boulevard sites had occurred, whereas little change was evident at Pt. Fermin. In that the Whites Point and Sunset Boulevard stations were subject to a high degree of sewage pollution, Dawson attributed the observed declines to sewage effects. Further, Dawson (Ref. 2) reported that several species of articulated coralline algae were capable of remarkable development within close proximity to marine sewage outfalls.

In an attempt to describe changes in the algal composition of the Southern California intertidal, Widdowson (Ref. 4) 'reoccupied' 15 of Dawson's original stations. Widdowson's study revealed a general and widespread decline in the marine intertidal flora near Los Angeles since 1956–1959. Sewage pollution was also implicated, although the degree to which a station was exposed to human traffic was reported to be more highly correlated with floral decline.

Subsequent to the 1969 Santa Barbara Oil Spills, several studies (e.g., Refs. 6, 29) were initiated to determine the effects of oil on marine populations. Nicholson and Cimberg (Ref. 5) surveyed 10 Southern California stations (8 corresponded to those of Dawson) in an attempt to evaluate the effects of oil on rocky intertidal populations. The results of their studies supported the conclusions of Widdowson (Ref. 4) in that a reduction in the variety of species in the Southern California intertidal algal flora had occurred. Comparisons between patterns of species distribution also revealed (Ref. 5) that certain green algae characteristic of environments rich in organic chemicals were more abundant in 1969–70 than in 1956–59. The presence of systems for the uptake of amino acids in *Ulva*, *Corallina*, and *Gelidium*, all of which have been reported (Refs. 4, 5) to be abundant in Southern California, have been demonstrated and implicated (Ref. 30) in the success of these algae in sewage-polluted environments.

Ecological work on the intertidal of the Southern California Islands has been done only on San Nicolas (Ref. 26) and Santa Cruz (Ref. 27). The biotas of these two islands, however, are influenced by different water types (Ref. 25) than that of San Clemente Island, whose marine intertidal communities have never been analyzed. Collections of algae have been made for most of the Southern California Islands although of the information available (Refs. 5, 23, and 24) none can be utilized to construct pictures of intertidal communities.

The cumulative effects of man and a general lack of quantitative information have posed severe problems when attempts have been made to assess the effects of sewage on marine organisms in Southern California. A number of studies (Refs. 9–18) mostly supported by state or local government agencies, have been performed over the past two decades in this regard. The majority of these studies, however, concern only subtidal benthic organisms. Consequently, other than the previously mentioned limited reports (i.e., Refs. 2–5), virtually no information is available on the direct effects of sewage on Southern California intertidal communities. The study reported in this section was designed to provide quantitative information detailing the specific changes in the structure of communities of intertidal macro-organisms under the stress of sewage pollution at Wilson Cove, San Clemente Island, California.

METHODS AND MATERIALS

COLLECTION OF DATA

Most of our knowledge of the ecology of marine organisms is based upon qualitative information. Quantitative studies have frequently employed methods similar to those developed by Manton (Ref. 31) and Abe (Ref. 32), in which sketches depicting distributional patterns of organisms within sample units are made in the field and subsequently used to obtain indices of abundance (e.g., cover or density). Other workers (Ref. 26) have employed movable metal grids subdivided by wires into small squares to facilitate estimates of abundances of organisms in the field. Such field techniques are generally time consuming, often physically exhausting, and therefore restrict the number of samples that can be measured within the time available for study. Consequently, techniques that expedite the process of obtaining quantitative data in the marine intertidal zone during the limited time this area can be studied are of considerable value. Waterproofed tape recorders have been employed in this regard (Refs. 25, 33, and 34) in an effort to increase the capabilities of obtaining quantitative ecological data in the subtidal.

A photographimetric technique (Ref. 35) that provides data which can be used to generate quantitative information (i.e., density, frequency, and cover) was the principal method of assessing standing stocks of intertidal organisms in this study. This method also has the advantage of being fast and relatively simple to use and therefore enables an increased sample size per unit of available time.

The terminus of the sewer outfall is located just to the south of Wilson Cove at approximately the +5.3 ft (+1.6 m) tidal level and is supported by a large cement pylon. Five transect lines were placed at preselected angles (3.5, 30, 58, 83, 337 deg) from magnetic north sighted from the center of the terminal cement pylon supporting the outfall pipe. Horizontal angles were determined with a Suunto (Model KB-14) liquid-filled sighting compass. Transect lines were laid out from the tip of the pipe to just below the waterline at low tide. Ring quadrats, 30 cm in diameter, were placed along transect lines at 1- or 2-m intervals, thus providing 0.07 m^2 stratified random plots for sampling distributions of organisms.

Data were obtained by photographing the numbered ring quadrats at right angles with a Nikonos (35 mm) underwater camera equipped with an electronic flash. The ring provided a calibrated scale for each photograph. Photographs were developed as 35-mm color transparencies, which were projected through a panel of glass (23 by 30 cm) onto a sheet of white paper taped to the side opposite the projector. The paper contained a grid of red dots spaced at 2-cm intervals. Red dots were employed to facilitate distinguishing grid points from detail within projected photographs. The density of points comprising the grid was selected so as to provide reliable estimates of cover. Slides were focused onto the paper without regard to the field of points in order to provide random assessments. The number of points (dots) superimposed on each species was then determined for individual quadrats. Percent cover values were obtained by expressing the number of "hits" for each species as a percentage of the total number of hits for the whole quadrat. Records were made of occurrence and percent cover for species within each sample. Species observed within quadrats but absent from scores were assigned a cover value of 0.5 percent. In many instances, more than one photograph was necessary per quadrat unit in order to describe vertical stratification; therefore, producing total cover of greater than 100 percent.

A Sony (Model TC 45) miniature tape recorder, enclosed in a waterproofed acrylic casing, provided a rapid method of taking notes in the field on the contents of photographed quadrats. These data minimized taxonomic and other problems encountered in interpreting transparencies in the laboratory. Additionally, observations on stratification and species interactions were recorded for subsequent analysis.

Relative vertical heights for each quadrat were measured from fixed reference points with a Suunto inclinometer or a Berger Service Dumpy Level (Model 110B) and a 25-ft Forestry Suppliers, Inc. fiberglass combination ruler–leveling rod (Model NE-25). In order to affix vertical tidal heights to quadrats, sightings of relative height at low water were performed twice a day on three different days. The height of low water in reference to MLLW (0.0 ft) was determined by observing the maximal tidal decline in a period 30 min on each side of the predicted time of low tide. Predicted tidal data for Wilson Cove were obtained from U. S. Department of Commerce 1972 tide tables for the west coast of North and South America and utilized to assign vertical tidal heights to low-water sightings. Repeatability of measurements on successive days was ±0.3 feet. The tidal heights of individual quadrats, expressed to the nearest 0.1 ft, were then determined by calibration with reference points which had been assigned tidal heights based upon the low-water sightings.

Four additional transect lines were established, two each in control areas to the north (42 m and 54 m) and to the south (90 m and 100 m) of the outfall pipe. These lines were established by randomly selecting points of origin within regions considered to be removed from the influence of the outfall and consisting of similar topographic profile to that area immediately below the outfall pipe. Lines were placed parallel to the angle of the outfall pipe, which corresponded to a position perpendicular to the shoreline. Ring quadrats were sampled at 1-m intervals along each of these transect lines employing the previously described techniques.

Due to the relative difficulties in gaining access to the island and the extensive sampling program employed, it was necessary to gather data on several different occasions. The outfall region was sampled on 14 and 26 February and 30 May 1972, whereas the control regions were assessed on 30 May and 14 June 1972. Observations have been performed on the study areas since June 1971, including intense observations from February to June in the year following the study. Seasonal changes in standing stock over the sampling period were considered to be minor when 30 May 1972 outfall samples were compared with those gathered during February of 1972. Consequently, all data gathered were grouped as being representative of outfall or control areas.

A total of 53 quadrat samples were assessed within the direct influence of the outfall plume. The two outermost transect lines in the outfall area were limited to samples within 10 m of the outfall pipe. Further samples along these lines were visually determined to be outside of the direct influence of the outfall plume and represented rapidly changing fringe communities. In the control areas, 46 quadrats were assessed. All samples from control regions were treated as a single collection representative of the intertidal region removed from sewage influence. Samples in the control and outfall regions were limited to below a vertical height of +5.3 ft (+1.6 m), the height of the outfall terminus.

ANALYSES OF DATA

Information obtained by the photographimetric sampling method provided quantitative data on the distribution of standing stock as a function of tidal height. These data were employed to compare intertidal populations and communities in the outfall region with those in control areas. Cover was measured directly from color transparencies; values for each species were averaged for each 0.5-ft tidal interval from −1.0 to +5.0 feet. Species cover in the control and outfall areas was then statistically compared using Wilcoxon signed-rank tests. Species frequency distributions (the percentages of sample plots in which each species was present) were similarly calculated for each 0.5-ft tidal interval. Diversity assessments, based on cover, were made employing four quantitative indices (i.e., Simpson's Index, Brillouin's Index, Shannon's Index, and Pielou's Evenness Index). Community stratification, used as a measurement of spatial heterogeneity, was determined directly from photographs taken of overstory, understory, and substrate for each quadrat. In an effort to objectively determine natural assemblages or groupings of organisms, control and outfall samples were subjected to statistical cluster analysis. Details of diversity and cluster analyses appear in the results and discussion.

A preliminary manipulative study was performed in order to document patterns of succession for use in analyses of cause and effect and to gain predictive insight into the effects of moving the outfall from its present location (i.e., recovery patterns). Sixteen uniform, weathered rocks were burned with ethanol and placed (four in each control area and eight in the outfall plume area) between +1.0 and +2.0 ft; subsequent community development was followed. Some of these rocks (several were lost through movement from storms) were then relocated between the outfall and control areas (others were left *in situ* for controls).

RESULTS AND DISCUSSION

FLORISTIC AND FAUNISTIC ASPECTS

The work to date has resulted in a reasonably complete mapping of the distributions of intertidal macro-organisms near Wilson Cove. We acknowledge that micro-algae, small epifauna, and infauna might well be metabolically very important; however, the analysis of distribution of these organisms requires highly specialized techniques and expertise, which constitute separate problems in themselves. By analogy, the seemingly relatively unstructured *Endocladia muricata – Balanus glandula* zone was found (Ref. 36) to be *extremely* complex in terms of infauna taxonomy alone. For these reasons, our samples included only those organisms constituting the macrobiota (i.e., the epibiota that could be discerned by unaided eye in the field or in photographs).

Twenty-two species were recorded in the outfall region including 9 animals and 13 macrophytes (Table 5). Animal species included 4 Mollusca, 3 Arthropoda, and 2 Coelenterata. Of the species of macrophytes, the Rhodophyta contributed 6, the Phaeophyta 5, and the Chlorophyta 1 species. Blue-green algae (Cyanophyta) were treated as a single taxonomic unit.

Of the 40 species from control area samples (Table 5), 10 were animals and 30 were macrophytes. Faunal components of the biota were limited to the Mollusca (6 species) and Arthropoda (4 species); floral components were distributed between 5 divisions of macrophytes. In terms of numbers of species, Rhodophyta (17) were primary followed by Phaeophyta (8), and Chlorophyta (3). Blue-green algae (Cyanophyta) and one angiosperm species were also present.

TABLE 5. Mean cover comparisons of animal and macrophyte species for control areas vs. outfall plume. Significance levels are for one-tailed Wilcoxon signed-rank tests based upon paired comparisons for each 0.5-ft tidal interval. (n.s. = not significant, $p > .05$)

SPECIES	MEAN COVER (%)		SIGNIFICANCE LEVEL
	Outfall Plume	Control Areas	
Animals			
Serpulorbis squamigerus	15.5	1.0	$p = .01$
Acmaea scabra	1.4	1.9	n.s.
Anthopleura elegantissima	0.3	–	–
Acmaea limatula	0.1	0.1	(a)
Balanus glandula	0.1	0.1	n.s.
Pachygrapsus crassipes	0.1	–	–
Anthopleura xanthogrammica	<0.1	–	–
Lottia gigantea	<0.1	–	–
Tetraclita squamosa	<0.1	2.5	$.05 > p > .01$
Chthamalus fissus	–	2.7	–
Acmaea strigatella	–	0.6	–
Haliotis cracherodii	–	0.2	–
Ligia occidentalis	–	<0.1	–
Littorina scutulata	–	<0.1	–

Table 5. (continued)

SPECIES	MEAN COVER (%)		SIGNIFICANCE LEVEL
	Outfall Plume	Control Areas	
Macrophytes			
Blue-green algae	43.1	18.4	$p < .005$
Ulva californica	11.5	<0.1	$p < .005$
Pseudolithoderma nigra	9.1	6.7	n.s.
Pterocladia capillacea	8.8	3.1	$.05 > p > .01$
Corallina chilensis	8.4	14.1	n.s.
Gelidium pusillum	5.7	0.3	$p < .005$
Eisenia arborea	3.2	3.1	(a)
Gelidium robustum	0.7	7.7	n.s.
Petalonia fascia	0.5	–	–
Gigartina canaliculata	0.3	8.8	$p < .005$
Scytosiphon lomentaria	0.2	–	–
Colpomenia sinuosa	0.1	2.8	n.s.
Peyssonellia sp.	0.1	0.3	n.s.
Egregia laevigata subsp. *borealis*	–	13.8	–
Lithophyllum decipiens	–	12.1	–
Halidrys dioica	–	5.3	–
Phyllospadix torreyi	–	1.8	–
Sargassum agardhianum	–	1.7	–
Rhodoglossum affine	–	1.1	–
Macrocystis pyrifera	–	0.8	–
Lithothrix aspergillum	–	0.4	–
Anisocladella pacifica	–	0.2	–
Codium fragile	–	0.2	–
Gigartina spinosa	–	0.2	–
Corallina vancouveriensis	–	0.1	–
Dictyota flabellata	–	0.1	–
Cladophora graminea	–	<0.1	–
Gelidium coulteri	–	<0.1	–
Laurencia pacifica	–	<0.1	–
Lithothamnium sp.	–	<0.1	–
Plocamium coccineum var. *pacificum*	–	<0.1	–
Unidentified red prostrate	–	<0.1	–

(a) Insufficient number of intervals containing cover for analysis

VARIATIONS IN COVER

General Patterns

Total cover was determined as the grand mean for each species' mean cover value calculated for each 0.5-ft tidal interval. Overall cover of organisms in the control areas (Table 6) was 112.6%, with macrophytes providing 103.4% and animals 9.2%. In the outfall area (Table 6), the total cover of biota was 109.3%, with macrophytes contributing 91.7% and animals 17.6%. Animal cover was concentrated (Fig. 3) below +2.0 ft in the outfall plume area and above +2.0 ft in control areas. Macrophyte cover was much greater below +2.0 ft in control areas, whereas cover was more evenly distributed as a function of tidal height in outfall samples (Fig. 3).

The effects of the outfall have been to significantly enhance animal cover and depress macrophyte cover below +2.0 ft, whereas above +2.0 ft, the reverse is true (Table 6). Increased macrophyte cover on the upper shore (Table 6, Fig. 3) has reduced the amount of bare rock here (Fig. 4) and is presumably attributable to the continual moistening of these surfaces by the splashing effects of discharged effluent.

TABLE 6. Mean cover comparisons of animals, macrophytes, and bare rock for control areas vs. outfall plume. Significance levels are for one-tailed Wilcoxon signed-rank tests based upon paired comparisons for each 0.5-ft tidal interval (n.s. = not significant, $p > .05$).

GROUP	MEAN COVER (%)		SIGNIFICANCE LEVEL
	Control Areas	Outfall Plume	
Total Cover of Biota	112.6	109.3	n.s.
Combined Animals			
Entire intertidal zone (−1.0 to +5.0 ft)	9.2	17.6	n.s.
Upper shore (+2.0 to +5.0 ft)	14.7	4.1	$p \cong .01$
Lower shore (−1.0 to +2.0 ft)	3.4	30.6	$p < .05$
Combined Macrophytes			
Entire intertidal zone (−1.0 to +5.0 ft)	103.4	91.7	n.s.
Upper shore (+2.0 to +5.0 ft)	55.8	87.1	$p \cong .01$
Lower shore (−1.0 to +2.0 ft)	150.3	96.4	$p \cong .01$
Bare Rock			
Entire intertidal zone (−1.0 to +5.0 ft)	18.2	6.1	$.05 > p > .01$
Upper shore (+2.0 to +5.0 ft)	33.0	8.5	$p \cong .01$
Lower shore (−1.0 to +2.0 ft)	3.3	3.7	n.s.

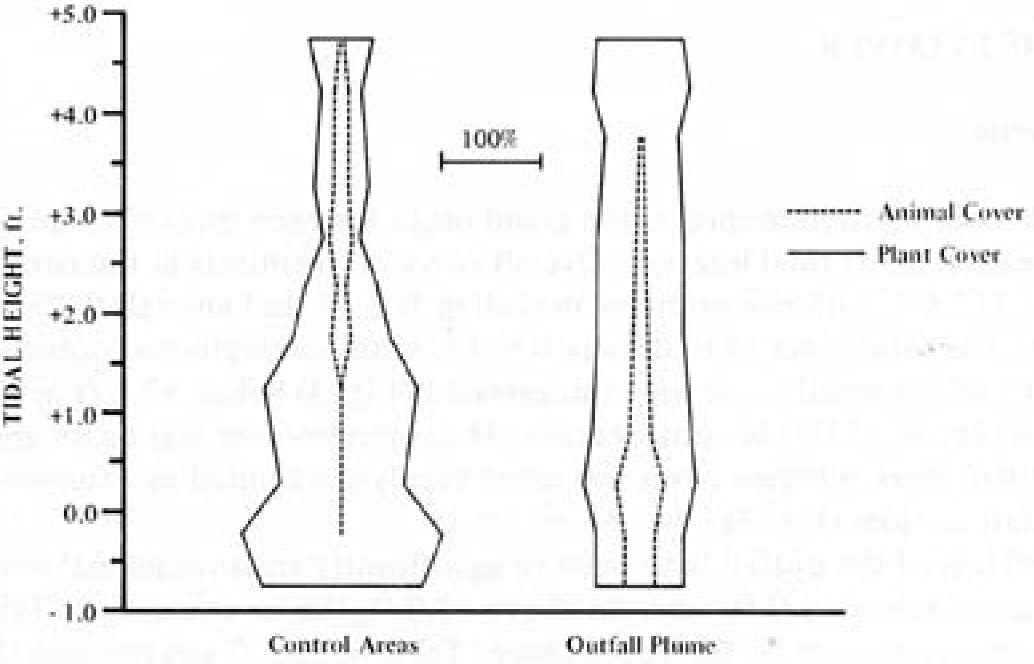

Figure 3. Comparative cover of combined animal and macrophyte species and bare rock on upper and lower shores in control and outfall plume areas.

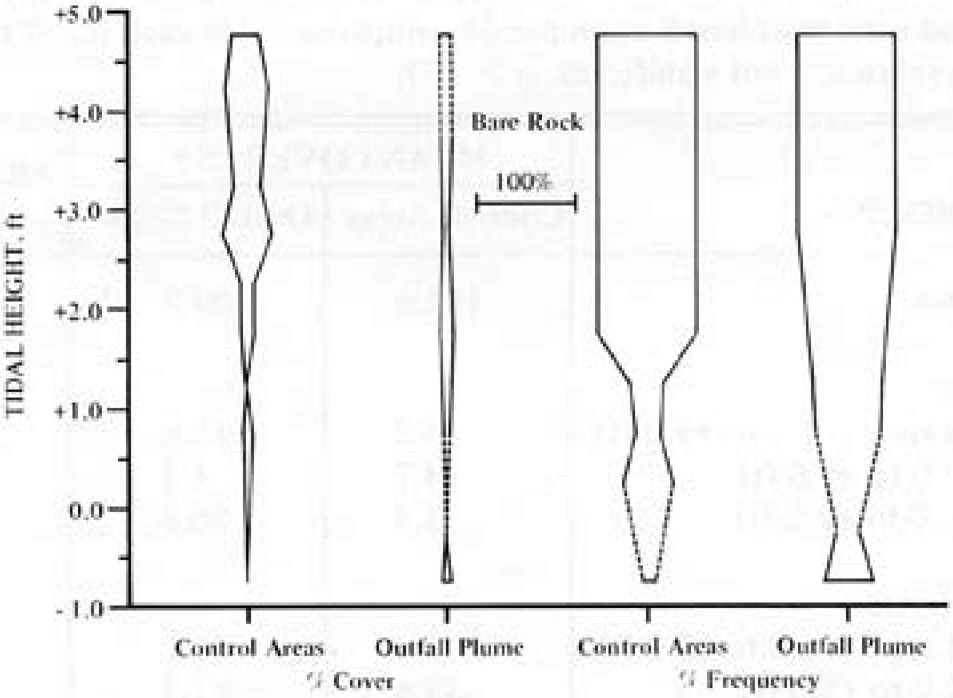

Figure 4. Comparative patterns of cover and frequency of bare rock as a function of tidal height in control and outfall plume areas. Dashed lines represent extrapolations over intervals lacking samples containing bare rock.

Individual Species

Control Areas. Blue-green algae were dominant (18.4%) in the control areas (Table 5) followed by *Corallina chilensis* (14.1%), *Egregia laevigata* subsp. *borealis* (13.8%), *Lithophyllum decipiens* (12.1%), *Gigartina canaliculata* (8.8%), *Gelidium robustum* (7.7%), *Pseudolithoderma nigra* (6.7%), and *Halidrys dioica* (5.3%). *Eisenia arborea*, *Pterocladia capillacea*, *Colpomenia sinuosa*, *Phyllospadix torreyi*, *Sargassum agardhianum*, and *Rhodoglossum affine* were also conspicuous in control area samples. The barnacles *Chthamalus fissus* (2.7%) and *Tetraclita squamosa* (2.5%) and the limpet *Acmaea scabra* (1.9%) provided most of the cover contributed by animal species in the control areas (Table 5).

The cover patterns (Fig. 5) of intertidal organisms in the control areas have been plotted against vertical tidal height. Blue-green algae were found throughout the range of samples but were most abundant above +3.0 ft, reaching maximum cover (67.6%) between +4.5 and +5.0 feet. *Peyssonellia* was the only other algal species found in samples taken above +4.5 feet.

The crustose forms *Lithophyllum decipiens* and *Pseudolithoderma nigra*, mostly confined to the sides and lower surfaces of rocks, contributed considerable cover below +4.5 feet. *Lithophyllum* reached maximum cover at a slightly lower level on the shore than did *Pseudolithoderma* (Fig. 5).

Corallina chilensis was found growing as a low turf on most of the primary rock substrate from +0.5 to +3.0 ft, with maximum cover (52.2%) between +1.0 and +1.5 feet. The majority of the *Corallina chilensis* sampled in the intertidal regions of control areas served as secondary substrate for the fleshy algae *Gigartina canaliculata*, *Colpomenia sinuosa*, *Laurencia pacifica*, *Gelidium coulteri*, and *Sargassum agardhianum*. *Gigartina canaliculata* and *Colpomenia sinuosa* represented the principal algal epiphytes on much of *Corallina*, with *Sargassum* becoming more prevalent near the lower limits of the turf's distribution (Fig. 5). Throughout the sampling period, both *Gelidium coulteri* and *Laurencia pacifica* were rarely encountered; but, during the following year, a considerable increase in *L. pacifica* in the control areas was noticed.

The fleshy brown algae (*Egregia laevigata* subsp. *borealis*, *Halidrys dioica*, and *Eisenia arborea*), the larger, fleshy red algae (*Gelidium robustum* and *Pterocladia capillacea*), and a marine angiosperm (*Phyllospadix torreyi*) became the dominant macrophytes below +1.0 ft (Fig. 5). *Egregia* reached maximum cover (51.5%) between MLLW and +0.5 ft; *Halidrys* (31.7%) between −0.5 and MLLW; and *Gelidium robustum* (33.4%) and *Phyllospadix torreyi* (16.3%) between +0.5 and +1.0 feet. *Eisenia* became dominant (26.5%) in the intertidal zone below −0.5 ft, comprising up to 100% of the cover in the regions immediately below the sampling limits of this study (−1.0 ft).

Acmaea scabra and *Chthamalus fissus* (Fig. 5) were the only animals sampled between +4.5 and +5.0 feet. *Littorina planaxis* was frequently observed above +5.0 ft, the upper sampling limit of this study. *Acmaea scabra* reached maximum cover (4.4%) in the interval between +3.0 and +3.5 ft and was more abundant than either *Acmaea limatula* or *Acmaea strigatella*. Whereas, *Chthamalus fissus* was the dominant barnacle, above +3.5 ft, *Tetraclita squamosa* became most abundant below this height. *Balanus glandula* formed only negligible cover in the control areas.

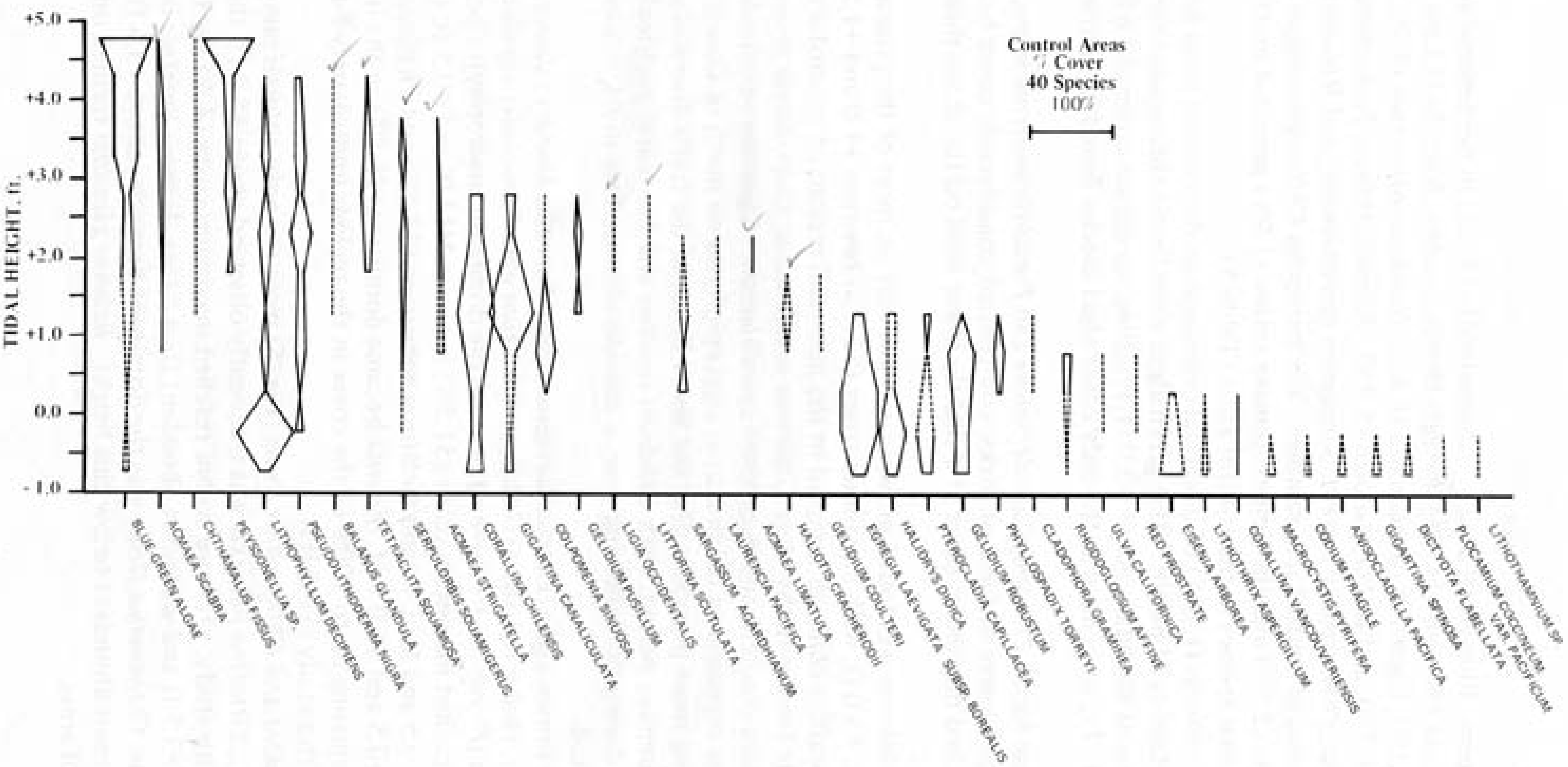

Figure 5. Cover patterns of intertidal organisms in control areas as a function of tidal height. In figures 5-8 the dashed lines represent extrapolations over intervals that lacked samples containing cover of a given species.

Serpulorbis squamigerus, the tube-forming mollusk, occurred in the interval from –0.5 to +4.0 ft, reaching maximum cover (4.7%) between +1.5 and +2.0 feet. *Serpulorbis* tubes were found as isolated individuals in cracks and on lower rock surfaces, and only infrequently were several tubes observed clumped together.

Outfall Area. Blue-green algae formed the greatest cover (43.1%) of macrophytes in the outfall plume area (Table 5), followed by *Ulva californica* (11.5%), *Pseudolithoderma nigra* (9.1%), *Pterocladia capillacea* (8.8%), *Corallina chilensis* (8.4%), *Gelidium pusillum* (5.7%), and *Eisenia arborea* (3.2%).

Serpulorbis squamigerus (15.5%) provided most of the animal cover followed by the limpet *Acmaea scabra* (Table 5).

The distributional patterns of intertidal organisms in the outfall plume area have been plotted (Fig. 6) against vertical tidal height. As in control areas, blue-green algae were also found throughout the range of outfall samples. Here, they were the most abundant algae sampled above +1.0 ft and the only algae sampled above +4.0 feet. Blue-green algae covered 58.5% of the rock surface between +1.0 and +5.0 ft and reached a maximum cover (100%) between +4.0 and +4.5 feet.

Pseudolithoderma nigra, *Gelidium pusillum*, and *Ulva californica* contributed considerable cover in the mid-intertidal zone (Fig. 6). *Pseudolithoderma* was abundant between +2.0 and +4.0 feet. The most common constituent of the mid-intertidal zone beneath the outfall pipe was a low turf consisting of *G. pusillum*, *U. californica*, blue-green algae, and small thalli of *P. capillacea*. *Gelidium pusillum* (11.9%) and *U. californica* (13.9%) reached maximum cover between +0.5 and +1.0 feet.

Pterocladia capillacea and *Corallina chilensis* (Fig. 6) were dominant between +0.5 and –0.5 ft; *Pterocladia* averaged about 21% and *Corallina chilensis* about 20% cover from –1.0 to +1.5 ft, with maximum cover of both between MLLW and +0.5 feet. *Corallina* utilized *Serpulorbis* tubes as a principal substrate and was observed only infrequently attached to rock. *Pterocladia*, *Ulva*, and *Colpomenia* utilized *Corallina*, when present, as a substrate.

Eisenia arborea was dominant (29.5%) in the intertidal interval –0.5 to 1.0 ft and formed up to 100% of the surface cover in the area immediately below the –1.0 ft limit of sampling.

Acmaea scabra occurred in the outfall area between +0.5 and +4.0 ft and, of limpet species, was more abundant (Fig. 6) than either *Acmaea limatula* or *Lottia gigantea*. The only barnacles sampled in the outfall plume region were *Balanus glandula* and *Tetraclita squamosa*, neither of which contributed much cover.

The dominant animal, *Serpulorbis squamigerus* occupied the greatest proportion of primary substrate between –1.0 and +1.0 ft and reached a maximum of 50.6% cover between 0.0 and +0.5 ft (Fig. 6). Throughout much of this portion of the shore, built-up masses of mollusk tubes, consisting of living and dead *Serpulorbis*, several decimeters thick at times, constituted the dominant feature. These tubes functioned as substrate for algae, particularly *Corallina chilensis*, and because *S. squamigerus* was extensively overgrown at times, it was not always easily quantified by our sampling method. Thus, we believe that these data represent a low estimate of cover for this species.

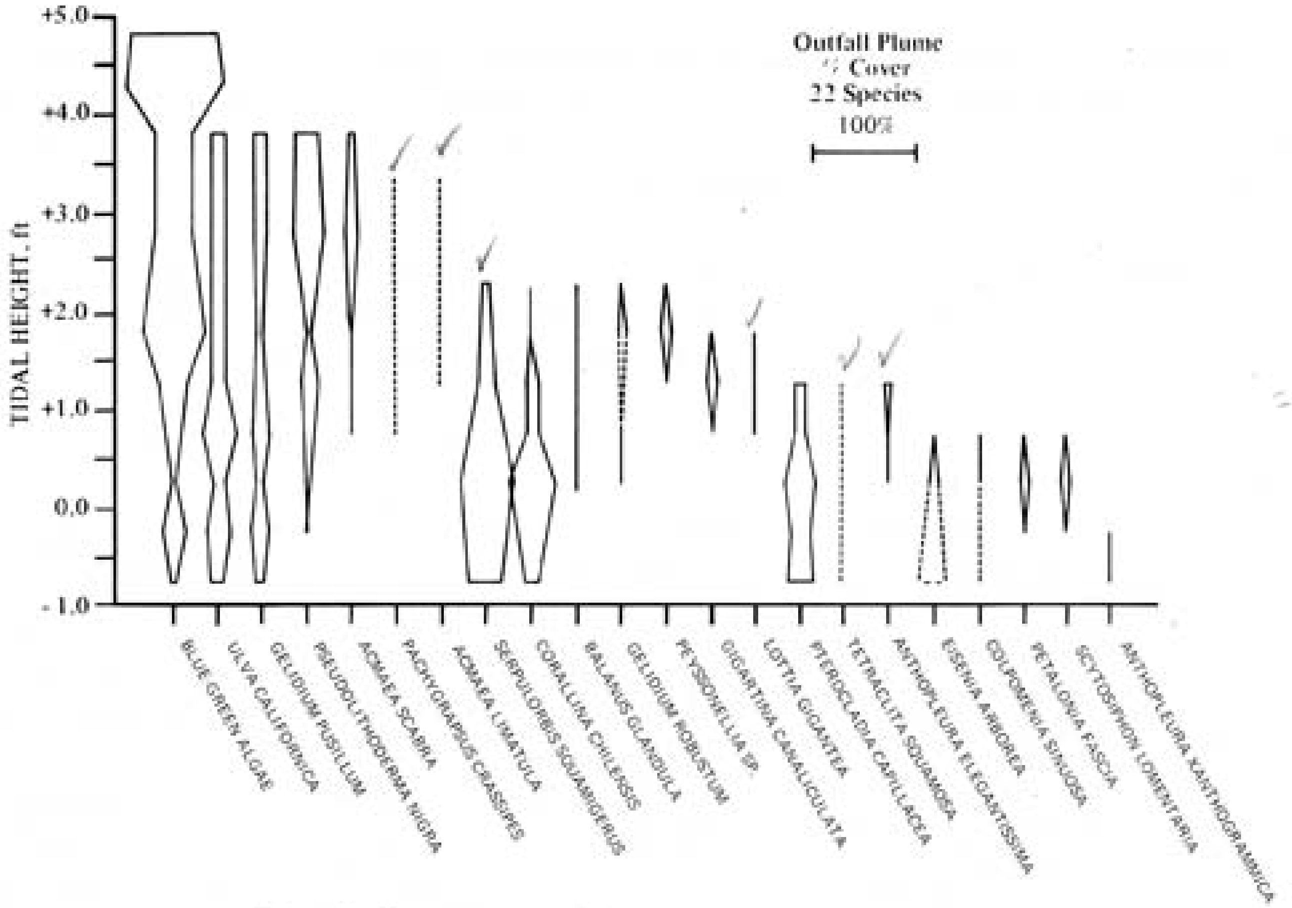

Figure 6. Cover patterns of intertidal organisms in outfall plume area as a function of tidal height.

Comparisons of Control and Outfall Areas. Five species of animals and 19 species of macrophytes were recorded (Table 5) in control-area samples that were absent from quadrats within the outfall plume. Additional species have been recorded from control areas (see Sections 1, 2) but these were not observed during the sampling period reported here. One of the five species of animals, *Ligia occidentalis*, the rock louse, was observed (see Section 2) in the outfall plume area. The organisms most conspicuously absent from the outfall plume were *Egregia laevigata* subsp. *borealis, Halidrys dioica, Sargassum agardhianum, Phyllospadix torreyi*, and the crustose-coralline alga *Lithophyllum decipiens*; these species covered about 35% of the control areas.

Earlier research (Ref. 20) described a reduction in brown algal standing stock and an absence of *Phyllospadix* in areas subject to discharged sewage. In this light, the patterns of intertidal distribution of *Egregia, Halidrys, Phyllospadix*, and *Sargassum* with respect to the outfall terminus give perhaps the best indication of the horizontal range of sewage effects. It appears that *Egregia, Halidrys*, and *Sargassum* (all brown algae) are absent within 10 m of the outfall terminus. *Phyllospadix torreyi*, however, appears to be an extremely sensitive indicator species in that it is limited in its intertidal distribution to distances greater than 25 m from the point of sewage discharge.

Four species of animals and two species of macrophytes were found (Table 5) in outfall quadrats but were absent from control area samples. Three of these (i.e., the animals *Lottia gigantea* and *Pachygrapsus crassipes* and the alga *Scytosiphon lomentaria*) were found (see Sections 1 and 2) in the control areas. *Pachygrapsus crassipes* was common in the control area, and its absence from control area samples no doubt resulted from its being hidden by the increased cover of larger macrophytes. *Petalonia fascia* and the anemones *Anthopleura* *elegantissima* and *A. xanthogrammica* were not observed in the control areas (see Sections 1, 2). The restricted occurrence of the anemone species within the outfall area is most probably correlated with the great increase in particulate organic matter provided by sewage.

Five species of animals and 11 species of macrophytes were present in both outfall plume and control area samples. A comparison by means of Wilcoxon signed-rank tests of the cover from both areas (Table 5) revealed that, of the animal species, *Serpulorbis squamigerus* was enhanced by sewage, whereas *Tetraclita squamosa* was reduced. Of the macrophyte species, blue-green algae, *Gelidium pusillum*, *Pterocladia capillacea*, and *Ulva californica* were significantly increased within the outfall plume, whereas *Gigartina canaliculata* was found to decrease. It is also likely that cover of *Gelidium robustum* was actually significantly less in the outfall area, although, because of its slightly elevated distribution there (see Figs. 5 and 6), Wilcoxon signed-rank tests revealed no significant difference. The enhancement of *Ulva* and *Pterocladia* in the sewage-affected area was comparable to the findings of Borowitzka (Ref. 37) who investigated an Australian marine sewage outfall.

The effects of sewage as determined by sampling and reconnaissance have resulted in the elimination of 23 species while apparently augmenting the establishment of at most 3 species within the area of greatest influence. Additionally, cover of *Serpulorbis squamigerus*, blue-green algae, *Pterocladia capillacea*, *Gelidium pusillum*, and *Ulva californica* has been increased. Presumably, these differences are due to either the absence or reduction of certain species (thereby reducing competition) or an enhancement effect (e.g., increased nutrients) which favors more sewage-tolerant species. These alternatives are discussed and evaluated below.

The abundant outfall population of *Serpulorbis* is hypothetically dependent upon the increase of detritus and particulate organic materials provided by the sewage as a principal food source. The fifteenfold increase of *Serpulorbis* observed in the outfall area (Table 6) may have additional (biotic) effects on intertidal community structure. The occupancy of rock surfaces in this region of the intertidal by *Serpulorbis* is, for example, coincidental with the absence of *Egregia*, *Halidrys*, and *Lithophyllum*, common constituents utilizing rock for substrate in similar regions of control areas.

The enhanced growth of blue-green algae in the outfall region was particularly evident on the upper shore (Fig. 6), where discharged sewage continually splashed exposed rocks. These eury-tolerant algae are subjected to the most direct effects, i.e., pure sewage diluted only at high tide by seawater. The growth of blue-greens has been increased markedly on these wet upper rocks, which show much less cover in comparable control area intervals. This increase in algal cover in the outfall region was, however, not matched by an increased abundance of grazing animals, e.g., *Acmaea* spp. Additionally, the absence of the barnacle *Chthamalus fissus* from this portion of the shore was also notable in the outfall area. Whether this absence was due to a "smothering" effect by blue-greens or intolerance of *Chthamalus* to sewage was not determined, but the latter is more likely the case.

Corallina chilensis was found to be equally abundant in control and outfall areas, whereas the other observed articulated (*Corallina vancouveriensis* and *Lithothrix aspergillum*) and crustose (*Lithophyllum decipiens* and *Lithothamnium* sp.) coralline algae were conspicuously absent from the outfall area. These results contrast somewhat with those of earlier reports (Refs. 2, 3), wherein the articulated coralline algae *Bossiella insularis*, *B. cooperi* forma, *Corallina vancouveriensis*, and *Lithothrix aspergillum* were found to comprise a conspicuously dominant component of the floras adjacent to sites of sewage discharge in Southern California.

The specific habitats of crustose corallines in the control areas were most frequently observed to be the sides and bottoms of crevices, between rocks and on rock surfaces beneath large brown algal overstory. The crevices between rocks are probably subjected to greater concentrations of effluent than most rock surfaces because these tend to accumulate pools of draining sewage during low tides. The large brown algae characteristic of the control areas are absent from the outfall region and, consequently, comparable habitats beneath algal overstory are unavailable.

VARIATIONS IN FREQUENCY

The mean frequencies of intertidal organisms were calculated from means generated for each 0.5-ft tidal height interval from -1.0 to +5.0 feet. Means for each interval were determined for a given species by calculating the percentages of samples within which that species was recorded.

Mean frequency determinations for control and outfall plume samples are presented in Table 7. Additionally, mean frequency was plotted against tidal height for the most abundant (mean frequency > 5%) species in the control (Fig. 7) and outfall (Fig. 8) areas. Generally, frequency data were found to closely parallel cover data with few exceptions. Probably the most significant discrepancy was that for bare rock. Whereas, cover data revealed about three times the amount of bare rock in control areas (Table 6; Fig. 4), differences were negligible when frequency data were compared (Table 7; Fig. 4). This is what one would expect since all portions of the intertidal zone contain at least some small nicks and patches of bare rock.

TABLE 7. Mean frequency of intertidal animals, macrophytes, and bare rock for control areas vs. outfall plume. Data based upon means of 0.5-ft tidal intervals.

SPECIES	MEAN FREQUENCY (%)	
	Outfall Plume	Control Areas
Animals		
Serpulorbis squamigerus	32.8	26.3
Acmaea scabra	30.5	56.8
Acmaea limatula	17.8	4.4
Pachygrapsus crassipes	17.8	–
Balanus glandula	6.3	7.9
Tetraclita squamosa	4.5	36.8
Anthopleura elegantissima	4.2	–
Anthopleura xanthogrammica	2.1	–
Lottia gigantea	1.2	–
Chthamalus fissus	–	34.8
Acmaea strigatella	–	31.0
Ligia occidentalis	–	1.7
Littorina scutulata	–	1.7
Haliotis cracherodii	–	1.4

Table 7. (continued)

SPECIES	MEAN FREQUENCY (%)	
	Outfall Plume	Control Areas
Macrophytes		
Blue-green algae	78.8	56.7
Ulva californica	64.3	1.4
Gelidium pusillum	51.7	10.0
Pseudolithoderma nigra	38.2	52.5
Corallina chilensis	29.8	45.0
Pterocladia capillacea	25.7	10.4
Eisenia arborea	6.4	9.8
Colpomenia sinuosa	3.8	20.7
Gelidium robustum	3.5	18.1
Peyssonellia sp.	1.8	7.2
Gigartina canaliculata	1.2	27.4
Petalonia fascia	1.2	–
Scytosiphon lomentaria	1.2	–
Lithophyllum decipiens	–	54.2
Egregia laevigata subsp. *borealis*	–	20.8
Halidrys dioica	–	13.8
Sargassum agardhianum	–	11.4
Phyllospadix torreyi	–	10.4
Corallina vancouveriensis	–	7.0
Lithothrix aspergillum	–	6.9
Rhodoglossum affine	–	4.9
Laurencia pacifica	–	3.1
Plocamium coccineum var. *pacificum*	–	2.8
Cladophora graminea	–	2.1
Anisocladella pacifica	–	1.4
Codium fragile	–	1.4
Dictyota flabellata	–	1.4
Gelidium coulteri	–	1.4
Gigartina spinosa	–	1.4
Lithothamnium sp.	–	1.4
Macrocystis pyrifera	–	1.4
Unidentified red prostrate	–	1.4
Bare Rock	66.3	68.8

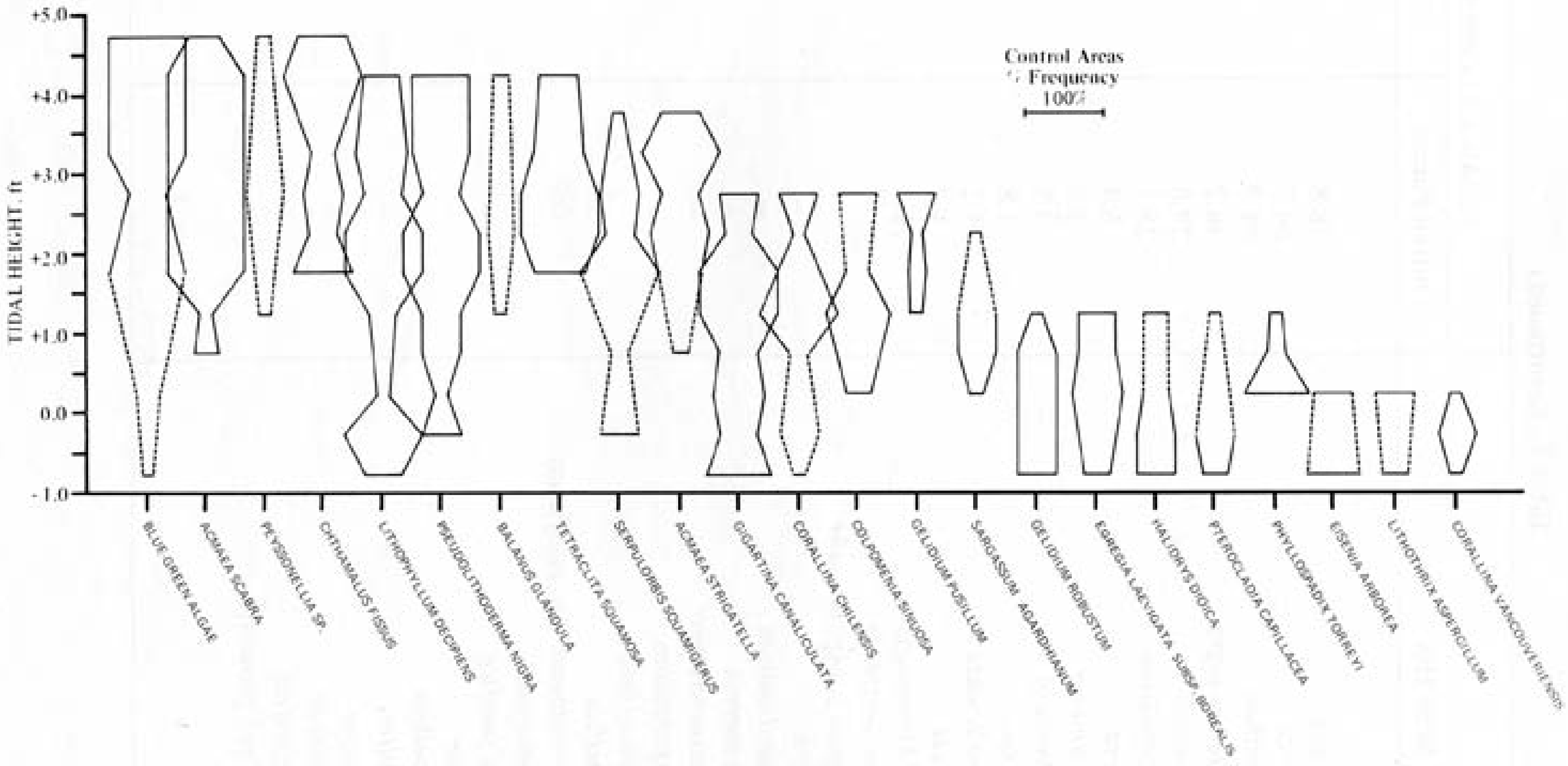

Figure 7. Frequency patterns of the most abundant (mean frequency > 5%) species in control areas as a function of tidal height.

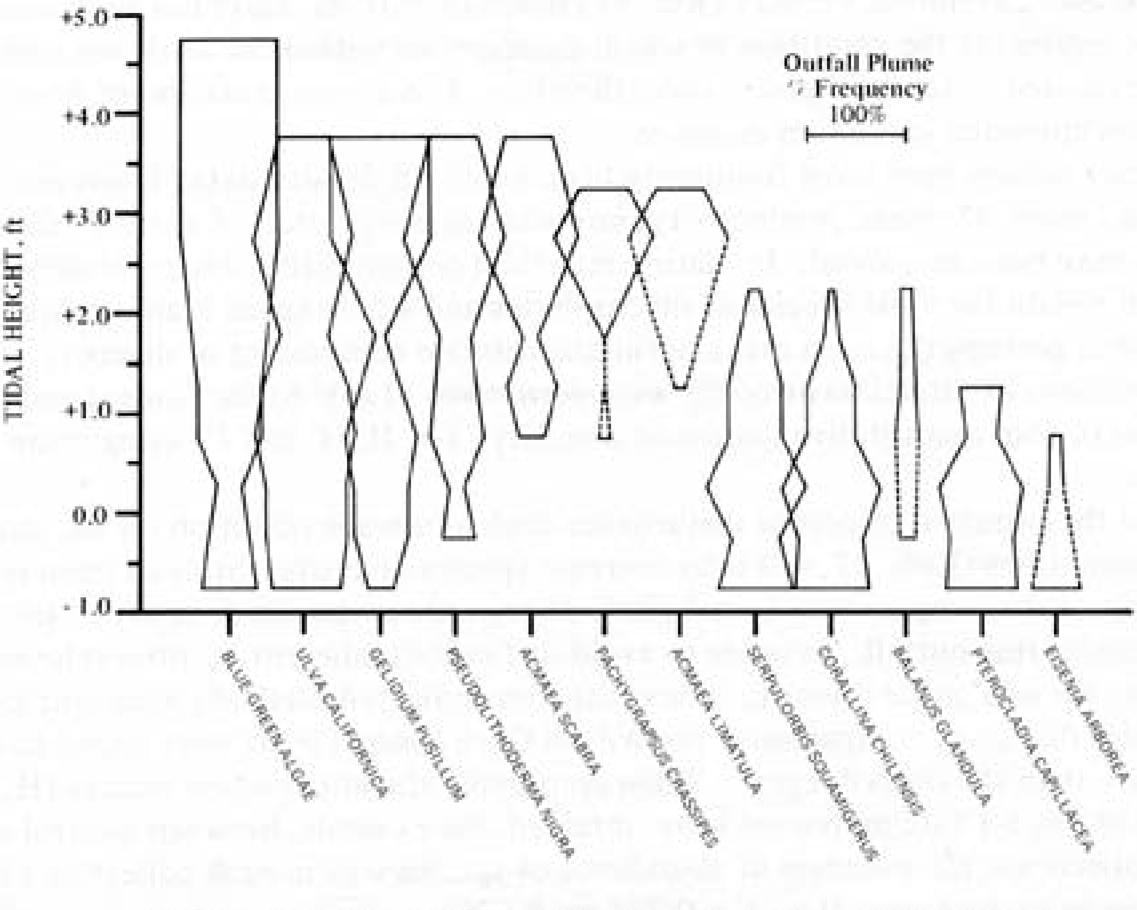

Figure 8. Frequency patterns of the most abundant (mean frequency > 5%) species in outfall plume area as a function of tidal height.

VARIATIONS IN COMMUNITY STRUCTURE

The term "community" is used here with reference to those aggregations of large and conspicuous (in terms of cover) organisms that occurred together frequently in samples. This approach leads, therefore, to a treatment of those intertidal regions that exhibit discrete groupings of organisms as consisting of more than one community. In an effort to determine the effects of the outfall at the community level, comparisons of diversity, stratification, and classification by cluster analysis were performed.

Species Diversity

It is important to recognize that species diversity has more than one connotation. One major component 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 a count of the number of species determined in a given set of samples. Several more quantitative expressions of species diversity have appeared in the literature which incorporate the relative abundances of sampled species and combine to a certain extent richness and evenness components. Of these, perhaps Simpson's (Ref. 38) Index of Diversity (λ) and two indices derived from information theory, Brillouin's (Ref. 39) Index (H) and Shannon's (H′) Index (Ref. 40) are most frequently employed in assessments of the diversity of biological collections. For purposes of comparison with information indices, the form of Simpson's Index (1-λ), where 1.0 represents maximum diversity, is usually employed. To assess evenness, Pielou's (Ref. 41) index ($J' = H'/H'$ max) has been used, where H' max represents the condition in which each species within the analyzed collection is equally represented in terms of abundance; therefore, J' is a representation of how closely the populations approach maximum evenness.

Diversity indices have most frequently been based on density data. However, representations (e.g., cover, biomass, productivity, importance values, etc.) of species other than density often have been employed. In marine intertidal communities, where density values are difficult to obtain for most species of macrophytes and where space is an essential resource, cover is perhaps the most meaningful quantitative component of diversity.

Comparisons of intertidal diversity were performed (Table 8) for control and outfall areas by means of four quantitative indices of diversity (1-λ, H, H′ and J′) using mean cover (Table 5) data.

One of the principal effects of disturbance such as sewage pollution on the structure of marine communities (Refs. 37, 42) is to decrease species diversity. Stresses from mixed domestic sewage, for example, were found (Ref. 37) to reduce species diversity in the vicinity of an Australian marine outfall. In order to avoid difficulties inherent in interpretations based upon the use of a single diversity index, the four indicated methods were employed. It is noteworthy that in *all* comparisons, the Wilson Cove control areas were found to have greater diversity than the outfall region. When employing the information indices (H, H′), differences of about 1.1 bits/individual were obtained, for example, between control and outfall area collections; the evenness of abundance of species within each collection (Table 8) was also greater in control areas (i.e., $J' = 0.735$ vs. 0.629).

TABLE 8. Comparisons of diversity in control and outfall plume intertidal areas. Calculations for diversity indices are based upon mean cover.

	No. Samples	No. Species	H′	H	I-λ	J′
Control Areas	46	40	3.912	4.135	0.910	0.735
Outfall Area	53	22	2.805	2.941	0.790	0.629

H′ = Shannon's Index of Species Diversity (Ref. 40)
H = Brillouin's Index of Species Diversity (Ref. 39)
I-λ = An expression of Simpson's measure of concentration (Ref. 38)
J′ = Pielou's measure of evenness (Ref. 41)

Stratification

Vertical layering or stratification patterns represent important contributions to community structure. In marine intertidal communities, stratification patterns are particularly evident owing to the arrangements of standing stock and the life forms of mature organisms. In Southern California much of this vertical layering is provided in the lower intertidal zone by species of large brown algae and *Phyllospadix*, which, with their epiphytes, exert a broad pattern of interaction with the smaller frondose and prostrate organisms occupying underlying substrate. A major effect of stratification is to provide increased habitat complexity (spatial heterogeneity) and, therefore, niche diversity within communities, thereby influencing greatly biotic and abiotic relationships.

A clear difference between control communities (103% macrophyte cover) and those of the outfall (92% macrophyte cover) is a reduction in stratification. Species providing the principal overstory in control areas were the brown algae *Egregia laevigata* subsp. *borealis*, *Halidrys dioica*, and *Eisenia arborea* and the marine angiosperm *Phyllospadix*. A lower canopy was provided by the frondose red algae, *Gigartina canaliculata*, *Laurencia pacifica*, *Gelidium robustum*, and, occasionally, *Pterocladia capillacea*, *Gelidium coulteri*, and the brown algae *Sargassum agardhianum* and *Colpomenia sinuosa*. This lesser stratification was primarily functional in the first 30 cm above primary substrate and was most frequently associated with a *Corallina chilensis* turf, upon which *Gigartina*, *Laurencia*, *Colpomenia*, and *Sargassum* most frequently were observed. Stratification resulting from *Corallina chilensis* and associated species was a principal feature in the intertidal zone of control areas below +3.0 feet. Below about +1.5 ft, intertidal communities were dominated by overstory produced by *Egregia*, *Halidrys*, *Phyllospadix*, and *Eisenia*. This overstory was much greater in magnitude, with individual plants reaching from one-half to several meters in length.

One of the most obvious differences between community stratification in the outfall plume area was the great reduction in overstory normally provided by *Egregia*, *Halidrys*, *Sargassum*, and *Phyllospadix* in the lower intertidal (<+1.5 ft). Much of the intertidal region here was dominated by a low turf consisting of blue-greens, *Gelidium pusillum*, *Ulva californica*, and small thalli of *Pterocladia capillacea* and, therefore, lacked the degree of stratification exhibited by control area communities. The establishment of such algal turfs in the rocky intertidal appears to be common on shores exposed to various forms of stress other than sewage, e.g., heavy sand abrasion*, or human traffic (Ref. 5). Since 1956 (Ref. 2), an increase in abundance of *Ulva*, *Gelidium crinale/coulteri*, and *Pterosiphonia* spp., all of which have a turfy habit, has been reported (Ref. 4) for the Southern California intertidal zone. The effects of turf formation on the abundance of certain animal species – for example, the barnacles *Balanus* and *Tetraclita* – are unstudied but probably important.

Community stratification in the outfall area was confined, with the exception of that provided by *Eisenia*, to the first 10 cm above the primary substrate. Frequently in the lower regions below +2.0 ft, *Corallina chilensis* grew simultaneously on *Serpulorbis* tubes while providing substrate for other algal species, (e.g., *Pterocladia capillacea*, *Colpomenia sinuosa*, *Ulva californica*). *Gigartina canaliculata*, *Sargassum agardhianum*, *Laurencia pacifica*, and *Gelidium coulteri*, common associates of the *Corallina chilensis* turf in the control areas, did not contribute to community structure in the outfall region. The greatest stratification

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**Author's observation.*

occurred below +2.0 ft, with a maximum being reached concomitant with maximum coverage of *Serpulorbis squamigerus* and *Corallina chilensis*. *Eisenia arborea*, the only large brown alga located within the outfall plume, provided an extensive overstory below −0.5 feet. This reduction in stratification reflects a concomitant decrease in community complexity and is most probably a contributing factor in the reduced species diversity in the outfall plume. This effect, however, appeared to have been minimized in the low intertidal and upper subtidal zones, as evidenced by similar cover of *Eisenia arborea* to that in the control areas.

Classification of Communities

In an effort to objectively analyze patterns of zonation within control and outfall areas, quadrat units were subjected to cluster analysis. Quadrat units demonstrating the highest overall similarity tend to form statistically grouped clusters which can then be employed to depict patterns.

Clustering of quadrat units was carried out by the weighted pair-grouping method adapted in part from Sokal and Sneath (Ref. 43). A computer program for this computation was obtained from Dr. John Ludwig (New Mexico State University) and modified for local computer use. Analyses were based upon percent cover values for species within stands; separate analyses were performed for samples taken within control areas and within the region of the outfall plume. Results of analyses were presented as dendrogram displays revealing the grouping together of originally separate samples. Additionally, clustering was performed on a combined group consisting of all samples taken from both areas.

Control Areas. The dendrogram display of the results of the cluster analysis of the samples taken within the control areas (Fig. 9) was interpreted as consisting of the following six distinct groups or assemblages: (1) Blue-Green Algae Group; (2) *Corallina chilensis–Gigartina canaliculata* Group; (3) *Pseudolithoderma* Group; (4) *Lithophyllum* Group; (5) *Eisenia* Group; and (6) *Egregia* Group.

- Blue-Green Algae Group: The principal constituents of samples clustered within this group were blue-green algae and unoccupied bare rock. The high-level limpet, *Acmaea strigatella*, was also common in samples grouped within this cluster.
- *Corallina chilensis–Gigartina canaliculata* Group: *Corallina chilensis* and *Gigartina canaliculata* comprised the dominant macrophyte cover of samples clustered within this group. *Sargassum, Colpomenia, Lithophyllum,* and *Pseudolithoderma* occurred in several samples; *Lithophyllum* and *Pseudolithoderma* were particularly prevalent when samples included the sides of rocks. Animal species found in stands within this group consisted of *Acmaea scabra, Acmaea strigatella, Serpulorbis squamigerus,* and *Tetraclita squamosa.*
- *Pseudolithoderma* Group: Other than unoccupied bare rock, the principal constituents of samples clustered within this group were the macrophyte species *Pseudolithoderma, Lithophyllum*, and blue-green algae and the animals *Tetraclita, Chthamalus, Acmaea scabra, Acmaea strigatella,* and *Acmaea limatula.* Sample units within this group frequently included sides of rocks and crevices between rocks, where the prostrate, encrusting growth forms, i.e., *Pseudolithoderma* and *Lithophyllum*, were found.

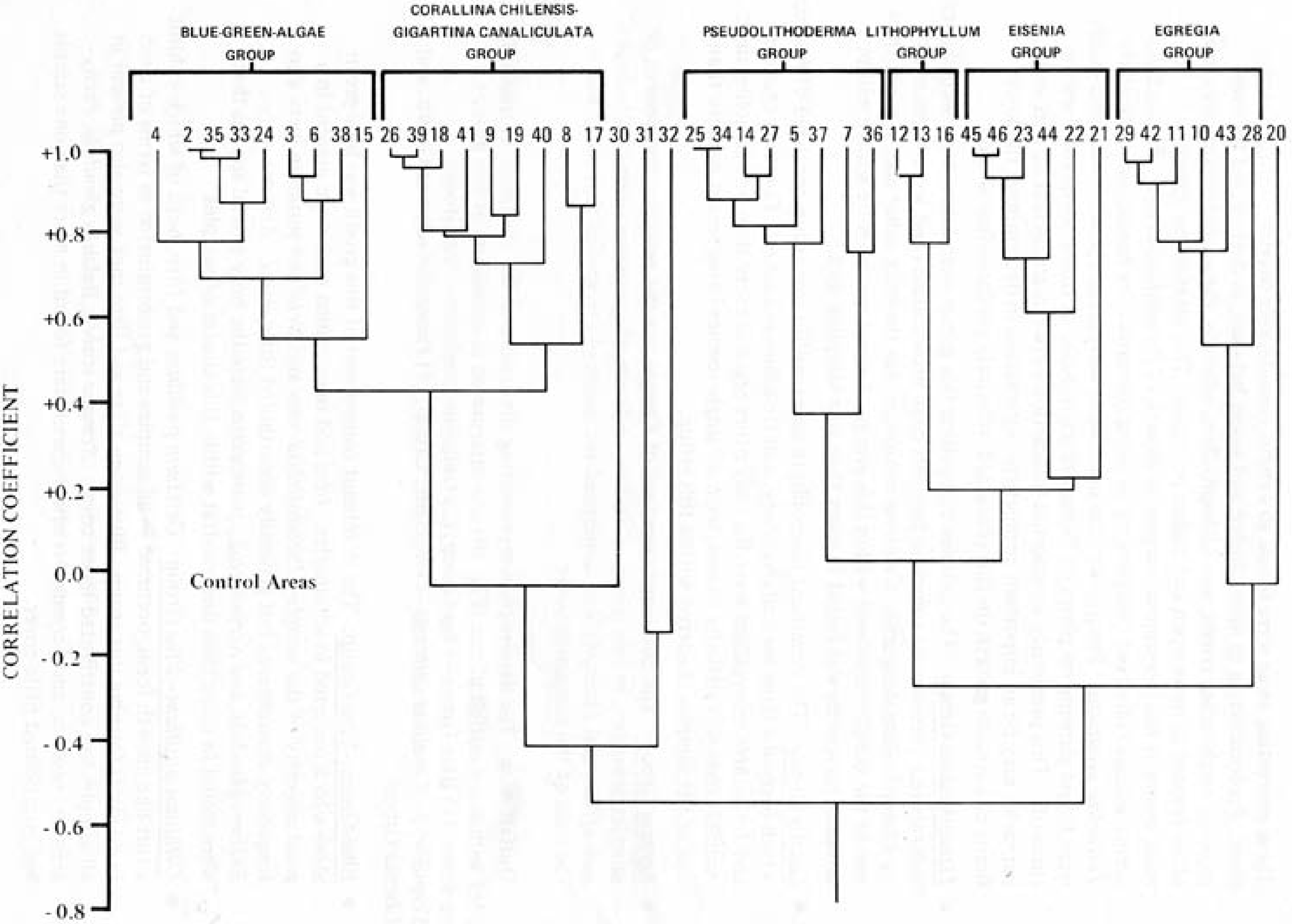

Figure 9. Dendrogram display of the clustering of quadrats sampled from control areas; this analysis is based upon percent cover data for all species within each stand.

These encrusting algae were found to exhibit considerable overlap in their distributions. Predominating in more shaded and lower habitats, as determined by overgrowing neighboring crusts, was *Lithophyllum*, whereas, *Pseudolithoderma* was most often favored in more open and higher positions. This interaction appeared to be most severe at the lowermost margins of growth of *Pseudolithoderma*. *Pseudolithoderma* was also observed overgrowing or being overgrown by barnacles, particularly *Tetraclita squamosa*. Frequently, the uppermost margins of *Pseudolithoderma* crusts were found growing on plates of *Tetraclita* individuals, at times completely sealing them off. This previously unreported interaction between an encrusting alga and barnacles may be an important competitive interaction in determining the lower limits of barnacle growth on this protected, relatively predator-free shore.

- *Lithophyllum* Group: The samples comprising this group were taken from well-shaded habitats (e.g., crevices or substrate beneath large brown algae) and were dominated by *Lithophyllum decipiens*. *Gelidium robustum* was the only other alga in more than one of the samples clustered within this group. Animal species were scanty within samples; no species was found in more than one sampling unit.
- *Eisenia* Group: The dominant macrophyte cover within this group consisted of *Eisenia*, which formed a large vertical overstory, and *Gelidium robustum*. *Corallina chilensis* and *Lithothrix aspergillum* were the only other algae in more than one sampling unit. Animal cover was virtually absent, with no single species being found in more than one of the samples clustered within this group.
- *Egregia* Group: The dominant overstory of *Egregia* was the principal component of samples belonging to this group. *Corallina chilensis*, *Colpomenia sinuosa*, *Rhodoglossum affine*, and *Lithophyllum* comprised the macrophyte species that contributed the bulk of the remaining cover.

Outfall Area. The dendrogram representing the results of the clustering of quadrats sampled within the outfall plume (Fig. 10) was interpreted as consisting of five groups. These were: (1) Blue-Green–*Ulva* Group; (2) *Gelidium pusillum*–*Ulva* Group; (3) *Serpulorbis*–*Corallina chilensis*–*Pterocladia* Group; (4) *Pseudolithoderma* Group; and (5) *Eisenia* Group.

- Blue-Green–*Ulva* Group: The dominant component of this group was blue-green algae which occurred in all samples. *Ulva* and unoccupied rock were present in a great majority of the samples; *Pseudolithoderma* and *Gelidium pusillum* were also frequently encountered but generally contributed little cover. *Acmaea scabra*, *Balanus glandula*, and *Serpulorbis squamigerus* were the only animal species that were found in more than one quadrat within this cluster of samples.
- *Gelidium pusillum*–*Ulva* Group: *Gelidium pusillum* and *Ulva*, both of which exhibit a turf-like growth form, occurred in all samples and predominated in terms of cover in quadrats forming this group. Blue-green algae and bare rock were also present in all samples but contributed lesser cover. *Acmaea scabra*, *Balanus glandula*, *Pachygrapsus crassipes*, and *Serpulorbis squamigerus* were found in more than one sample but contributed little cover.

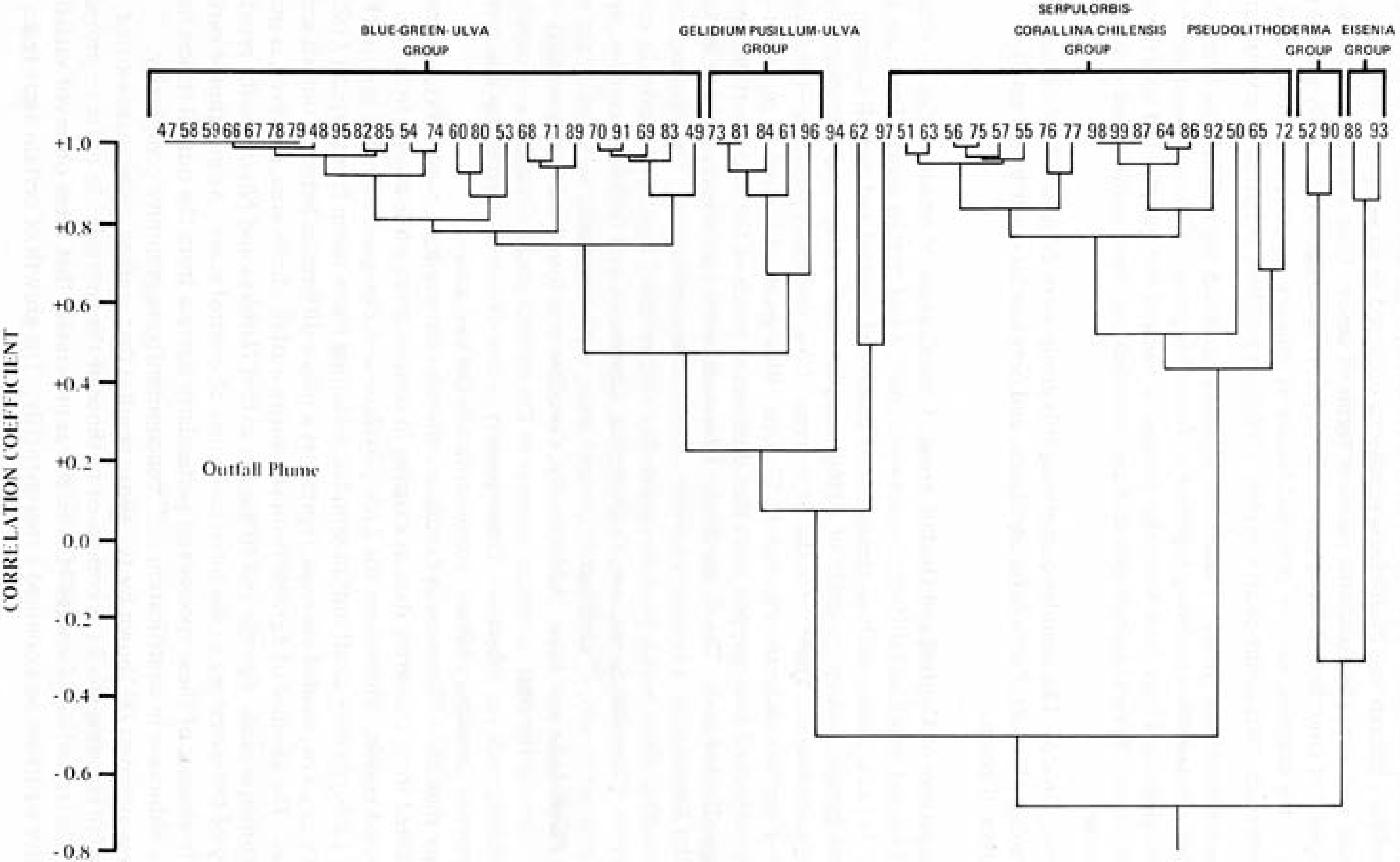

Figure 10. Dendrogram display of the clustering of quadrats sampled from the outfall plume; this analysis is based upon percent cover data for all species within each stand.

- *Serpulorbis–Corallina chilensis–Pterocladia* Group: Of the macrophyte species, *Corallina chilensis* and *Pterocladia capillacea* occurred in all samples within this cluster and were the dominant plants in terms of cover. *Ulva* was also present in all samples but contributed lesser cover. *Serpulorbis squamigerus*, the only animal in any of the samples, was the principal holder of primary substrate, i.e., rock, and was a dominant component of all samples. *Gelidium pusillum* occurred in several samples.
- *Pseudolithoderma* Group: *Pseudolithoderma* comprised the majority of living cover within the samples clustering together to form this group. *Gelidium pusillum*, blue-green algae, and bare rock were also present in each of the samples but contributed lesser cover. Several animal species were recorded but these contributed virtually no cover.
- *Eisenia* Group: The samples comprising this group were dominated by *Eisenia*. *Corallina chilensis, Pterocladia capillacea,* and *Serpulorbis* contributed small degrees of cover.

Comparison of Control and Outfall Areas. Classification of communities by clustering revealed several important differences between control and outfall areas. These are presented (Fig. 11) as a cluster-analysis treatment of combined control and outfall samples.

Three groups, consisting solely of outfall samples, were interpreted as distinct from control area assemblages. These were the Blue-green–*Ulva, Gelidium pusillum–Ulva*, and *Serpulorbis–Corallina chilensis–Pterocladia* Groups. Blue-green–*Ulva* and *G. pusillum–Ulva* assemblages comprised low-cropped turfs that dominated much of the mid-intertidal zone in the sewage-affected area. The *G. pusillum–Ulva*-dominated turf was replaced at its lower margin by the *Serpulorbis–Corallina chilensis–Pterocladia* community. The presence of considerable *Corallina* cover in this zone was much like that revealed in similar locales in control areas. However, *Gigartina, Sargassum, Colpomenia, Laurencia,* and *Gelidium coulteri*, species frequently associated with *C. chilensis* in control areas, were essentially replaced in the outfall area by *Pterocladia* and *Ulva.* Additionally, *Corallina* was found growing primarily on *Serpulorbis* tubes in the outfall region, whereas in the control areas, *Corallina* was mostly observed utilizing rock for substrate. Consequently, a low degree of correlation was revealed (Fig. 11) between *Corallina chilensis* communities in the two areas.

Other than the differences in *Corallina chilensis* communities, two additional groups were interpreted from clustering data as existing in control areas while absent from the sewage-affected region. These were the *Lithophyllum*- and *Egregia*-dominated groups (Fig. 11). The lack of *Lithophyllum* in all outfall samples, including those taken from typical *Lithophyllum* habitats, i.e., low, shaded crevices, represents a major difference between outfall and control areas. The absence of *Egregia* from the entire outfall plume area, however, is probably more consequential. *Egregia* and to a lesser extent *Halidrys* and *Phyllospadix* provided the majority of the overstory in the intertidal zones of control areas. As mentioned earlier, the complete absence of these species and particularly *Egregia* from the outfall region has resulted in a reduction in stratification and, concomitantly, community complexity.

It was apparent (as shown by the above results) that marked differences existed between outfall standing stocks as compared to those of the controls. In order to provide for the full understanding of sewage effects, it was imperative that these observed variations in community structure be examined experimentally. The growth of certain algae (e.g.,

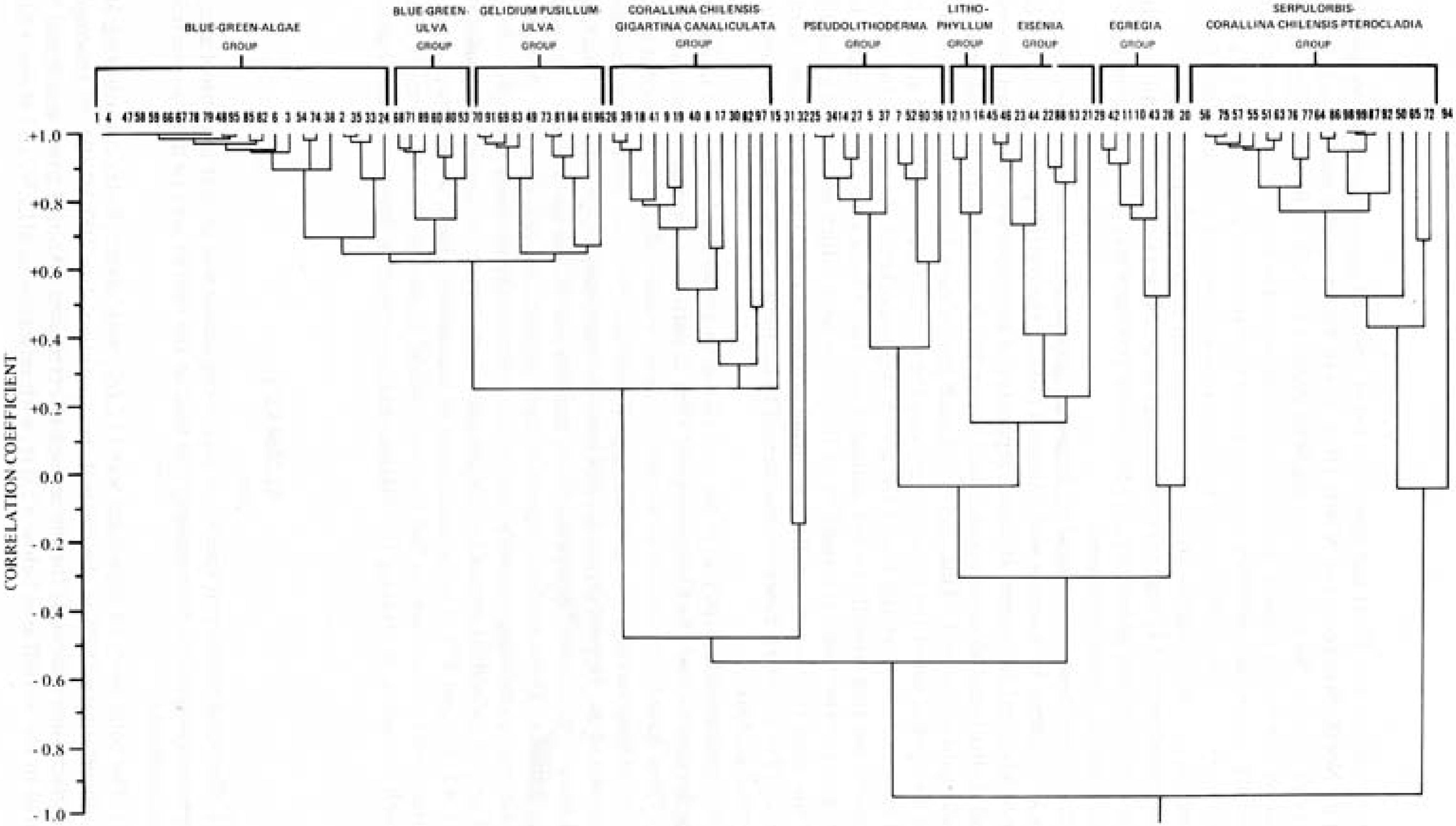

Figure 11. Dendrogram display of the differential clustering of all quadrats sampled from both control and outfall plume areas; this analysis is based upon percent cover data for all species within each stand.

Corallina, Gelidium, and *Ulva*) and invertebrates in polluted inshore waters may be related, as shown by North, Stephens, and North, (Ref. 30) to direct uptake and utilization of dissolved organic wastes. No attempt was made to include the role of heterotrophy in this study because this would require specialized techniques at the biochemical/ecological level. We did investigate, in part, whether variations in heterotropic capacities might be a tenable hypothesis to explain the differences between outfall and control communities. This was done by means of a manipulative study of succession on cleared substrates. The two hypotheses tested were: (1) that toxic substances alter species interactions and community development patterns or, alternately, (2) that waste products may stimulate growth to alter dominance roles of certain organisms.

These hypotheses were tested by following seral stages of succession (on uniformly similar rocks sterilized by burning with ethanol) both in the outfall plume and in the control areas. Once advanced seres were attained, replicates of the rocks were switched between outfall and controls and vice-versa; other rocks were left *in situ* as controls, and seral developments were again monitored. This study, although preliminary in nature, has resulted in a predictive interpretation of the effects of moving the outfall to an unpolluted area in the intertidal zone and also partially tested the above two hypotheses. In general the succession study supports the first hypothesis and indicates that the critical effect of the outfall has been to increase environmental instability in the plume area, which has caused a rapid demise of all but the most tolerant or rapidly colonizing organisms (e.g., blue-green algae, *Ulva, Gelidium,* and *Pterocladia*); however, the second hypothesis is in no way refuted and may also be important here.

The dominant macrophytes in the outfall region are all productive and rapid-growing forms (see Section 5), and the blue-greens and *Ulva* in particular have short and simple life histories. These have been referred to as opportunistic species (Ref. 44) or r-selected forms (Ref. 45) in contrast to the more specialized or K-selected (Ref. 45) forms characteristic of mature communities. Opportunistic species have the capability of quickly repopulating surfaces that have been denuded following either random winter storms or fluctuating levels of stressful pollutants. These kinds of organisms have smaller, turf-like growth habits and thereby decrease spatial heterogeneity, and reduce community diversity. Simpler life histories and greater individual productivities are also characteristic of species classically attributed (Refs. 45, 46, and 47) to early seral stages of succession. Thus, we interpret a primary effect of the discharged sewage on San Clemente Island to parallel that of naturally occurring stresses, such as storms, in creating fluctuating environments that favor early successional seres.

SUMMARY

(1) The total number of species of macro-organisms was greater in control areas (10 macro-invertebrates and 30 macrophytes) than in the outfall area (9 macro-invertebrates and 13 macrophytes).

(2) The total cover of organisms was 112.6%, with macrophytes contributing 103.4% and macro-invertebrates 9.2% in the control areas, compared to 109.3% (91.7% macrophytes and 17.6% macro-invertebrates) for the sewage-affected area. Animal cover was found to be concentrated in the outfall area below +2.0 ft, with reference to MLLW, and above +2.0 ft

in the control areas. Macrophyte cover in the controls was much greater below +2.0 ft, whereas it was evenly distributed over the entire intertidal zone in the outfall plume.

(3) Four species of macro-invertebrates and 19 species of macrophytes were absent from the outfall area but occurred in controls; two species of animals and one algal species were present in the outfall but were not encountered in control areas.

(4) The brown algal species *Egregia laevigata* subsp. *borealis, Halidrys dioica,* and *Sargassum agardhianum*, the marine flowering plant *Phyllospadix torreyi*, and the crustose-coralline alga *Lithophyllum decipiens* were conspicuously absent from the outfall; these species contributed about 35% of intertidal cover in control areas. Cover of *Serpulorbis squamigerus* (the tube-building mollusk), blue-green algae, *Ulva californica, Gelidium pusillum*, and *Pterocladia capillacea* was significantly enhanced in the outfall area, while that of *Tetraclita squamosa* and *Gigartina canaliculata*, and *Gelidium robustum* decreased. The sea anemones *Anthopleura elegantissima* and *A. xanthogrammica* and the brown alga *Petalonia fascia* were present in outfall samples but absent from control areas.

(5) Simple species counts and four different quantitative indices were employed in comparing the species diversity of control and outfall areas. In all comparisons, the control areas were considerably more diverse than the sewage-affected region.

(6) A great reduction in community stratification (spatial heterogeneity) and hence community complexity occurred in the outfall area. This reduction in stratification was primarily due to the absence of *Egregia, Halidrys, Sargassum*, and *Phyllospadix* from the sewage-affected area. In similar tidal intervals in the outfall area, a low turf consisting of blue-greens, *Ulva, Gelidium pusillum*, and small *Pterocladia* plants was apparent.

(7) A statistically based determination of assemblages of organisms (i.e., cluster analysis) revealed six control and five outfall groups. Three of the outfall groups (Blue-green–*Ulva, Gelidium pusillum–Ulva*, and *Serpulorbis–Corallina chilensis–Pterocladia)* and three of the control area groups (*Corallina chilensis–Gigartina canaliculata, Lithophyllum*, and *Egregia*) were distinct and characteristic of outfall or control areas, respectively.

(8) The critical ecological effect of the outfall, as revealed by manipulative succession studies, was to increase instability in the sewage-affected region, thereby providing potential habitats for only the most sewage-tolerant organisms. The organisms found to be in greatest abundance in the outfall plume are characterized by smaller growth forms and simpler and shorter life histories and were components of early stages of succession; hence the outfall communities are interpreted as consisting primarily of generalist (r-strategist or opportunistic) populations as compared to the control areas where specialists (K-strategists) prevailed.

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Studies on the effects of a low-volume discharge of raw sewage on rocky marine intertidal communities near Wilson Cove, San Clemente Island, California included taxonomic surveys and quantitative assessments of standing stock, community structure and primary production for the sewage-affected area and nearby unpolluted (control) areas. Additionally, a comparative populational study of the limpet *Acmaea limatula* revealed that only larger individuals were present in the outfall area. Near the outfall pipe, intertidal

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communities were characterized by lower species diversity, reduced standing stocks of large, canopy-forming intertidal macrophytes (which largely had been replaced by a low-growing algal turf) and an abundance of suspension-feeding animals. The most productive macrophytes were among those most abundant in the outfall area. Additional manipulative studies revealed that the outfall area consisted of disclimax communities.

BIOLOGICAL FEATURES OF INTERTIDAL COMMUNITIES NEAR THE U. S. NAVY SEWAGE OUTFALL, WILSON COVE, SAN CLEMENTE ISLAND, CALIFORNIA

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ADMINISTRATIVE STATEMENT

This report describes ecological studies of intertidal communities near the San Clemente Island sewage outfall conducted by scientists from California State University, Fullerton, and the University of California, Irvine, in cooperation with the Naval Undersea Center. These studies provide basic information on the environmental impact of typical domestic sewage from a small community.

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