CHAPTER TWO

SEASONAL ANALYSES OF STANDING STOCK AND COMMUNITY STRUCTURE OF MACRO-ORGANISMS

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INTRODUCTION

The nearshore waters of the Southern California Bight serve as a repository for more than 1.4 x 10^9 m^3 of partially-treated municipal sewage effluent per day. Historically, there has been much local concern over the effects of discharged waste waters on southern California marine life and, over the past few years, this has led to several government-supported research programs designed to provide much needed information.

Most of the operational outfalls in southern California discharge into subtidal environments where effects are not readily observable. Consequently, the scientific studies and monitoring programs have mostly been concerned with determining the effects of sewage on subtidal benthic communities (e.g., Allan Hancock Foundation, 1959, 1965; Southern California Coastal Water Research Project, 1973); few investigations have been performed on southern California rocky intertidal communities near outfall sites despite the reports (e.g., Dawson, 1959, 1965; Widdowson, 1971; Murray and Littler, 1974a, 1974b; Littler and Murray, 1975) of changes in the abundance and distributional patterns of species populations in areas of sewage perturbation.

The current study follows previous research (Murray and Littler, 1974a, 1974b; Littler and Murray, 1975) and is designed to determine the seasonal and annual dynamics of biological communities of macro-organisms under the influence of sewage. This intensive rather than extensive approach is prerequisite to the successful interpretation of productivity data and is ultimately necessary for success in ecosystem modeling.

STUDY AREA

San Clemente Island (see Fig. 1-1, Chapter One) is located approximately 70 kilometers from Los Angeles Harbor and 113 kilometers from San Diego, California, and is the most southern and the fourth largest of the southern California islands.

San Clemente Island is principally exposed to the warm waters of the southern California countercurrent, although water temperatures are generally slightly lower on the seaward side of the island due presumably to localized upwelling and the influence of the offshore California Current. The rocky intertidal biota of leeward San Clemente has its greatest affinities with the warmer-water communities of southern California. The nearest land mass is Santa Catalina Island which lies approximately 35 kilometers to the northeast. San Clemente Island is surrounded by deep waters, being bounded by the Santa Catalina basin to the north and the San Nicolas basin to the west, while the San Clemente basin lies to the southeast. The island is owned by the U.S. Navy, which has maintained an operational base at Wilson Cove on the northeast (leeward) portion of the island (Fig. 1-2, Chapter 1, this report) since 1937. Currently, the population at the facility averages around 300 civilian and naval personnel. The island is not open to the public and all access is strictly regulated by the Navy.

The study area is located approximately 450 meters to the south of the southern promontory demarcating Wilson Cove (32°0.3'N, 118°33.0'W). The study site is shielded by the island from prevailing winds and waves, and is typically exposed only to the relatively mild wind waves generated in the Outer Santa Barbara Passage; however, considerable wave shock is not unusual during the occurrence of periodic winter and spring storms.

Murray,S.N. & Littler,M.M. (1977). Seasonal analyses of standing stock and community structure of macro-organisms. *In:* M.M.Littler & S.N.Murray (Eds.), Influence of domestic wastes on the structure and energetics of intertidal communities near Wilson Cove, San Clemente Island (pp. 7-32). University of California, Davis: California Water Resources Center, Contribution No. 164.

The rocky intertidal lies at the base of an eroded bluff approximately six meters in height that shades the shoreline from the afternoon sun; the bluff forms the terminus of a long, steeply-pitched slope located between the U.S. Navy housing units and the sea. The rocky intertidal in this region lacks tidepools and is characteristic of the northern leeward island. The substrate consists of large metamorphic boulders with numerous free rocks (25-50 cm in diameter) which provide a mosaic habitat of crevices and vertical rock surface.

The Wilson Cove base is serviced by a sewage outfall that discharges untreated (raw) sewage into the rocky intertidal at a point 5.3 feet above mean lower low water (MLLW) at a rate of approximately 95,000 liters per day. Sewage consists primarily of untreated human wastes, food scraps, detergents, bleach, and about 182 liters per year of 90% pine-oil disinfectant. The sewage varies in composition over time as does the quantity of the discharge.

The present sewage outfall and treatment system has been in operation for over 20 years. Currently, the Navy is in the process of converting their sewage system to provide for the secondary treatment of effluent.

METHODS AND MATERIALS

Biological assessments were conducted in the area immediately beneath the sewage outfall and in nearby unpolluted areas of comparable topography and wave exposure. All control area sampling was performed at a distance greater than 30 meters from the outfall pipe to ensure analysis of unpolluted habitat as determined by the previously discussed (see Chapter 1, this report) environmental measurements of receiving waters. Biological assessments were performed for both outfall and control regions during December 1974, April 1975, October 1975, December 1975, and March 1976. A total of 572 plots was analyzed during the course of the study, with 310 obtained from the sewage-affected area and 262 from the control region. The number of samples analyzed during each visitation period averaged 114 (62 outfall and 52 control area plots).

The photographimetric method, developed for investigations of subtidal reef communities (Littler, 1971) and subsequently used by Murray and Littler (1974 b) and Littler and Murray (1975) during studies of rocky intertidal communities was employed with the modifications and details noted below. Photographs of labeled 30 cm x 50 cm quadrats (0.15 m^2) were taken at right angles to the substrate with 35 mm cameras equipped with electronic strobes. Sample plots were placed at 0.5 meter intervals along transect lines. A minimum of two photographs were taken for each sample quadrat, one using color slide film (Kodachrome 64) and the other Ektachrome infra-red slide film. The infra-red photographs were employed to increase accuracy in determinations of the abundance of various species of macrophytes, particularly the blue-green algae. In cases where multilayered communities occurred, more than one photograph was taken to measure stratification; these samples often yielded greater than 100% cover.

Cover was determined from the photographs by a point-intercept method; detailed field notes, obtained with the aid of a tape recorder enclosed in a water-proof acrylic housing, were heavily employed in the laboratory to interpret the contents of the photographs. Species observed in quadrats but not subtended by point-intercepts were assigned a minimum value of 0.1% cover.

Three transect lines were assessed for the outfall area located at preselected angles (4°, 30°, 58° magnetic) from the outfall terminus. These lines were determined from analyses of previous data (Murray and Littler, 1974 b; Littler and Murray, 1975) to include the shoreline most affected by the discharged effluent.

Three additional transect lines were established in the control area. These were located perpendicular to the shoreline (∿30° magnetic) at a horizontal distance of 42 meters (south line), 54 meters (middle line), and 64 meters (north line) northwest of the outfall pipe. Two of these lines were identical to the north control lines worked during our earlier studies, while the third (north) line was established at a predetermined distance from the existent lines to increase sample size in the unpolluted area.

During each assessment period, transect lines were sampled down to the lowest emergent plot. For the outfall region, samples were not taken above +5.0 feet, which is the tidal height of the outfall pipe. Control area plots were sampled up to a tidal height of +8.0 feet; however, the data included in reduced form herein have been restricted to +5.0 feet and below to enable comparisons of macro-organism abundance.

RESULTS

Distribution and Abundance Patterns of Species Populations

OVERALL BIOTIC COVER

Overall biotic cover averaged 119.3% for the controls, with macrophytes accounting for 110.8% and macro-invertebrates 8.5%. Mean macro-invertebrate cover was significantly greater (P<0.01) for the outfall region; however, significant differences between the two areas were not detected for macrophytes and combined macro-invertebrate and macrophyte cover (Table 2-1). The mean biotic cover averaged 130.0% at the outfall over the whole assessment period and consisted of 112.6% macrophytes and 17.4% macro-invertebrates (Table 2-1). Macrophytes were evenly distributed over the vertical range of sampled shoreline in the outfall area, while their cover was concentrated below approximately +2.0 feet for the controls (Table 2-2). For macro-invertebrates, the outfall area showed greatest cover below +1.0 feet, whereas in the control area cover was maximal above +2.0 feet. With respect to the outfall area, macrophyte cover was significantly less (P<0.01) and macro-invertebrate cover significantly greater (P<0.01) than in the control below +2.0 feet, while the reverse was true above +2.0 feet (Table 2-2).

Combined macro-invertebrate and macrophyte cover for the control and outfall areas showed little seasonal variability (Table 2-3) over the sampling period. For the outfall area, only the March 1976 assessment showed noticeably greater total cover (147.3%), while for the controls slightly greater cover was attained before April 1975.

TABLE 2-1

PATTERNS OF OVERALL BIOTIC COVER (IN PERCENT)

Group and Location	Dec. 1974	Apr. 1975	Oct. 1975	Dec. 1975	Mar. 1976	Mean	± S.D.
Macro-invertebrates							
Control	4.9	12.2	8.0	9.5	8.1	8.5	2.6**
Outfall	17.6	17.8	17.3	16.2	18.0	17.4	0.7
Macrophytes							
Control	116.8	118.8	103.9	108.4	105.9	110.8	6.7 n.s.
Outfall	106.9	108.3	108.4	109.9	129.3	112.6	9.4
Combined							
Control	121.7	131.0	111.9	117.9	114.0	119.3	7.5 n.s.
Outfall	124.5	126.1	125.7	126.1	147.3	130.0	9.7

Asterisks indicate significance levels at the P<0.01 level for the t-tests of differences between means.

n.s. = not significant, P>0.05

TABLE 2-2

PATTERNS OF COVER (IN PERCENT) FOR MACRO-INVERTEBRATES AND MACROPHYTES AS A FUNCTION OF TIDAL LEVEL

MACRO-INVERTEBRATES			MACROPHYTES		
UPPER SHORE (+2.0 to +5.0 ft)	Outfall	Control	UPPER SHORE (+2.0 to +5.0 ft)	Outfall	Control
December 1974	1.4	8.9	December 1974	98.7	70.8
April 1975	3.6	21.9	April 1975	101.5	66.6
October 1975	1.7	12.9	October 1975	105.9	55.9
December 1975	3.9	15.5	December 1975	104.9	74.3
March 1976	2.8	12.6	March 1976	118.7	62.3
Mean	2.7	14.4**	Mean	105.9**	66.0
Standard Deviation	1.1	4.8	Standard Deviation	7.7	7.2
LOWER SHORE (-1.0 to +2.0 ft)			LOWER SHORE (-1.0 to +2.0 ft)		
December 1974	33.6	1.0	December 1974	115.2	162.6
April 1975	31.9	2.3	April 1975	115.1	169.2
October 1975	32.9	3.1	October 1975	110.8	151.7
December 1975	28.4	3.5	December 1975	115.1	141.0
March 1976	33.3	3.4	March 1976	139.9	149.4
Mean	32.0	2.7**	Mean	119.2**	154.8
Standard Deviation	2.1	1.1	Standard Deviation	11.7	11.2

Asterisks indicate significance levels at the $P<0.01$ level for t-tests of differences between means.

Mean macro-invertebrate cover (17.4%) was highly constant for the outfall area over the study period (Table 2-1). With the exception of the first two visitations, a similar pattern of constancy was noted for the control areas. For December 1974, macro-invertebrate cover was approximately 40% less than the mean; during April 1975, cover was approximately 30% greater. These patterns were not repeated during the December 1975 and March 1976 assessments. An analysis of macro-invertebrate species cover by season indicated that the low value for December 1974 was mostly a result of the reduced cover of *Chthamalus fissus/dalli*; during April 1975 the peak in cover was attributable to increased cover provided by *C. fissus/dalli* and *Tetraclita squamosa rubescens*.

Macrophyte cover for the controls was maximal during April 1975 (118.8%) and was relatively constant (±7%) during the remainder of the study (Table 2-1). Little variation in macrophyte cover was also evident for the outfall region, with the exception of the March 1976 assessment period, where a 19% increase over the next highest value was recorded. The increased macrophyte cover obtained from the outfall for March 1976 was largely due to the increased abundance of *Ulva californica* and epiphytic growths of ectocarpoid filaments and colonial diatoms, and was mostly responsible for the increased total biotic cover observed during this sampling period.

TABLE 2-3

PATTERNS OF COVER (IN PERCENT) FOR DOMINANT MACRO-INVERTEBRATE AND MACROPHYTE POPULATIONS FOR THE OUTFALL AREA

Taxa	Dec. 1974	Apr. 1975	Oct. 1975	Dec. 1975	Mar. 1976	Mean	± S.D.
MACRO-INVERTEBRATES							
Serpulorbis squamigerus	16.4	14.6	15.3	12.6	15.6	14.9	1.4
Anthopleura elegantissima	0.4	1.1	1.0	1.3	0.9	0.9	0.3
Acmaea (Collisella) scabra	0.3	1.0	0.4	1.2	0.5	0.7	0.4
Tetraclita squamosa rubescens	0.2	0.6	0.2	0.1	0.8	0.4	0.3
Chthamalus fissus/dalli	0.1	0.3	0.3	0.3	0.2	0.2	0.1
MACROPHYTES							
Blue-green algae	44.8	42.6	37.5	30.7	41.6	39.4	5.6
Gelidium pusillum	17.5	20.1	25.8	21.1	16.7	20.2	3.6
Pseudolithoderma nigra	18.3	17.0	14.6	14.7	11.8	15.3	2.5
Ulva californica	7.0	13.0	10.8	17.8	21.6	14.0	5.8
Ectocarpaceae/Colonial Diatoms	0.1	1.8	8.8	13.2	13.6	7.5	6.3
Corallina officinalis var. *chilensis*	10.0	7.5	5.8	5.5	7.9	7.3	1.8
Pterocladia capillacea	5.1	3.1	2.3	2.0	4.7	3.4	1.4
Egregia menziesii	2.0	2.2	2.0	1.5	2.6	2.1	0.4
Gigartina canaliculata	1.6	1.0	0.0	1.7	2.2	1.3	0.8

OUTFALL COVER

Six macrophytes accounted for 92% of the outfall primary producer cover based on mean values obtained for the entire sampling period (Table 2-3). Encrusting and short turf-forming seaweeds dominated the species composition of the sewage-affected area; blue-green algae (39.4%) contributed the greatest macrophyte cover, followed by *Gelidium pusillum* (20.2%), *Pseudolithoderma nigra* (15.3%), and *Ulva californica* (14.0%). Filamentous Ectocarpaceae/colonial diatoms (7.5%) and *Corallina officinalis* var. *chilensis* (7.3%) also supplied significant macrophyte cover. Tube-forming mollusks consisting largely of *Serpulorbis squamigerus* (14.9%) provided more than 80% of the macro-invertebrate cover.

Seasonal variations in the abundance patterns of the dominant macrophytes and macro-invertebrates were generally not apparent, indicating that the biotic composition of the sewage-affected area remained relatively constant. Of the macrophytes, *Ulva californica*, an "opportunistic" species that frequently becomes abundant on perturbated shorelines, reached maximum cover (21.6%) during March 1976 and exhibited a low (7.0%) during December 1974. Additionally, a brown filamentous assemblage of Ectocarpaceae and colonial diatoms became apparent after the December 1974 visitation and continued to increase in abundance through March 1976 when it reached its greatest cover (13.6%). Neither the macrophytes nor the macro-invertebrates showed repeatable patterns of abundance over the two years of sampling, with the possible exception of *Tetraclita squamosa rubescens* which contributed greatest cover during each of the spring assessment periods.

The predominant macro-invertebrate and macrophyte cover has been averaged over the period of study (Fig. 2-1) as a function of tidal height to depict prevailing patterns of zonation. Blue-green algae were by far the most abundant of the macrophytes encountered above +3.0 feet and were the predominant algae in the outfall area above +1.0 feet (Fig. 2-1). Blue-greens reached greatest cover in the highest tidal interval samples (+4.0 to +5.0 feet) and formed thick slimy growths even on the rock surfaces exposed to the direct influence of sewage. *Ulva californica* and *Gelidium pusillum* formed a conspicuous turf throughout the intertidal and, along with the encrusting brown alga *Pseudolithoderma nigra*, were the dominant seaweeds (other than blue-greens) above +1.0 feet. *Gelidium pusillum* was most abundant below MLLW and throughout its intertidal distribution in the sewage-affected area was heavily epiphytized, along with *U. californica*, by slimy growths of blue-green algae and Ectocarpaceae/colonial diatoms. Ectocarpaceae/colonial diatoms, most abundant and prevalent between MLLW and +1.0 feet (Table 2-3), showed perhaps the strongest variation in abundance of all the common outfall macrophytes. Occasional clumped thalli of *Cladophoropsis fasciculatus* and *Colpomenia sinuosa* were encountered below +2.0 feet throughout the course of the study. *Corallina officinalis* var. *chilensis*, *Pterocladia capillacea*, and *Gigartina canaliculata* were the most highly conspicuous seaweeds below +1.0 feet.

Corallina officinalis var. *chilensis* characteristically formed a low turf and was frequently encountered growing on masses of mollusk tubes which occupied a significant portion of the primary substrate on the lower shoreline. *Pterocladia capillacea* and *G. canaliculata* were commonly sampled on *C. officinalis* var. *chilensis*, although both species grew well on rock and mollusk tube substrates. *Chaetomorpha linum, Gelidium pusillum, Gelidium*

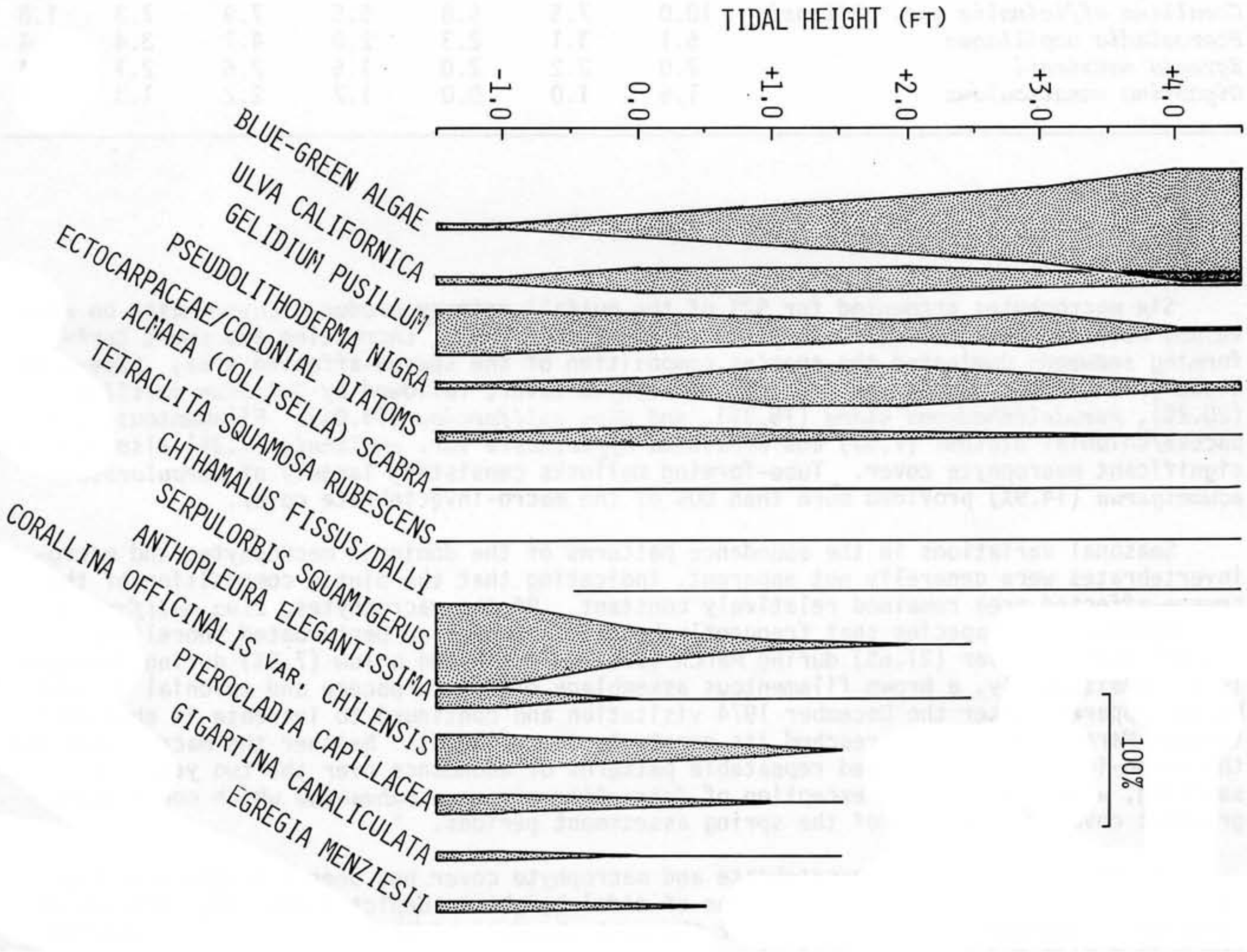

FIGURE 2-1 Cover patterns of the dominant organisms in the sewage-affected area as a function of tidal height.

coulteri, and *Laurencia pacifica* were also sampled on occasion from the coralline turf which commonly contained extensive growths of blue-greens and Ectocarpaceae/colonial diatoms (particularly at the upper limits of its distribution). *Egregia menziesii* was found occasionally below +1.0 feet, particularly along the periphery of the sewage area. *Eisenia arborea* was also sampled in this region of the shoreline, although in less abundance than *E. menziesii*. Scattered growths of *Hydrolithon decipiens* and *Lithophyllum proboscideum* were evident in the outfall area. *Acmaea (Collisella) scabra, Chthamalus fissus/dalli*, and *Tetraclita squamosa rubescens* were the most abundant animals above +3.0 feet (Fig. 2-1). *Acmaea (Collisella) scabra* supplied greatest cover above +4.0 feet as did *C. fissus/dalli*, while *T. squamosa rubescens* was most abundant between +3.0 and +4.0 feet. The limpets and barnacles sampled above +3.0 feet were commonly encountered on the vertical surfaces of rocks and were frequently heavily overgrown with blue-green algae. The owl limpet *Lottia gigantea* was encountered in several samples in this portion of the sewage-affected area but contributed little cover. The anemone *Anthopleura elegantissima* and the vermetid mollusk *Serpulorbis squamigerus* were the most abundant macro-invertebrates below +2.0 feet. *Anthopleura elegantissima* occurred most commonly in crevices, removed from the very center of the sewage discharge, while *S. squamigerus*, below MLLW, formed large dense beds and attained its greatest abundance. These beds contained reef-like masses of living and dead mollusk tubes and occupied the majority of primary substrate on the lower shoreline.

OUTFALL FREQUENCY

The patterns of macrophyte frequency (Table 2-4) typically paralleled the cover data (Table 2-3). Six macrophytes attained mean frequencies greater than 25%, based upon mean values for the period of study; *Ulva californica* (83.7%) and blue-green algae (80.0%) had the highest frequencies. The next most frequently sampled macrophytes included *Gelidium pusillum, Pseudolithoderma nigra,* Ectocarpaceae/colonial diatoms, and *Corallina officinalis* var. *chilensis*.

Macrophytes contributing the greatest mean frequencies dominated the qualitative appearance of the sewage-affected area where growths of blue-green algae and *Ulva californica* were evident over the entire intertidal zone. *Ulva californica*, which recorded the highest mean frequency, ranked slightly lower when cover was utilized as a measure of abundance, while blue-green algae, *Gelidium pusillum,* and *Pseudolithoderma nigra* did not. Blue-greens, *U. californica, G. pusillum*, and Ectocarpaceae/colonial diatoms are smaller algae that

TABLE 2-4

PATTERNS OF FREQUENCY (IN PERCENT) FOR DOMINANT MACRO-INVERTEBRATE AND MACROPHYTE POPULATIONS FOR THE OUTFALL AREA

Taxa	Dec. 1974	Apr. 1975	Oct. 1975	Dec. 1975	Mar. 1976	Mean	± S.D.
MACRO-INVERTEBRATES							
Acmaea (Collisella) scabra	46.9	46.1	41.2	47.7	50.5	46.5	3.4
Tetraclita squamosa rubescens	34.0	46.3	25.2	35.5	39.4	36.1	7.7
Serpulorbis squamigerus	36.1	27.1	29.0	34.6	30.8	31.5	3.8
Chthamalus fissus/dalli	26.4	32.0	35.5	31.7	26.9	30.5	3.8
Anthopleura elegantissima	19.9	21.0	20.6	33.7	19.8	23.0	6.0
MACROPHYTES							
Ulva californica	63.9	81.1	80.9	93.8	98.7	83.7	13.5
Blue-green algae	87.3	85.6	73.5	69.2	84.2	80.0	8.1
Gelidium pusillum	64.8	70.5	63.7	72.0	67.0	67.6	3.6
Pseudolithoderma nigra	72.4	70.2	57.6	68.9	57.8	65.4	7.1
Ectocarpaceae/Colonial Diatoms	2.7	14.7	31.7	66.7	79.7	39.1	33.1
Corallina officinalis var. *chilensis*	30.3	25.7	25.2	25.3	24.6	26.2	2.3
Pterocladia capillacea	18.8	10.6	11.0	17.8	18.1	15.3	4.1

possess rapid growth rates and are widespread over the vertical range of habitat sampled; accordingly, these macrophytes attained disproportionately high mean frequency values. The encrusting macrophyte taxa, with the exception of *Pseudolithoderma nigra*, received low mean frequency values. Commonly their habitat had been overgrown with slimy growths of turf-forming blue-green algae, *U. californica*, and *G. pusillum*. Macro-invertebrate frequency patterns (Table 2-4) were comparable to those derived from the cover data (Table 2-3) with the consideration that the smaller animals typically occurred more commonly in samples while contributing relatively little cover. The most commonly occurring animals were *Acmaea (Collisella) scabra*, *Tetraclita squamosa rubescens*, *Serpulorbis squamigerus*, and *Chthamalus fissus/dalli*. *Acmaea (Collisella) scabra*, *T. squamosa rubescens*, and *C. fissus/dalli* were most commonly sampled on the upper shore along the edges of irregular rock surfaces, while *S. squamigerus* and *Anthopleura elegantissima* were common components of the lower intertidal zone.

CONTROL AREA COVER

Seven macrophytes accounted for approximately 80% of the macrophyte cover based on mean values obtained for the period of study (Table 2-5); these were blue-green algae (20.2%), *Corallina officinalis* var. *chilensis* (16.3%), *Halidrys dioica* (11.8%), *Gigartina canaliculata* (11.7%), *Pterocladia capillacea* (9.8%), *Pseudolithoderma nigra* (9.7%), and *Egregia menziesii* (9.4%).

Consistent patterns of seasonal variation in the cover of the dominant macrophytes were few, although several taxa were interpreted to demonstrate seasonality (Table 2-5). The encrusting and blue-green algae showed conflicting patterns of seasonal abundance. Blue-green

TABLE 2-5

PATTERNS OF COVER (IN PERCENT) FOR DOMINANT MACRO-INVERTEBRATE AND MACROPHYTE POPULATIONS FOR THE CONTROL AREA

Taxa	Dec. 1974	Apr. 1975	Oct. 1975	Dec. 1975	Mar. 1976	Mean	± S.D.
MACRO-INVERTEBRATES							
Chthamalus fissus/dalli	2.6	6.6	4.2	4.9	3.5	4.4	1.5
Tetraclita squamosa rubescens	1.3	2.8	1.5	1.8	1.4	1.8	0.6
Acmaea (Collisella) scabra	0.8	1.8	0.7	1.5	1.0	1.2	0.5
Dendropoma lituella/rastrum	---	---	0.3	0.3	0.7	0.4	0.2
Serpulorbis squamigerus	0.1	<0.1	1.0	0.1	0.5	0.4	0.4
Spirobranchus spinosus	---	---	>0.1	0.4	0.6	0.4	0.3
MACROPHYTES							
Blue-green algae	23.7	22.2	11.8	24.5	18.6	20.2	5.2
Corallina officinalis var. *chilensis*	24.4	25.0	5.6	10.9	15.8	16.3	8.4
Halidrys dioica	10.6	9.2	19.2	8.7	11.3	11.8	4.3
Gigartina canaliculata	5.4	13.4	11.0	15.8	13.0	11.7	3.9
Pterocladia capillacea	13.9	12.4	7.7	5.8	9.1	9.8	3.3
Pseudolithoderma nigra	9.6	10.6	10.5	9.3	8.5	9.7	0.9
Egregia menziesii	3.6	3.7	16.3	9.4	13.9	9.4	5.8
Lithophyllum proboscideum	5.9	3.0	3.0	4.1	2.8	3.8	1.3
Eisenia arborea	7.2	2.2	5.5	1.6	1.6	3.6	2.6
Corallina vancouveriensis	2.3	3.8	1.8	7.2	2.1	3.4	2.2
Sargassum agardhianum	0.8	4.6	0.7	1.0	1.4	1.7	1.6
Hydrolithon decipiens	1.4	0.9	3.2	1.7	0.5	1.5	1.0
Gelidium pusillum	0.8	0.1	1.9	1.5	2.4	1.3	0.9
Laurencia pacifica	0.6	1.8	1.6	0.9	0.1	1.0	0.7
Gelidium purpurascens	0.4	1.0	0.5	2.2	0.7	1.0	0.7

algae, which formed a highly conspicuous zone on the upper shore, showed greatest cover during the winter and spring sampling periods for both years of the study and revealed a distinct decline in the fall. The epilithic encrusting algae (i.e., *Pseudolithoderma nigra*, *Lithophyllum proboscideum*, and *Hydrolithon decipiens*) maintained relatively constant mean cover profiles over the year, while seasonal patterns of abundance were apparent for certain of the frondose algae, the articulated corallines, and the canopy-forming species. Greater cover values were recorded for *Corallina officinalis* var. *chilensis*, *Pterocladia capillacea*, and *Eisenia arborea* for the December 1974 and April 1975 visitations, indicating an apparent decline in the abundance of these macrophytes during the succeeding year. On the other hand, *Gigartina canaliculata*, after the December 1974 visitation, and *Egregia menziesii*, after the April 1975 visitation, increased in abundance. Certain macrophytes (e.g., *Laurencia pacifica*, *Colpomenia sinuosa*, and *Laurencia snyderae*) contributed relatively little cover throughout the year but were more abundant during periods of warmer weather. These macrophytes could be distinguished as summer-fall annuals, even though *L. pacifica* was observed to perennate in the spring from basal portions remnant within the mid-intertidal coralline turf.

Although not completely substantiated by cover data, the most obvious seasonal variation in abundance of macrophytes occurred for the frondose epiphytes (inhabiting the mid-intertidal coralline turf) and the lower intertidal brown algae. Thalli of *Sargassum agardhianum*, *Colpomenia sinuosa*, *Laurencia pacifica*, *L. snyderae*, and *Gigartina canaliculata* (which comprised the most conspicuous of the coralline turf epiphytes) dominated the qualitative appearance of the mid-intertidal zone, particularly during the spring and fall seasons. These frondose species provided a green to reddish-brown color on the shoreline. The predominant constituent of the mid-intertidal coralline turf was *Corallina officinalis* var. *chilensis* which showed greatest cover during winter and spring. *Corallina vancouveriensis* also contributed significantly to the coralline turf and reached greatest abundance during December 1975; *Lithothrix aspergillum*, a minor turf component, appeared slightly more abundant during the summer.

Egregia menziesii contributed considerable cover in the lower intertidal zone during times of its greatest abundance and, along with fronds of *Halidrys dioica*, furnished the majority of community stratification below +1.0 feet.

Cover data for *Egregia menziesii* suggest greater abundance in the fall, while *Halidrys dioica* showed greatest cover during spring and fall. To more carefully quantify the abundance of lower intertidal kelp species in the control area, assessments of eight 3.14 m^2 (one quarter of a 4.0 meter diameter circle) plots were performed during each visitation. These plots ranged from -0.5 to +2.7 feet in tidal height and were located at the base of the south and middle transect lines. A thorough search of each plot was performed on each visit and the number of individuals recorded for juvenile and mature thalli of both *Egregia menziesii* and *Eisenia arborea* (see Fig. 2-2). These data revealed the maintenance of a relatively constant number of mature thalli for each of the kelps (*Egregia* 2.7 to 5.1 plants per square meter; *Eisenia* 2.6 to 4.4 plants per square meter). Recruitment patterns for the two species, determined by counts of juvenile thalli, were markedly different, with *E. menziesii* showing strong recruitment in the spring of both years and *Eisenia* showing a relatively constant level of recruitment throughout the year.

Cover for macrophytes has been averaged over the period of study as a function of tidal height (Fig. 2-3) to depict prevailing patterns of zonation. The most abundant macrophytes encountered above +3.0 feet were blue-greens and encrusting algae which favored crevices and vertical faces of rocks. Blue-green algae dominated the rocky intertidal zone above +3.0 feet, averaging 46.8% cover between +3.0 and +5.0 feet. The most abundant macrophyte between +2.0 and +3.0 feet was the encrusting brown alga *Pseudolithoderma nigra*. The short turf-forming alga *Gelidium pusillum* ranged from -1.0 to +5.0 feet and furnished its greatest cover between +1.0 and +3.0 feet. This region of the shoreline, where *P. nigra* and *G. pusillum* were most abundant, lies between the blue-green—*Chthamalus fissus/dalli*-dominated upper-intertidal and a mid-intertidal region characterized by a heavily epiphytized coralline algal turf. The coralline turf is composed mostly of *Corallina officinalis* var. *chilensis* along with *C. vancouveriensis* and *Lithothrix aspergillum*. *Corallina vancouveriensis* and *L. aspergillum* were most abundant below MLLW, whereas *C. officinalis* var. *chilensis* cover was greatest between +1.0 and +2.0 feet, although it covered at least 10% within each tidal interval ranging from -1.0 to +3.0 feet.

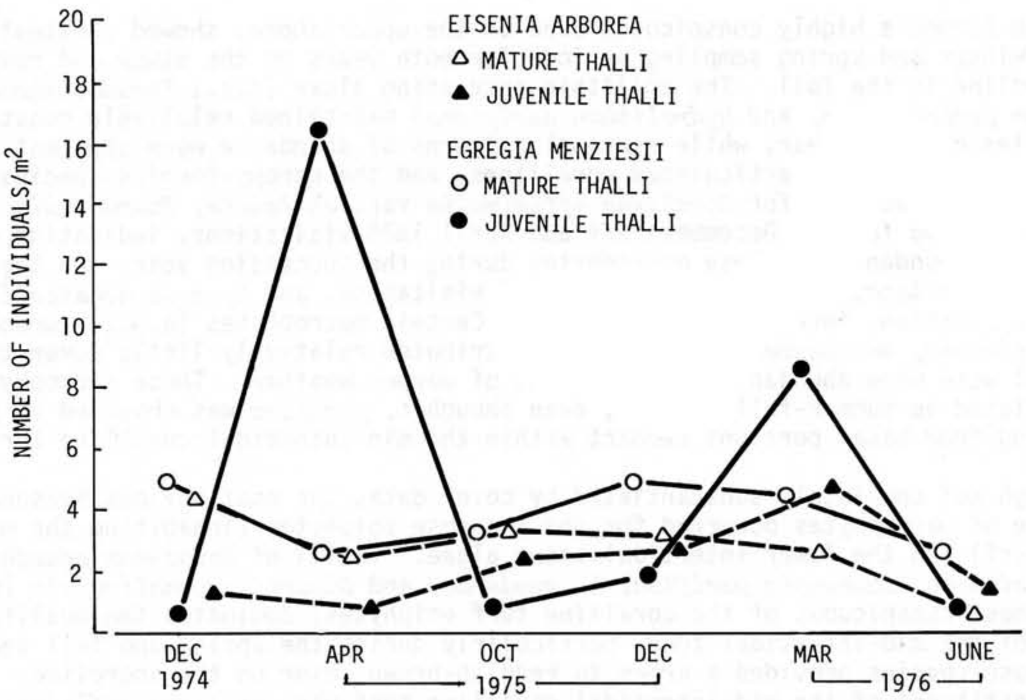

FIGURE 2-2 Standing crops of juvenile and mature thalli of *Egregia menziesii* and *Eisenia arborea* for the unpolluted shoreline. For *E. menziesii*, juvenile thalli were determined to possess five or less pneumatocysts, while for *E. arborea* juveniles had yet to lose their terminal blades.

The principal epiphytes on the coralline algal turf were frondose algae, including *Gigartina canaliculata, Colopmenia sinuosa, Laurencia pacifica, Sargassum agardhianum,* and *Pterocladia capillacea*, all of which were less frequently encountered attached to rock. *Gigartina canaliculata*, distributed from -1.0 to -4.0 feet, reached maximal cover between +1.0 and +2.0 feet. Although less broadly distributed (MLLW to +3.0 feet), *S. agardhianum* also contributed greatest cover between +1.0 and +2.0, while *Laurencia pacifica* was the most broadly distributed of the epiphytic species and supplied its greatest cover below MLLW. *Colpomenia sinuosa* occurred in samples ranging from -1.0 to +3.0 feet and showed a relatively even profile of abundance over its range. *Pterocladia capillacea* appeared most conspicuously below the *G. canaliculata*- and *S. agardhianum*-dominated portion of the coralline turf and reached its greatest cover below +1.0 feet; here it characteristically formed a dense bed of relatively large thalli that gradually diminished in regions of abundant kelp canopy.

Considerable community stratification was provided in the lower intertidal by brown algal canopy species, including *Halidrys dioica, Egregia menziesii,* and *Eisenia arborea,* which were distributed from the lower limits of sampling up to +3.0 feet. *Halidrys dioica* cover, concentrated between -1.0 to +1.0 feet, reached a maximum between MLLW and +1.0 feet, whereas *E. menziesii*, which was also most abundant below +1.0 feet, reached maximum cover below MLLW. *Eisenia arborea* supplied greatest cover below MLLW but was less abundant than either *E. menziesii* or *H. dioica*. Large thalli of all the brown algal canopy species were readily apparent in the subtidal below the lower limits of sampling. The encrusting corallines *Lithophyllum proboscideum* and, to a lesser extent, *Hydrolithon decipiens* occupied much of the primary substrate beneath *E. menziesii* and *E. arborea*. *Lithophyllum proboscideum* was maximal below MLLW and was not sampled above +3.0 feet; the much more broadly distributed *H. decipiens* attained maximum cover on the lower shore but was also a significant component of the intertidal biota above +3.0 feet.

Animals were not abundant on this shoreline (Table 2-5) and seasonal patterns of macro-invertebrate cover were not readily detectable. The barnacles *Chthamalus fissus/dalli* (4.4%) and *Tetraclita squamosa rubescens* (1.8%) and the limpet *Acmaea (Collisella) scabra* (1.2%) furnished nearly 90% of the total macro-invertebrate cover based on annual averages (Table 2-5). A possible exception was the slight decrease in cover recorded for *Chthamalus fissus/dalli* during the December 1974 assessment. The major zonational patterns of macro-invertebrates were derived from cover data averaged over the year and presented in Figure 2-3. *Chthamalus fissus/dalli*, which formed a conspicuous zone on the upper shore, furnished its greatest cover between +3.0 and +4.0 feet, as did *Acmaea (Collisella) scabra*. Individuals of *Littorina planaxis* and *L. scutulata* were commonly encountered among the barnacles, as was *L. planaxis*, on the shore above the upper limits of sampling, but both species contributed little cover. *Tetraclita squamosa rubescens* frequently occurred in greatest quantities immediately below the *C. fissus/dalli* belt. *Tetraclita squamosa rubescens* cover was maximal between +2.0 and +3.0 feet and was abundant over the tidal range +1.0 to +4.0 feet. The encrusting, tube-forming macro-invertebrates *Dendropoma lituella/rastrum*, *Spirobranchus spinosus*, and *Serpulorbis squamigerus* were most commonly found on the sides of rocks, in crevices, or beneath the lower intertidal brown algal canopy where they frequently occurred in association with encrusting coralline algae. *Dendropoma lituella/rastrum*, the most broadly distributed, reached its maximum cover between +2.0 and +3.0 feet. *Spirobranchus spinosus* and *S. squamigerus* were most abundant between MLLW and +1.0 feet. A tube-forming annelid, *Phragmatopoma californica*, and the limpet *Fissurella volcano* were commonly encountered in the lower intertidal, but yielded insignificant cover.

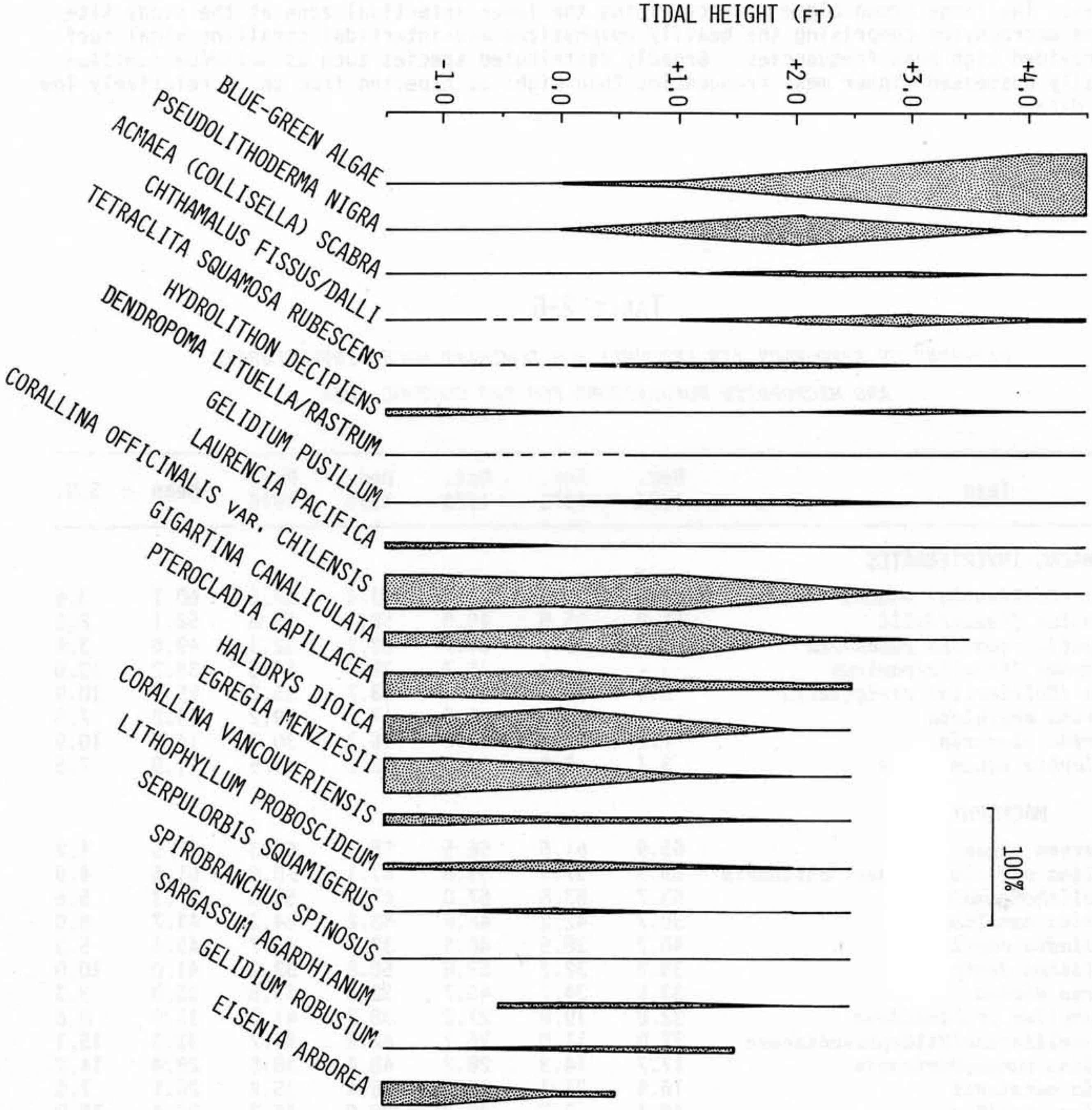

FIGURE 2-3 Cover patterns of the dominant organisms in the control area as a function of tidal height.

CONTROL AREA FREQUENCY

The patterns of macrophyte frequency (Table 2-6) characteristically paralleled those based upon cover (Table 2-5). Twelve macrophytes recorded mean frequencies greater than 25% calculated over the period of study. Blue-green algae (61.5%) and *Corallina officinalis* var. *chilensis* (61.5%) were the most frequently occurring macrophytes, followed by *Pseudolithoderma nigra* (57.3%), *Gigartina canaliculata* (44.7%), *Pterocladia capillacea* (43.4%), and *Hydrolithon decipiens* (41.0%). Also appearing in numerous samples were *Halidrys dioica, Lithophyllum proboscideum*, and Peyssonelliaceae/Hildenbrandiaceae.

The most conspicuous macrophytes were those that possessed the highest mean frequencies. Blue-green algae, which also contributed the highest mean cover, were one of the most commonly occurring macrophytes due to their tendency to occupy much of the primary substrate that was free of barnacles and encrusting red and brown algae above +2.0 feet. Due to the abundance of suitable habitat (i.e., shaded crevices and edges or rocks), the encrusting algae *Pseudolithoderma nigra, Hydrolithon decipiens,* and *Lithophyllum proboscideum* occurred commonly in samples. The large brown algae characterizing the lower intertidal zone at the study site and the macrophytes comprising the heavily epiphytized mid-intertidal coralline algal turf all provided high mean frequencies. Broadly distributed species such as *Gelidium pusillum* typically possessed higher mean frequencies than might be expected from their relatively low cover data.

TABLE 2-6

PATTERNS OF FREQUENCY (IN PERCENT) FOR DOMINANT MACRO-INVERTEBRATE AND MACROPHYTE POPULATIONS FOR THE CONTROL AREA

Taxa	Dec. 1974	Apr. 1975	Oct. 1975	Dec. 1975	Mar. 1976	Mean	± S.D.
MACRO-INVERTEBRATES							
Acmaea (Collisella) scabra	55.6	57.3	60.5	63.4	63.5	60.1	3.6
Chthamalus fissus/dalli	51.9	55.5	49.0	52.1	51.8	52.1	2.3
Tetraclita squamosa rubescens	44.8	46.7	51.7	52.7	52.3	49.6	3.6
Dendropoma lituella/rastrum	----	----	25.7	29.4	44.5	33.2	10.0
Acmaea (Collisella) strigatella	8.9	20.2	28.2	33.7	35.2	25.2	10.9
Littorina scutulata	----	----	5.5	17.8	19.2	14.2	7.5
Littorina planaxis	7.0	14.3	1.8	16.7	30.3	14.0	10.9
Serpulorbis squamigerus	3.7	5.5	12.5	22.2	15.5	11.9	7.5
MACROPHYTES							
Blue-green algae	65.9	61.6	56.5	58.3	65.3	61.5	4.2
Corallina officinalis var. *chilensis*	59.3	57.5	59.8	61.1	70.0	61.5	4.9
Pseudolithoderma nigra	53.7	53.8	57.0	67.1	55.0	57.3	5.6
Gigartina canaliculata	30.7	42.2	48.2	48.2	54.3	44.7	8.9
Pterocladia capillacea	48.2	38.5	48.5	37.3	44.7	43.4	5.3
Hydrolithon decipiens	35.9	32.2	52.8	50.8	33.2	41.0	10.0
Halidrys dioica	33.6	34.7	40.7	32.6	33.5	35.0	3.3
Lithophyllum proboscideum	32.8	19.8	27.2	38.7	41.0	31.9	8.6
Peyssonelliaceae/Hildenbrandiaceae	27.0	11.0	26.7	42.2	49.7	31.3	15.1
Corallina vancouveriensis	17.7	14.3	28.2	48.4	38.5	29.4	14.2
Egregia menziesii	16.4	21.7	30.3	26.4	35.8	26.1	7.5
Gelidium pusillum	18.1	3.7	29.3	29.9	46.2	25.4	15.8
Colpomenia sinuosa	13.0	19.3	25.3	21.5	43.5	24.5	11.5
Laurencia pacifica	11.1	13.3	27.2	25.5	39.5	23.3	11.5
Rhodoglossum affine	7.9	6.0	21.0	30.6	31.5	19.4	12.1
Sargassum agardhianum	13.0	18.5	20.7	23.2	13.5	17.8	4.5

The patterns of macro-invertebrate frequency (Table 2-6) were also highly comparable to the data for cover (Table 2-5). Five macro-invertebrates had mean frequencies greater than 25%, with the highest values recorded for the animals most commonly encountered above +2.0 feet on the shoreline, i.e., *Acmaea (Collisella) scabra* (60.1%), *Chthamalus fissus/dalli* (52.1%), and *Tetraclita squamosa rubescens* (49.6%). These upper intertidal macro-invertebrates typically possessed the highest mean frequencies, which reflects their importance in terms of abundance based upon cover (Table 2-5). The mobile limpets and periwinkles and the sessile barnacles were typically associated with blue-green algae and were most abundant on the heavily sampled horizontal surfaces of rocks, while the encrusting tube-forming animals were more commonly sampled in crevices and beneath the lower intertidal algal canopy.

PATTERNS OF COMMUNITY STRUCTURE

COMMUNITY DIVERSITY

A total of 93 taxa were sampled during the study, of which there were 35 macro-invertebrates and 58 macrophytes (Tables 2-7 and 2-8). Of these, 91 taxa were obtained from the control area and 53 taxa (23 macro-invertebrates and 30 macrophytes) were restricted to the unpolluted portion of the shoreline. Only two macro-invertebrates, *Lottia gigantea* and the black abalone *Haliotis cracherodii*, were encountered in only the sewage-affected samples. Reconnaissance of the unpolluted shoreline resulted in obtaining *L. gigantea* and *H. cracherodii* in the control areas. For *L. gigantea*, the control area population consisted of very few individuals with a highly scattered distribution, whereas for *H. cracherodii* numerous animals were encountered under larger rocks and in crevices throughout the control area. Hence, neither species was restricted to the intertidal near the outfall and, in the case of *H. cracherodii*, the methods used were apparently insufficient to accurately characterize the low population numbers.

In terms of numbers of macro-invertebrate taxa encountered in the outfall samples (Table 2-7), Mollusca predominated with eight higher order taxa (i.e., eight Gastropoda) followed by Arthropoda (three). For the macrophytes, Rhodophyta (16) dominated the sampled taxa followed by Phaeophyta (seven) and Chlorophyta (four). Similar patterns were evident for the control area (Table 2-8) with Mollusca (17) comprising the greatest portion of the sampled taxa (14 Gastropoda, one Bivalvia, and two Polyplacophora) followed by Arthropoda (five) and Annelida (four). Rhodophyta (33) contributed the majority of the macrophytes sampled followed by Phaeophyta (14) and Chlorophyta (eight).

Three methods were employed to quantitatively measure community diversity in an effort to facilitate within-site and between-site comparisons. Simple counts of sampled taxa have been utilized to assess community richness while Shannon's (Shannon and Weaver, 1949) quantitative index (H') based on $\log_e$ and Pielou's (1969) evenness index (J') were used to construct diversity patterns stressing the distribution of abundance among the taxa.

An inherent difficulty with the treatment of samples resulting from repeated visitations to an area is the tendency for the field investigators to locate more species with succeeding assessments. These are typically small or rare species and do not make significant contributions to abundance values derived from percent cover. For the outfall area it was more difficult to recognize small or rare species than for the controls, in part because of the thick coverage of blue-green algae or Ectocarpaceae/colonial diatoms in the upper and mid-intertidal which grew over and obscured many of the organisms occupying the primary substrate. Additionally, some difficulties were encountered in working the lower intertidal plots, particularly during periods of heavy discharge, because of the tendency for the sewage effluent to collect along the lower portions of the transect lines. However, the simple species counts reported herein appear to be representative of actual differences in species diversity between the two areas, and this is borne out by the diversity measures (H' and J') stressing the partitioning of abundance among species.

For the control areas, an approximate average of 90% more taxa were obtained in samples than for the outfall per visitation (Table 2-9). A mean of 52 macro-invertebrate and macrophyte taxa was recorded over the period of sampling for the control area as compared to 27 for the outfall. For both macro-invertebrates (16 vs. 9) and macrophytes (35 vs. 18), the number of control area taxa was almost twice that for the sewage-affected area. Combined macro-invertebrate and macrophyte diversity, as measured by H', averaged 2.63 for the control area as compared to 2.06 for the outfall. Similarly, the mean values for macro-invertebrate

TABLE 2-7

TAXA OF MACRO-INVERTEBRATES AND MACROPHYTES SAMPLED FROM THE OUTFALL AREA

Taxa	Dec. 1974	Apr. 1975	Oct. 1975	Dec. 1975	Mar. 1976
MACRO-INVERTEBRATES					
Annelida (Polychaeta)					
Serpulidae				X	
Arthropoda (Crustacea)					
Chthamalus fissus/dalli	X	X	X	X	X
Pachygrapsus crassipes	X	X	X	X	X
Tetraclita squamosa rubescens	X	X	X	X	X
Cnidaria (Anthozoa)					
Anthopleura elegantissima	X	X	X	X	X
Mollusca (Gastropoda)					
Acmaea (Collisella) digitalis		X			
Acmaea (Collisella) limatula				X	X
Acmaea (Collisella) scabra	X	X	X	X	X
Acmaea (Collisella) strigatella					X
Haliotis cracherodii	X	X	X	X	
Littorina planaxis		X	X		
Lottia gigantea	X		X	X	X
Serpulorbis squamigerus	X	X	X	X	X
MACROPHYTES					
Bacillariophyta					
Colonial Diatoms*	X	X	X	X	X
Chlorophyta					
Chaetomorpha linum					X
Cladophora spp.					X
Cladophoropsis fasciculatus	X	X		X	X
Ulva californica	X	X	X	X	X
Cyanophyta					
Blue-green algae	X	X	X	X	X
Phaeophyta					
Colpomenia sinuosa	X	X	X	X	X
Ectocarpaceae (filamentous)	X	X	X	X	X
Egregia menziesii	X	X	X	X	X
Eisenia arborea	X		X	X	X
Halidrys dioica					X
Pseudolithoderma nigra	X	X	X	X	X
Scytosiphon dotyi					X
Rhodophyta					
Carpopeltis divaricatus					X
Ceramium eatonianum				X	
Corallina officinalis var. *chilensis*	X	X	X	X	X
Corallina vancouveriensis				X	X
Gelidium coulteri		X			
Gelidium pusillum	X	X	X	X	X
Gelidium purpurascens				X	
Gigartina canaliculata	X	X	X	X	X
Gigartina spinosa				X	X
Hydrolithon decipiens	X	X			
Laurencia pacifica			X	X	X
Lithophyllum proboscideum	X	X	X	X	X
Lithothrix aspergillum	X	X	X		
Peyssonelliaceae/Hildenbrandiaceae	X	X	X	X	X
Pterocladia capillacea	X	X	X	X	X
Rhodoglossum affine				X	X

*Colonial Diatoms and filamentous Ectocarpaceae have been treated as a single taxonomic unit.

Table 2-8

SPECIES AND TAXA OF MACRO-INVERTEBRATES AND MACROPHYTES SAMPLED FROM THE CONTROL AREA

Taxa	Dec. 1974	Apr. 1975	Oct. 1975	Dec. 1975	Mar. 1976
MACRO-INVERTEBRATES					
Annelida (Polychaeta)					
Phragmatopoma californica				X	X
Serpulidae					X
Spirobranchus spinosus			X	X	X
Spirorbis spp.	X	X	X		
Arthropoda (Crustacea)					
Balanus tintinnabulum californicus					X
Chthamalus fissus/dalli	X	X	X	X	X
Pachygrapsus crassipes		X		X	X
Pagurus samuelis			X		X
Tetraclita squamosa rubescens	X	X	X	X	X
Cnidaria (Anthozoa)					
Astrangia sp.				X	
Corynactis californica					X
Ectoprocta (Bryozoa)					
Encrusting bryozoans				X	X
Mollusca (Bivalvia)					
Brachidontes adamsianus				X	X
Mollusca (Gastropoda)					
Acmaea (Collisella) conus			X		
Acmaea (Collisella) digitalis			X	X	
Acmaea (Collisella) limatula		X	X	X	X
Acmaea (Collisella) pelta				X	X
Acmaea (Collisella) scabra	X	X	X	X	X
Acmaea (Collisella) scutum					X
Acmaea (Collisella) strigatella	X	X	X	X	X
Fissurella volcano				X	X
Hipponix antiquatus					X
Littorina planaxis	X	X	X	X	X
Littorina scutulata			X	X	X
Dendropoma lituella/rastrum			X	X	X
Serpulorbis squamigerus	X	X	X	X	X
Tegula funebralis		X			
Mollusca (Polyplacophora)					
Cyanoplax hartwegii					X
Nuttallina fluxa			X	X	X
Porifera					
Brown sponge	X				
Orange sponge	X		X	X	X
White sponges					X
Stelata clarella					
Tethya aurantia var. *calif.*					
Yellow sponge					X
MACROPHYTES					
Chlorophyta					
Chaetomorpha linum				X	
Chaetomorpha spiralis					X
Cladophora graminea				X	
Cladophora spp.	X				
Cladophoropsis fasciculatus					X
Codium fragile	X				
Enteromorpha sp.				X	
Ulva californica	X	X	X	X	X

TABLE 2-8 (Continued)

Taxa	Dec. 1974	Apr. 1975	Oct. 1975	Dec. 1975	Mar. 1976
MACROPHYTES (Continued)					
Cyanophyta					
Blue-green algae	X	X	X	X	X
Blue-green colony				X	X
Phaeophyta					
Coilodesme rigida		X			X
Colpomenia sinuosa	X	X	X	X	X
Cylindrocarpus rugosus	X	X	X	X	X
Dictyota flabellata	X	X	X	X	X
Ectocarpaceae		X			X
Egregia menziesii	X	X	X	X	X
Eisenia arborea	X	X	X	X	X
Endarachne binghamiae					X
Halidrys dioica	X	X	X	X	X
Petalonia fascia	X				
Pseudolithoderma nigra	X	X	X	X	X
Ralfsia sp.	X		X	X	X
Sargassum agardhianum	X	X	X	X	X
Scytosiphon dotyi					X
Rhodophyta					
Anisocladella pacifica	X				
Bossiella orbigniana ssp. *dichotoma*	X		X	X	X
Carpopeltis divaricatus					X
Ceramium eatonianum				X	X
Corallina officinalis var. *chilensis*	X	X	X	X	X
Corallina vancouveriensis	X	X	X	X	X
Cryptopleura corallinara			X	X	X
Erythrocystis saccata			X		
Gastroclonium coulteri					X
Gelidium coulteri	X	X		X	
Gelidium pusillum	X	X	X	X	X
Gelidium purpurascens	X	X	X	X	X
Gigartina canaliculata	X	X	X	X	X
Gigartina spinosa	X	X	X	X	X
Haliptylon gracile	X		X		X
Herposiphonia tenella					X
Herposiphonia verticillata				X	X
Hydrolithon decipiens	X	X	X	X	X
Laurencia pacifica	X	X	X	X	X
Laurencia snyderae			X		
Laurencia spectabilis				X	X
Lithophyllum proboscideum	X	X	X	X	X
Lithothrix aspergillum	X	X	X	X	X
Nemalion helminthoides			X		
Peyssonelliaceae/Hildenbrandiaceae	X	X	X	X	X
Plocamium cartilagineum	X			X	X
Porphyrella californica					X
Prionitis lanceolata		X			
Pterocladia capillaceae	X	X	X	X	X
Pterosiphonia dendroidea	X	X	X	X	X
Rhodoglossum affine	X	X	X	X	X
Rhodymenia californica f. calif.	X	X		X	X
Tiffaniella snyderae		X			
SPERMATOPHYTA					
Phyllospadix torreyi				X	X

diversity (1.42 vs. 0.61) and macrophyte diversity (2.45 vs. 1.83) were greater for the unpolluted communities. The evenness measure (J') revealed similar pattern for the macro-invertebrates (0.53 vs. 0.28) but was highly comparable for the macrophytes (0.69 vs. 0.64) and the treatment of combined macro-invertebrates and macrophytes (0.67 vs. 0.63).

Diversity data characterized the unpolluted communities as consisting of greater numbers of taxa and showing greater H' diversity than those for the outfall, while for the macrophytes (which constitute the dominant proportion of cover for both the outfall and control regions) a comparable degree of cover evenness among taxa was evident for both areas.

Both outfall and control communities showed remarkable constancy in terms of diversity. For the control areas, the maximum difference from the mean for H' values was less than 3% for combined macro-invertebrates and macrophytes, while for the outfall approximately 9% was the comparable value; similar patterns held for J'. These data substantiate interpretations derived from analyses of seasonal abundance for species discussed earlier (see Tables 2-3 and 2-5).

TABLE 2-9

PATTERNS OF SPECIES DIVERSITY FOR CONTROL AND OUTFALL AREAS FOR SAN CLEMENTE ISLAND BASED UPON PERCENT COVER ABUNDANCE DATA

	CONTROL AREA			OUTFALL AREA		
	No. Species	H'	J'	No. Species	H'	J'
MACRO-INVERTEBRATES						
Dec. 1974	9	1.21	0.55	8	0.36	0.18
Apr. 1975	10	1.24	0.54	9	0.73	0.33
Oct. 1975	16	1.40	0.50	9	0.52	0.24
Dec. 1975	20	1.51	0.50	10	0.84	0.37
Mar. 1976	27	1.76	0.54	9	0.60	0.27
Mean	16	1.42	0.53	9	0.61	0.28
MACROPHYTES						
Dec. 1974	34	2.44	0.69	16	1.68	0.61
Apr. 1975	31	2.41	0.70	16	1.71	0.62
Oct. 1975	31	2.49	0.72	15	1.77	0.66
Dec. 1975	37	2.47	0.68	20	1.93	0.64
Mar. 1976	44	2.44	0.64	23	2.05	0.66
Mean	35	2.45	0.69	18	1.83	0.64
COMBINED MACRO-INVERTEBRATES AND MACROPHYTES						
Dec. 1974	43	2.56	0.68	24	1.90	0.60
Apr. 1975	41	2.61	0.70	25	1.98	0.62
Oct. 1975	47	2.67	0.69	24	2.00	0.63
Dec. 1975	57	2.67	0.66	30	2.17	0.64
Mar. 1976	71	2.65	0.62	32	2.25	0.65
Mean	52	2.63	0.67	27	2.06	0.63

COMMUNITY STRATIFICATION

Vertical layering (stratification) is an important aspect of community structure because variation in habitat complexity and niche diversity are involved. Stratification patterns generally become more pronounced on the lower shoreline in southern California rocky intertidal communities as a result of increased cover of larger brown algae and sea grasses. Although greater macrophyte cover was determined for the outfall area (Table 2-1), this was mostly due to the increased abundance provided (Table 2-2) in the upper intertidal (> +2.0 feet) by relatively unstructured growths of blue-green algae and epiphytic thalli of Ectocarpaceae/colonial diatoms. For the lower shoreline (below +2.0 feet), significantly more macrophyte cover was present in the control area (154.8% vs. 119.2%, $P<0.01$) due to the increased abundance there of "canopy" species such as *Egregia menziesii, Halidrys dioica, Eisenia arborea,* and *Phyllospadix torreyi*. A lower canopy (Fig. 2-6), consisting of *Gelidium purpurascens, Pterocladia capillacea, Sargassum agardhianum, Laurencia pacifica,* and *Gigartina canaliculata*, extended up to a maximum of about 30 centimeters above the primary substrate throughout most of the mid and lower portions of the intertidal and was much more developed in the control area than in the outfall where most of these species showed reduced abundance or were absent (see Tables 2-3 and 2-5).

Community stratification was confined in the sewage-affected region to within about ten centimeters above the primary substrate, with the exception of the lower intertidal brown algae. Most of the macrophyte cover in the mid-intertidal of the outfall area consisted of low turf-forming growths of *Ulva californica, Gelidium pusillum,* and diminutive thalli of *Pterocladia capillacea*. The large masses of calcified tubes contributed by existent and previous populations of *Serpulorbis squamigerus* dominated much of the lower intertidal primary substrate and provided means of attachment for various macrophytes (particularly *Corallina officinalis* var. *chilensis*) between tube orifices.

COMMUNITY CLASSIFICATION

To further analyze the patterns of community structure, each of the seasonal data collections were subjected to cluster analyses for both the outfall and the control areas. Additionally, single analyses were performed on the entire data collection for the control and for the outfall areas to detect seasonal variation in the biotic composition of individual plots.

For the outfall, the cluster analyses revealed five major groups of macro-organisms that appeared repetitively (Fig. 2-4): blue-green — *Ulva* group (AA), blue-green — *Pseudolithoderma* group (AB), *Gelidium pusillum* — *Ulva* — Ectocarpaceae/colonial diatoms group (B), *Serpulorbis* — *Corallina* — *Gelidium pusillum* group (C), and *Eisenia* — *Egregia* group (D). The first three groups contained the small turf-forming algae that predominated in the upper and mid-intertidal near the outfall, whereas members of the *Serpulorbis* — *Corallina* — *Gelidium pusillum* and the *Eisenia* — *Egregia* groups provided the majority of cover along the lower shoreline of the sewage-affected area. Many of the upper and mid-intertidal outfall plots showed fluctuations in the abundance of blue-green algae, *Gelidium pusillum, Ulva californica,* and Ectocarpaceae/colonial diatoms. Despite plot-specific changes in abundance of the aforementioned species, the mean abundance values of most of these species showed little variation over the year (Table 2-3). The tendency for seasonal variation within individual plots is interpreted herein as evidence that a short turn-over of rapidly growing algae is characteristic of the upper and mid-intertidal in the sewage-affected area.

Similar analyses of control area cluster diagrams revealed that the biotic character of individual plots maintained a high degree of constancy over the period of study, with seasonal variations in species abundance generally being insufficient to alter the major group to which a plot was assigned. For the control area's entire data set, including plots above +5.0 feet, seven groups (Fig. 2-5) consistently appeared over the study period. These were: blue-green algal group (AA), blue-green — *Chthamalus* group (AB), blue-green — *Chthamalus* — *Acmaea* group (AC), *Pseudolithoderma* — *Tetraclita* group (B), *Corallina* — *Gigartina* group (CA), *Corallina* — *Pterocladia* group (CB), and *Egregia* group (D).

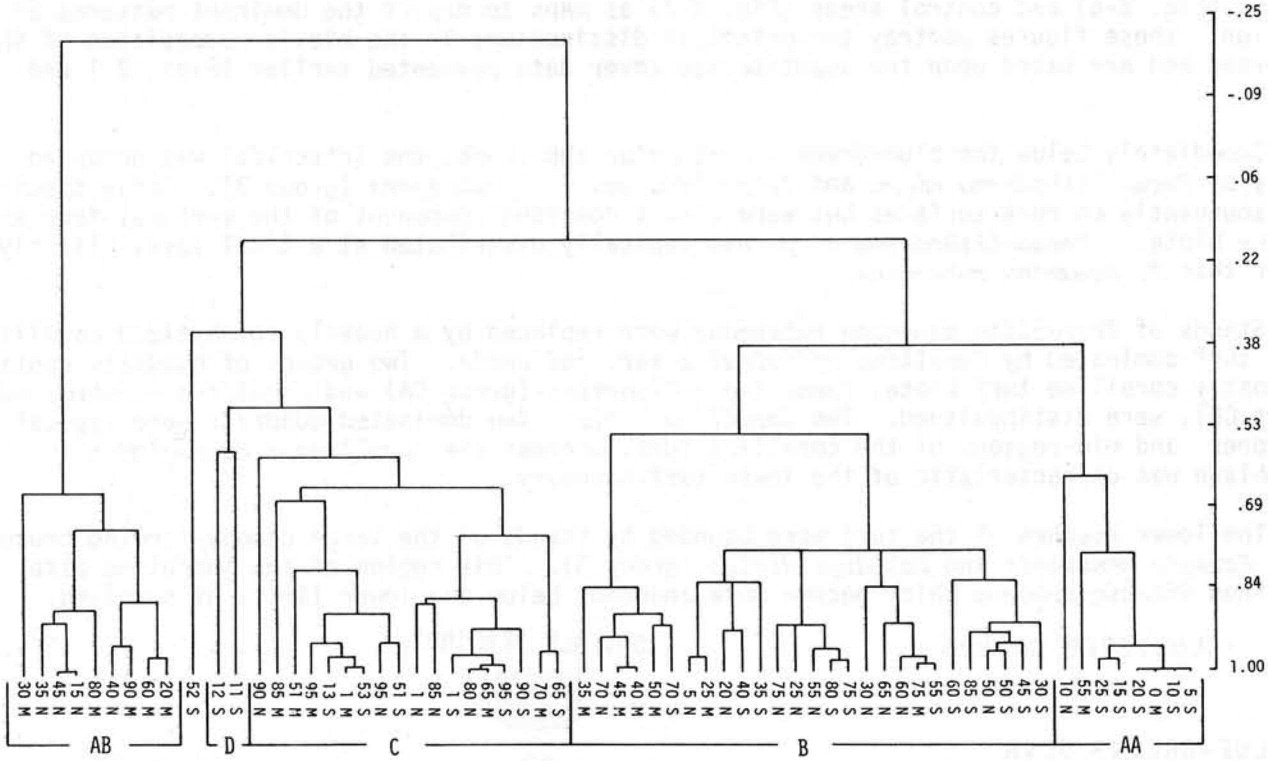

FIGURE 2-4 Dendrogram display of differential clustering of outfall quadrats sampled during March 1976. See text for explanation of groupings.

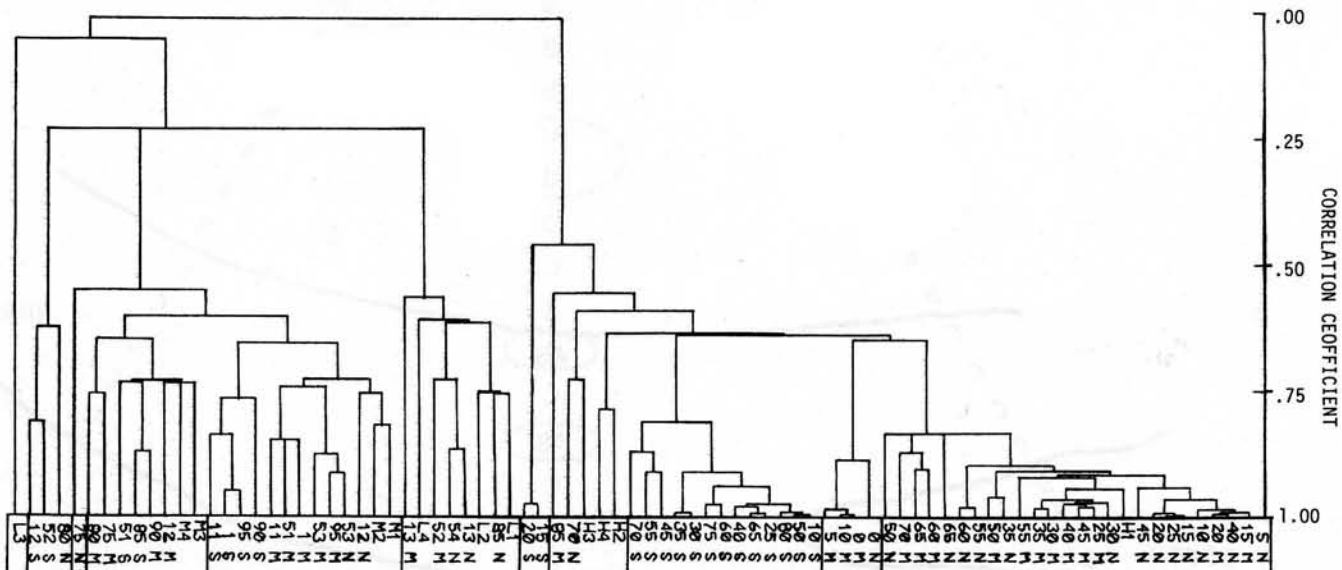

FIGURE 2-5 Dendrogram display of differential clustering of control area quadrats sampled during March 1976. See text for explanation of groupings.

DISTRIBUTIONAL PATTERNS OF SPECIES ASSEMBLAGES

The results of representative cluster analysis data have been presented for both the outfall (Fig. 2-6) and control areas (Fig. 2-7) as maps to depict the dominant patterns of zonation. These figures portray the principal distinctions in the biotic composition of the two areas and are based upon the quantitative cover data presented earlier (Figs. 2-1 and 2-3).

Immediately below the blue-green — *Chthamalus* spp. zone, the intertidal was occupied mostly by *Pseudolithoderma nigra* and *Tetraclita squamosa rubescens* (group B). These species grew abundantly on rock surfaces but were also a dominant component of the vertical face and crevice biota. *Pseudolithoderma nigra* was typically distributed at a tidal level slightly higher than *T. squamosa rubescens.*

Stands of *Tetraclita squamosa rubescens* were replaced by a heavily epiphytized coralline algal turf dominated by *Corallina officinalis* var. *chilensis.* Two groups of quadrats containing mostly coralline turf biota, *Corallina — Gigartina* (group CA) and *Corallina — Pterocladia* (group CB), were distinguished. The *Corallina — Gigartina* dominated quadrats were typical of the upper and mid-regions of the coralline turf, whereas the *Corallina — Pterocladia* assemblage was characteristic of the lower turf boundary.

The lower reaches of the turf were bounded by stands of the large canopy-forming brown algae *Egregia menziesii* and *Halidrys dioica* (group D). This region of the shoreline also contained *Eisenia arborea* which became more abundant below the lower limits of sampling.

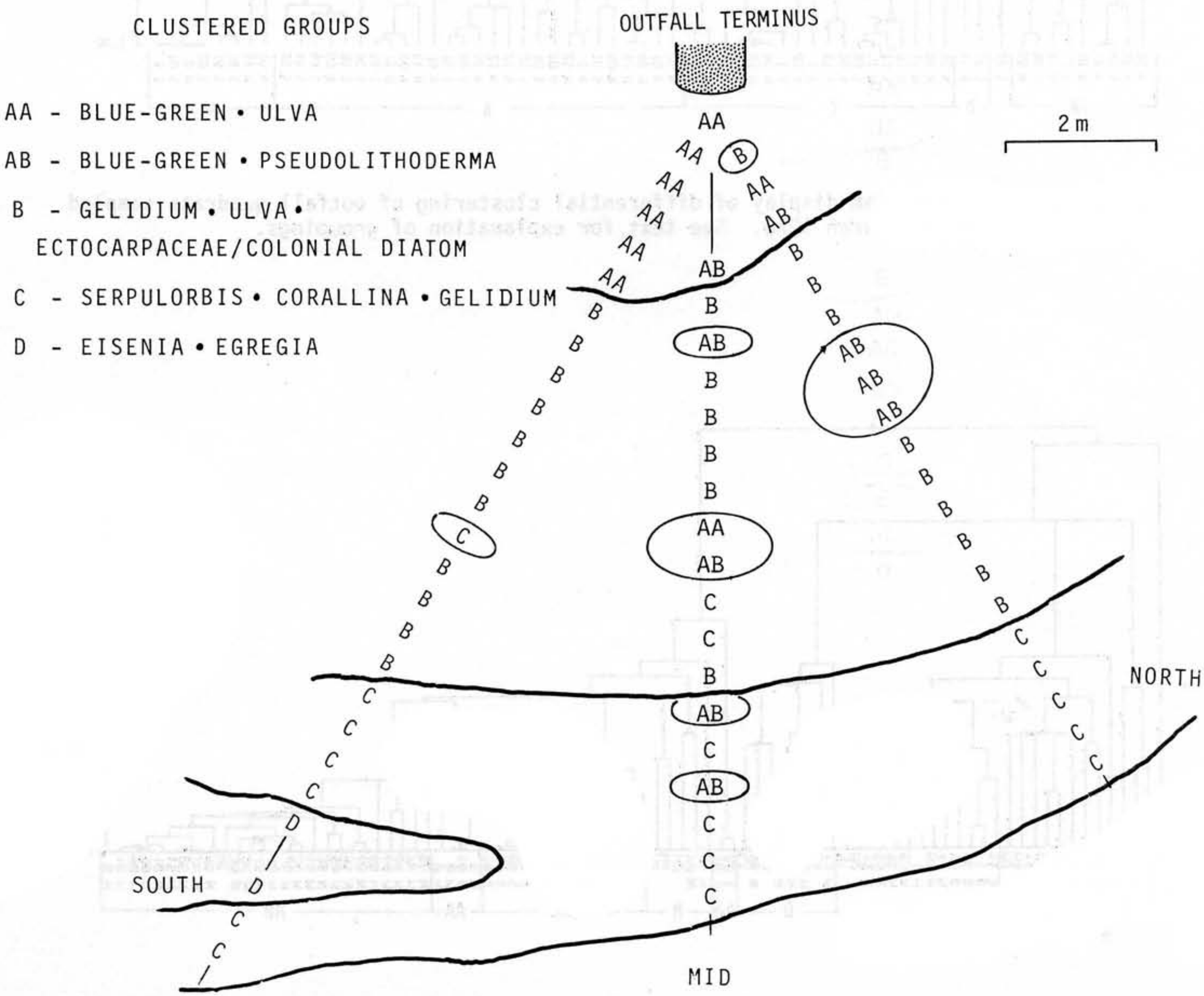

FIGURE 2-6 Distributional patterns of species assemblages for the outfall based upon March 1976 cluster analysis data.

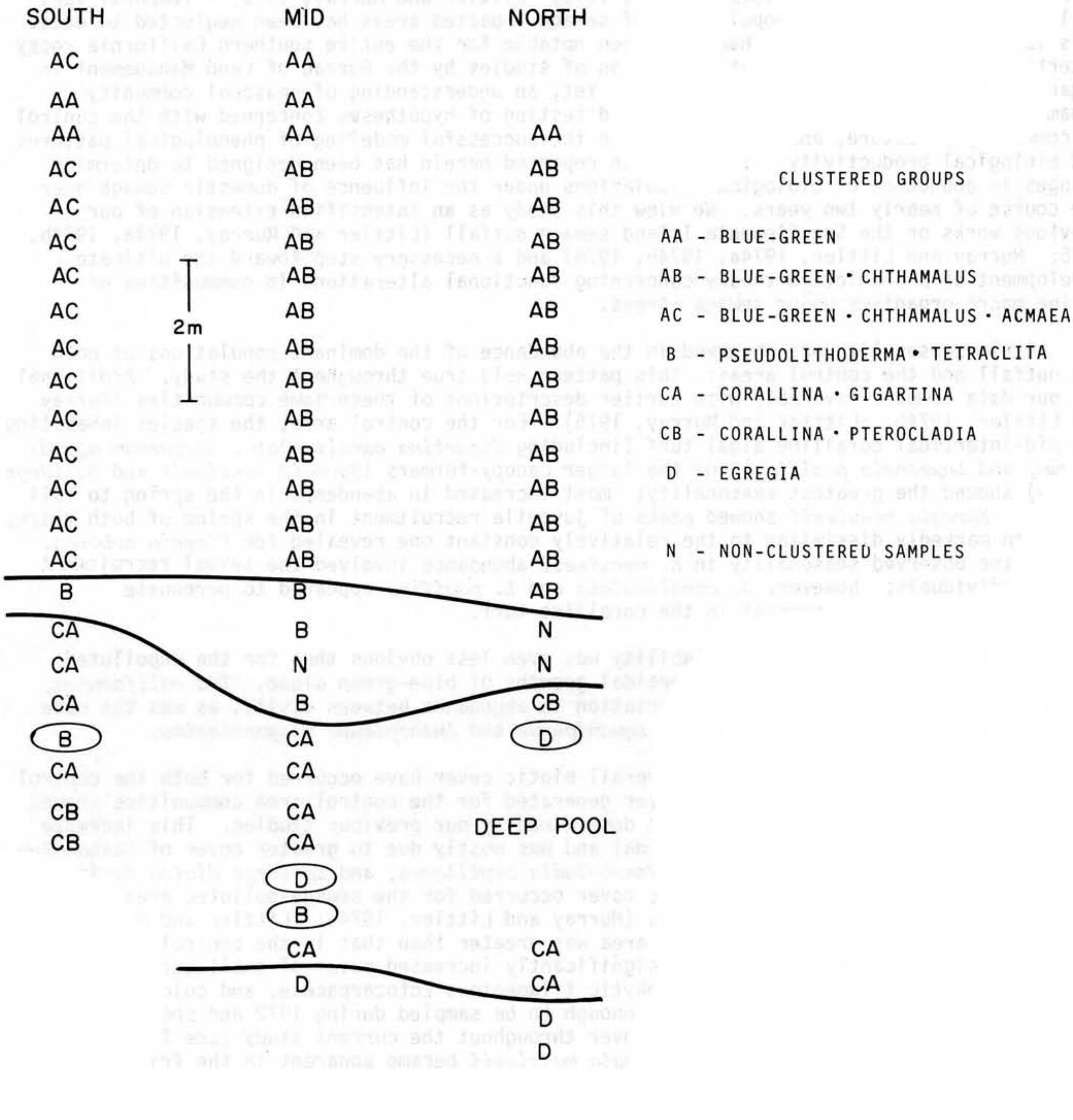

FIGURE 2-7 Distributional patterns of species assemblages for the control area based upon the March 1976 cluster analysis data.

DISCUSSION

It has been well documented that epibiotic marine communities undergo varying degrees of changes in species composition and abundance following exposure to sewage (e.g., Borowitzka, 1972; Edwards, 1972; Jones, 1973; Littler and Murray, 1975). Temporal variability of the constituent populations of sewage-impacted areas has been neglected to date. This lack of seasonal studies had also been notable for the entire southern California rocky intertidal zone until the recent initiation of studies by the Bureau of Land Management in regard to leasing of offshore oil tracts. Yet, an understanding of seasonal community dynamics is important to the generation and testing of hypotheses concerned with the control of community structure, and is essential to the successful modeling of phenological patterns and biological productivity. The research reported herein has been designed to determine changes in abundance of biological populations under the influence of domestic sewage over the course of nearly two years. We view this study as an intensified extension of our previous works on the San Clemente Island sewage outfall (Littler and Murray, 1974a, 1974b, 1975; Murray and Littler, 1974a, 1974b, 1976) and a necessary step toward the ultimate development of a predictive theory concerning functional alterations in communities of marine macro-organisms under sewage stress.

Little seasonality was observed in the abundance of the dominant populations of both the outfall and the control areas; this pattern held true throughout the study. Additionally, our data compare favorably with earlier descriptions of these same communities (Murray and Littler, 1974b; Littler and Murray, 1975). For the control area, the species inhabiting the mid-intertidal coralline algal turf (including *Gigartina canaliculata, Sargassum agardhianum,* and *Laurencia pacifica*) and the larger canopy-formers (*Egregia menziesii* and *Halidrys dioica*) showed the greatest seasonality; most increased in abundance in the spring to fall period. *Egregia menziesii* showed peaks of juvenile recruitment in the spring of both years, a pattern markedly dissimilar to the relatively constant one revealed for *Eisenia arborea*. Much of the observed seasonality in *E. menziesii* abundance involved the sexual recruitment of new individuals; however, *G. canaliculata* and *L. pacifica* appeared to perennate vegetatively from bases remnant in the coralline turf.

For the outfall, seasonal variability was even less obvious than for the unpolluted communities. The upper and mid-intertidal growths of blue-green algae, *Ulva californica,* and *Gelidium pusillum* showed little variation in abundance between visits, as was the case for the suspension feeders *Serpulorbis squamigerus* and *Anthopleura elegantissima*.

Since 1972, slight increases in overall biotic cover have occurred for both the control and outfall sites. The mean biotic cover generated for the control area communities showed only a slight (6.7%) increase over that determined by our previous studies. This increase was generalized over the entire intertidal and was mostly due to greater cover of *Chthamalus fissus/dalli, Pseudolithoderma nigra, Pterocladia capillacea,* and *Halidrys dioica* during 1974-1976. A 20.7% increase in biotic cover occurred for the sewage-polluted area since 1972 and, contrary to previous findings (Murray and Littler, 1974b; Littler and Murray, 1975), the biotic cover in the outfall area was greater than that in the control area. This increase was for the most part due to significantly increased cover of small turf-forming algae including *Gelidium pusillum,* epiphytic filamentous Ectocarpaceae, and colonial diatoms. The last two entities were not abundant enough to be sampled during 1972 and showed a continuous and unexplained increase in cover throughout the current study (see Table 2-3). Additionally, a sparse population of *Egregia menziesii* became apparent in the fringe of the outfall and contributed some cover during each of the biological assessments. *Egregia menziesii* had not been sampled in the outfall prior to this study and, despite careful searches, had not been recorded closer than ten meters from the outfall terminus. Its occurrence during 1974-1976 is evidence of limited recruitment in the sewage-polluted zone, although *E. menziesii* remained significantly less abundant than in the control area. As was the case in 1972, the conspicuous absence or reduction of canopy-forming species such as *Phyllospadix torreyi, E. menziesii, Sargassum agardhianum,* and *Halidrys dioica* resulted in less vertical stratification in the outfall.

The dominant populations have undergone little change in patterns of distribution and abundance in both the outfall and control areas since 1972. Blue-green algae, *Ulva californica, Gelidium pusillum, Pseudolithoderma nigra,* and *Serpulorbis squamigerus* were again found to be considerably more abundant in the outfall; similarly, *Egregia menziesii, Halidrys dioica, Sargassum agardhianum, Hydrolithon decipiens, Gigartina canaliculata, Chthamalus fissus/dalli,* and *Tetraclita squamosa rubescens* revealed greater cover in the unpolluted area. The only exception to our previous findings occurred for *Pterocladia capillacea* which reversed its 1972 pattern of greater cover in the outfall. It appeared that small thalli of *G. pusillum* have replaced *P. capillacea* along the upper limits of its outfall distribution where, previously (Murray and Littler, 1974b; Littler and Murray, 1975), diminutive thalli were abundant. The biological zones determined by cluster analysis (see Figs. 2-5 and 2-8) were essentially the same as those described during our previous studies.

As indicated by Goodwin (1975) and Andrews (1976), a reduction in diversity is a general characteristic of polluted biological communities. This has frequently been substantiated for sewage-perturbated epibiotic systems (e.g., Borowitzka, 1972; Edwards, 1972; Jones, 1973; Munda, 1974; Littler and Murray, 1975) and has again held true in this study for each of the seasonal analyses as determined by species counts and the Shannon-Weaver diversity index (H'). Diversities of the polluted and unpolluted communities showed only slight changes over time and were highly comparable with our previous findings for San Clemente Island. These data corroborate the results of populational abundance patterns in reflecting a highly constant structure of both the polluted and control biological communities. An average of 48% fewer species was sampled in the outfall area compared to the controls (see Table 2-9), a value almost identical with our previous determination of 49% (Littler and Murray, 1975) and with the 45% reduction in invertebrates reported (Jones, 1973) for polluted communities of kelp holdfasts. The greater intensity of the sampling program employed during 1974-1976 resulted in an approximate 33% increase in the number of taxa (relative to that recorded by Murray and Littler, 1974a) encountered during an average assessment for both study sites, in addition to numerous new species distributional records for leeward San Clemente Island (see Tables 2-7 and 2-8). However, the new species encountered were mostly rare and contributed little biological cover. Shannon-Weaver diversity was highly comparable with our previous work and averaged 2.67 for the control areas and 2.06 for the outfall vs. 2.71 and 1.94, respectively, for 1972 (recalculated from Murray and Littler, 1974b; Littler and Murray, 1975, to convert H'_2 to H'_e). Evenness, as measured by J', remained highly comparable with 1972 findings for the outfall and dropped slightly for control area communities, presumably due to the increased number of rare species sampled during this study.

Our standing crop assessments add considerable substantiation to our earlier hypotheses (Murray and Littler, 1974b; Littler and Murray, 1975) that the structure of the sewage-affected communities is the result of two major environmental features of the Wilson Cove effluent. These are the sporadic discharge of deleterious agents (such as 90% pine oil, bleach, detergents, and hot or fresh water) and the presence of solid and dissolved organic particulates which enter the marine environment as human wastes and food scraps from the mess hall.

The organisms most abundant in the upper and mid-intertidal of the outfall region were filamentous or short turf-forming algae, including blue-green algae, filamentous Ectocarpaceae, colonial diatoms, *Ulva californica,* and *Gelidium pusillum*, all of which have previously been reported in aquatic environments under sewage stress. Blue-green algae, which are characteristically highly tolerant of variable environmental conditions, have been frequently cited as dominant components of sewage-polluted benthic communities. For example, Golubic (1970) described heavy development of blue-green algal mats in sewage-polluted environments off the Adriatic coast, while similar observations have been recorded for coastal systems of western Norway (Munda, 1974) and previously for San Clemente Island (Murray and Littler, 1974b; Littler and Murray, 1975). Fogg (1973) has indicated that organic pollution modifies the composition of the epilithic blue-green algal flora, a finding preliminarily supported by our own observations. Diatoms (Golubic, 1970; Borowitzka, 1972) and filamentous Ectocarpaceae (Munda, 1974) have also been reported to occur in abundance near sites of sewage discharge, as have various green algae, such as *Ulva* and *Enteromorpha* (e.g., Cotton, 1911; Burrows, 1971; Borowitzka, 1972; Munda, 1974; Murray and Littler, 1974b; Littler and Murray, 1975). Experimental work has shown that *Ulva* can make use of ammonia-nitrogen under polluted conditions (Letts and Richards, 1911; Wilkinson, 1964) and that sewage-polluted sea water results in increased growth (Burrows, 1971). Further, the occurrence of *Ulva* in polluted inshore waters off southern California has been suggested (North *et al.*, 1972) to be related to its ability to utilize dissolved amino acids found in organic wastes. *Gelidium pusillum* has not been reported to be associated with sewage-polluted environments, with the exception of our previous studies for San Clemente Island, despite its presence as an abundant turf-forming constituent of the southern California intertidal algal flora (Stewart, 1976). However, Borowitzka (1972) has reported the enhanced abundance of the closely related *Pterocladia pinnata* for a polluted site in New South Wales, Australia.

The sewage-tolerant filamentous or turf-forming algae characteristic of the outfall communities all possess morphologically simple thalli with high surface to volume ratios and have high rates of productivity (Littler and Murray, 1974a, 1974b; Littler, 1977, Chapter Three). Additionally, all of these seaweeds allocate a large proportion of their resources to reproduction (vegetative, asexual, or sexual) and all have been characterized (see Chapter Six) as members of early successional stages in the development of epibiotic marine communities. These features led us earlier (Littler and Murray, 1975) to label this outfall species suite as r-selected strategists (see Stearns, 1976, for a review of the utilization of this label in light of life-history tactics) or opportunists (see Connell, 1972).

Owing to their high potential for growth and reproduction, r-selected strategists theoretically show rapid increases in abundance where resources become plentiful. The Wilson Cove sewage is viewed as contributing abundant supplies of nutrients while simultaneously sporadically emitting toxicants. This combination creates a potentially nutrient-rich but fluctuating environment, with the community development held in a disclimax state due to effects of the deleterious sewage components; hence, the domination by opportunistic or r-selected species. This interpretation is further supported by comparisons of the contents of specific quadrats from season to season and through perusal of the cluster analysis data. These reveal that the algal dominants for this region of the outfall showed considerable fluctuation within specific plots over the study period, indicating frequent recruitment and mortality.

The biotic communities occupying the peripheral and seaward margins of the outfall intertidal area showed less cover of opportunistic algae and increased abundance of suspension feeding animals. These macro-invertebrate populations presumably utilize the sewage-based detritus (see Chapter Five) and appear to consist of relatively large individuals. Our data suggest that these suspension feeders are maintained by the sewage inputs in that their abundances are very much lower in the unpolluted area, and that their populations are constant over time.

The mechanisms employed in the maintenance of seasonal constancy in the upper and mid-intertidal regions of the outfall are in contrast with those evident for the control area and also for the fringing areas of the outfall shoreline. The lack of change for the upper and mid-intertidal of the outfall has occurred at the populational level, as there appears to be a high turnover factor among individual algae. For the control areas, presumably with the exception of blue-green algae, the dominant species populations are generally more long-lived and more structurally complex. These populations have been interpreted (Littler and Murray, 1975) to more closely fit the pattern of K-selected strategists. Increased abundance of algae common in the control area, and apparently long-lived suspension feeding macro-invertebrates along the peripheral and seaward margin of the outfall zone, indicate biological communities enhanced by sewage detritus and partially removed from the diluted effects of effluent toxicants.

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INFLUENCE OF DOMESTIC WASTES ON THE STRUCTURE AND ENERGETICS OF INTERTIDAL COMMUNITIES NEAR WILSON COVE, SAN CLEMENTE ISLAND

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TECHNICAL COMPLETION REPORT

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