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THE SANTA BARBARA OIL SPILLS IN PERSPECTIVE

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INTRODUCTION

Two oil spills during 1969 in the Santa Barbara Channel affected an area undergoing major adaptive changes. These changes most probably occurred in response to air and sea water composition that has been steadily altered by human activities since the turn of the century. The first spill (January–April, 1969) loosed 11,290–112,900 metric tons [1] of crude oil from the sea floor near Union Oil Company's Platform A (Allen, 1969). The second spill (December 21, 1969) occurred from a break in an underwater pipeline serving Platform A, and an estimated 60 metric tons were released. Oil from the first spill affected approximately 100 miles of coastline (Fig. 1) and persisted in scattered patches for several months. In December, oil from the second spill was most conspicuous on Carpinteria State Beach (Plate 1A) and Hobson County Park and behaved differently from the crude oil of the first spill in that it remained frothy and fluid during its stay (about 1 month) in the intertidal, readily coating wet and dry surfaces alike. Crude oil is soft and glossy, quickly forming a shiny "skin" on exposure to air, then dulling and hardening after a day or two of weathering.

In the intertidal environment that is the subject of this paper, the effects of both spills were mediated by the time of year when the oil came ashore: winter months lack harsh summer insolation but do inflict large doses of fresh water (possible bleaching of algae due to rain is shown in Plate 1B) and mechanical disturbance from sand movements and storm surf (Plate 2B) on the beaches, leaving relatively fewer organisms to be affected.

Crude oil is a regular feature of the Channel environment, a consequence of variably active seeps that dot the floor of the Channel (Kolpack, 1971). Some seeps are nearly intertidal and fairly active, as at Coal Oil Point. Other seep areas are a mile or more offshore (Carpinteria) and of uncertain activity. Distance from shore is important as one of the factors governing the type of seep product (tarry gobs, iridescent slicks) affecting inshore populations. Measurements (Kolpack, 1971) of water around seeps show that some of the oil actually dissolves in the water column, but most of the oil separates according to specific gravity, fractions with the heavier asphaltic components sinking to form "tar mounds" and lighter components floating as thin slicks. Thin, iridescent slicks are largely dissipated by evaporation if they remain at sea for days; winds, currents and insolation make the presence of such slicks intertidally erratic and rare. If slicks reach shore (they usually do at Coal Oil Point), they are thoroughly worked across intertidal populations by surf. Gobs of tarry material from seeps adhere more readily to warm, dry surfaces than to cool, wet ones and thus stick selectively in the upper intertidal, especially during low tides combined with sunny weather.

There are some major differences between the Santa Barbara spills of 1969 and the *Tampico Maru* accident in Baja California during early spring of 1957 (North, Neushul and Clendenning, 1965; North, 1967). The *Tampico Maru* ran aground at the mouth of a small cove, releasing highly toxic dark diesel (8,000 metric tons) into a confined area, producing an immediate and spectacular kill of marine life. In contrast, the Santa Barbara incident resulted in the release of crude oil about seven miles offshore, producing slicks that remained at sea for several days. These either sank under the influence of tremendous amounts of sediment present from storm runoff or were driven onto beaches by wind and currents. This delay at sea allowed a natural product (crude oil) to lose many of its toxic volatile components through evaporation prior to its arrival on shore. An investigation made soon after the spill by Anderson, *et al.*[2] for the Western Oil and Gas Association reported few immediate deleterious effects on marine organisms of the mainland and Channel Islands.

The difference in consequences of spills according to the degree of refinement of the petroleum product involved is further illustrated by the release of 38,647 metric tons of #2 diesel fuel oil when the barge *Florida* ran ashore off west Falmouth in Buzzard's Bay, Massachusetts (Hampson and Sanders, 1969); a drastic kill of fish, worms, crustaceans and molluscs occurred rapidly, even before the application of detergents. Blumer and co-workers (1970) have pointed out that even though slicks may be sunk and/or dispersed to remove them from view, petroleum products persist in marine food chains. Thus immediate and spectacular kills from refined products that are relatively more toxic than crude oil (the difference in toxicity was pointed out by Clendenning in 1964) may be followed by subtle, long-term effects.

In comparing the Santa Barbara spills with another spill of crude oil, it is necessary to point out that cleanup methods may affect the health of marine

[1] One metric ton = 6.9 barrels, 1 barrel = 42 gallons (60° F, sp. gr. of 0.917 for California crude oil).

[2] Anderson, E. K., L. G. Jones, C. T. Mitchell and W. J. North, "Preliminary report on the ecological effects of the Santa Barbara oil spill."

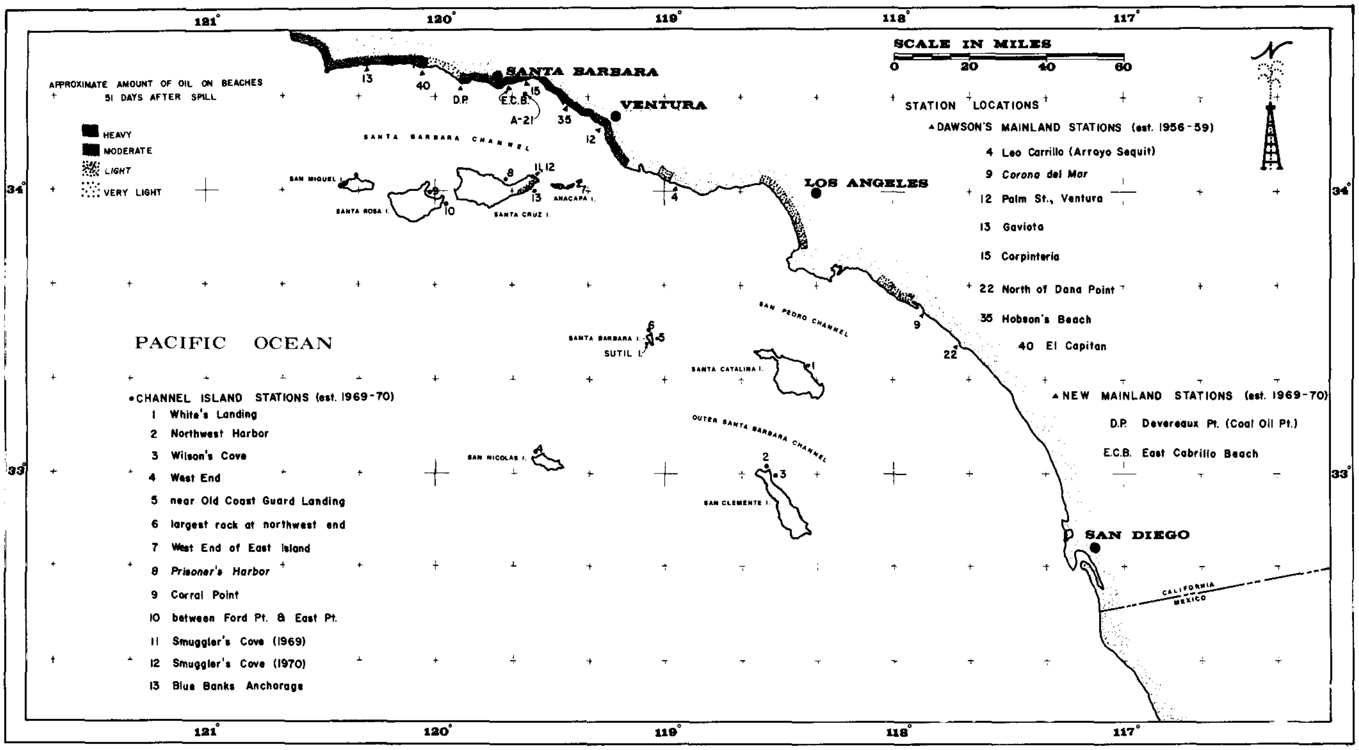

FIGURE 1. California from Point Conception south to Mexico. Locations of study beaches and extent of distribution of crude oil 55 days after the onset of the January 1969 spill (Allen, 1969) are shown. Smallest diameter stipples on coastline do not represent oil cover.

organisms. When the *Torrey Canyon* ran aground on the Seven Stones Reef, 15 miles from Cornwall, England (March 1967) 119,000 metric tons of crude oil escaped. This volume is comparable to that released during the Santa Barbara spills and the accident occurred twice as far from shore. Slicks from the *Torrey Canyon* thus had some time at sea to lose toxic volatile fractions, but cleanup operations involved extensive use of detergents and dispersants on and near shore, thus causing much of the mortality (Smith, 1968). As a result of observations that detergents, dispersants (some are kerosene-based) and their chemical kin were more toxic to marine organisms than crude oil, the spills from Platform A were handled in a different fashion than those from the English disaster. No dispersants were applied inside the one mile limit except when oil penetrated the Santa Barbara Harbor (Gaines, in press). Beaches were cleaned by broadcasting chopped straw over oiled areas (Plate 2A), then scooping the resultant gummy mess into trucks that hauled it away to be burned. During and immediately after the January 1969 spill a study made by marine biologists at the University of California at Santa Barbara (Foster, Neushul and Zingmark, 1969) did not report massive kills of intertidal organisms.

In summary, it is necessary to separate changes due to the Santa Barbara oil spills from the effect(s) of naturally-occurring oil, from seasonal changes, from responses to special events (such as record rainfall) during 1969, and from long-term effects of chronically altered air and water chemistry. These distinctions may be in part accomplished by careful selection of study sites so they span areas inside and outside the influence of the spills and represent combinations of factors affecting intertidal areas.

METHODS

Ten rocky intertidal stations were surveyed monthly from May, 1969 to June, 1970. Eight of these stations were identical with areas surveyed by Yale Dawson in 1956–59 and two were stations established since the first survey. Ranging from Gaviota State Beach, approximately 30 miles north of Santa Barbara, to Dana Point 60 miles south of Los Angeles (Fig. 1), these stations were:

- Gaviota State Beach (Dawson Station 13)
- El Capitan State Beach (Dawson Station 40)
- Coal Oil Point or Devereaux Point (Neushul, New Series 1: est. 1967)
- East Cabrillo Beach (Nicholson-Cimberg Station 1: est. 1969)
- Carpinteria State Beach (Dawson Station 15)
- Hobson County Park (Dawson Station 35)
- Palm Street, Ventura (Dawson Station 12)
- Leo Carrillo State Beach (Dawson Station 4)
- Corona del Mar (Dawson Station 9)
- 1 mile north of Dana Point (Dawson Station 22)

Line intercepts were chosen as the sampling method for this investigation. There are some problems with linear samples: they may miss rare organisms or those with extremely patchy distribution, but this can be overcome by carefully exploring the beach and listing all categories of organisms desired, then comparing this list with the list from the line intercept. This was done for each sample. A line intercept does not guarantee a sample of the complete range of tidal levels at which a particular organism dwells, but does yield a contiguous sample. The rapidity with which a line intercept may be completed (2–3 hours) over a long distance (200 to 500 feet) is a major point in favor of a method used where a site is steadily flooded by the incoming tide. Data were taken so that a quantitative estimate of density and percent occurrence of organisms along the populated length of the station line could be obtained. Finally, the surveys of Dawson and Neushul employed line survey methods comparable to the one used in the present study.

The details of the line intercept have been set forth (Nicholson and Cimber, 1971). Briefly, records were made of the substratum and organisms that intersected the tape at three inch intervals along the entire station line. The shore base point was always the end of the station line. Except when the stations were surveyed at night with the aid of miner's lamps, color transparencies were taken to record the visual aspect of the station area. All data are filed in the Herbarium of the Allan Hancock Foundation (Marine Plants).

Selection of stations to be surveyed was accomplished with the purpose of establishing field controls for the wide variety of factors operating in the field (Tables 1 and 2). Unfortunately, the Southern California mainland has no areas where human interference can be conclusively shown to be absent, thus making it necessary to turn to the Channel Islands for relatively undisturbed controls. For this purpose, 13 stations were established and distributed among all of the islands except for San Miguel Island. Two cruises during the fall of 1969 and one during spring 1970 were made in the Channel Islands and SCUBA divers collected representative samples of marine organisms from depths of 0′ to 10′, 10′ to 20′ and 20′ to 30′ in the station area. Dredging was used in water of 80′ to 120′ depth. No calculations of percent occurrence were made on the basis of the Channel Islands data: comparisons were based on presence or absence of intertidal-shallow subtidal species during appropriate months.

All data were compared on an equal taxonomic basis.

TABLE 1

Major Waste Discharges to Coastal Waters of San Diego, Los Angeles and Ventura Counties

Discharger and/or Location of Discharge	Date of Initial Discharge	Type of Discharge	Volume, mgd, (1970)	Outfall Length (ft.)	Terminus depth (ft.)
San Diego	1963	Primary Effluent	80	11,430	220
In addition, there are three power plants discharging a total of 597 mgd into San Diego Bay, with an average △ T of 12.1°F.					
San Elijo	1966	Primary Effluent	1.1	3,700	52
Encina (Joint Plant)	1965	Primary Effluent	4.5	5,300	100
Encina (Power Plant)	1954	Cooling Water	345	At Beach	
San Onofre Power Plant	1968	Cooling Water	506	2,600	13
San Clemente	1947	Secondary Effluent	1.8	700	12
Dana Point	1959	Primary Effluent	0.8	4,000	35
South Laguna	1955	Secondary Effluent	1.8	1,700	55
Laguna Beach	1958	Primary Effluent	2.0	3,000	80
County Sanitation Districts of Los Angeles County	1937	Industrial and Domestic	380.0	5,000	110
	1937	------	------	6,500	165
Palos Verdes Peninsula	1937	Primary Effluent	------	8,500	215
	1937	------	------	11,900	195
City of Los Angeles, Santa Monica Bay	1959	Industrial and Domestic, mostly Primary Effluent; some Secondary	335.0	effluent 26,400	200
	1957			sludge 36,960	330
City of Oxnard, Ormond Beach	1950	Industrial and Domestic	30.0	6,000	52
		Primary Effluent	------	--	------
City of Port Hueneme, Ormond Beach	1955	Industrial and Domestic	2.0	5,200	60
		Primary Effluent	------	----	------
City of San Buenaventura, Ventura	1938	Industrial and Domestic	1.8	2,500	30
		Primary Effluent	------	----	------
City of Avalon, Santa Catalina Island	about 1930	Raw sewage	Winter 0.14 Summer 0.44	400	125
Southern California Edison Co. El Segundo Generating Station, El Segundo	1953	Cooling	460.8 cooling	2,600	20
		Sewage	0.0045 sewage		
Redondo Beach Generating Station, Redondo Beach	1948	Cooling	1134.7	2,000	20
Ormond Beach Generating Station, Ormond Beach	1971 proposed	Cooling	640.0	1,800	20
Mandalay Generating Station, Oxnard	1958 *	Cooling	253.4	Discharge to Beach	------
City of Los Angeles Department of Water and Power					
Scattergood Steam Plant, El Segundo	1958	Cooling	518.8	1,250	15
Mobil Oil Company, Sea Cliff	1968 *	Oil Brines, Tanker Ballast	11.9	3,100	30
Continental Oil Co., Pitas Point	1967 *	Treated Seawater, Oil Brine	0.273	500	12
Standard Oil Co. of California, El Segundo	1951 *	Cooling, API water	72.0	400	15
Atlantic Richfield Co., Rincon Island	1962 *	Oil Brine	0.26	Rincon Island	Surface
Chancellor-Western Oil and Development Co., Rincon	1963 *	Oil Brine	0.30	nearshore	10
Phillips Petroleum Co., Punta Gorda	1967 *	Oil Brine	0.63	500	20
Standard Oil Co. of California, McGrath Beach	1961 *	Oil Brine	0.14	nearshore	4.0

* Year in which requirements were prescribed.

Compiled March 1971.

TABLE 2

Summary of Factors Affecting Mainland Stations

Factor	Station									
	Gaviota	El Capitan	Coal Oil Pt.	East Cabrillo	Carpinteria	Hobson	Palm St., Ventura	Leo Carrillo	Corona del Mar	North of Dana Pt.
Jan. 1969 oil spill (Allen, 1969)	Moderate amounts	Moderate amounts	Moderate amounts	Heavy amounts	Heavy amounts	Heavy amounts	Moderate amounts	None	None	None
Dec. 1969 oil spill	--	--	--	--	Moderate amounts	Moderate amounts	--	--	--	--
Natural oil seeps	Nearby	Nearby	Near shore active	--	About 1 mile offshore active	--	--	--	--	--
Substratum	Large rocks	Large rocks	Shelf and sand	Metal groin	Shelf and sand	Rocks	Rocks	Rocks	Shelf	Rocks
Sand movement	Little	Little	Moderate	Little	Moderate	Moderate	Heavy, station covered 69–70	Heavy, station covered 2 months	Moderate	Moderate
Usage	Public camping	Public camping	Public collecting, surfing	Public swimming	Public collecting, camping	Public clamming, camping	Public surfing	Public camping, surfing	Public collecting, swimming	Private surfing, swimming
Industrial effluents	--	--	--	--	--	--	Possible large amounts	Possible large amounts	Possibly affected by Newport Harbor water	--
Agricultural effluents	--	--	--	--	Possible moderate amounts	--	Possible moderate amounts	--	--	--
Nearest sewage outfall	See Table 1									
Fresh water	Small creek	Small creek	--	--	Nearby creeks, town flooded winter, 1969	--	Heavy, Ventura River	Heavy, large creek	--	--

TABLE 3

Occurrence of Oil on the Ten Rocky Intertidal Mainland Stations

Date	Stations									
	Gaviota	El Capitan	Coal Oil Point	East Cabrillo	Carpinteria	Hobson's	Palm St., Ventura	Leo Carrillo	Corona del Mar	North of Dana Point
5/69	--	--	--	413	--	34	--	--	--	--
6/69	42	0	24	380	1	8	--	--	--	--
7/69	40	16	49	479	75	30	0	0	8	0
8/69	0	0	88	230	0	0	--	0	22	0
9/69	1	0	35	384	0	0	--	0	11	0
10/69	20	30	96	177	5	0	0	0	21	0
11/69	38	12	41	--	--	0	--	0	--	0
12/69	23	--	195	308	106[2]	670[2]	--	0	--	--
1/70	--	0	8	251	1	291[2]	--	0	2	0
2/70	13	36	59	254	48	6	--	0	6	0
3/70	7	18	44	208	114	1	--	0	4	0
4/70	--	--	--	--	--	--	--	--	--	--
5/70	27	9	43	92	1	0	--	0	11	0
6/70	63	4	28	156	0	0	--	0	24	0
Total	274	125	710	3332[1]	351	1040	0	0	109	0
Average	25	11	59	277	32	80	0	0	12	0

Note: Table indicates number of times oil was observed at three-inch intervals along transect; dashes (--) indicate no oil data available.
[1] This represents the crude oil (persistent, weathered) deposited primarily during the January, 1969 spill; counted repeatedly.
[2] Oil (treated) deposited during the December 1969 spill.

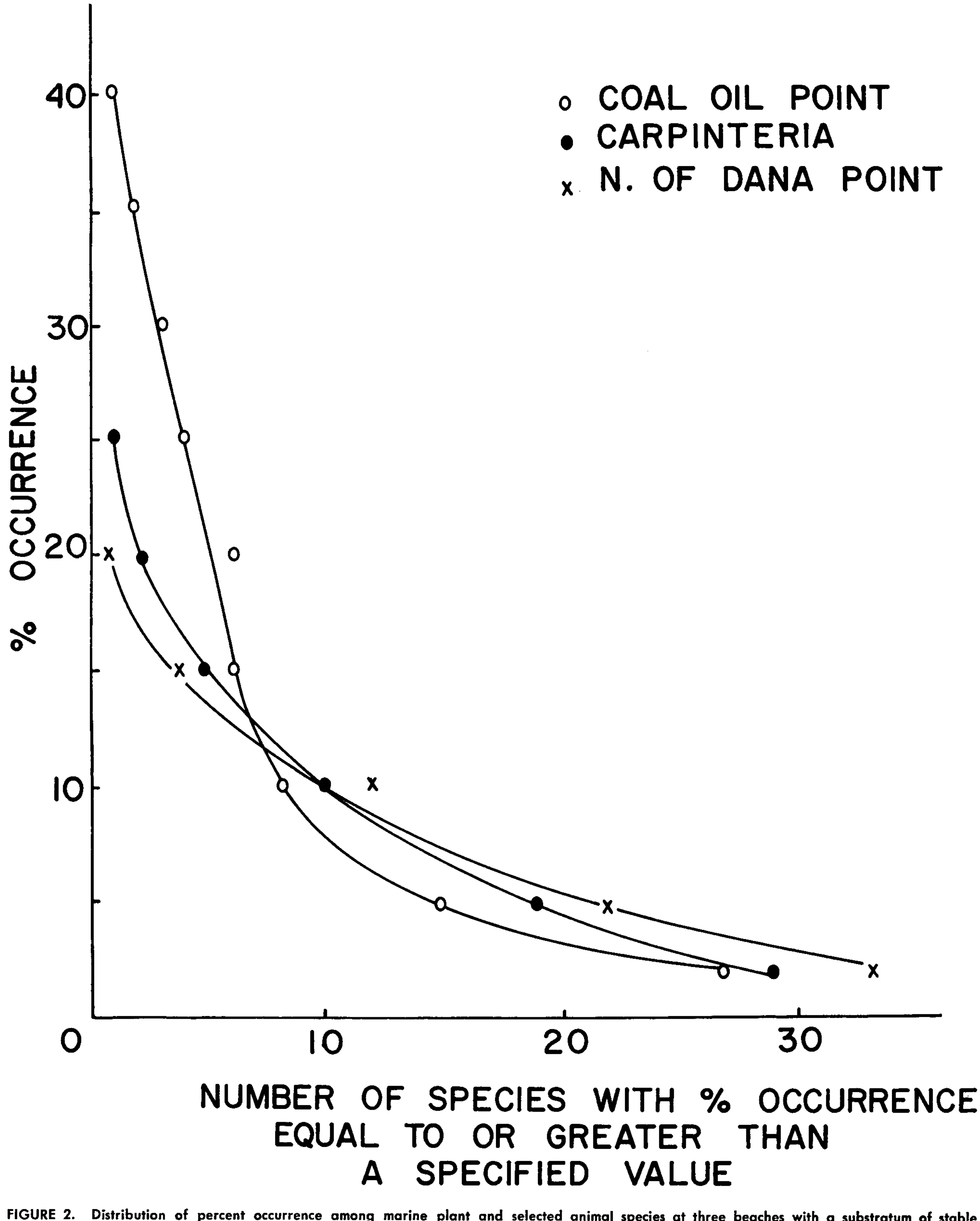

FIGURE 2. Distribution of percent occurrence among marine plant and selected animal species at three beaches with a substratum of stable rock. Crude oil from seeps is nearly continuous at Coal Oil Point, erratic and rare at Carpinteria and not known to occur at the beach one mile north of Dana Point (Salt Creek Road). (Coal Oil Point receives 50 to 70 barrels per day from the seeps (Allen, *et al.*, 1970).)

OBSERVATIONS

Crude oil from the first spill (January 1969; Fig. 1) persisted as hard asphaltic patches in the upper intertidal for at least 7 months, whereas oil from the second spill (December 1959) had been treated with agents that left it fluid and frothy, possibly accounting for the relatively rapid (about 1 month; see Table 3) disappearance of this oil from intertidal rocks. For reasons involving the probability of long-term repercussions, it is probably not safe to assume that no damage (or minimal damage) occurs, regardless of treatment or refinement of oil, even if it is present for only a short time.

Distribution of oil among the 10 beaches studied is shown in Table 3. At a given beach, oil adhered more readily to relatively warm, dry surfaces in the upper intertidal (Plate 6B) and stuck rarely and more reversibly in the cooler, wetter lower intertidal.

Coal Oil Point was the only beach under study where iridescent oil films were continuously present at times other than during the spills. Both the number of plant species and distribution of abundance within the species is noticeably different at Coal Oil Point if

TABLE 4

Percent Occurrence of Selected Marine Invertebrates at Three Stations During the Period from June 1969 through June 1970

Invertebrate / Date	Coal Oil Point											
	6/69	7/69	8/69	9/69	10/69	11/69	12/69	1/70	2/70	3/70	5/70	6/70
Acanthina	†	†	--	†	†	--	--	†	†	†	†	†
Acmaea	†	2	--	†	†	†	--	†	--	†	†	†
Anthopleura	41	11	8	25	38	25	26	37	30	33	37	45
Balanus	†	†	--	†	--	†	†	†	--	†	†	†
Chthalamus	3	†	†	†	†	†	†	†	--	†	†	†
Pollicipes	†	†	--	--	--	--	--	--	†	†	†	†
Tetraclita	--	†	--	--	--	--	--	--	--	--	--	--
Littorina	--	†	--	†	--	--	--	2	†	2	--	--
Mytilus	--	2	--	4	3	4	4	5	3	5	2	5
Pachygrapsis	*	*	*	*	*	*	*	*	*	*	*	*
Pagurus	†	2	2	†	2	†	†	†	3	†	†	†
Pisaster	--	--	--	†	--	†	--	--	--	--	--	--
Tegula	†	†	--	2	†	--	†	†	†	†	†	--

TABLE 4—Continued

Invertebrate / Date	Carpinteria											
	6/69	7/69	7/69	8/69	9/69	10/69	12/69	1/70	2/70	3/70	5/70	6/70
Acanthina	†	†	†	†	†	†	†	†	†	†	2	†
Acmaea	2	3	4	3	3	3	†	†	†	†	†	†
Anthopleura	24	26	29	32	26	13	15	34	14	33	22	18
Balanus	6	7	4	4	2	2	†	†	†	†	†	3
Chthalamus	11	14	11	10	6	7	5	6	5	7	4	7
Pollicipes	3	4	6	2	3	3	†	2	†	2	†	2
Tetraclita	--	†	--	--	†	--	†	--	†	--	--	--
Littorina	--	†	--	†	†	†	--	†	--	--	--	†
Mytilus	13	15	14	14	16	9	9	8	8	8	5	7
Pachygrapsis	*	*	*	*	*	*	*	*	*	*	*	*
Pagurus	†	†	†	†	†	†	--	2	†	†	--	†
Pisaster	--	†	--	--	†	--	--	--	--	--	--	†
Tegula	†	†	†	2	3	3	2	5	2	6	4	2

TABLE 4—Continued

Invertebrate / Date	Beach 1 Mile North of Dana Point										
	7/69	8/69	8/69	9/69	10/69	11/69	1/70	2/70	3/70	5/70	6/70
Acanthina	†	2	--	†	--	--	--	2	--	†	†
Acmaea	12	5	4	6	†	†	3	8	†	3	3
Anthopleura	8	7	5	10	2	2	6	--	7	2	5
Balanus	9	6	4	†	†	†	2	†	--	--	--
Chthalamus	45	32	29	10	33	33	26	27	34	51	31
Pollicipes	2	†	--	--	†	†	--	†	†	--	--
Tetraclita	†	†	4	†	--	--	†	--	†	†	--
Littorina	5	2	†	†	--	--	--	†	--	†	--
Mytilus	5	†	†	†	†	†	†	†	2	2	†
Pachygrapsis	*	*	*	*	*	*	*	*	*	*	*
Pagurus	†	3	5	4	7	2	8	5	5	3	2
Pisaster	†	--	--	†	†	--	†	†	†	†	†
Tegula	2	3	2	2	14	4	7	5	†	4	5

† = less than 2% occurrence.
* = observed but not recorded on the station line

TABLE 5

Percent Occurrence of Selected Marine Algae at Coal Oil Point During 1969 and 1970

Organism	Date											
	6/69	7/69	8/69	9/69	10/69	11/69	12/69	1/70	2/70	3/70	5/70	6/70
Phyllospadix spp.	5	17	38	8	4	8	2	2	5	4	13	13
Bryopsis hypnoides	--	--	--	*	--	--	--	--	--	--	--	--
Chaetomorpha aerea	--	--	--	--	--	--	--	--	--	*	--	--
Enteromorpha spp.	13	--	†	4	†	3	16	24	13	23	6	4
Ulva spp.	11	6	25	14	12	17	8	8	18	19	18	8
Ectocarpus spp.	--	†	†	--	--	--	*	--	--	--	--	--
Egregia laevigata	--	†	†	†	*	†	--	--	†	†	†	2
Endarachne binghamiae	--	--	--	--	--	†	†	†	†	†	--	--
Pelvetia fastigiata	--	--	--	--	†	--	--	--	--	--	2	--
Ralfsia spp.	--	--	--	--	--	†	2	†	†	2	†	†
Scytosiphon lomentaria	--	†	--	--	--	--	†	†	†	†	--	--
Agardhiella tenera	2	†	--	--	--	--	--	--	--	--	†	†
Anisocladella pacifica	--	--	--	--	--	--	--	--	†	--	--	--
Bangia fuscopurpurea	--	--	--	--	--	--	†	*	--	--	--	*
Bossiella spp.	--	--	--	†	†	--	--	†	--	--	--	--
Microcladia coulteri	--	--	--	--	--	--	--	--	--	†	--	†
Centroceras clavulatum	--	--	--	*	*	*	*	--	--	--	*	*
Ceramium spp.	13	13	24	7	13	4	†	4	5	7	10	5
Chondria nidifica	--	--	--	*	--	--	--	--	*	*	--	†
C. pacifica	--	--	--	*	*	*	*	--	--	*	--	--
Corallina vancouveriensis	†	2	†	3	8	13	13	8	5	8	†	3
Cryptopleura spp.	†	--	†	†	--	†	--	--	--	†	†	†
Gastroclonium coulteri	--	†	--	--	6	†	--	--	--	--	†	†
Gelidium coulteri	*	--	†	†	†	†	3	†	†	†	†	--
G. crinale	--	--	--	--	--	*	--	--	--	*	--	--
G. purpurascens	†	--	--	--	*	--	--	--	*	--	--	--
Gigartina canaliculata	11	5	4	9	8	5	3	5	7	3	7	8
G. leptprhyncos	3	†	†	--	†	†	†	†	†	2	6	†
G. spinosa-armata complex	--	†	--	†	--	--	--	--	--	--	--	--
Gracilariopsis spp.	*	†	4	†	*	8	6	†	2	3	*	†
Gymnogongrus spp.	--	--	--	--	†	--	--	†	--	--	--	--
Iridaea spp.	--	--	--	--	--	--	--	--	--	--	--	†
Laurencia spp.	--	--	--	--	†	--	--	†	--	--	--	--
L. pacifica	†	--	†	†	†	3	--	†	†	†	†	†
Lithothamnion spp.	--	2	--	--	†	--	†	†	--	*	--	--
Lithothrix aspergillum	--	--	--	*	--	--	*	†	--	--	--	--
Melobesia mediocris	--	7	--	7	3	3	†	†	†	--	--	--
Plocamium coccineum v. *pacificum*	--	†	--	*	--	*	--	--	*	*	†	†
Polysiphonia spp.	*	--	--	*	--	4	6	†	5	3	†	†
Porphyra perforata and *P. thuretii*	†	--	†	†	--	--	--	†	†	†	2	†
Pterosiphonia spp.	*	--	--	*	*	*	†	†	*	†	†	†
Rhodoglossum affine	--	--	†	--	†	--	--	--	--	--	--	--
R. americanum	--	--	--	--	--	†	--	--	--	--	--	--
Rhodymenia spp.	--	--	--	--	--	--	--	--	--	†	†	--
Smithora naiadum	5	12	34	†	--	†	*	†	--	--	--	10
Spermothamnion snyderae	--	7	--	--	*	*	*	--	--	--	--	--
Stenogramme interrupta	--	--	--	--	--	--	--	†	--	--	--	--
Diatoms	--	--	--	--	--	*	*	--	--	†	†	--

† = less than 2% occurrence.
* = observed but not recorded on the station line.

these statistics are used to compare it to other beaches (Fig. 2; Tables 4–7). Coal Oil Point was compared with Carpinteria State Beach and the beach 1 mile north of Dana Point because all three areas have similar (but not identical) species composition and physical substratum (principally stable rock reef, moderately open coast). In brief, Coal Oil Point has fewer species than the other two beaches, but some of them are highly abundant (Fig. 2). Plate 3B shows the visual aspect of this beach, covered in large part with patches composed of a single species (*Anthopleura* and *Phyllospadix* are most conspicuous in the photograph).

Representative oil damage to the upper intertidal is shown in Plate 3A. Barnacles (*Balanus*) tall enough to project beyond the crust of oil survived; shorter

TABLE 6

Percent Occurrence of Selected Marine Algae at Carpinteria State Beach During 1969 and 1970

Organism	Date											
	6/69	7/69	7/69	8/69	9/69	10/69	12/69	1/70	2/70	3/70	5/70	6/70
Phyllospadix spp.	11	8	6	3	9	4	9	6	10	8	10	7
Enteromorpha spp.	3	7	†	†	5	5	5	8	3	3	†	3
Ulva spp.	19	25	18	10	17	8	7	13	22	32	36	48
Cystoseira osmundacea	--	--	--	--	--	--	--	--	--	†	--	--
Egregia laevigata	3	†	†	†	2	†	†	†	†	†	3	5
Endarachne binghamiae	--	--	--	--	--	--	--	†	†	†	--	--
Laminaria sinclairii	†	--	†	--	--	--	--	--	--	--	--	--
Macrocystis pyrifera	--	--	--	--	--	--	--	--	--	--	†	--
Pachydictyon coriaceum	--	--	--	--	--	--	--	--	--	*	--	--
Ralfsia spp.	†	--	†	†	†	†	†	†	†	†	†	†
Scytosiphon lomentaria	†	--	--	†	--	--	--	--	--	--	--	--
Agardhiella tenera	--	--	--	--	--	--	--	--	†	†	4	2
Bangia fuscopurpurea	--	--	--	--	--	--	--	2	†	†	--	*
Bossiella spp.	†	†	--	†	†	†	†	†	†	†	†	†
Botryoglossum farlowianum	--	--	--	--	--	--	--	†	--	--	*	--
Centroceras clavulatum	--	*	--	--	--	--	--	--	--	--	--	--
Ceramium spp.	--	4	3	3	5	3	†	6	4	8	12	6
Chondria nidifica	--	*	--	--	*	*	*	*	--	*	*	*
C. pacifica	--	*	--	--	--	--	--	--	--	--	--	--
Corallina officinalis v. *chilensis*	--	--	--	--	--	--	--	--	--	--	--	--
C. vancouveriensis	†	2	†	2	4	8	8	15	5	10	3	3
Cryptopleura spp.	--	2	†	†	3	†	†	†	2	†	†	†
Gastroclonium coulteri	2	--	†	--	9	--	--	--	†	†	--	†
Gelidium coulteri	4	5	--	2	2	†	†	2	2	4	10	9
G. crinale	--	*	--	*	*	--	--	--	--	--	--	--
G. purpurascens	--	--	--	--	--	--	--	--	--	--	--	*
G. robustum	--	--	--	*	--	--	--	--	--	--	--	--
Gigartina canaliculata	10	17	11	9	12	7	10	9	7	10	9	14
G. harveyana	--	--	--	--	--	--	--	--	--	--	*	†
G. leptorhynchos	--	†	†	--	*	*	†	†	†	2	2	2
G. spinosa-armata complex	†	†	†	--	†	†	†	†	†	†	†	--
Gracilaria spp.	--	--	--	2	--	--	--	--	--	--	--	--
Gracilariopsis spp.	--	2	3	2	†	10	3	4	2	5	4	2
Grateloupia spp.	--	--	--	†	--	--	--	--	--	--	--	--
Gymnogongrus spp.	--	--	--	--	--	--	--	†	†	†	--	--
Iridaea spp.	--	--	--	--	--	--	--	--	--	*	--	--
Laurencia spp.	--	--	--	--	†	†	†	†	--	--	*	†
Lithothamnion spp.	--	--	†	†	†	†	†	--	†	†	--	*
Melobesia mediocris	--	--	†	†	†	2	†	2	*	--	--	*
Microcladia coulteri	--	--	--	--	--	--	--	--	--	†	†	†
Nienburgia andersoniana	--	--	--	--	--	--	--	--	--	*	*	--
Plocamium coccineum v. *pacificum*	--	*	†	†	*	*	*	*	--	*	*	†
Polysiphonia spp.	--	*	--	--	†	4	6	6	†	7	*	6
Porphyra perforata and *P. thuretii*	3	--	†	†	†	--	†	†	2	3	†	†
Prionitis spp.	--	--	--	--	--	--	--	--	†	--	--	--
Pterocladia pyramidale	--	--	--	--	--	4	--	--	†	--	--	--
Pterosiphonia baileyi	--	--	--	*	--	†	--	--	--	--	--	--
P. dendroidea	--	--	--	--	--	†	*	†	*	--	†	†
Rhodoglossum affine	--	†	--	--	--	--	--	†	†	†	†	†
R. americanum	--	--	--	--	--	†	--	†	--	†	--	--
Rhodymenia spp.	--	--	--	--	--	*	--	--	--	*	--	†
Smithora naiadum	6	7	6	3	7	†	2	2	†	7	8	8
Spermothamnion snyderae	--	--	†	†	--	--	*	--	--	--	--	--
Diatoms	--	--	--	--	†	--	*	--	8	†	--	--

† = less than 2% occurrence.
* = observed but not recorded on the station line.

TABLE 7

Percent Occurrence of Selected Marine Algae at the Beach One Mile North of Dana Point During 1969 and 1970

Organism	Date										
	7/69	8/69	8/69	9/69	10/69	11/69	1/70	2/70	3/70	5/70	6/70
Phyllospadix spp.	†	--	†	†	--	--	†	--	†	†	†
Enteromorpha spp.	--	2	5	--	--	--	--	--	--	--	†
Ulva spp.	2	17	13	4	8	--	†	4	5	12	8
Coilodesme rigida	*	--	--	--	--	--	--	--	--	--	--
Colpomenia sinuosa	†	--	--	--	†	--	--	--	--	4	†
Dictyopteris zonarioides	--	--	--	--	--	--	--	--	†	--	--
Dictyota flabellata	*	--	--	--	--	--	--	--	--	--	†
Ectocarpus spp.	†	--	--	--	3	--	--	--	--	--	--
Eisenia arborea	--	--	--	--	--	--	--	--	--	--	†
Egregia laevigata	2	2	†	†	†	†	2	†	†	†	7
Endarachne binghaniae	†	--	4	2	†	--	†	--	--	†	†
Hesperophycus harveyanus	--	--	†	--	--	--	--	--	--	--	--
Macrocystis pyrifera	†	--	†	--	--	--	--	--	--	--	†
Pachydictyon coriaceum	*	--	--	--	*	--	*	*	*	†	†
Pelvetia fastigiata	11	6	4	4	2	8	3	2	4	6	4
Petrospongium rugusom	2	--	†	--	--	--	--	--	--	--	--
Ralfsia spp.	†	--	5	3	7	†	8	4	3	3	4
Sargassum agardhianum	--	--	--	--	*	--	--	--	--	--	*
Scytosiphon lomentaria	--	--	--	--	--	--	--	--	--	†	--
Zonaria farlowii	*	--	--	--	*	--	*	--	*	*	†
Acrosorium uncinatum	--	--	--	*	--	--	--	--	--	--	--
Anisocladella pacifica	--	--	--	--	--	*	--	--	--	--	--
Bossiella spp.	4	--	2	--	†	--	--	--	--	--	†
B. dichotoma v. *gardneri*	--	--	--	--	--	--	†	--	--	--	--
Centroceras clavulatum	--	--	--	*	--	*	*	--	--	--	--
Ceramium spp.	†	--	--	†	--	*	7	6	†	†	†
Coeloseira compressa	†	--	--	--	--	--	--	--	--	--	--
Corallina officinalis v. *chilensis*	*	--	--	--	--	--	--	--	*	*	--
C. vancouveriensis	†	5	6	7	18	†	8	4	5	3	5
Cryptopleura spp.	--	--	--	--	--	--	--	--	--	--	*
Endocladia muricata	--	--	--	*	--	--	--	--	--	--	--
Erythrocystis saccata	†	†	†	†	†	--	--	--	--	--	†
Gastroclonium coulteri	†	--	--	--	--	--	--	--	†	†	--
Gelidium coulteri	4	--	--	2	†	--	4	7	19	2	†
G. crinale	*	*	*	*	*	*	*	*	*	*	*
G. purpurascens	--	--	--	--	*	*	*	--	--	*	*
G. robustum	--	--	--	--	*	--	--	--	--	--	--
Gigartina canaliculata	†	2	6	10	5	†	12	11	14	3	3
G. leptorhynchos	--	*	--	†	--	--	--	†	†	†	†
G. spinosa-armata complex	--	--	--	†	--	--	--	--	--	--	--
Gracilariopsis spp.	--	--	--	--	--	--	--	--	--	--	†
Grateloupia spp.	†	--	--	--	--	--	--	--	--	--	--
Herposiphonia secunda	*	--	--	--	--	--	--	--	--	--	--
Hildenbrandia sp.	†	--	--	--	--	--	--	--	--	--	--
Jania natalensis	*	--	--	--	--	--	*	--	--	--	--
Laurencia spectabilis	*	--	--	--	--	*	*	--	--	*	†
L. pacifica	2	7	9	10	9	†	4	2	†	2	8
Lithothamnion spp.	--	†	--	--	2	--	2	†	†	--	--
Lithothrix aspergillum	†	--	--	--	--	--	†	--	--	--	†
Melobesia mediocris	†	--	†	--	--	--	†	--	--	--	†
Plocamium coccineum v. *pacificum*	--	--	*	--	--	--	†	--	--	†	†
Polysiphonia spp.	*	--	--	*	5	--	†	--	†	*	--
Porphyra perforata and *P. thuretii*	*	3	--	--	--	--	3	†	2	†	--
Pterocladia pyramidale	*	†	--	†	4	†	5	3	*	†	3
Pterosiphonia dendroidea	--	--	--	--	--	--	†	--	--	--	--
Rhodoglossum affine	--	--	--	--	*	--	--	--	--	*	--
R. americanum	*	--	--	--	--	--	--	--	--	--	--
Smithora naiadum	--	--	--	--	--	--	--	--	--	--	†
Diatoms	2	--	--	--	--	--	--	--	--	--	--
Grazed or Turf Algae	10	†	†	†	†	†	†	†	†	†	†
Pterochondria woodii	--	--	--	†	--	--	--	--	--	--	--
GATGOR[1]	3	10	4	--	--	--	--	--	--	--	--

[1] GATGOR = Green Algae That Grow On Rocks: a term used to describe films of green algae consisting of unicellular forms and/or microscopic phases of macroscopic species.
† = less than 2% occurrence.
* = observed but not recorded on the station line.

species (*Chthalamus*) were smothered. Juvenile barnacles established themselves on weathered oil; they were lost when the asphalt layer finally crumbled away. Smothering in the upper intertidal was frequent but occurred in discontinuous patches.

Comparison of data from spring 1969 and 1970 is made in Table 8. There is a tendency for the beaches affected by the spills (Gaviota State Beach to Hobson County Park) to show an increase in plant species over spring of 1969. All beaches studied were subjected to flooding; exceptional cases are noted in Table 2. Hobson County Park was subjected to constant mechanical disruption by clammers.

Table 9 documents a decade-long downward trend in number of intertidal plant species. Factors affecting the study beaches during this time are qualitatively shown in Table 2 and more quantitatively in Table 1. The average decline in number of intertidal species of plants between 1956–59 and 1970 is 63%. Details of species recorded in 1956–59 but not recorded in 1969–70 may be found in an earlier paper (Nicholson and Cimberg, 1971; Tables 6 and 7). The latter tables show different constellations of species missing from each beach.

Winter and summer months are characterized by populations of different plant species and differing abundances of persistent species (Tables 5–7). An interesting feature of cobble beaches is that they usually show half the species in winter that they have in summer (Table 10); assuming that a sufficient variety of plants is present to show this type of change (Palm Street, Ventura is excluded on this basis: see Plate 4B). Large cobbles (1 to 2 feet in diameter) are radically shifted about by winter surf, mimicking the action of a ball mill.

Public use of beaches was found to be highly destructive of intertidal areas. Sightseeing in tidepools results in trampling of both plants and animals when they are especially vulnerable. In the case of upper intertidal seaweeds, these commonly dry out to the extent that they are brittle and fragile. Such plants are shattered by trampling. Clamming also results in considerable mechanical disturbance to a beach. At Hobson County Park each low tide was characterized by swarms of clammers (Plate 4A) who routinely took many limits apiece of the clam *Protothaca staminea*, failed to replace large rocks moved for digging (all to whom it was suggested that the beach would benefit by restoration of disturbed areas refused to make the effort), and who did not bury the clams they dug up but did not use. In May of 1970, nearly 80% of the station line was overturned by the activities of clammers. The devotion with which people will pursue free clams can be illustrated by the observation that clamming slackened only slightly during the time the intertidal was covered with oil in December 1969: at least 12 humans were observed with most of their clothes and bodies liberally smeared with oil, busily digging clams.

TABLE 8

Number of Plant Species Reported on Spring Stations, 1969–70

Stations	1969		1970		Change between June 1969 and 1970
	May	June	May	June	
Gaviota State Beach	--	23	10	18	−5
El Capitan State Beach	--	15	6	17	+2
Coal Oil Point (Devereaux Pt.)	--	19	24	26	+7
East Cabrillo Beach	6	5	6	6	+1
Carpinteria State Beach	--	19	30	32	+13
Hobson County Park	15	23	15	16	−7
Palm Street, Ventura	--	4	--	4	0
Leo Carrillo State Beach	--	22	19	16	−6
Corona del Mar	--	5	18	17	+12
One mile north of Dana Point	--	35	24	31	−4

TABLE 9

Number of Marine Plant Specimens Recorded on the Rocky Intertidal Mainland Stations During this Study Compared to Previous Investigations Conducted in Comparable Months (Fall-Winter)

Investigation and Year	Gaviota State Beach	El Capitan State Beach	Carpinteria State Beach	Hobson County Park	Palm St., Ventura	Leo Carrillo State Beach	Corona del Mar	One mile north of Dana Point
Dawson, 1959—Average 1956–1959	28	25	36	26	18	32	28	31
Neushul, 1967	13	20	29	13	17	14	--	--
Nicholson and Cimberg, 1969 to 1970 Average	13	7	26	7	4	7	9	14
Percent Decrease[1] Between 1956 and 1970	54	72	28	73	78	78	68	55

[1] $\text{Percent decrease} = \dfrac{\text{average ('56–'59)} - \text{average ('69–'70)}}{\text{average '56–'59}} \times 100$

Average Number of Species per Visit
Dawson 1956–59: 29 (8 stations)
Neushul 1967: 17 (6 stations)
Nicholson and Cimberg 1971: 11 (8 stations)

A heavy, persistent cover of sand may also dramatically reduce intertidal populations (Plates 5A, B, 6A), as happened at Leo Carillo State Beach in January and February of 1970. By February, the plants that had managed to survive longest (*Egregia menziesii* var. *laevigata* and *Macrocystis pyrifera*) had died back to stumps of stipes. By mid-March 1970, 15 young plant and one animal species were recorded on the uncovered portions of rocks. A similar sandfill with partial coverage of *Egregia* and *Macrocystis* was reported by Dawson in February 1958 (Dawson, 1965).

Preliminary surveys of the marine flora of the Southern California Channel Islands (Table 11) show an average number of species (36) obtained at single visits that is higher than the averages obtained during the mainland studies conducted between 1956 and 1970 (Table 9).

DISCUSSION

General Features of Intertidal Algal Populations in Southern California

The physical-chemical setting for marine organisms is established by circulation patterns of oceanic water, runoff from continental areas or other factors governing nutrient levels and the quality and quantity of light penetrating to various depths. Given sufficient time, species distribute themselves throughout a geographical area in patterns corresponding to the stresses (or lack of stresses) the environment dictates. Natural patterns need to be differentiated from disturbed patterns to avoid error in assigning presence or absence of species to conditions observed as a result of human activities. As an example, it is improper to attribute the absence of cold water and/or low light intensity adapted species to the presence of oil or sewage when the area in question is characterized by warm water and/or high light intensities.

If heavily populated industrial centers develop along a coastline, their use of coastal waters can affect previously-developed distribution patterns. The ways in which human activities affect marine populations can be arbitrarily divided into two categories based on duration of a condition(s): acute (short term effects) and chronic (long term effects). Arbitrariness of the above designations is evident if it is pointed out that a sufficient number of acute events can approach and/or equal a chronic state. An acute event may also produce subtle repercussions that outlast its initial phases.

One of the dominant features of the natural distribution of algae in Southern California is their coincidence with areas of predominantly cool or warm water. The northern and southern Channel Islands, two main current periods, and wind-governed periods of upwelling contribute to a complex circulation pattern.

Two currents dominate water conditions in California: the California and Davidson currents. Although the term current brings to mind the image of a river or of the Gulf Stream, these two currents on the West Coast are composed of a complex system of gyres and eddies that transports water north (Davidson Current) or south (California Current) at velocities usually between 0.25 and 0.5 knots. At the surface, the California Current governs circulation for most of the year. The Davidson Current stays submerged (200 m) until late fall and early winter when north winds weaken. Under these latter conditions it forms

TABLE 10

Number of Species of Marine Plants Present During Winter and Early Summer

Location	December 1969	June 1970	All Year Total	Type of Rocky Substratum
Gaviota State Beach (Dawson Sta. 13)	16	18	48	stable rock reef
El Capitan State Beach (Dawson Sta. 40)	8	17	34	unstable: large cobbles (1′ + dia.)
Coal Oil Point (New Series 1)	25	26	49	stable rock reef
East Cabrillo Beach (Nicholson-Cimberg 1)	7	6	18	metal groin
Carpinteria State Beach (Dawson Sta. 15)	25	31	54	stable rock reef
Hobson County Park (Dawson Sta. 35)	7	16	44	unstable: large cobbles
Palm Street, Ventura (Dawson Sta. 12)	10/69 4	7/70 4	4	unstable: large cobbles
Leo Carrillo St. Beach (Dawson Sta. 4)	13	16	41	cobble and stable rock
Corona del Mar (Dawson Sta. 9)	12	17	28	stable rock reef
One mile north of Dana Point (Dawson Sta. 22)	11/69 16	33	60	cobble and stable rock

TABLE 11

Preliminary Sampling of the Marine Flora of the Southern California Channel Islands: Intertidal and Shallow Subtidal Areas

Station	Date	Number of Species
Santa Rosa Island		
Corral Point	12/69	31
Between Ford Point and East Point	12/69	24
Santa Cruz Island		
Prisoner's Harbor	12/69	28
Smuggler's Cove	12/69	33
Smuggler's Cove	4/70	45
Blue Banks Anchorage	4/70	61 (14 fms: biological chain dredge)
Anacapa Islands		
Southern exposure on East Island	12/69	36
Santa Barbara Island		
Near Coast Guard Landing	12/69	33
San Nicholas Island		
Northwest End	12/69	41
Santa Catalina Island		
Isthmus Cove	1969–70	68

Note: Unless otherwise specified, data were obtained by skin and SCUBA divers at single visits. The Channel Islands are not as well explored as the mainland, so that species lists are minimal. This investigation added roughly 10% more species to the state's marine flora: some of these species are as yet undescribed and some were well-known, but had not been reported from California.

at the surface close inshore, extending from the tip of Baja California as far north as Washington.

Water circulation is further complicated by upwelling in many areas under the influence of winds blowing parallel to the shore. California shares this circulation pattern with Peru, since both coastlines have ranges of mountains that deflect winds into paralleling the shore. In California, upwelling is particularly strong south of the two large land masses of Cape Mendocino and Point Conception. Presence of offshore islands also affects water circulation on the continental shelf (Fig. 3).

Two prominent features of the circulation in the Santa Barbara Channel are a large counterclockwise gyre in the northern part of the Channel and a smaller clockwise gyre in the southern end. These two features strongly affect the distribution of marine organisms on the Channel shores.

The southern gyre can distribute any floating debris or liquid wastes (at least 30 or more mgd, see Table 1) discharged into the sea at Ventura-Oxnard-Hueneme to areas south of these settlements. And longshore drift can move 600 cubic yards of sand a day (contaminated or clean) south past a given point on a beach in average weather.

The northern gyre distributes cold water from regions north of Point Conception along the mainland side of San Miguel Island, Santa Rosa Island and the northwestern end of Santa Cruz Island. During August, a time of warm water (see temperature data in Fig. 3), islands influenced by this gyre show an average of 4°C cooler surface temperatures than the mainland waters opposite them.

One surprising feature of the annual temperature variation in the Channel is that the coldest temperatures occur in May. During May, the California Current is strong, sweeping cold water from the North. In November and December, warmer water from Baja California moves along close as far as Point Conception (the effect of this water is less north of the large promontory), but the effect of warm water is tempered by upwelling of cooler waters during this time. Seasonal differences in temperature encountered north (15°C in August, 10–13°C in March) and south (16–20°C in August, 14–15°C in March) of the cape and different durations of the temperature variations result in major floral and faunal changes at this point.

Marine algae favoring cold or warm waters distribute themselves accordingly, with intermediate forms on the islands of Anacapa, Santa Barbara and the southeastern end of Santa Cruz Island. Transition from cold water species (or forms) characteristic of habitats north of Point Conception to species adapted to warmer waters is more gradual in the Channel Islands than on the mainland because cold water swept south by the northern gyre allows species characteristic of the northern California mainland to penetrate farther down the island chain. A number of species found in Baja California are found on the more southerly Channel Islands of Santa Catalina and San Clemente. The bulk of the Channel Islands algal species are shared with the mainland.

A skeleton outline of the relatively undisturbed distribution pattern of species that existed around the turn of the century can be documented from collections of W. A. Setchell and N. L. Gardner, and such

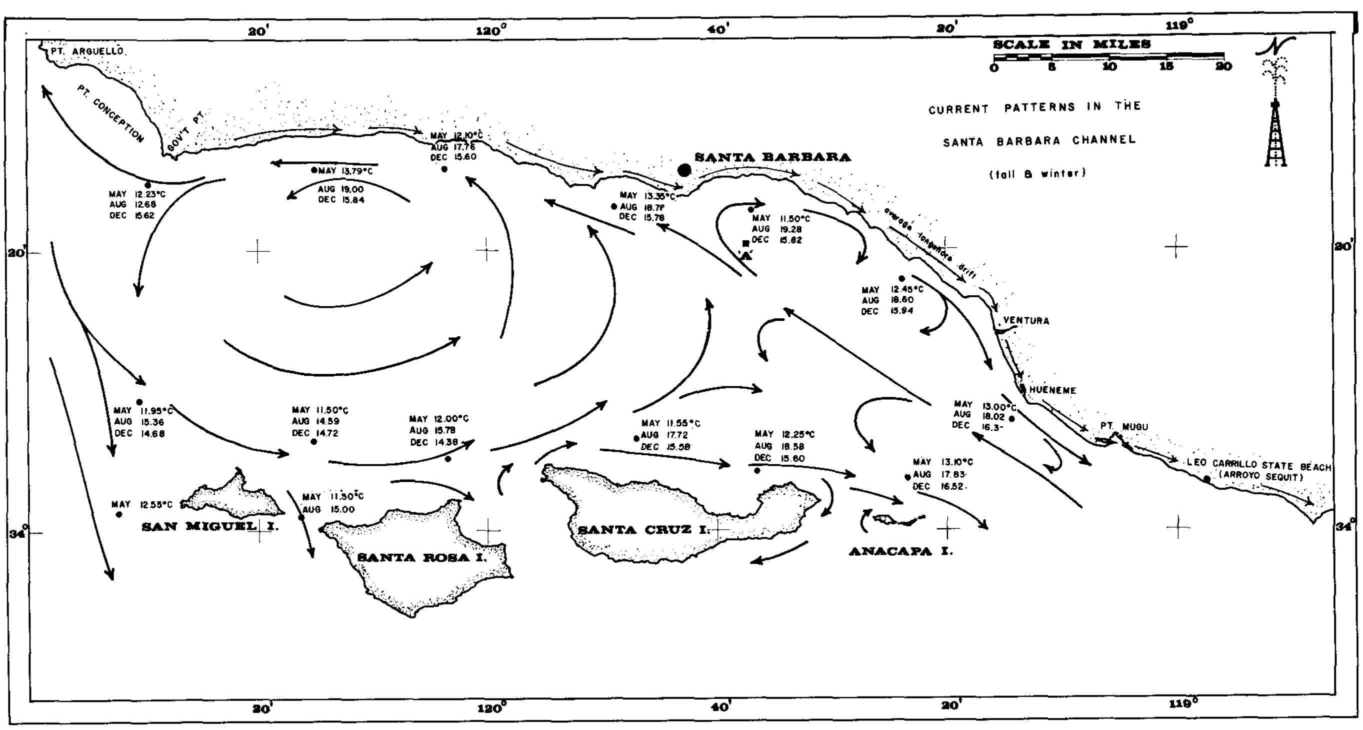

FIGURE 3. Fall and winter movements of surface waters in the Santa Barbara Channel. These were the currents prevailing at the time of both spills: note that the distribution of oil on the mainland and in the Channel Islands (Fig. 1) coincides with the pattern of flow. Temperature data are also shown (courtesy of Ronald Kolpack, Department of Geology, U.S.C.).

an outline is consistent with the circulation patterns of water briefly discussed above. Since the setting for the Southern California marine flora is composed of a variety of physical, chemical and geographical factors, it is not surprising that this variety is reflected in complex distribution patterns.

The diversity of the California flora at the turn of the century may now only be estimated, but Yale Dawson (1959) analyzed collections (intertidal and shallow subtidal) from the years 1895–1913 and felt that, as a conservative estimate, 60 conspicuous species made up the state's marine flora during a given season at a specific point on the coast. That this number is reasonable has been confirmed by findings at the stations surveyed in the Channel Islands by Nicholson and Cimberg (1971). The most thoroughly surveyed sites have minimum floras of 61 species (Blue Banks Anchorage, Santa Cruz Island) recorded from a single visit and 68 species (all year; Isthmus Cove, Santa Catalina Island). There have been 6 new records of macroscopic algae at Isthmus Cove added in the season following the 1969–1970 survey by USC, bringing the total to 74. The usual number of algal species at one visit in the Channel Islands varies between 28 and 45.

Island stations are here assumed to represent a relatively undisturbed condition, at least on the Pacific side of the islands which is freer than the mainland side from the influence of materials added to the water from mainland sources. The present island flora cannot be assumed to be identical with the hypothetical mainland flora of seven decades ago, but it can serve as a model baseline for comparison with Dawson's data gathered between 1956 and 1959. The major deviation in composition from mainland associations that the Channel Islands flora would be expected to show, would be a lack of dominance of species adapted to areas enriched by abundant natural runoff. In other words, the Channel Islands probably shared most species with the mainland, but the abundance of certain types was markedly different.

The intertidal plants in Southern California offer an example of populations responding to changing conditions. There has been a shift from waters unaffected by human-produced wastes to waters receiving nearly one billion gallons per day of assorted discharges (cooling effluents, industrial and municipal wastes, storm runoff from urban areas) from numerous ocean outfalls (Table 1). Dilution of these discharges is hindered by the restricted circulation between the mainland and the Channel Islands (Fig. 3 shows surface water movements in the Northern Channel). Wastes discharged into these gyres may be recirculated rather than efficiently diluted. In addition to changes in water chemistry, intertidal areas are now subject to photochemical smog (the water-soluble components of which dissolve on the wet surfaces of freshly exposed organisms, concentrating as exposure lengthens) the components of smog are thoroughly mixed into shallow water by waves on the ebb and flood tides. Because smog-borne heavy metals are not appreciably water soluble, they probably precipitate soon after their mixing into the water column and are likely to be found in the near shore sediments. A major exception to this route from atmosphere to sediment should be found in those areas where marine algae such as *Macrocystis* and diatoms secrete copious amounts of mucilages into the surrounding water, which are then capable of complexing heavy metals. In view of the continuous supply of heavy metals to the air and a ready mechanism for their introduction into the marine environment, their impact should be carefully investigated. This investigation was not able to concern itself specifically with the effects of smog components such as metals, but they are as important as the more readily observable effects of human usage of the beach areas. Mechanical disturbance arises from droves of sightseers, collectors, clammers, etc. (stampede effect). All of the above factors have, over the past eight decades, become increasingly chronic. During the period under consideration, there have occurred numerous incidents of acute exposure of marine populations to toxic materials intentionally or accidentally released. Thus the effects of acute incidents such as the Santa Barbara oil spills are superimposed on responses to chronic conditions and are influenced by antecedent events.

Changes (or dynamic equilibria) in the intertidal are most easily detected by monitoring populations of firmly attached organisms. Benthic seaweeds and sessile or sluggish animals attached to a rocky substratum allow repeatable sampling of the same populations over as long a time span as desired. It should be noted here that investigations in the rocky intertidal are affected by a number of factors related to regular exposure and inundation; the area available to sample is in a continual state of flux due to uneven tidal heights, shifting sand and rocks. There is also a continual change of species composition in the intertidal during the yearly cycle of seasons, making it imperative that samples from one year to the next be compared on the basis of similar months. Any comparative study must have baselines, without which detection of steady states or changes is impossible. In the case of the Southern California intertidal, the marine algae have been the only organisms for which a baseline exists.

There have been major changes in the number of species of intertidal plants at specific locations throughout most of Southern California. This conclusion is based on monitoring of 44 rocky beaches established as stations for checks on water quality in 1956–59 (Dawson, 1959), and resurveyed by Neushul (1967) and Nicholson and Cimberg (1971).

The dates and locations of these studies make it possible to draw three general conclusions regarding shifts in the composition of the intertidal flora. First, the change in number of species over the decade between 1959 and 1969 has been a decline amounting to an average value of 63% for the region between Point Conception and Dana Point. Second, the decline was well underway by 1967, (Table 9) at least in the Santa Barbara-Ventura region. Third, while the Santa Barbara spills of 1969 were responsible for specific destructive incidents, those oil spills cannot be the cause of the changes that occurred *before* them in time or *outside* their area of influence. The oil spills were responsible for kills of seabirds and losses of marine organisms in the upper intertidal when patches of their habitat were smothered. And, until the slicks were gone, they interfered with the settlement and establishment of marine populations on rocks. Effects of the sunken oil on deep water animals is not easy to assess (Fauchald, 1971), but the possibility exists that large areas of sediments were changed in texture and/or composition sufficiently to disturb their residents. Fauchald (1971) also reports a decrease in biomass of the echiuroid worm *Listriolobus pelodes* in the area ESE of Santa Barbara from a peak of 2,000 g/m^2 (surrounding areas varied between 1,100 and 1,800 g/m^2) in the state survey of 1959 to a present peak value of 800 g/m^2 (nearby areas show 8–180 g/m^2). This decline was not attributable to oil seep activity or to the oil spill, but it does fit a general picture of decline in many marine populations in Southern California. However, Hartman (1960) noted that there was a reduced fauna in oil seepage areas near Goleta (a short distance north of Santa Barbara).

Analysis and Interpretation of Data with Respect to the Presence of Oil and Other Influences on Intertidal Populations

The brief list offered below, consisting of factors affecting health of intertidal populations, is intended to outline the complex situation from which single events (such as oil spills) must be untangled.

i) exposure of wet surface films to smog at low tide, with probable adsorption and/or absorption of heavy metal complexes (Pb is a logical possibility), acid-forming moieties and the like which concentrate as evaporation proceeds;

ii) mixing of smog into the first few feet of sea water by wave action, producing a local alteration in water chemistry;

iii) trampling, clamming, collecting;

iv) special events such as flooding, Santa Ana winds at low tide, storm surf, smothering by sand;

v) chronically altered water chemistry from municipal wastes, industrial wastes and storm runoff from urban areas;

vi) chronic presence of oil in the Santa Barbara Channel;

vii) selective adhesion of oil to warm, dry surfaces.

With the possible exception of chronic changes in water chemistry and chronic presence of oil throughout the floor of the Channel, all the above factors act more intensely in the upper rather than in the lower areas of the intertidal.

Viewed in long-range perspective, the Santa Barbara oil spills of 1969 are incidents of abuse to coastal waters that have been subject to chronic human interference for at least seven decades. The downward trend in variety of intertidal plants is a reflection of altered environmental parameters. At least for the upper intertidal, the tendency is now for the area to be inhabited by species that are aggressive annual colonizers: *Ulva, Enteromorpha,* diatom films and GATGOR (note at end of Table 7), instead of normal abundant cover of the slower growing *Endocladia* and the perennial rockweeds *Pelvetia* and *Hesperophycus.*

In the lower intertidal, *Egregia* is particularly abundant at Emma Wood State Beach (immediately north of Ventura), Point Fermin (near Port of Los Angeles) and White's Point (site of 380 mgd discharge of sewage and industrial wastes). Young *Egregia* sporophytes are abundant (spring and late winter) up to the 2.5 foot level in the latter two areas and mixed populations of juvenile and mature plants grow at least as deep as 35′ subtidally. Most of the adults occur from 0.5 tide level or lower: all sporophytes are thicker and more coriaceous than comparable plants around Santa Barbara, San Diego and the Channel Islands. *Egregia* is often found interspersed with *Macrocystis* (for example at Anacapa Island and Point Lobos in Northern California) under relatively undisturbed conditions, but it may be a successful competitor of *Macrocystis* under present conditions around Point Fermin and White's Point. Whether or not these small *Macrocystis* beds (remains of once vast kelp forests in the Los Angeles region) at these sites are suffering from encroachment of *Egregia* is a worthwhile topic for investigation.

Another good colonizer has made its appearance in Southern California: the large brown seaweed *Sargassum muticum.* This alga was introduced from Japan (probably on shells of young oysters) into the Puget Sound region about 1947 (Fensholt, 1955; Scagel, 1956) and worked its way southward into Oregon and Northern California. It first appeared in Southern California in spring 1971, where it was reported from Orange County, San Diego County and Santa Catalina Island. As this *Sargassum* establishes itself in the lower intertidal and shallow subtidal, its abundance is being monitored quantitatively. Whether *Sargassum muticum* represents a potential pest, an interesting addition to the Southern California marine flora or a commercial source of brown algal polysaccharides remains to be seen.

Vulnerability of simplified ecosystems to invasion and epidemics have been adequately discussed elsewhere (Hutchinson, 1959; Woodwell, 1970) and the warnings of these authors are pertinent to the situation that has developed in Southern California. Loss of huge areas of subtidal kelp forests (Limbaugh showed in 1955 that at least 125 species of fish associated themselves with the "living reef" of a kelp bed), persistence of rapid colonizers in the upper intertidal and the invasion of the lower intertidal-shallow subtidal by a large seaweed from Japan lead to the conclusion that a decade-long decline of 63% in variety of intertidal algae has not been a neutral event. Since marine plants are a basic source of food and shelter for animals, it is reasonable to suppose that a decline in variety and/or quality of food (not necessarily quantity) will have repercussions throughout marine food webs of the entire southern portion of the state. Shifts in predation pressures occurring as a result of altered food supply of local regions can expose distant relatively undisturbed sites to upsets. For instance, dwindling kelp beds yield fewer good fishing grounds for large mammals (man included), increasing frequency of catches in remaining submarine forests may reduce available food, interfering with migratory patterns of birds and mammals dependent on nearshore foraging.

What can be said concerning the effects of oil on intertidal plants in view of the complexity of the background against which they must be interpreted? The best field evidence for chronic influence of oil comes from comparison of populations at Coal Oil Point, Carpinteria State Beach and the beach one mile north of Dana Point (Fig. 2; Tables 4–7). Two observations are noteworthy: the plants present in largest numbers may be oil tolerant or oil evading, particularly in the upper intertidal (given the small solubility of crude oil fractions in sea water, and long exposures, there is greater opportunity for oil films to cling to warmed and dried organisms in the upper intertidal) and there are fewer species than at Carpinteria or near Dana Point. Lower intertidal plant species are the main contributors to variety at Coal Oil Point.

That Carpinteria State Beach is inshore of an oil seep area cannot be ignored, but other than during oil spill periods, slicks and their accompaniment of petroleum smell were not observed. Table 3 shows that occurrence of oil patches at Carpinteria is about half that at Coal Oil Point and its presence is sporadic. Carpinteria has slightly fewer but more abundant species than the beach near Dana Point, possibly reflecting the greater occurrence of oil at Carpinteria. Additionally, in spite of the presence of natural oil, exposure to two oil spills and flooding in the winter of 1969, Carpinteria may be a healthier beach (28% decline in algal variety over a decade) than the beach near Dana Point (55% decline for the same period) which is nearer large sources of discharged wastes. There are a number of ways in which populations may register damage; the percent occurrence data from Carpinteria and the Dana Point area raise the interesting possibility that species abundance decreases prior to loss of a species. In regard to the way in which the phrase "loss of a species" is used here, there is no intention of concluding that any of the missing species will never return to these sites: but it is noteworthy that their occurrence is sufficiently erratic and patchy for them to disappear for significant periods from their normal habitats.

In comparing the spring months of 1969 and 1970, there is an indication that the beaches affected by oil spills (Gaviota to Hobson) and runoff in 1969 recovered more variety of species than the four southern beaches also affected by runoff (Table 8). This conclusion implies simultaneous damage from oil and fresh water, which both produce dead and bleached algae (as at Catalina in January and December 1969–70 after the second oil spill: see Nicholson and Cimberg, 1971). Except in cases where oil is observed present long enough to smother or injure living tissue (as in the case of the smothered barnacles), it is extremely difficult to distinguish oil-killed from fresh water-killed specimens. In the vicinity of active oil seeps there is also the possibility that there will be traces of oil in tissues; simple presence of oil does not guarantee its origin from a spill.

Laboratory investigations do, however, show a potential for certain fractions of oil to interfere with photosynthesis (Clendenning, 1964). Even if this interference is slight, it may be sufficient to upset the delicate balance between photosynthesis and respiration, gradually producing a loss of vitality in vegetative and reproductive phases. The latter effects are best observed in detail in the laboratory, since slow or subtle changes in vitality are not easily observed quantitatively in the field.

Summary of Observations and Conclusions

General or Long-term Trends:

1) There has been an average decline of 63% in variety of species of intertidal algae in Southern California (1956–1970).
2) The decline mentioned above was underway by 1967 at least in the Santa Barbara-Ventura region and continued in 1969–70 in the larger region between Point Conception and Dana Point.
3) Substantial losses in area of kelp forests, partial replacement of semi-permanent high intertidal species such as *Endocladia, Pelvetia, Hesperophycus* by algal films (GATGOR and diatoms), *Ulva* and *Enteromorpha* which are fast-growing annuals along with the invasion of lower intertidal-shallow subtidal areas by *Sargassum muticum* from Japan point to developing instability of associations of macroalgae.
4) It is suggested that altered air and water chemistry since the turn of the century combined with mechanical disruption of intertidal areas by public use have created an environment favoring the development of instability among marine algal populations.

Observed Effects of Crude Oil:

1) Barnacles that settled on weathered patches of oil were washed away when their substratum eroded away after further weathering.
2) Sessile organisms (algal films and barnacles) were smothered by discontinuous patches of oil.
3) Oil adhered selectively in the upper intertidal rather than in the lower intertidal due to greater length of exposure and consequent warming and drying of the former.
4) Chronic presence of oil (Coal Oil Point) in the intertidal produces a beach with fewer plant species, but those that can tolerate or evade the effects of crude oil are highly abundant.

PLATE 1A. Carpinteria State Beach at the time of the December 1969 spill, showing frothy oil on sand.

PLATE 1B. Bleached algae (white patches in foreground) at Carpinteria State Beach in late winter of 1969.

PLATE 2A. East Cabrillo Beach (Santa Barbara) in March 1969: cleanup operations employing chopped straw broadcast on crude oil.

PLATE 2B. East Cabrillo Beach Station Line: 7-foot section of metal groin smashed by storm surf in December 1969.

PLATE 3A. Oiled barnacles in the upper intertidal at Coal Oil Point.

PLATE 3B. Middle and lower intertidal at Coal Oil Point (near Goleta) showing large areas covered by the sea anemone *Anthopleura*. The dominant marine plants are *Phyllospadix, Ulva* and *Gigartina*.

PLATE 4A. Hobson County Park: improved facilities for camping completed in June 1969 attracted droves of clammers. Activity shown here is typical of each low tide—including low tides when the beach was covered by oil.

PLATE 4B. The beach at Palm Street, Ventura with green algal and diatom cover on exposed cobbles. Scene is west of Dawson's original station line, which was covered by sand in 1969–1970.

PLATE 5A. Leo Carrillo State Beach (Arroyo Sequit): onset of sandfill in winter 1969–1970. The kelps *Egregia* and *Macrocystis* protrude through the sand.

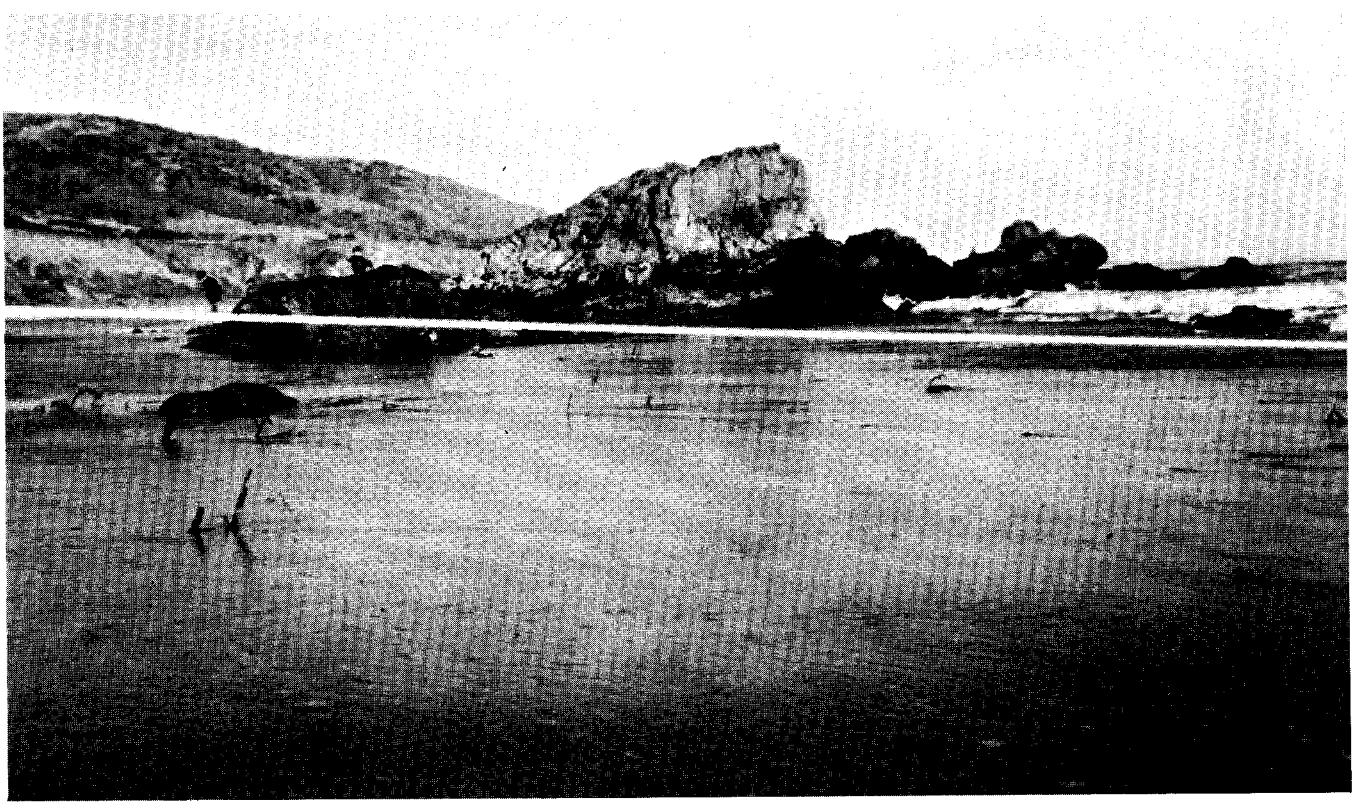

PLATE 5B. Leo Carrillo State Beach in February 1970: sandfill has smothered kelps, leaving behind scattered stumps of stipes.

PLATE 6A. Leo Carrillo State Beach in March 1970 after sand had been partially cut away, re-exposing rocks which were quickly repopulated.

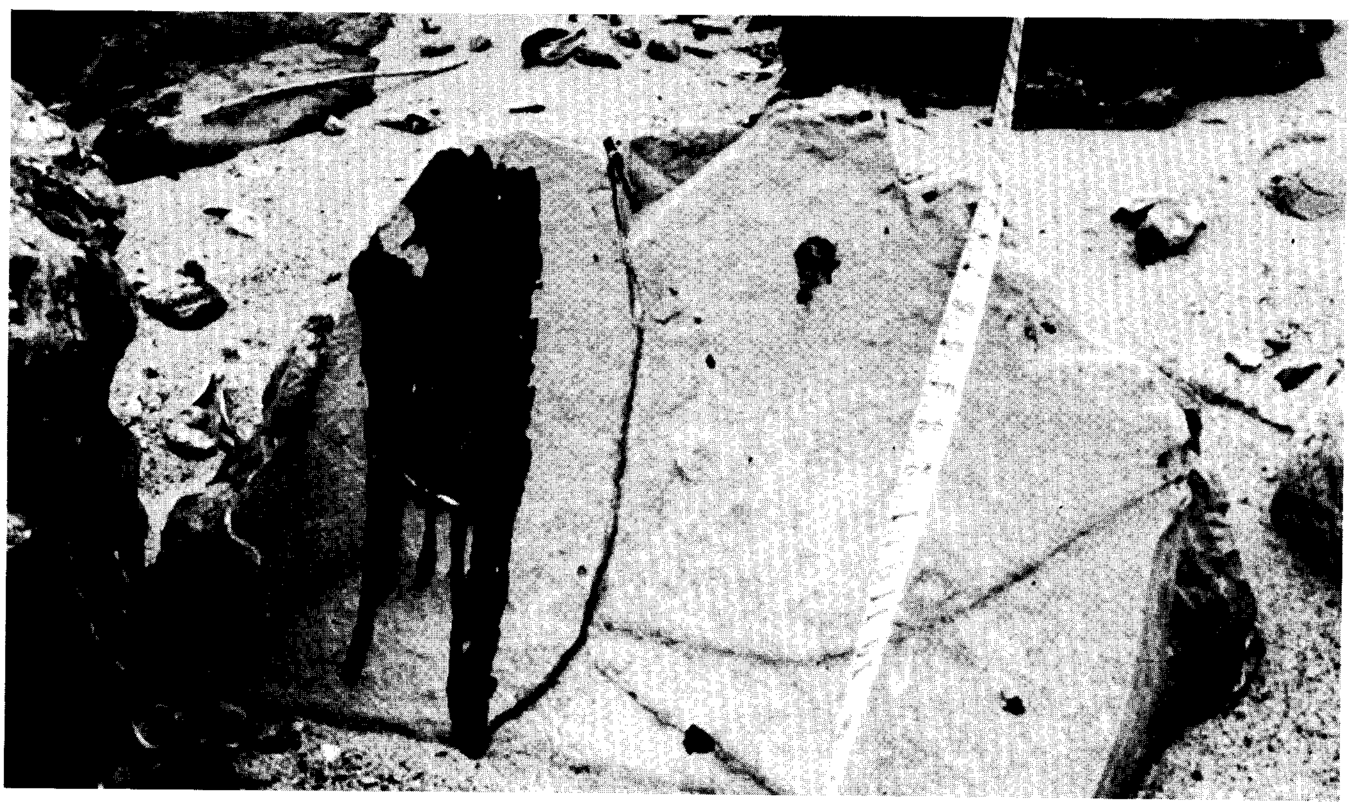

PLATE 6B. Corona del Mar: oil from an undetermined source on rocks in the upper intertidal. This beach is subject to heavy foot traffic and was the oiliest of the four southern beaches in this survey.

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