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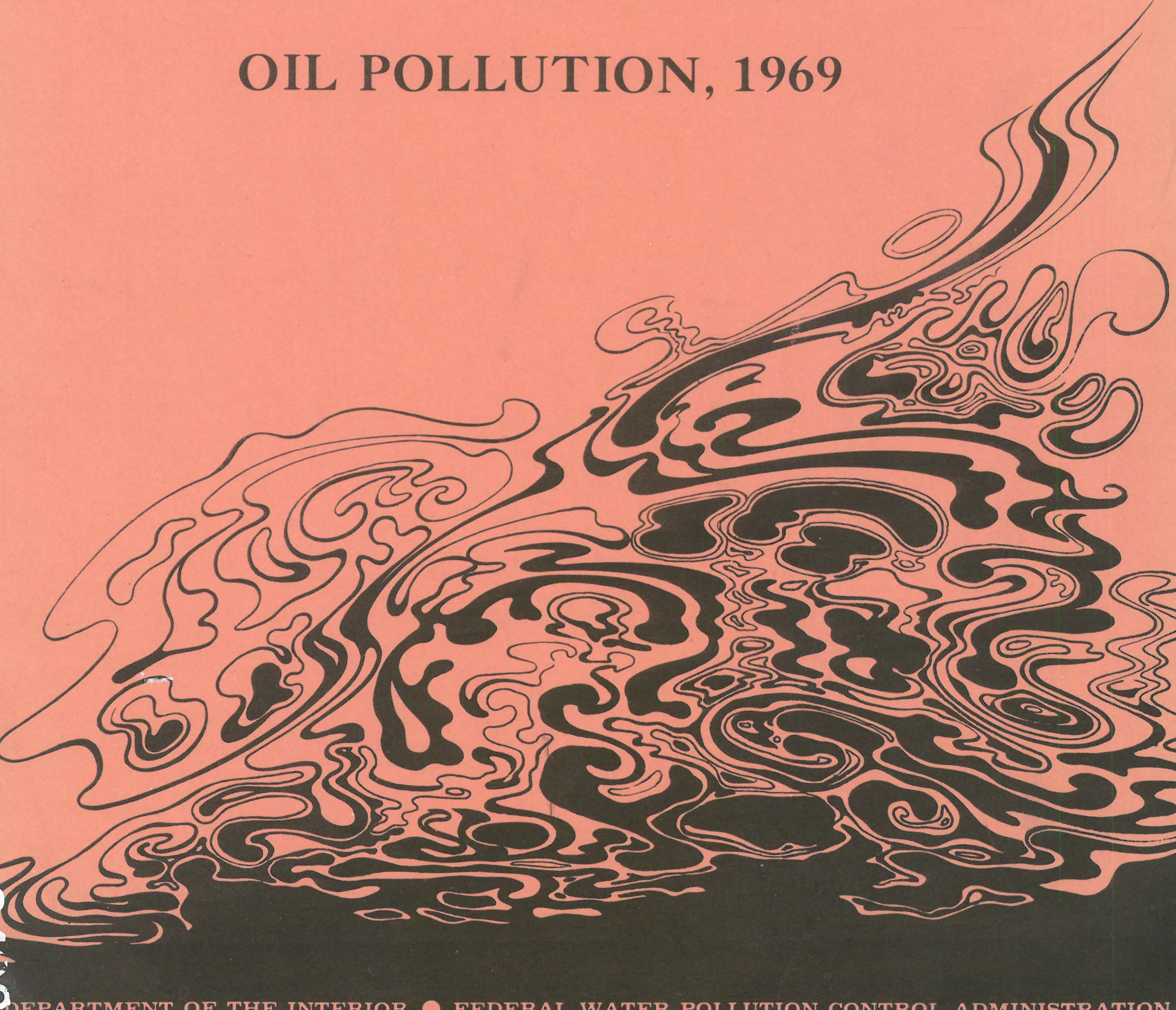
SANTA BARBARA
OIL POLLUTION, 1969



DEPARTMENT OF THE INTERIOR ● FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

SANTA BARBARA OIL POLLUTION, 1969

A Study of the Biological Effects of the Oil Spill Which Occurred at Santa Barbara, California in 1969

by

The University of California, Santa Barbara
Santa Barbara, California

for the

FEDERAL WATER QUALITY ADMINISTRATION

DEPARTMENT OF THE INTERIOR

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ABSTRACT

The initial flow of oil that began on January 28, 1969, from an offshore oil platform deposited an estimated 4,500 metric tons of pollutant oil on nearly 90 kilometers of coast by February 8, 1969. Winds, wave action, tides, and substrate determined the pattern of the oil distribution in the intertidal zone. Heavy biological damage occurred in intertidal surf grass and barnacle populations as a result of the oil pollution. Based on earlier surveys, the greatest negative biological change at a sample station was the loss of 16 plant species. However, these losses in species were attributable in most cases to sand movement and other storm-associated events. The potential long-term biological effects of the continuing pollution are discussed.

INTRODUCTION

In early February, 1969, crude oil began to wash up on the beach in front of the Marine Laboratory of the University of California at Santa Barbara. It was becoming apparent that this oil, coming from the site of an offshore drilling platform was not just another minor pollution incident. One might categorize minor pollution incidents which have occurred in the Santa Barbara area in recent months as 360 metric tons[1] spilled by an oil tanker on January 30, 1969; 235 to 465 metric tons of gasoline accidentally discharged from a tank farm at Gaviota on July 2, 1968; and 6.9 metric tons of crude oil spilled from Platform Hogan on June 18, 1968. Subsequent to the Santa Barbara spill, which still continues at the time of this writing, there were other smaller spills along the coast. The most recent was a discharge from a tanker which polluted the Pismo Beach region.

The Santa Barbara oil spill rapidly reached proportions comparable to major oil spills. The Torrey Canyon, in 1967, spilled between 30,000 and 39,000 metric tons. The Tampico Maru, a tanker wrecked off the coast of Baja, California, in 1957, spilled 8,600 metric tons of diesel oil. The Santa Barbara spill is estimated to have exceeded 11,200 metric tons by May 7, 1969 (Allen, 1969).

The events which occurred following the beginning of the Santa Barbara oil spill, have been repeatedly reviewed. The brief chronology presented here is to provide both an introduction to some of the major events and a frame of reference for the discussion at the end of this report.

On January 28, 1969, about 10 km off the coast of Montecito, a blow-out occurred on offshore drilling platform A. On January 29, 24 hours later, approximately 5,000 barrels (726 metric tons) of oil per day (Allen, 1969) was coming up through five cracks in the ocean bottom. Detergents were being spread in the area. Equipment to help stop the flow was being flown in from Texas, and by noon on the 29th of January, public officials, who were previously unaware of the situation, had been informed. On January 30, the oil slick covered approximately 390 square kilometers, and offshore winds held the slick away from the coast. On January 31, the slick was estimated at 520 square kilometers, and oil was beginning to come ashore on Rincon Beach. By February 1, the oil was spreading and Summerland, Carpinteria, and Anacapa Island were threatened. On February 4, oil was coming ashore in areas close to Rincon, and by February 4, Anacapa Island was surrounded by oil. The slick was estimated at this time to be between 520 and 1,300 square kilometers in size. By February 5, the Santa Barbara harbor was filled with oil and closed; some oil was in the Ventura Marina, and the slick was estimated to be 2,080 square kilometers in area. By February 6, a 32 km stretch of mainland had been polluted by the oil. On February 7, drilling mud was being

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1. There is often confusion over the units used in reporting amounts of oil. We have chosen to use the metric system throughout this report. Table 1 gives conversion factors.

Table 1

Conversion Factors

A. Conversion Factor for California Crude Oil, Specific Gravity = 0.917 at 60°F (Baumeister, 1958)

1 Gallon (U.S. Liquid) = 7.636 Pounds (Avoirdupois)

B. Other Conversions

1 Barrel = 42 Gallons (U.S. Liquid)

1 Barrel = 321 Pounds

1 Short Ton = 2,000 Pounds

1 Long Ton = 2,240 Pounds

1 Kilogram = 2.21 Pounds

1 Metric Ton = 1,000 Kilograms

1 Metric Ton = 1.1 Short Tons

1 Metric Ton = 6.9 Barrels

brought from Los Angeles to be pumped into the well. In order to soak up or sink the floating oil, 2,300 metric tons of straw were being brought in from the San Joaquin and Antelope Valleys per day, and at least 18 metric tons of talc and diatomaceous earth had been delivered.

There was understandable confusion as to the amount of oil which was being released during the early days of the spill. On January 30, Union Oil officials claimed that the Santa Barbara News Press misquoted them in stating that the seep was producing 5,000 barrels (726 metric tons) per day. Jerry Luboviski, Communications Director for Union Oil in Los Angeles, claimed that the rate was 500 barrels (72.6 metric tons) per day.[1] Independently, Alan A. Allen (1969), using color aerial photographs and the work of Blokker (1964) to help support thickness estimates, estimated the flow on February 2 to be a minimum of 726 metric tons per day. If the flow were 500 barrels (72.6 metric tons) per day, as estimated by "knowledgeable engineers" (Editor's Note in Jones et al 1969), a slick of 78 square kilometers would have been formed in three days. Instead, a slick of 520 square kilometers was formed in three days. On February 18, Union Oil estimated the flow which had been renewed by that date to be between .4 and 1.4 metric tons per day. A Fish and Game estimate was 6.9 metric tons per day, and a revised Union Oil estimate was between 6.9 and 13.8 metric tons per day. On March 2, the leak was reduced to 3.5 metric tons per day according to Department of Interior estimates.[3] On March 5, the Department of Interior estimated that the flow, after increasing again, had dropped from 35 metric tons per day back to 3.5 metric tons per day.[4] It became very clear that regardless of the accuracy of the measurement, this was going to be a sizeable oil pollution incident.

It has been estimated that as much as 226,000 metric tons of petroleum wastes per year are discharged on the sea surface by ships alone (ZoBell, 1963). Pilpel (1968) has pointed out that the quantities of oil being handled by ships, pipelines, and in other ways makes it almost inevitable that some of this oil will find its way into the sea. He also points out that the cleaning of tanks by oil tankers at sea, which releases a heavy, oily sludge, may be of greater world-wide significance than the releases from wrecked tankers.

ZoBell (1963) provides a comprehensive review of the occurrence and effects of oil on the sea. A more recent unpublished bibliography and literature review done by the Batelle Memorial Institute (1967) and made available to us, provides additional up-to-date information about marine oil pollution in general.

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1. Santa Barbara News Press, January 30, 1969.

2. Santa Barbara News Press, February 18, 1969.

3. Santa Barbara News Press, March 2, 1969.

4. Santa Barbara News Press, March 5, 1969.

Organization of Report

This report consists of the introductory material, two short papers, and a general discussions. Bibliographic material for each part of the report is located at the end of that part. The first paper, _The Santa Barbara Oil Spill, I. Initial Quantities and Distribution of Pollutant Crude Oils_, deals with the amounts of stranded oil and its distribution. The second paper, _The Santa Barbara Oil Spill, II. Initial Effects on Littoral and Kelp Bed Organisms_, deals with the preliminary biological effects that we observed. A treatment of aspects of the Santa Barbara pollution problem that relates our observations to those of others and considers the broader implications of marine pollution in general, has been incorporated in the discussion section.

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THE SANTA BARBARA OIL SPILL I.

INITIAL QUANTITIES AND DISTRIBUTION OF POLLUTANT CRUDE OIL[1]

by

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INTRODUCTION

Pollution of the California coast has been a threat of increasing severity for the last 40 years. In response to this threat, the late E. Yale Dawson carried out surveys of the flora of the intertidal region at a series of sites along the coast from Government Point, Santa Barbara County, to Bird Rock, La Jolla, San Diego County (Dawson, 1959). The original surveys were done in 1956 and 1957. Some of these were resurveyed by phycology students at the University of California at Santa Barbara in 1966 and 1967.[2] These studies provide a standard of reference against which change in the biota of the intertidal can be measured. They provide a basis for evaluating the effects of marine pollution of various sorts.

On January 28, 1969, threat became reality for the coast near Santa Barbara. Drilling operations on ocean platform "A" of the Union Oil Company (Fig. 1) resulted in an uncontrolled flow of oil from a deep reservoir through fissures in oil-bearing sands to the sea floor. Winds and currents began driving the oil ashore in the vicinity of Santa Barbara three days after the spill began. Some 61 kilometers of coastline had been oiled by the fourth day, and eventually, over 161 kilometers of coast, including the Channel Islands, were affected (see map, Fig. 1). An oil pollution problem of major proportion was clearly at hand.

The reaction to the oil spill was immediate and vigorous. Action was taken to stop the flow of oil, clean up the beaches, and survey the damage. As a part of this effort, biologists at the University of California at Santa Barbara (U.C.S.B.) took steps to begin determinations of

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[1] This study was supported by the Federal Water Pollution Control Administration, Grant #14-12-516 and in part by NSF GB 5952 and GH 43.

[2] A comprehensive collection of oil pollution literature including these unpublished student surveys, is deposited in the Oil Archives of the University of California at Santa Barbara library.

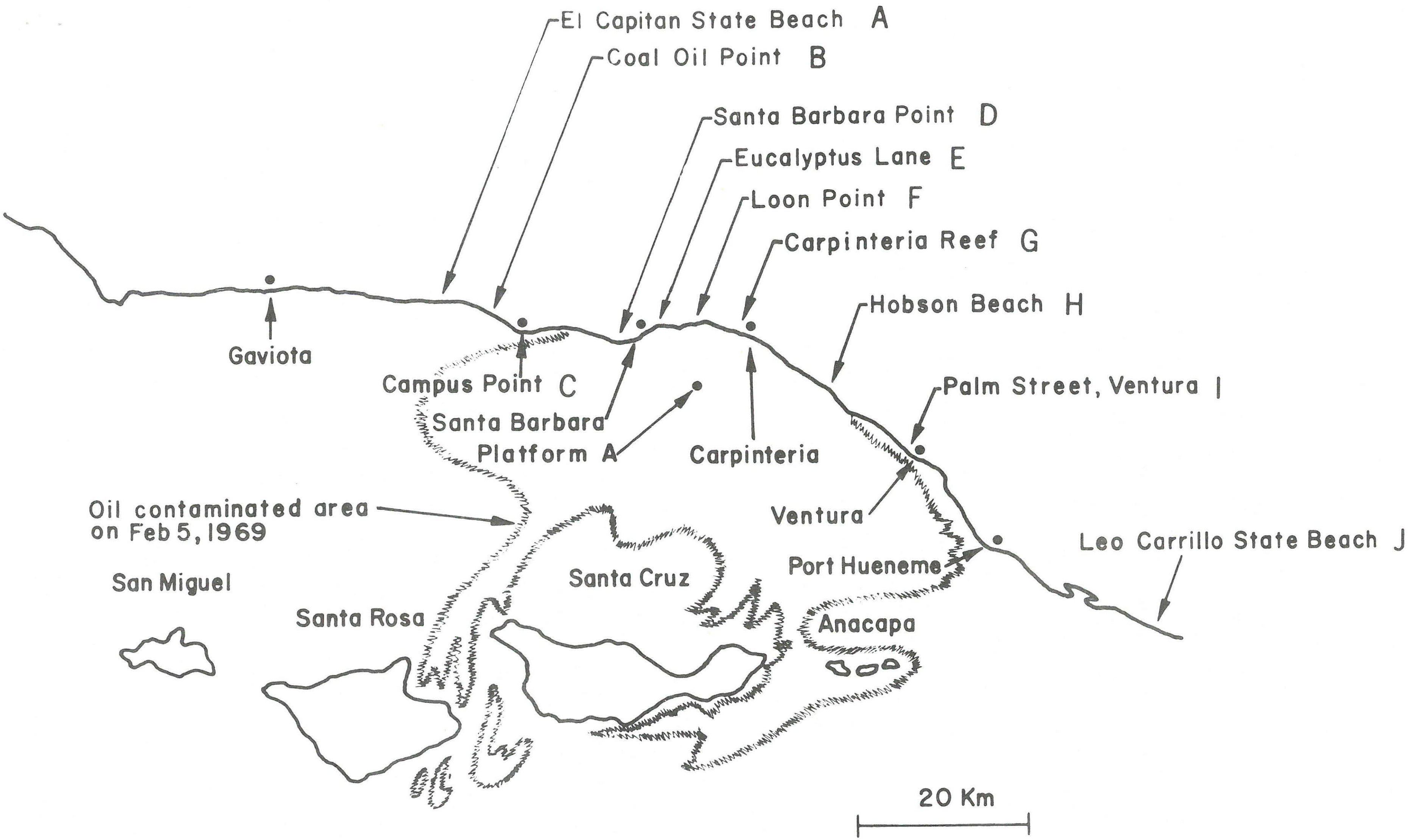

Figure 1

Map of Santa Barbara area showing location of intertidal transects, (El Capitan State Beach, Station A, through Leo Carillo State Beach, Station J), offshore drilling platform A, and extent of oil contamination on February 5, 1969, as measured by Allen.

the effects on the marine life along the coast. The resources, which we could bring to bear, were meager compared with the total problem. Nevertheless, we felt that work done promptly, even though limited in extent, would be more valuable than waiting to do a comprehensive, better-instrumented study later.

The work discussed in this paper centered on the reactivation of the Dawson intertidal surveys. Two questions were considered: 1) What was the oil dosage in the intertidal at the survey sites? 2) What were the effects of the dosage on the biota? This paper reports measurements of the dosage. The biological effects are reported by Foster, Neushul, and Zingmark (1969).

The Santa Barbara oil pollution problem has become the subject of nationwide controversy. It is our intent to give here only a factual report of our measurements and our methods of analysis. We have discussed other measurements which we consider pertinent, treating these in a straightforward and factual manner without making value judgments. It is for others to resolve the complicated legal and economic questions that have arisen.

CHRONOLOGY

Natural seeps of crude oil from submerged strata have long been a familiar feature of the ocean off the California coast. Early records from the voyages of Captain George Vancouver in 1792-94 document the appearance of an oil slick in the Santa Barbara Channel. In recent times, increased public use of beaches has stimulated studies of this source of oil pollution. The concentration of natural seepage oil on beaches in the Santa Barbara area was measured by Mertz (1959). The highest recorded concentration is 100 pounds per 500 square feet (1 kilogram per square meter) for Coal Oil Point measured on June 12, 1958; the average for the year 1958 at Coal Oil Point being 21.5 pounds per 500 square feet (.2 kg/m^2). The location of natural oil seeps can be seen from the air.

The new, man-made oil seep at Santa Barbara created a slick which was readily visible in aerial photographs. Aerial photographs of the slick were measured as a basis for determining the area covered by the spill, the thickness of the oil being determined from its color (Alan A. Allen, personal communication[1]). Previous studies by Blokker (1964), combined with color-thickness relationships established by the American Petroleum

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1. The authors are indebted to A. A. Allen, General Research Corporation, Santa Barbara, for making this data available prior to its publication.

2. One barrel of petroleum = 42 U.S. gals., luq., 60°F. One metric ton = 6.9 barrels. (These conversions for California crude oil with a specific gravity of 0.917).

Institute, support the assumption that oil appearing dark blue-black on the surface of the sea is on the order of 0.001" in thickness or greater. Thus, the area of a black oil slick multiplied by 0.001" gives a conservative estimate of its volume. Measurements of the increase in volume of the growing slick, would thus give a day-by-day rate of flow. In this way, Allen estimated the average daily flow rate during the initial massive spill as on the order of 5,000 barrels (726 metric tons) per day.[1] The oil flowed at this rate for the $10\frac{1}{2}$ days from January 28 to February 7, 1969. The flow was then reduced temporarily. By this time, well over 50,000 barrels (7,260 metric tons) of crude oil had flowed into the Channel waters. After four days, the leak resumed at a reduced rate and has been flowing at various rates ever since. Allen estimates that a minimum of 78,000 barrels (11,290 metric tons) of oil flowed into the Channel during the first one-hundred days of the spill. The maximum figure could be greater by an order of magnitude since 0.01" thicknesses are common in oil spills, and parts of the Santa Barbara slick were probably thicker, especially near the platform. Hence, the actual figure probably lies between 78,000 and 780,000 barrels (11,290 and 112,900 metric tons). Table I compares the magnitude of the Santa Barbara pollution one-hundred days after its start with other major oil spills.

In the first eight days, the oil slick spread out over the surface of the ocean to cover an area of approximately 1,700 square kilometers. The limit of the slick on the eighth day, according to Allen, is shown on the map in Fig. 1. By this time, the oil had been coming ashore on Santa Barbara beaches for nearly five days.

Measurements of oil dosage in this study were made on February 8, 9, 10, and 13. Since the leak was temporarily halted on February 7, only part of the oil from the first massive outflow had reached the coast and was included in our measurements. The subsequent stranding of additional floating oil and the flow of new oil after the 13th, has produced a complex dosage pattern. This paper deals only with the initial oil pollution amounts and distribution.

MATERIALS AND METHODS

Eight of Dawson's 1956-1957 intertidal transect sites and one additional site were selected for sampling (Fig. 1). A tenth sampling site, Station J on Figure 1, was not oiled during the period of this survey and is therefore not included in any other figures or tables. The oil ashore as of February 13, was still within the confines of the most northern and most southern of the stations.

A rapid sampling method, using readily-available and inexpensive materials, was employed at each station. A measuring tape was attached at the high tide level near a convenient land mark and extended along the

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[1] *Op.cit.* 2.

Table I

Summary of Major Marine Oil Spills

Spill	Amount Spilled (metric tons)	Dosage on Shore (metric tons/km)	Source of Information
Total Oil Spilled from Ships in 1964	226,000	-------	ZoBell 1963
Torrey Canyon Oil Tanker Wreck 1967	119,000	59 to 169*	Smith 1968
Tampicu Maru Oil Tanker Wreck 1957	8,000	27,000	North *et al* 1964
Santa Barbara 1969 (First 100 Days)	11,290 to 112,900	51.4**	see text

* These figures calculated from the dosages given for the Cornish and French Coasts. The tonnages given in Smith, were assumed to be long tons. 1 Long ton = 1.02 metric tons.

** Dosage after first 11 days.

transect line to the water's edge. Five equidistant points were marked on the line and the substrate beneath each point was sampled for oil. Sampling was done by pushing the open end of a one-pound coffee can, which had a small hole in the bottom, into the sand. By putting ones finger over the hole to maintain a partial vacuum, a core of wet sand and oil was extracted. When the sample point fell on a rocky substrate or dry sand, the oil, if present, was scraped from an area corresponding to the area of the sampling-can opening. Samples were removed from the cans, placed in aluminum foil, labeled, sealed, and stored at 2°C prior to analysis. Sampling cans that became fouled with oil were discarded and replaced with new ones for subsequent sampling. This sampling method yielded cores of oil and sand ranging from 5 to 15 cm deep. In most cases, the oil formed a surface layer and did not penetrate deeply into the sand. Oil from the core samples was separated from the sand by dissolving it in ether. Following the evaporation of the solvent, the oil was weighed.[1]

Sand movements along local beaches have covered oily layers with a meter or more of sand in certain areas. This covering phenomenon had not occurred at our stations at the time of sampling. The sand at these stations generally formed only a thin layer over a primarily rock substrate.

In addition to the core method, black and white aerial photographs[2] of areas around Santa Barbara Point (Station D) and Eucalyptus Lane (Station E) were used to derive a partially independent estimate of intertidal oil dosage. Oil on the water surface, in the offshore kelp beds, and on the intertidal zone could be identified from these photographs. The appearance of intertidal surfaces was designated as being black (heavy oil), grey (moderate to light oil), or clean. The area of each of these three surface types was measured directly from the aerial photographs with a polar planimeter. Areas of black and grey coverage thus obtained were converted to dosage of oil with the aid of the core sampling data from the two stations. The average of the highest two core values for each station was considered as representative of oil amounts in black areas. An average of the two lowest core values was considered as representative of the amount of oil on grey areas.

Calculations of the potential amount of oil which could have come ashore by February 8 were made using Allen's estimates of the total flow from the platform. To use this method, one has to assume that the oil spread in a uniform circular pattern from the spill site. A sector of this circular pattern, constructed by drawing lines from the platform to El

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1. Analysis of core samples was carried out by the Federal Water Pollution Control Laboratories, Alameda, California.

2. Aerial photographs were taken by and are available from Mark Hurd Aerial Surveys, Inc., Goleta, California. In addition, the set of photographs used in this report are on file in the Oil Archives of the U.C.S.B. library.

Capitan and to Port Hueneme, is assumed to have come ashore. The dosage ashore on February 8, can then be estimated by multiplying the total flow over the eleven days from January 28 to February 8 by the ratio of the number of degrees in the sector divided by 360 degrees. This "sector" estimate does not take into account currents, winds, or the amounts of oil held by the kelp. However, it is useful in making comparisons with the estimates derived by the core and aerial photographic methods. Evaporation and emulsification rates of crude oil were not considered in any of the dosage calculations.

RESULTS

Oil and gas flowed at high pressure from fissures in the sea floor at the site of the leak and formed a spectacular "boiling" pool of oil on the surface. From there the oil spread in an irregular pattern of streaks and patches, changing with time and shaped by wind, tides, and currents. Experience with the Torrey Canyon disaster indicated that the course of the oil could be predicted "after the event" by assuming that the oil moved relative to the water with a velocity vector about 3.3 to 3.4% of the relative wind vector (Smith, 1968).

The Davidson Current moves up the Southern California coast in the winter (from Los Angeles towards San Francisco). This weak current by itself might have brought at least part of the oil from Platform A to Santa Barbara and the coast to the west (See Fig. 1).

Counteracting this, the prevailing winds usually blow from the northwest. Ordinarily, the movement of the oil due to wind action would more than offset that due to the current. Unfortunately for Santa Barbara, at the time the oil began gushing from the ocean floor, two severe storms came into the area, one immediately after the other, accompanied by gale winds from the southeast. These strong winds pushed much of the oil from the initial spill onto the Santa Barbara coast. The limits to which the oil slick had spread by February 5 are shown in Figure 1.

As the oil slick moved toward the beach, its course was obstructed in many places by the dense floating canopy of giant kelp, *Macrocystis Angustifolia* (Figures 2 and 3). The surface foliage in the canopy became heavily coated with oil. Significant quantities of oil were retained by the kelp canopy. However, the kelp is covered with water and a thin layer of mucilage and the oil did not adhere to its surface (Foster, *et. al.*, 1969). The beds thus acted as a reservoir which only temporarily impeded the passage of the oil. Later, depending on wind and tide, the trapped oil was released from the kelp and blown onto the coast or out to sea. From the air, the oil could be seen to stream from the kelp canopy onto the beach (Figure 3). Kelp harvesting firms reported that on February 6 the kelp beds from Coal Oil Point to Carpinteria, covering an area of over 33 square kilometers, were blackened by oil (Kelco Co., personal communication). However, detailed measurements of the exact amount of oil in the beds at any one time could not be made

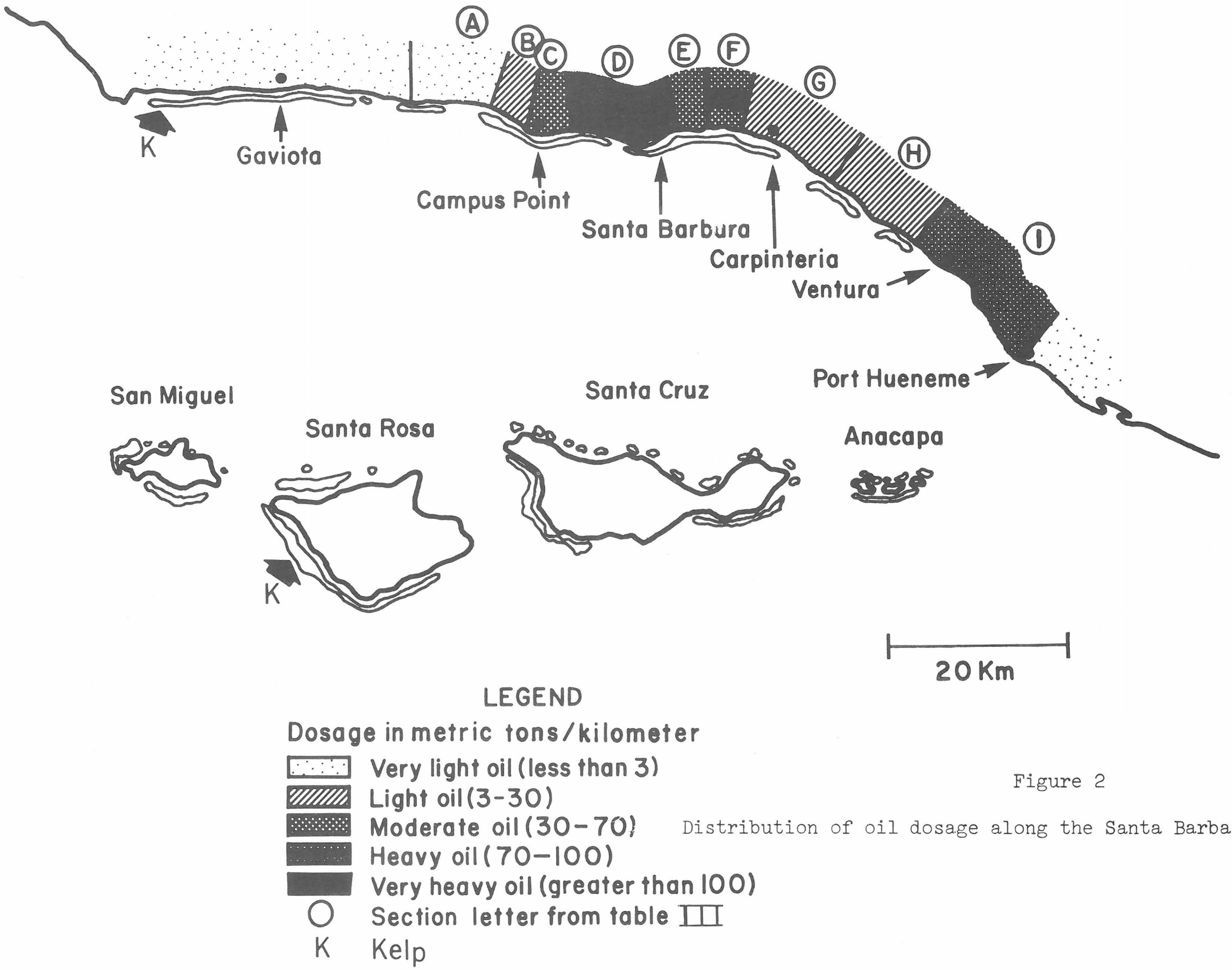


Figure 2

Distribution of oil dosage along the Santa Barbara coast

Figure 3

Aerial photograph taken over Station E on February 14, 1969.

A: Oil streaming from offshore kelp bed.

B: Black area of heavy oil on intertidal.

C: Intertidal transect, Station E.

Scale in meters.

from black and white aerial photographs since both plants in unoiled pre-pollution photographs and those in oiled beds appear black. Also, there is a complex mosaic of oil thicknesses seen in and around the beds.

The oil comes onto the coast with the tide, and each successive wave brings the oil higher and higher on the intertidal zone. At flood tide, the spray and surge coat the upper intertidal zone. As the tide ebbs an irregular coating of oil is left as a patchy covering over the entire intertidal zone (Figures 4 and 5).

Coastal areas polluted as shown in Figures 4 and 5 remain this way only so long as the oil continues to flow in from the sea. The oil sticks to dry, rough surfaces, and adheres weakly to wet surfaces. With water coming in on successive tides, the oil coating floats off wet surfaces and is redeposited in the high littoral zone, on cliffs, and on the upper parts of rocks exposed long enough to dry between tides. A typical beach on which the oil has been redeposited in this manner is shown in Figure 6. The oil here is heavy enough in places to form pools. Warming by the sun causes the oil to flow from the pools down on the beach (Figure 7).

The basic measurements of oil pollution using the core method are presented in Tables IIA and IIB. They give the amount and distribution of the oil on the beach at the Dawson survey stations. All stations were surveyed on February 8, and certain selected stations were further surveyed on February 9, 10, 12, and 13.

The dosage on Saturday, February 8, is listed in Table IIA. On this eleventh day of the spill, the oil had been flowing onto the beaches from four to seven days and was continuing to flow on this date. The entries in the Table are the "raw data"--that is, the measurements of oil in the core samples--modified only by dividing the weight of oil in each sample by the area of the coffee can (8.1×10^{-3} m^2) to give the concentration in kg/m^2. The data in each row gives the measurements at each survey station with individual measurements at the five core positions being listed in order from the cliff to the sea, with the average being listed at the right. Remarks on the state of the beach at the time of the survey are also included.

The dosage on successive days for certain of the survey stations are listed in Table IIB. The core sample data has been treated and is presented in the same way in both tables.

The highest concentration measured was 10.6 kg/m2 at the cliff position at Santa Barbara Point on February 8. The highest average over the survey line was 5.6 kg/m^2 for the same station. The average on February 8 for the four adjacent stations in the Santa Barbara area, stretching from Campus Point to Loon Point, was 3.4 kg/m^2 (Stations C, D, E, and F; Figure 1).

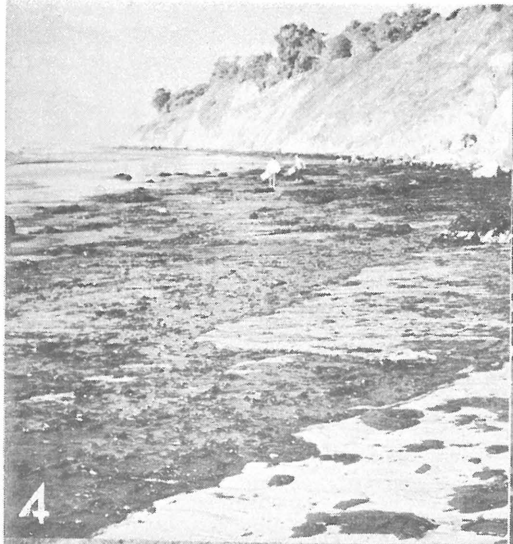
We emphasize the temporal nature of our results. They are the oil dosage on a particular beach on a particular day. We recognize that our results

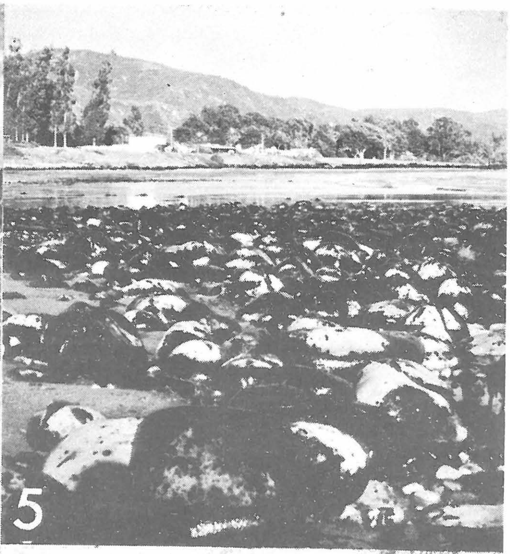
Figure 4

Distribution of oil at ebb tide on Arroyo Burro Beach (part of coastal section D, Figure 2), February 6, 1969.

Figure 5

Distribution of oil on rocky intertidal in the vicinity of Station F, March 4, 1969.





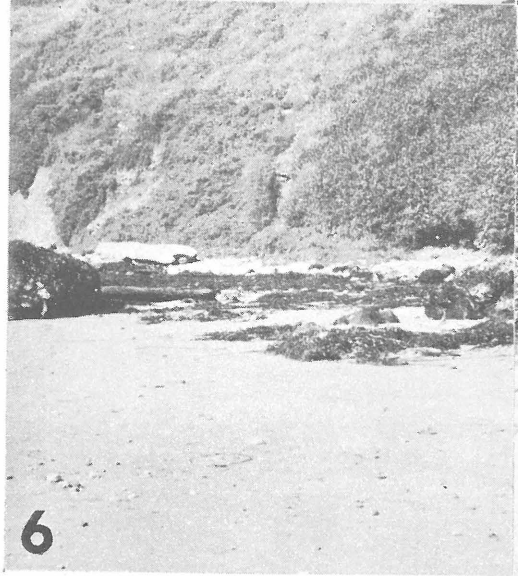


Figure 6

Oil redeposited in the high intertidal at Arroyo Burro Beach.

Figure 7

Oil running down from high intertidal pool of oil and debris.

Table IIA

Oil Measured from Core Samples Taken February 8, 1969

Station		Oil Dosage (kg/m^2) Position						Remarks
Original Dawson Number	New Designation	Cliff ---------------- Ocean						
		1	2	3	4	5	Ave.	
40	A	0.12	0	0	0	0.64	0.15	Area generally clean; old oil on rocks.
--	B	0.09	0.01	0.11	0.12	0.20	0.11	Sand relatively free of oil; fresh oil on upper rocks on top of old tar; 80% of drift seaweed covered with oil.
28	C	1.02	0.74	5.76	1.76	0.02	1.86	Sandy areas covered with oil soaked kelp and debris.
27	D	10.59	8.10	3.09	0.70	--	5.62	Area covered with oil up to 5 cm deep and oil covered with hay.
39	E	1.84	4.04	2.49	0.04	--	2.10	Oil over entire area and covering a large tide pool; very thick in spots.
38	F	4.57	4.53	6.87	3.28	1.67	4.18	Oil covering beach and in water. Storm debris covered with oil.
15	G	0.20	4.25	0.01	0.15	0	0.92	Oil thin and patchy; mostly in upper intertidal.
35	H	0.35	0.19	0.32	0.01	0.05	0.18	50% of beach covered; oil up to 2 cm thick in places.
12	I	2.23	3.91	4.60	7.47	2.52	4.15	Oil in blobs covering 80 - 90% of beach. Oil reddish brown in color.

Table IIB

Oil Measured from Core Samples Taken after February 8, 1969

Date	Station	Oil Dosage (kg/m^2) Position						Remarks
		Cliff			Ocean			
		1	2	3	4	5	Ave.	
2/10/69	C	5.05	1.94	7.36	3.83	--	4.55	Debris stuck together by heavy oil cover. Oil tar on rocks beneath new oil.
2/9/69	D	0.25	0.02	0.10	0.23	0.05	0.13	Thin layer of sand covering oily layer beneath. Rocks and sand in high intertidal 50% covered.
2/9/69	F	4.08	0.05	0.11	2.51	--	1.69	No comments.
2/9/69	G	0.62	0.35	0.04	0.59	0.23	0.37	More oil at water's edge than on 2/8. High tide area coverage as on 2/8.
2/12/69	H	0.83	0.47	0.23	0.04	0.04	0.32	80% coverage of thin oil up to 2mm thick. Water brown with some floating oil patches.
2/10/69	I	0.59	0.04	0.02	0.02	0.01	0.14	Blobs of oil gone and sand covered with thin oily film. Beach cleaned naturally. No oil visible in core samples. Some oil still on high rocks.
2/10/69	D	5.28	0.06	0.07	0.02	--	1.36	Much oil removed since 2/8; workmen raking and bulldozing oil-hay mixture. Gooey underlayer still present.
2/13/69	F	--	0.52	2.50	0.49	--	1.17	High rocks very oily; low rocks only have small spots of oil. Straw and oil soaked debris on and between rocks.
2/13/69	I*	0.27	0.01	0.04	0.01	0.86	0.24	No comments.

* Two samples taken at each position 50 feet apart. Derived numbers represent the average of the two samples.

may be criticized on the basis that our samples are too meager and our observations, day by day, far too limited. In their defense, our data are consistent with other measurements, as will be discussed shortly, and in addition, ours are the only explicit, systematic measurements, so far as we know, of the oil distribution on the beaches coming from the Santa Barbara oil spill. In the spirit of the March Hare, as he replied to the Mad Hatter's complaint: "It was the best butter, you know."

We have estimated the total oil ashore on February 8 from the oil sample measurements. The calculations were made as follows: We divided the length of the coast up into sections, as shown in Figure 2. Each section contained one of the Dawson survey stations: it stretched from midway between the Dawson station to the west, to midway to the Dawson station to the east. We assume that the average oil dosage for the entire area of a particular section equals the average at the Dawson station contained in the section. We also assume that the average width of the beach is the same as that at the Dawson station at the time of the sampling, and in some stations we have added the height of the oil splashed up on the cliff to the width of the beach.

The total weight of oil on a section of the beach, T, is given by $T = (c\ l\ w) \times 10^{-3}$, metric tons, and the concentration of oil per unit length of the coastline, t, by $t = (T/l) \times 10^{-3}$, metric tons/km where c = concentration, kg/m^2, from Table IIA; l = length of beach, meters; w = width of beach, meters. T, t, c, l, and w are listed in Table III. In Figure 2, t, for each section is indicated by a cross-hatched pattern in which the range of concentrations is indicated by the type of cross-hatching; t is given section by section along a chart of the coast. In Figure 8, t is plotted as a bar graph with t as ordinate, and distance along the coast as abscissa (i.e., the coastline is "straightened out"). The total weight of oil ashore on February 8 from El Capitan to Port Hueneme is given in Table III. We estimate that the total amount was 4,508 metric tons.

From planimetric analysis of aerial photographs as dosage figure of 76 metric tons per kilometer was obtained for Section D, and 59 metric tons per kilometer for Section E. This can be compared with core method estimates of 118 and 63 metric tons per kilometer respectively (Table III and Figure 8). The planimetrically determined dosage for Section D is based on the average area of grey and black regions of the shore around Station D on February 7 and 10. The averages of high and low core measurements for February 8, 9, and 10 were used to estimate the weight of oil stranded on Section D. Dosage on Section E was obtained by averaging black and grey areas from photographs taken over Station E on February 5 and 14 (Figure 3 is part of the photograph taken on February 14), and combining this information with the core data taken on February 8.

Using the flow rate estimates of Allen along with the uniform spread assumptions discussed previously, the amount of oil which could have come ashore in the 190 degree sector, defined by lines from Platform A to El Capitan and Port Hueneme, was calculated. If the flow rate was the lower estimate of 5,000 barrels (726 metric tons) per day, then in

Table III

Estimates of Total Oil Dosage Derived from Core Samples and Aerial Photographs

Section Station in Section (Fig.1)	Section Letter (Fig.2)	Width of Beach (m)	Added Width of Oiled Cliff (m)	Total Width (m) (w)	Horizontal Length of Section (m) (1)	Area of Section (m^2)	Ave.Oil Dosage (kg/m^2) (c)	Total Oil on Section (metric tons) (T)	Ave.Oil on Section (metric tons/km) (t)	Ave.Oil From Aerial Photos (mt/km)
A	A	18	0	18	6,494	116,892	0.15	18	2.7	--
B	B	35	0	35	3,241	113,435	0.11	13	3.9	--
C	C	30	0	30	8,102	243,060	1.86	452	55.8	--
D	D	18	3	21	11,343	238,203	5.62	1,339	118.1	76
E	E	30	0	30	6,250	187,500	2.10	394	63.0	59
F	F	21	2	23	5,556	127,788	4.18	534	96.1	--
G	G	18	0	18	11,806	212,508	0.92	196	16.6	--
H	H	18	0	18	13,427	241,686	0.18	44	3.2	--
I	I	15	2	17	21,529	365,993	4.15	1,519	70.5	--

Total Length of Coast: 87.7 kilometers

Total Area of Beach: 1,847 km^2

Total Oil Dosage on Beach: 4,508 metric tons

Average Oil Dose on Coast: 51.4 metric tons/kilometer

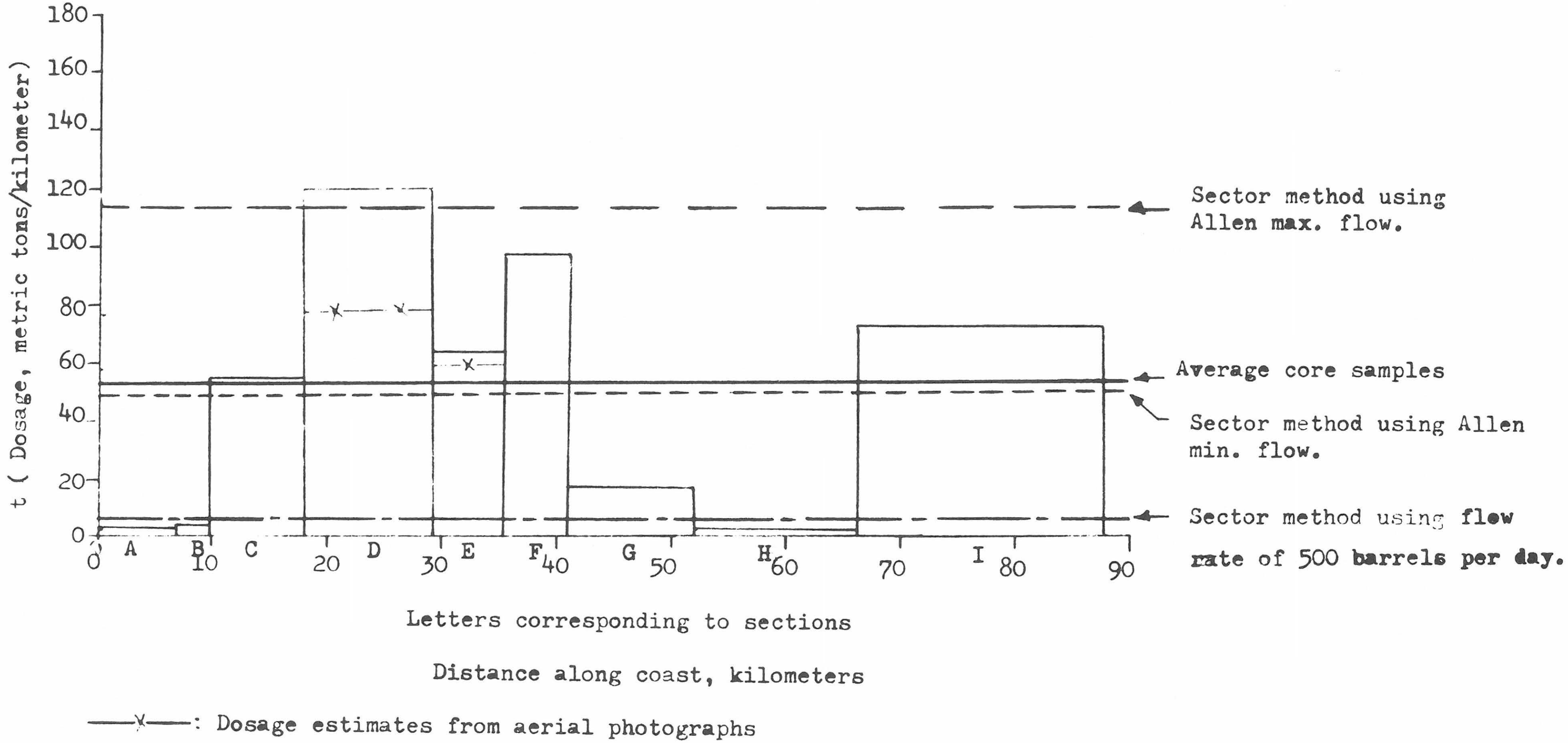


Figure 8

Section dosages on February 8, 1969, computed from core sample data, and comparison with other estimates (see text for Allen's flow rates).

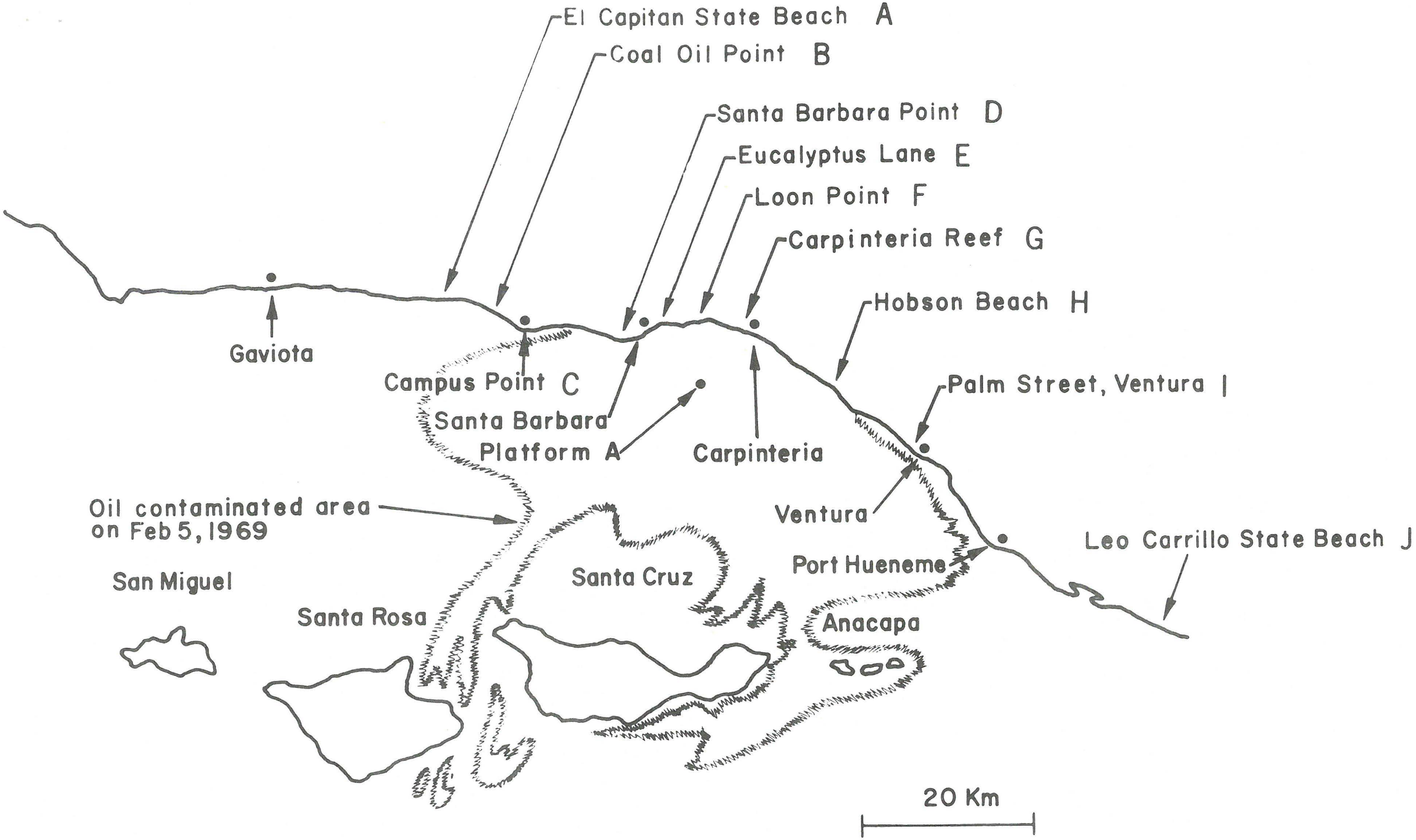


Figure 1

Map of Santa Barbara area showing location of intertidal transects, (El Capitan State Beach, Station A, through Leo Carillo State Beach, Station J), offshore drilling platform A, and extent of oil contamination on February 5, 1969, as measured by Allen.

Table I

Summary of Major Marine Oil Spills

Spill	Amount Spilled (metric tons)	Dosage on Shore (metric tons/km)	Source of Information
Total Oil Spilled from Ships in 1964	226,000	-------	ZoBell 1963
Torrey Canyon Oil Tanker Wreck 1967	119,000	59 to 169*	Smith 1968
Tampicu Maru Oil Tanker Wreck 1957	8,000	27,000	North *et al* 1964
Santa Barbara 1969 (First 100 Days)	11,290 to 112,900	51.4**	see text

* These figures calculated from the dosages given for the Cornish and French Coasts. The tonnages given in Smith, were assumed to be long tons. 1 Long ton = 1.02 metric tons.

** Dosage after first 11 days.

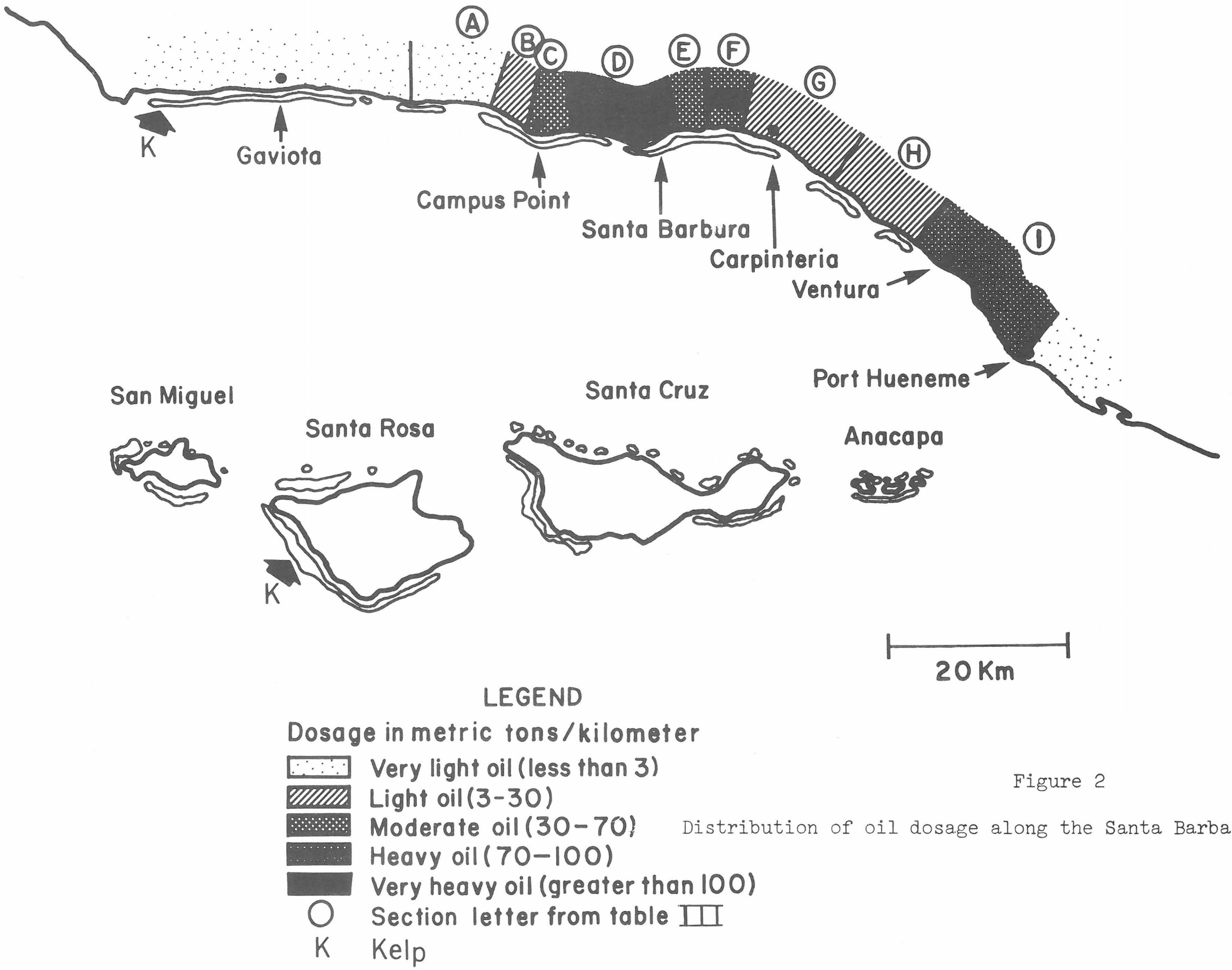


Figure 2

Distribution of oil dosage along the Santa Barbara coast

Table IIA

Oil Measured from Core Samples Taken February 8, 1969

Station		Oil Dosage (kg/m^2) Position Cliff ---------------- Ocean						Remarks
Original Dawson Number	New Designation	1	2	3	4	5	Ave.	
40	A	0.12	0	0	0	0.64	0.15	Area generally clean; old oil on rocks.
--	B	0.09	0.01	0.11	0.12	0.20	0.11	Sand relatively free of oil; fresh oil on upper rocks on top of old tar; 80% of drift seaweed covered with oil.
28	C	1.02	0.74	5.76	1.76	0.02	1.86	Sandy areas covered with oil soaked kelp and debris.
27	D	10.59	8.10	3.09	0.70	--	5.62	Area covered with oil up to 5 cm deep and oil covered with hay.
39	E	1.84	4.04	2.49	0.04	--	2.10	Oil over entire area and covering a large tide pool; very thick in spots.
38	F	4.57	4.53	6.87	3.28	1.67	4.18	Oil covering beach and in water. Storm debris covered with oil.
15	G	0.20	4.25	0.01	0.15	0	0.92	Oil thin and patchy; mostly in upper intertidal.
35	H	0.35	0.19	0.32	0.01	0.05	0.18	50% of beach covered; oil up to 2 cm thick in places.
12	I	2.23	3.91	4.60	7.47	2.52	4.15	Oil in blobs covering 80 - 90% of beach. Oil reddish brown in color.

Table IIB

Oil Measured from Core Samples Taken after February 8, 1969

Date	Station	Oil Dosage (kg/m^2) Position						Remarks
		Cliff				Ocean		
		1	2	3	4	5	Ave.	
2/10/69	C	5.05	1.94	7.36	3.83	--	4.55	Debris stuck together by heavy oil cover. Oil tar on rocks beneath new oil.
2/9/69	D	0.25	0.02	0.10	0.23	0.05	0.13	Thin layer of sand covering oily layer beneath. Rocks and sand in high intertidal 50% covered.
2/9/69	F	4.08	0.05	0.11	2.51	--	1.69	No comments.
2/9/69	G	0.62	0.35	0.04	0.59	0.23	0.37	More oil at water's edge than on 2/8. High tide area coverage as on 2/8.
2/12/69	H	0.83	0.47	0.23	0.04	0.04	0.32	80% coverage of thin oil up to 2mm thick. Water brown with some floating oil patches.
2/10/69	I	0.59	0.04	0.02	0.02	0.01	0.14	Blobs of oil gone and sand covered with thin oily film. Beach cleaned naturally. No oil visible in core samples. Some oil still on high rocks.
2/10/69	D	5.28	0.06	0.07	0.02	--	1.36	Much oil removed since 2/8; workmen raking and bulldozing oil-hay mixture. Gooey underlayer still present.
2/13/69	F	--	0.52	2.50	0.49	--	1.17	High rocks very oily; low rocks only have small spots of oil. Straw and oil soaked debris on and between rocks.
2/13/69	I*	0.27	0.01	0.04	0.01	0.86	0.24	No comments.

* Two samples taken at each position 50 feet apart. Derived numbers represent the average of the two samples.

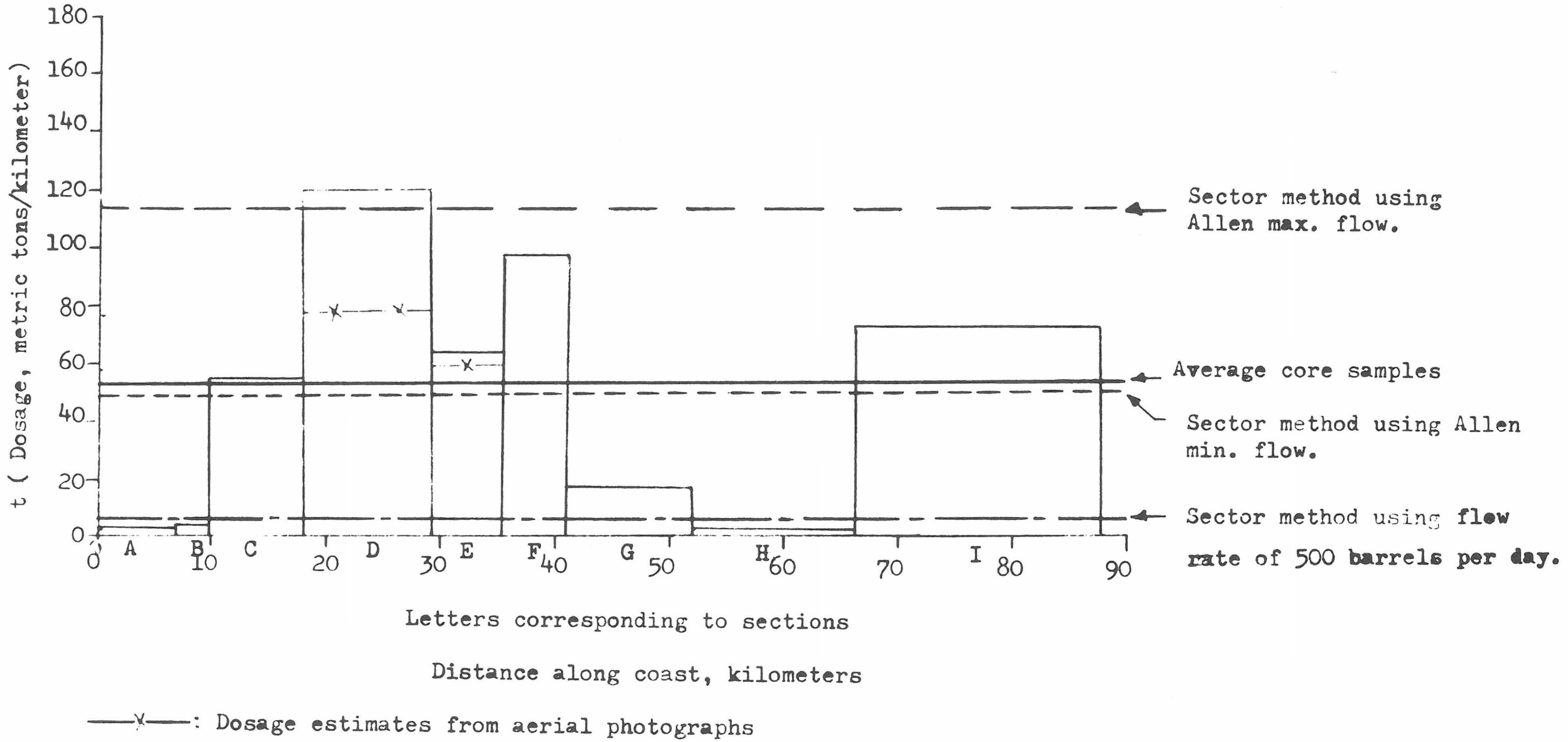


Figure 8

Section dosages on February 8, 1969, computed from core sample data, and comparison with other estimates (see text for Allen's flow rates).

the eleven days from January 28 through February 7, a total of 7,986 metric tons would have been released. If that portion of the oil released into the above sector was ashore by February 8, the amount on shore would have been 4,218 metric tons[1], or 48 metric tons per kilometer from El Capitan to Port Hueneme. Using Allen's high estimate of the initial flow (12,000 barrels of 1,740 metric tons per day[2]), the amount of oil on shore on February 8 would have been 115 metric tons per kilometer. These values are shown graphically in Figure 8.

Union Oil Company[3] and "knowledgeable engineers" (Editor's Note in Jones et al 1969) estimated the flow in this early phase of the spill to be 500 barrels (72.6 metric tons) per day. Using the sector method described above, the amount of oil on shore on February 8 from this rate of flow would have been 4.7 metric tons per kilometer. This is also shown in Figure 8.

CONCLUSIONS AND DISCUSSION

The simple core method used in this study provides a crude estimate of the amounts of oil on the intertidal zone, as do planimetric measurements from aerial photographs. More and probably larger cores should have been taken during this study. Also, the relationship between cores and aerial photometry could be more precisely established. However, the fact that the amounts of oil on the shore, as determined from our two sampling methods, agree to a certain extent with each other and with the sector estimates using Allen's data suggests that the problem of determining oil dosages on the shore is not insurmountable.

Aerial photographs clearly show the distribution of oil within kelp beds. The amount of oil held in the 33 square kilometers of kelp offshore from the stations studied increases the total dose for the area, since much of this eventually was stranded and in a sense constitutes a part of the initial dose figure.

The distribution of the initial oil dose in space and time suggests that its effect on the marine biota will not be uniform. Organisms in the lower or middle intertidal regions were intermittantly covered with oil that in most cases was washed away within a relatively short time (Foster et al, 1969). In contrast high tide regions, and particularly rock surfaces that dry during intertidal periods, were heavily covered and the cover was not rapidly removed by natural means.

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1. (7,986 metric tons) (190/360) = 4218 metric tons.

2. Allen's figure is 16,000 barrels per day, which included a 25% addition of evaporation. We have subtracted this 25% addition, since most of the evaporation of volatiles takes place before the oil reaches the coast.

3. Santa Barbara News Press, January 30, 1969.

ACKNOWLEDGEMENTS

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THE SANTA BARBARA OIL SPILL II.
INITIAL EFFECTS ON LITTORAL AND KELP BED ORGANISMS[1]

by

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INTRODUCTION

The massive flow of oil from an offshore drilling accident that occurred near Santa Barbara, California, on January 28, 1969, is producing a situation that differs substantially from previously studied oil-pollution incidents. Crude oil has continued through July 30, 1969, to flow from the sea floor even though the initial massive out-pouring has not continued. As soon as it became evident that the oil flow was likely to continue, efforts were made to determine the amount and distribution of oil in the littoral zone (Foster, Charters, and Neushul, 1969). The effects of this pollution on the living marine resources of the Santa Barbara area immediately became a subject of great concern. This study is an appraisal of the short-term biological effects of the initial oil dose.

The effects of oil pollution on marine life, following tanker wrecks such as that of the Tampico Maru and the Torrey Canyon have been studied in detail (North, Neushul, and Clendenning, 1964; O'Sullivan and Richardson, 1967; Bellamy et al, 1967; Smith, 1968). A recent literature review, the Batelle Memorial Insititute Report (1967), summarizes some of the effects of these and other pollution incidents.

In anticipation of increased domestic and industrial pollution along the Southern California coast, the late E. Y. Dawson (1959) made careful, systematic observations and collections of the marine flora at intertidal locations from the Santa Barbara area to San Diego. His descriptions, herbarius specimens, and photographs were made available by the Hancock Foundation of the University of Southern California and used in the present study. Some of these intertidal stations were also the subjects of University of California at Santa Barbara (U.C.S.B) algology

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class projects in 1966 and 1967. These intertidal studies provided the floral baseline for comparisons after the recent oil spill. Additional information of a more general nature on the flora and fauna of the coast was also available, Ricketts and Calvin, (1962); Light _et al_, (1961). During the course of this study, additional information was obtained from persons involved in marein biological studies at the U.C.S.B. Marine Laboratory and at neighboring colleges and research facilities. The sizes and condition of the kelp beds along the coast are of concern to the kelp harvesting and processing industry, whose representatives also provided valuable information.

A collection of readily available information about the local marine biota lead us to attempt a direct before and after comparison of marine life and to relate this to the amount and distribution of the pollutant. In principle, this simple approach to a complex problem should produce an intelligent answer. However, the complexities of ecosystem analysis often obfuscate even the simplest approaches to the most obvious problems. Nevertheless, this rational was followed in our attempt to provide a first glimpse of the ecological effects of the man-made oil seep that now exists off the Santa Barbara coast.

MATERIALS AND METHODS

Nine of Dawson's stations, distributed from El Capitan State Beach in Santa Barbara County to Leo Carillo State Beach in Los Angeles County, and one new station, previously studied by the algology class mentioned above in 1966, were selected for study (Foster _et al_, 1969). Stations C, D, and G are primarily rocky, while the other 7 stations are located on substrates of varying proportions of rock and sand. Stations A and J were selected _a priori_ as control stations, outside the region of oil pollution. However, the El Capitan station eventually received a relatively light dose of oil, and the rocks at the Leo Carillo station were almost completely covered with a thick layer of sand as a result of unusually severe winter storms. This complicated our attempts to compare the normal flora of polluted and completely unpolluted stations.

Dawson was providing a biological baseline of species number and distribution against which the usual decrease in diversity, resulting from pollution, could be contrasted. He used a line-transect method and identified plant species that grew along an outstretched line from high tide mark to the water's edge, noting all macroscopic plant species and their relative abundance within a few feet of the line. The algology students re-ran these same transects using similar methods. While the information thus obtained gives a gross indication of the species present on and close to the transect line, the method is questionable as an accurate measurement of the total species in the area.

During the present study, teams of observers, using the transect method, ran a total of 25 low tide transects at the ten stations between February 11, 1969, and March 3, 1969. Some stations were repeated more than once because of poor tidal conditions during some of the initial surveys. Species within a few feet of the line were listed using portable tape recorders. Organisms with oil on them were noted, along with organisms observed damaged or dead as a result of oil coverage (oil directly on plants which were white, oiled brown algae with green thalli, etc.). The relative degree of coverage by the oil on particular transect populations was also recorded, along with estimates of the percentage of dead organisms. Stations A, C, D, F, and G were revisited periodically from April 26 to June 4 to assess further changes and to look at organisms noted previously as being oiled.

Since no information on the animal populations at specific stations before the oil spill was available (aside from the general references discussed above), comparisons could be made only between oiled and unoiled animals present after the pollution along the transects. In general, notation of oil on specific animals, and animals noted dead and oiled provided the basic "effects" information.

Kelp beds offshore from Station B to H were examined periodically by boat from March 10 to April 19. Surface fronds were collected and brought into the laboratory for observation of oil damage and enumeration of organisms normally found in association with the kelp canopy.

Scuba diving observations of the benthic communities under the kelp canopy were limited by the high turbidity during the initial months of the spill. However, much useful and reliable information was ultimately gathered in this way.

A wealth of observations and photographs were contributed by U.C.S.B. Marine Laboratory personnel and interested individuals in the Santa Barbara area. This information was verified by the authors whenever possible.

RESULTS

Intertidal Plants

The species lists derived from the intertidal transects were first used to determine if any mass mortality or gross change had occurred. This determination was complicated by the unusually violent storms and record-breaking rainfall in the area, which occurred in January and February, 1969, before and during the early phase of the spill.

Table 1 lists the total number of species found at the 10 stations by Dawson in 1956-1957, the algology students in 1966-1967, and by our investigations in February and March, 1969. Also shown are the differences between the total species found by the various investigators.

The differences in species found by Dawson and by our surveys after the initial oil dose were used to rank the stations in terms of change in

Table 1

Total Number of Plant Species Found at Intertidal Survey Stations in 1956-7, 1966-7 and 1969

Station	Location	a Dawson 1956-7	b Students 1966-7	c After Pollution 1969	Differences (c-a)	(b-a)
A	El Capitan State Pk.	18	20	20	+ 2	+ 2
B	Coal Oil Point	18[1]	18	31	+13	0
C	Campus Point, UCSB	13	14	12	- 1	+ 1
D	Santa Barbara Point	29	40	21	- 8	+11
E	Eucalyptus Lane	22	20	14	- 8	- 2
F	Loon Point, Montecito	27	26	17	-10	- 1
G	Carpinteria Reef	14	29	34	+20	+15
H	Hobson Beach	21	13	12	- 9	- 8
I	Palm Street, Ventura	19	17	9	-10	- 2
J	Leo Carillo St. Beach	18	14	2	-16	- 4

[1] Value inserted is equal to student's value. No Dawson data for this station.

species since 1956-1957 (Table 2, Rank 1). Station J received a rank of 1 since it underwent the greatest negative change, and station G received a rank of 10, undergoing the greatest positive change. Station C at Coal Oil Point was not one of the original Dawson stations. For the purposes of comparison, this station was assigned a total species number of 18 for 1956-1957, corresponding to the findings of the algology students in 1966 -1967.

The stations were also ranked by type of intertidal substrate, the rank of 1 denoting a station with an almost completely sand substrate (Station J), and a rank of 10 denoting an almost completely rock substrate (Station G). This ranking might indicate regions susceptible to storm induced sand scouring, and thus could be related to storm damage in general (Table 2, Rank 2).

Ranks were compared using the methods of Kendall (1955) as adapted by Ghent (1963) for biological use. Table 2 shows that a comparison of ranks 1 and 2 gives an S value of 37 and a Tau (a measure of correlatior between ranks) of +.82; a perfect positive correlation being +1. The P value is .00058, indicating a significant correlation.

If the stations are ranked according to the oil dosage (Table 2, Rank 3) as determined for each station on February 8, 1969 (Foster _et al_ 1969) amd then compared with the change in flora ranking, Tau equals +.2 and P equals .2358; indicating a low correlation with little significance.

As an indication of normal changes over long periods, the algology student-Dawson floral changes were ranked (Table 2, Rank 4) and compared with the substrate ranking. In this comparison Tau equals +.53 and the P value is .0197, indicating the overall change over approximately ten years is also correlated with substrate, the correlation being significant at the 5% level.

The initial heavy dose of oil had deleterious effects on many of the algae and on the surf grass. Table 3 summarizes the oil coverage and mortality observed at the various stations.

Phyllospadix torreyi, a common surf grass, was heavily coated with oil in the intertidal, especially at stations receiving the largest initial dosages. This plant is still being affected at those stations that continue to be polluted from the continuing spill and from oil redistribution when the high intertidal rocks are cleaned. The common method of cleaning the upper rocks with hot water washes the oil back into the lower intertidal, where it can recontaminate the surf grass.

ZoBell (1963) summarizes much of what is known about the effects of oil on intertidal organisms and specifically points out the susceptibility of marine grasses to oil pollution. The surf grass in the Santa Barbara area readily takes up and holds oil, the blades sticking together in dense black clumps. Figure 1 illustrates this situation at Station D on February 13, 1969. The exposed portions of oiled plants eventually turn brown and gradually disintegrate. Moribund blades are shown in

Table 2

Rankings and Correlation Tests

Rank 1: Species Changes Between Dawson and After Initial Pollution Surveys. (Most Negative Change = 1, Most Positive = 10)

Station:	J	I	F	H	E	D	C	A	B	G
Rank:	1	2½	2½	4	5½	5½	7	8	9	10

Rank 2: Substrate Type (Most Sand = 1, Most Rock = 10)

Station:	J	I	F	E	H	A	D	C	B	G
Rank:	1	2	3	4	5	6	7	8	9	10

Rank 3: Oil Dosage on February 8, 1969 (Most Oil = 1, Least Oil = 10)

Station:	D	F	I	E	C	G	H	A	B	J
Rank:	1	2	3	4	5	6	7	8	9	10

Rank 4: Species Changes Between Dawson and Student Surveys (Most Negative Change = 1, Most Positive = 10)

Station:	H	J	E	I	F	B	C	A	D	G
Rank:	1	2	3½	3½	5	6	7	8	9	10

Rank Comparisons

1. Rank 2 with Rank 1

   S = 37, Tau = +.82

   Var (S) = 1

   P = .00058

2. Rank 3 with Rank 1

   S = 9, Tau = +.2

   Var (S) = 123

   P = .2358

3. Rank 2 with Rank 4

   S = 24

   Var (S) = 124

   P = .0197

Table 3

Plants Observed Oil Covered and/or Dead Along Station Transects

Plant	Dates and Stations Plants Observed Covered	Amount of Oil on Transect Population[1]	Dates and Stations Plants Observed Dead	Population Mortality Along Transect[2]	Remarks
Phyllospadix torreyi	2/11,2/13/3/1 (D)	***	3/1,6/4 (D)	50-60%	Percent of exposed blades damaged.
	3/13,3/16 (E)	***			
	2/13,3/4,3/16 (F)	***	5/5 (F)	90-100%	
	2/12,3/15 (G)	***	3/15,5/4 (G)	30-50%	
	3/17 (I)	***			
Enteromorpha compressa	2/8 (B)	*	4/26 (A)	1-5%	Thalli white.
	2/12,3/15 (C)	**	3/15 (C)	10-20%	
	2/10 (D)	**			
	2/11 (G)	**	2/11 (G)	20%	
	2/12 (H)	**			
Chaetomorpha aerea	3/1 (E)	*			
Ulva californiea	2/12 (H)	*	4/26 (A)	1-5%	Thalli white.
Ralfsia sp.	2/10,2/11,2/13 (D)	**			
Egregia laevigata	2/10,2/13,6/4 (D)	***			Oiled stipes with some blades green and some blades gone.
	5/5 (F)	**			
	3/15,5/4 (G)	**			
Porphyra sp.	3/1,3/13 (A)	*	4/26 (A)	1-5%	Thalli white.
	2/8,3/14 (B)	**	3/14 (B)	1-5%	
			5/4 (G)	20%	
Endocladia muricata	3/1 (A)	*			

Table 3, Continued

Plants Observed Oil Covered and/or Dead Along Station Transects

Plant	Dates and Stations Plants Observed Covered	Amount of Oil on Transect Population[1]	Dates and Stations Plants Observed Dead	Population Mortality Along Transect[2]	Remarks
Hildenbrandia sp.	2/13 (D)	*			
Rhodoglossum affine	2/13 (D)	*			
Gigartina leptorynchos	3/4,5/5 (F) 2/12 (G)	** *			
Gigartina canaliculata	3/4,5/5 (F)	*	4/26 (A)	1-2%	
Chondria nidifica	3/15 (G)	**			

1. Amount of oil on transect population represents average over dates given in second column.
2. Percents represent mortality along transect as estimated by the field investigator.

Legend: * = light oil coverage
** = moderate oil coverage
*** = heavy oil coverage

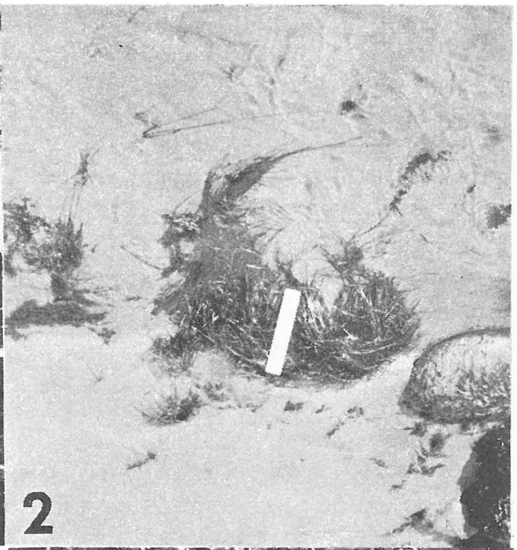
Figure 2. When this photograph was taken, all of the nearby algae were clean, but the grass still held large quantities of oil. As Table 3 shows, up to 100% of the exposed blades were killed at some stations. Plants growing in the extreme low intertidal and subtidal were largely undamaged, no doubt protected from direct contact with the oil by the water covering them. The California Department of Fish and Game (C. Turner, personal communication) reported a similar contamination of the surf grass on Anacapa Island. Here, too, subtidal plants were undamaged, polluted blades of intertidal plants turned brown, and plants in unpolluted areas remained green in both the inter- and subtidal regions.

The basal rhizomes of P. torreyi are frequently covered by sand and perhaps vegetative growth will ultimately restore the populations to their initial condition. The effects of the continuing pollution on long-term survival cannot be assessed at present. Damage to flowers and seeds may produce long-term changes. In addition, the extensive plant and animal community associated with the intertidal surf grass (Ricketts and Calvin, 1962) was certainly modified in polluted areas, and may take a considerable time to recover.

The green algae Enteromorpha compressa, Chaetomorpha aerea, and Ulva californica, found in the upper mid and high intertidal, were only slightly damaged by the oil pollution except in regions that were completely coated and/or hot-water cleaned. In contrast with P. torreyi, the oil did not stick to these plants in large quantities, and was repeatedly wahsed off and reapplied with successive tides. Plants that were damaged were generally in the high intertidal, where the oil could remain on the thalli and dry during an average tidal cycle.

When the initial dose contaminated the coast, Ulva californica was sparse. Figure 3 shows the Ulva habitat at Station F on March 4, 1969. Oil coverage was extensive and heavy, and examination of the substrate showed only a few scattered plants. After this large dosage, weathering, wave and sand abrasion, and probably bio-degradation (ZoBell, 1963) removed most of the oil from this mid intertidal area. By early May, there was a dense growth of new Ulva californica on these cleaned areas and in regions where the rocks showed only traces of oil. Therefore, the pollution to date has had little effect on the mid intertidal Ulva growth.

Enteromorpha compressa replaces Ulva in the high intertidal and it was also relatively sparse at the time of the initial dose. However, due to its higher position relative to the tides, it was exposed to direct oiling for longer periods of time and damage was more severe. Some of the oiled high intertidal plants are shown in Figure 4. In thinly oiled areas the oil dried on the plants or at their bases, and the plants turned white. In more thickly oiled regions, the oil became less viscous when warmed by the sun and ran down over new areas, often covering previously unpolluted plants. Moreover, oil that remains in the high intertidal reduces the effective area for future attachment and thus, indirectly, reduces population size. Figure 5 shows this phenomena at Station D. New Entermorpha is found on unoiled rock surfaces only.



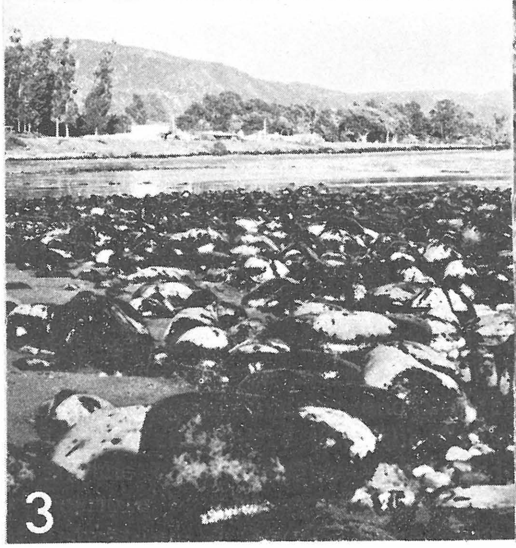


Figure 1

Oiled Surf Grass at Station D, February 13, 1969. Note workmen raking oiled straw on beach.

Figure 2

Clump of Oiled and Heavily Damaged Surf Grass at Station F, May 5, 1969. 6 inch ruler for scale.

Figure 3

Ulva Habitat at Station F, March 4, 1969.

Figure 4

Oiled *Enteromorpha* at Station C, March 15, 1969. Scale in centimeters.

The majority of the common brown algae found in the Santa Barbara area occur in the lower intertidal and subtidal and remained protected from much of the initial large oil dose. *Egregia laevigata*, found in the extreme low intertidal and shallow subtidal, is entirely exposed at some stations during extreme low tides, and its surface fronds received heavy doses of oil. However, like the green algae, the oil did not stick readily to the plant surfaces. At some stations oil was noted on plants near the holdfast, and marginal blades in these areas were frequently green or completely gone, Figure 6. The distal ends of the *egregia* plants appeared undamaged and showed continued growth during successive surveys.

The red algae, in contrast to the brown and green algae, appeared to hold the crude oil over long periods of time. *Porphyra* sp. was found to retain oil and become brittle when contaminated by crude oil from the *Torrey Canyon* (Smith, 1968), and this was also observed during the Santa Barbara spill. Fortunately, the heaviest pollution occurred before the usual spring bloom of *Porphyra*, and mortality was low except at Station G. There, a large population was exposed on top of an extensive muscle bed, and many plants were oiled and white. The other red algae, occurring primarily in the mid and low intertidal, retained oil for long periods of time but appeared to be relatively undamaged.

INTERTIDAL ANIMALS

A summary of oiled and dead animals observed in connection with the oil pollution is given in Table 4.

The common intertidal anemone, *Anthopleura elegantissima*, was oiled at Stations G and H, the oil sticking primarily to pieces of shell and debris which normally adhere to the body wall. Even with heavy oil doses, no dead animals have been observed. The high resistance of this organism to oil pollution has been previously noted by North *et al* (1964) and Smith (1968).

Damage to the barnacle *Chthamalus fissus* was extensive. Approximately 90% of the transect population was killed at Station D, the initially most heavily oiled station. Similar percent mortalities were recorded by John Cubit (personal communication), who compared the relative numbers of alive and dead barnacles on oiled and unoiled populations in the vicinity of Station D. The animals were frequently observed sweeping the oil with their cirri, which no doubt contributed to their high mortality. In high intertidal areas, much of the damage was done as a result of the oil drying on and apparently physically smothering the animals. If the covering of oil was thin, the barnacles often cleared an opening through it and showed no immediately obvious ill effects. If the oil was too thick for clearing, death almost always ensued. Figure 7 shows cleared and uncleared oil patches on a group of barnacles at Station C. Barnacle mortality extended to the mid intertidal as a result

Table 4

Animals Observed as Oil Covered and/or Dead

Animal	Dates and Stations Animals Observed Covered	Amount of Oil on Transect Population[1]	Dates and Stations Animals Observed Dead	Population Mortality Along Transect[2]	Remarks
Anthopleura elegantissima	2/12,3/15 (G)	***			Oil on body debris.
	2/12 (H)	**			
Chthamalus fissus			4/26 (A)	1%	
	3/14 (B)	*			
	2/12,3/15 (C)	*	2/12,3/15,4/28 (C)	20%	
	2/11 (D)	***	4/26 (D)	80-90%	
	3/1 (E)	***			
	2/13 (F)	***	5/5 (F)	10%	
	3/17 (I)	*			
Belanus glandula	3/15 (C)	**			
Mitella polymerus	2/12,3/15 (C)	**	4/28 (C)	1-5%	
	3/1,5/4 (G)	**	3/1,5/4 (G)	1-5%	
Pachygrapsus crassipes			2/11 (D)	1 individual	
Pagurus samuelis	3/4 (F)	**			Oil on hermit crab shells.
Orchestoidea sp.			2/8 (D)	1 individual	
Mytilus spp.			4/26 (A)	1%	
	3/15 (C)	***	3/15,4/28 (C)	1%	
	2/12,5/4 (G)	*			
	2/12 (H)	*			

Continued

Table 4, Continued

Animals Observed as Oil Covered and/or Dead

Animals	Dates and Stations Animals Observed Covered	Amount of Oil on Transect Population[1]	Dates and Stations Animals Observed Dead	Population Mortality Along Transect[1]	Remarks
Acmea spp.	4/26 (A)	*			Oil on shells and feet.
	4/28 (C)	***			
	2/11,4/26 (D)	***			
	3/1 (H)	*			
Pisaster ochraceous			2/10 (D)	1 individual	
Strongylocentrotus purpuratus			2/10 (D)	1 individual	

1. Amount of oil on transect population represents average over dates station was visited, as does percent mortality.
2. Percents represent mortality along transect as estimated by field investigator.

Legend:
* = light oil coverage
** = moderate oil coverage
*** = heavy oil coverage.

of the oil clinging to the rough surface of barnacle populations. The oil stays on these populations and is highly resistant to natural cleaning. Figure 8, taken at Station F on May 5, 1969, illustrates a heavily oiled barnacle population in the mid intertidal. Surrounding rocks which received heavy doses of oil were almost completely cleaned by natural action, while the oil on the barnacles persists.

The gooseneck barnacle, *Mitella polymerus*, occurs at Stations A, B, C, and G on exposed rocky outcrops. Mid intertidal individuals received moderate doses of oil at Stations C and G, and oil tended to stick to their plates. As was the case with *Chthamalus fissus*, gooseneck barnacles were also killed, when the oil became thick enough to physically smother them. All dead individuals had a very heavy coating of oil over them, and in many instances, their cirri were encased in dried oil.

Mortality was probably not as high as that for *C. fissus* because *Mitella* occurs lower in the intertidal in areas generally exposed to surf, which rapidly cleans off the oil before it has a chance to dry.

Only one individual of the genus *Orchestoidea*, the common sand amphipod, was observed oiled and dead. Although these organisms occur in large numbers in the sandy intertidal, they apparently remained beneath the surface of the sand during the initial oil dosage. Another sand dweller, the blood worm *Thoracophelia mucronata*, has been observed in its usual abundance since the initial pollution.

Mytilus spp. (mussels) commonly occur in association with *Mitella polymerus* and were similarly oiled. Individuals were assumed dead due to oil when they were gaping open, would not close upon stimulation, and contained heavy coatings of oil. In general, however, mussels suffered little damage.

Various chitons and limpets (*Acmea* spp.) were frequently seen with heavily oiled shells, but no dead individuals were noted. When pried off the substrate, they exhibited oiled feet which indicated they were moving and perhaps even grazing over the oil. Similar resistance and feeding behavior is noted by Smith (1968).

As Table 4 shows, the observed damage to echinoderms was slight. Moreover, the animals observed dead and oiled could have died naturally and then been oiled. Oil did not seem to stick readily to the starfish or the urchins, and their position in the lower intertidal apparently protected them from prolonged exposure.

KELP BEDS

Offshore kelp beds, having a surface canopy consisting almost entirely of *Macrocystis angustifolia*, received the first dose of incoming oil. The floating fronds held large quantities of oil, especially during low tides. From the beach, the normal brown color of the beds was changed to black. With changing winds, currents, and tides most of the oil held by the kelp was eventually released, and much of it moved shoreward to further pollute the coast. As was the case with most of the mid and low intertidal green and brown algae, the oil that came in contact with the kelp, did not stick to healthy fronds, perhaps due to the natural covering of mucus on blades and stipes. Oil was occasionally seen adhering to patches of damaged tissue.

Boat surveys conducted offshore showed no abnormal decay or damage after the initial oil dose. Animals in a few collections from the kelp canopy in both heavily and lightly polluted beds were similar in kind and abundance, and were representative of the normal kelp canopy community as described by Limbaugh (1955).

Diving surveys off Station D showed no oil beneath the kelp canopy. Over 200 dives by various persons were made in the Santa Barbara area kelp beds during and after the initial pollution under the supervision of D. Duckett, the U.C.S.B. campus diving officer. None of the divers reported oil on the bottom or any obvious changes in the subtidal environment (D. Duckett, personal communication). Divers have noted oil on the bottom in Santa Barbara harbor and immediately outside the harbor, but this is probably a result of the use of oil sinking agents in the area.

CONCLUSIONS AND DISCUSSIONS

The rank correlations indicate that major floral changes correlate well with substrate type. Gross species change are therefore probably a result of the interaction of substrate with the record winter storms which occurred in the area previous to and during the initial pollution.

Although highly significant damage occurred to the <u>Phyllospadix</u> <u>torreyi</u> and <u>Chthamalus</u> <u>fissus</u> populations in polluted areas, widespread damage to other intertidal organisms during the early stages of the oil pollution was not immediately obvious. Jones <u>et</u> <u>al</u> (1969) in a popular article, concludes that there was no extensive ecological damage. This conclusion seems overoptimistic. Jones <u>et</u> <u>al</u> did not report changes in surf grass and barnacle populations observed during this study.

It seems clear that overall damage was definitely related to initial dose, especially in the case of surf grass and barnacles.

Many factors have influenced the survival of intertidal organisms. In the areas studied, these include intertidal substrate, previously existing biota, positions of the organisms in the intertidal zone, tidal levels at the time of the pollution, extent of offshore kelp beds, length of time the oil stays at sea, and methods of clean-up.

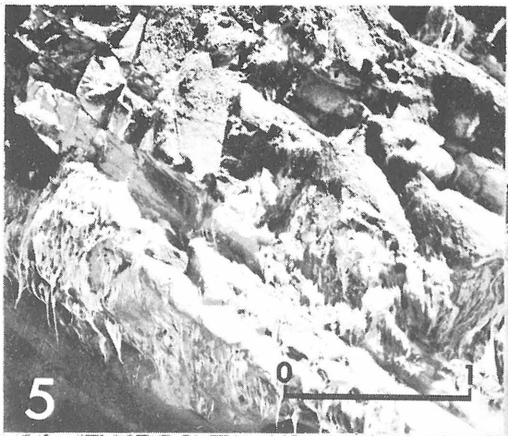
The clean-up methods being used on sandy beaches (absorption of the oil with straw and mechanical removal of the oiled straw and sand) seem to have little obvious effect on the existing sand biota. However, cleaning of the rocky high intertidal with hot water has removed an extensive community of limpets, snails, crabs, and algae along with the dried oil. Not only are the organisms damaged, but the oil removed runs down to repollute lower intertidal areas, Figure 9.

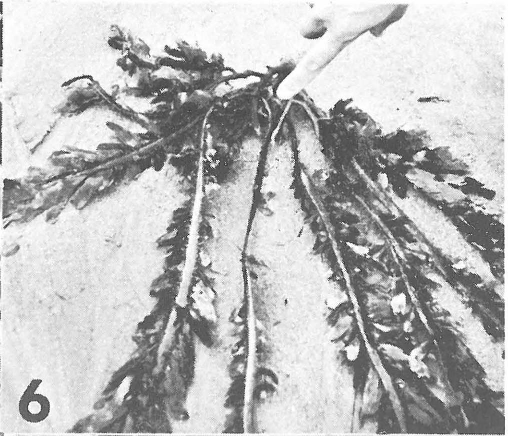
The effects of chronic long-term oil pollution on rocky intertidal regions and offshore kelp can be estimated by examining the effects of the natural oil seeps at Coal Oil Point in Goleta. There seems to be no obvious lack of kelp in the vicinity of the seeps. The beds are not as thick as others along the coast, but this may well be due to substrate availability and grazing pressure rather than oil. The oil in some cases comes out of small fissures on the bottom adjacent to attached plants.

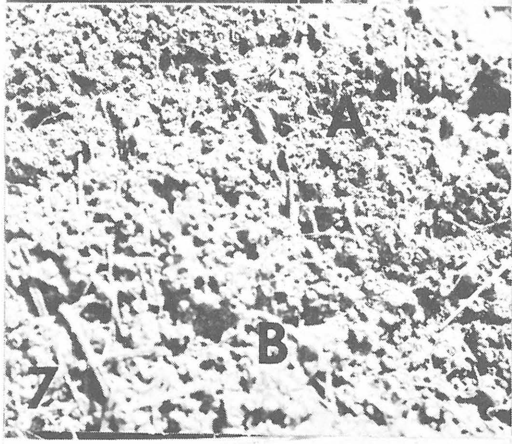
However, the effect of regular and continued doses of oil on the intertidal regions at Campus Point, which is "downstream" from the Coal Oil seeps, is immediately obvious even to the most casual observer (Figure 10). Of the total rock surface on the point, approximately 60% of the tops of rocks are covered with tar along with 30 to 40% of the sides. In some areas, the layer of tar is over 6 centimeters deep. Areas not covered are generally in the mid to low intertidal region.

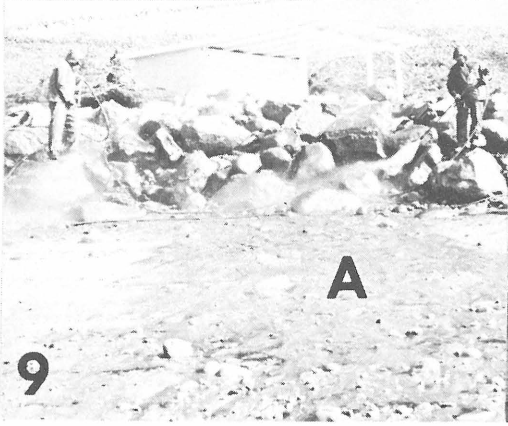
The new man-made seep around Platform A is now adding to the amounts of oil coming from natural seeps. If the new seep continues to flow, it is likely that tar build-up will occur in previously unaffected areas. Macroscopic plants and animals have not been observed to attach and grow on the tar substrate. Therefore, it appears that these seeps, and other that may result from further drilling activity, may drastically reduce the availability of intertidal surfaces that would otherwise be occupied by intertidal marine organisms.

In conclusion, it should be emphasized that this preliminary study records only some of the more obvious and immediate effects of the oil pollution. Man-made pollution has obviously influenced the complex communities of marine plants and animals in the study area. There is clear indication that a subtle and gradual erosion of this natural resource has begun. W. J. North (1964) has documented the gradual disappearance of kelp forests along the Palos Verdes and Point Loma coasts in Southern California. The reduction in kelp abundance started in the 1920's and was complete by the early 1960's. This gradual but nonetheless complete destruction of a major coastal marine community is probably being duplicated elsewhere along the Southern California coast at the present time. Whether repeated or continuing oil pollution contributes to long-term ecological degradation in the Santa Barbara region remains to be seen.









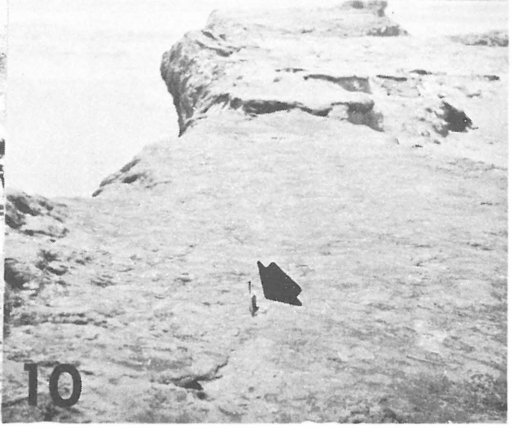


Figure 5

Enteromorpha Growing on Oil-free Areas at Station D, April 26, 1969. Scale in meters.

Figure 6

Egregia Collected at Station G on May 5, 1969. Investigator is pointing at oil covered stipes, where marginal blades are missing.

Figure 7

Oiled Chthamalus at Station C, April 28, 1969. Some individuals have cleared an opening in the oil (A), while others have no (B).

Figure 8

Heavily Oiled Barnacles at Station F on May 5, 1969. Note clean surrounding rocks.

Figure 9

Cleaning of High Intertidal Rocks with Hot Water in the Vicinity of Station F, May 5, 1969. The oil removed runs down the beach (A).

Figure 10

Rock Surfaces at Station C. The large cork borer in the foreground (arrow) is buried over 4 cm. into the old tar.

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GENERAL DISCUSSION

The amount of oil coming from the Coal Oil point natural seeps has been estimated by Mertz (1959) and is discussed in Part II of this report. Calculations based on Mertz's estimate of the amount of oil on the beach would indicate that no more than 100 gallons (35kg) per day are seeping out of the sea floor in this area. Recent spills discussed in the introduction of this report have contributed additional pollutant material along the coast. Now, the spill from Platform A is adding more crude oil to the marine environment. Allen (1969) estimated that the man-made Santa Barbara oil seep was still producing about 8,000 gallons (27,600 kg) per day in early May. Present estimates[1] range from less than 100 gallons (35kg) per day to from 840 to 1,260 gallons (2,900 to 4,300 kg) per day. Although the recent oil spill is highly significant in terms of the total oil pollution along the Southern California coast, it is obvious that oil pollution in the area did not begin with the blow-out on Platform A; chronic pollution has affected certain parts of the coast and selected offshore areas for many years.

The establishment of biological study sites by the California Water Pollution Control Board in the mid 1950's provided invaluable data against which the immediate effects of this pollution could be determined (Dawson, 1959). The usefulness of these studies is illustrated by Figures 1 and 2. Figure 1 was taken by Dawson along the transect at Station D. Figure 2 was taken the same place in February, 1969. Dawson's observations in the Santa Barbara area were re-studied and checked by student observers in 1966-1967. These student studies indicated that there had been no gross changes in the marine flora along the Santa Barbara and Ventura coasts for 10 years. This type of information, as brief and imperfect as it is, and based on only two surveys, is still the best that is available.

Dawson's collection of voucher specimens is on file at the Hancock Foundation Herbarium at the University of Southern California. Information obtained by examining these collections includes the size and reproductive condition of the plants and their vertical distribution in the intertidal zone. By reducing this information into a form that can be handled by a computer, it is possible to re-assemble the individual floras that Dawson studied and to obtain some idea of the reproductive condition and vigor of the species he collected at each station. In this way, it is possible to rapidly assess the condition of a given intertidal region, as it relates to Dawson's findings. For example, the presence or absence of sea grasses can be immediately checked, and their survival in the future can be followed. The authors have already reduced much of Dawson's original information to a computer format, and this has yielded much valuable information, especially on the probable reproductive condition of plants at the time of the initial oil dose.

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1. Estimates from various sources were published in the Santa Barbara News Press, August 5, 1969.

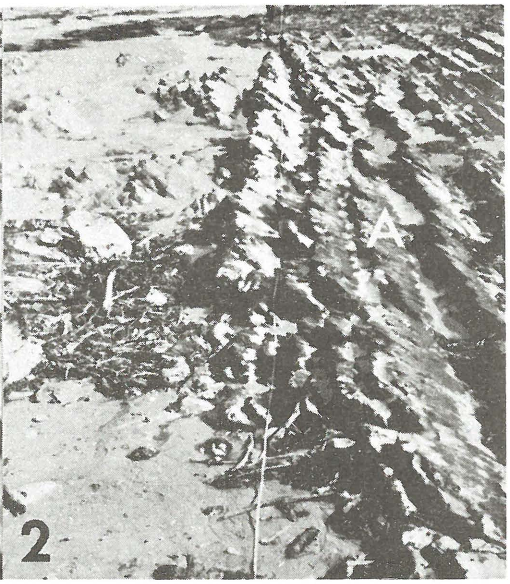

Figure 1

Picture of Dawson's Transect at Station D, 1956.
A: Algae on rocks.

Figure 2

Picture of Dawson's Transect at Station D, 1969.
A: Oil on rocks.

However, the number of plants so far reduced is small (less than 1,000), and much more information is needed before a reasonably complete picture of the flora can be developed. Additional information on the abudance of each species at each station is also needed. Finally, similar information for the animal species would have been extremely useful in investigating the effects of the Platform A spill.

The intertidal and immediate shallow subtidal regions of our coasts are small in area, yet they support a diverse and vulnerable population of plants and animals. The unique and beautiful giant-kelp forests that occur along the Southern California coast covered a mere 100 square miles when originally surveyed. This included the kelp forests on the Channel Islands as well as those on the mainland. As indicated in the present study, the oil on these now much reduced beds has not produced any immediately observable damage. There has been no obvious decrease in the amount of kelp nor any obvious damage to the plants themselves. But this does not imply that we can continue to pollute the environment where these organisms live, and expect to see them survive in their present state.

W. J. North and his associates (1964) have documented the gradual erosion of the kelp beds in Southern California, especially those near Palos Verdes and Point Loma. The observation of a similar erosion of intertidal organisms led Dawson (1959) to establish his intertidal stations along the coast. The gradual loss of a marine resource due to pollution is not always detectable after a short-term study such as that reported here. Nevertheless, the gradual erosion over a period of many years can destroy organisms just as completely as can a single, massive pollution incident. We definitely need more effective environmental monitoring in order to detect situations where our physical and biological resources are being taken from us; monitoring which continues not just during major environmental crisis, but for years.

It seems likely that there will be continued flow of oil from the man-made seep off the Santa Barbara coast. From our preliminary observations, the main effect of these seeps will be to reduce the availability of intertidal surfaces for the attachment and growth of marine organisms. The effects may also be long-term, influencing the growth and reproduction of various marine organisms, especially the surf grass and its associated flora and fauna in the intertidal. The examples of the loss of marine resources along the Palos Verdes and Point Loma peninsulas over a 40 year period are used to emphasize the fact that conclusions obtained a few months after a pollution incident of this sort should not be held as proof that there will not be long-term effects and gradual erosion of natural resources which we have seen in other locations. The offshore resources of Southern California have been shown to be extremely frail and vulnerable. Every effort should be made to apply modern ecological technology to the monitoring and protection of these resources as a necessary investment in our environment.

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As the Nation's principal conservation agency, the Department of the Interior has basic responsibilities for water, fish, wildlife, mineral, land, park, and recreational resources. Indian and Territorial affairs are other major concerns of America's "Department of Natural Resources."

The Department works to assure the wisest choice in managing all our resources so each will make its full contribution to a better United States—now and in the future.

MARCH 3, 1849