United States
Environmental Protection
Agency

Office of
Water Program Operations
Washington, DC 20460

EPA-430/9-79-014

Water

EPA

Oil Spill
Bahia Sucia, Puerto Rico
18 March 1973
Environmental Effects

OIL SPILL

BAHIA SUCIA, PUERTO RICO

18 MARCH 1973

ENVIRONMENTAL EFFECTS

Contract 68-10-0542
TRC Project 62284

July, 1975

EPA REVIEW NOTICE

This report has been reviewed by the Office of Water Programs, EPA, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

ABSTRACT

The following surveys were done to assess the impact of oil that was spilled in the vicinity of Cabo Rojo, Puerto Rico. The first survey began within a week of the spill and the second was done three months later. There was a pattern to the behavior of the oil and its effect. Regardless of ecological domains, e.g., mangroves or *Thalassia* beds, the oil first affected the epibenthic and intertidal communities. The oil penetrated the sediments shortly after the spill but the impact on the benthic infauna was not clearly seen until three months following the spill.

This report was submitted in fulfillment of Contract 68-10-0542, Order No. 68-01-1116, under the sponsorship of the Oil and Special Materials Control Division, Office of Air and Water Programs, Environmental Protection Agency.

FOREWORD

This report is the product of a scientific investigation conducted to determine the short term impact of a major oil spill at Cabo Rojo, Puerto Rico. It is part of a series of reports on major oil spill investigations funded by the Environmental Protection Agency. A principal objective of these investigations is to develop a background of knowledge and understanding of methods and tools used in assessing the environmental damage which can ultimately be applied for setting environmental priorities in spill response and cleanup.

The Caba Rojo study provides an indication of some of the gross effects which were observed within certain biological communities; however, it points out the problems associated with not having ecological baseline information available to use in assessing the impact of the oil on biological populations. The report emphasizes the need for initiating damage assessment activities immediately following an oil spill to detect the immediate effects, particularly for tropical and subtropical marine communities.

Hopefully, this report will provide insight for future impact assessment activities to be conducted in accordance with the 1977 Amendments of the Federal Water Pollution Control Act.

CONTENTS

FIGURES

TABLES

CONCLUSIONS

1. The epibenthic communities in the *Thalassia* beds and in the mangroves, and intertidal communities of mangrove prop roots were among the first to show the effect of the oil by an initial mortality to the population. Three months later there was a noticeable recolonization in the epibenthic communities of the *Thalassia* and a slight recolonization in the mangroves.

2. Benthic communities under *Thalassia* and mangrove were affected initially by the oil, and showed major losses of individuals and diversity three months after the oil spill.

3. The appearance of beach sand indicated that the beach cleanup operations were partially successful. However, oil remained below the beach surface and oil sheens were still visible on the water near the beach after three months.

4. In Survey I, the heavy losses of crabs indicated that the oil disturbed their habitat. A census made three months later on the site indicated that fiddler crabs of various sizes were repopulating the area.

5. Infrared analysis showed that during the three-months between surveys, there was a considerable reduction in hydrocarbon concentration at all stations, except in the sediments of the *Thalassia* beds, in the sediments of the north and south mangrove areas, and in the mangrove silt.

RECOMMENDATIONS

1. Trenching and pits are efficient methods of oil recovery, and can be improved by lining the trenches and pits to prevent oil seepage into subsurface sand.

2. More boom should be employed to prevent oil drifting with unexpected wind shifts, and to corral the oil as quickly as possible.

3. Beach harrowing and sorbents are very inefficient and possibly detrimental to biota.

4. Short-term biological assessment should begin promptly after a spill, and must be followed by later assessments to determine if immediate effects are important or lasting.

5. Follow-up studies should be done to determine the long-term effect of oil on the various communities in the Cabo Rojo area.

INTRODUCTION

On 18 March 1973 a major oil spill occurred near Cabo Rojo, Puerto Rico. The area where the spill was detected is designated by the X on Figure 1. VAST/TRC was requested by the United States Environmental Protection Agency to carry out two field surveys to assess the acute biological damage caused by the oil in the two major ecological communities in this region: the Thalassia beds and the mangroves. The first study was done between 24 March and 17 May, 1973, while the second occurred between 30 June and 17 July, 1973. Since the oil came ashore in Bahia Sucia (see Figure 2), this area was the principal study area.

The following is a chronological summary of events[1] that transpired between the time when the accident was first reported and the arrival of VAST/TRC personnel. The events are presented in a tabular form in Appendix A.

At 1041 hr, 18 March 1973, local police advised the Captain of the Port (COTP), San Juan, that the motor vessel, Zoe Colocotronis, had run aground in the vicinity of La Paraguera, Puerto Rico. By 1430 hours, the vessel's exact location was determined to be 17°54' N, 66°59' W, close to a shoal area. At this time, a large oil slick was spotted extending from this position to a point two miles east of Cabo Rojo and drifting towards the beach (see Figure 1). At 1145 hours that day, the vessel's agent advised the COTP, San Juan, that the vessel had freed itself with no damages and was no longer spilling oil. The vessel was continuing to Guayanilla, ETA 1430 hrs, 18 March 1973. However, at the same time, a U.S.C.G. helicopter observed that the vessel apparently discharged oil to lighten its load. The vessel had stopped discharging oil and was afloat under her own power. The approximate position was three miles offshore from Phosphorescent Bay, a popular tourist attraction in Puerto Rico. The vessel proceeded to the Commonwealth Oil Refining Company (CORCO) terminal and commenced offloading. The vessel, under charter to Mobil Oil, was carrying 180,000 BBLs of crude oil from Venezuela to CORCO. The oil was expected to come onshore somewhere between Cabo Rojo and Punta Tocon some time during the evening of 19 March 1973. The regional response team and local government officials were alerted. CORCO advised the COTP, San Juan, that Mobil Oil agreed to accept all cleanup costs. Mobil Oil, however, failed to confirm this, so a pollution contingency fund contract number was assigned, pending positive assumption of cleanup responsibility by one of the companies involved. The Commonwealth of Puerto Rico planned to require the vessel to post bond. At 0015 hrs, 19 March 1973, a USCG helicopter observed a very thick oil slick ashore from Bahia Sucia to Cabo Rojo and offshore oil extended from La Parguera to El Combate. Winds were easterly at ten knots, seas moderate. Cleanup operations involving ten men from Commonwealth Public Works Department and 180 bags of sorbent were underway. At 0805 hrs, 19 March 1973, Captain Ramsey of Mobil Oil reported from Hess that Mobil would pay all costs incurred and that he would be on the scene during the afternoon of 19 March. By 0815 hrs, 19 March 1973, On-Scene Coordinator (OSC) from COTP, San Juan, arrived with 100 extra bags of

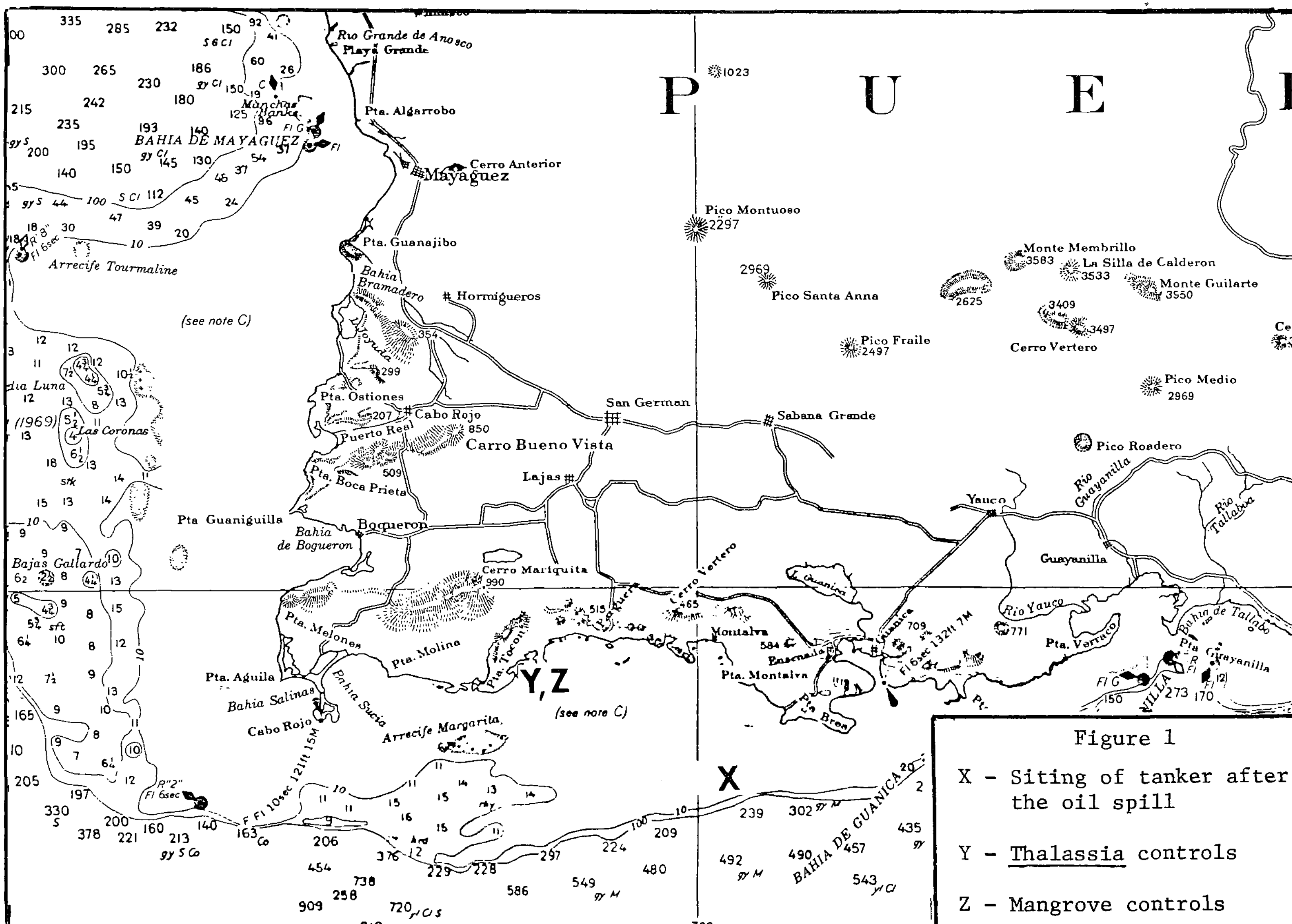
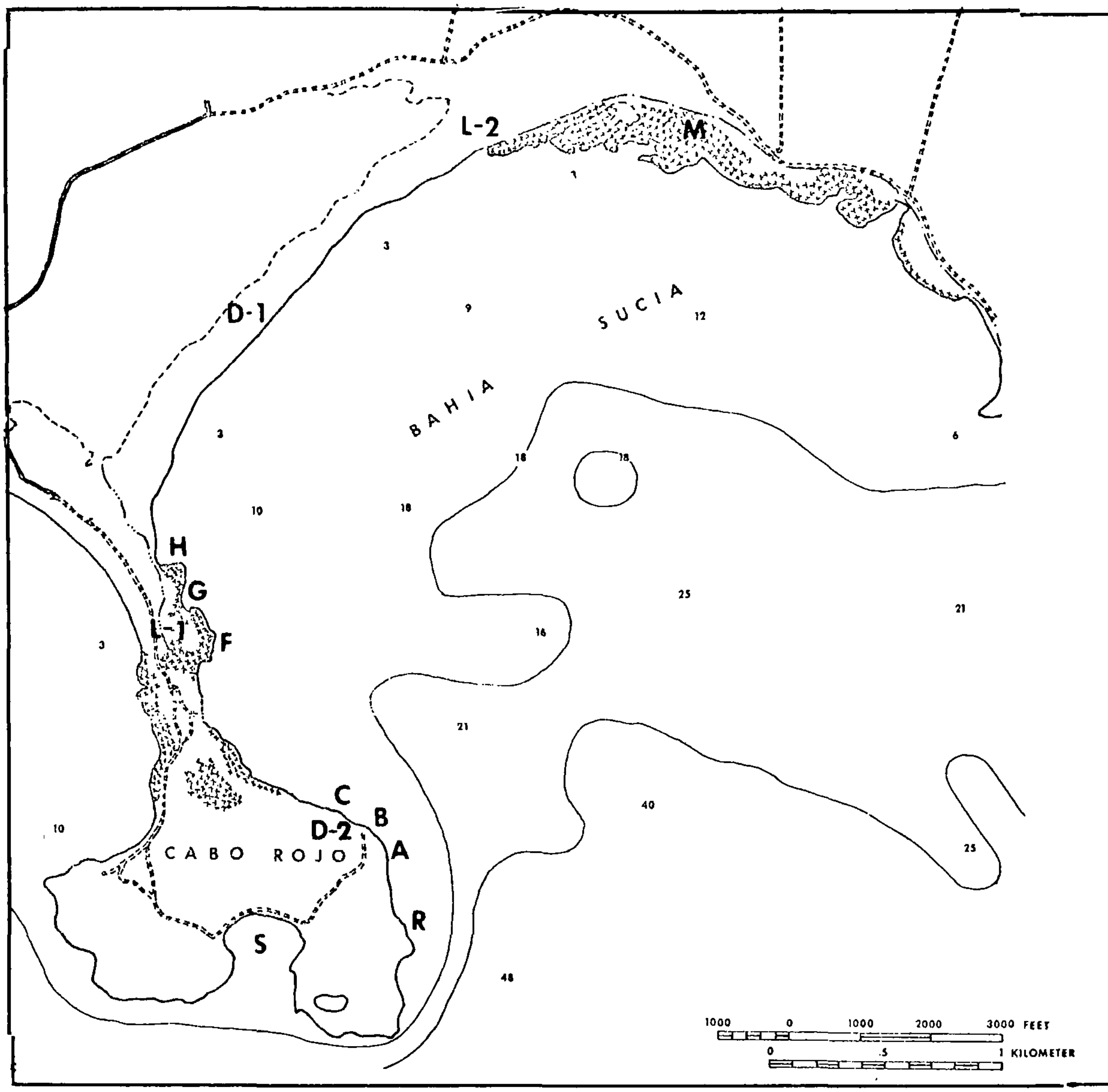


Figure 1

X - Siting of tanker after the oil spill

Y - Thalassia controls

Z - Mangrove controls



A	Short Thalassia	H	North mangrove
B	Thalassia flats	L-1	Western lagoon
C	Long Thalassia	L-2	Crab lagoon
D-1	Main Beach area	M	Upper mangrove area
D-2	Small Beach area	R	Rocky shore
F	South mangrove	S	Shark Bay
G	Silt mangrove		

Figure 2: Location of Oil-contaminated Sampling Stations in Bahia Sucia, Puerto Rico

sorbent and a 640 ft boom.

At 0915 hrs, 19 March 1973, the slick was sited on two shore locations: (a) at the cliff face (67°11.0' W) and (b) east of Cabo Rojo between 67°11.6' W and 67°11.5' W, 17°57.6' N. Between 0940 and 1000 hrs on the 19th, officials from the Commonwealth's Environmental Quality Board (EQB) and the Department of Natural Resources made separate overflights. Regional EPA representatives arrived and were transported to the scene at 1700. During the 19th, cleanup operations continued and the vessel posted bond. However, the company had not accepted the responsibility. At 1630 hrs, 19 March 1973, a U.S.C.G. overflight revealed that the slick moved north, parallel to the west coast of Puerto Rico.

On 20 March 1973, cleanup operations continued. The vessel's master, crew, and logs were subpoenaed and a complaint against the captain, M. Michalotoulis, was filed in U.S. District Court by EPA lawyers. An arrest was to be made following EQB hearings. These hearings, which were to determine the damage caused by the spill, began on 22 March 1973. The vessel's captain was arrested on the 23rd of March and was released on bail that same day.

The VAST/TRC field survey team was activated by EPA Region II on 21 March 1973. On the following day, representatives of this team met with Mr. Richard Dewling and Dr. Royal Nadeau for a briefing on the situation at Cabo Rojo. The scope of the field survey, including chemical procedures, was outlined. The field team departed for Puerto Rico on 24 March 1973 and established a field base at the Nuclear Science Center, University of Puerto Rico, Mayaguez.

GENERAL OBSERVATIONS

A preliminary survey to determine the extent of oil contamination in the Cabo Rojo area was made by our survey team on 24 and 25 March. The survey included the entire coastline between Cabo Rojo and La Parguera (Figure 1). We observed that the heaviest concentrations of oil were confined to the western portion of Bahia Sucia and that small amounts of oil were washing ashore on the western side of Shark Bay, S in Figure 2. Figure 3 demonstrates the general condition in Bahia Sucia. The dark

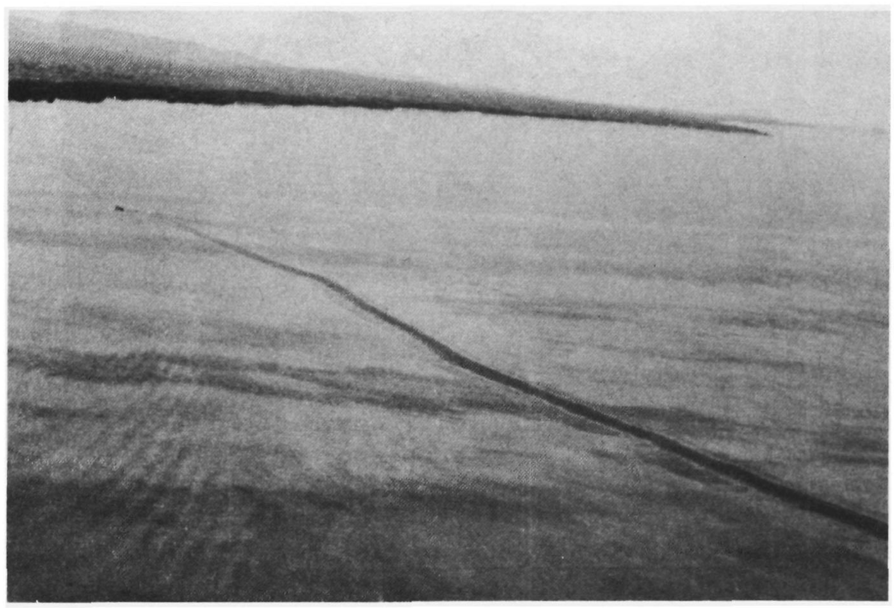


Figure 3: Photo of a Boat Path through Oil-covered Water in Bahia Sucia. The photo was taken during the afternoon of 31 March 1973. The dark line is oil-free water. This view is towards Punta Molina.

line is a trail made in the otherwise oil-covered water by a small boat. The view is across the Bahia towards Punta Molina. Some weathered oil could be seen at the high tide line on the eastern side of Punta Molina.

Rocky Shores

The rocky shore zone, R in Figure 2, along the seaward section of the western shore of Bahia Sucia is primarily limestone cliffs. The rock rubble at the base of the cliffs is both pitted and eroded (Figure 4A).

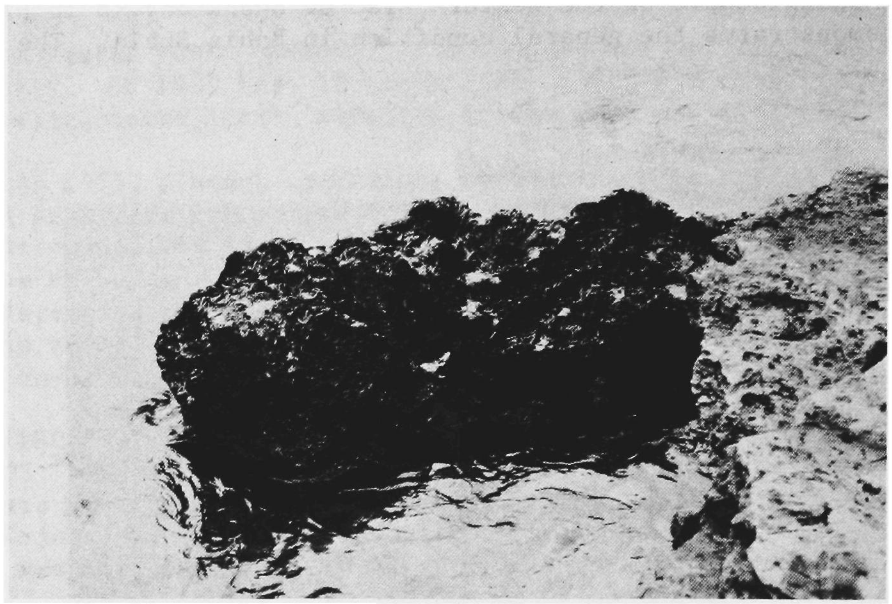


Figure 4A: The Rocky Shore Zone at Cabo Rojo. Photo taken on 25 March 1973. Pitted rock rubble at the base of the cliffs.

An oil-free zone extended along this shore from the tip of Cabo Rojo to a point 400 m north along Bahia Sucia. Beyond this point, the vertical faces of the cliffs were covered with a thick band of oil. The width of the band varied from one to three meters, depending on the extent of the splash zone. Figure 4B illustrates the conditions along the oiled rocky shore line.

The surface of the water washing the rocks in the oiled zone was heavily coated with oil. The oiled rocks were devoid of visible signs of life, except for subtidal algae. It was not clear whether this condition resulted naturally from the exposed nature of the habitat, or from the presence of oil.

Figure 4B: The Rocky Shore Zone at Cabo Rojo. Photo taken on 25 March 1973. Oiled rocks in the north end of the rock zone.

Beach Areas

The major beach area around Bahia Sucia was located at Dl on Figure 2. The southern half section of beach confronted the largest concentrations of floating oil in the entire Bahia Sucia. It was here where the effort of oil recovery took place. (See Cleanup Operations section). This beach was made of white, calcareous sand sloping gently up to the upper end of the intertidal zone where there was a sand-filled narrow detrital seagrass step about 20 to 30 cm. high. The terrain above this step was sandy and mostly covered with sea grape. During the cleanup operations large sections of sea grape vegetation were demolished to provide an access road about 20 m. wide along the length of the oil-covered beach. The intertidal beach section, as well as the offshore waters, were thoroughly covered with oil during the duration of Survey I (Figure 5). During Survey II (three months later) oil sheens could still be seen on the water and oil-soaked sand was observed starting at 10 to 15 cm. below the intertidal beach surface.

Biologically, the beach was considered to be less productive than the mangroves or Thalassia beds and thus not selected as a sampling location due to the project's limited resources and the difficulty in finding an area undisturbed by cleanup operations. However, physically the beach probably became a significant storage and continuous, long-term, small source of hydrocarbon to the offshore waters and the environs.

North of the rocky shore near Cabo Rojo was a small beach area, D2 in Figure 2. This beach had a narrow intertidal zone that was covered with wrack (mostly detrital sea grasses). The beach itself had a shallow berm which contained numerous crab burrows and some scrub vegetation. The latter was comprised mostly of red and white mangrove, sea grape, grass, and Badis. At the time of the first survey wind-driven oil had completely covered the water along the beach shore for a relatively short time, leaving a narrow band of oil, about 0.5 m. wide, along the beach. We also observed a surface sheen of oil extending far offshore, as well as tarry deposits on sandy shallows. Cleanup operations on this beach consisted of raking and use of sorbents.

Figure 5: Beach Scene in Bahia Sucia - Survey I. Photo taken on 26 March 1973. There is extensive litter and oil-covered water just off shore.

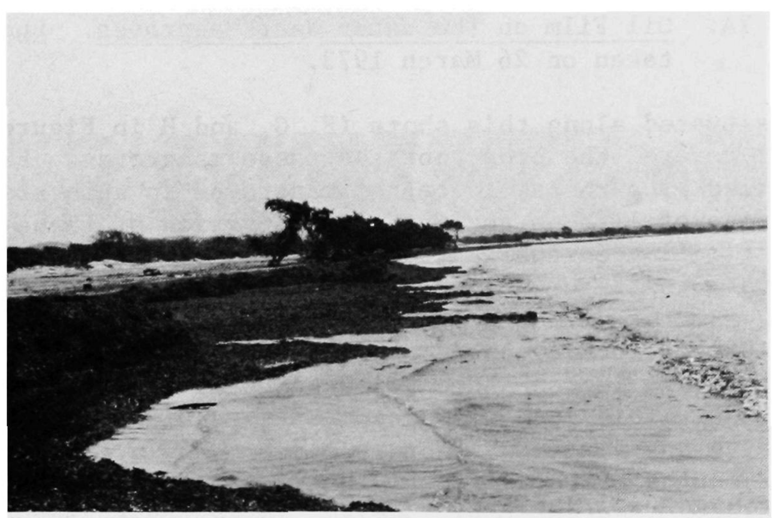


Figure 6: Northward View of Beach Area during Survey II. Photograph taken on 1 July 1973.

Mangroves

In Survey I, the water along the western shore of Bahia Sucia was covered with a visible film of oil (Figure 7A). Oil penetrated a man-

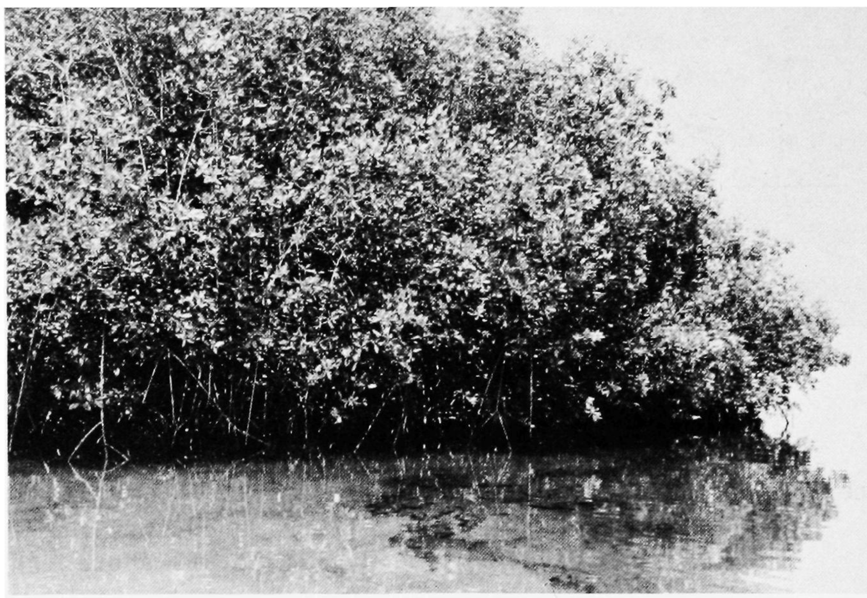


Figure 7A: Oil Film on the Water Near Mangroves. Photo taken on 26 March 1973.

grove area situated along this shore (F, G, and H in Figure 2) and a layer of oil covered the prop roots of these mangroves. Figure 7B shows the oiled prop roots of the red mangroves in this area. There was no visible sign of life on the intertidal portion of these prop roots and the oil floating on the water surface was too thick to allow subtidal observations (Figure 8A).

There was a lagoon located behind this mangrove area, L-1 in Figure 2. Oil penetrated this lagoon and covered both the water surface and the intertidal zone. This zone was densely packed with crab burrows. We did not observe any dead crabs nor were there any signs of fresh diggings at the mouths of the burrows. Unoiled mangroves and *Thalassia* beds were selected east of Bahia Sucia. These areas are designated by Z and Y in Figure 1. Conditions in this control region are shown in Figure 8B.

In Survey II the intertidal regions of the oiled mangroves were littered with plant debris and were heavily silted. Deposits of dead *Thalassia* had accumulated on the bottom adjacent to the South mangrove site. Many

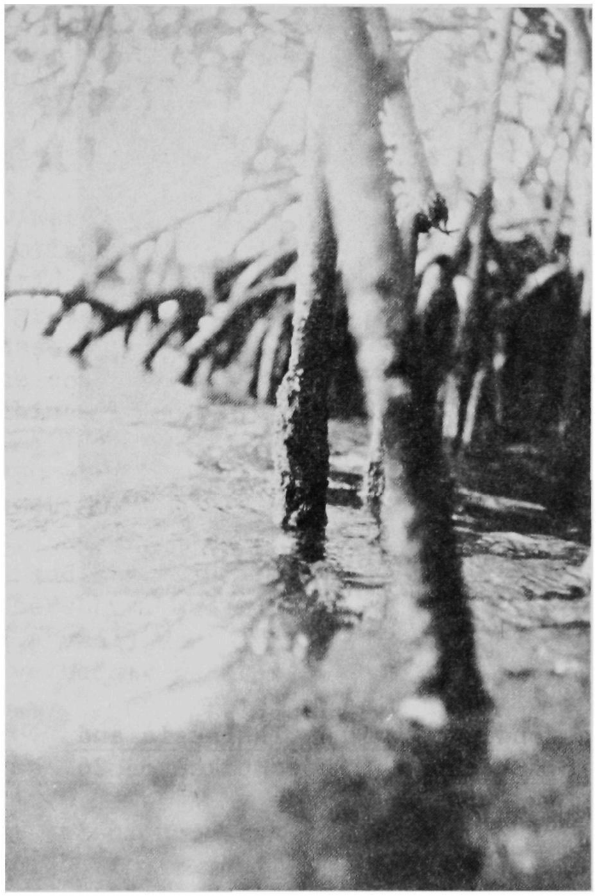


Figure 7B: Intertidal Region of Prop Root Zone of the Red Mangrove. Survey I at Station H. Photo taken on 26 March 1973.

Figure 8A: Oil in Red Mangroves at Station G (Silt Mangrove), Survey I. Photograph taken on 27 March 1973.

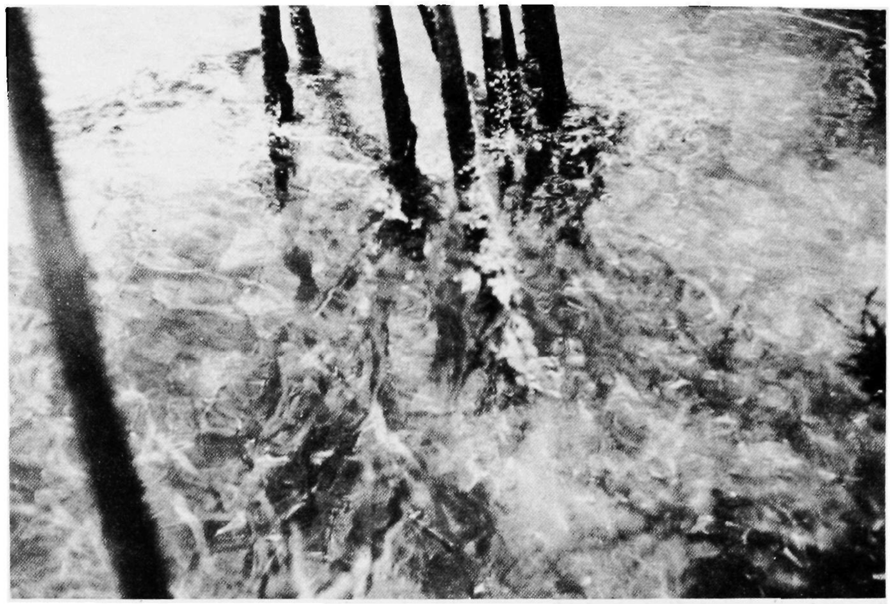


Figure 8B: Characteristic Condition at the Thalassia and Mangrove Control Stations. Photo taken on 26 March 1973.

hydroids and sponges could be seen in this area and the latter were attached to both the prop roots and substrate. There were many dead sea urchins at this location. The calcareous alga, Halimeda, was abundant on the bottom nearby the mangroves.

The benthos near the "silt" mangroves (G), was also littered with dead Thalassia by Survey II. However, oil-coated Manatee grass (Syringonium sp.) at this location was rooted and green; as were green algae and Halimeda. There were still oil slicks evidenced on the water surface and prop roots.

Field observations at the northern mangroves (H) suggested that oil penetrated the sediments because our walking squeezed oil up from the sand. Some dead Thalassia also accumulated in this location. However, there was not a large accumulation of Thalassia detritus at the mangrove control stations.

There is a second mangrove area in Bahia Sucia, M in Figure 2. During the early stages of Survey I, this area was clear of oil. However, during the first of April, there was a wind shift and oil was carried from the southwest portion of Bahia Sucia north to this mangrove area.

The oil penetrated the canals which intersected the shoreline, and covered the banks of these canals. These banks had broad intertidal zones which were densely packed with crab burrows. Consequently, the intertidal zones were covered with oil. Heavy mortalities among at least four species of crabs were then observed.

Thalassia

Shallow water (mostly less than 1/2 meter in depth) extended about 100 meters offshore from the beach (D2, Figure 2) to a small *Porites* reef. The subtidal areas between the reef and the beach were covered with turtle grass (*Thalassia*) interspersed with several other varieties of sea grasses. Near the reef was a diverse faunal community associated with the coral nodes. Organisms in this community included starfishes, sea urchins, brittlestars, snails, limpets, and hermit crabs.

Within 50 meters of the beach the grass beds were occasionally broken with sandy depressions which harbored schools of anchovies and small wrasses. No starfish were seen in this zone. Several recently dead sea urchins and some live ones which were losing their spines were picked up along the shore. Within the intertidal area a dead oil-soaked sea cucumber and a small dead lobster were found. The adjacent beach did have some live hermit and sand crabs.

Hydrographic Conditions

Offshore water currents in the Cabo Rojo region are part of the North Equatorial Current, and run westward, parallel to the coast. The annual average magnitude is 0.14 m/sec. with small annual variations of approximately 0.02 m/sec. One high and one low tide occur daily. The intertidal zone is thus very small due to the tidal range of less than one foot (30 cm). Observations made at Bahia Sucia indicated a longer duration of flood tide over ebb (the flood ran north and ebb ran south at about the same magnitudes on the west shore), suggesting a possible CW net flow along the shores of the bay.

The offshore water salinity varies 2 or 3 ppt. during the year and averages 35.4 ppt. Surface water temperatures have a very small range from 25°C to 32°C.

Winds in the semiarid Cabo Rojo region are from the southeast or east southeast. The average annual rainfall is 30 inches (76 cm), offset by an annual average evaporation rate of 80 inches (203 cm).

Cleanup Operations

There were two phases to the beach cleanup operations: (1) containment by oil booms, and (2) recovery by a trenching-pumping method. During containment, booms were deployed perpendicular to the beach. The oil would be corralled near the beach instead of drifting eastward along the shore. However, on 1 April, there was a wind shift and the oil moved south out of Bahia Sucia. The booms were relocated off the mangroves along the west shore of Bahia Sucia to keep the oil in the mangroves from spreading out into the bay.

The removal procedure consisted of trenches cut into the beach at right angles to the shoreline. Oil flowing into these trenches was pumped directly into tanker trucks (Figure 9). This method was an effective and ingenious way of removing a large portion of floating oil blown against the beach by prevailing winds.

Minor cleanup efforts with particulate sorbent materials were relatively ineffective due to the small percentage recovery of the sorbent, and the higher affinity of sand particles for the oil.

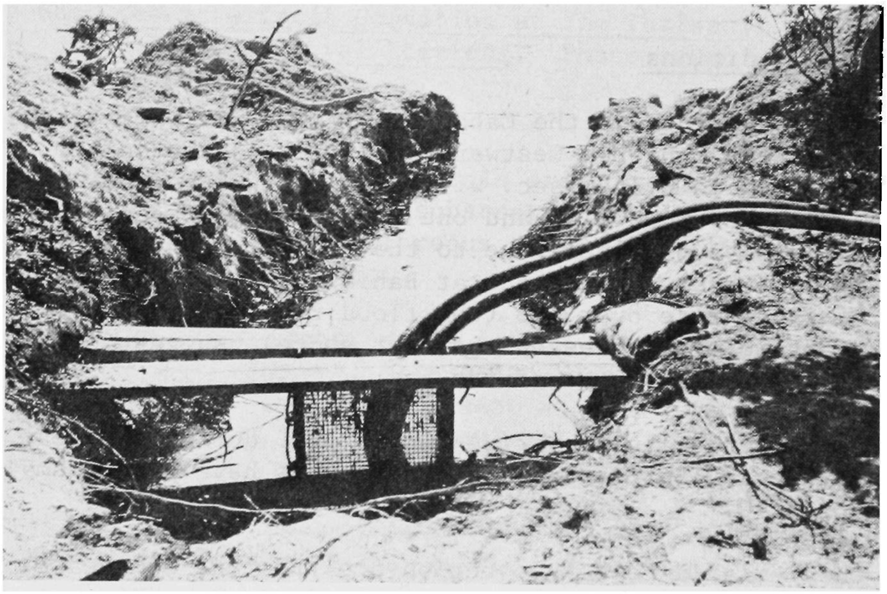


Figure 9: Trench-pit System for Oil Recovery. Photo taken on 26 March 1973.

The west shore of Bahia Sucia was chosen for intensive study in Surveys I and II. The specific study areas shown in Figure 2 include short *Thalassia* beds (A), *Thalassia* flats (B), long *Thalassia* (C), and the south (F), silt (G), and north (H) mangroves which were mentioned in the previous section. The corresponding control areas were located well east of the westward drifting oil (Y,Z Figure 1). Physical parameters of temperature, salinity, dissolved oxygen, and specific gravity were measured at each station (see Table 1).

Thalassia Beds

The three *Thalassia* study areas represented the seagrass beds typical of Bahia Sucia. The southernmost station, Figure 2, was dominated by short *Thalassia*. The grass was at an average depth of 15 cm below the surface (Figure 10). Station B, the *Thalassia* flats, had numerous sandy depres-

Figure 10: Sampling Station in Short Thalassia Beds - Survey I. Photo taken on 27 March 1973.

sions and the area was partially exposed at low tide. The grass at this location was short but it did not appear to be the same variety seen at Station A. The third station, C, was in approximately one meter of water. The substrate here was level and supported a tall *Thalassia* community. Two comparable control stations were established on an island offshore from Isla Cueva (Z, Figure 1).

TABLE 1

PHYSICAL PARAMETERS OF THE WATER AT THE VARIOUS STATIONS

	SURVEY I				SURVEY II			
LOCATION	SALINITY 0/00	TEMPERATURE (°C)	DISSOLVED OXYGEN (ppm)	SPECIFIC GRAVITY	SALINITY 0/00	TEMPERATURE (°C)	DISSOLVED OXYGEN (ppm)	SPECIFIC GRAVITY
Short *Thalassia* O	38.5	31.0	12.2	1.0240	37.5	29.3	9.2	1.0240
Short *Thalassia* C	39.6	30.6	--	1.0250	37.3	28.3	13.8	1.0242
Long *Thalassia* O	37.5	30.5	12.9	1.0237	37.5	29.0	8.8	1.0240
Long *Thalassia* C	38.0	30.0	8.2	1.0240	37.5	29.0	12.4	1.0242
Thalassia Flats O	36.8	30.0	12.9	1.0234	37.4	29.5	8.8	1.0240
North Mangrove O	39.0	32.1	4.4	1.0246	30.8	30.8	9.3	1.0246
North Mangrove C	37.3	27.0	8.0	1.0245	38.5	31.2	13.8	1.0240
South Mangrove O	30.5	31.2	9.8	1.0249	37.9	30.5	13.9	1.0245
South Mangrove C	37.3	27.0	8.0	1.0245	37.1	31.8	13.9	1.0240
Silt Mangrove O	39.0	32.5	7.9	1.0242	37.9	30.2	12.4	1.0245
Silt Mangrove C	38.4	30.0	6.9	1.0243	37.8	30.0	10.9	1.0244

A stake marked the center of each station (see Figure 10). Macrofauna and flora were identified and counted while walking or snorkling over a six meter diameter around the stake. All macro-organisms within the station were counted and identified. Smaller epibenthic organisms were sampled by random placement of wire grids (25 cm x 19 cm). Organisms within six such grids were collected and preserved for identification and enumeration. All preservation was done by first fixing the sample in 10% formalin for 24 hours, then transferring the sample to 70% isopropyl alcohol. Infauna were sampled by taking three cores (10 cm diam. x 13 cm deep) at each station, then screening through two mesh sizes (1.5 and 1 mm). The coarse fraction (1.5 mm) was wet weighed and sorted in the field laboratory. The fine fraction (1 mm) was stained with Rose Bengal solution, preserved in 70% isopropanol and sorted under dissecting microscopes in the laboratory.

Samples for chemical analysis at each station included one liter of water (sampled at mid-depth and acidified in the field with 5 ml 1:1 H_2SO_4), one sediment core (6.5 cm diam. x 12 cm deep) of each grassy area, and a sample of Thalassia. All samples were collected in glass containers prepared by washing in carbon tetrachloride (nanograde MCC). These samples were extracted in the field laboratory using the method outlined in Appendix B. They were returned to the TRC chemistry laboratory for infrared analysis.

Mangroves

The three stations were established in the oil-saturated mangrove community on the western shore (see Figure 2), two on the exposed side and one in the leeward side of a mangrove island shown in Figure 7A. Comparable control stations were located near Isla Cueva (Y, Figure 1). At each mangrove station, three prop roots which were not yet imbedded were wrapped in aluminum foil to keep the root community intact. The roots were cut off above the water level and sealed in plastic bags. At the field station, the prop roots were soaked in alcohol, wrapped in alcohol-soaked cheesecloth, and transported back to the laboratory where they were frozen within 48 hours of collection. Infauna was sampled by taking three benthic cores at each station and treating them as described in Thalassia methods. One mid-depth water sample and one sediment core from each station were collected and analyzed as in the Thalassia methods.

Statistical Methods

Our assessment of the effects of the spilled oil are based on comparisons of diversity and abundance both between the oiled and control study areas as well as between surveys. However, the taxonomic keys that were available did not enable us to identify all our faunal and floral samples to the same level of taxonomic specificity. In order to settle on a taxonomic unit that would be applicable to all the communities we studied, we developed the faunal group. This unit was the basis of our comparisons of faunal diversity observed at the various areas. We define the faunal group as the most specific taxon that is common to all animals that clearly belong to a particular taxonomic group. In most cases, the faunal group was at the "family" taxonomic level.

The statistical comparisons of faunal group diversity between oiled and control communities and between surveys are based on a test of differences between the mean number of faunal groups observed at the respective communities. The difference is used to calculate a statistic called the student's "t." This statistic has a Gaussian or normal distribution similar to the distribution of observations about the mean of a population and it is a tool to determine whether two independent groups of observations are the same.[2] To apply this test we lumped all possible sources of variation in the biological communities, i.e., migration, seasonal changes, and the invasion of oil into the control areas. A particular limitation on this statistical test is the sample size. As will be seen in the following section, there were three samples taken from a given community. Although this can introduce errors into statistical comparison, it cannot affect the field observations. Consequently, our conclusions and recommendations are based on the observed faunal diversity and abundance in the various communities.

Chemical

The methods used in our chemical analysis are summarized in Appendix B.

Thalassia Beds

General Ecology

Thalassia or turtle grass is a common seagrass found along the Gulf shore of Florida, down through the Florida keys and on the islands of the Caribbean Sea. Its growth generally begins at the mean low spring tide level and extends out to depths ranging from 20 to 75 m[3]. Local distribution patterns suggest that this grass is limited by exposure to environmental stresses. Jackson[4] observed that Thalassia on back reef areas on the north coast of Jamaica had shorter leaves than the grass in protected deeper adjacent locations. This observation coincides with Humm's[3] conclusion that seagrass serves as a sediment trap and stabilizes the bottom substrate.

The calm waters and high solar radiation associated with this grass allow the growth of various algae genera, i.e., Penicillius, Halimeda, Udotea, Dictyota, Valonia, and Caulerpa.[5] Algae are known for their ability to secrete materials which stabilize sediments.[6,7] The general bottom stability combined with excessive sedimentation can lead to a series of successive changes that eventually result in an invasion by mangroves.[5]

The Thalassia is the basic producer for a wide variety of herbivorous animals such as sea urchins, parrot fish, sea turtles, and Manatees.[3] The grass also provides protection and camouflage for its endemic filter feeders and deposit feeders.

Epibenthic Community

Tables 2, 3, and 4 summarize our observation of the macro-epibenthic organisms at the Thalassia stations during Surveys I and II. A total area $\approx$ 28 m^2 was examined at each station. In the first survey, the oiled long Thalassia and oiled Thalassia flats had a paucity of faunal groups (Table 3). However, the oiled short Thalassia and all the controls had a similar faunal composition. Sea urchins were most common, followed by decapod arthropods (i.e., shrimp), and sponges.

During the second survey in July, there was a slight increase in the number of faunal groups in the oiled long Thalassia and in the oiled Thalassia flats (Table 4), but the abundance was low. No particular faunal group seemed to dominate these two stations. The control areas and the oiled short Thalassia showed a general decline in the number of faunal groups and abundance between surveys. However, the sea urchins (Echinoidea) did persist in the oiled short turtle grass.

Close analysis of the epibenthic organisms in six grids (each 19 x 25 cm) taken from each of the grass stations during Surveys I and II are summarized in Tables 5 and 6. The faunal pattern seen in the macro-study

TABLE 2

SUMMARY OF DENSITY AND DIVERSITY

MANGROVE BENTHIC COMMUNITY						
		SURVEY I	SURVEY II	SURVEY I	SURVEY II	
HABITAT	STATION	NUMBER OF FAUNAL GROUPS PER 3,063 CM^3		NUMBER OF INDIVIDUALS PER 3,063 CM^3		"t" TEST OF FAUNAL GROUPS H_o = (P=0.95)
Mangrove-North	H-Oily	2	4	12	4	
Mangrove-South	F-Oily	5	0	28	0	Oil_I = $Control_I$:Accept
Mangrove-Silt	G-Oily	4	2	6	3	Oil_{II} = $Control_{II}$:Accept
Mangrove-North	Control	0	5	0	12	
Mangrove-South	Control	4	4	5	8	$Control_I$ = $Control_{II}$:Accept
Mangrove-Silt	Control	9	5	39	6	
MANGROVE PROP ROOT COMMUNITY						
		NUMBER OF FLORAL AND FAUNAL GROUPS PER 3 x 2 CM^2*		NUMBER OF INDIVIDUALS PER 3 x 2 CM^2*		
Mangrove-North	H-Oily	4	13	1 + algae	28 + algae	
Mangrove-South	F-Oily	2	4	3 + algae	6 + algae	Oil_I = $Control_I$:Reject
Mangrove-Silt	G-Oily	2	2	algae	2 + algae	Oil_{II} = $Control_{II}$:Accept
Mangrove-North	Control	12	9	32 + algae	33 + algae	
Mangrove-South	Control	15	8	17 + algae	63 + algae	$Control_I$ = $Control_{II}$:Reject
Mangrove-Silt	Control	8	9	21 + algae	9 + algae	
		NUMBER OF FAUNAL GROUPS PER ENTIRE PROP ROOT**		NUMBER OF INDIVIDUALS PER ENTIRE PROP ROOT**		
Mangrove-North	H-Oily	1	7	1	24	
Mangrove-South	F-Oily	4	6	8	32	Oil_I = $Control_I$:Reject
Mangrove-Silt	G-Oily	0	1	0	1	Oil_{II} = $Control_{II}$:Accept
Mangrove-North	Control	9	4	172	53	
Mangrove-South	Control	9	6	169	53	$Control_I$ = $Control_{II}$:Reject
Mangrove-Silt	Control	11	4	136	16	

TABLE 2
(continued)

SUMMARY OF DENSITY AND DIVERSITY

THALASSIA EPIBENTHIC COMMUNITY						
		SURVEY I	SURVEY II	SURVEY I	SURVEY II	
		NUMBER OF FLORAL AND FAUNAL GROUPS PER 6 X 475 CM^2		NUMBER OF INDIVIDUALS PER 6 x 475 CM^2		
Thalassia Beds short	A-Oily	4	9	17	19	Oil_I = $Control_I$: Accept
Thalassia Beds Long	C-Oily	0	10	0	19	Oil_{II} = $Control_{II}$:Accept
Thalassia Flats	B-Oily	2	6	3	6	
Thalassia Beds short	D-Control	6	6	30	30	$Control_I$ = $Control_{II}$:Accept
Thalassia Beds Long	E-Control	5	10	10	25	Oil_I = Oil_{II}:Accept
THALASSIA BENTHIC COMMUNITY						
		NUMBER OF FAUNAL GROUPS PER 3,063 CM^3		NUMBER OF INDIVIDUALS PER 3,063 CM^3		
Thalassia Beds short	A-Oily	12	13	55***	40	Oil_I = $Control_I$:Accept
Thalassia Beds Long	C-Oily	24	7	90***	15	Oil_{II} = $Control_{II}$:Accept
Thalassia Flats	B-Oily	13	5	52***	45	
Thalassia Beds short	D-Control	12	8	24****	29	$Control_I$ = $Control_{II}$:Accept
Thalassia Beds Long	E-Control	7	10	19	24	

*Based on microscopic survey of 3 x 2 cm^2.

**Based on visual survey of the whole mangrove prop root.

***Primarily worms.

****Primarily molluscs and echinoderms.

TABLE 3

SURVEY I -- MACROINVERTEBRATE

COMMUNITIES OF *THALASSIA* STATIONS

SAMPLED BY WALKING SURVEY OF 39.0 m^2

	LONG THALASSIA		SHORT THALASSIA		FLATS
	OILY	CONTROL	OILY	CONTROL	OILY
ANNELIDS					
Polychaetea				1	
ARTHROPODS					
Decapoda		2	5	6	
CNIDARIA (COELENTERATES)					
Anthozoa		5	3	12	
CHORDATES					
Tunicata		1		1	
ECHINODERMS					
Crinoidea		1			
Echinoida (sea urchins)		14	9	12	
Holothuroidea		2		5	
MOLLUSCS					
Bivalva		1	2		
Gastropoda			2	1	
PORIFERA (Sponges)			6	5	6
TOTAL FAUNAL GROUPS	0	7	6	8	1
TOTAL INDIVIDUALS	0	26	27	43	6

TABLE 4

SURVEY II -- MACROINVERTEBRATE

COMMUNITIES OF THALASSIA STATIONS

SAMPLED BY WALKING SURVEY OF 39.0 m^2

	LONG THALASSIA		SHORT THALASSIA		FLATS
	OILED	CONTROL	OILED	CONTROL	OILED
ANNELIDS					
Polychaeta					
Hermodice? Type K				1	
ARTHROPODS					
Decapoda					
Paguridea	1		1		
Brachyrhyncha			2	2	
Penaeidea					1
Scyllaridea			1		
COELENTERATES					
Anthozoa	*		*		
ECHINODERMS					
Echinoidea	1		7	2	*
Asteroidea		1			
Holothuroidea		1		3	2
Ophiuroidea		2			
MOLLUSCS					
Polyplacophore	1				
Bivalvia	1				
SPONGES (Porifera)	*	*			
TOTAL FAUNAL GROUPS	4	3	4	4	2
TOTAL INDIVIDUALS	4	4	11	8	3

* Present but not quantified or included in totals.

TABLE 5

SURVEY I -- EPIBENTHIC COMMUNITIES OF *THALASSIA* BEDS

TOTALS OF SIX (19 x 25 CM) GRIDS PER STATION

	SHORT *THALASSIA*		LONG *THALASSIA*		FLATS
	OILED	CONTROL	OILED	CONTROL	OILED
GREEN ALGAE					
Halimeda sp.	--	--	--	15.0g*	--
Penicillus capitatus	8	--	--	--	4
ARTHROPODS					
Decapods					
Brachyrhyncha	2	4	--	3	1
Majidae	--	1	--	--	--
COELENTERATES					
Zoanthidea	--	14.0g*	--	14.0g*	--
CHORDATES					
Tunicate	--	6	--	--	--
ECHINODERMS					
Ophiuroidea	1	--	--	2	--
Helothuriodea	--	2	--	--	--
MOLLUSCS					
Gastropoda	14	17	--	6	--
TOTAL FLORAL AND FAUNAL GROUPS	4	6	0	5	2
TOTAL INDIVIDUALS (FAUNA)	17	30	0	11	1

* Wet weight, not included in totals of individuals

TABLE 6

SURVEY II -- EPIBENTHIC COMMUNITIES OF THALASSIA BEDS

TOTALS OF SIX (19 x 25 CM) GRIDS PER STATION

CLASSIFICATION	SHORT THALASSIA		LONG THALASSIA		FLATS
	OILED	CONTROL	OILED	CONTROL	OILED
ALGAE					
Brown Algae					
Dictyota sp.	*	--	*	--	--
Padina sp.	--	--	--	--	*
Green Algae					
Halimeda	--	*	*	--	*
Penicillus capitatus	--	--	--	--	*
ANNELIDS					
Polychaete Families					
Serpulidae-Type A	--	1	--	--	--
Terebellidae -Type 0	--	--	--	1	--
ARTHROPODS					
Amphipoda	--	--	--	--	2
Decapoda					
Paguridea	--	6	1	1	--
Acarina	1	--	--	--	--
ECHINODERMS					
Ophuiroidea	1	--	--	1	--
Echinoidea	--	--	--	1	--
MOLLUSCS					
Bivalvia	--	1	--	1	--
Polyplacophora	1	--	--	--	2
Gastropoda genera					
Astraea	--	--	--	2	2
Cantharus	--	--	1	--	--
Cerithium	6	16	7	9	--
Columbella	--	--	1	--	--
Modulus	4	6	6	1	--
Morum	--	--	1	--	--
Tegula	1	--	--	6	--
Turbo	3	--	1	2	--
SPONGES (Porifera)	2	--	1	--	--
TOTAL FLORAL AND FAUNAL GROUPS	9	6	10	10	6
TOTAL INDIVIDUALS (FAUNAL)	19	30	19	25	6

* present but not quantified, not included in totals

in Survey I was valid for the grid analysis. The oiled long Thalassia and oiled Thalassia flats showed the lowest number of groups and the lowest abundance (Table 5). The control areas and the oiled short Thalassia were similar in faunal composition with gastropods the most frequently observed group.

In the second survey, there was a general increase in diversity and abundance at all but the short Thalassia control area (Table 6). The oiled long Thalassia grids contained six genera of gastropods while in the previous survey, there were none. The other areas, which showed an increase in diversity between surveys, were uniform in the types of faunal groups.

Benthic Infaunal Community

Observations of infaunal communities contained in a benthic grab ($3063\ cm^3$) taken from each station during Surveys I and II are summarized in Tables 7 and 8. During the first survey the communities did not show any depletions that could be related to the oil spill. All the areas showed a uniform mix of faunal groups that are available in the Cabo Rojo region (Table 7). The oiled long Thalassia had the greatest abundance and number of faunal groups.

However, in Survey II there was a reduction in numbers of faunal groups in the oiled long Thalassia and oiled Thalassia flats (Table 8). Although the infauna at the control long Thalassia slightly increased in abundance and diversity, there was a 3-fold decrease in numbers of groups of organisms (diversity) and a 4-fold decrease in numbers of individuals in the oiled long Thalassia benthic community. The most substantial depletion occurred in the bivalve and polychaete groups. The numbers of groups and abundance of infauna decreased in Survey II in the oiled Thalassia flats; however, there was an exceptional increase in numbers of one family of polychaetes, the Onuphidae. This pattern is reminiscent of the disproportionate increase in numbers of Capitellidae in response to the Falmouth Oil Spill in Massachusetts.[10]

Between surveys there appeared to be a general decline in the appearance of the oiled Thalassia beds. It appeared that a large amount of the grass had died and had been washed away, leaving more numerous and extensive pits of loose sand than were present on the first survey. The death of turtle grass was evident by the extensive windrows of dead blades washed up on the beaches and lying on the bottom at the edges of the mangroves on Survey II. Furthermore, exposed roots and rhizomes lined the edges of the sand pits suggesting that a great deal of erosion had taken place with the death of the grass following the oil spill.

Mangroves

General Ecology

The mangroves are the culmination of coastal succession in the tropical

TABLE 7

SURVEY I -- BENTHIC INFAUNAL THALASSIA COMMUNITIES

PER 3,063 CM^3

	SHORT THALASSIA		LONG THALASSIA		FLATS
	OILED	CONTROL	OILED	CONTROL	OILED
ANNELIDS					
Polychaete Families					
Arabellidae-Type L	5	--	16	--	1
Amphinomidae	1	--	--	--	--
Capitellidae-Type B	--	--	7	--	8
Eunicae	1	--	--	--	--
Glyceridae-Type M	--	--	1	--	1
Nephytidae-Type F	--	--	1	1	--
Onuphidae-Type I	--	1	4	--	2
Polynoidae-Type N	--	--	--	--	1
Syllidae-Type K	32	--	7	--	7
Terebellidae-Type O	--	--	--	2	--
Species Unknown-Type P	--	1	23	1	--
Mutilated*	31	2	33	--	--
ROUNDWORMS					
Nematoda	1	--	3	--	12
ARTHROPODS					
Amphipoda	4	--	--	--	--
Decapoda					
Paguridea	--	1	2	1	--
Brachyrhyncha	--	1	--	--	2
Pycnogonida	--	--	1	--	--
Isopoda	--	--	2	--	--
COELENTERATES					
Anthozoa	1	4	6	7	14
CHORDATES					
Tunicata	--	--	2	--	--
ECHINODERMS					
Ophiuroidea	--	3	1	3	--
MOLLUSCS					
Bivalvia genera					
Anomalocardia	--	--	1	--	--
Brachiodontes	1	--	--	--	--
Chione	2	--	1	--	--
Codakia	5	3	4	4	1
Macoma	1	--	--	--	--
Gastropoda genera					
Anarchis	--	1	1	--	--
Astrea	--	--	1	--	--
Marginella	--	3	--	--	--
Nassarius	1	--	--	--	--
Olivella	--	--	--	--	1
Polinices	--	--	--	--	1
Retusa	--	--	1	--	--
Rissonia	--	--	2	--	--
Tegula	--	4	--	--	--
Truncatella	--	--	1	--	--
Turbo	--	1	1	--	--
Unknown	--	1	1	--	1
TOTAL FAUNAL GROUPS	12	12	24	7	13
TOTAL INDIVIDUALS	55	24	90	19	52

*Not included in total of faunal groups or individuals; cause of mutilation unknown.

TABLE 8

SURVEY II -- BENTHIC INFAUNAL THALASSIA COMMUNITIES

PER 3,063 CM^3

	SHORT THALASSIA		LONG THALASSIA		FLATS
	OILED	CONTROL	OILED	CONTROL	OILED
ANNELIDS					
Polychaete Families					
Capitellidae-Type B	2	1	--	--	--
Flabelligeridae, Type U	--	--	--	--	1
Hermodice?-Type K	1	--	--	--	2
Nereidae-Type Q	3	--	1	--	--
Onuphidae-Type I	9	--	--	1	40
Sabellidae-Type S	--	--	--	--	1
Terebillidae-Type O	--	--	--	4	--
Unknown-Type R	--	1	--	--	1
Mutilated, Type Unknown*	2	1	--	3	3
ARTHROPODS					
Amphipoda	1	--	--	4	--
Decapoda					
Brachyrhyncha	--	1	--	--	--
Majidea	1	--	1	--	--
Isopoda	--	--	2	2	--
ROUNDWORMS					
Nematoda	2	--	--	--	--
ECHINODERMS					
Ophiuroidea	5	5	3	1	--
Echinoidea	1	--	--	--	--
Holothuroidea	--	1	2	--	--
MOLLUSCS					
Bivalvia	11	16	5	5	--
Polyplacophora	2	1	1	1	--
Gastropoda	1	3	--	4	--
Aspidobranchia	1	--	--	1	--
Nudibranchia	--	--	--	1	--
TOTAL FAUNAL GROUPS	13	8	7	10	5
TOTAL INDIVIDUALS	40	29	15	24	45

*Not included in totals of faunal groups or individuals.

environment. They became established on the silt and detritus of calcareous algae that are associated with Thalassia beds.[5] The mangroves modify the physical nature of a coast line in two ways:[3] (1) they absorb the impact of waves during storms, and (2) the organic debris which accumulates among the prop roots is converted to peat which then provides a substrate for terrestrial succession.

Zonation is frequently observed in mangrove stands through the tropical areas of the world.[8] In Puerto Rico there are three types of mangroves:[5]

Figure 11: Thalassia Beds During Survey II. Photo taken on 1 July 1973.

the red (Rhizophora mangle), a seaward or pioneer form; the black (Avicennia nitida), a germinous type; and the white (Laguncularia racemosa), more terrestrial in nature.

Through a tidal cycle the prop roots, particularly of the Rhizophora can be completely exposed and completely inundated. Consequently, the mangroves must tolerate daily extremes of environmental stress. The Rhizophora are one of several mangrove genera that have lenticels, or pores in the roots for gas exchange. These lenticels facilitate root respiration. Oxygen in these roots is consumed when the roots are covered with water and is replenished when the roots are exposed.[8]

The mangroves provide habitats for a wide variety of organisms including barnacles, crustaceans, algal grazing snails, bees, and reptiles. The submerged roots provide shelter and a substrate for filter feeders, such as tunicates, hydroids, tube dwelling annelids and sponges, and mangrove oysters.[5]

Prop Root Communities

There was observable disturbance in both the benthic and prop root communities (See Table 2). In the first survey (Tables 9 and 10), the oil affected both the macroinvertebrate and microinvertebrate communities in the prop root regions and the benthic infaunal communities (See Table 13).

The macroinvertebrate and microinvertebrate prop root communities from the three oiled mangroves, (F, G, and H in Figure 2) showed less than half as many faunal groups as was observed in the control areas. The abundance of organisms at the oiled area was also less than half of the control regions (see Tables 9 and 10). The macroscopic organisms in the oiled areas were essentially missing, while the control areas showed a community comprised mostly of tanaids and amphopods. Smaller organisms on the three prop root zones were mainly algae (Table 10). The uppermost zone of the roots in the oil and control areas had the least algae coverage. Regardless of the effects of oil, this upper zone in both areas is most likely to experience extremes in temperature and desiccation stress. Consequently, the impact of oil on the epifauna is not clear. In addition, the oil may have clogged the lenticels and stressed mangrove respiration. However, in the lower zones the algal coverage in the oil and control areas showed differences that may be related to the spilled oil. The maximum algal coverage of 6 cm^2 in the oiled areas was 30% (1.8 cm^2) and this was in the lowest prop root region of the north mangroves, Station H. The control areas had algal coverage ranging from 25% to 75%.

Three months later in Survey II, animals were returning to the mangrove areas. This is shown in Tables 11 and 12. The macroinvertebrates in the north (Station H) and south (Station F) had representatives from several polychaete and arthropod groups. The silt area (Station G) was still devoid of animals. The control areas were dominated by Arthropods, particularly the amphipods and tanaids.

The microinvertebrate community in the middle and bottom regions of the prop roots increased in diversity, but it was still dominated by algae (Table 12). Maximum algal coverage in the oiled area reached 90%: this was in the silt mangrove area. However, this area did not show the increase in faunal diversity seen at the two adjacent oiled mangroves. The northern oiled mangrove showed the greatest diversity of faunal

TABLE 9

SURVEY I -- MACROINVERTEBRATE COMMUNITY

FOR MANGROVE PROP ROOTS

CLASSIFICATION	NORTH		SOUTH		SILT	
	OILED	CONTROL	OILED	CONTROL	OILED	CONTROL
ANNELIDS						
Polychaete Families						
Hermodice?-Type K	--	--	--	6	--	3
Nephtyidae-Type Q	--	--	--	--	--	1
Sabellidae-Type S	--	--	--	3	--	--
Flabelligeridae-Type U	--	1	--	--	--	--
Unknown-Type P	--	--	1	--	--	--
Unknown-Type V	--	4	--	1	--	--
Unknown-Type X	--	--	--	--	--	1
Mutilated*	--	5	2	3	--	--
ARTHROPODS						
Amphipoda	--	24	--	21	--	74
Cirripedia*	--	--	--	--	--	--
Decapods						
Brachyrhyncha	--	3	4	3	--	2
Majidae	--	--	--	--	--	2
Caridea	--	--	--	--	--	4
Isopoda	1	--	--	--	--	--
Tanaidacea	--	130	--	124	--	--
COELENTERATES						
Hydrozoa*	--	--	--	--	--	--
MOLLUSCS						
Bivalvia	--	3	2	2	--	28
Gastropoda	--	1	--	5	--	2
Aspidobranchia	--	1	--	--	--	--
SPONGES (Porifera)	--	5	1	4	--	10
CHORDATES						
Tunicata	--	--	--	--	--	9
TOTAL FAUNAL GROUPS	1	9	4	9	0	11
TOTAL INDIVIDUALS	1	172	8	169	0	136

* Denotes presence of the organism, but no quantification; not included in totals.

TABLE 10

SURVEY I -- MICROSCOPE SURVEY

OF MANGROVE PROP ROOTS.

A TOTAL OF 3 ($2cm^2$) GRIDS.

CLASSIFICATION	NORTH		SOUTH		SILT	
	OILED	CONTROL	OILED	CONTROL	OILED	CONTROL
TOP ZONE						
ALGAE						
Bostrichia sp.						0.1 cm^{2a}
Filamentous Type A	2 cm^{2a}	0.02 cm^{2a}	1.6 cm^{2a}	2.0 cm^{2a}	--	--
ANNELIDA						
Polychaete Family						
Serpulidae (tube)	--	--	--	--	--	--
White calcareous substance*	--	--	--	2.8 cm^{2b}	--	--
ARTHROPODA						
Cirripedia	--	29	--	--	--	15
Isopoda	--	--	--	4	--	1
COELENTERATA						
Hydrozoa	--	--	--	0.20 cm^{2a}	--	--
MID ZONE						
ALGAE						
Bostrichia sp.	--	0.04 cm^{2a}	--	--	--	--
Caulerpa racemosa	--	0.04 cm^{2a}	--	--	--	--
Filamentous Type A	1.5 cm^{2c}	0.88 cm^{2b}	--	2.1 cm^{2b}	--	3.54 cm^{2c}
Filamentous Type B	.02 cm^{2a}	0.40 cm^{2a}	--	0.1 cm^{2a}	--	--
Filamentous Type C	--	--	--	0.4 cm^{2a}	--	--
ANNELIDA						
Polychaete Family						
Sabellidae (Tubes)*	0.1 cm^2	--	3	1	--	16
Serpulidae (Tubes)*	--	--	--	0.06 cm^{2a}	--	--
ARTHROPODA						
Amphipoda	--	--	--	--	--	2
Cirripedia	--	3	--	1	--	--
Isopoda	--	--	--	1	--	--
CHORDATES						
Colonial Tunicata	--	--	--	--	--	0.10 cm^{2a}
White calcareous substance*	--	1.22 cm^{2b}	--	--	--	--
COELENTERATES						
Hydrozoa	--	0.34 cm^{2c}	--	--	--	--
MOLLUSCS						
Gastropoda	--	--	--	--	--	3
PORIFERA (SPONGES)						
Encrusting tan sponge	--	1.8 cm^{2a}	--	0.2 cm^{2a}	--	--

continued

TABLE 10

(continued)

SURVEY I -- MICROSCOPE SURVEY

OF MANGROVE PROP ROOTS.

A TOTAL OF 3 ($2cm^2$) GRIDS.

CLASSIFICATION	NORTH		SOUTH		SILT	
	OILED	CONTROL	OILED	CONTROL	OILED	CONTROL
BOTTOM ZONE						
ALGAE						
Bostrichia sp.	--	0.80 cm^{2a}	--	--	--	--
Filamentous Type A	1.84 cm^{2c}	2.02 cm^{2c}	--	1.8 cm^{2a}	0.6 cm^{2b}	0.21 cm^{2b}
Filamentous Type B	--	--	--	1.6 cm^{2a}	0.4 cm^{2a}	--
Filamentous Type C	--	--	--	1.1 cm^{2a}	--	--
ANNELIDA						
Polychaete Family						
Sabellidae (Tube)*	--	--	--	--	--	--
Mutilated*	--	--	--	2	--	--
ARTHROPODS						
Isopoda	--	--	--	8	--	--
CHORDATES						
Tunicata						
Colonial	--	--	0.20 cm^{2a}	--	--	0.70 cm^{2a}
Solitary	--	--	--	--	--	--
COELENTERATES						
Hydrozoans	--	0.34 cm^{2c}	--	--	--	--
ROUNDWORMS						
Nematode-Type A	--	--	--	3	--	--
PORIFERA (SPONGES)'						
Encrusting tan sponge	--	--	--	0.40 cm^{2a}	--	--
TOTAL FLORAL AND FAUNAL GROUPS	4	12	2	15	2	8
TOTAL FAUNAL INDIVIDUALS	1	32	3	17	0	21

*Not included in total of faunal groups or individuals.

[a]Coverage in 1 out of 3 zones

[b]Coverage in 2 out of 3 zones

[c]Coverage in 3 out of 3 zones

TABLE 11

SURVEY II -- MACROINVERTEBRATE COMMUNITY

FOR MANGROVE PROP ROOTS

CLASSIFICATION	NORTH OILED	NORTH CONTROL	SOUTH OILED	SOUTH CONTROL	SILT OILED	SILT CONTROL
ANNELIDS						
Polychaete Families						
Arabellidae - Type L	2	--	--	--	--	--
Hermodice? - Type K	2	--	--	--	--	--
Polynoidae - Type N	--	--	--	1	--	--
Sabellidae - Type S	1	--	2	--	--	--
Serpulidae - Type A	--	--	--	2	--	--
Unknown - Type V	--	--	13	--	--	--
ARTHROPODS						
Amphipoda	1	31	4	15	--	2
Decapoda						
Caridea	--	--	8	--	--	--
Brachyrhyncha	6	--	3	5	1	4
Tanaidacea	--	20	--	18	--	--
Isopoda	11	--	--	12	--	1
CHORDATES						
Fish larvae	1	--	--	--	--	--
Tunicata	--	1	--	--	--	--
MOLLUSCS						
Bivalvia	--	--	--	--	--	9
Gastropoda	--	1	2	--	--	--
TOTAL FAUNAL GROUPS	7	4	6	6	1	4
TOTAL INDIVIDUALS	24	53	32	53	1	16

TABLE 12

SURVEY II -- MICROSCOPE SURVEY OF MANGROVE PROP ROOTS

A TOTAL OF 3 (2 CM^{2a}) GRIDS.

CLASSIFICATION	NORTH		SOUTH		SILT	
	OILED	CONTROL	OILED	CONTROL	OILED	CONTROL
TOP ZONE						
ALGAE						
Filamentous Type A	--	1.0 cm^{2a}	--	--	--	--
Filamentous Type B	--	1.0 cm^{2a}	--	--	--	--
Red Filamentous Type C	--	0.04 cm^{2a}	--	--	--	--
ANNELIDS						
Polychaete Family						
Serpulidae-Type B	--	--	--	2	--	--
ARTHROPODS						
Cirripedia	4	31	6	54	2	5
MOLLUSCS						
Bivalvia	--	--	--	--	--	1
White Calcareous Substance*	--	--	--	0.04 cm^{2a}	--	--
MID ZONE						
ALGAE						
Bostrichia sp.	--	--	0.2 cm^{2a}	--	--	1.0 cm^{2a}
Encrusting algal mat	--	--	--	--	--	0.6 cm^{2a}
Filamentous Type A	4.0 cm^{2b}	2.0 cm^{2b}	2.0 cm^{2a}	3.0 cm^{2b}	--	0.3 cm^{2a}
Filamentous Type C	0.2 cm^{2a}	--	--	--	--	--
ANNELIDS						
Polychaete Family						
Serpulidae-Type A	1	--	--	--	--	--
ARTHROPODS						
Cirripedia	11	--	--	--	--	--
Isopoda	1	--	--	--	--	2
COELENTERATES						
Hydrozoa	3	2	--	--	--	--

continued

TABLE 12

(continued)

SURVEY II -- MICROSCOPE SURVEY OF MANGROVE PROP ROOTS

A TOTAL OF 3 (2 CM^{2a}) GRIDS.

CLASSIFICATION	NORTH		SOUTH		SILT	
	OILED	CONTROL	OILED	CONTROL	OILED	CONTROL
BOTTOM ZONE						
ALGAE						
Filamentous Type A	4.2 cm^{2c}	3.0 cm^{2b}	3.3 cm^{2c}	4.0 cm^{2b}	5.4 cm^{2c}	2.3 cm^{2b}
Filamentous Type B	--	1.0 cm^{2a}	--	--	--	--
ANNELIDS						
Polychaete Families						
Arabellidae	1	--	--	--	--	--
Sabellidae (tube)	--	--	--	4	--	7
Serpulidae (case)	4	--	--	--	--	--
Mutilated	--	--	--	1	--	--
ARTHROPODS						
Amphipoda	7	--	--	1	--	1
Decapoda						
Caridea	--	--	--	3	--	--
Tanaidacea	1	--	--	--	--	--
CHORDATES						
Tunicata	--	--	--	2	--	1.06 cm^{2a}
Red Calcareous encrustation*	--	1.2 cm^{2b}	1.0 cm^{2a}	--	--	--
COELENTERATES						
Hydrozoa	1.0 cm^{2a}	--	--	--	--	--
MOLLUSCS						
Gastropoda	--	--	--	1	--	--
PORIFERA (SPONGES)	0.8 cm^{2a}	0.8 cm^{2a}	--	--	--	--
TOTAL FLORAL AND FAUNAL GROUPS	13	9	4	10	2	9
TOTAL INDIVIDUALS (FAUNAL)	28	33	6	63	2	9

* Not included in totals.

[a] Coverage in one out of three zones.

[b] Coverage in two out of three zones.

[c] Coverage in three out of three zones.

TABLE 13

SURVEY I -- BENTHIC INFAUNAL MANGROVE COMMUNITIES

PER 3,063 CM^3

CLASSIFICATION	NORTH		SOUTH		SILT	
	OILED	CONTROL	OILED	CONTROL	OILED	CONTROL
ANNELIDS						
Polychaete Families						
Arabellidae - Type L	1	--	--	--	--	--
Hermodice? - Type K	--	--	--	--	--	3
Glyceridae - Type M	--	--	--	2	--	--
Terebellidae - Type J	--	--	--	--	1	--
Unknown Type F	--	--	--	--	1	--
Mutilated*	1	--	12	--	7	3
NEMATODA (Roundworms)	--	--	14	--	--	3
ARTHROPODS						
Amphipoda	--	--	--	1	2	22
Isopoda	--	--	--	--	--	4
Unidentified Larvae	--	--	1	--	--	--
COELENTERATES						
Anthozoa	11	--	9	1	2	1
ECHINODERMS						
Ophiuroidea	--	--	--	--	--	1
MOLLUSCS						
Bivalvia	--	--	--	--	--	1
Gastropoda	--	--	--	1	--	3
Aspidabranchia	--	--	--	--	--	1
NEMERTINA (Ribbonworms)	--	--	1	--	--	--
SPONGES (Porifera)	--	--	3	--	--	--
TOTAL FAUNAL GROUPS	2	0	5	4	4	9
TOTAL INDIVIDUALS	12	0	28	5	6	39

* Not included in totals.

groups; various arthropod representatives were most frequently observed at all three depths.

Benthic Infaunal Community

Table 13 summarizes the faunal composition we observed in the benthic infaunal community during Survey I. There was no clear pattern that related to the movement of oil as described in the summary of events (Appendix A). The oiled northern mangroves, Station H in Figure 2, was dominated by anthozoans. The other two oiled mangrove stations, F and G, contained nematodes and polychaete worms. Only the silt control area showed a fairly diverse community, but it was also dominated by one faunal group: amphipods.

In the second survey, we noticed a decline in abundance at all three oiled mangrove stations, and there was a marked reduction in the number of faunal groups at the south oiled mangrove location (Table 14). The anthozoans and polychaete groups seen in March and April were missing and no particular group moved into these areas during the three months between surveys.

The control areas changed between surveys. However, there was no clear trend in the controls that can be attributed to seasonal variations or contamination of the control areas by oil.

Fiddler Crab Habitats

There were lagoons located inland from the mangroves on the western shore and on the northern shore of Bahia Sucia. The respective lagoons are designated L-1 and L-2 in Figure 2. The southern-most lagoon (L-1) was visited in our first survey during March. We did not observe any signs of crab mortality that could be attributed to the spilled oil. However, the wind shift on 1 April 1972, which drove the oil northward into the canals associated with lagoon L-2, did result in extensive mortalities in at least four species of crabs in this area. The total area affected was approximately 0.6 km^2. Table 15 represents a summary of our observations. The fiddler crab suffered the greatest number of deaths.

By Survey II, oil was still present. However, an increase was noted in numbers and species of crabs. The main members were ghost crabs (*Ocypode albicans*) and fiddler crabs (*Uca sp.*) of all sizes.

Chemical Analyses

The results of the chemical analyses of oil in Surveys I and II are summarized in Tables 16 and 17. The infrared spectroscopy technique used determines total hydrocarbon content. The infrared peak, 2930 cm^{-1}, which we used to interpret the infrared absorption spectra, is considered to encompass oil and oil-related compounds.[9]

TABLE 14

SURVEY II -- BENTHIC INFAUNAL MANGROVE COMMUNITIES

PER 3,063 CM^3

CLASSIFICATION	NORTH		SOUTH		SILT	
	OILED	CONTROL	OILED	CONTROL	OILED	CONTROL
ANNELIDS						
Polychaete Families						
Capitellidae-Type B	--	2	--	--	1	--
Hermodice?-Type K	--	1	--	2	--	1
Nereidae-Type Q	--	--	--	3	--	1
Onuphidae-Type I	--	1	--	1	--	--
Mutilated*	3	--	--	1	--	--
ARTHROPODS						
Amphipoda	--	--	--	--	--	2
Decapoda						
Panuridea	1	--	--	--	--	--
ECHINODERMS						
Ophiuroidea	1	1	1**	--	--	1**
MOLLUSCS						
Bivalvia	1	7	--	2	--	1
Gastropoda	1	--	--	--	--	1
PORIFERA (SPONGES)	--	--	--	--	2	--
TOTAL FAUNAL GROUPS	4	5	0	4	2	5
TOTAL INDIVIDUALS	4	12	0	8	3	6

*Not included in totals of faunal groups of individuals.

**Fragment

TABLE 15

MORTALITIES AT FIDDLER CRAB HABITAT, SURVEY I

AREA $\approx$ 0.6 KM^2

DATE	SPECIES	NUMBER DEAD
3 April 1973	*Uca sp.*	62
	Ocypode albicans	7
	Callinectes ornatus	3
7 April 1973	*Uca sp.*	198
	Cardisoma guanhumi	3
	Callinectes ornatus	3
	Ocypode albicans	12

TABLE 16

FIELD SURVEY I

TOTAL HYDROCARBON CONCENTRATIONS IN PPM OF OIL IN SAMPLES

HABITAT	STATION	WATER	SEDIMENTS	GRASS
Thalassia, short	A Oily	2.70	254.7	1130.2
Thalassia, long	C Oily	0.92	151.8	6160.0
Thalassia, flats	B Oily	2.17	5360.1* 274.5**	134342.0
Thalassia	Control	0.40	N.D.	56.3
Mangrove, south	F Oily	0.40	33.6	--
Mangrove, silt	G Oily	0.70	43.6	--
Mangrove, north	H Oily	0.72	68.0	--
Mangrove	Control	N.D.	6.0	--
Blanks	--	N.D.	--	--

* (0 - 5 cm depth)

** (6 - 12 cm depth)

N.D. - Not detectable, limit of detection

TABLE 17

FIELD SURVEY II

TOTAL HYDROCARBON CONCENTRATIONS IN PPM OF OIL IN SAMPLES

HABITAT	STATION	WATER	SEDIMENTS	GRASS
Thalassia, short	A Oily	N.D.	21.3	30.2
Thalassia, long	C Oily	N.D.	39.7	12.3
Thalassia, flats	B Oily	N.D.	3.4* 3.5**	25.0
Thalassia	Control	***	N.D.	4.8
Mangrove, south	F Oily	0.20	25.0	--
Mangrove, silt	G Oily	0.20	215.8	--
Mangrove, north	H Oily	0.20	27.8	--
Mangrove	Control	0.20	3.1+ 4.8++	--
BLANK -- BROKEN IN TRANSPORT				

* (0 - 6 cm depth)

** (6 - 12 cm depth)

*** Missing

\+ Silty Sediment

++ North Sediment

N.D. Not Detectable, Limit of Detection

Analysis of water samples collected during Survey I showed hydrocarbons at two of the three *Thalassia* stations (Table 16). Grass samples were analyzed for hydrocarbon. Samples taken from the *Thalassia* flats had the greatest hydrocarbon content; the long grass was second and the short *Thalassia* was third. The pattern was also seen in sediment samples taken from the various areas.

The hydrocarbon content in the water in the oiled mangroves was less than 1.0 ppm (Table 16). However, substantially higher levels were detected in the sediments of these oiled stations. We did not detect hydrocarbons in the 2930 cm^{-1} range in the sediments from the control mangroves.

In the second survey, there was a general improvement, i.e., decrease in hydrocarbon content, at all the oiled stations (Table 17). In many instances, there was an order-of-magnitude reduction in the levels of hydrocarbons in the 2930 cm^{-1} range. A notable exception was the sediments from the oiled silt mangroves, Station G. Here the hydrocarbon concentration had doubled between surveys. Also the hydrocarbon concentration in the water and sediment at the central mangrove station increased from non-detectable to 0.20 ppm and 3 to 4 ppm respectively.

DISCUSSION

The biological and chemical data show a sequential change in the biota of Bahia Sucia that can be related to the observed movement of the oil[1] and the long-term behavior of spilled oil.[10,11] The organisms which were first affected by the oil either occupied the intertidal areas of the mangroves or were associated with the epibenthic community in the *Thalassia*. The benthic organisms in both areas seemed to be unaffected by the oil, although it had penetrated the sediments. During the three months following the spill there was some recovery in the intertidal and epibenthic communities, but there was a marked depletion of faunal groups in the benthic communities.

A similar sequential pattern was observed by Sanders, *et. al.*[10] in the first three months following the oil spill at West Falmouth, Massachusetts. This pattern was also noted at the site of the Casco Bay, Maine, oil spill.[11] The scope of our impact studies was three months following the spill; however, we feel that the disturbance in the benthic communities will last at least one year.

Thalassia Beds

The *Thalassia* beds showing the greatest impact of oil in Survey I were the long *Thalassia* and the *Thalassia* flats. These two areas have fewer faunal groups and higher hydrocarbon concentrations than the oiled short *Thalassia* and the control areas (Tables 3, 4, 16). The short seagrass beds were closer to the open sea than the other two oiled seagrass beds. Consequently, the short grass area may be subjected to wave action more frequently than the other two; this is a likely cause for the reduced impact that was seen in the short grass.

The epibenthic community showed an increase in the number of faunal groups between surveys. Molluscs particularly increased in the oiled long *Thalassia* during the three months following the spill. The composition of epibenthic communities in all three areas was similar to that expected for a tropical lagoon.[12]

The benthic infaunal community in the *Thalassia* declined between surveys, particularly in the long grass and in the flats. In Survey I, sediments from both of these areas had particularly high concentrations of hydrocarbons. It appears that the effect of oil on organisms in the sediments proceeds at a slower rate than in the water column.

The qualitative change in the appearance of the *Thalassia* may be caused by a natural phenomenon as well as by oil. Sea urchins are known to graze on turtle grass and grazing by the sea urchin, *Diadema antillarum* has been known to cause extensive damage to sea grass beds in the U. S. Virgin Islands.[13] Our general field observations have shown that sea urchins were dying or losing their spines; there were none in long *Thalassia* nor *Thalassia* flats and only sparsely represented in short *Thalassia*. Thus, damage to *Thalassia* is probably not attributable to sea urchins.

Mangroves

The initial impact of oil in the mangroves was a disturbance to the organisms in the upper root zone of the mangrove community. This is expected since this is the area most likely to be covered with oil that is floating on water. Eventually the oil penetrated the sediments. The chemical analyses of hydrocarbons (Table 16) shows this pattern. The decrease in hydrocarbon content at two sites (Table 17) between surveys indicates that these sediments lost oil, but only additional future observations would determine the removal rate. The increase in hydrocarbon at the mangrove silt area may be related to the smaller flushing rate and consequent deposition of fine particles in this area, compared with higher flushing rates and sediment erosion at the other mangrove stations.

At the present time we have no way of determining the long-term (greater than three months) effect of spilled oil on the health of the mangrove plants themselves. The plants are major contributors to the biological and physical characteristics of the community. A serious long-term deterioration of the mangrove plants can lead to extensive modification in patterns of coastal succession and in a reduction of habitats available to organisms in the Bahia Sucia. The magnitude of these problems can best be measured by future resurveys of this area.

Beach Cleanup Operations

Visual observations indicated a general improvement in the Bahia Sucia area between the first and second surveys. This was due to the combination of beach cleanup operations and natural factors, such as weathering and tidal action.

The concept of a trenchpit system to remove oil from the beach area appeared to be effective. Trenches dug perpendicular to the shoreline convey floating oil into the pits from which the oil is pumped into trucks. This is a simple method and oil recovery appears to be high. However, lining the trenches and pits with plastic sheeting may be wise to prevent seepage of oil into the subsurface sand or to keep subsurface water from mixing with oil. Perhaps a system of trench liners and portable cisterns can be adapted for this purpose.

Harrowing sorbent into the sand to soak up oil can lead to further mixing the oil through the sand. The sand particles do as well as, or better than, the sorbent particles in adsorbing the oil and the harrowing or raking produces a small percentage recovery of the sorbent material. Thus, the method is fairly ineffecient. Also, little is known about the effect of the sorbent material on organisms.

On the whole, the beach area was cleaned on the surface but oil was still present below the sand surface. This oil probably does slowly leach out into the water and becomes a source of long-term pollution in Bahia Sucia.

REFERENCES

1. Pollution Reports Nos. 1-9, 19-23 March, 1973.

2. Duncan, A. J., Quality Control and Industrial Statistics, Irwin, Inc., Homeward, Illinois, 1959, 114-116.

3. Humm, H. F., "Seagrasses and Mangroves," A Summary of Knowledge of the Eastern Gulf of Mexico, Institute of Oceanography, State University System of Florida 1973.

4. Jackson, J. B. C., "The Ecology of the Molluscs of Thalassia Communities, Jamaica, West Indies," Marine Biology, 14:304-337 (1972).

5. Matthews, B. M., "An Ecological Guide to the Littoral Fauna and Flora of Puerto Rico," Department of Education Press, San Juan, Puerto Rico, 1967.

6. Aller, R. C. and Dodge, R. E., "Animal-Sediment Relations in a Tropical Lagoon, Discovery Bay, Jamaica," J. Mar. Res., 32:209-232 (1974).

7. Frost, J., J. Sed. Pertol. (1974).

8. Walter, H., Ecology of Tropical and Subtropical Vegetation, Van Nostrand Reinhold, New York, 1971, 150-166.

9. M. Gruenfeld, personal communication.

10. Sanders, H. L., The West Falmouth Oil Spill, Woods Hole Oceanographic Institute, Woods Hole, Massachusetts, 1973.

11. VAST, Inc., Oil Spill, Casco Bay, Maine, July 22, 1972, Environmental Effects, final report for the Office of Water Programs, Environmental Protection Agency, October, 1973.

12. Collard, S. B., and D'Asaro, C. N., "Benthic Invertebrates of the Eastern Gulf of Mexico," A Summary of Knowledge of the Eastern Gulf of Mexico, Institute of Oceanography, State University System of Florida, 1973.

13. Ogden, J. C., et. al., "Grazing by the Echinoid, Diadema antillarum Philippi: Formation of Halos around West Indian Patch Reefs," Science, 182:715-717 (1973).

14. Georg, Wust. Stratification and Circulation in the Antillean-Caribbean Basins, Part One.

15. Almy and Carrion. "Shallow water Stony Corals of Puerto Rico," Carib. Journal of Science, vol. 3, no. 2, 1963.

16. Coker and Gonzalez. Hydrographic Conditions near Parguera, 1960, pp. 11-16.

APPENDICES

APPENDIX

APPENDIX A

A CHRONOLOGICAL SUMMARY

OF THE

EVENTS IMMEDIATELY FOLLOWING THE ACCIDENT

TIME	DATE	ACTION
1041	18 March 1973	Police advised the Commander of the Port (COTP), San Juan, that the vessel, Zoe Colocotronis, ran aground in the vicinity of La Parguera, Puerto Rico.
1145	18 March 1973	The vessel's agent notified the COTP that the ship ran aground, was afloat with no damages, was no longer spilling oil, and was proceeding to Guayanilla.
		A U.S.C.G. helicopter observed that the vessel apparently discharged oil to lighten its load and had ceased discharge of the oil and was under way. The vessel proceeded to CORCO.
1430	18 March 1973	Vessel was located at 17°54' N and 66°59' W. Oil slick extended from this position to two miles east of Cabo Rojo.
	18 March 1973	Oil expected to come ashore between Cabo Rojo and Punta Tocon on 19 March 1973. The regional response team and local officials were alerted.
		COTP advised by CORCO that Mobil Oil agreed to accept all cleanup costs. This was not confirmed by Mobil Oil and a cleanup contingency fund was set up.
		The Commonwealth of Puerto Rico planned to require the vessel to post bond.
0015	19 March 1973	U.S.C.G. overflight observed that the slick came ashore from Bahia Sucia to Cabo Rojo and extended offshore from La Parguera to El Combate.
	19 March 1973	Cleanup crews from Commonwealth Public Works Department were under way.
0805	19 March 1973	Captain Ramsey of Mobil Oil reported that Mobil Oil will pay all costs incurred.
0815	19 March 1973	Two U.S.C.G. helicopters were on-the-scene and the OSC had obtained sorbent from Sun Oil and 640 ft of boom.
0915	19 March 1973	Oil was located ashore at the cliff face (67°11.0' W) and east of Cabo Rojo between 67°11.5' W and 67°11.5' W, 17°57.6' N.
0940 to 1000	19 March 1973	Overflight by officials of the Commonwealth Environmental Quality Board and Department of Natural Resources.
	19 March 1973	Transport of EPA Region II strike force to the scene. Containment operations in progress.
		Commonwealth requires vessel to post additional bond.
1630	19 March 1973	U.S.C.G. overflight reveals that slick has moved north parallel to the west coast of Puerto Rico.
	19 March 1973	Vessel posts bond but company has not yet accepted responsibility.
1700	19 March 1973	EPA strike force transported to the scene.
	19 March 1973	Cleanup operations in progress.
	20 March 1973	Cleanup operations in progress. West of England P & I Club assumes contracting responsibilities.
	20 March 1973	Ship's master, crew, and logs subpoened by local EQB. A complaint is filed against the vessel Captain M. Michalotoulis. Arrest will be made following EQB hearings.
	22 March 1973	EQB hearings begin and the U. S. Attorney filed a complaint in the federal District Court against the ship's captain
	23 March 1973	Ship's captain arrested and released on bail.
	24 March 1973	TRC personnel arrive in Mayaguez, Puerto Rico, to begin surveys

APPENDIX B

CHEMICAL METHODS

Field Extractions

All extractions were carried out using Spectrograde CCl_4. All glassware used for extractions was rinsed three times with Spectrograde CCl_4, except where noted. Spectrograde CCl_4 cannot be obtained on short notice in Puerto Rico, so for some extractions the glassware was rinsed in reagent grade CCl_4 to conserve Spectrograde supplies for the extractions. The blanks reflect this method of preparation.

Water

Water collected and acidified in the field with 5 ml 1:1 H_2SO_4 was placed in a separating funnel and tested for pH of 3 or lower by bringing the wetted stopper of the separating funnel into contact with pH-sensitive paper. Hydrocarbons were extracted by shaking the water with 25 ml CCl_4, allowing the phases to separate, and draining off the lower phase (CCl_4 + hydrocarbons) into a 100 ml volumetric flask. Three additional extractions were performed, rinsing the sample bottle each time with the 25 ml portion of CCl_4 to be used in the extraction and adding the extract to the volumetric flask. The stoppers were fitted snugly into the flasks, covered with aluminum foil, and taped down to seal them for shipment to the TRC laboratory.

Sediment

Approximately 50 gm wet weight (later increased to 100 gm) of sediment from a thoroughly mixed core sample was placed in a 250 ml beaker and stirred with four separate portions (25 ml each) of CCl_4, each portion being poured off into a single 100 ml volumetric flask which was sealed for shipment as specified under Water.

Grass

Samples of grass (40 to 60 gm) were wet weighed and extracted following the procedure described under Sediment.

Oil

Five ml of oil collected from the beach area at Cabo Rojo was diluted to 100 ml in a volumetric flask and sealed as specified under Water.

Blank

The blank was prepared by adding 100 ml of CCl_4 to a volumetric flask prepared in the field.

Laboratory Analysis

Samples from the field laboratory were passed through a funnel containing one inch of anhydrous sodium sulfate to remove all water and returned to the original volumetric flask where their volume was brought to 100 ml with additional CCl_4 (Spectrograde). After mixing, the extract was scanned in the range of 4200 cm^{-1} to 2600 cm^{-1} using a silica cell (1 cm) in a Perkin-Elmer Model 727 Infrared Spectrophotometer with CCl_4 in the reference beam.

Dilutions of 2.0, 4.0, 10.0, 16.0, 20.0, and 30.0 mg per 100 ml (Figure B-1) were used to calibrate the instrument on the same day that the samples were run. The concentration of oil in the samples was then read directly from the standard curve. The standards were tested before and after passing them through the anhydrous sodium sulfate to test the recovery rate which was found to be 100 percent.

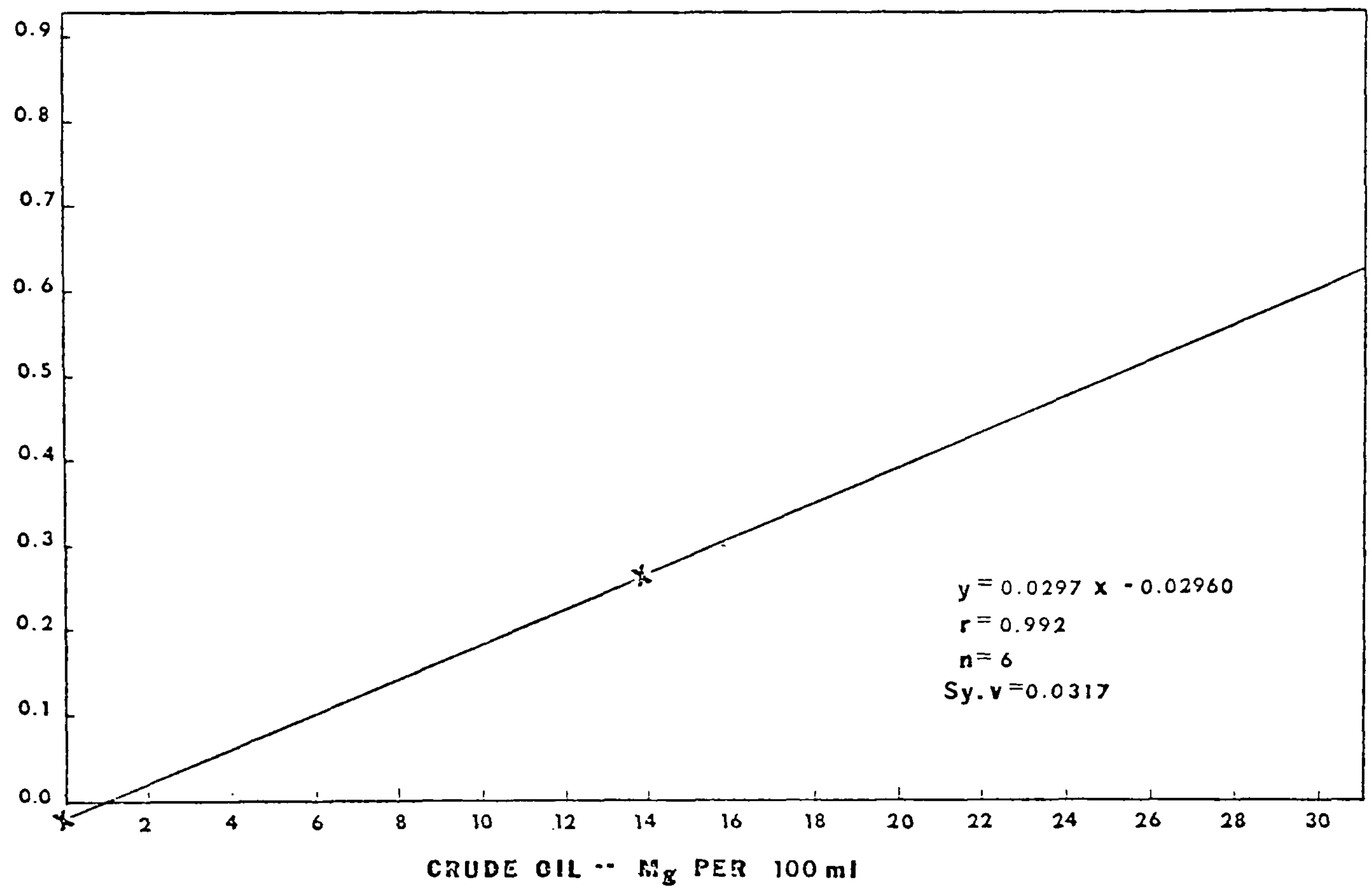


Figure B-1: Calibration of Infrared Spectrophotometer Using Dilutions of Crude Oil from the Beach at Bahia Sucia

☆ U. S. GOVERNMENT PRINTING OFFICE : 1980 620-228/4063