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Survey of tar, oil, chlorinated hydrocarbon and trace metal pollution in coastal waters of the Sultanate of Oman

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PREFACE

The terms of reference of the mission, which took place from 25 September to 4 October 1980, were to carry out a quantitative survey of the extent of oil pollution along the coast of Oman and to determine the major sources of oil pollution.

The present report contains the results of the survey for oil slicks and tar balls in coastal waters and on beaches of the Sultanate of Oman. During the mission a number of environmental samples were taken for chemical quantification of oil as well as other substances. These analyses were conducted in the IAEA International Laboratory of Marine Radioactivity in Monaco and in the Kuwait Institute for Scientific Research.

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Members of the mission carried out the work in their own scientific capacities. Therefore, their views and conclusions do not necessarily reflect the official views of the two sponsoring organizations.

The mission team wishes to thank the Government of the Sultanate of Oman for the material support furnished during the period of the survey. Special thanks are due to Mr. Salim Khalfan Fatah and Sultan Saif Al-Falahi of the Ministry of Communications and Mr. Zaid Ali Al Ghassani of the Council for Conservation of the Environment and Prevention of Pollution for their personal assistance and effective co-ordination of logistical support in the field. The helicopter transport provided by the Royal Oman Police Force and ground transport supplied by the Office of the Wali of Dhofar is acknowledged with appreciation. The survey was greatly facilitated by the advice and laboratory facilities furnished by Mr. Arnold E. A. McLeod of the Government Central Laboratory and through assistance with sample collection rendered by Mr. Mohamed A. Al-Barwani of the Directorate-General of

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*The International Laboratory of Marine Radioactivity operates under a tripartite agreement between the International Atomic Energy Agency, the Government of the Principality of Monaco and the Oceanographic Institute (Paris). The laboratory is situated in the Musée Océanographique in Monaco.

Fisheries. Photographic coverage of the survey was ably performed by Mr. Tibor Farkas, UNEP, Geneva. Translation and field assistance given by Dr. Saad El Wakeel, Consultant to UNEP's Regional Office for West Asia in Beirut is also greatly appreciated.

This report has been prepared within the framework of the Kuwait Action Plan.

CONTENTS

I INTRODUCTION

More than half of all oil transported in the world passes through the narrow Strait of Hormuz on the north coast of Oman. Estimations made in 1978 showed that approximately 160,000 m^3 of oil were contained in surface slicks in the Gulf and its approaches and that there was a clear increase in number and percentage of positive slick sitings near the Strait of Hormuz (Oostdam, 1980). For years there have been repeated reports by the local population of heavy tar loads on Omani beaches. This situation appears to result primarily from the practice of tankers discharging their ballast waters on inward-bound voyages before they reach the Gulf. The combination of heavy tanker traffic in the coastal area, insufficient deballasting facilities in the Gulf and lack of enforcement of national and international deballasting restrictions exacerbates the problem for the Gulf region. This is particularly true for Oman since it is situated at the entrance to the Gulf where most deballasting takes place. Ironically only about 4 per cent of all tankers loading in the Gulf call at Omani oil terminals.

Oman has perceived this oil pollution as a threat to its extensive fishing industry which covers a coastline of roughly 1900 km. Oil production in Oman is relatively small and the country is working to preserve its traditional sources of income. Seeking scientific documentation to support Oman's concern for remedying the situation through the establishment of deballasting facilities in the Gulf, the Oman Ministry of Communications requested the United Nations Environment Programme (UNEP) to arrange for a scientific survey of the extent of oil pollution along the Omani coast. In fulfillment of the request UNEP sought the collaboration of the International Laboratory of Marine Radioactivity (ILMR), Monaco, which was responsible for organizing and carrying out the scientific aspects of the survey that ensued. The goal of the survey was to document, in quantitative and qualitative terms, the present state of oil and tar pollution on beaches and in coastal waters.

Scope of survey

The survey took place during the period 25 September to 4 October 1980. Given the time available and Oman's long coastline (approx. 1900 km), the survey team concentrated on estimating the standing crop of tar on beaches as a preliminary assessment of the present extent of oil pollution along the Omani coast. Logistical support in the form of helicopters, small boats and land transport provided by the Omani Government permitted the surveying of 11 beaches* covering representative

*The selection of these stations was made prior to the survey in consultation with representatives from the Council for Conservation of the Environment and Prevention of Pollution, Ministry of Communications, Directorate General of Fisheries, Maritime and Sea Ports Affairs, Authorities from Port Qaboos and Port Raysut, Ministry of Petroleum and Minerals, Royal Oman Police Force, Meteorological Section of the Civil Aviation Department, Musandam Development Committee, Government Central Laboratory, Diwan of the Sultanate of Oman and the Office of the Wali of Dhofar.

coastal areas from the Strait of Hormuz to near the border with Yemen (figure 1a). During the entire period, wind and sea conditions were light and daytime temperatures ranged from mid-30s to low 40s °C. The south-west monsoon (May-September) which affects the southern half of Oman (UNESCO, 1976a) had just ended.

In addition to the beach survey, water, surface sediment, fish, oysters, mussels and neuston were sampled when time and location permitted (sampling locations are illustrated in figure 1b). Some of these samples have been chemically analysed for petroleum hydrocarbons, chlorinated hydrocarbons and selected heavy metals. Results of the beach tar survey are presented in section III of this report and those of the chemical studies are presented in section IV.

II GENERAL PROCEDURES

Logistics: Helicopters provided access to all beaches north of Al Qurum and on Masira Island. The remaining beaches were accessible by road from either Muscat or Salala. Boats for marine collection were provided by the Royal Oman Police Force, Raysut Port Authority and the Directorate General of Fisheries.

Tar collections: The beaches were surveyed using methods specified by UNESCO (1976b). At each location sites for three or four 1-metre wide transects were randomly selected. Transects were measured from the water's edge perpendicularly up the beach face to the high tide mark. A typical transect layout is shown in figure 2. All tar lumps within the 1-metre wide transects, which could be picked up between thumb and forefinger, were collected, placed in plastic bags and labelled. The tar from each transect was kept separately so that means and standard deviations could be calculated. Although an attempt was made to remove as much sand and shell material as possible from the tar ball surfaces, some of these particles inevitably stuck to the tar. The small additional weight of adhering particles was probably compensated for because some extremely small tar particles were not collected. Therefore no corrections for trapped sand and shell fragments were made. The collected tar was transported to the Government Central Laboratory in Muscat and each bag weighed to the nearest 0.5 gramme. This method has been shown to give an accurate assessment of the amount of tar on a particular beach transect regardless of the state of the tide or the width of the beach face (Anderlini and Al-Harmi, 1979).

Sediments: Surface sediments were taken with a small stainless-steel Van Veen grab sampler operated by handline. The surface layer (top 1 cm) in undisturbed grabs was carefully removed with a spatula and frozen in glass jars for hydrocarbon analyses. Separate aliquots from the same grabs were frozen in plastic Twirl Packs (R) for heavy metal and mineralogical composition analyses.

Biota: Mussels (Mytilidae) and rock oysters (Crassostrea margaritacea) were removed from intertidal rocks by hammer and chisel and frozen whole before dissection. Fish were caught by handline and immediately dissected. Neuston and pelagic tar were collected by towing a neuston sled or small plankton net along the sea surface for prescribed periods of time depending upon water and ship conditions. Small pieces of pelagic tar, if present, were carefully removed from the sample for eventual weighing, and the remainder of the neuston sample was frozen for metal analyses. All sampling gear and dissection instruments were precleaned and procedures were designed to minimize sample contamination from boats, gear and handling.

III SURVEY OF TAR AND OIL POLLUTION ON BEACHES OF THE SULTANATE OF OMAN

Summary

Over half of the world's crude oil supply is transported from the Gulf area via tankers through the narrow Strait of Hormuz which forms the northern boundary of the Sultanate of Oman. Repeated sightings of floating oil slicks in coastal waters and large quantities of tar observed on beaches prompted Omani officials to request scientific assistance in assessing the problems of oil pollution in Oman.

This report gives the result of a UNEP-sponsored survey carried out in co-operation with the ILMR of the IAEA conducted from 25 September to 4 October 1980. Quantitative beach sampling yielded average standing stocks of tar ranging from 5 to 2325 g/m of shoreline with an overall average of 224 g/m. Values are among the highest reported for any world area and show a trend of increasing levels of oil residues close to the Strait of Hormuz. All the beaches surveyed showed evidence of chronic tar deposition. The data supports the premise that tanker deballasting is a major source of oil pollution along the Omani coast.

Results and observations

Beaches near Hormuz

1. Bukha: Floating tar was sampled in waters approximately 2 km offshore from the beach station. The surrounding waters appeared very clear and clean and virtually no pelagic tar was noted in the sample. Because the bottom in this area was extremely rocky, sediments and water samples were taken approximately 15 km north near Khasab Bay. Tar, very fresh and sticky, was collected from three transects on Bukha beach just east of the harbour (figure 3). Quantitative estimates for tar balls for the three transects were as follows:

Transect	Length (m)	Tar (g)
a	27	315.0
b	13	1051.0
c	12	574.0
		$\bar{X}$ = 647.0

Oysters were also taken from nearby intertidal rocks for later analyses.

2. Isolated beach 3 km north of Bukha: Four transects of equal length were made between water line and the recent high tide mark. Fairly copious amounts of large tar balls were noted high up on the beach face mixed in with much natural and manmade debris (figure 4). This material must have been deposited during an earlier storm and was in such a large quantity that it was not practical to separate it from the large amounts of associated debris. Because of this difficulty and since it was

so far above the designated transects, it was not included in the transect estimate. However, for standing stock assessment, it is estimated that collections along the transect represented only one-third of the stock if the oil residues observed on the higher reaches of the beach were taken into account. The four transects gave the following results (not adjusted):

Transect	Length (m)	Tar (g)
a	50	174.0
b	50	304.0
c	50	1211.0
d	50	1413.0
		$\bar{X}$ = 775.0

It is interesting to note that while no pelagic tar was collected by neuston tows only 3 km to the south, tar was observed suspended in the water in the nearshore zone. Only very small specks were seen in the surface layer. However, larger tar balls were observed moving along the bottom toward shore. These were then deposited on shore in the swash zone.

3. Lima: Since time was limited, only a visual survey of tar on the rocky beach was made. The tar was more weathered than that found at either stations 1 or 2 on the Gulf side of the Strait of Hormuz. It was estimated that a similar average amount (i.e. 775 g/metre beach) as that noted for the transects at station 2 north of Bukha was present here at the time observations were made.

Oysters were collected from the rocks at the northern end of the beach.

Just south of Lima near the border of the United Arab Emirates, several oil slicks, one of which was very large (figures 5a and 5b), were observed from the air. These long bands of frothy oil parallel to the shore line, were several kilometres in length and appeared to be moving onshore. Bands of oil were noted as far south as Fujairah.

Beaches between Hormuz and Greater Muscat

4. Shinas: This long and steeply-sloped beach was composed of sand of a reddish-metallic colour. The winds were south-easterly and the surf was striking the beach face at a slight angle. The high berm showed signs of recent tar pollution (figure 6). This tar was very fresh and sticky. The inclusion of an encrusting rust-like substance suggests that it had originated from tanker washings. Above the berm zone were scattered dry, weathered tar balls encrusted with a green organic coating. Three transects were sampled and gave the following results:

Transect	Length (m)	Tar (g)
a	60	744.5
b	60	638.5
c	60	1717.0
		$\bar{X}$ = 1033.0

5. Al Khabura: The beach was sloped similar to that at Shinas. The area sampled was just north of a longshore bar near Al Khabura. There was a light north-easterly

wind (45°). An extremely heavy concentration of plastic objects, tin cans and wood debris was found on the upper reaches of the beach face above the normal high tide mark (figure 7a). There was also a large amount of tar associated with this debris (figure 7b). Tin cans which had been washed ashore were counted and an average abundance of 8.5 cans/m beach was computed. An average can weighed 250 g. Thus, weights of tin cans plus other debris of as much as 2 tonnes per kilometre of beach may be typical for this area.

Tar was collected from four transects along the beach; fresh oil mixed with sand and shell was also present but was not included in the collection. Again most of the tar was preferentially accumulated on the downwind side of the beach and was particularly heavy in a band near the high tide mark (figures 8a and 8b). The results were:

Transect	Length (m)	Tar (g)
a	50	545.0
b	52	456.5
c	50	202.5
d	54	155.0
		$\bar{X}$ = 340.0

Beaches near Muscat

6. Al Qurum: The site selected for transects was landward of the eastern tip of a partially submerged wreck about 1 km north-west of the Gulf Hotel. Just east of this site is the outlet of an extensive mangrove swamp. The lagoon area could have been a receptacle for debris from the storm tides noted on other beaches. Tar collections were made at low tide but as at other stations, the majority of the tar was found within a few metres of the high tide line. Very little tar was noted on this beach but visual observations in the shallows of the surf zone indicated the presence of small suspended particles of tar. At the time of the survey, and subsequently, tanker traffic through the Strait of Hormuz had been drastically reduced, which might be taken as evidence that oil and tar pollution would be less than normal. On the other hand insurance restrictions by Lloyd's of London had the result that almost all tankers normally using the Hormuz route were temporarily anchored close to the Omani coast, below 24° latitude, awaiting orders to proceed into the Gulf to load. This situation could have led to an increased possibility of pollution. It is unclear what the continued effect of these two situations had on standing stocks of tar found on the beaches in the Al Qurum area. The results from the transects are:

Transect	Length (m)	Tar (g)
a	42	45.0
b	43	28.0
c	45	17.5
		$\bar{X}$ = 30.0

7. Ras Al Hamra: The enclosed beach, which is roughly 750 m long, was sampled at the eastern end near rocky cliffs. Some suspended tar was noted in the water. Three transects were sampled at mid-tide with the following results:

Transect	Length (m)	Tar (g)
a	16	61.0
b	12	32.0
c	15	15.0
		$\bar{X}$ = 36.0

Oysters on the nearby rocks were also sampled.

8. Mina Al Fahal: The beach adjacent to the Petroleum Development Oman Limited (PDO) loading area was sampled with three transects. The wind was from the north-west and much suspended tar was washing ashore with the tide. Although the tar was obviously fresh, many different-sized discrete tar balls were observed (figures 9a to 9d). It was apparent that an oil spill, observed just offshore PDO the previous day, was beginning to reach the beach. The area near a small jetty which bisected the beach was sampled. Wind and wave action was causing the tar to accumulate predominantly on the north side of the jetty. Almost all the tar collected was fresh. Estimates reported here are probably on the low side because a large amount of suspended tar was observed washing ashore at the time the transect estimates were made. The results from the three intertidal transects were:

Transect	Length (m)	Tar (g)
a	25	3166.5
b	25	325.0
c	25	71.5
		$\bar{X}$ = 1188.0

Samples of intertidal sediment were also taken off the end of the jetty and prepared for hydrocarbon and trace metal analyses.

Just offshore from the PDO complex is the main tanker anchorage and loading area for Greater Muscat. On 28 September 1980, the day prior to the tar survey carried out on Mina Al Fahal beach, neuston nets were towed for pelagic tar and surface sediments were sampled for hydrocarbons. The depth of the water column in this area was about 35 m. The water was extremely clear with visibility of about 10 m and no significant amounts of tar were found in surface samples. However, upon return toward the harbour, an area of roughly 3 km^2 was observed which was covered with floating fresh tar patches (figures 10a and 10b). The patches were oozing oil and it was decided not to drag the net through the area but rather to make visual observations coupled with weight determinations of randomly-sampled tar patches. The following weights were determined:

1 medium lump	30.0 g
6 medium-small lumps	65.5 g
1 large lump	40.5 g
1 small lump	9.5 g
	$\bar{X}$ = 23.0 g/lump.

A density of approximately 1 lump/m^2 was observed from the boat. Thus, a crude estimate of total oil spilled in the affected area would be roughly 70 tonnes.

Unfortunately an attempt to locate the source of this spill among the many anchored tankers was unsuccessful.

Masira Island

9. Dahrai Beach: A long strand of white sand beach on the eastern side of the island a few kilometers south of Ras Hilf was sampled for tar. The southern extremity of the beach is very rocky and the entire area is well known as a turtle nesting site. A large quantity of tar was found high up on the rocky beach. Distribution of these large lumps was very patchy and it was not possible to make a quantitative estimate that would be representative of the beach as a whole. Some of the tar balls were extremely large, measuring over 10 cm in diameter (figure 11). Since these were so far above the normal tide marks they were excluded from the transect measurements. The four transects sampled on the sandy portion of this beach two kilometres to the north of the fishing village gave the following results, which must be considered minimal due to exclusion of the large tar balls high up the tidal zone:

Transect	Length (m)	Tar (g)
a	35	28.0
b	35	213.0
c	35	152.0
d	35	162.0
		$\bar{X}$ = 139.0

Oysters were collected from the rocks just in front of a small fishing village.

On the opposite side of the island (west side facing the Strait) near the village of Dawwah, oysters were collected from the rocks. One sediment grab consisting mainly of coral and sand was prepared for hydrocarbon and metal analyses. A large pig-faced bream (Lethrinus nebulosus) was caught by handline offshore and dissected immediately upon return to Dawwah.

Salala Beach Area

10. Taquah Beach: Because the beaches near city areas of Salala were reputed to be periodically cleaned by local personnel, an isolated stretch of white, coralline sand located about one hour's drive north-east of Salala and just west of Taquah was selected for sampling. As appeared to be typical for the Salala area, very little tar was found. Three transects along the beach in front of the mangrove lagoon gave the following results:

Transect	Length (m)	Tar (g)
a	40	5.0
b	40	10.0
c	40	1.0
		$\bar{X}$ = 5.0

11. Maghsail Beach: The beach is located about one hour's drive south-west of Raysut Harbour. The monsoon season had just ended, very little tar or debris was noted on the beach, but the beach surface was strewn with rocks. Light winds were

from the south-east and the surf was breaking directly on shore. Four transects gave the following results:

Transect	Length (m)	Tar (g)
a	25	2.0
b	25	3.0
c	25	54.0
d	25	1.5
		$\bar{X}$ = 15.0

The high value at transect c was due to finding one large tar lump.

The local people expressed great interest in the beach work. One fisherman produced a collection he had made of tar balls and shells from dead lobsters which he claimed washed ashore during the monsoon (figure 12). Although no cause-effect relationship could be established, his query as to whether there was any connection between the tar balls and the dead lobsters suggested a keen awareness of the potential effects of oil pollution among the local Omani fishermen.

Other spots in the Salala area were also sampled. Just outside Raysut Harbour, near Salala, two 15 minute neuston tows and three sediment grabs were taken. No tar was found in neuston samples. Two of the sediment samples were sandy, the third which was taken near the harbour entrance consisted of very fine, organic rich mud. Mussels (Mytilidae) and oysters (Crassostrea margaritacea) were taken from rocks on the western side of Raysut Harbour. Freshly caught hamour (Epinephelus tauvina) and pig-faced bream (Lethrinus nebulosus, common name: Hamishka) from Salala waters were dissected into muscle and liver samples at the local fisheries station.

A summary of the tar results for the various stations, as well as estimates of the present standing stock of tar along the Omani coastline is given in tables 1 and 2. Results of chemical analyses are presented in section IV.

Discussion and conclusion

Several general features concerning tar pollution along the coast of Oman are noteworthy. On a given beach, as a general rule, most tar appeared to accumulate in bands along the high tide mark. Furthermore, on beaches which were notably scalloped, the highest concentrations of tar were found on the windward side of sand cusps or obstructions such as jetties and rock outcrops. Similar observations have been made with tar ball surveys on Kuwaiti beaches in the northern Gulf (Anderlini and Al-Harmi, 1979). At times, especially on the northern Omani beaches, large tar lumps were noted in dune vegetation far above the high tide mark. These were probably deposited during storm conditions. The weathered condition of these tar balls contrasted markedly with the fresh, sticky oil found in the intertidal area. The latter oil contained stains of red iron oxide, indicating they originated from tanker ballast washings.

There was a clear trend for increasing tar pollution along a gradient from the southern border with Yemen to the Strait of Hormuz (table 1). This finding correlates well with recent reports of increased oil spills in the vicinity of Hormuz (Oostdam, 1980) and is consistent with the complaint that tankers begin discharging ballast waters well down the Omani coast so that the ships are nearly

empty upon entering the Gulf for loading. The single high concentration of tar noted at Mina Al Fahal resulted from a recent spill that apparently took place the day before the beach was sampled. It was estimated, by visual observations, that roughly 70 tonnes of oil were spilled in a very limited area. Observations of this single spill underscores the significance of contributions from tanker loading operations in limited areas as well as the rapidity with which this pollution reaches the beach. The effect of these operations becomes especially clear when one compares Mina Al Fahal with background values at the nearby beaches of Al Qurum and Ras Al Hamra (table 1). Outside the area of localized oil spills, the highest tar concentrations were observed around the Strait of Hormuz, most notably on the Gulf side near Bukha.

Average tar weights of over 2 kg/m beach are comparable to maximum values found at certain coastal sites in Kuwait during 1979 (Anderlini and Al-Harmi, 1979). In general, the distribution of tar on the Oman coast is consistent with data on the predominant wind and current patterns for the September-October period (UNESCO, 1976a). Furthermore, on several occasions, knowledgeable local people stressed that far less tar is found on Omani beaches during the autumn than in the spring. This was supported by a visual tar survey at Al Qurum made by a previous United Nations mission in May 1980 (Fowler, personal communication). Thus, it should be stressed that values given for many of the beaches in the present survey are probably minimal when compared to tar levels typical for other seasons of the year. This is particularly true for the beaches surveyed in the Salala area since the recent monsoons had most likely thoroughly cleaned the beaches just prior to the present study. Yet all the beaches surveyed showed evidence of chronic tar deposition.

Also of importance was the observation that on three occasions (excluding the oil spill at Mina Al Fahal), at widely separated locations, offshore tar collections made by towing a neuston net yielded negligible quantities of floating tar. Along the shore adjacent to the area where the pelagic tar collections were made, only very small pieces of tar were suspended in the surface waters. However, much larger and presumably heavier pieces of tar were suspended in the subsurface waters and were collecting near the water line on the beach. These were deposited on the beach as the tide receded. These observations coupled with findings of significant amounts of tar on the beach suggest that neuston sampling is not an adequate means of estimating oil pollution loads reaching coastal waters in the Arabian Sea or Gulf areas.

Geographic comparisons of standing crop of tar indicate that Oman suffers severe contamination by oil from tanker operations (table 3). Average levels of nearly one-quarter tonne of tar per kilometre of beach in Oman, while somewhat lower than that recently reported for Kuwait (Anderlini and Al-Harmi, 1979), are substantially higher than those measured in most areas of the world. This is particularly striking when one considers that calculations reported here are quite conservative for reasons discussed above. The results strongly support the claim that tanker washings from inbound Gulf traffic are affecting the tar levels on Omani beaches. It must be remembered that this survey gives a picture for tar conditions at only one point in time during the year and, given the probability that tar conditions in Oman vary significantly with the season, it would be highly advisable to examine the beaches on a more regular basis. It is suggested that the newly-created Oman Council for Conservation of the Environment and Prevention of Pollution consider this aspect when planning future studies in the region in the framework of the Kuwait Action Plan (UNEP, 1978).

IV CHEMICAL ANALYSIS OF PETROLEUM HYDROCARBONS, CHLORINATED HYDROCARBONS AND HEAVY METALS IN COASTAL AREAS OF THE SULTANATE OF OMAN

Summary

As part of a general survey of tar and oil pollution in the coastal waters of the Sultanate of Oman, sediment and biota were sampled from selected sites and analysed for petroleum hydrocarbons, chlorinated hydrocarbons and heavy metals. Most of the sediment and shellfish samples contained some petroleum contamination. Total petroleum hydrocarbons in rock oysters increased along a gradient from southern Oman to the Strait of Hormuz in a manner consistent with the beach tar observations described in section III of this report. Hydrocarbon levels in oysters are indicative of low to moderate chronic pollution when compared to shellfish from other coastal waters and are in the same range of values reported for rock oysters from Kuwait. The relatively low hydrocarbon levels in biota, coupled with visual observations of very little floating tar, suggests that oil released into Omani coastal waters aggregates and sinks and arrives at the beach as heavy solid or semi-solid tar lumps.

Samples were also analysed for chlorinated hydrocarbons and selected trace metals. Except for elevated levels of cadmium at Lima and Dahrai, heavy metal concentrations are, in general, relatively low compared to levels from other more industrialized areas of the world. Chlorinated hydrocarbon concentrations (PCB, DDT, etc.) were also low compared to levels from other geographical regions. In particular, the very low level of DDT and its metabolites measured in environmental samples indicates no local input of these pesticides into the coastal waters.

Several suggestions and recommendations are given with the aim of improving the effectiveness of any further pollution studies conducted in the future.

Methods

Sample collection

Sites for collection of rock oysters and mussels were chosen where rocky outcrops with attached fauna could be seen near to beaches surveyed for tar pollution as described in section III. The provision of boats by the various authorities credited above enabled the collection of sediment and fish from coastal waters near Raysut Harbour, the Straits side of Masira Island, Muscat tanker anchorage area and Khasab Bay near Hormuz. Sampling stations are shown in figure 1b.

Oysters were chipped off intertidal rocks using a hammer and chisel and sealed in plastic bags. Sediments were collected by dropping a small stainless steel grab sampler on a hand line from a small boat. Undisturbed surface sediment was carefully scraped into solvent cleaned glass jars for organic analyses using a stainless steel spatula. Samples were placed in pre-cleaned plastic containers and Twirl Packs for sedimentology and metal analyses. Fish were caught by hook and line and immediately dissected into muscle and liver samples. Those intended for organic

analyses were packaged in solvent washed aluminium foil. Tissues intended for metal analyses were placed in Twirl Packs. Samples were frozen and transported to the Monaco and Kuwait laboratories for chemical analyses. Thorough precautions were taken to minimize contamination of samples from dissecting instruments, sample containers or handling procedures (Bernhard, 1976). All equipment was cleaned with glass distilled solvent before use in the organic analyses.

Analysis

Organics: Samples were defrosted and prepared for solvent extraction as follows. Shells on molluscs were removed and tissue was drained and weighed. Sediments were mixed with a spatula and examined to make sure they were free of macrofauna. All oyster samples were ground in a Virtis homogenizer with three times their weight of pre-combusted sodium sulfate. An equal weight of Na_2SO_4 was used for other samples. Homogenates were transferred to the pre-extracted cellulose thimble of a Soxhlet apparatus and continuously extracted with hexane for 8 hours. Hexane extracts were concentrated to approximately 10 ml by rotary evaporation and transferred to Kuderna Danish evaporators. Volumes were reduced to approximately 1 ml in the graduated glass tubes. Total lipid weights were determined by carefully evaporating 10 ul aliquots of the extracts on to the weighing pan of a Cahn 4400 micro-balance. Hydrocarbons were separated from other lipids by charging extracts on to columns of partially deactivated silica/alumina gel and eluting with solvents of increasing polarity. Fraction 1 was eluted with one column volume of hexane and contained mostly saturated hydrocarbons. Fraction 2 was eluted with one volume of 10 per cent toluene plus one volume of 20 per cent toluene in hexane and contained most of the unsaturated and aromatic hydrocarbons including most of the chlorinated hydrocarbons. Fraction 3 was eluted with one volume of toluene and contained the more condensed ring polynuclear hydrocarbons. In the biological samples this last fraction contained as much as 3 per cent of the total lipid weight and the majority was assumed to consist of biogenic components. Thus quantitative data for F3 is not included in the tables of results for the biological samples. Lipid to adsorbant ratio was always greater than 50 to 1. All extracts were analysed on a Varian high-resolution glass-capillary gas chromatograph equipped with an electron-capture detector. Concentrations of selected halogenated hydrocarbons were determined by comparison of peaks to those generated by pure standards. Total extractable hydrocarbons were determined in each fraction gravimetrically. The oyster extracts were analysed on a Carlo Erba glass-capillary gas chromatograph equipped with flame ionization detection. Hydrocarbons eluting in the C_{12} to C_{35} n-paraffin boiling range were quantified by comparison to peak areas generated by a mixture of 12 n-paraffins and 17 aromatic hydrocarbon standards boiling over this range. Complete procedural blanks were run with each batch of samples. Blank values were subtracted from values obtained for chlorinated hydrocarbon analyses. Blanks were below detection in the gravimetric determinations and showed no significant contribution over the C_{12} to C_{35} boiling range when analysed by FID gas chromatography. Analytical details for measuring petroleum and chlorinated hydrocarbons are described in Burns and Smith (1981a) and Elder et al. (1976), respectively.

Metals: Environmental samples were prepared for metal analyses in the following manner. Frozen sediments were freeze-dried, ground to a homogenous powder and approximately 1 g of this prepared sediment was leached with 5 ml of 50 per cent conc. HNO_3 for 2 hours at 95°C in a Technicon block digester. Samples were then centrifuged, decanted and pellet rinsed with deionized water. Supernatant and all washings were combined for analysis. Sample volumes were made up to 25 ml and analysed by atomic absorption spectrophotometry (AAS), using standard conditions with a Perkin-Elmer 305B AAS.

Total organic carbon (TOC) determinations were made on aliquots of selected samples using methods described by Khalaf et al. (1979).

Rock oysters (tentatively identified as Crassostrea margaritacea) and mussels (Perna perna L.) were thawed and carefully removed from their shells using acid-rinsed plastic knives and spoons. The soft parts were rinsed with deionized water to remove adhering sand and shell fragments. These tissues along with fish samples were then refrozen, freeze dried and ground to a homogenous powder in an agate mortar and pestle. Aliquots of this material (0.5 - 0.8 g) were heated with 20 ml of redistilled conc. HNO_3 at 95°C until dry. Residues were then redissolved in 5 per cent redistilled conc. HNO_3 and filtered through acid-washed, deionized water-rinsed Whatman No. 41 filter paper to remove any remaining particulate matter. Volumes were made up to 15 ml final volume with 5 per cent redistilled conc. HNO_3. Samples were subsequently analysed by Inductively Coupled Argon Plasma (ICAP) emission spectroscopy (Jarrell-Ash Model 950, Series 800 ICAP Atom-Comp) for all metals except Hg using a biological matrix programme in the spectrum shifted mode. Freeze-dried sediments were prepared for mercury analysis by the method described by United States EPA (1979), while biological tissues were prepared by a slightly modified EPA method. Initial digestions were made using 0.5 - 0.8 g of freeze-dried tissues in 10 ml redistilled, conc. HNO_3 and left overnight at room temperature. The samples were then heated in a water bath for 2 hours at 65-70°C. Final oxidation was carried out with $KMNO_4$ until the purple colour persisted for at least 15 minutes. Two ml of potassium persulfate were then added and excess permanganate reduced by addition of hydroxylamine NaCl. Just prior to determinations, Hg was released by addition of 5 ml of stannous chloride and the vapour swept into a closed loop, double beam mercury analyser (Fisher Company).

Metal concentrations in all samples are reported as ug/g (ppm) dry weight.

Results and discussion

Petroleum hydrocarbons

Gravimetric data for total petroleum hydrocarbon content of sample fractions presented in table 1 are expressed as ug/g wet weight and mg/g lipid weight. As will be evident below, a value of 0 means that the total hydrocarbon concentration was too low to be accurately measured gravimetrically. When extracts are examined by more sensitive methods however, such as gas chromatography, trace components can be quantified. The gravimetric data show approximate values for total hydrocarbons in samples but give no structural information useful for determining the origin of the residues. To estimate the contribution from "pollution", total hydrocarbons must significantly exceed that expected from purely biogenic sources. Concentrations for total hydrocarbons were expressed as the sum of fractions divided by the wet weight of sample extracted or by the total extractable lipid weight of samples.

The ability of sediments to retain hydrocarbons depends on grain size, mineral content and associated lipid and other organic material. In general, under identical conditions, a sandy sediment with low organic carbon content will show a much lower hydrocarbon concentration than an organically rich clay, even when inputs are similar. Thus, expression of total hydrocarbons per gram lipid provides a clearer indication of hydrocarbon retention in sediments of different composition. With no background data to estimate what the hydrocarbon concentration should be in "normal" uncontaminated sediments from this area, comparisons have been made with other ocean areas. Burns and Smith (1977, 1981a) obtained total hydrocarbon concentrations of between 4 and 20 mg/g lipid (approximately 0.2 to 5.0 ug/g wet

weight) in sediments from uncontaminated coastal waters in Australia. Lack of contamination in their samples was confirmed by gas chromatographic and fluorescence analyses. Sediments containing higher concentrations showed contamination with petroleum hydrocarbons. Areas receiving inputs of petroleum from shore-based discharges showed sediment levels varying from these biogenic levels up to and exceeding 300 mg/g lipid or about 400 ug/g wet weight. Using these and similar data from other coastal areas for comparison, it can be estimated that most of the sediments collected in Oman contained some petroleum contamination. The largest concentration on a lipid weight basis was seen at the Mina Al Fahal beach site and resulted from the oil spill observed washing ashore during the sampling operations. Sediment samples did not contain obvious tar balls. These were quantified separately by beach survey at Mina Al Fahal (see section III of this report).

The problem of distinguishing biogenic from "pollutant" content is magnified in biota like fish which often synthesize large quantities of biogenics such as squalene and pristane. Rough comparison can be made with results of intercalibration exercises organized under the auspices of the National Science Foundation's International Decade of Ocean Exploration Programme (Farrington et al., 1973, 1976a). The IDOE cod liver oil samples showed as much as 0.9 mg/g lipid of biogenic hydrocarbons determined gravimetrically in addition to the petroleum added for the intercalibration exercises. Variation in biogenic hydrocarbon content is expected between different species and between different tissues in the same fish. Concentrations expressed per gram lipid were nearly identical in the L. nebulosa caught at Masira and Salala. Thus, it is likely that the hydrocarbon composition is mostly biogenic. However, future studies should give priority to examination of fisheries products by more selective analytical methods.

The use of shellfish as indicators of ambient water quality with respect to oil pollution in coastal waters was described by Burns and Smith (1981b). Data from the Oman samples follow a general trend of low levels at southern stations increasing to higher levels of total hydrocarbons along a northerly gradient (table 4). Hydrocarbon values lie in the range of low to moderate chronic pollution when compared, for example, to levels seen in shellfish from Australian coastal waters recently reported by Burns and Smith (1981a). Oyster extracts were further examined by gas chromatography permitting an assessment of hydrocarbon type in samples. Results are presented in table 5. The gas chromatograms showed that all extracts contained degraded oil residues in addition to biogenic components.

Table 6 gives a comparison of the gravimetric and gas liquid chromatography (GLC) determinations and a brief interpretation of GLC data. Here it is seen that at very low concentrations the gravimetric results are only accurate to about a factor of 2 compared to the GLC determinations. Lack of agreement at higher levels results from the fact that a large part of the composition of these samples is so high boiling that it does not elute from the GLC column and thus is not quantified in the GLC analysis. This is a further indication of the presence of petroleum hydrocarbons in these samples. Because total values are relatively low, it is the composition of hydrocarbons given by the chromatograms which yields the most information about the degree of petroleum contamination in samples. Reference is made to reviews by Farrington et al. (1976b) and Wakeham and Farrington (1980) for details of interpretation of hydrocarbon data in marine samples.

Listed in table 5 are parameters to illustrate the identification of petroleum contamination in a matrix of biogenic components. For example, phytane is used as a marker compound for petroleum as it is usually absent in uncontaminated samples. Isoprenoid hydrocarbons are generally more resistant to bacterial degradation than the n-alkanes, thus the ratio of phytane to its neighbouring alkane, C18, is provided as a rough indication of the relative state of biodegradation in samples.

The ratio of unresolved material, (another marker for petroleum residues) to the C18 peak is further indication of degradation. C15 and C17 are often seen as biogenic components having been synthesized by marine algae and subsequently incorporated into the tissues of filter feeding shellfish. In general, the patterns of hydrocarbons seen in the oyster samples agreed with the beach data (see section III). Samples from Raysut and the more southerly stations were composed of about 50 per cent non-biogenic hydrocarbons (table 5). Samples from the more northern areas showed larger percentages of petroleum compared to the biogenics, reaching the extreme at Hormuz where biogenics were not visible over the background of crude oil hydrocarbons. There was also a shift to higher boiling residues in the more northerly stations. This is indicated in samples where the boiling range exceeds C_{35} which is the upper limit on the chromatographic system. In these samples the baseline did not return to background during the normal programmed analysis.*

Anderlini et al. (1981) reported gas chromatographic analyses of extracts from the pearl oyster P. margaritifera collected from six coastal stations around Kuwait. Although their results were reported in terms of dry tissue a rough conversion to wet weight made by assuming a 90 per cent water content (Goldberg et al., 1978) indicates the Oman values fall intermediate among the Kuwait data.

The lack of exceedingly high levels of hydrocarbons in the oyster extracts and neuston tows (see section III) confirms the visual observations that there was not as much oil present in the water column as would be expected on the basis of the amount of tar seen on the beaches. Thus, the hydrocarbon analyses, coupled with visual observations of very little floating tar but the occurrence of heavy tar balls along the ocean bottom near to the shores, suggests that tar surveys on beaches are the best indications of the amount of oil pollution in an area adjacent to offshore tanker operations.

Chlorinated hydrocarbons

Results of the chlorinated hydrocarbon analyses are presented in table 7. Included in the table for comparison are values for PCB in similar kinds of samples from the Mediterranean Sea. In general, the Oman data indicate a relatively low level of contamination from these compounds. For example, PCB concentrations in sediments off Monaco are generally of the order of 50 ng/g wet weight (Elder et al., 1976), a level typical for coastal sediments away from the influence of large-scale pollution. In open Mediterranean Sea sediments, concentrations in the top centimeter range down to roughly 0.3 - 4.5 ng/g wet weight (Villeneuve et al., 1980). The levels measured in the Oman coastal sediments are at the lower end of this range.

The concentrations of chlorinated hydrocarbons in fish were moderate. In all cases liver contained an order of magnitude more PCB and pp'DDE than did muscle tissues; however, values were not high when compared to those in similar samples of Mediterranean fish (table 7; Bernhard, 1978).

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*High boiling deposits remaining on the GLC column required extensive bake out times at high temperature between sample injections. This quickly destroyed the column and caused extreme stress on the analytical system. As biological samples generally contain lower boiling residues than sediments from a given area, it was decided not to attempt GLC analysis on these sediment samples.

The single sample of mussels collected near Raysut contained approximately 8 ng/g (dry weight) of PCB as Arochlor 1254. Goldberg et al. (1978) found PCB levels ranging from 3 to 8700 ng/g (dry weight) in mussels from the coastal United States and Marchand et al. (1976) reported values of 40 - 2700 ng/g (dry weight) in similar species from the NW Mediterranean. Likewise, the levels of pp'DDE (0.5 ng/g-dry weight) in mussels from Oman are far below those (2 - 1700 ppb-dry weight) measured in these organisms from the coastal United States by Goldberg et al. (1978). The data comparison suggests that the waters of southern Oman at present contain only very low levels of chlorinated hydrocarbons.

Since oysters were collected from more areas than other biological samples, these results provide a wider basis for comparison. Table 8 gives ranges of chlorinated hydrocarbons in oysters from United States coastal waters, France and Kuwait. PCB and DDE levels in the Oman samples are similar to those reported for Kuwait and fall in the low end of the range given for oysters from the Atlantic coast of the United States and France.

Metals

The results for the sediment analyses are given in table 9. The most noteworthy feature is the generally higher levels of Cr, Cu, Fe, Mn, Ni and Zn in sediments from the Muscat anchorage area compared to those from the other locations in Oman. The Muscat anchorage samples were composed principally of muddy clay and contained a much higher fraction of fine-grained sediments. Concentrations of these particular elements generally correlate positively with the fine-grained fraction of marine sediments. Samples from the other three sites were substantially coarser and contained relatively large fractions of sand. The order of magnitude higher vanadium concentration at Mina Al Fahal Beach correlates with observations of oil pollution. Relatively high levels of V are often associated with crude oil and Mina Al Fahal Beach, which is adjacent to the Muscat anchorage zone, receives a substantial amount of oil spilled during tanker loading operations. This indication is supported by the relatively large concentration of total hydrocarbons that was also found in these sediments (see table 4).

Trace metal concentrations in surface near-shore sediments from Kuwait have been recently reported (Anderlini, 1982 in press; unpublished results). Those results are also listed in table 9 for comparison with the Oman data. Anderlini, 1982, (in press) compared their data with sediments from a wide variety of unpolluted world areas and concluded that trace metal concentrations observed in Kuwait sediments were within the range of values reported for other comparable areas. Although there is an ample spread of values among the Oman sediments due to the variable sediment composition, the concentrations are quite similar to those found in Kuwait. Only Cd and Pb appeared to be slightly higher in Oman sediments. Taken collectively, the sediment data suggest that at present there is no wide-spread contamination of the coastal zone by heavy metals.

The results of analyses of trace metals in fish muscle and the one sample of mussels are given in table 10. With the exception of Ni in hamour, trace metal concentrations in fish muscle are remarkably similar in the three samples. The relatively low metal levels in all fish samples are typical of those measured in uncontaminated fish muscle. Hg concentrations are well below the 0.5 ug/g wet weight limit enforced by many countries as the highest acceptable concentration in commercial fish tissue (Officer and Ryther, 1981). Comparison of metal data with concentrations in fish measured in other pollution surveys indicate that trace metal concentrations in Omani fish are similar to those from other uncontaminated geographical regions (ICES, 1974; Bernhard, 1978).

During the past several years, a variety of mussel species, including P. perna, have routinely been used as biological monitors of metal pollution (ICES, 1974; Fowler and Oregioni, 1976; Goldberg et al., 1978; Aissi, 1981; Asso, 1981). Comparison of the Oman data with these studies from other geographical areas indicates that mussels in the Salala region are not under the influence of metal pollution.

Results of analyses of oyster tissue are given in table 11. The data are scattered and show no major trends between the different locations. For several of the elements (e.g. Zn, V, Mg, Mn, Cu and Cd) concentrations appeared to be slightly higher at the more northerly stations, Bukha and Lima, than those in the south, e.g., Raysut and Dharai. However, any attempt to relate these concentration differences to input is questionable since the oysters from Bukha and Lima contained significantly less lipids in their tissues, a fact which could lead to an increase in metal concentration calculated on a dry weight basis. The relatively high Hg level in oysters from Ras Al Hamra may indicate a local input of this metal. However, this concentration falls within the range of Hg values which have been measured in similar species of Atlantic oysters (Alzieu et al., 1976; Establier, 1978). The cause for the somewhat elevated Cd concentrations found at Lima and Dharai is unknown. It may merely be a reflection of high natural levels of the element in the surrounding environment. However, both areas were contaminated with oil (see section III of this report) and as a result the Cd in oysters may be related to pollution by tanker washings in the area. Future studies should examine these aspects in greater detail. With respect to the remaining elements where comparisons can be made, the majority of the values listed in table 11 are similar to background concentrations of the same elements reported in Atlantic Coast oysters sampled during the United States Mussel Watch Programme (Goldberg et al., 1978).

For comparison, table 11 also contains metal values for rock oysters from two stations in Kuwait (Anderlini, unpublished). The data show that oysters from Oman contain somewhat higher concentrations of Ag, Cd, Co, Ni, Pb and V than oysters living at the northern end of the Gulf. However, since oysters generally display strong seasonal variations in their metal content (Phillips, 1980), direct comparisons even between the same species collected in different seasons are difficult to make.

V CONCLUSIONS

The results of these studies carried out in Oman's coastal waters confirm that oil pollution by tankers operating offshore and accidental discharge of oil during tanker loading operations introduce large quantities of crude oil into the coastal ecosystems. Data from the chemical analyses of oysters were consistent with beach tar observations and showed a trend of increasing oil pollution from the country's southern border to the Strait of Hormuz. Locally high concentrations of tar were seen in areas near the tanker loading facilities in Muscat. These trends were much more obvious from the beach tar data than from the chemical analyses of environmental samples.

With respect to halogenated hydrocarbons and heavy metals, levels are relatively low in Oman samples compared to those from other more industrialized areas of the world.

The major pollution problems in Oman appear to arise from intermittant discharges of crude oil to the sea surface. The chemical compositon of the Middle Eastern crudes and local meteorological conditions are most likely responsible for the relatively

quick removal of spilled oil from the ocean surface. Fast rates of evaporation of light fractions and photo-chemical condensation reactions increase the weight of oil residues thus causing the remaining tar to aggregate and sink. Thus, most of the oil that reaches the coast arrives as heavy solid or semi-solid tar lumps. These can be collected and weighed for assessing coastal pollution loads. Chemical analyses of biological and other environmental samples confirmed these general trends. One aspect of the environmental sampling that made interpretation of the biological data difficult is that there appeared to be more than one species of rock oyster sampled. Unfortunately, species indentification as C. margaritacea was based only on the sample from Ras Al Hamra. Visual observations of morphological features suggested that the survey dealt with at least two species. For example, similarities were great between oysters from Bukha, Lima and Dawwah. The oysters from Ras Al Hamra and Raysut appeared similar but differed slightly in shell shape from the first group. The Dharai oysters had much thicker shells than other oyster samples and their mantle tissue had a bluish colour which was not seen in other samples. The fact that the oysters from Bukha and Lima both had significantly lower lipid concentrations than the other samples lends some credence to the visual differentiation.

VI RECOMMENDATIONS

In the context of this pilot study, several suggestions are given for consideration in designing future assessments of pollution in Oman's coastal waters.

1. Tar surveys of the sites should be carried out at least seasonally for a complete year to confirm these preliminary observations and to assess the temporal variability of tar loads on the beaches. Additional sampling sites such as Ras Al Hadd, Ras Madraka and Ras Sauqira, should be included to extend the coverage to the large areas of the coast not sampled in this survey.

2. Assessment of ambient water quality with respect to dissolved/dispersed hydrocarbons and other pollutants could be made by using bivalve shellfish such as rock oysters as indicator species. These organisms are ideal since they appear to inhabit the entire coast of Oman and are found in other areas of the Gulf as well. If the organisms are carefully collected, taking precautions not to contaminate the samples with the various pollutants of interest, the same samples could be used for chlorinated hydrocarbon and heavy metal analyses. However, as noted in this survey, there appeared to be more than one species of oyster available in the coastal areas sampled. Pollutant content varies with species as is evident in the different tissue concentrations of petroleum hydrocarbons, chlorinated hydrocarbons and metals in oysters and mussels collected at the same sampling site in Raysut. Thus, to facilitate comparison of data from different locations in Oman and throughout the Gulf region, attempts should be made to collect the same species. In this repsect, the various species of bivalves available in Oman must be identified and their distributions noted.

3. For an extended monitoring programme, if identical species cannot be collected at each location, experiments must be conducted to determine relative differences in uptake and retention characteristics of different organisms. This could be accomplished by analysing the different species from areas where their ranges overlap.

4. To study details of spatial dispersion of specific discharges, a monitoring programme could use transplants of one shellfish species as a more uniform biological indicator.

5. Expression of results of organic pollutant analysis on a lipid weight basis should help reduce population variation and accentuate trends.

6. Further studies could emphasize problems such as incorporation of toxic hydrocarbons into edible species, effects of oil pollution on coastal ecosystems and the transport of specific pesticides through coastal environments in areas of heavy usage.

7. Consideration should be given to the inclusion of sampling stations near sites of future industrial, agricultural or commercial activities. Baseline data from these locations will be useful in assessing the impact of pollution arising from such activities in future years.

8. The pilot study indicated that chlorinated pesticides are not entering the marine environment from land-based sources even near highly agricultural areas e.g. Salala. This may be a reflection of the preference for use of organophosphorus pesticides in these areas and some consideration should be given in the future to examining the presence of these compounds in marine samples.

9. This study emphasized analysis for only selected contaminants. To diagnose other potential pollutants and more detailed aspects of the problems identified, more sophisticated analysis such as combined gas chromatography-mass spectrometry should be conducted on selected samples.

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Table 1 : Quantities of tar on beaches of the Sultanate of Oman. Mean values for each beach are given in g tar/metre of shoreline.

Station	Date (1980)	Transect (m)	Tar (g)	(X g/m shore)
1. Bukha	3/10	27	315.0	647
		13	1051.0	
		12	574.0	
2. Bukha* (3 km north)	3/10	50	174.0	775*
		50	304.0	
		50	1211.0	
		50	1413.0	
3. Lima	3/10	visually assessed		775
4. Shinas	28/09	60	744.5	1033
		60	638.5	
		60	1717.0	
5. Al Khabura	27/09	50	545.0	340
		52	456.5	
		50	202.5	
		54	155.0	
6. Al Qurum	26/09	42	45.0	30
		43	28.0	
		45	17.5	
7. Ras Al Hamra	1/10	16	61.0	36
		12	32.0	
		15	15.0	
8. Mina Al Fahal	29/9	25	3166.5	1188
		25	325.0	
		25	71.5	
9. Dahrai (Masira)	2/10	35	28.0	139
		35	213.0	
		35	152.0	
		35	162.0	
10. Taquah	30/09	40	5.0	5
		40	10.0	
		40	1.0	
11. Maghsail	30/09	25	2.0	15
		25	3.0	
		25	54.0	
		25	1.5	

*These values should be multiplied by a factor of 3 to get estimates of total amount of tar per metre of shoreline. See text for explanation.

Table 2 : Estimates of standing stock of tar on beaches of the Sultanate of Oman during the period 26 September to 3 October 1980. Values do not include islands and are extrapolations for regions based on data collected from individual beaches typical of a given region.

Region (No. refers to location in figure 1)	Beach length* (km)	Tar (g/m)	Standing stock (tonnes)
Gulf side			
1. Bukha	33	647	21.35
2. Bukha (3 km north)	30	2325	69.75
Gulf of Oman - Arabian Sea side			
3. Lima	120	775	93.00
4. Shinas	90	1033	92.97
5. Al Khabura	125	340	42.50
6. Al Qurum, and 7. Ras Al Hamra (average of two sample sites)	85	33	2.80
8. Mina Al Fahal	20	1188	23.76
Muscat-Ras Al Hadd**	195	33	6.44
Ras Al Hadd-Ras Madraka (i.e. 9. Masira Island)	580	139	80.62
Ras Madraka-Yemen border (i.e. 10. Taquah, and 11. Maghsail)	690	10	6.90
TOTAL LENGTH:	1968 km	TOTAL TAR:	440 tn.

* Estimated by planimeter measurements of French hydrographic charts.
**Tar (g/m) estimate based on that from Stations 6 and 7.

Table 3 : Comparison of tar concentrations reported for different world areas. Most values in g/m of shoreline except those designated by * which are computed in g/m^2 of beach surface. N.C. means not computed.

Location	Tar (g/m shore) Range	Average	Reference
U.S.A.			
East coast	19-81	42	15,37
West coast	0.003-23.9*	1.35*	31
Canada			
West coast	0 0.043	0.023	45
Bahama Islands	1-130	N.C.	14
Bermuda 1971-1972	98-220	171	13
1978-1979	115-1108	195	30
Caribbean Islands	0-1,000	N.C.	38
Mediterranean & Red Sea			
Egypt	3.5-380*	134*	43
Malta	0.5*		referred to in 43
Israel	3,625		referred to in 43
Eilat coast	6,000 maximum		6
India			
West coast	2.2-758*	28*	16,17
East coast	5.9-139*	20*	16,17
East Africa	10-100	N.C.	referred to in 13
Kuwait	25-1912	387	3
Oman	5-2325	224	this work

Table 4 : Total hydrocarbons in environmental samples from Sultanate of Oman. F_1, F_2, F_3 are fractions eluted from column chromatography procedures as explained in text.

Sample	Type	Total extractable hydrocarbons F_1 (µg)	F_2 (µg)	F_3 (µg)	gm wet wt	mg lipid	Total hydrocarbons µg/g wet	mg/g lipid
SEDIMENTS								
Raysut #1 (outside harbour)	sandy clay	112	97	155	47	3.7	7.7	98.4
#2 (outside harbour)	sandy clay	55	140	140	39	3.8	8.6	88.1
#3 (harbour entrance)	fine clay mud	135	300	305	39	9.3	19.0	79.6
Dawwah	sand	185	317	0	107	3.4	4.7	147.6
Muscat anchorage #1	sandy clay	0	130	0	52	1.7	2.5	76.5
#2	sandy clay	80	225	0	44	1.7	6.9	179.4
Mina Al Fahal beach	sand	835	537	285	143	7.8	11.6	345.2
Khasab Bay, Hormuz	sand	42	0	0	51	3.7	0.8	11.3
FISH TISSUES								
Epinephelus tauvina (grouper or hamoor) Salala	muscle	225	222	*	253	233.7	1.8	1.91
	liver	150	395	*	46	232.2	11.7	2.35
Lethrinus nebulosus (sea bream or hamiska) Salala	muscle	124	250	*	116	394.6	3.2	0.95
	liver	555	232	*	6	71.2	131.2	11.05
L. nebulosus Dawwah	muscle	20	17	*	115	131.3	0.3	0.28
	liver	2,595	3,730		18	571.0	345.6	11.07
SHELLFISH TISSUE								
mussels Raysut		0	42	*	28	287.0	1.5	0.15
oysters Raysut		260	260	*	45	297.0	11.5	1.75
Dahrai		137	545	*	32	411.5	21.5	1.65
Dawwah		940	155	*	29	252.8	37.5	4.33
Ras Al Hamra		710	345	*	33	450.5	32.1	2.34
Lima		245	125	*	34	112.0	10.9	3.30
Bukha		385	55	*	32	104.0	13.7	4.23

*presumed to be biogenic lipids

Table 5 : Results of gas chromatographic analyses of hydrocarbon fractions from oyster extracts expressed as *ug/g wet tissue (10^{-6}) or **ng/g (10^{-9}). Resolved peaks were quantified by comparison to the external standard closest in boiling point in the C_{12} to C_{35} boiling range. Unresolved components (URE) were quantified by using an average response factor over the appropriate boiling range (analyses were done on a 20 m WCOT glass column coated with SE-52, helium carrier gas, temperature programme 50° to 260°C, 3°/min plus 260° hold, on-column injection, flame ionization detection. Erba Fractovap.)

Oysters	unresolved		resolved		h.c. C12 to C35		lipid	n-C15	n-C17	pristane	n-C18	phytane	phytane	URE C18	%URE
	F1*	F2*	F1*	F2*	µg/g wet	mg/g lipid	%	**	**	**	**	**	C18	C18	
Raysut	1.8	1.6	0.6	1.4	5.4	0.8	0.7	21.3	24.0	6.6	6.8	3.0	0.4	0.2	62
Dawwah	13.0	5.1	1.3	0.6	19.9	2.3	0.9	63.3	50.9	14.4	7.6	4.9	0.6	1.7	91
Dahrai	2.5	5.8	2.1	5.6	16.0	1.2	1.3	43.3	64.7	17.0	7.8	1.9	0.2	0.0	52
Ras Al Hamra	8.9	7.5	1.3	0.9	18.4	1.4	1.4	79.9	81.6	28.8	7.9	7.4	0.9	0.9	90
Lima	7.5	5.3	0.5	0.3	13.6	4.1	0.3	25.0	23.1	9.1	2.3	14.1	6.1	5.1	94
Bukha	6.0	3.1	0.5	0.3	9.9	3.0	0.3	9.5	27.8	9.8	3.0	10.4	3.5	0.8	86

Table 6 : Comparison of gravimetric and gas chromatographic determinations of total hydrocarbons in oyster extracts

Oysters		Total µg hydrocarbons		µg/g wet wt		Description based on g.c.
		C_{12} to C_{35}	grav.	g.c.	grav.	
Blank	F1	4.3	0			few low boiling peaks from extraction solvents.
	F2	2.7	0			
Raysut	F1	118	260	2.4	5.8	biogenics with small amount of degraded petroleum C12 to C32
	F2	131	260	3.0	5.8	range underneath. Max. at C21.
Dahrai	F1	146	137	4.6	4.3	mostly biogenics with small background highly degraded petroleum
	F2	366	545	11.4	17.0	C12 to C33. Max. C20.
Dawwah	F1	386	940	13.3	32.4	degraded petroleum C13 to C35+ max. URE at C25.
	F2	169	155	5.8	5.3	
Ras Al Hamra	F1	346	710	10.0	21.6	degraded crude oil C15 to C33 max. URE at C20.
	F2	278	345	8.4	10.5	
Lima	F1	273	245	8.0	7.2	very degraded crude oil C13 to C35+ boiling range. Max. at
	F2	191	125	5.6	3.7	C20. Few biogenics.
Bukha	F1	209	385	6.5	11.9	very degraded crude oil C13 to C35+. Max. URE at C23.
	F2	132	55	3.4	1.7	

Table 7 : Results of analyses for chlorinated hydrocarbons expressed as *ng/g wet weight (10^{-9}) or **pg/g wet weight (10^{-12}) and comparison with similar measurements on samples from the Mediterranean reported in Elder et al. (1976), Villeneuve et al. (1980) and Marchand et al. (1976). (Analyses were done on a Varian 3700 g.c. equipped with a 25 m WCOT SE-52 column, N_2, carrier gas, electron capture detection. Temperature programmed 110°-210° at 8°/min). Mediterranean values for tuna and oyster from Elder, Fowler and Villeneuve (unpublished results).

Sample		H.C.B.**	Lindane**	pp'DDE**	pp'DDD**	pp'DDT**	PCB as Arochlor 1254*	PCB in samples from the Med.*
SEDIMENTS								
Raysut #1 (outside harbour)		75	83	19	39	84	1,00	coastal sediments: 50
#2 (outside harbour)		44	100	22	26	40	1,00	
#3 (harbour entrance)		136	214	22	29	49	0,90	
Dawwah		13	31	5	4	10	0,30	
Muscat anchorage #1		16	49	13	7	15	0,40	open sea: 0.30 - 4.5
#2		20	68	14	7	24	0.40	
Mina Al Fahal Beach		10	105	4	9	15	0.35	
Khasab Bay, Hormuz		11	49	16	8	37	0.50	
FISH TISSUES								
E. tauvina (Salala)	muscle	6.4	64	57	16	44	0.49	
	liver	27	5	740	110	220	2.34	
L. nebulosus (Salala)	muscle	19	32	190	15	73	0.54	tuna muscle: 5.3 - 95.1
	liver	160	3	3200	670	350	5.10	
L. nebulosus (Masira)	muscle	3	24	140	32	120	0.25	tuna liver: 185 - 1130
	liver	320	1550	1750	nd	140	9.10	
SHELLFISH TISSUE								
Mussels Raysut		28	140	49	nd	600	0.87	40 - 2700
Oysters Raysut		nd	170	170	96	280	1.80	
Dahrai		140	140	390	170	270	9.10	
Dawwah		9	120	280	250	145	1.80	310 ng/g
Ras Al Hamra		150	370	410	350	250	7.50	(dry weight)
Lima		38	59	250	140	nd	4.00	
Bukha		36	51	102	48	87	3.00	

Table 8 : Ranges of PCB and DDE levels in oysters from different geographical areas

Location	PCB (Arochlor 1254) ng/g dry wet	pp'DDE	Reference
Oman	*18 - 91	*1 - 4.1	This study
Kuwait	4 - 71	0.6 - 5.5	Anderlini et al. (1981)
United States (Atlantic Coast)	15 - 336	5 - 30	Goldberg et al. (1978)
France (Atlantic Coast)	200 - 4,200	1 - 30	Alzieu et al. (1976)

* Based on a dry weight/wet weight ratio = 0.1

Table 9 : Results of trace metal and total organic carbon analyses of marine surface sediments from Oman. Metal values are ug/g (ppm) dry weight except Fe (% dry weight). Trace metal concentractions for similar sediments from Kuwait (Anderlini et al., in press; unpublished results) are also shown for purpose of comparison.

	% T.O.C.	Ag	Cd	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn	Hg
Muscat anchorage												
28/09/80 St. 1	1.17	3.77	2.50	109	16.0	1.60	389	252	50	3.8	36	0.020
28/09/80 St. 2	-	4.08	2.90	115	15.8	1.73	242	261	49	3.1	33	0.014
Mina Al Fahal Beach												
29/09/80	-	5.21	3.26	29.2	3.65	0.36	124	45	52	26.0	11	0.012
Khasab Bay, Hormuz												
3/10/80	-	6.05	4.03	16.1	4.84	0.21	44	21	63	3.2	12	0.012
Raysut Harbour												
30/09/80 St. 2 (outside harbour)	2.20	5.36	4.02	23.2	5.40	0.28	35	21	56	0.5	16	0.024
30/09/80 St. 3 (harbour entrance)	1.95	3.66	4.70	37.8	12.2	0.61	81	37	58	ND	28	0.023
Kuwait coast mean (range) 1/03/79	1.00	-	1.05 (0.8-3.0)	69 (33-120)	21 (13-51)	1.5 (0.7-2.0)	410 (167-500)	97 (55-120)	23 (12-50)	14 (10-18)	45 (24-89)	0.03

* N.D. = Not detected
\- = insufficient sample for analysis

Table 10 : Results of trace metal analyses of fish and mussel tissues. Values are mean concentrations in ug/g (ppm) dry weight of duplicate analyses.

	Ag	Al	Ba	Cd	Co	Cr	Cu	Fe	Mg	Mn	Mo	Ni	Pb	Sn	V	Zn	Hg
FISH MUSCLE																	
E. tauvina (Salala)	0.01	3.7	0.20	0.05	ND	3.3	0.65	19	1250	0.27	ND	1.9	0.21	11.7	0.07	13.6	-
L. nebulosus (Salala)	0.01	2.0	0.13	0.13	0.02	3.2	0.51	13	1180	0.19	ND	0.08	0.24	12.3	0.09	10.6	0.56
L. nebulosus (Dawwah)	0.01	3.0	0.37	0.04	ND	3.4	0.41	12	1370	0.18	ND	0.14	0.25	12.2	0.07	9.9	0.29
MUSSELS (soft parts)																	
P. perna L. (Raysut)	0.08	9.9	0.86	7.6	0.42	3.1	4.0	60	4660	3.3	0.39	5.0	ND	9.0	1.26	37.5	-

ND = not detected

- = insufficient sample for analysis

Table 11 : Trace element levels (ug/g dry) in rock oysters from Oman. Values (Mean ± 1σ) are based on pooled replicates (n = 2 - 5) with at least 5 individuals per replicate. Element concentrations in the same species from Kuwait (Anderlini, unpublished results) are also included for comparison.

Loaction	Ag	Al	Ba	Cd	Co	Cr	Cu	Fe	Mg	Mn	Mo	Ni	Pb	Sn	V	Zn	Hg
OMAN																	
Raysut	1.9 ±0.09	12.8 ±0.37	0.68 ±0.005	13.7 ±0	1.0 ±0.02	0.30 ±0.04	79 ±0.6	78 ±2.6	3890 ±3.5	1.7 ±0.03	2.7 ±0.01	2.3 ±0.09	4.5 ±0.10	6.5 ±0.02	3.6 ±0.03	286 ±0.05	0.41 ±0.011
Dahrai	1.4 ±0.14	19.5 ±1.35	0.45 ±0.008	20.5 ±0.45	0.75 ±0.07	1.2 ±0.32	39.6 ±0.95	78 ±3.0	3650 ±78	6.0 ±0.17	2.1 ±0	2.5 ±1.3	8.0 ±2.1	4.5 ±0.07	2.7 ±0.02	232 ±5.4	0.21 ±0.012
Dawwah	2.6 ±0.38	49.2 ±3.26	0.99 ±0.05	6.2 ±0.03	1.1 ±0.04	1.1 ±0.18	106 ±0.7	167 ±21	4540 ±37	6.2 ±0.08	10.7 ±0.12	3.8 ±1.3	5.0 ±0.05	5.3 ±0.21	3.9 ±0.12	1870 ±16	0.52 ±0.04
Ras Al-Hamra	0.89 ±0.19	23.5 ±1.32	0.45 ±0.03	4.4 ±0.05	0.26 ±0.05	0.84 ±0.09	126 ±2.12	131 ±3.98	5040 ±95	7.3 ±0.07	5.8 ±0.10	2.3 ±0.19	1.07 ±0.39	6.9 ±0.27	3.7 ±0.13	985 ±13	0.70 ±0.012
Lima	2.6 ±0.10	25.1 ±3.47	2.0 ±0.13	22.2 ±0.19	1.3 ±0.08	1.1 ±0.79	66.8 ±0.58	115 ±0.05	5890 ±39	4.7 ±0.06	4.0 ±0.10	2.6 ±0.005	9.3 ±4.9	5.1 ±0.08	5.7 ±0.13	424 ±0.9	-
Bukha	2.5 ±0.21	18.1 ±1.34	0.53 ±0.10	3.7 ±0.30	1.0 ±0.14	0.55 ±0.21	170 ±13.6	100 ±7.3	5220 ±356	8.6 ±0.66	9.7 ±0.71	3.3 ±0.49	4.7 ±0.67	5.2 ±0.75	4.1 ±0.22	1690 ±140	0.46 ±0.003
KUWAIT																	
Doha (outside Kuwait City)	0.28 ±0.04	24.4 ±7.1	1.13 ±0.68	1.51 ±0.29	0.07 ±0.05	2.1 ±1.5	124 ±16.7	145 ±43	2790 ±724	11.1 ±9.86	6.2 ±4.1	0.34 ±0.14	ND	8.8 ±2.2	0.71 ±0.14	629 ±166	0.11 ±0.01
Bnaid Al-Gar (within Kuwait City)	0.85 ±0.02	25.5 ±2.15	0.46 ±0.022	1.56 ±0.28	0.09 ±0.02	3.0 ±0.11	120 ±0.95	183 ±4.05	2990 ±682	18.3 ±3.3	0.10 ±0.045	0.33 ±0.007	0.36 ±0.095	11.7 ±0.85	0.72 ±0.04	662 ±211	0.31 ±0.002

N.D. = not detected

- = insufficient sample for analysis

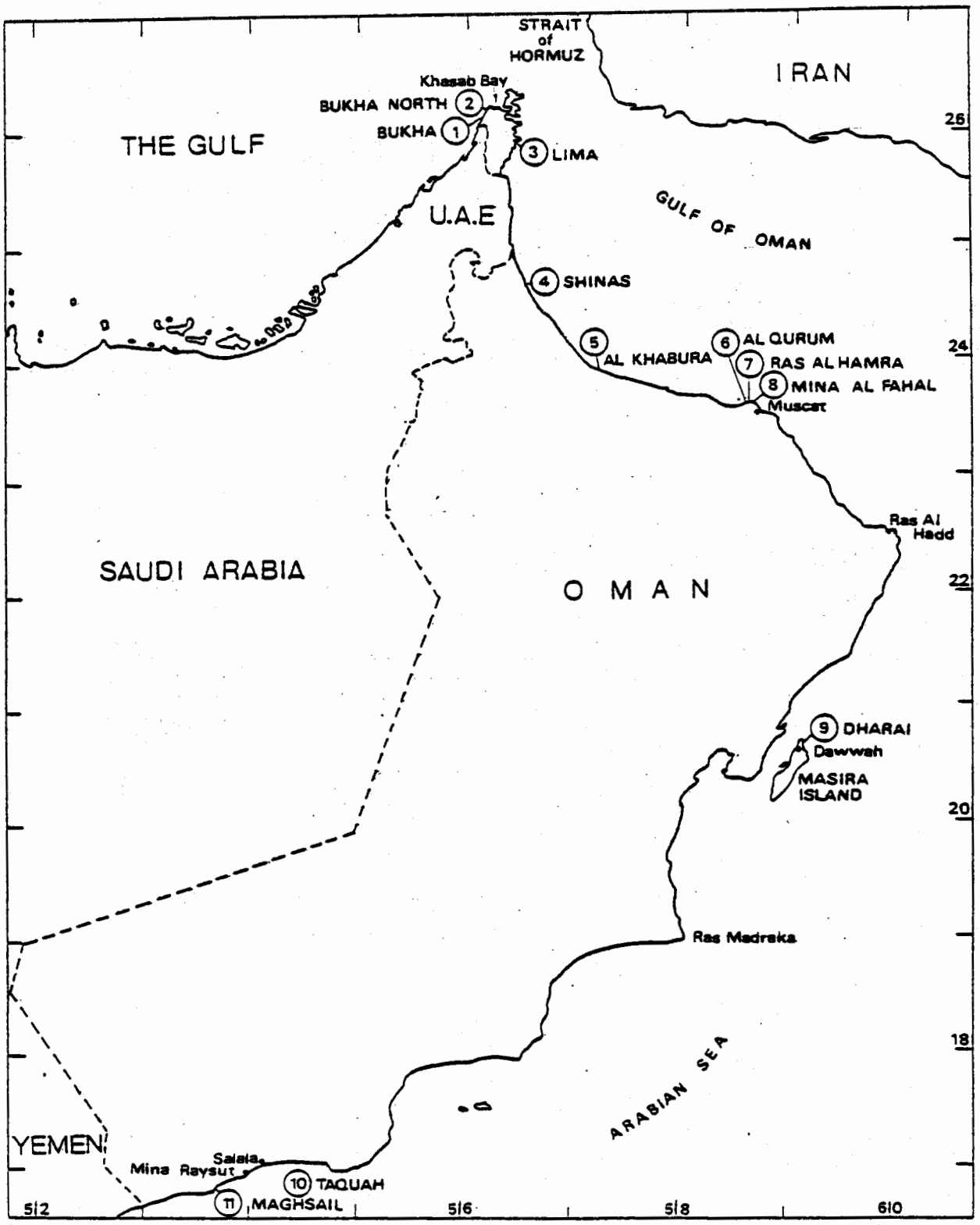

Figure 1a : Coastal stations sampled in the Sultanate of Oman during the period 26 September to 3 October 1980

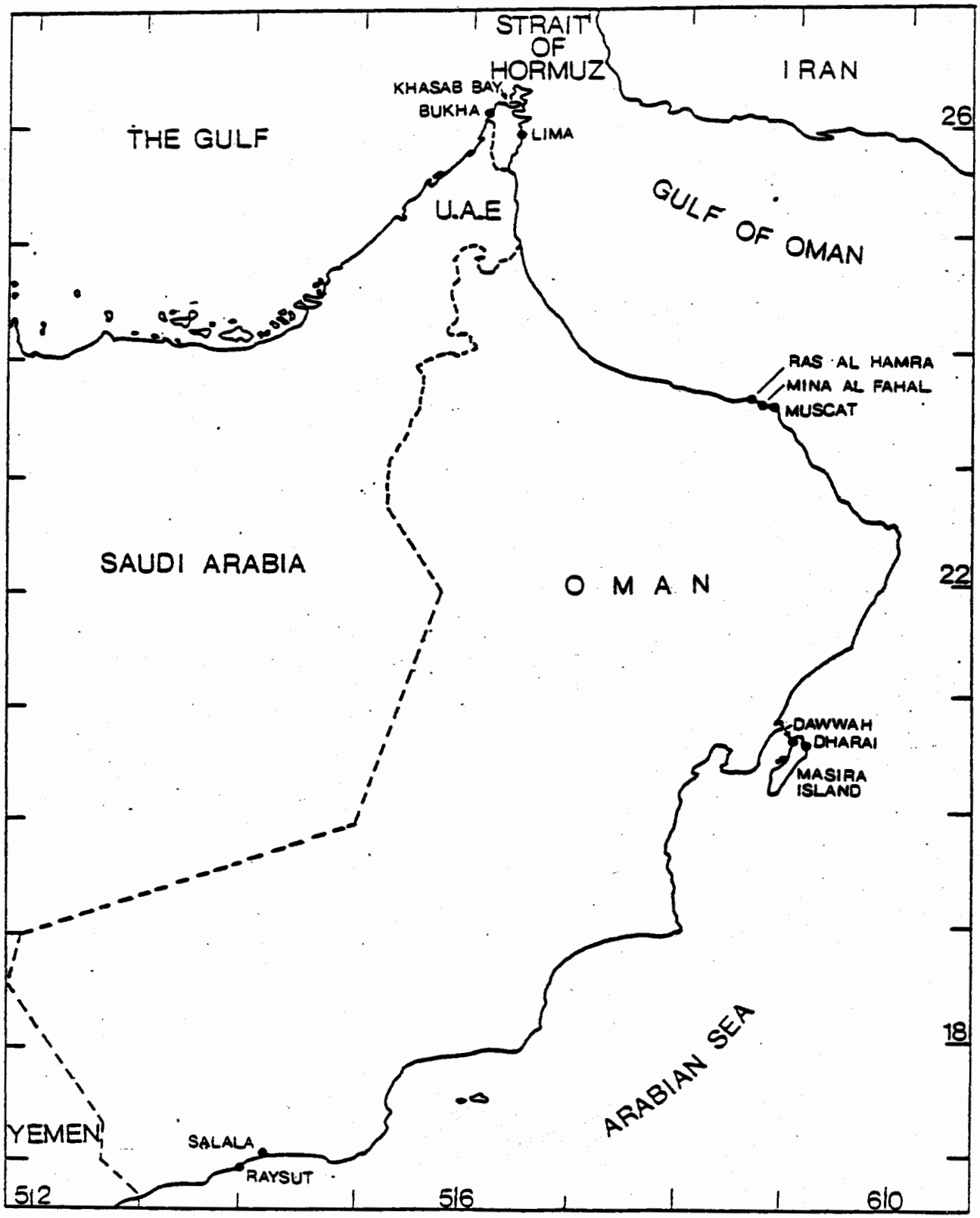

Figure 1b : Locations in the Sultanate of Oman where sediment and biota were sampled

Fig. 2. Typical beach transect used for tar ball survey.

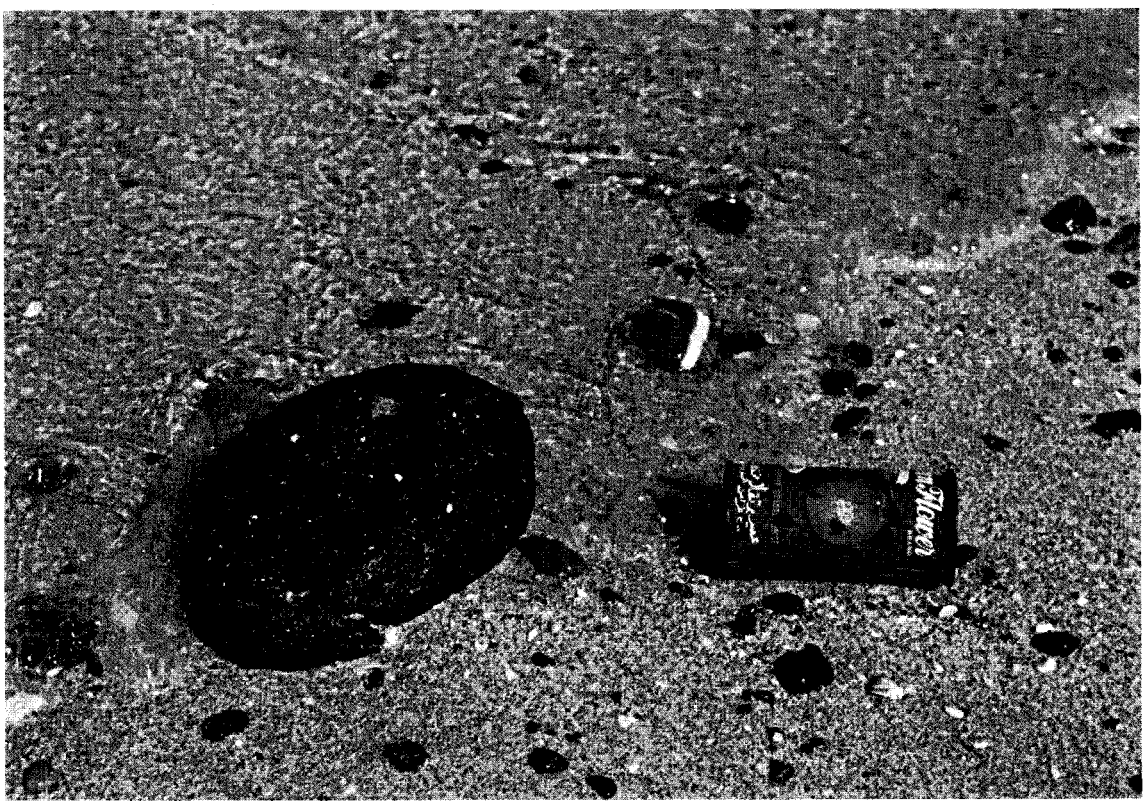

Fig. 3. Large tar ball on Bukha Beach.

Fig. 4. Large tar balls found above high-tide mark on beach 3 km north of Bukha.

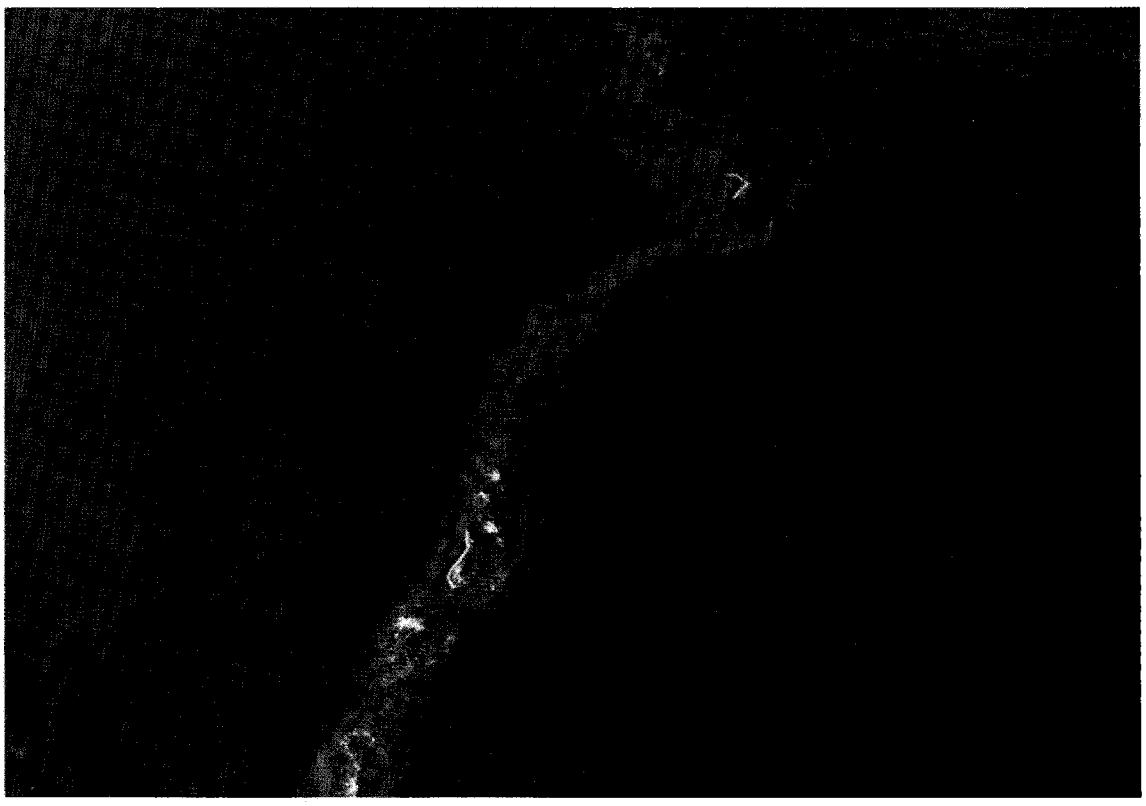

Fig. 5 (a). *Aerial view of oil slicks at sea off the coast of the Musandam Peninsula, 3 October 1980.*

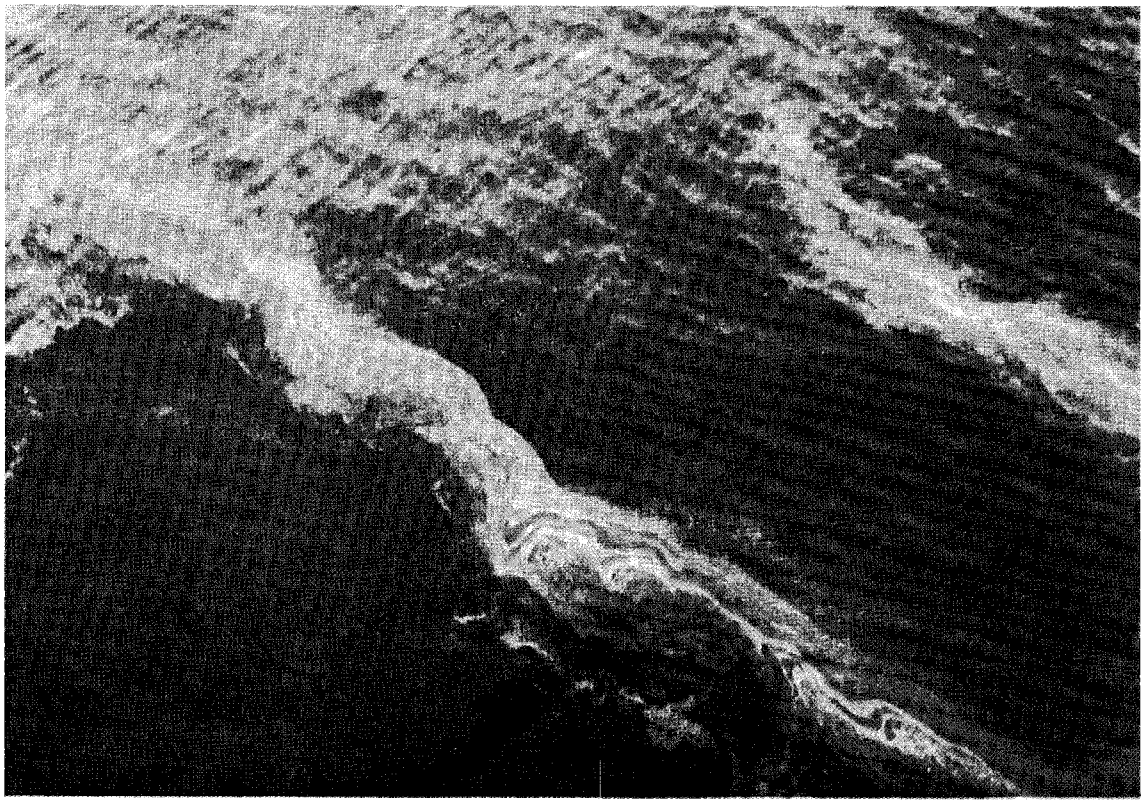

Fig. 5 (b). *Aerial view of oil slicks at sea off the coast of the Musandam Peninsula, 3 October 1980.*

Fig. 6. Fresh tar on upper beach face at Shinas.

Fig. 7 (a). *Al Khabura, band of litter.*

Fig. 7 (b). *Al Khabura, tar sieve from litter.*

Fig. 8 (a). *Banding of tar along high-tide mark at Al Khabura. (close-up).*

Fig 8 (b). *Extended view along beach face.*

Fig. 9 (b). *Tar washing ashore at Mina Al Fahal fresh flat lump in swash zone.*

Fig. 9 (a). *Tar washing ashore at Mina Al Fahal lumps in intertidal zone.*

Fig. 9 (c). *Tar washing ashore at Mina Al Fahal numerous small lumps in surf zone.*

Fig. 9 (d). *Tar washing ashore at Mina Al Fahal rounded lumps in intertidal zone.*

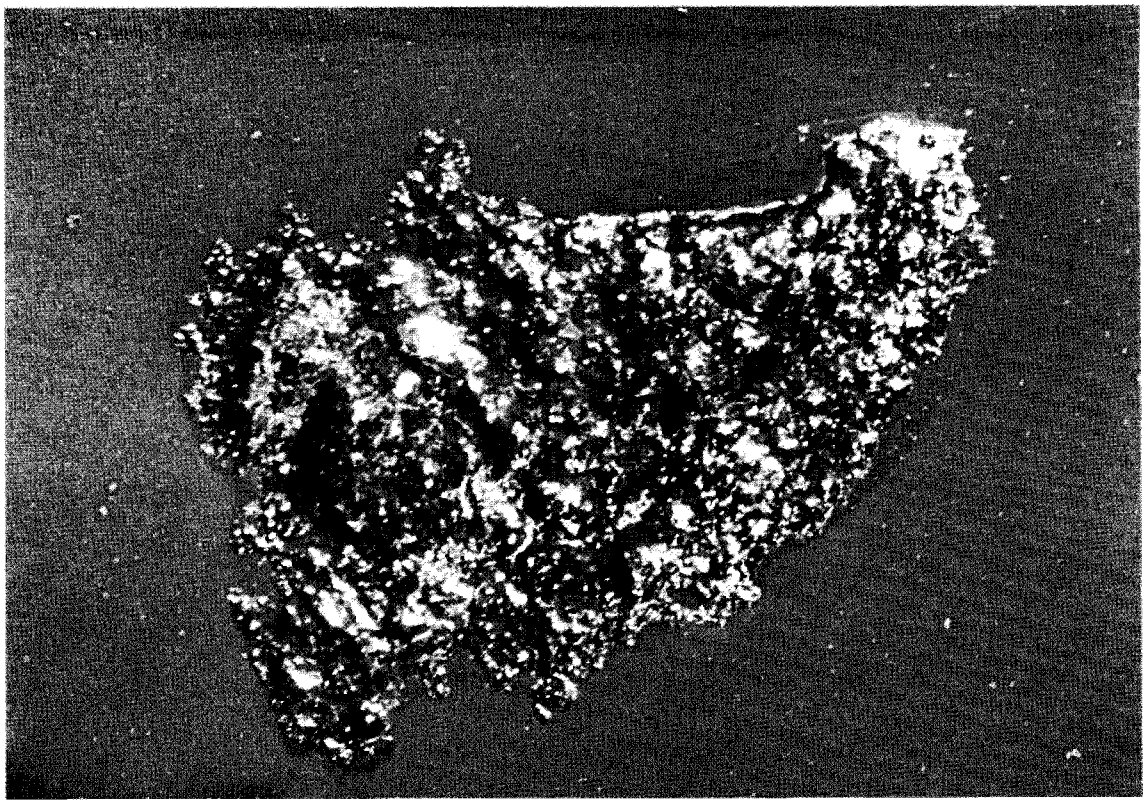

Fig. 10 (a). *Oil spill near Muttrah harbour on 28 September 1980 floating patch of fresh oil.*

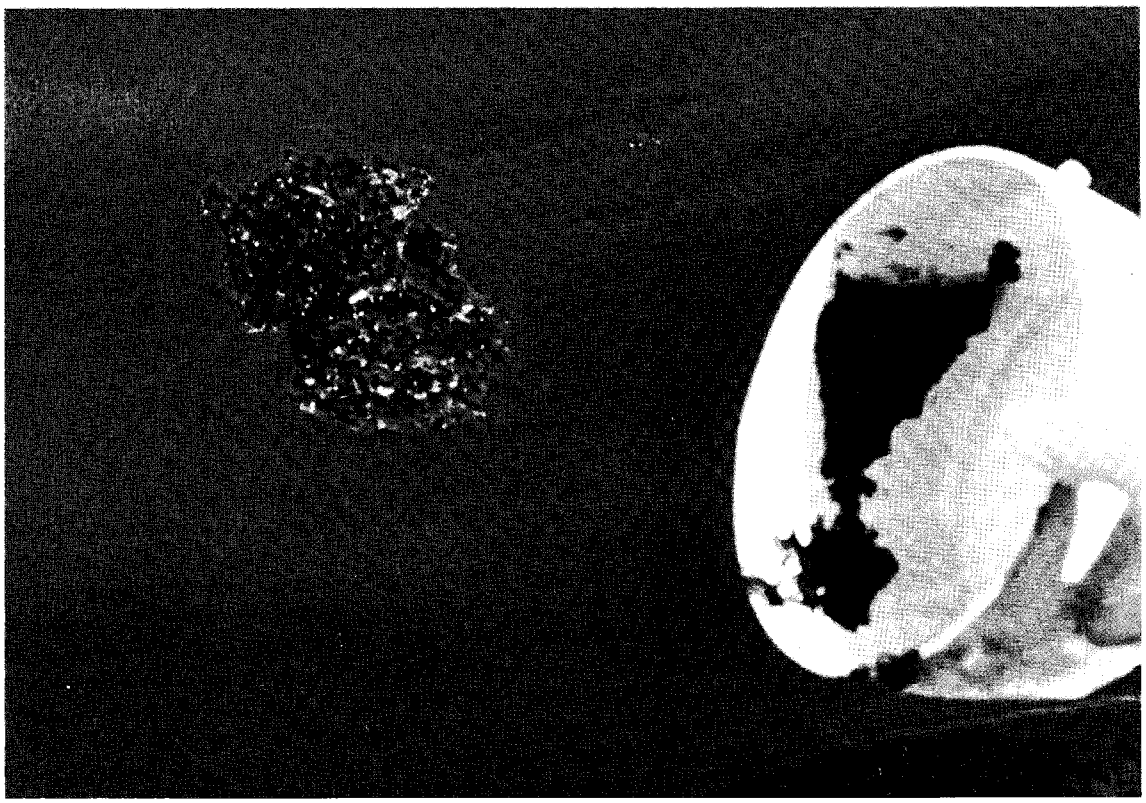

Fig. 10 (b). *Oil spill near Muttrah harbour on 28 September 1980 collection of floating patches.*

Fig. 11. Large tar balls observed at Dahrai Beach on Masira Island.

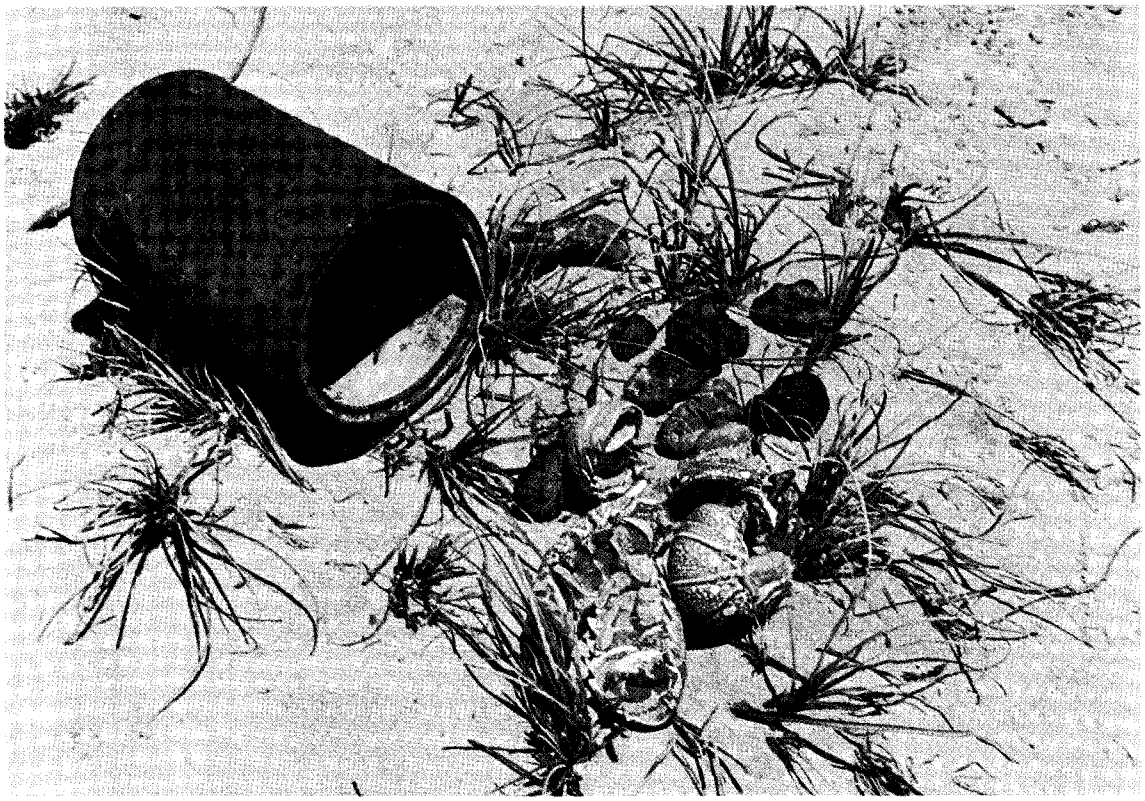

Fig. 12. Maghsail Beach — tar balls and dead lobsters collected by a local fisherman during the monsoon season.

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