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Studies on the Phytoplankton of Littoral Waters of the Arabian Gulf as Impacted by Oil Spills

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STUDIES ON THE PHYTOPLANKTON OF LITTORAL WATERS OF THE ARABIAN GULF AS IMPACTED BY OIL SPILLS

by

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A Thesis
Submitted to the
Faculty of The Graduate College
in partial fulfillment of the
requirements for the
Degree of Master of Arts
Department of Biology

Western Michigan University
Kalamazoo, Michigan
August 1984

STUDIES ON THE PHYTOPLANKTON OF LITTORAL WATERS OF THE ARABIAN GULF AS IMPACTED BY OIL SPILLS

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Western Michigan University, 1984

A study of the effect of oil pollution on two intertidal areas of the Saudi Arabian Gulf coast was undertaken. One area was severely impacted by oil; the other was relatively clean. The organisms studied also indicated the effects of pollution were diatoms and blue-green algae.

Members of the diatom genus Amphora were more numerous in the clean water area than in the polluted section, confirming their preference for relatively clean habitats. Members of the diatom genus Asterionella, a more resistant group, were much more abundant in the polluted area.

Blue-green algae which also tolerate pollution were also more abundant in the polluted waters. Together these organisms are excellent indicators of the quality of the environment in which they are found.

Due to the fact that information regarding the dynamics of the biota of the Arabian Gulf is relatively scarce, it is impossible at this time to make recommendations for improving the situation. There is a serious need for the development of methods and laws for controlling this problem of pollution. Unfortunately, at present, political problems are such that there is little hope of such agreements being developed.

ACKNOWLEDGEMENTS

I wish to express my deepest appreciation to Dr. Clarence J. Goodnight, my major advisor, for his continued encouragement and suggestions concerning all aspects of this thesis. I wish also to thank my fellow graduate student, Fardin Oiliaei, for her aid in the laboratory aspects of this study. In addition, I wish to express my appreciation to Dr. Joseph Engemann and Dr. William Van Deventer who served as thesis committee members. Other friends and colleagues at Western Michigan University have been unstinting in their encouragement during this study; I am grateful for their thoughtfulness and consideration.

Finally, I wish to thank my wife and family who supported me during this work and patiently accepted my frequent absences.

Hamdan S. Al-Ghamdi

بسم الله الرحمن الرحيم

وجعلنا من الماء كل شيء حي

صدق الله العظيم

God says in the Quran -
"We made every living thing of water"

1323911

AL-GHAMDI, HAMDAN SALEH

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CHAPTER I

INTRODUCTION

One of the major pollution problems in the coastal waters of the world is the result of oil spills. Nowhere is this more evident than in the Arabian Gulf, where numerous large tankers loaded with petroleum from the oil-rich shores of Saudi Arabia traverse the waters in their passage to the Indian Ocean on their way to all parts of the world.

In recent years the war between Iraq and Iran has increased the problem enormously. Due to the destruction of the oil wells of the coastal area of Iran, there have been enormous amounts of oil released into the Gulf. As a result, the entire Gulf is heavily impacted with oil slicks and in many cases masses of formed tar balls are clearly visible. These float toward the beaches, polluting them with sticky masses of oil.

Where the prevailing wind blows toward the shore, the mass of oil and tar balls intermingles with the usual beach debris, producing a seriously polluted shoreline. In other places the beach may be relatively clear, supposedly due to differences such as current and topography.

The purpose of this study is to compare the plankton of two beaches, one which is heavily impacted with oil and the other which is relatively clean.

Geography of Saudi Arabia

The kingdom of Saudi Arabia is strategically located in the Arabian peninsula, a location which functions as a link between Africa and Asia. This kingdom occupies approximately 75% of the peninsula, having an area of some 900,000 square miles (2,300,000 square kilometers). The Arabian Peninsula is surrounded on three sides by water, with the Red Sea separating it from Africa and the Arabian Gulf separating it from Iran and much of Iraq (Stacey, 1977).

The north of Saudi Arabia is bordered by the countries of Iraq, Jordan, and Kuwait. Several small states fringe the coastal areas of the Arabian Peninsula. These include Qatar and the United Arab Emirates. Saudi Arabia is bordered on the south by North and South Yemen and the Sultanate of Oman. (See Figure 1.)

The Arabian Peninsula is rich in oil deposits; in fact, oil revenues form some 80% of revenue in Saudi Arabia. The tremendous deposits of oil are found under Saudi Arabia's coastal lowland along the Gulf about 220 miles (352 kilometers) from Ras al-Khafji in the north to Salwah in the southeast. (See Figure 2.)

Petroleum was first discovered in Saudi Arabia in 1937 after four years of drilling. Actually the first petroleum concession was granted in 1923, but it took several years of exploration before there was actual production. Today Saudi Arabia is the second largest producer of crude oil in the world and is the biggest crude oil exporter (Aramco, 1982). The kingdom was one of the founding members of OPEC (Organization of Petroleum Exporting Countries). The chief producer of oil in

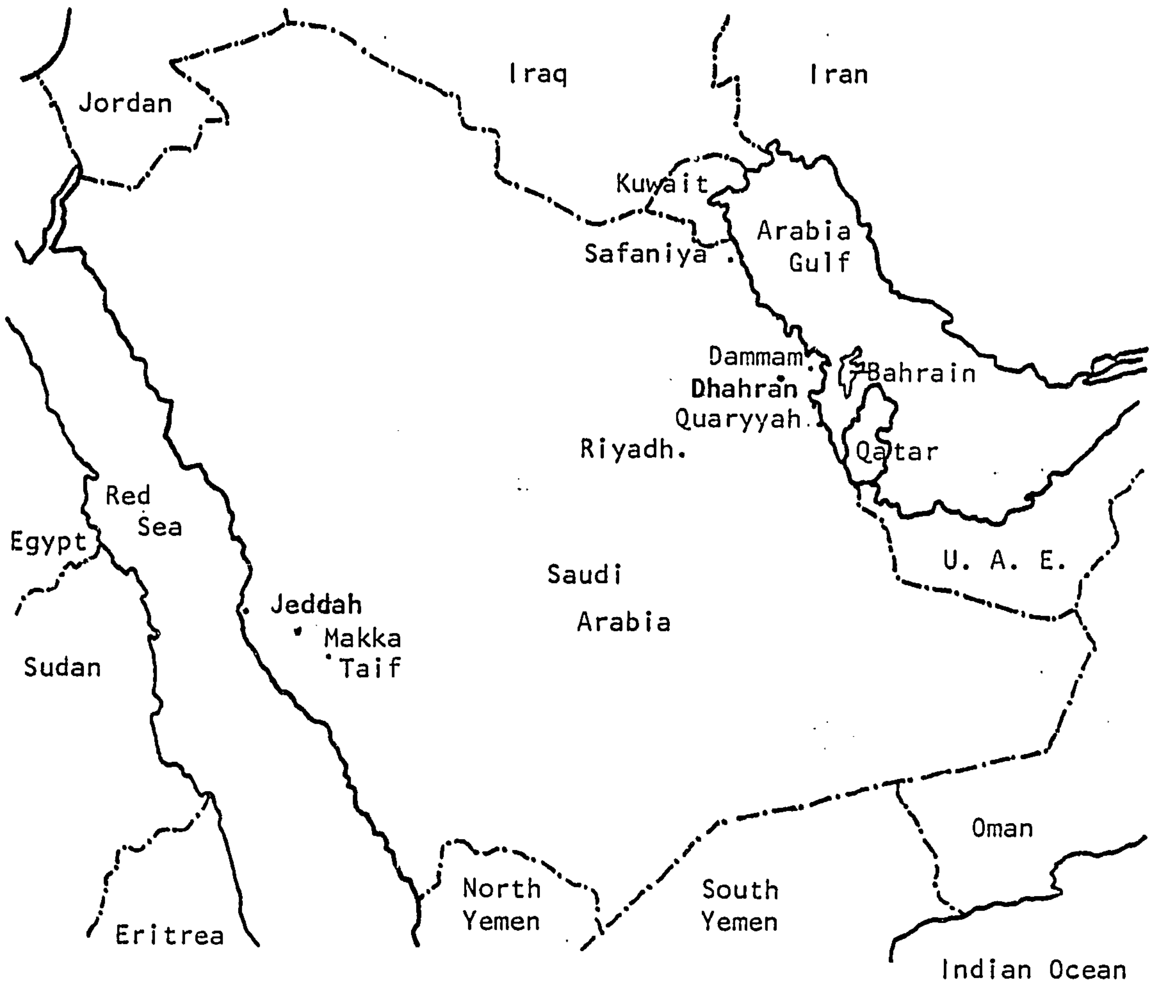


Figure 1. Saudi Arabia and Neighboring Countries

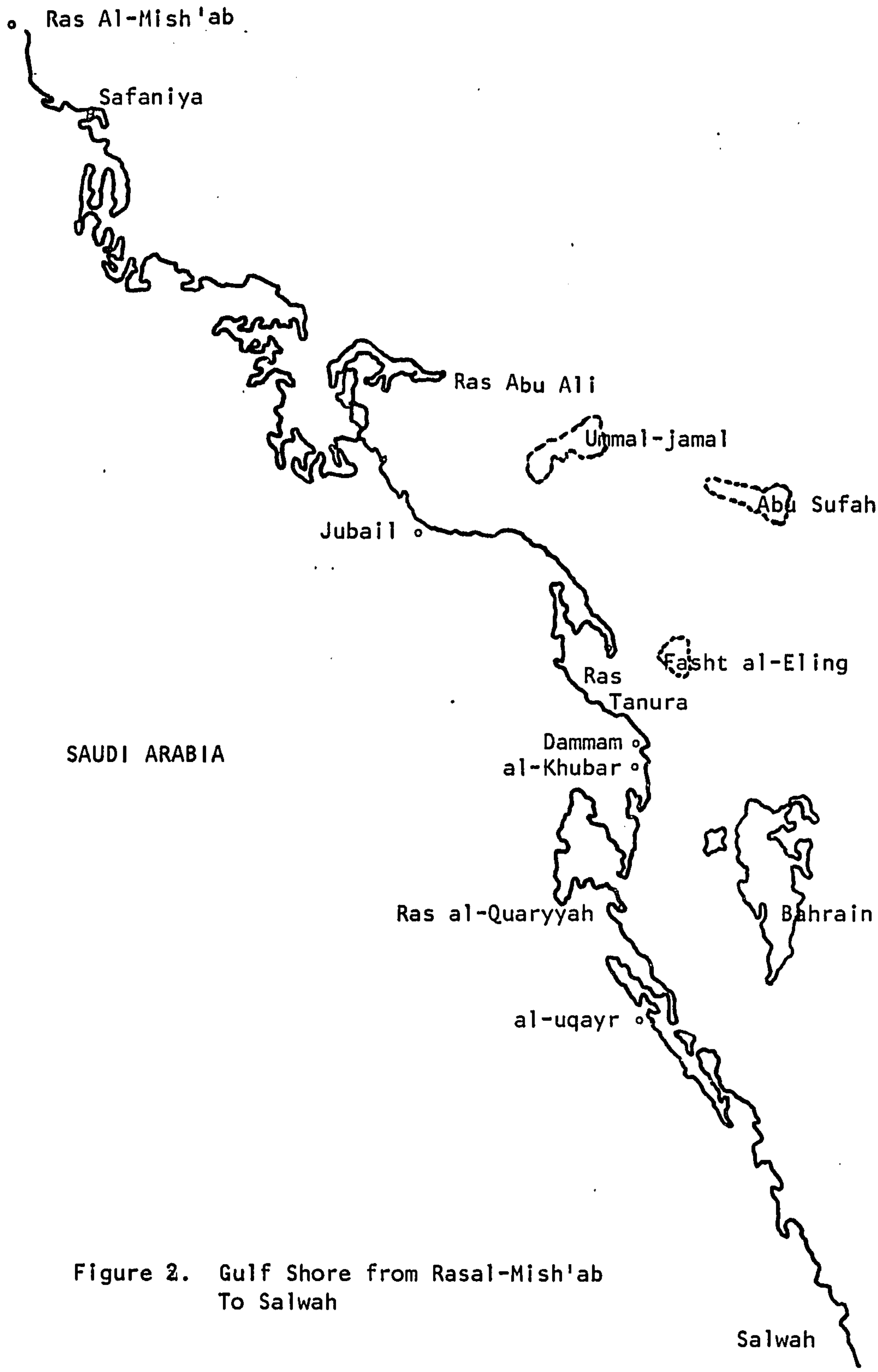


Figure 2. Gulf Shore from Rasal-Mish'ab To Salwah

Saudi Arabia is Aramco (Arabian American Oil Company); but other companies are present, including the Getty Oil Company of the United States and the Arabian Jabines Oil Company.

Climate and Weather

The climate of Saudi Arabia is basically hot and dry in the summer, a typical desert climate. The temperatures are somewhat milder in the winter. In the western and eastern regions, the temperature is high and is accompanied by relatively high humidity at all times of the year. During the summer months, the temperature is as high as 45° to 50° C. Precipitation in the form of rain falls primarily during the months from October to April. The southern areas of the country are very cold in the winter and temperate in the summer.

The dominant religion of Saudi Arabia is Islam. Makka and Madina are the Holy cities in the country.

Politically, the country is divided into four regions. These are Najd, Hajaz, Asir and Eastern Province.

Economy of Saudi Arabia Oil Production

The discovery of oil deposits and their development have brought great sociological changes in Saudi Arabia. The tremendous wealth has resulted in an accelerated rate of economic growth. Two modern and new industrial cities have been built on the Arabian Gulf and on the Red Sea. Improved schooling, health facilities and housing have become available for all the people of the kingdom.

Most of the coast, lying two hundred-twenty miles on the western

part of the Arabian Gulf from Salwah south to Ras al-Khafje north, is sandy beach. The winds usually blow in from the southeast and northwest. The salinities range from about 38.5‰ to 70‰; the lowest salinities are on the north and the highest at the southern end. Temperatures rise to 55° C in the summer and the surface of dry sand exposed to the summer sun rises to about 70° C. The combination of high temperatures, the salinities, and oil pollution along this coastal area has affected the biology of the area.

Marine Pollution

Without any doubt, water is one of the most abundant and important substances on this earth. It is a major component of the protoplasm of both plants and animals. Because of its unique physical and chemical properties, it enters into most of the complex reactions which make life processes possible.

The amount of water on the earth has remained essentially constant over the many millions of years that the earth has existed. At our present time, water covers approximately 72% of the earth's surface, representing a volume of approximately 1.5 billion cubic miles. About 97% of this total volume is found in the oceans, with only 3% as freshwater. Less than one-third of that small amount actually represents usable freshwater.

This present discussion will be concerned primarily with some of the problems that occur in marine environments when pollution occurs.

In order to better understand the pollution problems of the marine environment, certain definitions are needed. Often words are used

carelessly, but it is important to have exact definitions. The word "ocean" refers to the several bodies of water, e. g., Atlantic, Pacific, Indian, which cover nearly three-fourths of the earth's surface. A sea is usually a large body of salt water, less in size than the ocean, and more or less landlocked. It usually has a connection with the larger ocean. Examples of seas are the Mediterranean Sea and the Arabian Sea. The term "sea", however, is often applied to inland waters. Usually such seas have a high content of salt. Best known among these are the Great Salt Lake in the State of Utah in the United States and the Dead Sea in the Middle East. A gulf is a portion of the ocean or sea which extends into the land. It is a partially landlocked sea and is usually larger than a bay. Examples of these are the Gulf of Mexico and the Arabian Gulf.

Sea water is an extraordinarily complex entity. While its composition may vary from one area to another, there are certain parameters which are relatively constant. For example, sea water contains approximately 3.5% salts. The types and amounts of salts vary; the most abundant are those of sodium, iodine, and magnesium, with those of gold and silver being relatively rare.

Pollution of the marine environment has always occurred, but in recent years the problem has become more severe. Pollution has many origins. Some of these problems originate from the disposal of chemical waste materials from various industries, organic wastes from cities and towns in the coastal areas, and numerous other materials resulting from human activities. In recent years, the greatest problem of marine pollution has resulted from the spillage of oil into the oceans. Such pollution results in severe damage to the marine environment; it may

even result in the extinction of important, often unique, organisms.

Since World War II, the amount of oil being transported across the oceans of the world has increased enormously. Prior to this war, the transport of crude oil represented only 26% of the 80 million tons of oil carried by ships. The amount has increased to approximately 80 million tons and represents 50% of the total amount of material transported over the oceans.

The first record of oil being transported by tankers dates from 1861 when the 224-ton brig "Elizabeth Watts" carried petroleum across the Atlantic. The tankers gradually increased in size and capacity, and in 1938 a typical seagoing vessel had a capacity of about 1200 tons. At present, tankers may have a capacity of more than 10,000 tons. These monstrous tankers carry both crude and refined petroleum from the oil fields or refineries of various parts of the world to areas where it will be used. Over 50% of sea traffic now consists of oil tankers.

While oil production occurs in many parts of the world, a large portion originates from off-shore wells in Venezuela, the Gulf of Mexico and the Arabian Gulf. Thousands of oil wells are located within the shallow waters of the continental shelf. In port areas a major source of pollution occurs when the tankers are cleaned and the washings are deposited in the docking areas.

In each year there are approximately 60 incidents involving accidental oil spillages. Three and one-half million tons of petroleum are released into the ocean each year from tankers and commercial vessels. Most is from oil tankers, but other commercial vessels

contribute to this total.

In 1967 Fletcher surveyed 285 oil spillages at sea and found that most of them resulted from accidental damage to a tanker's hull. During 1970, 12 tankers were involved in collisions and seven were severely damaged when they encountered heavy storms at sea. On land, a large amount of the transport of oil is through pipelines. Spillages from these are less frequent but often very damaging to the terrestrial environment.

In 1971, 45 casualties were reported in Smith (1972). Twelve of the damaged tankers went aground, 10 sank or suffered storm damage, 12 experienced severe damage during storms at sea, and 11 were involved in collisions.

While the main contributor to the problem of marine pollution is that of accidents in ports or on the high seas, accidents may also occur during exploration and production, in storage areas, and in pipeline breaks. Spent lubricants from incompletely burned fuels and from untreated disposed material of industrial facilities and industrial waste also contribute an equal or larger amount of oil to the pollution problem. Thus it has been estimated that the total amount of oil entering the ocean from various sources amounts to between five and 10 million tons per year (Smith, 1972).

The Effects of Oil Spills on Marine Life

The deleterious effects of oil pollution on marine organisms and the resulting effects upon food recovered from the sea are usually severe. During the first few days after a spill, the crude oil and

other petroleum products contain many substances that are poisonous to marine organisms. Some effects are immediate; others occur only after some period of time. The oil may mix with the water, especially when there is much turbulence. In the long term, the oil will continue its damaging effect upon bottom dwelling plants and animals. The effects of the oil spillage may persist for many years after the spill. The exact length of the time for which this damage persists is not well known (Grassle et al., 1979).

Some bacteria normally present in the ocean will attack and slowly degrade the spilled oil. Fuel oil, an important derivative of crude petroleum is more toxic than the crude. Therefore, it has effects that are not totally comparable to those of the unaltered crude.

Hydrocarbons from an oil spill enter the marine food chain and are concentrated in the fatty parts of the organisms that ingest the oil.

When the oil enters the fat and flesh of the animals, it is isolated from the natural degradation processes of the animal. It may be poisonous not only to marine organisms but to many other animals, including man. Oil not only affects the physiology of the organism, but also may affect its behavior. When the oil is deposited in water, it may dissolve in the sea water or become dispersed through the water column.

Numerous marine animals are adversely affected by oil spills. This list includes large numbers of species of molluscs, crustaceans, echinoderms, polychaetes, coelenterates, and notably, edible shellfish such as lobsters, oysters, scallops, and clams. Large numbers of these latter animals, many of which are important commercially, have perished.

Those animals which manage to survive are often severely damaged, necessitating the closing of the shellfish industry in some areas. Marine pollution results in many undesirable effects. The first and most obvious effect of pollution is a reduction in the diversity of the organisms within an environment. Only those forms which are highly tolerant to the pollutant will survive. While the total number of plant and animal individuals surviving pollution may be greater than previous to the introduction of the toxic material, the variety of species will be severely reduced. While most forms of pollution exert a direct or indirect effect on the marine environment, oil spills have a direct and often dramatic immediate effect.

Fish, seabirds, mammals, even man, are immediately affected and the damage to the appearance of the shore area may be extreme.

At present, our knowledge of the effects of oil pollution on marine organisms has been obtained both from experimental observations and direct observations of actual incidents or chronically polluted habitats. However, much remains to be learned of the long term impact of this pollution upon the total environment.

The Arabian Gulf

The Arabian Gulf is part of the shallow marginal sea of the Indian Ocean that lies between the Arabian Peninsula and Iran. The sea area is approximately 92,500 square miles (240,000 square kilometers). It is an inland sea with a length of about 500 miles. The width averages 100 miles, varying from 180 miles to a mere 26 miles at the Strait of Hormuz.

In depth, the Gulf ranges from 240 to 300 feet, with the greatest depths lying near the Iranian coast. The Gulf is bordered on the northeast and east by Iran, on the northwest by Iraq and Kuwait, and on the west and southwest by Saudi Arabia, and Qatar. On the south and southeast it is bordered by the United Arab Emirates and part of Oman.

Along the Arabian coast where the Gulf is relatively shallow (usually less than 120 feet in depth), there are numerous islands and some salt domes. There are also accumulations of coral and various skeletal remains. The Arabian Gulf receives a small amount of fresh water in the northwestern area where the Tigris and Euphrates-Karun Rivers enter. The water temperature in the Gulf ranges from 85° to 90° F (24-32° C), in the Strait of Hormuz and from 60° to 90° F (16-32° C) in the northwest. The salinity generally ranges between 37‰ and 70‰.

The highest temperatures and salinities are found in the area near the Arabian coast. The tidal range varies from approximately 4 to 5 feet near Qatar to 10 to 11 feet in the northwestern area and 9 to 10 feet in the southeast. Waves average about 10 feet in the southern Gulf. The winds in the Arabian Gulf predominantly come from the northwest and the average wind velocity is between 5 and 7 m/second. Occasionally, the winds come from the northwest and have speeds as high as 35 miles per hour.

Precipitation is generally low, varying from 2.5 to 11 inches per year. Humidity is highest at Bahrain and Bandar Abbas. Even the slightest physical exertion in this area results in profuse perspiration.

At present, portions of the Arabian Gulf are being filled in by deposits from the Mesopotamian rivers. In this basin, thousands of feet of sediments have accumulated. These sediments, along with evaporites, have produced the areas of vast oil resources.

Oil was first discovered in the Arabian Gulf before World War I. This discovery occurred in Iran in 1908 and was made by a British company. The first oil was shipped in 1912 from Abadan Port. Following the discoveries in Iran, oil was subsequently discovered in Iran in the Kipkuk Fields in October of 1929. Since 1945 most oil production has been in the Saudi Arabia-Kuwait neutral zone.

Concessions have been granted in both on-shore and off-shore oil fields in that area since 1949. Bahrain Island is also one of the oil producing areas, first discovered in 1932. The first shipment from there was in 1939 and consisted of some 30,000 barrels.

Production began in Qatar in 1960 with 115,000 barrels being produced daily. In October of 1960, oil was found in the United Arab Emirates. Exports were commenced in December of 1963. In Kuwait, the first exploratory well was drilled in 1939.

Oil was discovered in Saudi Arabia in 1939, with a daily production of 1,357 barrels. Production of oil first began in Oman in August of 1956 with some 132,000 barrels being produced each day. The first commercially profitable wells were found in 1962. Some of these oil fields were discovered in off-shore and some in on-shore areas and most of the oil exported has gone through the deep water ports of the Arabian Gulf.

The countries mentioned above are now considered the world's

greatest oil producing region with a production just under 10,000,000 barrels per day in 1967.

Because the Arabian population is increasing at a rate between 6% and 10%, pollution of the Gulf has become a more serious problem. Table 1 contains statistical data to indicate the area population and the amount of daily crude oil production for Gulf countries. With the total population increasing by some 500,000 each year, the demand for domestic water, irrigation water for agriculture, and the needs of industry, the pollution of the Gulf is of great concern. The Gulf is both the source of water and the sink for waste water. Unfortunately, the rate of evaporation from the Gulf of Oman exceeds the inflow from rainfall and the rivers which empty into it. It appears that ecological problems are being compounded, and soon the damage will be such that recovery will not be possible.

Shipping accidents, pipeline breaks, and well seeps are all possible sources of pollution. The Arabian Gulf had 26 oil load terminals in 1976 and 10 vessels entering the Straits of Hurmuz each day. Harbors are often so congested that ships must wait as much as several weeks before loading. The extent and effect of pollution in the Gulf is exasperated by this congestion at the ports.

The total amount of oil spilled by vessels in the world in 1978 was estimated at 10,000,000 m^3. The amounts in the Arabian Gulf account for not more than 15-20%. The amount is estimated between 150,000 and 200,000 m^3 (Oostdam, 1978). Table 2 indicates a review of Arabian Gulf oil spillage. Table 3 is also a summary of oil spills reported covering both on-shore and off-shore spills from 1975 to 1983

Table 1

Statistical Data on Area Population and the Amount of Crude Oil Production for Gulf Countries (1980)

Country	Area km2	Population	Daily Crude Oil Production 1980
Saudi Arabia	2,300,000	10,442,000	9.9 *
Iraq	438,400	13,600,000	2.6
Kuwait	24,300	1,477,000	0.4
Bharian	600	470,000	0.05
Qatar	10,500	203,000	0.5
United Arab Emirates	82,000	1,000,000	1.7
Oman	212,000	964,000	0.28
Iran	1,621,000	39,830,000	1.4
Total	4,688,800	67,986,000	16.83
World	140,889,500	3,733,396,000	41.68

* Million barrels

Source: Al-Majalla (1983).

Table 2

A Review of Arabian Gulf Oil Spillages

Date	Name of Tanker Installation	Location	Amount of Oil Spilled	Type of Oil Spilled
Nov. 1983	Liberian	Aghi Jari Arabian Coast	361,500 barrels	crude oil
Aug. 1966	British Crown	Arabian Gulf	Thousands of barrels	crude oil
Nov. 1969	Pipeline Fracture	Arabian Gulf	over 175,000 gallons	crude oil
Apr. 1970	Pipeline	NW Shore of Tarut Bay, Saudi Arabia Coast	100,000 barrels	Arabian light crude oil
Dec. 1971	Oil Well	80 miles SW of Laban, Arabian Gulf	100,000 barrels	crude oil
June 1974	Getty	Mena Saud Saudi Arabia	35,000 barrels	crude oil
July 1974	Getty	Khafje, Kuwait, Saudi Arabia	several thousand barrels	crude oil
Aug. 1980	Oil Well	from an unidentified source	201,000 barrels	crude oil
Oct. 1980	Oil Well	Hasbah, off-shore of Saudi Arabia	501,000 barrels	thick crude oil
Feb. 1983	Oil Well	Nowrus field Arabian Coast	800,000 cubicmeters	heavy crude oil

Compiled from various sources.

Table 3

Off-Shore and On-Shore Spills Comparison of 1975-1983
in Saudi Arabia Area

Location	1975	1976	1977	1978	1979	1980	1981	1982	1983
Off-Shore	2,210*	31,169	586,277	544,538	1,555	130,000	6,900	4,763	1,936.5
On-Shore	--	--	3,523	1,660	375,641	12,884	17,474	37,673	2,120
Total	2,210	31,169	589,800	546,198	380,046	142,000	23,884	23,880	4,056.5
	Since late January 1983 to July 1983 about 80,000 cubic meters (400,000 barrels) of oil have entered the Saudi Arabian area from Iran (Nowrus oil field).								400,000
									404,056.5

* barrels

Source: ARAMCO Oil Spill Report, Meterological and Environmental Protection Administration, 1982 to 1983.

in the Saudi Arabian area. Some 142 major industrial installations are planned for the Arabian Gulf coast. These are to include 60 refineries and similar plants associated with oil, 11 cement plants, 8 fertilizer plants, 26 desalination and power plants, aluminum and copper refineries, plastic plants, a titanium mill and other industries. All of these will probably add to the pollution load emptied into the Gulf.

The marine life of the Arabian Gulf thus occupies an environment which is severely stressed; one which is characterized by temperature extremes as well as by high, often fluctuating salinities. Because so many organisms are unable to exist in such a stressed environment, the diversity of the biological communities in the Gulf is rapidly disappearing. Many groups of organisms are already absent from this area due to heavy pollution from these many different sources.

Oil which is spilled at sea is lighter than water and spreads over the water's surface at a rate which is influenced by many factors such as gravity, surface tension, viscosity, source point, wind, waves, and currents. Crude oil may spread into thin layers, and the action of the waves and wind elongates, distorts, and breaks the slicks into moving patches of oil. The largest amount of oil is contained near the leading edges of the patch. Both wind and current affect the oil patches, at times breaking up the oil spill and increasing the rate of physical emulsification. (See Figure 3.)

Plankton

Steen's Dictionary of Biological Terms (1971) defines plankton as

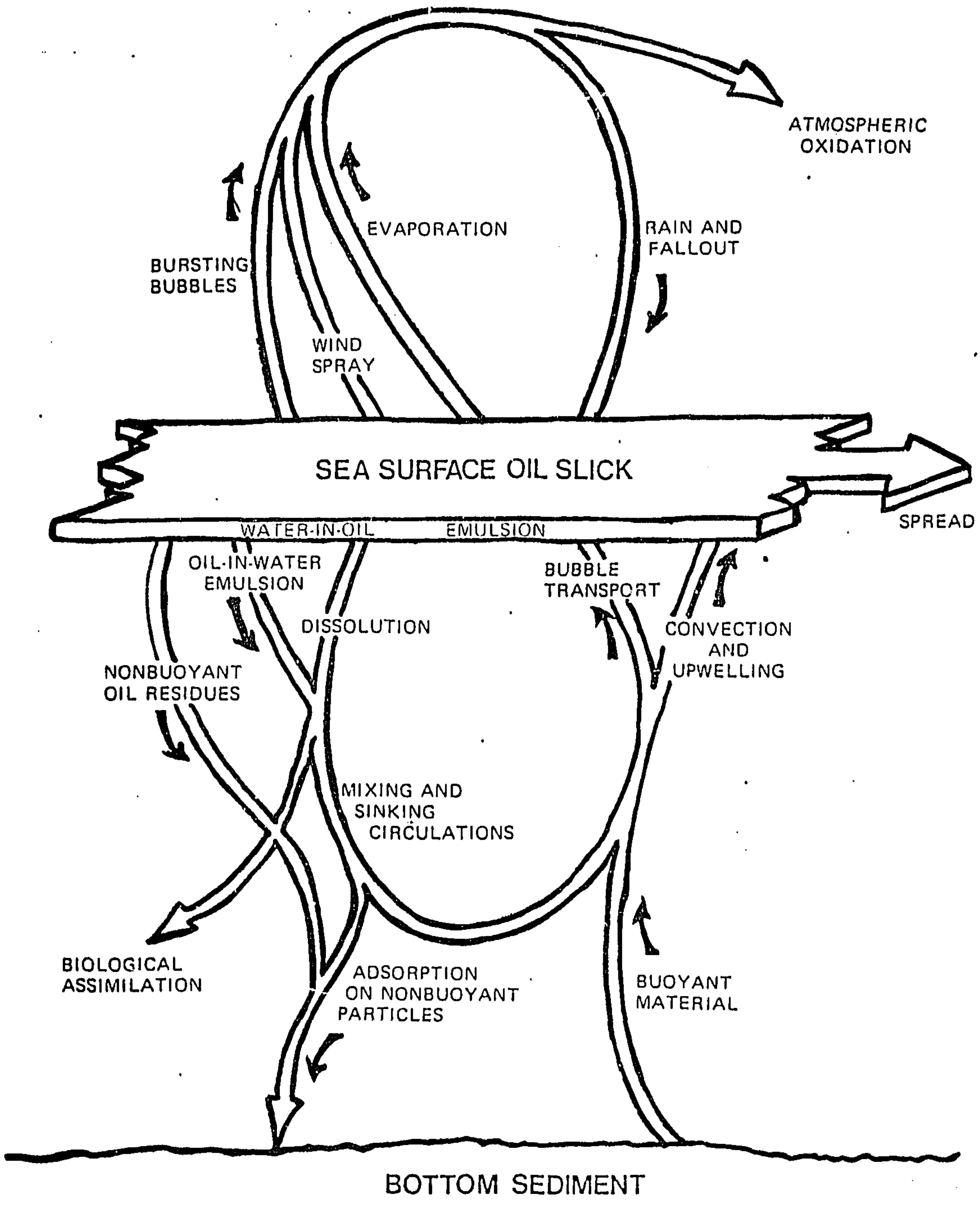


Figure 3. Natural Forces Which Disperse and Modify Oil Slicks on Water (Garett, 1972).

"aquatic organisms of freshwater, brackish, or sea water which float passively or exhibit limitations to locomotor activity: phytoplankton, zooplankton, and nannoplankton."

One of the first biocoenoses to be given a special name was that assemblage of mostly microscopic organisms collectively termed "plankton". These planktonic organisms are found in the oceans, freshwater bodies of water and many other different marine habitats. They are classified into a number of different groupings, using size as the primary criterion. They are subdivided thus:

1. The ultra and nannoplankton, consisting largely of unicellular algae along with bacteria, fungi, and some invertebrate eggs, size is less than 0.05 mm. in length. Phytoplankton tend to dominate this grouping.

2. The microplankton and mesoplanktonic organisms consist of many larval juvenile forms (especially those of crustaceans), fish eggs, protozoans and appendicularians. The size of this group varies from 0.05 and 0.9 mm. It is a mixture of both phytoplankton and zooplankton.

3. The macroplankton is composed of crustaceans, fish, larvae, chaetognaths, ctenophores, thaliaceans, etc. These forms are at least 1 mm in length and ordinarily do not include any phytoplankton (Corner, 1978).

The chief components of the marine phytoplankton are found within the algal groups. Included with this phytoplankton are diatoms, dinoflagellates and coccolithophorids, silico flagellates, and cryptomonads.

The diatoms range upward in size from two μ (one μ = 1/1000 mm). Dinoflagellates are motile organisms with two flagellae: one drives

the organism forward, the other is responsible for the characteristic rotating motion. Other microflagellate representatives of the phytoplankton undoubtedly play a significant role in the primary production capacity of oceans and inland waters.

Zooplankton are divided into two groups: temporary plankton consisting of planktonic eggs and larvae of members of the benthos and nekton; permanent plankton consisting of all those animals that complete their life cycles in a floating state.

Crustaceans are the most important members of the zooplankton and their migrations in the ocean vary with the stage in their life cycle, the season of the year, latitude, hydrographic structure, and metereological conditions. Currents which flow near continents are important to planktonic production in any given area.

The primary role of phytoplankton is that of serving as food for zooplanktonic forms. Zooplankton, in turn, is used directly as food by fish or mammals. Some serves as food for human consumption.

All marine organisms have been exposed repeatedly to petroleum from submarine seeps, accidental spillage resulting from off-shore production, and transport of crude oil.

Plankton is particularly affected by this contamination because of their possession of soft, permeable outer membranes. They also may absorb significant amounts of dissolved organic matter directly from the water (Cushing & Walsh, 1976). Oil spillage has a direct effect upon plankton.

Crude oil contains a complex mixture of compounds which enter the aquatic environment and gradually move into the water column.

Cyclo-alkanes (naphthenes) particularly cyclopentane derivatives with substituted rings, are particularly toxic. The alkene representatives which have been found in both phytoplankton and zooplankton are generally absent from crude oil. Some hydrocarbons found in the crude oil are shown in Figure 4.

Hydrocarbons dispersed through the water column in the water solution form droplets and compounds which may reach the sea bottom, particularly if they are weighted down with mineral particles. On the sea floor, oil persists for long periods and can continue to damage the bottom life. This sediment may be spread over great distances under the influence of tidal movements and wave action and thus affect areas not immediately polluted by the oil spill.

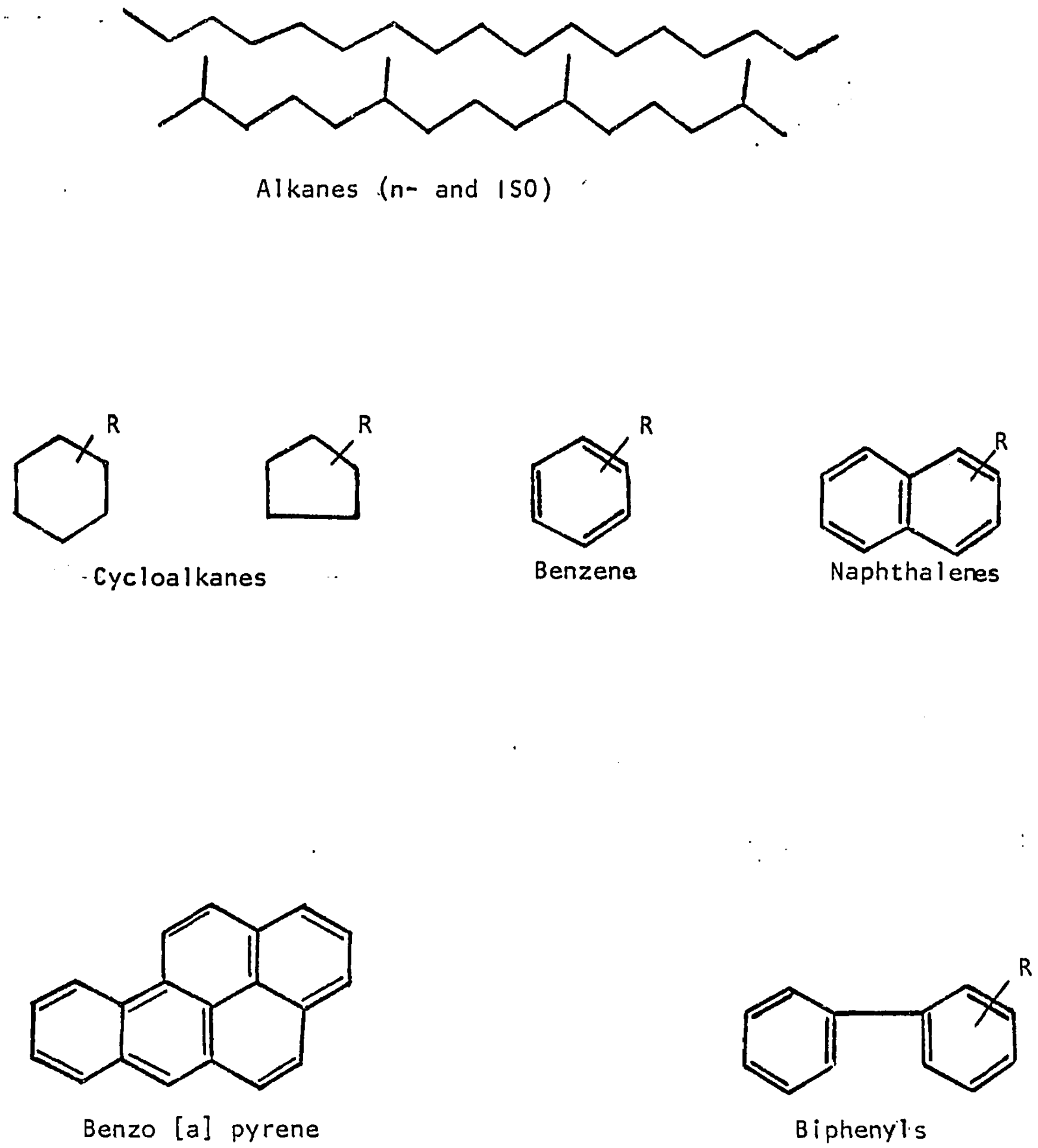


Figure 4. Structural Formulae of Various Hydrocarbons Found in Crude Oil. R - represents several types of alkyl substituents.

Source: Corner, 1978.

CHAPTER II

REVIEW OF LITERATURE

Because Saudi Arabia is one of the major oil producing countries of the world and because much of the oil is transported through the Arabian Gulf, the Gulf was a natural location in which to study the effects of oil pollution upon marine plankton.

As a general introduction to the geography, land forms, economics, and history of Saudi Arabia, the book from Stacey International (1977), The Kingdom of Saudi Arabia, was consulted. Information on the Arabian Gulf itself, including its history, geography, economy, and general background was obtained from two sources: Hay (1959), The Persian Gulf States; and The Gulf Implications of British Withdrawal, from the Center for Strategic and International Studies at Georgetown University (Anonymous, 1969).

The study of the effect of oil on the Arabian Gulf has been reviewed in a number of studies and reports. Most of the more important publications were consulted in detail, but it was impossible to examine the many voluminous reports which exist.

The background of the production and transportation as well as the highlights of the long history of Arabian oil production together with the changing economy and customs of the Arabia world, were reviewed in detail in an Aramco handbook published in 1968.

A whole series of reports concerned with the extent and importance of oil spills was available both from Aramco and from the Ministry of

Petroleum and Mineral Resources of Saudi Arabia. Individual reports have been published by Walgate (1978), Oostdam (1978), Lehr and Belen (1983) and Lehr (1983).

Using this above information as background material, the main portion of this literature review will concentrate on the principle subject of this study; that is, the effect of oil pollution on marine organisms. Smith (1972) authored a review on the effect of oil pollution on general marine ecology; he considered some individual orgamisms. In 1976, Giam published an important paper on the effects of hydrocarbons on phytoplankton. Since this study was largely concerned with the phytoplankton, the publication proved to be very important in this present investigation. The study was basically an investigation of long term biological effects on organisms. This was important in the understanding of our results.

As the problems of oil spillage and their effect upon marine life at all taxonomic levels gained in importance, many studies were undertaken and published. Malins (1977) published a significant book detailing the effects of petroleum pollution on the organisms of the arctic and subarctic regions. His well-documented report on biological effects proved valuable in areas far removed from his region of emphasis. Handa (1977) studied the effect of pollution on marine plants and Lannergren (1978) studied the effect of oil spills on the plankton of the North Sea.

A study published by Corner (1978) was an extremely valuable source of information on the effects of hydrocarbon pollution on marine plankton. Grassle et al. (1979) published information on the effects of

crude oil on marine organisms and on the general ecology of an area. The American Petroleum Institute (1980) and Karydis (1981) both wrote extensive accounts on the effect of hydrocarbons on marine organisms.

In order to obtain a more nearly complete background for the identification and ecology of the various marine organisms concerned in this study, a number of books and treatises were consulted.

Palmer (1962) published on the subject of algae in water supplies, while Wimpenny (1966) wrote a book, The Plankton of the Sea. Cholnoky (1968) published, in German, an impressive book on the ecology of diatoms. Zeitzschel, in cooperation with Gerlach (1973), did an extensive study on the biology of the Indian Ocean, the body of water of which the Arabian Gulf is a portion. Another study on the planktonic life of the Arabian Gulf was done by Price (1979) on shrimp larvae.

As most of the present study was concerned with diatoms, some recent handbooks on diatoms and algae in general were consulted. These included Hansmann (1973), Bold and Michael (1978), Vinyard (1979). This latter publication on the Diatoms of North America was especially valuable for determining the genera which were encountered.

The general ecology of the sea and the biological processes involved were well explored by Cushing and Walsh (1976) in a book entitled The Ecology of the Sea, Two additional important publications include one by Basson et al. (1977) and another by Lipscombe (1982). Both were concerned with the Arabian Gulf. The latter book is well illustrated and is a landmark study of the ecology of the Arabian Gulf.

CHAPTER III

METHODS OF STUDY

The site chosen for this study is located approximately 76 miles (116 kilometers) south of Dammam in an area called Quaryyah (52° 54′ north and 50° 5′ east). (See Figure 5.) Two study stations were chosen. One of these stations was highly polluted, the other relatively clean. Even though these two stations were in close proximity, there were great differences between them. The differences were attributed to the prevailing winds and the local topography.

The polluted station (station #1) was very easily recognized due to the large amount of debris scattered over the shore area. Most conspicuous were the oil and large masses of tar which had been washed ashore and had covered all debris and sand with a sticky mass. The sea bottom was also covered with oil and tar balls were common in the water. Many dead animals were found above the tide line. By contrast, the clean station (station #2) was relatively clean. The white sand and shore bottom of the shallow areas of the sea were quite free of oil.

Sampling at each station was carried out at approximately weekly intervals from the month of May until August of 1983. In all, six or seven samples were taken at each station.

For these samples, a plankton net of #25 mesh with openings 0.85 mm in diameter was used. A homeopathic vial of 34 ml capacity was attached to the lower opening of the net. For each sample, 50 liters of sea water were poured through the net and the plankton was collected

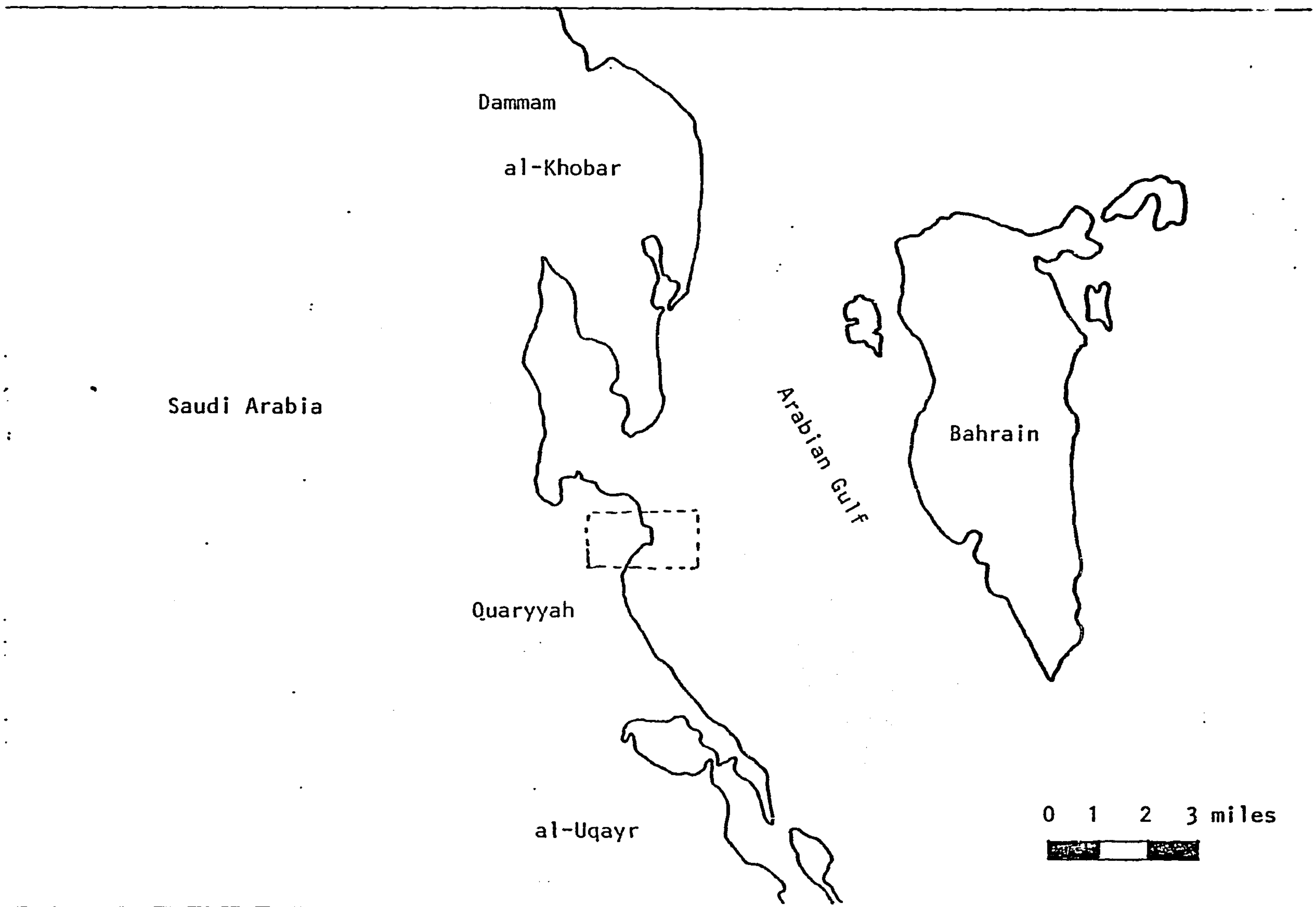


Figure 5. Map Showing Location of Study Area "Quaryyah" in Saudi Arabia

in the vial. Samples were preserved with three to five drops of the preservative FPA (formalin-proprionic acid-alcohol). This agent effectively killed and preserved the plankton organisms after they were collected. The samples were then stored at a temperature of 40° F (5° C) until they were examined.

For the identification of the planktonic diatoms, a drop of the sample was spread on a microscope slide. Several different keys were used for this identification. Most important of these were the studies of Vinyard (1979), Palmer (1962), and Wimpenny (1966). All identifications were checked by Dr. C. J. Goodnight.

For the quantitative analysis of the diatoms in the phytoplankton in the sample, four individual counts of the contents of each sample vial were made. After the contents of the vial had been thoroughly agitated, one ml of the sample was removed and placed in a Sedgewick-Rafter Chamber. This counting chamber is 50 mm long, 20 mm wide and 1 mm deep. The total volume is 1 ml. The coverglass is 25 mm wide by 60 mm long and is placed over the counting cell. Sixteen (16) strips (the entire slide) were examined for each of the several slide preparations.

The results were calculated for each sample and reported as the number of individuals per milliliter.

The four cell counts for each vial were averaged and then multiplied by 34 to obtain the number of individuals in the vial. This calculation gave an estimate of the number of each species within the sample. This then gave the number of individuals occurring in 50 liters of sea water, the unit which was being used for comparison of the

polluted and unpolluted samples.

CHAPTER IV

RESULTS AND DISCUSSION

The number of known species of diatoms in the world has been variously estimated, with some 100,000 having been described (Vinyard, 1979). It has also been noted that only 10,000 of these described species are actually valid species (Grullard & Kilham, 1977).

In size, diatoms range from 3 µ to 4 u in length. Diatoms are numerous and varied in oceanic waters. Because the diatoms are so varied in structure and habit and because each species has rather specific requirements, they are excellent indicators of the quality of the environment. For this reason, it was conceived that a profitable assessment of the quality of an aquatic environment would be to compare the diatom population of two coastal areas. Both areas studied were in shallow localities, one was relatively free of oil, the other was highly polluted.

The diatoms were identified to genus in this study. The identification to genus is relatively easy, but identification to species is extremely difficult due to the large number of closely related species whose differences may be physiological rather than structural.

While both study stations had approximately the same number of diatom genera, the relative numbers of different forms were very noticeably different. The results are reported in Table 4 for diatoms in polluted and in Table 5 for diatoms in clean area. Members of the genus Amphora are known to require relatively clean waters and were relatively

Table 4

Diatoms in Polluted Area for Each Sample of 34 ml

Sample Number	1	2	4	6	8	10	13	Avg. in samples taken from 50 L
Amphiprora							136	19.42
Amphora sp. 1					42.5			6.07
Amphora sp. 2		153	144.5		546	892.5		248
Asterionella	1105	1895.5	382.5	6171	731	637.5	5678	2371.5
Biddilphia						59.5		8.5
Bacillaria	34							4.85
Chaetoceros	391	68						65.57
Cymbella				127.5	289	93.5	348.5	122.64
Diploneis					51			7.28
Fragilaria					178.5	17		27.92
Gryosigma			42.5	59.5	229.5	102	144.5	82.57
Licmophora					34			4.85
Navicula	459	280.5	739.5	1020	4522	739.5	2091	1407.35
Nitzschia	144.5			136		297.5		82.57
Thalassionema	119		34	680	225.5	512.5	790.5	320.35
*Anabena	348.5	2210	127.5	637.5	637.5	238	525.5	674.92
*Chroococcus	246.5	1249.5	646	909.5	688.5	42.5	238	574.35

*Though these are not diatoms, these blue-green algae are excellent indicators of polluted conditions.

Table 5

Diatoms in Clean Area for Each Sample per 34 ml

Sample Number	3	5	7	9	11	12	Avg. in Samples taken from 50 L
Amphiprora	161.5	59.5	85	34		42.5	63.75
Amphora	1725.5	1351.5	1938	1572.5	289	841.5	1284.66
Asterionella	2677.5	603.5	416.5	212.5			651.66
Chaetoceros	170	153		314.5	178.5		136
Cocconeis		42.5	85				21.25
Cymatopheura	136	59.5	34				38.25
Cymbella	544	425	255	136	34	127.5	253.58
Fragilaria	469.5	85	102	34			115.08
Gryosigma	294	280.5	289	102	93.5	425	247.33
Navicula	2456.5	2439.5	1538.5	1190	297.5	561	1413.83
Nitzschia	297.5	255	280.5	119	76.5	297.5	221
Thalassionema	739.5	824.5	561	612	136	195.5	511.41
*Anabena	1377	493	1487.5	178.5	85	238	643.08
*Chroococcus	459		493	110.5		59.5	187

*Though these are not diatoms, these blue-green algae are indicators of polluted conditions.

more numerous in the clean areas than in the polluted ones. On the other hand, members of the genus Asterionella, which are abundant everywhere, were able to withstand the effects of pollution; this becomes evident when the average numbers in the two tables are compared: 2371/50 liters in the polluted areas as compared with 652/50 liters in the clean areas.

The genus Navicula contains many species, some of which are able to stand impacted waters, others which prefer clean waters. They were present in approximately equal numbers in both habitats.

While members of many genera were too few in number for generalizations as to their importance, they were present in notably larger numbers in the oil polluted stations than in the clean ones. This indicates that those forms that are able to live in impacted areas often multiply in great numbers, possibly, in many cases, due to the disappearance of other forms that may feed on them and in that way normally limit their numbers.

Blue-green algae are in a different grouping of algae than are the diatoms: however, because they are so able to stand poor conditions, some are used extensively as indicators. For this reason, it was interesting to note the numbers of two of the common genera, Anabena and Chroococcus. Members of the genus Anabena were found relatively abundantly in both areas; however, members of the genus Chroococcus were found quite abundantly in the polluted areas, and only a few specimens were found in the clean areas.

Pollution detection, based on the presence or numbers of biological materials, is better than chemical or physical factors used alone

(Stein & Denison, 1967; Goodnight, 1973). Since diatoms are extremely varied as to species and are abundant in all oceanic areas, they represent an excellent group of organisms to relate to disturbed areas.

Physical-Chemical Analysis

The physical conditions in all stations during the period of collecting the samples are shown in the Appendix (Tables 6-12). Data is taken from Aramco and the Meterology and Environmental Protection Administration (MEPA). The chemical parameters were tested by the author and Dr. Goodnight during the period of study in May 1983. The test apparatus was the portable laboratory manufactured by Hach (DREL/1c with colorimeter).

A brief summary of the results of these tests is as follows:

1. In both areas, the chloride content was 446 ppm.

2. Only very minor variations occurred in the pH values between the two stations. The waters tend to be highly alkaline, with a pH reading of 8.2.

3. No potassium (K) was found at either station. Also, no free acid was noted, nor was there any measurable iron content.

In the area of the open seas when oil spills occur, the natural wave and wind action are helpful in dissipating the oil, breaking up the oil slicks, and thus reducing the toxic effects. This breaking up of the oilslick into smaller units also reduces the rate of transport of the spilled oil to other locations, promotes its degradation, and mitigates the effects upon marine birds. In near shore and coastal areas, the potential for ecological damage from oil spills is far

greater, however, present data appears to indicate that the spills of crude oil have no serious long term effects.

The analysis needed for the actual prediction of possible deleterious effects of oil spills is difficult and must be designed to include many different factors. Among these important factors are such details as the volume and type of oil spilled, the weather and sea conditions, the season of the year, and the unique characteristics of the body of water so affected.

The oil rich states surrounding the Arabian Gulf are discovering the unfortunate concommitants of economic growth, including pollution. Saudi Arabia, Bahrain, Iran, Qatar, Kuwait, Oman and the United Arab Emirates met in Kuwait under the aegis of the United Nations Environmental Program (UNEP) to determine what could best be done to clean up the Arabian Gulf and its coastline. Two environmental protection treaties were developed. The first treaty pledges the states "to prevent, abate, and combat pollution" and the second to cooperate in case of an emergency (for example, a shipping or well accident).

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

Conclusion

A study of the Arabian Gulf was undertaken to study the effects of pollution upon an area that is impacted with oil spills. Other well-documented studies have shown that oil spills have a profound and extremely detrimental impact upon the biota by changing the composition and relative abundance of the different species.

To investigate the effect of oil pollution upon planktonic organisms, two areas, both located in intertidal zones, were investigated. One area was relatively clean; the other highly impacted with oil spills. Because of the diversity of planktonic diatoms, they were selected as the index organisms. Both areas proved to have a diversity of diatoms, but the composition of the fauna was different in the two areas.

Members of the genus Amphora were more numerous in the clean water area, confirming the fact that they require relatively clean waters. On the other hand, members of the genus Asterionella, a group that can endure polluted conditions, was much more abundant in the area impacted with oil.

Blue-green algae (not diatoms) were also more abundant in polluted waters. This is characteristic of this group of plants.

These algae (diatoms and blue-green) together are useful organisms for indicating the condition of aquatic environments.

Recommendations

Information regarding the biology of the Arabian Gulf is, at this time, insufficient for the complete understanding of the complex relationships that exist among the numerous plants and animals that compose its biota. For this reason, it is difficult to make conclusions regarding the effect of oil spillages. Therefore, many more studies need to be done on the organisms, their life histories, and their interrelationships. Aramco scientists have done several studies, the most important of which is The Biotypes of the Western Arabian Gulf, by Basson et al. (1977).

A limited amount of research has been done on the biota of the Arabian Gulf by the Institute of Ecology at UPM, Aramco, and MEPA. It is essential that more studies be done in order properly to devise methods and laws for controlling pollution. All of those countries bordering on the Gulf need to be involved in this effort. The present unsettled situations of this area will aggravate this problem and also postpone reasonable solutions.

APPENDICES

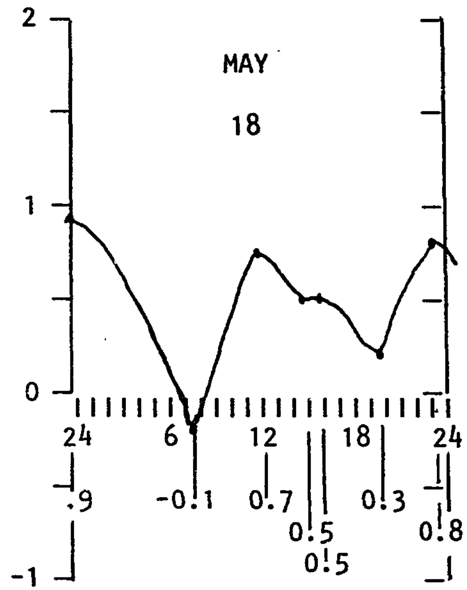
Table 6

Time of High/Low Tide, Date and Temperature
Quaryyah, Saudi Arabia, May 18, 1983

Day	Hours 0/12	Hours 1/13	Hours 2/14	Hours 3/15	Hours 4/16	Hours 5/17	Hours 6/18	Hours 7/19	Hours 8/20	Hours 9/21	Hours 10/22	Hours 11/23
18	0.8	0.7	0.5	0.4	0.4	0.3	0.1	- 1	-0.1	0.1	0.4	0.5
W	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.3	0.3	0.4	0.6	0.8

Wednesday

Time h. m.	Height ft.	Height m.
18/0737	-0.1	-0.0
1234	0.7	0.2
1514	0.5	0.2
1556	0.5	0.2
1944	0.3	0.1
2345	0.8	0.3



Time Sample Taken

6:00 P.M.

Temperature 41.6 - 25.5 C°

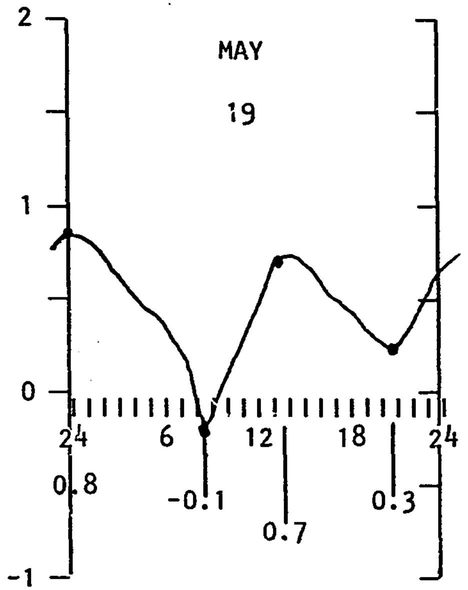
Table 7

Time of High/Low Tide, Date and Temperature
Quaryyah, Saudi Arabia, May 19, 1983

Day	Hours 0/12	Hours 1/13	Hours 2/14	Hours 3/15	Hours 4/16	Hours 5/17	Hours 6/18	Hours 7/19	Hours 8/20	Hours 9/21	Hours 10/22	Hours 11/23
19	0.8	0.8	0.6	0.5	0.4	0.4	0.3	0.1	-0.0	-0.0	0.1	0.4
Th	0.5	0.6	0.7	0.6	0.6	0.6	0.5	0.4	0.3	0.3	0.4	0.6

Thursday

Time h m.	Height ft.	Height m.
19/0829	-0.1	-0.1
1347	0.7	0.2
2040	0.3	0.1



Time Sample Taken

12:00 P.M.

Temperature 40.7 - 26.5 C°

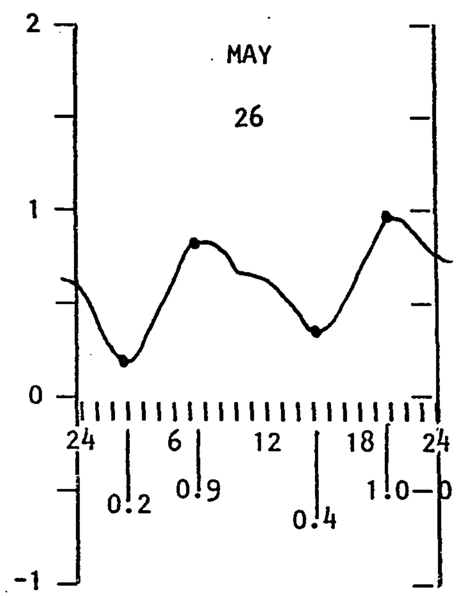
Table 8

Time of High/Low Tide, Date and Temperature
Quaryyah, Saudi Arabia, May 26, 1983

Day	Hours 0/12	Hours 1/13	Hours 2/14	Hours 3/15	Hours 4/16	Hours 5/17	Hours 6/18	Hours 7/19	Hours 8/20	Hours 9/21	Hours 10/22	Hours 11/23
26	0.7	0.5	0.3	0.2	0.3	0.5	0.8	0.9	0.9	0.8	0.8	0.8
Th	0.8	0.7	0.5	0.4	0.4	0.6	0.8	1.0	1.0	0.9	0.8	0.8

Thursday

Time h. m.	Height ft.	m.
26/0256	0.2	0.1
0734	1.0	0.3
1513	0.4	0.1
1948	1.0	0.3



Time Samples Taken

11:00 A.M.

12:00 P.M.

Temperature 38.9 - 24.5 C°

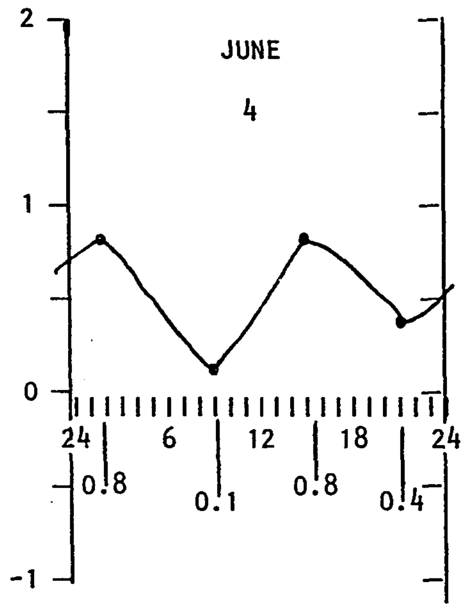
Table 9

Time of High/Low Tide, Date and Temperature
Quaryyah, Saudi Arabia, June 4, 1983

Day	Hours 0/12	Hours 1/13	Hours 2/14	Hours 3/15	Hours 4/16	Hours 5/17	Hours 6/18	Hours 7/19	Hours 8/20	Hours 9/21	Hours 10/22	Hours 11/23
4	0.8	0.8	0.8	0.7	0.7	0.6	0.5	0.3	0.2	0.1	0.2	0.3
Sa	0.5	0.6	0.7	0.8	0.8	0.8	0.7	0.6	0.5	0.4	0.5	0.6

Saturday

Time	Height	
h. m.	ft.	m.
4/0144	0.8	0.2
0910	0.1	0.0
1526	0.8	0.3
2115	0.4	0.1



Time Samples Taken

12:00 P.M.

1:00 P.M.

Temperature 43.4 - 27.2 C°

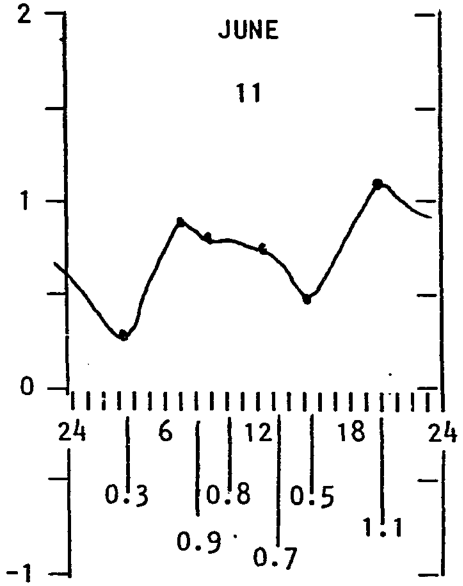
Table 10

Time of High/Low Tide, Date and Temperature
Quaryyah, Saudi Arabia, June 11, 1983

Day	Hours 0/12	Hours 1/13	Hours 2/14	Hours 3/15	Hours 4/16	Hours 5/17	Hours 6/18	Hours 7/19	Hours 8/20	Hours 9/21	Hours 10/22	Hours 11/23
11	0.7	0.6	0.4	0.3	0.3	0.5	0.7	0.8	0.9	0.9	0.8	0.7
Sa	0.7	0.7	0.6	0.5	0.5	0.7	0.9	1.1	1.1	1.1	0.9	0.8

Saturday

Time h.m.	Height ft.	Height m.
11/0324	0.2	0.1
0811	0.9	0.3
1004	0.8	0.2
1308	0.7	0.2
1527	0.5	0.2
1958	1.1	0.3



Time Samples Taken

5:00 P.M.
6:00 P.M.

Temperature 45.0 - 28.0 C°

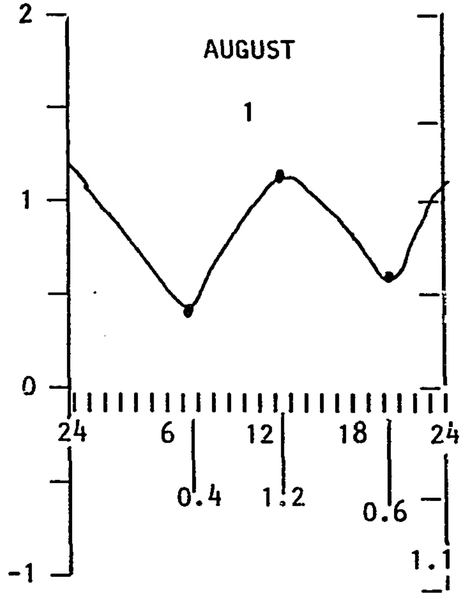
Table 10

Time of High/Low Tide, Date and Temperature
Quaryyah, Saudi Arabia, August 1, 1983

Day	Hours 0/12	Hours 1/13	Hours 2/14	Hours 3/15	Hours 4/16	Hours 5/17	Hours 6/18	Hours 7/19	Hours 8/20	Hours 9/21	Hours 10/22	Hours 11/23
1	1.2	1.2	1.1	0.9	0.8	0.7	0.6	0.4	0.4	0.5	0.7	1.0
M	1.1	1.1	1.1	1.1	1.0	0.9	0.8	017	0.6	0.6	0.8	1.0

Monday

Time h.m.	Height ft.	m.
1/0753	0.4	0.1
1323	1.2	0.4
2017	0.6	0.2



Time Samples Taken

9:00 A.M.

10:00 A.M.

Temperature 39.2 - 28.3

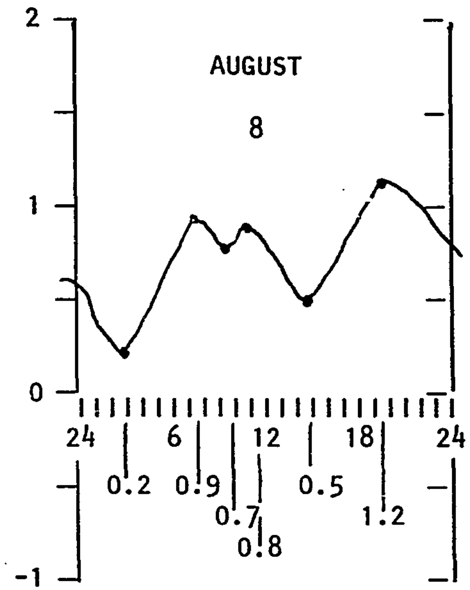
Table 12

Time of High/Low Tide, Date and Temperature
Quaryyah, Saudi Arabia, August 8, 1983

Day	Hours 0/12	Hours 1/13	Hours 2/14	Hours 3/15	Hours 4/16	Hours 5/17	Hours 6/18	Hours 7/19	Hours 8/20	Hours 9/21	Hours 10/22	Hours 11/23
8	0.6	0.4	0.2	0.2	0.3	0.5	0.7	0.8	0.9	0.8	0.7	0.8
M	0.8	0.7	0.6	0.5	0.7	0.9	1.1	1.2	1.2	1.0	0.9	0.9

Monday

Time h.m.	Height ft.	Height m.
8/0247	0.2	0.0
0735	0.9	0.3
0958	0.7	0.2
1127	0.8	0.2
1441	0.5	0.2
1923	1.2	0.4



Time Samples Taken

6:00 P.M.

7:00 P.M.

Temperature 41.5 - 15.8 C°

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