MARINE PLANTS OF THE ARABIAN GULF AND EFFECTS OF OIL POLLUTION

P.G. JACOB AND S. AL-MUZAINI
Environmental Sciences Department,
Environmental and Earth Sciences Division, Kuwait Institute for Scientific Research,
P.O. Box 24885, Safat - 13109, Kuwait

ABSTRACT

The primary producers in the Arabian Gulf include the macroalgae, phytoplankton, mangroves and intertidal vegetation. Their study is essential to understand the impact of oil pollution; however, few such studies have been done in the Arabian Gulf. A total number of 1485 species of primary producers are reported from this region. Important oceanographic features of the Arabian Gulf influencing species diversity, standing stock, seasonal and spatial variations are discussed. The effects of oil pollution from spills in the Arabian Gulf from the start of large-scale commercial extraction 60 years ago are also discussed.

Keywords: Marine plants, Arabian Gulf, oil pollution.

INTRODUCTION

Studies on the primary producers of the Arabian Gulf are essential for clarifying and understanding many phenomena in this area. Although, there have been several large taxonomic expeditions in the region but most of them focussed on marine animals. The present communication provide the synthesis of available information on the primary producers of the Arabian Gulf and effects of oil pollution in the Gulf.

General features of the Arabian Gulf

The Arabian Gulf, which lies within the region delineated by 24-30°N and 48-56°E, is a shallow basin with an average depth of 35 m (Fig. 1). The volume of water in this area is about 7800 km³ (Reynolds, 1993). The climate in this region is affected by extra tropical weather systems.

The hydrographic conditions in the Arabian Gulf were studied by different investigators (Brewer and Dyrssen, 1985). Generally, the temperature of seawater in the different seasons range from 14°C to 35°C with an increase in the southward direction. The salinity increases gradually from southern to northern parts of the region. The higher salinity in the Gulf is due to high evaporation rate. The hydrographic conditions in this region depend, generally, on the water
balance in the basin, which is affected by climatic conditions and the current system. Evaporation rate of the Arabian Gulf is estimated to be 350 km$^3$/year while precipitation and run-off are 24 and 5 km$^3$/year. In the strait of Hormuz, water inflow is 2696 km$^3$/year while outflow is estimated to be 2375 km$^3$/year (Reynolds, 1993). The flushing time of water, which must be partially controlled by exchange in the Strait of Hormuz is calculated as being 3-5 years.

The river input mainly through the Shatt Al-Arab, gives the Arabian Gulf considerable fresh water influx at the northwest end. However, the high loss of water through evaporation is not compensated by the river inflow, or by precipitation. Salinities are, therefore, abnormally high, reaching 38.5-41%, or up to 70% at the head of such inlets as the Gulf of Salwah, and even 100% or more in shallow lagoons (Basson, Burchard, Hardy and Price, 1977).

---

Fig. 1. Main topographic features of the Arabian Gulf.
Factors affecting primary productivity in the Arabian Gulf

The surface layers of the Arabian Gulf tend to be mixed by the predominant northwest winds (the 'Shamal'). As a result of this circulation, the Gulf waters are well oxygenated down to the bottom. No minimum oxygen layer exists in this shallow Gulf. In a study covering most of the Arabian Gulf, Dorgahm, Muf-tah and El-Deeb (1987) reported the dissolved oxygen in the surface water across the whole area from 4.21 - 5.32 ml l\(^{-1}\). In the water column up to 40 m depth the oxygen concentrations were generally more than 4 ml l\(^{-1}\).

According to Halim (1984), the offshore waters of the Gulf are higher in nutrient content. Off Kuwait and in the vicinity of the Shatt Al-Arab, the waters are considerably richer in silicate than that off Qatar and the coast of the United Arab Emirates. The northeast Gulf appears to be poorer in both silicates and phosphates. Dorgahm, Muf-tah and El-Deeb (1987); El-Gindy and Dorgahm (1992) reported that along the water column, nitrate at most stations showed a gradual increase in the upper 10 m. The nitrate/phosphate ratio in the northwestern Gulf was significantly low. From the investigations, it is clear that there is a disturbance in the distribution of the nutrients along the water depth in the northwestern part of the Arabian Gulf, possibly related to the northwesterly wind system that greatly affects the oceanography of the Arabian Gulf.

In another study, nutrients in the Arabian Gulf and the Gulf of Oman were measured. Statistical analysis of the results clearly showed three distinct types of seawater in the area (El-Samra, 1988), the proper water of the Arabian Gulf, the seawater of the Gulf of Oman, and a mixed water, with intermediate values of nutrients.

The inflow of nutrient-rich (phosphate, nitrate and silicate) water from the Gulf of Oman into the Arabian Gulf could reach the northeastern coast of the UAE and approach the north coast of Qatar, as indicated by nutrient isolines. The calculated P:N:Si values indicate a nitrogen deficiency in the area. Hence, productivity within the Arabian Gulf is limited by the nitrogenous nutrient, and not silicate (El-Samra, 1988).

Primary productivity in the Arabian Gulf

All types of chlorophyll-bearing plants recorded in the Arabian Gulf under different groups make varying contributions to the primary productivity of this habitat, depending on their abundance.

The Arabian Gulf is a coastal sea possessing some of the world's most productive plant systems. In the Arabian Gulf, a number of studies have been made to estimate primary productivity from total counts of phytoplankton cells, chlorophyll analyses, light-and-dark bottle techniques and by the radioactive \(^{14}\)C tracer techniques (Jacob and Al-Muzaini, 1990; Sheppard, Price and Roberts,
Most of these studies are confined to specific locations and do not cover the whole year. The primary productivity of the northwestern Arabian Gulf has been estimated to be about 161 mg C m$^{-3}$ day$^{-1}$. This was estimated by the ordinary light dark bottle oxygen method using surface water samples. Seasonal variations in the quality and quantity of phytoplankton in the Garma marshes of Iraq were studied during August 1980 to October 1981 (Al-Saboonchi, Mohammad and Barak, 1982). A total of 63 genera belonging to five major groups of phytoplankton were identified. The highest phytoplankton growth was observed in spring. Primary productivity of the coastal waters of Qatar was studied using $^{14}$C technique. Productivity of phytoplankton of the coastal waters of Kuwait were also studied from cell counts and chlorophyll content (Jacob, Zarba and Anderlini, 1980). Surface primary productivity computed from chlorophyll a ranged from 39 to 2727 mg C/m$^3$. Standing stock of phytoplankton increased during the latter part of the year, from September to December. Along the beaches of the southeastern coast of Kuwait, chlorophyll pigments were high during the warmer months (April to July) of 1979 to 1980. Primary productivity values computed from chlorophyll a ranged from 60 to 600 mg C/m$^3$. Standing stock of phytoplankton (mg C/m$^3$) ranged from 164 to 602 (Jacob, Zarba and Mohammad, 1982).

From a study on primary productivity along the coastal waters of Kuwait conducted during 1983-84 using $^{14}$C tracer technique, it was found that the primary productivity ranged from 0.2 to 1.6 mg C m$^{-3}$ h$^{-1}$ (Literathy Shublaq and Al-Hassan, 1988).

**Primary producers of the Arabian Gulf**

The bacteria and fungi that live in the sea also form part of the marine flora. All the major classes of fungi are represented in the sea. However, little work has been done on these groups and on their role in primary production in the Arabian Gulf (Shamshoon, Zairia, Abdulritha and Yacoub, 1990). Therefore, these two groups are not covered in the present study.

Although a number of classification schemes are followed by different authors, primary producers in the Arabian Gulf are grouped into seven major divisions, in the present study (Table I).

**Cyanophyta** (Blue-green algae) mark the littoral fringe on Arabian Gulf shores, forming a 'black zone' on rocky shores or a blue-green algal mat on mud flats.

Dorgham, Mufah and El-Deeb (1987) reported that the blue-green algae *Anabaena* sp. and *Trichodesmium* sp. were the most abundant among phytoplankton species in both Saudi and Qatari waters. These two algae may contribute to the slightly higher nitrate-phosphate ratio in the latter two regions as a result of nitrogen fixation, compared to Kuwaiti waters, which was depleted
Table 1 – Marine plants recorded in the Arabian Gulf.

<table>
<thead>
<tr>
<th>Phylum</th>
<th>No. of species recorded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cynophyta</td>
<td>87</td>
</tr>
<tr>
<td>Chrysophyta</td>
<td>888</td>
</tr>
<tr>
<td>Pyrrhophyta</td>
<td>331</td>
</tr>
<tr>
<td>Chlorophyta</td>
<td>51</td>
</tr>
<tr>
<td>Phaeophyta</td>
<td>38</td>
</tr>
<tr>
<td>Rhodophyta</td>
<td>60</td>
</tr>
<tr>
<td>Anthophyta</td>
<td>30</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1485</strong></td>
</tr>
</tbody>
</table>

of such algae. El-Samra, Muftah and Dorough (1986) detected algal nitrogen fixation in the Arabian Gulf waters in autumn, which may indicate the importance of this source in the total nitrogen budget of the Gulf. They estimated the contribution of nitrogen fixation to be 0.4 - 6.3 kg N km\(^{-2}\) day\(^{-1}\). Basson, Burnchard, Hardy and Price (1977) and Al-Saadi and Hadi (1987), have also recorded blue-green algae in the Arabian Gulf.

*Phyrrophyta* (Flagellates) is composed mainly of six classes in the Arabian Gulf.

*Dinophyceae* (Dinoflagellates) includes a total of 211 species. Class *Chlorophyceae* (Planktonic Green Algae) includes a total of 82 species. They are mostly from the northwestern part where fresh water from the Shatt Al-Arab comes in. Class *Euglenophyceae* (Euglenoid Flagellates) contains seven species which have been recorded from the estuarine waters of the northwestern Arabian Gulf (Al-Saadi and Hadi, 1987). Fifteen species silicoflagellates belonging to the class *Chrysophyceae* have been recorded from the Arabian Gulf, mostly from the northwestern part. Class *Haptophyceae* (Coccolithophores) includes the colonial form *Phaeocystis pouchetii* (Hariot) Lagerth which often forms conspicuous greenish-brown globules in the coastal waters of the northern Arabian Gulf, has a motile flagellate phase with cell characteristics typical of this class (Jacob and Zarba, 1981). Some species like *Vaucheria pilobolides* Thuret of this class are included in a separate group named as Xanthophyceae by Al-Hassan and Jones because of the presence of pigments like fucoxanthin (Al-Hassan and Jones, 1989). A total of 15 species of Cooccolithophores have been recorded in the Arabian Gulf. Only one species in the class *Cryptophyceae* has been recorded in the Arabian Gulf.

*Chlorophyta* (Green algae) are particularly characteristic of the higher eulittoral zone in the Arabian Gulf. *Dunaliella salina* (Dunal) Teodoresco, one of the
algae, is a free-swimming, unicellular, naked biflagellate and microscopic. It is found in highly saline shore pools and salt lakes of the Arabian Gulf coasts where it produces 'blooms' that turn the water brownish-red (Al-Hasan and Sallal, 1985; Jones, 1986). Most of the other species recorded are macrophytes (Nizzamuddin and Gessner, 1970; Basson, 1979a and b).

Phaeophyta (Brown algae) are usually found at the edge of the sublittoral fringe in the Arabian Gulf. Anthophyta of the Arabian Gulf includes a number of flowering plants that can tolerate high salt content in the soil and water. They occur along the shores and shallow waters of Arabian Gulf (Halwagy and Halwagy, 1977 and Nelson-Smith, 1984). These usually form the mangrove and sea-grass communities.

Mangroves and associated intertidal flats and marshes represent one of several critical marine habitats in the Arabian Gulf. Sea-grass beds may be regarded as underwater meadows or pastures, characterized by high biological productivity.

One of the Anthophytes, Salicornia herbacea Linnaeus can be irrigated with highly saline seawater. Experimental culture of Salicornia sp. and mangrove plants (Avicennia sp.) are being done at selected sites along Kuwait's coast by the Food Resources Division of the Kuwait Institute for Scientific Research. Salicornia sp. produces protein-rich fodder apart from oil extraction from the seeds.

Species diversity and standing stock variability among primary producers in the Arabian Gulf

During the present study, a total of 1485 species names of primary producers of the Arabian Gulf have been gathered from published studies (Jacob and Muzaini, 1990). It is hoped that this will form the basis of future species-diversity index estimations in the Arabian Gulf biotopes in the context of pollution monitoring studies.

Macro-algae and Marine Anthophytes: The marine macroalgal and anthophytic flora from the Arabian Gulf are little known.

The first contribution from the Arabian Gulf was made by Endlicher and Diesing (1845), who described four species of brown and two species of red algae. More extensive work was carried out by Borgesen (1939), who described 103 species (22 green, 26 brown, 9 blue-green and 46 red algae). His contribution is based on the 1937 collections of M. Korie and some others. Newton (1955a and b) published two lists, one each from Bahrain and Kuwait, containing 71 species (13 green, 26 brown, 12 blue-green and 20 red algae). Her study was based on collections by others, she did not provide descriptions. These list included some species previously reported by Borgesen (1939) from the Arabian
side of the Gulf. Nizzamuddin and Gessner (1970) described 68 species of marine algae from the eastern side. Basson, Burchard, Hardy and Price (1977) and Basson (1979a and b) conducted taxonomic studies of the marine algae (Chlorophyta, Phaeophyta, Cyanophyta and Rhodophyta), mostly collected over one-year period along the Arabian Gulf coast of Saudi Arabia. He provided descriptions for 84 taxa of marine algae, of which 38 (seven Chlorophyta, five Phaeophyta, 14 Cyanophyta and 12 Rhodophyta) were reported for the first time from the Gulf. The systematic identification included 15 Chlorophyta, 20 Phaeophyta, 16 Cyanophyta and 33 Rhodophyta. Basson (1989) and Basson, Mohammad and Arora (1989) did further studies on the marine macroalgae of the Bahraini coast. Jones (1986) also listed and described marine algae of the seashores of Kuwait. Al-Hasan and Jones (1989) provided a list of 105 species of marine algae of the coasts of Kuwait of which 89 species are new to Kuwait.

Information on the salt-tolerant marine Anthophytes (flowering plants) of the Arabian Gulf, existing in mangroves, intertidal zones or sea-grass beds have also been provided by a number of investigators (Jacob and Al-Muzaini, 1990). In the Arabian Gulf, mangroves occur along the upper intertidal zone in certain embayments. However, they are poorly developed and patchy in distribution, partly because of intensive human use in the past but largely due to present-day coastal infilling. Avicennia marina (Försskal) Vierh. ex Thwait is the most important species of the mangroves in the Gulf. Mangroves are absent from Iraq and Kuwait, perhaps due to climatic effects of latitude. In Iran, there is an estimated 89,000 ha; the largest stand is in the Khoran Straits, and is included within the 82,000 ha Hara Protected Region (IUCN, 1976). In Saudi Arabia, mangroves are limited to a few stands in Tarut Bay and to the South of Abu Ali. Remaining stands of any significance in Bahrain are found at Sanad. Mangroves also occur in the southern parts of the region, with the densest stands fringing the Gulf of Hormuz. Mangroves are also found around Oman, with particularly dense stands at Mahw. The mangroves along the Arabian Gulf coast have now largely been removed presumably for human use. The direct uses of mangroves are numerous, e.g. fuel, construction, fishing, textiles, food, drugs, beverages and household items. By functioning as a critical marine habitat to various animals (e.g., shrimps, fish, birds and mammals) they are of great economic and scientific interest.

Sea-grasses in the Arabian Gulf occur as underwater meadows or pastures, characterized by high biological productivity. Three particularly euryhaline species are represented in the inner Gulf: Halodule uninevis (Försskal), Halophila ovalis and Halophila stipulata. In Oman, additional species such as Syringodium isoetifolium and Cymodocea serrulata are also present. Sea-grass ecosystems represent one of several critical marine habitats and provide food or shelter to more than 500 plant and animal species (Basson, Burchard, Hardy and Price, 1977). In
Saudi Arabia, the approximate locations of some of the major grass beds have been mapped, although the extent and distribution in most countries have not yet been determined.

Conservational status of the sea-grass beds is variable, although acutely threatened in certain areas like the Saudi and Bahraini coasts following coastal dredging and infilling. Sea-grass plays a key role in maintaining the productivity of local fisheries and coastal waters in general. Turtles and Dugong feed directly on the growing plants, as do certain commercial fish, such as Siganus spp. Also associated with sea-grass are many animals that rely on this habitat for larval settlement and growth. These include species of great economic and cultural importance, such as the commercial shrimps and pearl oysters. Basson, Burchard and Price (1977) calculated the approximate dollar value of the Tarut Bay (410 km²) in Saudi Arabia. If sea-grass in the bay were incorporated into food chains, the estimated value of the fish yield would be $8 million. If, instead, the grass were to be converted at the same efficiency (1% overall) into shrimps, the calculated value would be nearly $12 million. On the other hand, if the sea-grass were grazed directly by green turtles at an efficiency of 19%, the turtle yield would be estimated at $46 million. The values of these natural resources are based on 1977 prices, and the calculations are highly approximate and theoretical. However, they demonstrate the considerable value of local biological resources, which, if managed correctly, are renewable.

*Phytoplankton:* Phytoplankters, composed largely of floating microalgae and some sedentary diatoms, are the most important primary producers in the Arabian Gulf, outweighing the macroalgae and marine Anthophytes. Sedentary diatoms attached to sediment particles and other substrata in shallow waters, where sufficient light penetrates, play a significant role in the food web of benthic organisms. Only very limited studies have been done on these sedentary forms (Jacob, Zarba and Anderlini, 1980). Basson and Mohammed (1989) reported on the occurrence of the tube-dwelling diatom Nitzschia martiana (C.A. Agardh) Van Heurck from marine sediments near Ad Dur in Bahrain. This is the first record of any tube-dwelling diatom from the Arabian Gulf.

The published studies on floating microalgae (phytoplankton) are insufficient to give a complete picture of the phytoplankton population in the Arabian Gulf. They deal with either certain groups of phytoplankton or with localized areas (Oshite, 1979; Al-Shihab and Al-Hasan, 1986; Dorgham and Mufthah, 1986 and Habashi, Nageeb and Faraj, 1993). Al-Kaisy (1976) published data on the phytoplankton collected from the Arabian Gulf off Kuwait, Qatar and U.A.E. during December, 1968. There are also some general review reports on the plankton distribution over the whole Gulf area. Most of these studies depend on a small number of stations and do not cover the whole annual cycle (Halim,
1984). The Arabian Gulf phytoplankton are less well known than that of the neighbouring Red Sea. Wood (1963) in his checklist of the Indian Ocean phytoplankton species, reports only two dinoflagellates from the Gulf, although Bohm (1931) recorded 34. Later Al-Kaisi (1976) raised the total to 102. However, according to Halim (1984) the waters of the Arabian Gulf are poorer than those of the Gulf of Oman and the Red Sea, both in biomass and in diversity. On the other hand, Al-Kaisi (1976) reported a considerable richness of phytoplankton in most regions of the Gulf. The list of 1303 phytoplankton species recorded during studies in the Arabian Gulf prove him right.

Among recent studies on the phytoplankton of the Arabian Gulf, those of Al-Saadi and Hadi (1987) are important. Al-Saadi and Hadi (1987) reported 527 species of phytoplankton in the Gulf, dominated by diatoms (79%) followed by dinoflagellates (13%). Data collected during the present review, diatoms (68.3%) dominate the species composition, followed by flagellates (25.5%) and Cyanophytes (6.2%).

Dorgham, Muftah and El-Deeb (1987) conducted a systematic study on the phytoplankton and related physico-chemical parameters during 7-24 November, 1984. The study covered most of the Arabian Gulf. The main objective was to observe the autumn phytoplankton. They found that the investigated area was characterized by a significant diversity of species and low biomass. The maximum number of phytoplankton taxa recorded in the area (223) consisted of 134 species and varieties of diatoms, 86 dinoflagellates, two blue-green algae and one silicoflagellate.

The dominant diatom species in the whole area were *Thalassionema nitzschioides* Hust. Grun., *Thalassaiothrix frauenfeldii* Grun. and *Climacodiun frauenfeldiannum* Grun. In addition to these species, *Chaetoceros* sp. dominated the Saudi and Kuwaiti waters. The dinoflagellates were dominated by *Ceratocorys magnum*, Ornithocercus thurnii (Schm.) Kofold and Skogsberg, *Dinophysis caudata*, *D. caudata* var. *tripos*, Ceratium *masiliense* (Gourret) Jorg and *C. furca* (Ehr.) clap or Lachm. They found that the blue-green algae *Anabaena* sp. and *Trichodesmium* sp. were the most abundant among the phytoplankton species in both Saudi and Qatari waters. These two algae may lead to a slightly higher nitrate-phosphate ratio in the latter two regions as a result of nitrogen fixation, compared to Kuwaiti water, which was depleted of such algae. This may indicate the importance of this source in the total nitrogen budget of the Gulf. El-Samra, Muftah and Dorgham (1986) estimated the contribution by algal nitrogen fixation to be 0.4 - 6.3 kg N km\(^{-2}\) day\(^{-1}\).

Habashi, Nageeb and Faraj (1993) studied the distribution of phytoplankton in the western part of the Arabian Gulf during April - May 1992. Phytoplankton populations collected by vertical hauls were dominated by diatoms which con-
stituted about 59% of the total phytoplankton number, while dinoflagellates and blue-green algae constituted about 40% and 1% respectively. Sixty-five phytoplankton species were identified, 47 diatoms, 16 dinoflagellates and 2 blue-green algae. The highest phytoplankton count (5904 cells/l) and chlorophyll concentration (9.6 mg/m³) were recorded in the Kuwait Bay in the north. Both parameters decreased sharply in the southern stations.

Comparison of the present with previous works on Gulf phytoplankton shows significant variations. A total of 275 phytoplankton taxa were recorded in whole Gulf in December 1968 whereas 116 were recorded in Kuwaiti waters in 1972 (Al-Kaisi, 1976 and Jamal and Pavlov, 1976). Dorgham, Muftah and El-Deeb (1987) recorded 223 taxa, and considered that the genetic and species composition of the phytoplankton population showed significant variations over the past 15 years. In Kuwaiti waters, the number of diatom genera increased, but the overall number of species decreased. On the other hand, the number of dinoflagellate genera and species increased in the Kuwaiti and Qatar regions. The apparent increase in dinoflagellate species listed in the available records throughout the last 60 years may be an indication of the allochthonous origin of some of them. The water circulation in the Gulf supports this assumption, since many species would have been transported into the Gulf from the Arabian Sea and Gulf of Oman. However, it should be stressed that the waters of the Arabian Gulf still have peculiar natural features, so that a variety of species are exclusively Gulf flora.

Oil pollution and marine plants

The Arabian Gulf is best known throughout the world for the production and export of petroleum. The extraction of oil in commercial quantities began over 60 years ago. The vast majority of this oil is carried from loading terminals throughout the length of the Arabian Gulf, predominantly along its western and southern coasts through the Straits of Hormuz.

The major pollution facing the Arabian Gulf is related to the petroleum industry. They include mainly oil spillage from refineries, offshore drilling activities (exploration and production) and oil transport. The area was also subjected to deliberate spilling of oil during the Gulf conflict in 1991. Oil pollution can range from diffuse chronic pollution to large single releases, such as accidental spills. The standing stock of spilled oil is about 160 million tonnes and at a residence time of one year this figure must also represent the annual input (Oostdam, 1980). This suggests that the Arabian Gulf receives 15-20% of the world total of marine oil spillage. Other estimates show that oil pollution in the Arabian Gulf represents over 3% of the total oil-pollution in the world, thereby contributing 47 times the average estimated amount for a marine environment of a similar surface area (Golob and Brus, 1984; Linden, Larsson and Al-Alawi,
Even though oil spills as major as the Nowruz and the Gulf war spills have occurred during the past few years, chronic discharges of oil and its products still contribute the largest quantities. The transportation of oil alone is considered to be responsible for more than 80% of the total pollution (Nelson-Smith, 1972; 1984).

The Arabian Gulf's shallow and highly productive waters and the surrounding region suffered an unprecedented environmental onslaught triggered by Iraq's invasion Kuwait (Readman, Flowler, Villeneuve, Cattini, Oregoni and Mee, 1992). Sinister black oil slicks and poisonous smoke from blazing oil wells combined to create one of the world's largest ecological catastrophes severely affecting the marine environment of the Arabian Gulf. Rough estimates indicate that 12.5 million barrels of Kuwait crude oil was spilled from Mina Abdullah and Mina Al-Ahmadi, some 50 km south of Kuwait City during January-May 1991 (Al-Muzaini, Jacob, Mal-Allah and Al-Hatlan, 1993).

The Arabian Gulf ecosystem seems to be unique (Sheppard, Price and Roberts, 1992). It recovered without any apparent ill-effects from the release of crude oil from the Al-Nowruz oil well during the Iran-Iraq war and the more recent Gulf war. Months later, it was hard to trace the impacts of such large spills on the Gulf's ecology. There might be a number of reasons for such accelerated oil pollution self-purification processes (Khordagui, 1991).

The ecological system has been acquainted with this particular kind of pollution for thousands of years, through natural oil seeps originating in the seabed. Oil leaking into the Gulf through natural seeps over long periods of time seems to have created a blend of microorganisms that are adapted and acclimatized to oil pollution. The presence of such specially resistant strains of microorganisms promotes the hydrocarbon biodegradation process to a large extent in comparison with other places around the world.

The exceptionally high ambient temperature in this area of the Gulf (sometimes reaching 35°C during the summer) accelerates the evaporation of light toxic fractions and some intermediate products of biodegradation and photo-oxidation processes. In addition, high temperatures also lead to a fast rate of biodegradation.

The rate of photo-oxidation also is very high in the Arabian Gulf when compared to other parts of the world (Literathy, Morel, Zorba, Samhan, Al-Bloushi, Al-Hashash, Al-Matrouk, Jacob and Saeed, 1992). This discrepancy was attributed to the rareness of cloud formation, the long duration of daylight, and the shallowness of the eastern coastal waters of the Gulf. At this shallow depth, sunlight is able to penetrate and reach the bottom, causing photo-oxidation of dispersed and precipitated oil on the seabed.
The unique environmental conditions in the Arabian Gulf are very different from those of the Alaska Sound or the North Sea. The information gathered from these regions of the world cannot simply be extrapolated to the Arabian Gulf. Even without doing anything to combat the large oil spills which have occurred during the Gulf war of 1991, the ecosystem of the Arabion Gulf show no marked ill-effects from the catastrophe (Al-Ghadban and Jacob, 1993).

However, the continuous large scale discharges of oil in the long run might damage the physical, chemical and biological nature of the Arabian Gulf, including its marine plants. Oil pollution superimposed upon demanding natural conditions in the Arabian Gulf may lead to serious disturbances of the equilibrium, which in a less stressed system could more readily absorb.

The major impact of oil pollution is not always associated with the acute oil spills that create much public concern, but rather they are associated with the long-term chronic oil contamination of the coastal waters from continuous discharges from harbours, oil terminals, atmospheric fallout and sewage-plant effluents. In the case of oil pollution, the fate of oil (i.e., where it ultimately affects the aquatic ecosystem) and how it is transported will strongly depend on the source, the composition of the polluting oil and the conditions influencing the physical, chemical and biological weathering processes in the aquatic ecosystem.

Some of the effects of oil on the marine ecosystem, including macrophytes and phytoplankton of the world oceans, were discussed by Nelson-Smith (1972). In suspensions of fresh crude oil in seawater, large number of active and apparently healthy flagellates or ciliates clustered around the droplets (Spooner, 1970).

Shailaja (1988) studied the effect of dissolved petroleum hydrocarbons in the environment on phytoplankton biomass, measured as chlorophyll a, near the oil-tanker route in the southern Bay of Bengal. She found that the effect of dissolved petroleum hydrocarbons on phytoplankton biomass varies depending on the nature rather than the quantity of petroleum hydrocarbons present. This is supported by culture studies with unialgal Nitzschia sp. in seawater spiked with the water-soluble petroleum hydrocarbon fraction of light Arabian Crude.

Variation in sensitivity of microalgal species to particular oils or refined products suggests that the initial toxicity of petroleum water-soluble fractions is probably a function of specific molecules, most likely the nitrogen, sulfur and oxygen.

Seaweeds, like most plants but unlike the majority of animals, can suffer damage over a considerable area without losing their capacity to recover. Any ill effects of an oil spill are thus likely to last for a shorter time amongst intertidal seaweeds than animals. Emulsified oil may cling more readily, and seem to

The sea-grasses appear to suffer rather more than most of the algae. Diaz-Pifferer (1962) referred to a continued degeneration of *Thalassia* sp. beds several months after the spill in Puerto Rico. Sheltered tropical shores often merge into mangrove swamps, where the network of exposed roots is important in obtaining oxygen for the buried portion of the system, but also acts as a trap for drifting oil. Diaz-Pifferer (1962) and Rutzler and Sterrer (1970) described considerable damage to *Rhizophora* sp. and *Avicennia* sp. caused by stranded oil. Spooner (1970) found that, although leaves of the dwarf mangrove *Avicennia* sp. were heavily oiled after a pipeline break in Tarut Bay in the Arabian Gulf, their roots remained clean and the majority of plants thus survived. The weathered Kuwait crude stranded on salt marshes in Cornwall was not treated with emulsifier, unlike most rocky shores there. *Puccinellia maritima* and other plants were dying in one transect surveyed by Cowell, but very little damage had been done in general.

As far as the Arabian Gulf is concerned, no studies have been conducted on the effects of oil on the marine micro algae, except that of Dorgham, Muftah and El-Deeb (1987). They noticed close relationship between the physico-chemical parameters and oil pollution in the Arabian Gulf, and the diversity of species and biomass of phytoplankton. In the Arabian Gulf, oil exploitation and industrialization have developed very quickly during the last two decades. The northwestern region of the Arabian Gulf is heavily polluted and several oil spills were observed. These spills are allowed to disperse either naturally or sometimes by chemical dispersants. The oil dispersants commonly used in the Arabian Gulf are Shell Servo 2000, Exxon OSD9517 and Shell LTX, which are toxic. The use of these oil dispersants also undoubtedly have a significant effect on the Arabian Gulf biota in general, and phytoplankton in particular. It should be mentioned that several kilometres of oil pipelines extend on the Gulf floor between oil wells and the coast, and a number of platforms for crude oil export have been established inside the Gulf. Further, oil spills, which may have been discharged from tankers passing the Gulf, were observed in this area. All these could be sources of oil pollution in the Gulf. Extremely low phytoplankton cell numbers (1,400-2,200 cells l⁻¹) were observed at some of the locations in the Arabian Gulf. This is attributed to the effect of oil pollution. The highest level of oil pollution was reported at these stations. Two patterns were observed in Saudi waters, where these stations are situated. The oil-polluted region was characterized by a larger number of dinoflagellates (38-65%), which in other parts did not exceed 30%. The number of diatom species was significantly higher than dinoflagellates at most stations of the area, but the opposite was observed at the highly polluted stations. The highest concentration of dissolved hydrocarbon (546 ppb) in Saudi
water was recorded, particularly in the area of the significantly low phytoplankton biomass (El-Samra, Emara and Shunbo, 1986).

Although numerous reports have been written on the oil industry of the Arabian Gulf the effects of spilled oil on the macrophytes have not been investigated in detail. Since several hundred thousand barrels of oil were discharged into the sea following the Nowruz blow-out in 1983 and the Gulf war in 1991, a fair amount would have inevitably reached the seabed, particularly since it was heavy crude and relatively little was subsequently observed on shores. Mangroves, associated intertidal flats/marshes, seaweed and sea-grass beds represent one of the several critical marine habitats in the Arabian Gulf, and the effects of this spill on them are not fully known.

Mangroves and marshes which have high biological productivity, are good oil traps, and rated as the most vulnerable shoreline habitat (Gundlach and Hayes, 1978). The Arabian Gulf shoreline is inevitable subject to a certain amount of oiling, although the effects on mangroves specifically have not been considered in detail. However, studies in other parts of the world indicate that the final extent of the impact may not be apparent immediately after a spill. Ideally, mangroves should be protected from oil by booms or absorbent pads, as they are difficult to clear.

It has already been pointed out that macroalgaes and sea-grass beds occur along the coasts of all Arabian Gulf countries, including the southern coast of Oman. There is a little published information on the effects of oil pollution on sea-grass beds. In fact, few studies in the Arabian Gulf have addressed the problem directly. However, oiling of sea-grass beds is bound to occur, particularly following major disasters such as the Gulf war spills of 1991, the 1983 Nowruz oil spill and the earlier (1970) Tarut Bay spill.

Al-Thukair and Al-Hinai (1993) studied the distribution and environmental status of the algal mat located on the east coast of Saudi Arabia following the Gulf war spill in 1991. They observed algal mats in different sites of Abu Ali and Tanajib areas. Remote sensing techniques and ground truth verification were used to provide information on their existence. Pre and post oil spill satellite images were acquired for comparisons and assessments. Locations and site status (heavily oiled, recovering, and no algal mats) were mapped. Although recovered site are found in both areas, recovery seemed to be slower in Abu Ali area as compared to Tanajib. Different types and formations of algal mats were found in both areas. This differentiation is more likely due to coastal topography and tidal regimes rather than other environmental factors like temperature and salinity.

Durako, Kenworthy, Fatemy, Valavi and Thayer (1993) made an assessment of the toxicity of Kuwait crude oil on the photosynthesis and respiration of sea-
grasses (*Halophila ovalis*, *H. stipulacea* and *Halodule uninervis*) of the northern Arabian Gulf. They found that the Gulf war oil spill primarily impacted the intertidal communities rather than the submerged plant communities of the northern Arabian Gulf.

Kenworthy, Durako, Fatemy, Valavi and Thayer (1993) studied the ecological effects of the Gulf war oil spill on sea-grass communities of northwestern Saudi Arabia approximately one year after the spill. They also concluded that sea-grasses in the northeastern Arabian Gulf have not experienced acute or long-term degradation as a direct result of the spill.

It is apparent that little information is presently available on the impact of oil on the primary producers of the Arabian Gulf from systematically conducted studies covering the complete annual cycle. Therefore, all the types of primary producers in the Arabian Gulf, like the macro-algae, intertidal salt tolerant plants, mangrove vegetation and sea-grass beds, should be studied in addition to phytoplankton. For assessing the seasonal and spatial distribution and abundance of the primary producers, the latest remote sensing technologies, involving satellites or aerial photography, should be employed (Bender, 1988). Remote sensing studies should be supported by *in-situ* measurements of primary productivity using $^{14}$C tracer techniques.

The Arabian Gulf is a single water body. Studies conducted near Kuwait, Qatar or Oman alone will not provide the complete picture of the primary productivity or other oceanographic processes. The oceanographic processes in the Arabian Gulf should be viewed as a whole, and studies should be conducted under the supervision of such international bodies as the Regional Organization for the Protection of the Marine Environment (ROPME). Detailed monitoring sites should be established in all the Gulf countries to assess the impacts of oil on the vitally important primary producers that form the basis of existence of all other marine organisms in this ecosystem.

ACKNOWLEDGEMENTS

The authors are grateful to Dr. Dhari Al-Ajmi, Director, EES/Division for supporting this study. Thanks are also due to Ms. Paz Medida for typing the paper.

REFERENCES


