The effects of the 1991 Gulf War on the marine and coastal environment of the Arabian Gulf: Impact, recovery and future prospects

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1. Introduction

1.1 The Arabian Gulf environment

The clear, shallow waters, warm temperatures and an inflow of nutrients from the Tigris and Euphrates Rivers make the Arabian Gulf one of the most productive water bodies in the world. Pelagic productivity is typical for waters of this latitude, and it is the benthic communities of the Gulf which are responsible for its high productivity values (Sheppard 1993). Coral reefs, especially on the offshore islands are the most diverse of the sub tidal ecosystems, providing a substrate for many organisms and shelter and feeding ground for numerous fish (Basson et al. 1977). They are highly productive, but cover only a small area and so are of relatively minor importance in a regional sense. Seagrasses are common in shallow areas, forming the basis of many food chains. At least four seagrass species are known for the region, but the majority of communities are dominated by Halodule uninervis.
Seagrasses are also an important habitat for commercial shrimp (e.g. *Penaeus semisulcatus*), pearl oysters and many other organisms. Mudflats occupy extensive areas of the intertidal zone. Their productivity is often enhanced by Cyanobacteria-dominated algal mats. Naturally occurring mangroves are found in association with tidal flats and are represented by a single species, *Avicennia marina*. Mangroves are much less extensive in the Gulf (125-130 km²) than in the Red Sea (400-500 km²) (Price *et al.* 1994b).

![Map of the Gulf area and surrounding nations](image)

**Figure ii: Map of the Gulf area and surrounding nations**

The Gulf lies entirely north of the Tropic of Cancer, and so strictly it is sub-tropical, though its location within the large, arid, East Asia land mass (see fig. ii.) creates a climate which is more intensely tropical in the summer and more temperate in the winter than most seas of equivalent latitude (see table i.). These conditions create a significantly raised salinity, of up to 70 ppm in some embayments (Sheppard 1993). These natural environmental stresses mean that the biota of the Gulf lives at the extreme limits of its environmental tolerance; and this is
an important consideration when considering the effects of additional stresses, such as those arising from the 1991 Gulf War.

**Table i: Temperature extremes recorded from Arabian coral reef areas (from Sheppard et al. 1992). Notice the high degree of adaptation by this group of species which elsewhere have lower tolerances to temperature fluctuations**

<table>
<thead>
<tr>
<th>Location</th>
<th>Latitude</th>
<th>Min. / °C</th>
<th>Max / °C</th>
<th>Range / °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saudi Gulf</td>
<td>27°N</td>
<td>11.4</td>
<td>36.2</td>
<td>24.8</td>
</tr>
<tr>
<td>Qatar Gulf</td>
<td>24°N</td>
<td>14.1</td>
<td>36.0</td>
<td>21.9</td>
</tr>
<tr>
<td>Abu Dhabi Gulf</td>
<td>25°N</td>
<td>16.0</td>
<td>36.0</td>
<td>20.0</td>
</tr>
<tr>
<td>Kuwait Gulf</td>
<td>29°N</td>
<td>13.2</td>
<td>31.5</td>
<td>18.3</td>
</tr>
<tr>
<td>Suez Red Sea</td>
<td>29.5°N</td>
<td>17.5</td>
<td>30.0</td>
<td>12.5</td>
</tr>
<tr>
<td>Aqaba Red Sea</td>
<td>29°N</td>
<td>20.0</td>
<td>28.0</td>
<td>8.0</td>
</tr>
</tbody>
</table>

The biological environments of the western and southern coasts of the Gulf are relatively well-studied. This is fortunate in terms of understanding impacts of the Gulf War in the region, since the west in particular is where most impacts were concentrated. However, it must be remembered that fully half of the shoreline of the Gulf is that of the eastern coast which borders Iran, and details of the biota and habitats of the latter are extremely poorly known. The Gulf on the whole is dominated by soft-substrate ecosystems and includes several so-called critical marine habitats (Ray 1976). Ecological attributes of these include: high biological productivity; provision of nutrients, feeding, breeding or nesting areas for marine and other animals; areas particularly rich in species; and areas important for sustaining populations of species at some or all phases of their life cycle. In the Gulf, critical marine ecosystems are mostly confined to shallow water less than 10-12m (Price et al. 1993b). An important consideration is that this area coincides with areas of greatest human activity.

Due to its enclosed and shallow nature (average depth of only 35m), the Gulf is particularly subject to the accumulation of anthropogenic contaminants (Randolph et al 1998). There is only a very narrow exchange through the Strait of Hormuz into the Gulf of Oman, which means that the time required for all of the Gulf’s water to come within the influence of the open sea is 2.4 years (Hunter 1983); or an actual flushing time of 3 -5.5 years (Sheppard 1993). It suffered complete drying out in the late Pleistocene, so its current relatively low biotic diversity is perhaps as much a result of its relatively recent existence in recent times as of the extremes of environmental conditions which it experiences (Sheppard 1993).
Considering that approximately 49% of the world’s oil production comes from the Gulf states and passes through the Gulf, its liability to pollution is about 48 times that of any other similar area on earth (Al-Awadhi 1999). Therefore it is important to remember that the Gulf was already possibly the most chronically oil-polluted marine area in the world even before the war. It was already suffering environmental impacts associated with local exploration, exploitation, refining, routine handling and discharge of ballast-water, bilges and slop oil as well as natural seeps (Zarba et al. 1985). Sediment concentrations of petroleum hydrocarbons (mainly from anthropogenic sources) recorded between November 1979 and December 1980 in samples from Kuwait ranged from 1 – 291 μgg⁻¹ dry weight (Zarba et al. 1985). Many species had already evolved a degree of natural resistance to the effects of oil pollution. During the Iran-Iraq war, a total of around two million barrels of oil was discharged into the Gulf, including one and a half million barrels from the Nowruz blow-out in 1983. Local impacts occurred on the fishing industry, coral reefs and dugongs, but damage was modest and largely ignored by the world’s press and ecological recovery was also fairly rapid. Thus, two opposing sets of hypotheses may be suggested (Sheppard 1993). On one hand is the suggestion that given the natural severe stresses, Gulf species may not have much scope to deal with additional anthropogenic impacts. On the other hand, species which do occur in the Gulf are clearly naturally adapted to extreme conditions, and may weather pollution events better.

The socio-economic development of the Gulf region is highly dependent on its marine environmental quality. Most of the population’s freshwater supply is derived from the Gulf and the Red Sea through desalination plants. Fisheries are a multi-million dollar industry and the artisanal fisheries are a resource of great social significance. The major commercial fisheries are for penaeid shrimp, but groupers, jacks and Spanish mackerel are also significant. The coastal and marine environments are internationally significant for a number of bird species, green and hawksbill turtles and dugongs; many organisms are endemic to the region. Discovery of oil in the Gulf during the 1930s and 1940s led to a massive increase in shipping; and was principally responsible for the immense economic wealth and strategic importance associated with the region today.
1.2 Pollution impacts of the Gulf War

**Burning oil wells**

Having invaded Kuwait on 2\textsuperscript{nd} August 1990, Saddam Hussein declared that ‘if he had to be evicted from Kuwait by force, then Kuwait would be burned’ (Sadiq & McCain 1993). Saddam proved to be a man of his word; upon evacuation, from 3\textsuperscript{rd} February 1991, Iraqi troops set fire to over six hundred oil wells in several Kuwaiti oil fields (see fig. i.). Around 500 million barrels of oil were emitted (or ignited) from burning wells during the remainder of 1991 (Readman \textit{et al.} 1992). Approximately 22 Gg of sulphur dioxide, 18 Gg of soot, and thousands of tonnes of carbon monoxide and oxides of nitrogen emanated from the wells on daily basis in the early stages (Husain 1995). Besides this, significant amounts of toxic metals and carcinogenic constituents were also released into the atmosphere for several months (Husain 1998). These massive emissions caused serious concern in the scientific community over possible catastrophic environmental consequences within and outside the Gulf region (Browning \textit{et al.} 1991; Sheppard & Price 1991).

**The oil spill**

At the end of January 1991, the Iraqi army discharged around 6 million barrels of oil into the Arabian Gulf (Randolph \textit{et al.} 1998). As the largest spill in history, international press heralded this event as ‘the world’s worst ecological disaster’. By comparison, the spill from the Ixtoc 1 was less than 4 million barrels, and from the Amoco Cadiz, Torrey Canyon, Exxon Valdez and Braer less than 2 million barrels in each case. Initially, there were two separate oil slicks. The main emission lasted from 22\textsuperscript{nd} to 26\textsuperscript{th} January and was caused by the deliberate discharge of oil from the Mina Al-Ahmadi Sea Island terminal in Kuwait. The second slick was released from three tankers anchored at Kuwait’s port of Mina Al-Ahmadi. Five other tankers and several other terminals added oil throughout the spring and early summer (Reynolds 1993). Approximately half of the oil simply evaporated, and more than a million barrels were confined in large pits carved out of the desert (Randolph 1998). Prevailing winds directed the spill southwards. Between March and May 1991, about 905 thousand barrels of oil washed ashore along much of the coastline from Kuwait south to the Abu Ali peninsula, a hook of land which halted the southern advance of the spill in Saudi Arabia.
Other impacts

At least 80 ships were sunk during the war, many of which were carrying oil and munitions. These ships, along with those lost during the Iran-Iraq conflict will remain a chronic source of contamination in the Arabian Gulf for many years (Sadiq & McCain 1993).

The destruction of sewage treatment plants in Kuwait led to the discharge of over 50,000m$^3$d$^{-1}$ raw sewage into Kuwait Bay, threatening the intertidal ecosystems; polluting public beaches and downgrading the quality of seawater used for desalination (Gerges 1993).

The shelling and bombing in Iraq from air raids and rockets led to the complete destruction of six oil wells as well as refineries and storage depots. Toxic chemicals were emitted into soil and running water from the destruction of chemical industrial plants (UNEP 1993). The potential fate of G-nerve chemical warfare agents in the area has also caused concern; such chemicals include:

- Tabun (GA) - ethyl phosphorodimethylamidocyanidate
- Sarin (GB) - isopropyl methyl-phosphonofluoridate
- Soman (GD) – pinacolyl methylphosphonofluoridate

Accidental or deliberate release of these chemicals into the Gulf would have serious consequences for the power desalination plants located along the Gulf shorelines, contaminating a sole drinking water resource (Khordagui 1996).

Environmentalists widely criticized the schemes to drain marshlands in the Shatt-al-Arab at the confluence of the Tigris and Euphrates rivers, arising from military and engineering activities (North 1993). This displaced hundreds of thousands of Marsh Arabs and caused partial desertification. The bandicoot rat and a type of smooth-coated otter, once indigenous to the marshlands, are now thought extinct (Doyle 2003). This marsh system known as the Third River Project, acts as a pollutant sink and filters the pollutants contained in the run-off. These include residues from agricultural chemicals, sewage-related pathogens and minerals, and sediments. Investigation by the Kuwait Institute for Scientific Research (KISR) indicated that the northern Kuwaiti waters were displaying lower salinity values than had been previously recorded for this area. Such changes in the water budget of the Gulf could have profound and irreversible effects on its ecology and fisheries (Al-Yamani et al. 1997). The effects of the marsh drainage have been exasperated by Turkey’s attempts to harness the flows of the Tigris and Euphrates by the construction of 22 dams. This could cause a
reduction in the flow of Shat Al-Arab by as much as 50%, and the resultant consequences on the Gulf will become increasingly significant (Al-Awadhi 1999).

1.3 Vulnerable areas within the Gulf

The north-west coastline from the Mina Al-Ahmadi terminal to Qatar, a total length of around 900km was identified as being the most vulnerable area by the World Conservation Monitoring Centre (1991), since it was the location of a number of environmentally sensitive sites:

- A ribbon of coral reef extending from the Saudi border to Ras Tammurah at the mouth of the Gulf of Bahrain which provided spawning grounds for a number of commercially significant fish species.
• The mudflats at Khawr al Mufatteh, close to the Kuwait-Saudi border were a key site for migratory birds, providing over wintering and rich feeding grounds for over million individuals from Europe and Northern Asia.

• Mangrove areas around Manifa, Tarut Bay and Dawhat Zalum in the Gulf of Bahrain supported numerous marine species, providing spawning and nursery areas for several commercially important fish species.

• The seagrass beds in the Gulf of Bahrain, particularly around Tarut Bay, Dawhat Zalum and Dawhat Salwah supported a population of the highly endangered Dugong, together with sea turtles and commercial shellfish, shrimp and fin fish species.

• Sandy beaches along the Saudi shore, and particularly offshore islands such as Karan, provide globally significant nesting beaches for the Green Turtle; while beaches on the Iranian coast and its offshore islands support major populations of the Hawksbill Turtle.

• Oyster beds, shellfish, shrimping and fisheries areas, particularly in the Gulf of Bahrain and around Qatar were threatened. These fisheries were vital to the local community, both for consumption and export.

Throughout the Arabian Gulf region and specifically in the three countries of Kuwait, Iraq and Saudi Arabia there are a total of more than 3,650 animal species. Of these, 50 are recognized internationally as being threatened with extinction, including 20 species of bird, 20 mammal species, three reptiles, two fishes, four molluscs and an insect (World Conservation Monitoring Centre 1991)
2. The aftermath and longer term effects

2.1 Preliminary scientific findings

Due to the circumstances of war, early scientific response to the spill was impossible. However, as soon as was practicable, international scientific teams began to address the situation. There were two main efforts. The first centred around the cruises of the research vessel ‘Mt Mitchell’, under the auspices of the National Oceanic and Atmospheric Administration of the USA (NOAA), Regional Organisation for the Protection of the Marine Environment (ROPME), various UN agencies and the Saudi Arabian authorities. The second, commencing sometime after the spill, was the setting up and continual monitoring of a wildlife sanctuary for the Gulf Region by the European Union (EU) and the National Commission for Wildlife Conservation and Development of the Saudi Arabian government (NCWCD) (Krupp & Jones 1993). The sanctuary, which extends northward from the southern limit of the major pollution, is situated in the Dawhat ad Dafi and Dawhat ad Musallamiya area, near Jubail, Saudi Arabia, and includes a number of the offshore islands. Monitoring the recovery of the area is to continue indefinitely.

The Kuwaiti oil fires

Oiling and petroleum hydrocarbon contamination was confined mainly to the north-western parts of the Gulf while air pollution and reduced solar radiation from the burning oil wells was more widespread. The smoke plume widths ranged from 15 to 150km for distances up to 1,000km away from the fires (see fig. v.), reducing ground-level sunlight, visibility and temperature beneath the plume (UNEP 1993).
According to measurements made by the National Center for Atmospheric Research (NCAR) and the University of Washington teams, only 10-15% of the sun’s radiation was transmitted through the thickest part of the super-composite plume (Hobbs & Radke 1992). The increase in particulate matter and smoke density caused a significant decrease in air and sea surface temperatures. As depicted in fig. vi., measurements at Manifa Pier, between Kuwait and Dharan, showed a decline of 2.5°C in the mean sea temperature in 1991 (Husain 1998). Although local and regional temperatures and solar flux were reduced under the plume, there is no evidence that regional weather patterns were consistently affected (UNEP 1993). Interestingly, levels of combustion-derived carcinogenic PAHs in the marine environment at that time (e.g. UNEP 1993; Price et al. 1994 found 1-450ngg⁻¹ dry weight for pyrene in sediments) were of the same order as those measured in several coastal areas of the United States and Northern Europe.
Heavy metals which are associated with the soot have detrimental effects on biological systems. It is apparent that ecosystems have naturally occurring levels of heavy metals; however, additional amounts of these can stress the delicate balance necessary for the efficient performance and survival of an ecological community (Mukhtasor et al. 2001). Middleditch 1984 has reviewed toxic effects on individual species. Nickel has adverse effects on many species in the ocean environment, namely polychaetes, bivalves, gastropods, crustaceans and fish. Similarly, chromium is toxic to bivalves, crustaceans and fish. The particular effects of chromium are inhibition of polychaetes’ spawning and suppressed reproduction. These chemicals are a potential threat to fish larvae and eggs, adult copepods, copepod nauplii, krill and amphipods. Fish are most susceptible to the water soluble fraction (WSF) of crude oil. The exposure of contaminants to marine organisms depends on the physico-chemical characteristics of contaminants, trophic level of organisms and mode of intake (Mukhtasor et al. 2001). There is a possibility that grazing animals such as camels, sheep and marine animals might have transmitted contaminants to humans through the food chain (Husain 1995).

The Oil spill

Spilled oil spreads, weathers and sinks. Weathering includes the chemical and physical processes of evaporation, dissolution, vertical dispersion, emulsification, photochemical and
biochemical degradation, and sedimentation. Fig. vii. shows the extent and state of the oil spill after almost two months.

![Map of the Gulf oil spill](image)

**Figure vii: Extent of the oil spill and types of oil slicks on 16th March 1991 (from World Conservation Monitoring Centre 1991)**

Typically, around half of spilled oil adsorbs to bottom sediments where oxidation processes are hindered. In this way, measurements of oil concentrations in marine sediments are on the whole more indicative of oil pollution than measurements in the water column. During the initial surveys, highest levels of contamination were found along the heavily-impacted coast of Saudi Arabia between Ras Al Khafji and Ras Al Ghar, where concentrations of total petroleum hydrocarbons (expressed as Kuwait crude oil equivalents) ranged from 62 - 1400 μgg⁻¹ dry weight in surface sediments, 570 - 2600 μgg⁻¹ dry weight in clams and 9.6 – 31 μgg⁻¹ dry weight in fish muscle (Price et al. 1994). Gas chromatographic analysis indicated that much of the spilled oil in at least the surface layer of the intertidal zone had substantially degraded within a few months of the spill. Hydrocarbon contamination originating from the spill was generally restricted to within approximately 400km from the source (see fig. viii.). Analysis of biota and physical characteristics demonstrated that a full range of Gulf intertidal
habitats was present within the impacted area (Jones & Richmond 1992). By December 1991, most intertidal oil had been finally deposited on the upper shore between the high water spring and high water neap marks (Watt et al. 1993). Outside the immediate area of impact, petroleum hydrocarbon and trace metal levels in sediment and bivalves were generally as low as, or lower than, those concentrations measured at the same sites before the war.

![Figure VIII: Concentrations of Kuwait crude oil equivalents found in marine sediments, bivalves and fish at various distances from the location of the spill (from Fowler et al. 1993). Notice that contamination is restricted to within 400km of the spill.]

Access to the entire Kuwait coastline was forbidden during the initial survey, owing to mines and unexploded ordnance (Readman et al. 1996a). Surprisingly, concentrations of hydrocarbons in the vicinity of Bahrain were lower than pre-war (1983-1986) levels, probably as a result of decreased tanker traffic and associated deballasting during and after the conflict (Readman et al. 1996a).

Broad scale coastal surveys were undertaken by the International Union for the Conservation of Nature (IUCN) in 1991, 1992 and 1993, and comparisons made with baseline data collected at the same sites in 1986, before the war. Unsurprisingly, oil levels were significantly higher in 1991 than during 1986. However, in 1992 and 1993 levels had decreased and were comparable to those recorded in 1986, suggesting some recovery of at least surface substrata (Price et al. 1994). Concentrations of oil at the most heavily soiled sites such as Ras Al Khafji, Ras Al Mishab and Ras Al Ghar, decreased by more than 50% during the period 1991-1992; gas chromatographic analyses revealed that by 1992 only the
most refractory compounds associated with the oil remained (Readman et al. 1996a). However, concentrations of petroleum hydrocarbons actually increased between 1992 and 1993 in parts of the north-western Gulf, probably from increased tanker traffic (Readman et al. 1996a). Thus, while coastal environmental recovery was undoubtedly in progress, average patterns were masking localized or extreme pollution that may have been ecologically harmful (Randolph et al. 1998).

In August 1992, more than one and a half years after the Gulf War oil spill, relatively high and toxic concentrations of contaminants remained in the nearshore surface waters of Kuwait and Saudi Arabia. Toxicity tests on heart urchin larvae indicated that the subsurface water column was not toxic, but the sea-surface micro layer at about half of the sites sampled demonstrated significant toxicity (Price et al. 1994). The surface micro layer represents an important spawning and feeding ground for many fish, shrimps and shellfish and a source of transport and deposition of contaminants onto intertidal beaches.

### 2.2 Clean-up and bioremediation activities

More than one million barrels of oil were collected offshore using skimmer ships contracted or operated by Saudi Aramco while more than half a million barrels were collected on the shoreline by means of booms and skimmers (Alam 1993). The diversity of ecosystem types around the shoreline of the Gulf meant that a number of different techniques were necessary for effective clean-up, and these are summarized in table ii.

<table>
<thead>
<tr>
<th>Ecosystem</th>
<th>Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mangroves</td>
<td>• Low pressure irrigation and a sprinkler system to release oil gently</td>
</tr>
<tr>
<td>Salt marsh</td>
<td>• Flooding with seawater</td>
</tr>
<tr>
<td></td>
<td>• Inducing agitation by winds generated by helicopters</td>
</tr>
<tr>
<td></td>
<td>• Sprinklers on the upper intertidal zones</td>
</tr>
<tr>
<td></td>
<td>• Release of water from perforated pipes in the higher intertidal zone</td>
</tr>
<tr>
<td>Rocky shores</td>
<td>• Solvent and high pressure jets to wash away the oil</td>
</tr>
<tr>
<td>Sandy beaches</td>
<td>• Mechanical tiller to enhance aeration and stimulate biodegradation</td>
</tr>
</tbody>
</table>
Biodegradation of oil

Although the waters of the Gulf, being subjected to long-term chronic oil pollution, should show high levels of hydrocarbons, unexpectedly low levels have been recorded on numerous occasions (e.g. Dou Abul 1994 in the north-western Gulf; Zarba et al. 1995 in Kuwaiti surface sediments). These low levels have been attributed to rapid breakdown due to high air and water temperatures, intensive solar radiation, rapid bacteria action and high water mixing rates (Floodgate 1995). An investigation, carried out by Indian scientists (Sen Gupta et al. 1993) found that in spite of the massive releases of oil during the Gulf War, very little found its way out of the Gulf into the Arabian Sea. It can therefore be inferred that the epuration mechanisms of the Gulf are rapid (Floodgate 1995).

The significance of oxygen in the biodegradation of oil has been illustrated by Smith (1996). Fayad & Overton (1995) suggested that it was the presence of naturally occurring microorganisms in the marine system of the Gulf that were responsible for the biodegradation of oil. Some genera of microorganisms were more effective in degrading several polycyclic aromatic hydrocarbon (PAH) compounds. The degradation rate of PAHs was found to be much faster than that of saturated hydrocarbons in the absence of nutrients. It was also apparent that activity of microorganisms responsible for the degradation of the aromatic fraction of the oil, especially the sulphur-containing compounds ceased in the presence of nutrients. Since aromatic compounds are the most environmentally damaging, the use of bacterial cultures that preferably degrade PAHs is an important consideration for bioremediation technology. Moreover, the specificity of microorganisms for hydrocarbon compounds indicates that a mixed community is necessary for complete biodegradation (Hannah 2003).
2.3 Effects on species

Fisheries

Some of the fish species in the Arabian Gulf live close to edge of their thermal tolerance range of 1°C (McCain et al. 1993) with the tolerance of larval stages being even more restricted than that of adults (Sheppard et al. 1992). Most marine organisms in the Gulf, including shrimp, typically breed during a transition period in the Spring when a significant rise in sea water temperatures occurs (Husain 1998). Therefore, temperature changes brought about by the presence of the smoke plume, especially when combined with the pollution effects of the oil spill, could have had seriously deleterious effects on commercial fisheries in the region.

Fortunately, however, there were few unequivocal effects of oil pollution that were attributable solely to the 1991 releases (Gerges 1993). There was a long period where fishing was physically impossible or reduced in heavily oiled areas; fishnets were destroyed by tar and approximately 10 000 tonnes of fish were tainted (World Conservation Monitoring Centre 1991).

Insufficient research has been carried out into the possibility of risks to human health from PAHs associated with fishery products. Toxicity may be affected by a number of factors, such as: consumption patterns; food preparation techniques; dose-response and hydrocarbon distribution within the products (Gerges 1993). Experiences from other oil pollution studies generally suggest that commercially caught fishery products do not constitute a health risk to the consumer (Gerges 1993).

Shrimp fisheries

Data for shrimp fisheries at the time display a real and sudden decline in shrimp stocks (see fig. ix.). Although adult shrimp are relatively hardy animals, their eggs and larvae are less so. Severe reduction in water or habitat quality therefore has the potential to disrupt spawning activity and success. In 1991-1992, the Saudi Gulf shrimp stock showed a decline in spawning biomass to about 1-10% and a decline in the total biomass to about 25% of the pre-war levels, (see fig. ix.) causing a loss in revenue in the region of approximately US$41 million (Price et al. 1994). A plankton survey showed that egg and larval abundance fell significantly in 1992 (Price et al. 1993aa). The decline in spawning biomass by at least an
order of magnitude and the resultant reduction in recruitment increased the sensitivity of the stock to recruitment over-fishing.

Figure ix: Catch per unit effort for the SAFISH shrimp fishery from 1982 – 1992 (from Mathews et al 1993)

Causes suggested for the decline in shrimp production included the decrease in solar energy; deposition of soot on the water surface and oiling in sub tidal and tidal areas due to the spill. These declines were especially serious, since fishing had ceased at the onset of the war for several months, which would have normally led to a rise in stocks. However, it was not proven conclusively that war-related events were the cause of the decline, and movement of shrimp, rather than mortality was regarded as a possible cause of these patterns. In further support of this, it was evident that, while poor catch rates characterized Saudi Arabian waters immediately after the war, Kuwait enjoyed bumper harvests in 1992-1993 (Roberts et al. 1993).

The Bahraini shrimp stock is fished very near its maximum sustainable yield (MSY), and is therefore sensitive to any major environmental impacts. Pollution effects of the Gulf War were evident, effort of the fishery fell by less than 10%, but landings fell by about 50%. Surplus production models indicated that any further increase in effort would lead to little or no increase in landings, leading to a moratorium on the issue of new licences. Economic losses caused by the war to the Bahrain fishery in 1991-1992 were estimated at US$3.35 million (Price et al. 1994).
Shellfish

Many molluscs and crustaceans accumulate metals in their tissues in proportion to the degree of environmental contamination and can be used as indicators of marine metallic pollution. Heavy metals are an integral component of any crude oil. Their concentrations may vary, but a significant proportion of the total heavy metal input into marine environments occurs through the burning of fossil fuels (Bu-Olayan & Subrahmanyam 1997). Differences in the pattern of metal occurrence and a significant increase of Cu and Zn concentrations in various organs of the crab *Portunus pelagicus* have been reported from the Kuwait coast (Al-Mohanna & Subrahmanyam 2001 see fig. x.). Similar effects, along with a significant increase in Pb were reported in the snail, *Lunella coronatus* and pearl oyster, *Pinctada radiata* (Bu-Olayan & Subrahmanyam 1997). These findings were considered to be associated with the contribution from the 1991 Gulf War oil spill.

![Figure x: Comparison of mean concentrations of trace metals reported for decapod crustaceans worldwide with pre- and post-conflict Kuwaiti values](image)

Avian species

Birds were the most severely affected group of organisms, and at least three thousand wintering seabirds, mainly cormorants and grebes died in the immediate aftermath of the spill between January and April 1991. The hardest hit species were the Great Crested Grebe (*Podiceps cristatus*), Black-necked Grebe (*Podiceps nigricollis*), Great Cormorant (*Phalocrocorax carbo*) and Socotra Cormorant (*Phalacrocorax nigrogularis*), whose
wintering populations on the Arabian side of the Gulf are estimated to have suffered mortality ranging from 22% to more than 50% depending on the species; however, no bird species had its world population reduced to such an extent that recovery was impossible (Evans et al. 1993).

The coastal zone is critical to wintering waders and a number of censuses have been undertaken (Zwarts et al. 1991; Evans et al. 1993; Symens et al. 1995). Despite considerable fluctuations in populations, no overall post-war decline is evident (Price 1998). Seabird populations have shown a general increase since 1991, although the Socotra Cormorant was slower to recover, and was reported by Symens et al. to be less abundant in 1995 than pre-war (1981) levels.

In 1991, tern colonies in the Jubail Marine Wildlife Sanctuary produced the highest hatching success and chick survival ever recorded, as a result of reduced heat stress caused by solar blanketing by the burning oil wells (Symens & Alsuhaibany 1996). This increase in reproductive success would have partly offset any negative impacts on the terns caused by oil and toxic effects from the smoke. A further case where multiple confounding factors are in evidence is that of wader populations. Low abundances were recorded immediately after the war at Dawhat ad Dafi, an area heavily oiled, but in this case, the population decline was actually the result of reduced nutrient input to the bay, as a result of changing land-use patterns (Evans & Keijl 1993).

**Sea turtle species**

All seven marine turtle species are endangered, and face various anthropogenic and natural threats. They are listed on appendix I of the Convention on International Trade in endangered Species (CITES), and although there have been numerous studies carried out; relatively little is known of their biology. Green turtles are mainly found in seagrass areas, foraging around the north coast of Jubail and offshore islands. Hawksbill turtles are primarily associated with coral reefs around the islands. Key nesting sites exist on the islands of Karan and Jana. The vast distances travelled by turtle species between feeding and breeding grounds necessitate cooperation between the nations of the Gulf for their protection.

Preservation of nesting sites has been recognized as a priority in sea turtle conservation. There was a major effort to attempt to clear Karan Island beaches in April 1991 before the breeding season as significant layers of oil on beaches would have made nesting difficult or impossible. However, many rookeries in the area were already subjected to high levels of oil
pollution, marine waste and war debris. The presence of oil is known to significantly affect hatch rates and survival of juvenile turtles. Temperature reductions may have affected the sex ratios of turtles hatching in 1991, and this could have repercussions in the future. In an investigation of the Gulf’s beaches, the National Commission for Wildlife Conservation and Development (NCWCD) determined that some turtles had died and that most Karan Island Green turtles had lesions (Sadiq & McCain 1993). Tar has also been observed to block up turtles’ mouths and nostrils, and studies of green and loggerhead turtles have shown that they are unable to distinguish between balls of tar and food. Greenpeace reported in 1992 that a green turtle was found to contain $4.050 \mu g g^{-1}$ oil in liver tissue and $3.10 \mu g g^{-1}$ in stomach tissue.

**Marine mammals**

Although most marine mammals are thought to be highly intelligent and mobile, able to simply move away from oil-impacted areas, they still have to contend with the indirect effects of loss of habitat and food. Moreover, there have been numerous sightings of marine mammals such as dolphins (Greenpeace 1992) and dugongs (Preen 1991) swimming in oil slicks, even when clean water was nearby. Due to their position at the top of the food chain, cetacean predators are susceptible to the effects of bioaccumulation of toxic substances. Some of the poisonous compounds within oil such as PAHs and heavy metals are known to be particularly persistent. There is very little information available on the abundance and distribution of marine mammals in the Gulf, but it is likely that the Gulf War oil spill had an effect on them. Between late February and mid April 1991, at least 93 marine mammals died in the western Gulf, including 14 dugongs, 57 bottlenose dolphins, 13 humpback dolphins, 1 finless porpoise and 8 unidentified cetaceans (Preen 1991). However, since these carcasses were found south of the main area impacted by the spill, it is possible that the deaths were due to another cause. However, there has been consistent correlation between marine mammal die-offs and oil pollution impacts in the Gulf in recent years (Greenpeace 1992). The humpback dolphin and finless porpoise, in particular are susceptible to high levels of oil pollution; both of these species are listed on CITES Appendix I, recognizing that these species are endangered (Klinowaka 1991). It is possible that the Gulf populations are isolated and therefore even more vulnerable (Greenpeace 1992).
2.4 Effects on ecosystems

On all polluted shores, even though there was initially complete oil cover, only the littoral fringe and upper eulittoral were seriously impacted, resulting in 100% mortality in most habitats at this level (Jones et al. 1998). Surviving bivalves (*Amiantis umbonella*) showed no sign of reduction in growth rates in 1991 so presumably oil lifted off the substratum during high tide, allowing infauna to continue feeding (Jones et al. 1998). Reduction in both depth and horizontal extent (see fig. xi.) occurred progressively on all shores and is confirmed by hydrocarbon analysis of sediments (Readman et al. 1996). Furthermore, monitoring of shores and settlement panels (Jones *et al.* 1994) confirmed recruitment from the plankton, demonstrating that coastal waters were already free of toxic levels of pollutants.

![Figure xi: Extent of tar cover across varied sites on the Saudi coast (from Jones *et al.* 1998)](image)

Initial results revealed complete absence of key species from the littoral fringe of all but mangrove habitats, and between 80 and 100% loss in species diversity in the upper eulittoral (Watt *et al.* 1993). From 1991-1992, reductions in tar cover were apparent, combined with the appearance of algal mat cover (see fig. xii.) on most soft substrate shores (Jones *et al.* 1994).
Fig. xii. documents the sequence of algal mat appearance, extent and final reduction. Initial appearance is likely to be related to the stable substrate provided by oil sheets, once these had become consolidated and non-toxic, together with the elimination of other biota (Hoffman 1996). Their eventual disappearance appeared to be due to grazing by opportunistic gastropods such as *Pirinella conica* and *Cerithidea cingulata*, bioturbation by these and burrowing crabs and a natural cycle of annual drying and peeling of mats during summer as observed on unpolluted Gulf shores (Jones *et al.* 1998).

This phase in the recovery cycle was as short as 2-3 years on predominantly rocky shores, but extended to over 4 years on soft sediment shores (see fig. xii). On unpolluted shores, algal mats occupy a narrow zone in the upper eulittoral, the upper boundary is determined by desiccation and littoral fringe crab bioturbation and grazing, while the lower boundary is controlled by gastropod bioturbation and grazing. Hence, return to full recovery of an impacted shore is signalled not by complete disappearance of algal mats, but by increase in communities which control their distribution (Jones *et al.* 1998). When evaluating recovery rates on impacted shores, it is important to take into account the natural fluctuations in population density, as a result of the highly variable temperatures and salinities experienced in the region. Species diversity, on the other hand is normally relatively stable, and gives a better indicator of the severity of oil pollution effects. Recovery rates for biodiversity on Saudi Arabian shores appear to fall within the overall timescale for shores elsewhere;
however they appear to be longer than for other subtropical shores which show a time scale of 2-5 years for rocky and 5 years for salt marshes (Jones et al. 1998). A summary of the recovery processes for Gulf shores after the oil spill is given in table iii.

**Table iii: Recovery sequence for Arabian Gulf shores after impact by oil (from Jones et al. 1998)**

<table>
<thead>
<tr>
<th>HEAVY OIL IMPACT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top shore reached by spring-tides only</td>
</tr>
<tr>
<td>Degradation of biota</td>
</tr>
<tr>
<td>Weathering of oil</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ROCK</th>
<th>SOFT SUBSTRATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peeling of thin oil layers</td>
<td>Crust formation of surface oil</td>
</tr>
<tr>
<td>Pavement formation of thick oil</td>
<td>Adsorption of oil onto sand, drying to form friable sediment</td>
</tr>
<tr>
<td>Recolonization by barnacles, littorinids, Metopograpsus</td>
<td>New growth from oiled halophytes, recolonization by seed</td>
</tr>
<tr>
<td>Density fluctuations</td>
<td>Bioturbation by <em>Nasima</em></td>
</tr>
<tr>
<td>Colonization from lower shore</td>
<td></td>
</tr>
<tr>
<td>Species diversity normal</td>
<td>Species diversity normal</td>
</tr>
<tr>
<td>Densities normal</td>
<td>Densities normal</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TWO TIMESCALE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diversity: 3-5 years</td>
</tr>
<tr>
<td>Abundance: 3-5 years</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ROCK</th>
<th>SOFT SUBSTRATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peeling of algal mat + oil</td>
<td>Peeling of algal mat + oil</td>
</tr>
<tr>
<td>Adsorption of oil onto sediment</td>
<td>Adsorption of oil onto sediment</td>
</tr>
<tr>
<td>Recolonization by pioneer species</td>
<td>Recolonization by pioneer species</td>
</tr>
<tr>
<td><em>Perinereis vancaurica, Pirinella conica</em></td>
<td></td>
</tr>
<tr>
<td>Density fluctuations</td>
<td>Density fluctuations</td>
</tr>
<tr>
<td>Grazing, Bioturbation</td>
<td></td>
</tr>
<tr>
<td>Algal mat regression</td>
<td></td>
</tr>
<tr>
<td>Species diversity normal</td>
<td></td>
</tr>
<tr>
<td>Densities normal</td>
<td></td>
</tr>
</tbody>
</table>

**Recruitment and seasonal changes in biota**

As species diversity on impacted shores increased, recruitment of replacement species must have occurred onto these shores. In the majority of species, this took place via planktonic larvae, as demonstrated for rocky shores with the settlement of barnacles, *Eurapia permitini, Chthamalus malayensis* and *Balanus amphitrite*; on sandy shores by settlement of the crab, *Scopimera scabricauda* and the bivalves, *Dosinia hepatica* and *Tellina arsionensis*; and on muddy shores by settlement of the worms, *Nasima dotilliformis, Manningis arabicum* and *Owenia* spp (Jones et al. 1998). Initially, large fluctuations in settlement and survival were recorded on polluted shores, but by 1995, populations recruited through the plankton were approaching the densities recruiting onto unimpacted shores (Jones et al. 1998).
For species without planktonic larvae (littorinid gastropods, isopods and amphipods) recruitment was much slower, and took up to five years to occur in some areas for species such as the snails *Nodolittorina subnodos a* and *Planaxis sulcatus*. For these species, recruitment originated either from small resident populations surviving the initial impact of the oil or by other means such as attachment to drifting weeds (Jones et al. 1998).

On polluted soft substrate shores there was an initial high recruitment of pioneer species such as the fluke, *Pirinella conica* and the polychaetes, *Perinereis vancaurica* followed by the regression of algal mat cover. Similarly on rocky shores, initial heavy settlement of species such as *Balanus amphitrite* in 1991-1992 onto surfaces devoid of species due to oil pollution has receded as a balanced biotic community has developed (Jones et al. 1998).

In 1998, Jones et al. recorded a heavy settlement of the polychaetes *Owenia* spp. and *Melinna* spp. and the bivalves *Tellina arsionensis* and *Dosinia hepatica* in synchrony on impacted and unimpacted shores. Survival levels of the same order of magnitude for these species on all shores were an indication that impacted shores were nearing balanced community structure.

**Salt marshes**

Almost all of the salt marshes along the Saudi coast were impacted by oil in 1991. The zone between the spring and neap high water marks was covered by a continuous band of oil and tar, with devastating effects on fauna and flora. Due to the presence of numerous crab burrows, the oil penetrated up to 60cm into the fine grained, usually impermeable sediments (Barth 2001) and became compacted (see fig. xiii). All benthic fauna as well as most halophytes were decimated after the oil settled along the shores. In addition these regions are generally found at the rear of bays, receiving little wave action to assist in the natural cleaning process (Jones et al. 1998). On a small number of sites, fine sediments were deposited by tidal action; this undisturbed substrate allowed the rapid colonisation of cyanobacteria, which had formerly been excluded due to bioturbation by crabs and polychaetes. The complete destruction of the salt marsh biota and some deposition of new sediment created an ideal environment for the growth of algal mats. This layer of laminated cyanobacteria was impermeable and created an anaerobic environment, which became colonized by purple sulphur bacteria which appeared to utilize the sulphide formed by sulphate reducing bacteria degrading organic matter within the mat. Thus the surface of the tar became an interesting and unexpected microbial ecosystem (Floodgate 1995). Barth (2001) noted that even ten years after the spill, liquid oil was still present in the upper sediments; and hydrocarbon
concentrations were very similar to those of 1991, with values of up to 50 μg g⁻¹, heavily restricting the recolonization of original biota.

Figure xiii: Oiled crab burrows in halophyte salt marsh (2nd April 1992) A: Heavily oiled sediment surface in the dead marsh. Two oil-encased crab burrow entrances are shown in the middle of photograph. B: Broken open crab burrow from the same area. Surface of the sediment, which is mostly mud, is at top. Burrow is lined with liquid oil (from: Hayes et al. 1993)

In areas where no new sediments had been settled, the cyanobacteria were actually contributing to the bioremediation process. Fracturing of the algal mats due to desiccation helped to break up the tar crust (see fig xiv.). The effects of wind and water then remove the dried mats together with part of the tar. Recovery of diversity in the mid and upper eulittoral was due to recolonization by the pioneer species Pirinereis vabcaurica and Perinereis conica, and during 1994-1995 heavy settlement of Owenia spp. and Dosinia hepatica occurred.
Figure xiv: Algal mats curling up at the edges and lifting the tar layers during extended dry periods (from: Krupp & Jones 1993)

Tar crusts are still present in other areas devoid of cyanobacterial growth, preventing crabs and other organisms from burrowing into the sediment. In 2001, Barth observed some *Arthrocemum macrostachyum* within the tar encrusted substrate, but only in areas where the crust had been broken.

Tidal channels play a major role in recolonization in a number of areas. The fresh sea water and food supply provides a suitable habitat for a number of organisms which break up the adjacent sediments. This action increases the oxygen concentration within the sediment significantly, accelerating the biodegradation of the oil. The crabs are then able to expand into areas of degraded oil, and the process continues; the break up of the tar crust allowing the recolonization of plant species. 10 years after the spill, Barth (2001) recorded the occurrence of this process only in areas 5 to 15 metres adjacent to tidal channels. Recovery was found to be generally slower than in other ecosystems and Barth 2001 suggests that a time span of one or two decades will be necessary to completely break up tar cover (provided that cyanobacteria grow there each year). Only 20% of salt marshes could be considered fully recovered in 2001 whereas about 25% were completely devoid of life without any sign of regeneration (Barth 2001).
Mangroves

The mangroves of the Saudi coast only consist of one species, *Avicennia marina*, and are commonly found in association with salt marshes. This species is known to be tolerant to oil pollution, provided the pneumatophores are not totally covered with oil. It is able to develop anomalous adventitious aerial roots and pneumatophores after oiling, contributing to its ability to survive oil pollution (Böer 1993). Furthermore, the rhizodermis of the pneumatophores may form a natural oil barrier. Around half of the trees were affected by the spill, and 30% died. Natural regeneration, however, was fairly rapid and the first mangrove seedlings germinated after two years.

By making use of the widely distributed tidal channels as discussed, benthic organisms colonized the sediments adjacent to the channels, breaking up the tar crust and oxygenating the sediment. Due to stronger water currents, a higher rate of inundation by sea water and a narrow network of tidal channels, the process occurred much faster in this ecosystem type than in the salt marshes. At the seaward edge of the tar sheets, the cycle of algal mat colonization, peeling and removal by tidal action was the major force in tar removal (Jones et al. 1998). Species diversity on the lower shore reached normal levels by 1993, and with the regression of the algal mat in 1994 (see fig. xii), normal diversity was reached at the top of the shore.

By 1995, on mud and mangrove shores, over 90% reduction of the original oil cover had occurred (Jones et al. 1998). Species abundances increased rapidly on the lower and midshore during 1994 following settlement by *Owenia* spp., *Dosinia hepatica* and *Tellina arsionensis*. In the upper eulittoral, the pioneer species, *Perinereis vancaurica* and *Pirinella conica* increased in abundance, initiating recovery patterns seen elsewhere (Jones et al. 1998). 10 years after the spill, most sites were aerobic and well bioturbated; benthic organisms had reached their original abundance and diversity and the oil was well degraded or undetectable (Barth 2001). Today, the only visible impacts are some remains of dead plants and very few tar residues. In these ecosystems, actual recovery rates were much faster than previously estimated by Böer (1994).

Sandy shores

Most sandy beaches on the Saudi Arabian coast are narrow due to their exposure and wave activity. The strong wave action generally promotes sediments with a larger grain size, allowing the oil to penetrate to a greater depth. However, the wave energy also increases
oxidation rates, accelerating the degradation processes. When oil accumulates in silty or muddy sediments of calm water bays, contamination generally persists longer (Randolph et al. 1998). Several million gallons of oil remained in the subsurface of the intertidal zone one year after the spill, with a 15-20cm penetration depth on exposed sandy beaches (Hayes et al. 1993). Because of the unusually great depth of penetration and the amount of oil remaining, it was predicted by Hayes et al. 1993 that oil contamination was likely to remain for many years and possibly decades. Sediment toxicity was found at several sites within the Jubail Marine Sanctuary. Although all beaches received some oil deposits in 1991, the physical energy of the waves was enough to break up the tar crusts within the first 2 to 4 years after the oil spill. Today, the only remaining evidence is a few oiled pebbles scattered around the beaches. Around 80% of the sandy shores had recovered in 2001, albeit with some oil residues remaining buried underneath new sand, although hydrocarbon concentrations greater than 20 μg g\(^{-1}\) were rare and species composition was comparable with control sites (Barth 2001). In cases of higher hydrocarbon concentrations, again the oxygen deficit below an impermeable tar crust was responsible for the persistence of the oil.

Most sandy beaches could be considered fully recovered after five years, since the high oxygen concentrations in most sandy sediments led to a significant degradation of the oil allowing recolonization.

**Rocky shores**

Although heavily impacted by the spill in 1991, physical wave action accelerated the oil degradation; and rocky shores were observed to be free of oil as early as 1992 (Jones et al. 1992). Many key species were present by 1993, although the key top shore gastropods *Nodolittorina subnodosa* and *Planaxis sulcatus* were only found alive for the first time in 1995 (Jones et al. 1998). In a number of areas, residual oil had hardened and become part of the rock surface, covered with barnacles and other sessile biota.

**Coral reefs**

Coral reefs, although generally regarded as fragile ecosystems, are surprisingly resistant to oil pollution. Since reefs are essentially subtidal, and oil tends to float, impact is normally minimal as long as the slick passes over the reef fairly quickly, without major inhibition of photosynthetic activity. Since oil is fat soluble, it commonly accumulates in the fatty tissue of the gonads. The acute effects of a major oil spill in the Caribbean, near the Panama Canal included: increased mortality; reduced reproduction; fewer ova per gonad and reduced
settlement in *Styllophora*. Coral cover in this case decreased by 76% at 5 – 3 metres and by 56% at 3 – 6 metres on heavily oiled reefs (Guzman *et al* 1994).

Following the Nowruz oil spill in 1983, there was an increase in algal cover on coral reefs in the Gulf, which also lead to an apparent reduction in invertebrate abundance. A secondary impact was increased sedimentation as a result of oiling, resulting in complete or partial smothering of the coral polyps, killing the coral. In the case of the 1991 spill Downing & Roberts (1993) pointed out two other longer-term problems to be considered. The slight reduction in water temperature, due to the persistent smoke layer above the northern Gulf, when exaggerated by cold winter temperatures could expose reef corals to water temperatures close to or below their lethal limit. Secondly PAHs present in the soot fall-out may have had a toxic effect on the reef biota.

The coral reefs of the Gulf are the most important repositories of biodiversity in the region and also among the most productive offshore ecosystems (Basson *et al*. 1977, Sheppard *et al*. 1992). Reef associated fisheries have been exploited by artisanal fisherman since earliest history. There are several coral cays in the Gulf which support significant nesting populations of green and hawksbill turtles as well as several species of tern. A background of detailed knowledge of the reef ecology in the Gulf, particularly in Kuwait, greatly aided assessments of the impact of the oil spill.

The reefs were only slightly affected by the oil or not at all and, surprisingly, in some areas, a significant increase in coral cover was recorded from 1992-1994 (Vogt 1995). A patchy distribution of mortality in *Acropora* and *Porites* was apparent on offshore Kuwaiti reefs as early as 1992 (Price *et al*. 1994). However, it is unlikely that the war was the primary cause, due to the region’s history of bleaching events and coral kills during the 1980s. Reduced insulation and low water temperatures in 1991 could conceivably have contributed to the coral mortalities. The Gulf is at the northerly limit of coral reef distribution. Each winter, Kuwait’s corals survive low water temperatures, and are smothered by the algae *Colpomenia* sp. and *Giffordia* sp. (Downing & Roberts 1993). Their survival under these conditions is probably at least partially dependent on lipid stores built up during the previous summer. Reduced sunlight and lower temperatures during the summer of 1991 may have prevented the accumulation of normal levels of lipid reserve, impairing the ability of corals to tolerate low winter water temperatures (Harriot 1993).

At Qit’at Urayfijan, there was evidence of impact, probably closely linked to the war, but recovery was rapid; conversely, the Getty reef, in close proximity to a beach heavily impacted
by oil was completely unaffected (Downing & Roberts 1993). Fish populations had recovered from the effects of the oil spill by 1994 (Krupp & Almarri 1996). However, analysis of long-term trends indicated an apparent decline in fish population size across species at Kubbar between pre- and post-war counts.

Most of Saudi Arabia’s reefs showed no or little evidence of pollution damage. However, at Abu Ali, most fish present in 1992 were juveniles, indicating that there had been recolonization following a mass mortality, probably in December 1991, maybe as a result of cold water temperatures (Price et al. 1994). At Jurayd and many other reefs, anchor damage from fishing and recreational diving (Downing & Roberts 1993) appears to be a problem which must be considered, and proper management of human activity on these reefs is an urgent priority.

Reef corals are particularly sensitive to environmental stresses. Concern that coral may have succumbed to some of the aforementioned effects of oil on growth processes has instigated geochemical analysis of colonies in the area. Through analysis of the four outer rings of a Saudi Arabian Coral, (see fig. xv.) enrichment of fresh oil on the outside and higher concentrations of degraded oil within the head were apparent; along with relatively high levels of mercury in Kuwaiti corals of 140 – 230ngg⁻¹ (Price et al. 1994).

Figure xv: A computer enhanced scan of an X-ray of a coral (Porites mea) from Qaru Island, Kuwait; showing the axis of coral growth and 8 year-bands (from Readman et al. 1994)
More recent technology has shown that growth bands may be used as historical markers of pollution events which, using specific terpenoid bio-markers, can be sourced to specific oil fields such as Kuwait, Iranian or Arabian crude oils (Readman et al. 1996b).

Many workers (e.g. Price et al. 1994) have concluded that natural fluctuations in the coral reef community may have effectively masked any supposed impact of the Gulf War. Long term monitoring of populations on Kuwait’s reefs should be continued to provide the data necessary to underpin the management of these important habitats.

**Seagrasses**

Ecological and physiological studies on seagrasses do not suggest acute or long-term degradation of this important nursery and feeding habitat for a number of commercially important fish species (Durako et al. 1993, Kenworthy et al. 1993). In a study of seagrasses in the Gulf one year after the oil spill, Kenworthy et al. (1993) recorded that the most abundant species was *Halodule uninervis*. It was found that specific productivity for this species was similar to other reported rates for healthy populations of *Halodule* species. Other seagrass species present were *Halophila ovalis* and *Halophila stipulacea*. Leaf morphology and indicators of vegetative growth suggested that all three species were healthy.

Given that oiling was superimposed onto an already existing set of stress factor, these species demonstrated an exceptional capability to thrive under the ambient conditions as well as the conditions they were exposed to during the spill. This is probably because there were few intertidal seagrass beds in the north-western Gulf and most of the oil floated through to the intertidal and supratidal zones. In a situation where the petroleum products were well mixed by physical energy (wind or wave turbulence) or where extensive intertidal beds occurred, the seagrasses could experience a greater impact (Kenworthy et al. 1993).
3. Recent events and the future of the region

3.1 Environmental effects of the recent conflict in Iraq

On 21st March 2003, UNEP announced that its Post Conflict Assessment Unit (PCAU) had initiated a desk study of the environment of Iraq. Clearly humanitarian aid is by far the first priority. Beyond these immediate needs, Iraq faces a multitude of long-term issues, arising from both direct damage from the war and years of neglect; such as the establishment of environmental systems to deal with hazardous waste; water and sewage treatment; ground contamination and air pollution. To these ends, much of the environmental efforts of forthcoming years will need to be directed towards imposing regulations; establishing monitoring regimes and training personnel.

Iraq has the second largest oil reserves in the world, after Saudi Arabia. The Rumaylah field in the south contains about 1000 wells, and the Kirkuk oil field in the north contains around 500 wells. Thus the potential for environmental terrorism similar to that in 1991 was a serious concern to environmentalists. The U.S. military also took the threat seriously, dropping propaganda leaflets with stern warnings against setting oil wells alight. Fortunately, although some wells were set alight, it was nowhere near the scale of 1991.

Further problems are caused by the massive amount of human waste, rubbish and toxic material generated by thousands of coalition troops as they crossed the desert. Most of this waste was simply buried in pits, leading to a necessity for continued long-term monitoring to assess the possibility of groundwater contamination. Depleted uranium has created concern among Iraqi doctors, who believe that it has caused a dramatic increase in childhood cancer rates and birth defects since 1991 (Mayell 2003). The country is littered with more than
twelve million land mines and other unexploded weaponry (Mayell 2003), which accelerate environmental damage indirectly by forcing people to move from fertile areas to marginal lands that are environmentally fragile, causing an inevitable loss of biodiversity. Studies in Mozambique, Sudan and the Afghanistan-Pakistan border area show that refugee camps are associated with deforestation, encroachment on vulnerable ecosystems and protected areas, water pollution, sanitation degradation, air pollution and loss of vulnerable species (Mayell 2003).

3.2 Local attitudes

A report in *The Islamic Republic Shipping Company Magazine* (1997) suggested that environmental problems in the Gulf were a direct result of the activities of the naval fleets of the United States:

‘On October 19, 1989, the U.S. in a blatant attempt to support Iraq, ordered bombing of Iran’s Reshadat and Resalat oil platforms by its battle ships, frigates and jet fighters, causing tens of thousands of oil barrels to pour into the sea per day. On April 18, 1988, the Salman oil platform in the Lavan oil field and Nasr oil platform in the Sirri oil field were bombed and destroyed by six American warships, causing hundreds of thousands of oil barrels to pour into the Persian Gulf until the platforms were rebuilt.’

…The constant high level of military presence in the area is described as a contributing factor to pollution:

‘Naval fleets of over 100 American warships, present in the Persian Gulf are polluting the Persian Gulf environment in different ways, such as throwing trashes, like empty drink bottles and food cans into the sea, thus causing the death of mammals such as whales and dolphins.’

…The United States’ ‘war games’ are also blamed for causing chemical, nuclear and sound pollution in the gulf:

‘The U.S. seems to have chosen the Persian Gulf as a place to test the weapons of its naval forces. The formation of the 5th naval fleet is just a cover up for this purpose because the National U.S. Sound and Marine Life Service which is responsible for the 1972 law on protection of mammals living in the sea has enacted new regulations which ban making sound more than 120 decibels in the American seas.’
According to a recent article in *National Geographic News*, the environment is not generally regarded as a priority issue in many Middle Eastern countries. Occasionally, there is evidence of concern for climate change, although this is often regarded as a western conspiracy to deprive them of income (Mayell 2003 — *an American*). Putting the Gulf war oil spill into perspective, the annual discharge of oil into Los Angeles Bay area is around 250,000 tonnes, about a third of the Gulf spill (Hannah 2003).

Clearly, there is a high level of inherent suspicion of western activities in the area, and this can have only been increased by the recent invasion of Iraq. Any future environmental management processes in the area must involve local scientists and communities in order to have any lasting level of success. Unfortunately, many westerners appear to currently have a rather patronizing attitude towards these great races originating from the cradle of civilization, and such attitudes must be overcome to prevent further conflict and allow the sustainable use of the rich natural resources of the area.

### 3.3 Lessons learnt from the 1991 response and future considerations in the management of war-related environmental problems

While the Gulf shows some acclimation to oil pollution, war-related events imposed an additional ecological burden on coastal systems that are naturally stressful and influenced by multiple background human impacts (Price 1998). Overall, there is evidence of ecological recovery of sandy and rocky shores; although full recovery of marsh and mangrove biota may take longer in some cases. Initial acute impacts on bird populations were overcome fairly rapidly. However, negative effects on fisheries caused substantial economic losses for a number of the Gulf nations, although a full recovery is now evident.

The total cost of the clean up from the 1991 war been estimated at more than US$700 million (McClain 2001). Even now, Kuwait is still trying to cope with problems left from unignited oil which formed around 300 lakes and pools that are sinking into the sand, contaminating some 40 million tonnes of soil (McClain 2001). If the full ecological impact of war damage is difficult to assess, full assessment of ecological costs can be even more problematic, when costs are spread over many people and are diffuse in both space and time (Milner-Gulland 1999). Marine renewable resources often contribute significantly to national economies and even geopolitical stability. Indeed, their effective assessment and management is fundamental to sustainable development. Ironically, an oil spill can actually show up as a
benefit in national accounts, since ecological damage would be ignored, but clean-up costs would be included as national spending, and hence increase Gross Domestic Product (GDP) figures (Milner-Gulland 1999).

A major difficulty in assessing and managing the impacts of the Gulf War is dealing with the highly variable temporal and spatial scales over which marine processes operate. Upholding regional and international agreements is particularly important in seas like the Gulf, whose cross-boundary resources constitute a valuable commons shared by eight countries and utilized by many more. There have been major increases in the use of the coastal zone as a repository for solid wastes, and this is becoming a serious environmental issue (Sheppard et al. 1992). However, war-related issues have often been viewed in isolation, rather than within a wider coastal zone management context, resulting in an incomplete picture. Adopting a study unit with sufficiently large spatial scale is critical, particularly in the assessment of migratory species such as birds and sea turtles. This approach also allows a better understanding of effects such as El-Niño Southern Oscillations (ENSOs) and coral bleaching.

Table iv: Phases of the oil spill clean-up (from Tawfiq & Olsen 1993)

<table>
<thead>
<tr>
<th>Phase</th>
<th>Description</th>
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<tbody>
<tr>
<td>Phase I</td>
<td>Spill combating, defence and protection of vital facilities</td>
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<tr>
<td>Phase II</td>
<td>Recovery of floating oil</td>
</tr>
<tr>
<td>Phase III</td>
<td>Clean-up of environmentally sensitive habitats</td>
</tr>
<tr>
<td>Phase IV</td>
<td>Shoreline clean-up</td>
</tr>
<tr>
<td>Phase V</td>
<td>Restoration of damaged habitat, disposal of recovered contaminants and assessment of long-term environmental damage</td>
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</tbody>
</table>

A further and fundamental issue concerns achieving consensus on what actually is the overall environmental problem, and how it should be resolved, if indeed there is a solution (Price 1998). Lack of a clear, common goal has been partly responsible for the range of both assessment and management approaches. The rapid clean up of the Gulf War spill (see table iv.) may not necessarily have been the optimal response given the Gulf’s perturbed and dynamic background. Furthermore, the limited effectiveness or even detrimental consequences of beach clean up of oil spills have been documented on numerous occasions. Little evidence has been found of significant biological improvement on cleaned-up sites over the natural recovery in impacted areas (Watt et al.1993). Saudi Arabia was responsible for the record recovery of over 1 million barrels of oil using skimmer ships (Tawfiq & Olsen
Protection of the Saudi coastal infrastructure enabled the Kingdom to maintain increased oil production levels, stabilizing global oil prices.

In 1991, the UN Security Council resolved that Iraq was liable for all direct environmental damage to Kuwait’s terrestrial environment and its natural resources. In September 1995, Kuwait filed a US$385 million claim against Iraq for environmental damage due to Iraq’s occupation. The specific claims made to the UN were for damages to health, coastal areas, maritime environment, groundwater resources and desert environment (McClain, 2001).
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