THE STATUS OF CORAL REEFS IN SAUDI ARABIA - 2000

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Executive Summary
Saudi Arabia's Red Sea coastline extends southward approximately 1,840 km from the Jordan border to the border with Yemen. The Saudi Arabian Gulf extends southward approximately 1072 km from the Kuwaiti border to the border with Qatar. The Gulf coast is much more developed (40 %) than the Red Sea coast. In some areas along the Red Sea, the impact on the marine environment is severe. The presence of most of Saudi Arabia's oilfields in the Gulf has been a significant factor in the development of the region

Coral reefs are found fringing the entire length of the Saudi Arabian Red Sea coastline and the offshore islands, and are generally in good condition with the exception of those near Jeddah and Yanbu. There were 194 species of corals recorded in the early 1980s along the Saudi Arabian coast with the greatest diversity in the central portion. In the Arabian Gulf, the reefs mostly appear as small pinnacles or outcrops, and as patch reefs between Ras Al-Mishab Saffaniyah and Abu Ali, and between Abu Ali and Ras Tanura, and as fringing reefs around the offshore islands.

Several surveys have recently been carried out in Saudi Arabian waters, spanning much of the eastern Red Sea and western Arabian Gulf. A semi-quantitative study was carried out in September 1999 in which seventy-nine sites were surveyed in the Farasan Islands Marine Protected Area. A monitoring programme was conducted during 1997-1998 that investigated coral reef health and surrounding water quality along the Saudi Arabian Red Sea coast. Coral reef substrate composition was analysed near Karan, in the Jubail Marine Wildlife Sanctuary, and at the inshore reefs off the peninsula of Abu Ali. Reef benthos along three unmarked transects was recorded with a video camera in July 1994 and compared with recordings from the same area during August 1999. Another comparison of live coral cover was conducted using two permanent transects placed perpendicular to the shoreline of Karan in water depths ranging from 2 - 6 m. Reef fish near Karan were monitored along 50 m transect lines.

Mass coral mortality occurred due to bleaching in the central-northern Saudi Arabian Red Sea in late 1998, extending from Jeddah to the Gulf of Aqaba. Bleaching was patchily distributed and highly variable in intensity. The most intense bleaching occurred near Rabigh, where > 65 % of total coral cover was bleached or recently dead. In the Arabian Gulf, in lagoon waters off Karan, the average live coral cover was 33 %. On the reef slope live coral cover dropped from 23 % in 1994 to just 1 % in 1999. At Abu Ali more than 99 % of colonies were dead with only small pockets of surviving coral tissue. In the Farasan islands, abundances of live coral, dead coral and other benthic lifeforms varied greatly among sites.

Percent covers of live *Acropora*, *Porites* and other live corals, increased with distance from the mainland, while abundance of dead coral declined with distance from the mainland. Significant levels of coral mortality were observed close to the mainland. Coral coverage at the Abalat Islands declined from approximately 80 % in 1993 to about 10 % in 1999. *Porites* colonies suffered 100 % mortality. Mean monthly sea surface temperatures were found to be unusually high (> 32 ºC) three months prior to the first report of coral mortality. No major coral die-off was recorded around Karan.

Threats to Saudi Arabia's coral reefs originate primarily through industrial development and maritime transport. With these are associated risks of oil spills, landfilling, pollutant discharges, effluents from desalination activities and a number of other major impacts. Most acute damage to reefs is localised and restricted to offshore islands (in the Gulf) and around major urban areas (in the Red Sea).

Saudi Arabia is signatory to regional and international agreements which place obligations upon it for prevention of pollution and protection of resources, including coral reefs. Among these are a number of international agreements and memoranda of understanding, and a series of national laws and royal decrees that are pertinent to coral reef conservation. The Kingdom lags behind in the development and implementation of marine protected areas. Many areas have been proposed and suggested, dating back to the mid- and late 1980s, and remain that way to date. With the exception of the Farasan islands, protected in 1996, and the Jubail Wildlife Sanctuary which was developed shortly after the Gulf war, there have been no other recent marine protected areas established. Currently there are 32 proposals for marine protected areas being put forward for the Red Sea alone.

Saudi Arabia has carried out a number of programmes and adopted a number of legal measures to conserve coral reefs. These include laws on pollution discharges and the establishment of protected areas. However, a number of issues remain unresolved or poorly addressed. These include foremost enforcement of existing emission standards, industrial development which includes landfilling, and integration of the public and private sectors in reef conservation.

1. Introduction

Saudi Arabia's Red Sea coastline extends southward approximately 1,840 km from the Jordan border north of Haql (29°30'N) to the border with Yemen at Oreste Point (16°22'N). The continental shelf extends offshore for distances < 1 km in the Gulf of Aqaba to > 100 km in the Farasan Bank. The Saudi Arabian Gulf extends southward approximately 1072 km from the Kuwaiti border (28°30'N) to the border with Qatar (25°15'N).

The climate is extremely arid and much of Saudi Arabia's biological productivity is confined to a narrow coastal strip, where coral reefs, mangroves and seagrass communities predominate. Average rainfall is less than 70 mm/year along the broad coastal Tihama plains of the Red Sea (Al Wejh: 16 mm/year; Jeddah: 63 mm/year; Jizan: 63 mm/year). Inland, above the coastal escarpment, it may exceed 200 mm/year.

In the Arabian Gulf, wind speeds range between 1 m/s in September to 4 m/s in June and July. Air temperatures range from 12 ºC in January to 37 ºC in August. Average annual maximum temperature is 46.5 ºC and water temperature generally ranges between 15 and 33

ºC, with extremes recorded at 10 ºC and 40 ºC (MEPA/IUCN 1992). The narrow straits of Hormuz restricts water exchange with the Arabian sea, which combined with high evaporation rates creates high-salinity water within the Gulf, with a turnover rate of three to five years (Hunter 1983).

Over 15 % of the population lives in the Red Sea coastal zone and over 5 % in the Arabian Gulf coastal zone, and urban and industrial development has had severe impacts on the coastal lands and waters, particularly adjacent to the major coastal towns and cities. Much of this development involved extensive land-filling and dredging which destroyed substantial areas of the intertidal and subtidal nearshore habitats (Chiffings 1989). In Jeddah, the Corniche development and other urban expansion continues this trend of destruction of habitat and natural resources (Child & Grainger 1990). In addition, an average 25,000 to 30,000 ships are associated each year with the oil production and petrochemical industries on both coasts (Lintner et al.1995).

The central Red Sea, including the Outer Farasan Bank, contains many species which are absent from the northern and southern reaches of the Red Sea. There is evidence that coral abundance is important in explaining species distribution in this zone as well as temperature. The southern Red Sea has many species which are more suited to sediment loaded waters which occur here because of terrigenous input and water mixing across the wide shallow coastal shelf. The highest sea temperatures are found in this zone and coral development is restricted. There is a lack of deep water habitats.

The Saudi Arabian Gulf coast is much more developed than the Red Sea coast. At present, about 40 % of the Gulf coast has been developed. In the Red Sea a smaller proportion of the coastline has been developed, but in some areas (for instance around Jeddah) impact on the marine environment is severe. The presence of most of Saudi Arabia's oilfields in the Gulf has been a significant factor in attracting development to the region (MEPA/IUCN 1989).

The Red Sea and Arabian Gulf exhibit markedly different bio-physical conditions, with the Arabian Gulf exhibiting more extreme changes in water temperature, in part related to the comparatively shallow nature of the Gulf, in particular close to shores (over 25 % of the Gulf is only 5 - 10 m deep; MEPA/IUCN 1992a). Species of corals appear more tolerant than their counterparts in the Red Sea, and up to a critical point are able to withstand environmental extremes that would normally kill corals in most other reef areas outright (Sheppard & Sheppard 1991). Waters and coastal habitats of the Gulf were adversely affected by massive oil spills during the Gulf War, with different habitats and biota being differentially affected (Krupp et al. 1996). Coral reefs were little affected (Vogt 1996), exhibiting high cover in most sites surveyed subsequently. More severe effects to reefs occurred in 1998, when elevated sea temperatures caused major death of shallow water corals in some areas (Vogt & Al Shaikh in press).

The Red Sea coast and islands support a variety of coastal and marine habitats, related largely to oceanographic regime, degree of exposure, and topographic features, particularly the distribution of suitable antecedent topography for development of coral reefs, mangrove stands and seagrass beds. The area has a complex tectonic history of uplift and subsidence, related to the rift development of the Red Sea from the movements of the Arabian and African tectonic plates. The present series of living coral reefs are the latest in a chronological sequence of raised (uplifted) and submerged reefs that have developed at

various times over the past several hundred millenia. In many cases the present reefs are developed on earlier reef structures. Detailed descriptions of the geology, physical environment, climate, hydrology, oceanography and habitats of the Red Sea and wider Arabian Region are presented by Fishelson (1971), Mergner (1971), Scheer (1971), Ormond et al. (1984a), Edwards & Head (1987), Crossland et al. 1987, IUCN/UNEP 1988, Benthoux (1988), Sheppard & Sheppard (1985, 1991), Behairy et al. (1992) and Sheppard et al. (1992).

The Saudi Arabian Red Sea coast is divisible into several relatively homogeneous areas in terms of the variety and distribution of coastal and marine habitats and reefs: the Gulf of Aqaba in the north, the northern-central section from immediately south of the Gulf of Aqaba to Jeddah, and the central-southern region from south of Jeddah to the Yemen border and including the Farasan Bank and Islands.

The Gulf of Aqaba is deep and relatively narrow, and is characterized by its geographical isolation and the number of species that are either restricted to or from the area, including several species of reef-building corals and fish. The extreme north of the Gulf contains species presently known from nowhere else in the Red Sea (MEPA 1987). Cool sea temperatures and a dispersal 'bottle-neck' into and out of the Straits of Tiran may be important factors in these species distributions. Reefs are typically narrow, fringing the steep mainland coast.

The northern-central Red Sea has a much higher diversity of reef and coastal habitat types than the Gulf of Aqaba, including large expanses of coastal marshes (sabkha), seagrasses, macro-algae and mangrove stands, and reefs fringing both the mainland and islands and offshore patch and barrier reefs. The area is renowned for the presence of the Al Wajh Bank, a large, relatively shallow area bordered by a barrier reef system on its seaward edge and incorporating many islands and reefs. The Bank is unique in several respects and is the current focus of marine protected areas planning by the NCWCD. With the exception of reefs in the vicinity of coastal towns and cities, most remain in good condition (NCWCD-JICA 2000, DeVantier et al. in press).

The central-southern area, including the Outer Farasan Bank and islands, has a different bio-physical and geomorphological character to the northern area and Gulf of Aqaba. The area contains species which are more suited to more turbid sediment-loaded waters which occur here because of terrigenous input and water mixing across the wide shallow coastal shelf. The highest sea temperatures are found in this zone and coral development is restricted. The Farasan Islands and surrounding waters and reefs have been designated as a major protected area.

Thus coral reefs fringe much of the entire length of the Saudi Arabian Red Sea coastline and the offshore islands (Fig. 1), and are generally in good condition with the exception of those near Jeddah and Yanbu (PERSGA 1998). Five areas in particular have been noted for their coral reefs: the Tiran Islands, the Al Wajh Bank, the reefs north of Yanbu, between Obhur and Thuwal north of Jeddah, and the outer Farasan Bank (MEPA/IUCN 1992b). In the Arabian Gulf (Fig. 2), the reefs mostly appear as small pinnacles or outcrops, and as patch reefs between Ras Al-Mishab Saffaniyah and Abu Ali, and between Abu Ali and Ras Tanura, and as fringing reefs around the offshore islands (MEPA/IUCN 1992a).

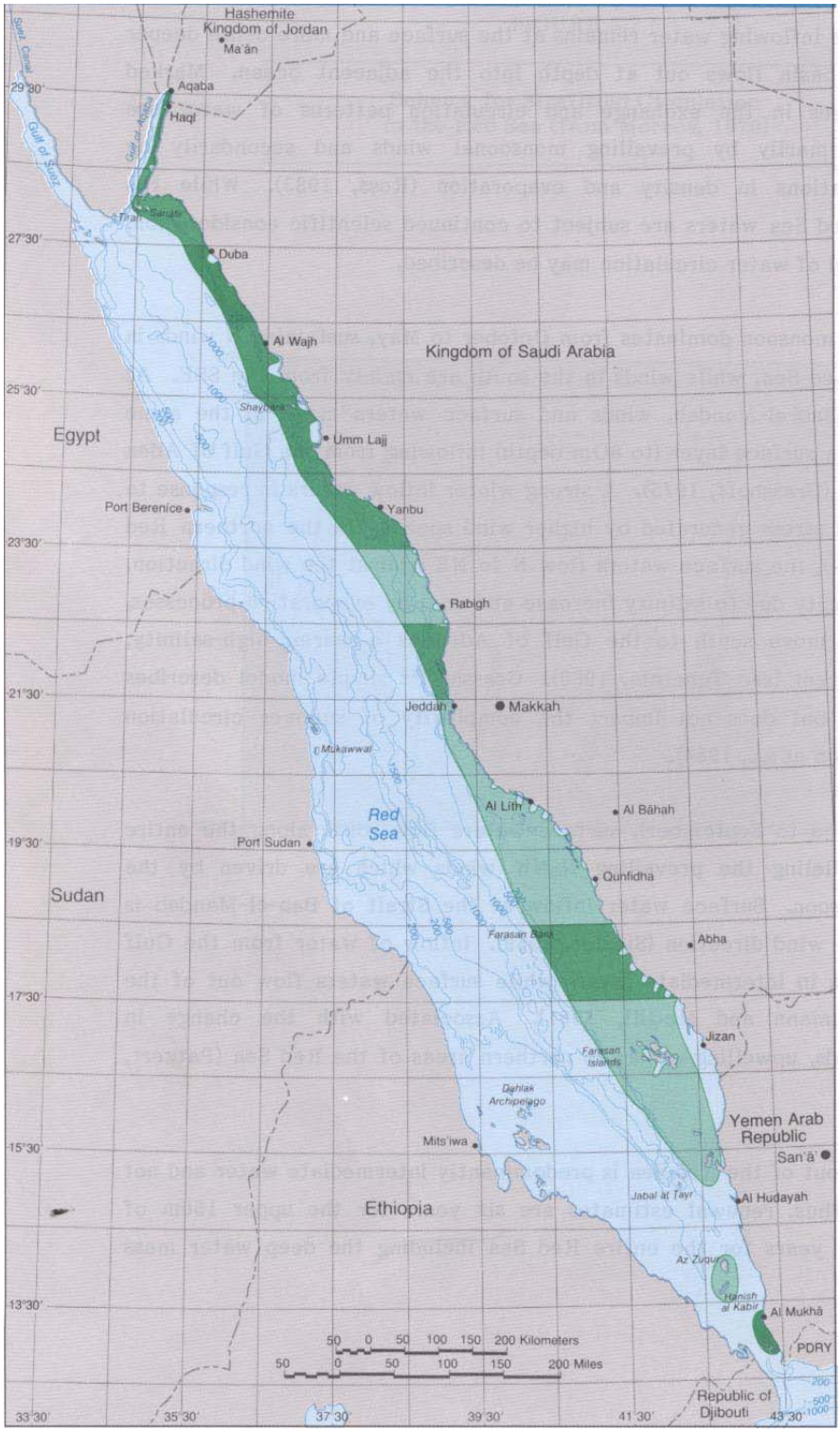

Fig. 1: Map of the Saudi Arabian Red Sea coast indicating coral reef densities: Dark shading represents areas where > 8 % of a (500 m × 500 m) quadrat was reef, moderate shading = 4-8 % of a quadrat, light shading < 4 % of a quadrat (Source MEPA/IUCN 1992b).

Fig. 2: Map of Saudi Arabian Gulf coastline indicating coral reef locations
(Source: MEPA/IUCN 1992a).

The near-continuous coral reef tract of the Red Sea has high local, regional and global conservation significance. With the exception of reefs in the immediate vicinity of coastal cities and towns (particularly Jeddah and Yanbu), these reefs generally have low levels of human use and impact. The region includes most of the world's major reef types, including mainland fringing reefs, island fringing reefs, platform patch reefs, 'pinnacles' and barrier reefs. Reefs are often developed in sharms along the mainland coast, a characteristic reef-form largely restricted to the Red Sea. While most reefs are actively accretional, levels of reef

development vary widely, from subsurface patch reefs with no reef flat (mostly in the Al-Wajh Bank and southern area), to narrow 'contour' fringing reefs with reef flats < 30 m wide (in the Gulf of Aqaba) to large platform and barrier reefs with reef flats often > 100 m wide, to tower reefs similar to atolls (on the Farasan Bank). These reef types support coral communities with highly variable levels of living and dead coral cover, species diversity and unique community composition, including species endemic to the region and others presently undescribed. The communities also support other reef-associated species of high conservation value and/or economic importance.

2. Methods

i. Geographical Scope

Several major research initiatives have been carried out in Saudi Arabian waters since the 1980s, spanning much of the eastern Red Sea and western Arabian Gulf. Substantial research has been undertaken in the Red Sea over the past several decades (see Mergner 1984, Sheppard et al. 1992 for reviews). The first major broad-scale surveys of coastal and marine habitat types and biodiversity of the Red Sea coast were undertaken in 1980s (Ormond et al. 1984a-c), which identified ca. 70 key sites for conservation, and also recommended establishment of five larger multiple-use marine protected areas (MPAs) in the Gulf of Aqaba, the Tiran Island chain, the Wedj Bank (herein Al-Wajh Bank), the Outer Farasan Bank and part of the Farasan Islands. To date, only the Farasan Islands have been designated as a MPA.

Reef types and composition of the coral fauna of the Saudi Arabian Red Sea were assessed in the early-mid 1980s (Sheppard & Sheppard 1985, 1991, Antonius et al. 1990), producing a comprehensive coral species inventory for the Saudi Arabian Red Sea. Subsequently, a monitoring programme was conducted during 1987-1988, investigating coral reef health and surrounding water quality along the Saudi Arabian Red Sea coast (Awad 2000). Black and White Band Diseases, shut-down-reaction and tissue bleaching were taken as pathogenic indicators, and more than twenty hydrographic, chemical and pollution parameters were used for describing the surrounding environment.

More recently (1997-99), the distribution and composition of coastal and marine habitats of the central-northern Red Sea, from north of Jeddah to Haql in the Gulf of Aqaba were assessed in a study conducted jointly by the National Commission for Wildlife Conservation and Development (NCWCD) and Japanese International Co-operation Agency (JICA). This study produced detailed site bio-inventories for corals, fish, other benthos, algae, sea-grasses, coastal vegetation and birds, and assessed the distribution and abundance of marine mammals and turtles. Combined with socio-economic assessments of patterns of human use and detailed habitat mapping prepared from aerial photos and satellite images, the data were used to define key reefs and larger reef areas of high conservation significance for MPA planning (NCWCD-JICA 2000, DeVantier et al. in press).

Further south in the Farasan Islands Marine Protected Area (FIMPA), abundances of live coral, dead coral, and coral-feeding crown-of-thorns starfish *Acanthaster planci* and snails *Drupella* spp. were assessed in 1999 (Al-Yami & Rouphael 2000).

In the Arabian Gulf, effects of the Gulf War oil spills on coastal and marine habitats and species (Krupp et al. 1996), and on coral cover and community composition were assessed at sites along the mainland coast and offshore islands (Vogt 1996). More recently, the effects of mass coral bleaching in 1998 were examined, using the same sites as were established for the Gulf War assessment (Vogt & Al Shaikh in press).

ii. Survey Techniques

Methods have ranged from broad scale habitat mapping using colour aerial photos and satellite imagery, rapid ecological and impact assessments, biodiversity studies of a variety of taxonomic groups and studies of coral cover, abundances of predators and diseases.

Habitat Mapping: Distribution and composition of coastal and marine habitats of the central-northern Red Sea were assessed using high resolution aerial photos and satellite images, combined with extensive ground-truthing (Ormond et al. 1984a-c, NCWCD-JICA 2000). The NCWCD-JICA data were incorporated into detailed GIS habitat maps of the distribution of coral reefs, seagrass and algal beds, mangroves and sabkha along the central-northern Red Sea coast and offshore islands.

Rapid Ecological Assessment: The distribution of different coastal and marine habitat types including coral reefs along the Red Sea has been documented using several rapid assessment methods (IUCN 1984, Dawson Shepherd & Ormond 1987, Price et al. 1998, Gladstone 1997, Rouphael & Al Yami 1999, DeVantier et al. in press).

The biological resources, resource uses and impacts along the coastline were assessed at ca. 1400 geographically discrete coastal and offshore sites (Price et al. 1998). The sites were selected every ca. 10 km along the shoreline and offshore islands. Each site comprised a 500 m × 500 m quadrat bisecting the beach, covering the immediate terrestrial, supra-tidal, inter-tidal and immediate sub-tidal zones. Within the quadrat, the abundance or ecosystems and species groups and magnitude of resource uses / impacts were estimated and recorded semi-quantitatively on ranked scales. The abundance of biological resources was also scored using a ranked 0 - 6 scale and scores were based on estimates of the relative abundance within each quadrat. Similar methods were used subsequently in the Yemen Red Sea and Gulf of Aden coasts, providing a uniform broad scale assessment.

Further rapid assessments of coral reefs (levels of reef development, benthic cover and various environmental attributes) of the Red Sea were undertaken in 1998-99 (DeVantier et al. in press). The surveys were conducted at 145 sites along the central-northern Red Sea coast and offshore islands. In meandering SCUBA swims of 30 - 45 min. duration at each site, ecological and substratum attributes were assigned to standard ranked cover categories, based on an assessment integrated over the length of the swim (see DeVantier et al. in press for detail).

Distribution and status of coral reefs around the Farasan Islands were assessed using semi-quantitative methods in the early 1990s, towards developing a management plan for the Farasan Islands MPA (Gladstone 1994a). Follow-up surveys of the reefs in the area were undertaken in 1999 (Rouphael & Al Yami 1999).

Biodiversity Assessment: Taxonomic inventories of some key elements of reef fauna and flora have been undertaken in the Red Sea (e.g. corals - Sheppard & Sheppard 1991,

DeVantier et al. in press) and Arabian Gulf (reviewed in Sheppard et al. 1992, Krupp et al. 1996).

A comprehensive inventory (including taxonomic revision of previous records and synonymies) of corals in the Saudi Arabian Red Sea was compiled by Sheppard & Sheppard (1991). These authors made extensive field collections, and also reviewed the many previous taxonomic lists published from the broader Red Sea (e.g. Scheer & Pillai 1983). More recently, further coral bio-inventories were compiled in the central-northern Red Sea (see DeVantier et al. in press for detail). Inventories of reef-associated fish, benthos, algae and sea-grasses were also made in 1998-99 (NCWCD-JICA 2000). Reef fish composition and abundance have been assessed using both quantitative (belt transects, collecting stations) and semi-quantitative (visual census) field methods (Ormond et al. 1984a-c, NCWCD-JICA 2000). In the quantitative assessments, numbers and/or log abundance estimates and/or sizes of fishes were made in single or replicated belt transects of known volume. In the semi-quantitative assessments, fish species lists and abundance estimates were compiled at point census stations or during SCUBA swims, using standard rapid assessment methods (see e.g. English et al. 1997).

Coral and fish species composition of the Saudi Arabian portion of the Arabian Gulf (wihtin the Jubail Marine Wildlife Sanctuary) were assessed in permanently marked belt transects, as part of an assessment of the effects of the Gulf War oil spills on coastal and marine communities (Krupp et al. 1996). These transects were resurveyed in 1999, following major bleaching-induced coral mortality in the region in 1998 (Krupp & Almarri 2000, Vogt & Al Shaikh 2000).

Long-term Monitoring: Baseline quantitative data on live and dead coral cover (replicated line-transects) and fish abundances (replicated belt transects) were collected using the Reef Check protocol (Hodgson 1999) in the Al Wajh Bank in 1999 (NCWCD-JICA 2000, DeVantier et al. in press). Follow-up monitoring surveys will be undertaken at these sites by NCWCD in the future. Recommendations for development of a monitoring program in the Farasan Islands were made by Gladstone (1994b). Rouphael & Al Yami (pers. comm.) plan to establish baseline monitoring stations using replicated line transects (benthos) and belt transects (fish) in the area.

Coral reef substrate composition and cover were analysed initially in 1992 in the Jubail Marine Wildlife Sanctuary, along 50 m transect lines (Vogt & Al-Shaikh 2000). In 1999, follow-up monitoring surveys to assess coral cover were conducted using both permanent and unmarked transects at Karan Island and at the inshore reefs off the peninsula of Abu Ali, in water depths ranging from 2 - 6 m. Allen et al. (2000) have also conducted long term monitoring of sites in the Arabian Gulf.

Reef fish near Karan Island in the Jubail Marine Wildlife Sanctuary were monitored along 50 m transect lines. Fish numbers were counted by species in an area one m either side of the transect and two m above the reef. All fish specimens greater than 20 mm in length were recorded. The reef fishes have been monitored annually between 1992 and 1995, and biannually thereafter (Krupp & Almarri 2000). Fish counts taken between 1992 and 1997 were used as a baseline for conditions prior to the 1998 coral bleaching event. In August 1999, three fish counts were made at each of two transects perpendicular and three transects parallel to the coastline of Karan Island.

4. Status of Coral Reefs – Benthos and Fish

i. Summary

In 1998-99, living cover of reef-building corals at individual reefs ranged from < 10 % to > 75 % while soft corals ranged up to 50 % cover. High cover of dead coral (> 20 %) occurred on some reefs following coral bleaching or predation. High cover of living corals was associated with reefs of relatively high exposure to wave energy and high water clarity. High coral cover was usually present on the shallow reef slopes of exposed fringing, patch and barrier reefs. With some important exceptions, deeper reef slopes (> 10 m), reefs in low wave energy environments and reefs with low water clarity usually had lower living coral cover than their shallow, more exposed counterparts.

The Red Sea coral communities were composed of at least 260 species of reef-building stony corals from 68 genera in 16 families of the Scleractinia. The coral communities were composed predominantly, both in terms of composition and cover, by the families Acroporidae, Faviidae and Poritidae. A diverse mix of soft corals, hydrozoan fire corals, gorgonians, corallimorpharians and zoanthids were also present.

Species diversity of scleractinian stony corals at individual sites in the central-northern Red Sea ranged from ca. 20 – 100 spp. (regional average: 61 spp.). There were four major coral community types, related largely to degree of exposure, water clarity, depth and steepness of reef slope. Notably, there was only minor variability in species composition among the assemblages, with the entire region exhibiting a high degree of homogeneity in terms of coral community composition, both latitudinally and longitudinally.

Reefs with moderate to high species diversity and abundance and living coral cover were widely distributed, with no clear latitudinal or longitudinal trends. Such reefs have high significance for replenishment, because of their potential as sources of large numbers of propagules of coral and of other reef-associated taxa.

ii. Disturbances

Overall, most reefs of the central-northern Saudi Arabian Red Sea were in good to excellent condition in 1998-99 (DeVantier et al. in press). There was little to no direct human impact (e.g. destructive fishing, anchor damage, coral mining or pollution) on the great majority of reefs, other than reefs in urban areas subject to land reclamation, urban run-off or littering. Coral communities on some reefs (ca. 10 % of those surveyed) had also been adversely affected to greater or lesser extent by coral bleaching or predation.

Bleaching was patchily distributed and highly variable in intensity, being most intense on reefs near Rabigh, where > 2/3 of total coral cover was bleached or recently dead (~20 - 40 % absolute cover). On worst affected reefs, bleaching occurred at the base of the reef-slopes (> 20 m depth), but was usually most intense in depths < 6 m, where > 1/2 of all coral species had been affected. High mortality (> 90 %) occurred within the most susceptible taxa, notably fire-corals *Millepora* spp., soft corals and a wide variety of stony coral taxa (DeVantier et al. 2000).

Bleaching followed a warm-pool of surface waters in July-September 1998, with sea surface temperatures elevated by > 1 ºC above mean monthly averages for a period of about one month (NOAA 'Hotspots' satellite imagery). Patterns of mortality to upper coral colony surfaces suggest that radiation effects may also have been implicated at some locations.

Other forms of recent coral mortality in the Saudi Arabian Red Sea included predation by crown-of-thorns starfish *Acanthaster planci* and muricid snails *Drupella* spp. Such predation had no noticeable effect on coral cover or community composition on most reefs, where starfish and snail populations were at low levels. However, coral cover and community structure had been affected by larger populations of the starfish on some patch reefs in the Al-Wajh Bank and Farasan Islands. The higher starfish population inside the Al-Wajh Bank may be related to over-fishing of predatory fishes in the families Lethrinidae, Balistidae, Labridae, Serranidae and Lutjanidae.

iii. Conservation Value

The area spanning the Farasan Islands to Haql in the Gulf of Aqaba is one of the most important coral reef areas for marine protected areas management on a global scale. Most of the region is presently little affected by local human impact, other than in the vicinity of coastal cities and towns where reef fishing, land reclamation, urban run-off and coastal littering has occurred. Major additional threats include ship wrecks and oil spills and global impacts from future climate change (bleaching and reduction in reef-building capacity from projected changes in ocean alkalinity). Reefs in some areas of the region appear to be naturally buffered against the worst effects of coral bleaching, because of the prevalence of cool water upwelling.

Reefs of high conservation value in terms of representativeness-uniqueness and 'quality' (i.e. high species diversity, high coral cover, and importance as reservoirs of biodiversity and replenishment) are widely distributed, from the Gulf of Aqaba and Tiran areas in the north, Duba - Al-Wajh, the Al-Wajh Bank, Umluj - Ras Baridi, Yanbu - Rabigh and the Farasan Bank in the south. Four sub-regions are of special conservation importance:

The Gulf of Aqaba: For the high levels of coral cover and species diversity, including species that are rare or apparently absent from other parts of the region (e.g. *Cantharellus doerderleini*, *Caulastrea tumida*). Of particular note are the characteristic narrow 'contour' reefs (< 50 m in total width) developed on steep coastal slopes. These narrow reefs were among the most species-rich of the entire region. The high diversity is particularly significant given the restricted reef area, cool sea temperatures, and given that the Gulf of Aqaba is at the north western-most extent of reef development in the entire Indo-Pacific region.

The Tiran Area: Extending from the mainland coast north of Duba to the entrance to the Gulf of Aqaba, for the wide variety of different biotopes and reef types, forming unique reef complexes with high zoogeographic significance. These reef complexes support a high species diversity including Red Sea endemic corals, presently undescribed coral species and species with restricted distributions otherwise rare or absent in the Red Sea.

The Al-Wajh Bank: For the greatest range of reef types (and other marine and coastal habitats) in the region. As with the Tiran area, reefs of the Al-Wajh Bank support Red Sea endemic corals, undescribed coral species and species with apparently restricted distributions. Its size and diversity of reef habitats, and likely high level of ecological connectedness in

terms of larval dispersal in ocean currents, both within the Bank and to other parts of the Red Sea, afford it great conservation significance.

The Farasan Islands and Farasan Bank: Supports a wide variety of reef types, including 'tower' reefs (Ormond et al. 1984a) and other marine and coastal habitats not present in other areas. The Farasan Islands support the first large Marine Protected Area in the Saudi Arabian Red Sea.

iv. Reef Distribution

Red Sea: The central-northern area from north of Jeddah to Haql in the Gulf of Aqaba supports a near-continuous coral reef tract composed of a wide range of reef types. The area supports relatively complex reef geomorphology, being comprised of mainland and island fringing reefs, various forms of patch reef, coral pinnacles and 'ribbon' barrier reefs (Ormond et al. 1984a provide a comprehensive review of the geomorphology and distribution of these reef types).

Mainland fringing reefs are distributed along much of the coastline, and are often developed in the entrances and sides of sharms, a characteristic reef-form largely restricted to the Red Sea (Ormond et al. 1984c). Extensive mainland fringing reefs occur around Rabigh, Ras Baridi, Umluj, Al-Wajh-Duba and in the Gulf of Aqaba, the latter often being narrow (< 30 m width), developed as 'contours' on the relatively steep sub-littoral topography (Fishelson 1980). Island fringing reefs are commonly developed in the Tiran area and from Duba - Al-Wajh Bank - Umluj.

Circular / elongate patch reefs are also widespread in offshore waters (< 50 m depth). Some patch reefs support sand-coral islands (cays), while others are submerged and resemble coral carpets (*sensu* Riegl & Piller 1999). Both forms are common in the Al-Wajh Bank and south from Umluj - Rabigh. 'Reticulate' patch reefs ('labyrinths / mazes' *sensu* Ormond et al. 1984a), composed of interconnected networks of reef matrix separated by sand, and forming intricate reticulate patterns, are particularly well developed in shallow waters (< 10 m depth) of the Tiran area and southern Al-Wajh Bank. Pinnacles (individual corals and coral 'bommies' surrounded by sand) are present in shallow waters (< 10 m depth), particularly in the Al-Wajh Bank and Tiran areas (DeVantier et al. in press).

Barrier reefs composed of platform and 'ribbon' reef structures are developed further offshore on the edge of the 'continental' slope, where water depths increase from < 50 m to > 200 m. The best-developed barrier reef system occurs along the seaward margin of the Al-Wajh Bank. The barrier is formed of a continuous line of reefs stretching for ca. 100 km and separated by several narrow (< 200 m width) channels (Ormond et al. 1984a, DeVantier et al. in press). Another barrier reef system of different gross geomorphological structure, the 'Little Barrier Reef', occurs further south near Yanbu (Ormond et al. 1984a, Sheppard & Sheppard 1985). The central-northern Saudi Arabian Red Sea does not support atoll-like or 'tower' reefs, more characteristic of southern areas and the outer Farasan Bank (Ormond et al. 1984a).

To the south of Jeddah, reefs become less well developed along the mainland coast, as differences in topographic features, sediment and turbidity tend to restrict coastal reef growth progressively towards the Yemen border (Price et al. 1998). Further offshore however, complex reef structures are developed on the Farasan Bank and islands (Ormond et al.

1984a), including tower reefs, similar in gross geomorphology to atolls, rare or absent in other areas of the Saudi Arabian Red Sea.

Levels of reef accretion among the various reef types range from small (< 1 ha) subsurface patch reefs - carpets with no reef flat to narrow fringing reefs with reef flats < 50 m wide to large fringing, platform and barrier reefs with reef flats often > 100 m wide.

Arabian Gulf: By comparison with the extensive development and large extent of the Red Sea reefs, the Saudi Arabian portion of the Arabian Gulf supports minimal area of coral reefs and coral communities, being confined to small fringing reefs around Abu Ali, and several offshore patch reefs, most of which support small coral islands (cays – e.g. Jana and Karan Islands). Despite their small geographic scale, these reefs are notable for being developed in extreme environmental conditions inimical to coral growth in most reef areas globally (Coles 1988, Coles & Fadlallah 1991, Fadlallah et al. 1993). The reefs are known to support < 100 species of stony corals and ca. 600 spp. of reef-associated fishes. These reefs are already protected within the Jubail Nature Sanctuary marine protected area, established following the 1991 Gulf War (Krupp et al. 1996). These reefs survived the effects of the Gulf War oil spills, but were affected to greater or lesser degree by bleaching in 1998 (Vogt 1996, Vogt & Al Shaikh 2000).

v. Coral Diversity

Red Sea: Sheppard & Sheppard (1985) identified 116 coral species or species groups in thirteen coral assemblages in the central-northern area of the Red Sea, the most distinctive being those from exposed locations dominated by species of *Acropora* and those from sheltered locations dominated by species of *Porites* (also see Antonius et al. 1993). Reefs around Yanbu were notable in supporting both a higher coral diversity and number of assemblage types than had previously been reported from the Red Sea. For the entire Red Sea, 194 species of corals were recorded in the early 1980s along the Saudi Arabian coast with the greatest diversity in the central portion (MEPA/IUCN 1987). This species list was revised by Sheppard & Sheppard (1991) and Sheppard (1997) with 140 species from the Gulfs of Aqaba and Suez (54 genera, 15 families) and 150 species (49 genera, 14 families) from the central Red Sea.

More recent surveys have expanded this list substantially, with approximately 260 species in 68 genera of 16 families of reef-building Scleractinia now known to occur in Saudi Arabian Red Sea waters (Table I). Of these, 26 species were previously undescribed (Veron in press) and ca. 50 species were distribution range extensions into the Red Sea. Several additional species had been described from the Red Sea in the 19th century, but had either been synonymised or lost from recent species lists (e.g. the branching *Acropora variolosa* (Klunzinger 1879), *Favites vasta* Klunzinger, 1879 and *Echinopora forskaliana* Milne Edwards & Haime, 1849 (Wallace 1999, Veron 2000). A further 16 species synonymised by Sheppard & Sheppard (1991) are considered herein as valid species in the Red Sea (Veron in press, DeVantier et al. in press).

A further ca. 30 taxa of soft corals, fire corals, zoanthids and gorgonians were recorded in the NCWCD-JICA Study (2000). However, because of difficulties of field identification and lack of taxonomic expertise in the non-scleractinian taxa, actual species diversity is substantially higher (L. DeVantier pers. obs., and see e.g. Reinicke 1997 for comprehensive review of the soft coral family Xeniidae).

Table I: Taxonomic composition of Red Sea scleractinian coral fauna, based on Sheppard & Sheppard (1991), Sheppard (1997) and the NCWCD-JICA Study (*) (Source: DeVantier et al. in press).

Family	*Genus*			*Species*		
	N – C Red Sea	Red Sea	N – C Red Sea *	N – C Red Sea	Red Sea	N – C Red Sea *
Astrocoeniidae	1	1	1	2	2	2
Pocilloporidae	4	4	4	8	8	11
Acroporidae	4	4	4	32	32	64
Poritidae	4	4	3	10	10	27
Siderastreidae	4	4	4	6	7	10
Agariciidae	4	4	4	16	16	21
Fungiidae	6	6	7	21	21	26
Oculinidae	1	1	1	1	1	2
Pectinidae	3	3	3	3	3	7
Mussidae	5	5	5	8	8	15
Merulinidae	2	2	2	3	3	3
Faviidae	15	15	16	40	41	61
Caryophylliidae	6	8	2	6	9	2
Dendrophylliidae	4	4	3	6	7	10
Trachyphylliidae	1	1	0	1	1	0
Rhizangiidae	2	2	0	2	2	0
Total	66	68	59	174	180	261

At individual sites in the central-northern Red Sea, stony coral species richness ranges from ca. 20 – 100 species, with a further 5 - 15 non-Scleractinian taxa (DeVantier et al. in press). Average site diversity for scleractinian corals was 61 species, with deep sites usually slightly more species-rich than shallow sites. Highest diversity (> 75 spp.) occurred in ca. 17 % of sites, representing all major reef types, and with wide geographic distribution. There were no clear latitudinal or longitudinal trends, although reefs in the northern Gulf of Aqaba were particularly rich, given their high latitude location at the extreme north-west of reef development (with the adjacent Gulf of Suez) in the entire Indo-Pacific Region. Some species in the coral assemblages have very widespread Indo-Pacific distributions, others appear restricted to the Arabian Region or Red Sea (Veron 1986, 1993, 1995, 2000, Hoeksema 1989, 1993, Sheppard & Sheppard 1991, Sheppard 1997, Wallace 1999). Thus the Saudi Arabian Red Sea supports a unique composite fauna of coral species known from the following biogeographic provinces or sub-provinces:

- Widespread across the entire Indo-Pacific - e.g. *Pocillopora damicornis* and *Gardineroseris planulata;*
- Widespread in the Indo-west Pacific - e.g. *Stylophora pistillata, Acropora muricata* (previously *A. formosa,* see Wallace 1999);
- Previously known only from the Pacific Ocean – e.g. *Cantharellus noumeae*;
- Widespread in the Indian Ocean - e.g. *Coscinaraea monile* and *Siderastrea savignyana*;
- Widespread in the western Indian Ocean - e.g. *Acropora hemprichii*;
- Red Sea 'endemics' - e.g. *Symphyllia erythraea*, *Merulina scheeri, Cantharellus doederleini;*
- Presently undescribed spp.

Several corals thought to be endemic to the Red Sea are well represented and widely distributed within the central-northern area (Sheppard & Sheppard 1991, DeVantier et al. in press), notably *Echinopora fruticulosa*, *Echinopora forskaliana, Merulina scheeri, Stylophora wellsi*, *Symphyllia erythraea* and *Acropora variolosa*, all occurring in > 1/3 of sites (DeVantier et al. in press). Others were relatively uncommon (ca. 10 % of sites: *Stylophora mammilata*, *Favites vasta* and *Erythrastrea flabellata*) or rare (< 2 % of sites: *Cantharellus doerdeleini* and *Alveopora ocellata*).

Some of these differences in abundance may be explained by habitat preferences. For example, *S. mammilata* prefers reef slopes > 20 m deep, areas which have not been extensively sampled. *Erythrastrea flabellata* was found only in the northern area (N of Umluj), consistent with previous studies (although one colony has been reported from the Gulf of Aden, Sheppard & Sheppard 1991). *Cantharellus doederleini* is considered endemic to the northern Red Sea (Chadwick-Furman & Loya 1992, Hoeksema 1993). *Alveopora ocellata* was recorded from the Al-Wajh Bank and adjacent waters. Three of these species (*Stylophora wellsi, Favites vasta* and *Symphyllia erythraea*) are now known to occur outside the Red Sea, their distributions extending into the Arabian Sea (L. DeVantier pers. obs., Veron in press). Conversely, most of the undescribed species are presently known only from the central - northern Red Sea (Veron in press), although further work in the larger Arabian and western Indian Ocean regions may extend their distribution ranges.

Arabian Gulf: The Arabian Gulf is relatively depauperate in coral species in comparison with the Red Sea, supporting considerably less than 100 scleractinian taxa (Sheppard & Sheppard 1991). Sheppard (1997) lists 62 species from 27 genera in 11 families (Table II). Notably the families Astrocoenidae, Oculinidae and Caryophylliidae were not represented, while the Fungiidae and Pectiniidae were represented by a single species (*Cycloseris cyclolites* and *Echinophyllia aspera* respectively). Furthermore the speciose families Acroporidae, Poritidae, Mussidae and Faviidae are all poorly represented in the Arabian Gulf in comparison with the Red Sea. The depauperate nature of the Arabian Gulf coral fauna has been attributed to the harsh environmental conditions (temperature extremes, limited suitable antecedent topography for reef development and turbid waters), to a likely dispersal bottleneck through the Straits of Hormuz and to a partial dispersal barrier in the Arabian Sea (Sheppard & Sheppard 1991, Sheppard et al. 1992).

Table II: Comparison of Red Sea and Arabian Gulf stony coral fauna (after Sheppard 1997 for Red Sea genera and Arabian Gulf genera and species and DeVantier et al. in press for Red Sea species).

Family	*Genus*		*Species*	
	Red Sea	Arabian Gulf	Red Sea	Arabian Gulf
Astrocoeniidae	1	0	2	0
Pocilloporidae	4	3	11	4
Acroporidae	4	2	64	13
Poritidae	4	2	27	6
Siderastreidae	4	5	10	7
Agariciidae	4	1	21	5
Fungiidae	6	1	26	1
Oculinidae	1	0	2	0
Pectinidae	3	1	7	1
Mussidae	5	2	15	3
Merulinidae	2	1	3	1
Faviidae	15	7	61	16
Caryophylliidae	8	0	2	0

Dendrophylliidae	4	2	10	5
Trachyphylliidae	1	0	0	0
Rhizangiidae	2	0	0	0
Total	68	27	261	62

vi. Coral Communities

Red Sea: Within the central-northern Red Sea region, 10 coral communities encompassing ca. 20 coral assemblage types have been described (Sheppard & Sheppard 1991, Table III). Whilst differentiating these assemblage types, the authors noted the high degree of similarity in species composition within the region, where species at most individual reefs were a subset of the larger regional species-pool.

Table III: Major coral communities of northern - central Red Sea (Source: Sheppard & Sheppard 1991).

Reef type, exposure and habitat	*Dominant coral species*	*Location in Red Sea*	*Characteristic Assemblages*
Shallow patch reef, exposed in sandy plain	*Acropora horrida, A. formosa*	Suez	None
Shallow exposed fore-reef slopes	*Acropora hyacinthus, A. humulis*	North - central	None
Shallow - mid-depths, moderate exposure	None	North	None
Sheltered fringing reefs, backs of patch reefs	*Porites lutea*	North - central	None
Shallow - mid-depths in north, mid-deep in central region, moderate exposure	None	North - central	A) *Millepora* B) None C) *Goniopora*
Moderately turbid and exposed mid-depths	None	North - south	None
Mid-depths, patch-reefs in sand	*Pocillopora damicornis, Acropora eurystoma, A. clathrata*	Central	None
Patch- and barrier reefs, mid-depths	*Pocillopora verrucosa, Acropora hemprichi*	Central	None
Barrier and exposed fringing reefs, shallow	*Acropora hyacinthus, A. digitifera, A. humilis A. danai, A. hemprichi, Pocillopora verrucosa*	Central	A) *A. hyacinthus* B) *A. danai* C) *P. verrucosa*
Barrier, patch- and fringing reefs, mid-depths	*Porites*	Central - south	*A) Montipora a circumvallata* *B) Goniastrea pectinata*

More recent studies in the area (DeVantier et al. in press) have confirmed the high degree of homogeneity in species composition within the region. There were, however, major differences in abundance of particular taxa in certain biotopes, and thus clear zonation patterns in the structure of coral communities. These were related largely to degree of physical exposure, water clarity-irradiance, depth and steepness of reef slope (Done 1982, Sheppard 1982). Most of the assemblage types previously described for the central - northern Red Sea (Table III) were represented in the four major community types described below. These community types form part of a continuum, with particular species exhibiting differences in occurrence and abundance related to site-specific habitat characteristics and disturbance-histories.

Arabian Gulf
Coral communities range in composition from large monospecific stands, mostly of *Acropora* and *Porites* spp. to more diverse assemblages composed of massive poritids and faviids (Vogt 1996). Community structure at individual sites appears to be related to exposure, water clarity, temperature and depth.

vii. Coral Cover
Red Sea: There is considerable variability in cover of stony and soft corals in response to reef-specific characteristics and disturbance histories, and species-specific tolerances to stress, particularly exposure, levels of sedimentation, turbidity and illumination.

In 1998-99 in the central-northern Red Sea in 1998-99, living cover of stony corals (including *Millepora* spp.) ranged from < 10 % to > 75 %, with an average of ca. 35 % (DeVantier et al. in press). Approximately 17 % of sites had high living stony coral cover (> 50 %), particularly on shallow reef slopes, where large mono- and multi-specific stands of *Acropora*, *Porites* and *Millepora* were often conspicuous. Cover usually declined on the deeper slopes.

Dead standing corals and rubble were relatively minor components of cover (< 10 %) at most sites (average ca. 7 %). Highest levels of dead coral (30 %) occurred following intense coral bleaching (the expulsion of symbiotic microalgae – zooxanthellae, and pigments by the corals when stressed) in August-September 1998 (DeVantier et al. 2000). Mass coral mortality following the bleaching was patchily distributed and restricted to < 10 % of reefs surveyed. Bleaching and subsequent coral mortality were most intense on reefs near the town of Rabigh, where up to 90 % of total coral cover was bleached or recently dead (20 - 40 % absolute cover). Bleaching occurred down to the base of the reef-slopes (> 20 m), but was most intense in depths < 6 m, where greater than half the coral species had been affected (DeVantier et al. 2000). Further high coral mortality occurred and on patch reefs in the Al-Wajh Bank following predation by crown-of-thorns starfish *Acanthaster planci* (DeVantier et al. in press).

Cover of soft corals in the central-northern Red Sea ranged up to 50 %, but usually was < 30 % (average ca. 9 %). Large beds of *Xenia* spp. and stands of *Sinularia cf. capitalis* covering 100s of m^2, were a characteristic feature of some sites, the latter species forming large tree-like colonies to 2 m height and contributing substantially to reef accretion (also see Reinicke 1997, Schuhmacher 1997). Cover of turf, coralline and macro-algae was usually low (< 10 %) in these coral dominated areas. Cover of algae usually increased on the inner reef flats.

Although some reefs with high living coral cover occurred in sheltered habitats, particularly subsurface patch reefs of the Al-Wajh Bank, high cover of stony corals, soft corals and crustose coralline algae were all commonest on shallow reefs of high exposure with steep slopes and high water clarity.

Further south, in the Farasan Islands Marine Protected Area (FIMPA), abundances of live coral, dead coral and other benthic lifeforms also varied greatly among sites. Percent covers of live *Acropora*, *Porites* and other live corals, increased with distance from the mainland, while abundance of dead coral declined with distance from the mainland (Al-Yami & Rouphael 2000). Significant levels of coral mortality were observed close to the mainland. For example, coral coverage at the Abalat Islands declined from approximately 80 % in 1993

to about 10 % in 1999. *Porites* colonies, some in excess of 1.5 m diameter, suffered 100 % mortality. Mean monthly sea surface temperatures were found to be unusually high (> 32 ºC) three months prior to the first report of coral mortality in 1996.

Arabian Gulf: In the Arabian Gulf, in the shallow lagoon waters off Karan Island, the average live coral cover was 33 % during the 1992 and 1994 surveys. In 1999, the results were only slightly lower (31 %), indicating that lagoon communities had not deteriorated significantly. On the reef slope however, live coral cover dropped from 23 % in 1994 to just 1 % in 1999. At Abu Ali more than 99 % of colonies were dead with only small pockets of surviving coral tissue on the major reef-building *Porites harrisoni*. During earlier surveys (1994) extensive *Acropora* communities were recorded at the eastern tip of the peninsula. In 1999, not a single colony was found alive. A likely cause of the coral mortality in shallow waters was the high sea surface temperatures, which exceeded 34 ºC in the summer of 1998 (Vogt & Al Shaikh 2000).

viii. Damage and Coral Mortality

Overall, most reefs (ca. 90 %) of the central-northern Red Sea were in good to excellent condition in terms of the ratio of live : dead coral cover and levels of injury to coral species in 1998-99 (DeVantier et al. in press). There was little to no direct human impact (e.g. destructive fishing, anchor damage, coral mining or pollution) on the great majority of reefs, other than reefs in urban areas subject to land reclamation, urban run-off and pollution or littering. Most damaged reefs occur in the immediate vicinity of the major coastal cities and towns.

At most sites outside these areas, levels of injury and death of corals were low (< 10 % cover of dead corals), with < 20 % of species present exhibiting injury, and < 20 % average injury to those species. Coral communities on ca. 10 % of reefs surveyed had been adversely affected by bleaching, by coral predation (mostly by crown-of-thorns starfish *Acanthaster planci*) or by sedimentation (DeVantier et al. in press).

Coral Bleaching: No evidence of mass bleaching or other forms of major coral mortality were found during surveys in the central-northern Red Sea in May - June 1998. Most reefs appeared to be in good condition. No bleaching was reported from other areas of Saudi Arabia at the time, although reefs further to the south in the Arabian Sea and greater Indian Ocean had already bleached extensively (Wilkinson et al. 1999). By October 1998, bleaching was patchily distributed throughout the Saudi Arabian Red Sea, extending north from the Farasan Islands to reefs around Jeddah and Yanbu (NCWCD pers. comm.). Reefs offshore from Rabigh and north to Yanbu experienced intense bleaching, causing high levels of coral mortality, while others (Ras Baridi, Al-Wajh Bank, Gulf of Aqaba) were little affected or unaffected. Minor bleaching occurred at some locations near Haql in the Gulf of Aqaba, and minor - moderate bleaching occurred in the Tiran area near Jazirat Muksoor. Bleaching was most widespread and intense in the shallower coral communities (depths < 6 m), where recently dead and bleached corals accounted for up to 90 % of the total cover of hard corals, soft corals and fire-corals *Millepora* spp. Deeper communities had also been affected, with coral mortality to ca. 15 % of species present (DeVantier et al. 2000).

Of the 325 zooxanthellate anthozoan taxa recorded during the pre- and post-bleaching surveys in May-June and September-October 1998, 124 taxa exhibited injury at one or more of the sites (84 species pre-bleaching, 101 species post-bleaching). Both the proportion of

coral species with injury and also the level of average injury per species increased from the pre- to post-bleaching surveys. As with coral cover, levels of injury to individual species were most intense on reefs around Rabigh, where over half of all species had been affected, with coincident high mortality (~ 90 %) to worst-affected taxa (DeVantier et al. 2000). Coral species that were worst affected by bleaching-related injury represented a wide range of genera and growth forms. Many of the worst affected taxa were uncommon, occurring at low abundance in few sites. Such species may be particularly susceptible to local extinction following such catastrophic mortality.

Extensive coral bleaching was reported to have occurred on reefs of the Farasan Islands, although the level of subsequent mortality and species affected are not known at present (NCWCD, pers. comm.). Precise timing of the bleaching at the Farasan Islands is not known. Rouphael & Al Yami (1999) suggested that extensive coral mortality in the nearshore Abalat Islands occurred in 1996, following elevated sea surface temperatures.

Coral Predation: Predation by crown-of-thorns starfish *Acanthaster planci* and muricid snails *Drupella* spp. had no noticeable effect on coral cover or community composition on most reefs in the Saudi Arabian Red Sea, where starfish and snail populations were at low levels. However, coral cover and community structure had been adversely affected by larger populations of the starfish (ca. 100 *A. planci* ha^{-1}) on patch reefs in the Al-Wajh Bank (DeVantier et al. in press). At the patch reef sites in the Al-Wajh Bank, the starfish had caused substantial reductions in living coral cover and coincident increases in dead coral cover and shifts in relative abundance and community structure. Starfish and snails were also implicated in coral mortality in the Farasan Islands (Rouphael & Al Yami 1999).

vii. Fish Communities

Numerous studies have documented species composition and abundance of reef fishes in the Red Sea. Recent diversity estimates vary greatly. Randall (1983) lists 325 species, although this was not a comprehensive systematic account, rather a pictorial account of common taxa. Ormond & Edwards (1987) record 508 species, substantially less than Botros (1971) with 776 species, Dor (1984) with 1,000 species or Goren and Dor (1994) with 1248 species. Differences among these various estimates are in part due to distinctions in the definition of 'reef fish', with the more conservative estimates being based on a stricter interpretation of the definition. Although many Red Sea reef fishes have distribution ranges that extend outside the Red Sea, to the Gulf of Aden, Arabian Sea and greater Indian Ocean and Indo-Pacific regions, others are presently considered 'endemic' to the Red Sea (Klauswitz 1987). Levels of endemism vary among different groups of fishes, being particularly notable in the Chaetodontidae. These endemics and other Arabian and western Indian Ocean species give a characteristic structure to Red Sea reef fish assemblages in comparison with their central Indo-Pacific and eastern Pacific counterparts. Major threats to diversity and abundance of fishes in the Red Sea include increasing fishing pressure, and development pressures near coastal towns and cities.

In the Arabian Gulf, over **600 (Fareed, any comments or more accurate quotes?)** fish species are now reported, even though the area of coral reefs is highly limited and naturally stressful conditions for tropical marine fishes prevail. Additionally, these reef fish populations are threatened by oil pollution and habitat destruction. These threats notwithstanding, reef fish populations were found to be in a healthy condition during recent

surveys (Krupp & Almarri 2000). Species compositions and population densities were within the range of previous years.

5. Status of Coral Reef Fisheries

i. Summary

Until 1981, Saudi Arabia's fishery was exploited almost exclusively by artisanal fishermen from small boats and larger Sambouks. Saudi Fisheries, an industrial fishery company began in 1991 and currently lands around 1,500 metric tons of shrimp and a similar amount of finfish. Despite this, landings remain dominated by the artisanal sector.

ii. Fishery Distribution

Coral-reef based fisheries are distributed along the length of the Red Sea, with the highest proportion of fishing boats being based in the south (Table IV). It must be noted, however, that the greater number of boats in the south does not represent an increase in fishing pressure on coral reefs, rather it represents the greater number of trawlers that make up the prawn and non-coral reef-based fisheries.

Table IV. Distribution of fishing boats along the Saudi Arabian coast in 1983/84 (Source: Housa 1985).

Location	*Number of Boats*
Tabuk	16
Wejh	50
Umm Lajj	199
Yanbu	259
Rabigh	215
Jeddah	254
Al-Lith	95
Qunfidha	117
Jizan	470
Total	1675

iii. Fishery Composition and Trends

Although fishery statistics have been analyzed for different sectors (Table V), differences between the various sources do not allow standardization or comparisons. A significant problem is that fishery statistics are normally aggregated for both the Red Sea and Arabian Gulf fisheries. A reliable long term series of catch and effort data, required for specific management suggestions, is not presently available.

Table V: Distribution of Red Sea catch and effort (Source: Kedidi et al. 1984).

Region	*# Fishermen*	*Annual Landings (tons)*	*Catch/Unit Effort (tons/fisherman/ year)*	*Production (tons/km of shoreline)*
Haql-Duba	29	80	2.758	0.3
Duba-Wejh	39	90	2.307	0.6
Wejh-Umm Lajh	86	250	2.903	1.4
Umm-Laj-Yanbu	225	670	2.978	4.4
Yanbu-Rabigh	320	1,030	3.218	5.9
Rabigh-Jeddah	303	880	2.904	6.1
Jeddah	284	1,180	4.140	---

Jeddah-Lith	174	460	2.644	4.1
Lith-Qunfudha	176	580	3.294	6.6
Qunfidha-Suquayq	156	1,030	6.606	7.3
Suquayq-Gizan	50	320	6.400	2.9
Gizan-Yemen Border	371	2,390	6.442	35.7
Farasan Islands	195	1,250	6.441	7.7
Total/Average	2,408	10,210	4.08	10.72

Note: Jeddah landings included significant amounts of fish caught in Sambouks which operated in the Lith and Qunfudah sectors which was added to those sectors

There is an increasing trend of productivity from north to south. Over 74 % of the annual Red Sea landings come from the southern section between Al-Lith and the Yemen border (MAW 1989). This is indicated both by increasing production/km of shoreline and per fisherman. This increase is based on productivity and size of the fishing grounds.

Red Sea landings are evenly divided between benthic species associated with coral reefs and the continental shelf and pelagic species (Table VI).

Table VI: Species composition of Saudi Arabian Red Sea landings (Source: MAW 1986).

Species	*% of Total Landings*	*Species*	*% of Total Landings*
Spanish Mackerel	30.4	Sharks	2.0
Jacks	12.0	Mullets	2.0
Cutlass Fish	3.0	Parrotfishes	1.0
Cobia	0.1	Wrasses	0.1
Indian Mackerel	3.0	Sea Breams	0.03
Emperors	13.9	Surgeon Fish	0.02
Groupers	13.0	Rabbit Fish	0.02
Snappers	8.0	Goat Fish	0.01
Barracudas	7.0	Miscellaneous	4.4

6. Threats to Coral Reef Biodiversity

i. Summary

Local threats to Saudi Arabia's coral reefs originate primarily through industrial development and maritime transport. With these are associated risks of oil spills, landfilling, pollutant discharges, effluents from desalination activities and a number of other major impacts. Most acute damage to reefs is localised and restricted to offshore islands (in the Gulf) and around major urban areas (in the Red Sea). Global threats include potential mass bleaching events associated with a global warming trend (Wilkinson et al. 1999) and possible reductions in reef building through loss of calcification linked with changes in ocean alkalinity from carbon dioxide increases (Kleypas et al. 1999).

ii. Oil Pollution

The intensive monitored physio-chemical, chemical and pollution levels in water and sediment, oil and its derivatives (persistent carcinogens) were correlated with coral disease in the Red Sea. Coral reef health was not affected south of Jeddah but to the north there were significant levels of diseases, especially Black Band Disease (Awad, 2000).

iii. Industrial Development

Along the Gulf coast, industrial development is concentrated around Jubail, Saffaniya Juaymah, Tarut Bay including Ras Tanura, Qatif, Dammam, and Al Khobar. Industrial developments include refineries, petrochemical plants, power plants, desalination plants, waste water treatment plants, and other primary and secondary industries. Along the Red Sea coast, on a more modest scale than along the Gulf coast, industrial development is concentrated at Jeddah, Yanbu, Rabigh, and Jizan. Oil refineries and other petroleum facilities have been constructed at Yanbu where the Trans-Arabian Pipeline (TAPLINE) terminates**.** Desalination plants, waste water treatment plants, and power plants are sited intermittently along the coast.

iv. Marine Transportation

Marine transportation plays an important role in coastal development. The Arabian Gulf is a major oil tanker and commercial shipping area. Large industrial ports along the Saudi Arabian Gulf coast are located at Tanagib, Saffaniya, Jubail, Juaymah, Ras Tanura, and Dammam. An estimated that 25,000 to30,000 ships transit the Red Sea annually (Lintner et al. 1995). Much of this is associated with transport of crude oil and petrochemical products between the northern Red Sea port of Yanbu, the Suez canal and the Egyptian oil pipeline from the Gulf of Suez to the Mediterranean. The Red Sea receives many times more pollution from marine transport and refinery inputs than the global average. It is inherently dangerous to maritime traffic because of its narrow and congested deep water navigation routes which are bounded on either side by very restricted anchorages and coral reefs. Shipwrecks and collisions continue, despite advances in safety and navigational systems. Even at a major port such as Jeddah, 5 - 10 spills and maritime accidents occur annually.

v. Commercial and Residential Development

Commercial and residential development is clustered around urban areas. On the Gulf coast, developments around Jubail and further south around Tarut Bay / Dammam / Al Khobar are responsible for a great deal of the coastal land development. On the Red Sea coast, the expansion of urban/residential areas also has considerable effect on the coastline, but less so than on the Saudi Arabian Gulf coast. The major areas of urban and related development are found around Jeddah, Yanbu, Rabigh, and Jizan.

vi. Landfilling

Landfilling is one of the most disruptive activities to coastal and marine resources. Land-filling has caused severe and permanent destruction of coastal habitats and has changed sedimentation patterns that have damaged adjacent resources. Changes in water circulation caused by landfilling has altered the distribution of plant and animal communities. In the Gulf coast, landfilling activities include the port at Dammam, industrial and residential landfill projects at Madinat-AI Jubail-AI Sinaiyah, and residential landfill developments along the Tarut Bay, Al Khobar-Dammam coastline. On the Red Sea coast the seabed drops off to over 20 meters immediately following the reef edge, creating a boundary for fill operations. However, landfilling has taken place mostly around Jeddah, causing the death of large tracts of fringing reefs, Yanbu, and Jizan.

vii. Dredging

Dredging causes destruction of the resources in the dredged area and often has indirect impacts from increased sedimentation. On the Gulf coast, extensive dredging has been conducted at Jubail, and to deepen shipping channels and harbours at Jubail and Dammam.

Approximately 46.5 km^2 (4650 hectares) of coastal habitats have been dredged along the Saudi Arabian Gulf coast as a result of these projects (MEPA/IUCN 1989). On the Red Sea coast, dredging has been concentrated around Jeddah, Yanbu, and in Sharm Jubba (north of Duba).

viii. Water Pollution

There are numerous sources of coastal water pollution including discharges of oil and other chemicals, and effluents from industrial and residential sources. Some urban areas have waste water treatment facilities, but many in many places these are are inadequate or non-existent. In the Gulf, the major areas with water pollution problems include the Saffaniya - Tanagib area, Jubail, and the Tarut Bay complex. On the Red Sea coast, Jeddah, Yanbu, and Rabigh are the main areas with pollution problems.

ix. Desalination

There is extensive use of desalinated water to meet demands of the population and industry. As of 1992 there were eighteen desalination plants operating along Saudi Arabia's Red Sea coast (Table VII), with a total combined capacity of 726,343 m^3/day (SWCC 1992). In Jeddah the desalination plant produces a major portion of the NO_2 and SO_2 emissions and contributes heavily to the particulate and trace metal emissions load. Discharges into the marine environment from the Jeddah plants include chorine and anti-scalant chemicals and 1.73 billion m^3 of brine at 51 ppm at 41°C.

Table VII: Seawater desalination plants on the Red Sea coast of Saudi Arabia (Source: PERSGA 1998).

Location	*Capacity m^3/day*	*Start Up Date*	*Location*	*Capacity m^3/day*	*Start Up Date*
Haql	3,785	1989	Jeddah II	37,850	1978
Duba	3,785	1989	Jeddah III	75,700	1979
Al-Wajh II	473	1979	Jeddah IV	189,250	1982
Al-Wajh IIa	825	1986	Jeddah ROI	48,827	1989
Al-Wajh IIb	1,032	1989	Shuaibah	181,800	1989
Umm Lujj	3,785	1986	Al-Birk	1,952	1984
Yanbu	95,000	1980	Assir	75,700	1989
Rabbegh	1,204	1982	Farasan Isl.	430	1979
Aziziah	3,870	1987	Farasan Isl.	1,075	1989

x. Recreation and Tourism Activities

Recreation and tourism have caused significant disturbances to coastal and marine habitats. Collection of corals and other souvenir species, a widespread practice in the 1970s and 1980s, have contributed to the loss of coral reef-assiciated fauna. These pressures are not severe along the mainland coast of the Gulf, but some of the coral islands and reefs are threatened. Along parts of the Saudi Arabian Red Sea coast, particularly near Jeddah and Yanbu, the reefs have been damaged by extensive food and souvenir collecting and spearfishing.

xi. Bleaching

The most recent mass bleaching event in 1997-98, the largest ever recorded, affected reefs world-wide. There are now widespread concerns that the incidence and intensity of bleaching is increasing, perhaps linked with a global warming trend (Hoegh-Guldberg 1999, Timmerman et al. 1999, Wilkinson et al. 1999).

xii. Changes in ocean chemistry

Increasing atmospheric carbon dioxide is expected to alter the alkalinity of the world's oceans over the next century, making it increasingly difficult for corals and other carbonate secreting organisms to grow. Present predictions are that calcification rates may slow by as much as 2/3 over the next 50 years, with catastrophic effects on reef growth and marine biodiversity in general (Kleypas et al. 1999).

xiii. Interrelationships among Institutions for Environmental Management

Many of the environmental problems facing the Kingdom require an integrated approach for their solution. Such an approach has been difficult due to the strongly sectoral organization of its government. Recent efforts in creating advisory councils and a national coastal zone management plan may begin to address this issue. Environmental monitoring and enforcement of existing environmental regulations will also need to be improved.

7. Marine Protected Areas (MPAs) and Level of Management

i. Background

Protection of marine habitats in Saudi Arabia has a fairly recent history. In 1977, the small island of Umm al-Qamari was given *de facto* protected area status by the national hunting regulations of 1977. Asir National Park was established by the Ministry of Agriculture and Water in 1981 (NCWCD 1990). Following this, MEPA identified forty-six coastal areas for inclusion in a system of coastal protected areas (MEPA/IUCN 1987). Under Saudi Arabia's Environmental Protection Coordinating Committee (EPCCOM) these were designated Environmentally Sensitive Areas. In 1987, the National Commission for Wildlife Conservation and Development (NCWCD) was formed with the express mission of handling the Kingdom's wildlife and conservation management issues, and its own classification system (Table VIII).

Table VIII: NCWCD conservation categories and their IUCN equivalents
(Source: Child & Grainger 1990).

NCWCD Category	*IUCN Equivalent(s)*
Special Natural Reserves	I. Strict Nature Reserve/Scientific Park II. National Park IV. Nature Conservation Reserve or Managed Reserve/Wildlife Sanctuary
Natural Reserves	I. National Park IV. Nature Conservation Reserve or Managed Reserve/Wildlife Sanctuary
Biological Reserves	I. Strict Nature Reserve/Scientific Park IV. Managed Reserve
Resource Use Reserves	V. Protected Landscape or Seascape VI. Resource Reserve VIII. Multiple Use Management Area/Managed Resource Area. IX. Biosphere Reserve
Controlled Hunting Reserves	VIII. Managed Resource Area.

Special Natural Reserves are intended as prime sites of high biological excellence which emphasize conservation of biological diversity. All exploitive activities within the area of Special Natural Reserves are strictly regulated. Natural Reserves are areas of lesser natural

excellence which have undergone some alteration and which may be either managed by the NCWCD or other agencies. Biological Reserves are proposed to carry out conservation priorities which include protection of important rangeland seed stocks, demonstration of the benefits of range lands management, protection of critical water catchment areas, protection of local biological communities or coastal resources. Resource Use Reserves are relatively large areas in which the emphasis is on sound resource management rather than pure conservation goals. Finally, Controlled Hunting Reserves are areas in which wildlife is managed with the aim of providing improved and sustainable hunting at some time in the future when game population have recovered (as a result of management activities).

By 1989, this program had placed 2.4 % of Saudi Arabia's total area (51,405 km^2) under protected status. In 1990, the NCWCD published its "Plan to Protect Areas in Saudi Arabia" that presented a system of protected areas which, if designated, would place 12.8 percent of Saudi Arabia's land mass under conservation management.

ii. Summary

The Kingdom of Saudi Arabia has established a number of extensive terrestrial protected areas, but lags behind in the development and implementation of marine protected areas. Many areas have been proposed and suggested, dating back to the mid- and late 1980s, and remain that way to date. With the exception of the Farasan islands, protected in 1996, and the Jubail Wildlife Sanctuary which was developed shortly after the Gulf war, there have been no other recent marine protected areas established. With the resurgence of PERSGA and its Strategic Action Plan this is expected to change, with up to 32 proposals for protected areas being put forward for the Red Sea alone.

iii. MPAs Declared

Yanbu Royal Commission Protected Area: This areas is protected by the Royal Commission through an agreement with the Meteorological and Environmental Protection Administration. It covers an area of ca. 5 km^2 and encompasses fringing reefs, mangroves, and seabird nesting sites.

Umm al Qamari: Established in 1977 and covering an area of only 2 km^2, this small protected area in the southern Red Sea has two small islands with surrounding fringing reefs, and is an important habitat for thousands of seabirds.

Farasan Islands: Established in 1996 and covering an area of 3310 km^2, this Terrestrial and Coastal Reserve is an archipelago of small islands at the southern extreme of Saudi Arabia's Red Sea shores. It is an important habitat for mangroves, seagrass, coral reefs, marine mammals, marine turtles, seabirds and endemic gazelle, and is threatened by fishing, development and recreation activities.

iv. *de facto* and Planned MPAs

Jubail Wildlife Sanctuary: This is a *de facto* protected area awaiting Royal declaration. Established in 1994 and covering an area of 2300 km^2, research and baseline surveys to identify the main ecosystems were carried out after the Gulf wear. The Sanctuary encompasses important wetlands for seabird migration and nesting areas for birds and sea

turtles. The most extensive coral reefs in the Saudi Arabian Gulf are also found within the Sanctuary borders.

Straits of Tiran: Straddling the Saudi Arabia / Egypt border, it encompasses islands and extensive coral reefs with diverse reef associated fauna in the transition area between the gulf of Aqaba ad the Red Sea. Is an important marine turtle and dugong habitat. There is tourist activity on the Egyptian side.

Ras Suwayhil: Proposed to cover an area of 267 km^2, the site encompasses pristine and diverse coral reefs and reef associated fauna, and is a prime example of the Gulf of Aqaba reefs and high cliffs. Habitat for seabirds and dugong.

Sharm Zubayr: Proposed to cover 80 km^2, the area encloses open coastline and a sharm with fossil reef cliffs, narrow fringing reefs and the northernmost mangroves in the Red Sea. A causeway has been proposed to cut through the area.

Ghubbat Bal'aksh: Covering 33 km^2, this is a sharm and open coastline with coral reefs with a particularly high species diversity, seagrass beds, and seabirds, subject to unregulated recreation activities.

Sharm Dumagyh and Sharm Antar: Covering an area of 70 km^2, these two inlets contain fringing reefs, seagrass beds, mangrove areas and are habitats for green and hawksbill turtles and seabirds. The area is subject to fishing and recreation pressures.

Al-Wedj Bank: Including Sharm habban and Sharm Munaybirah, this protected area will cover 2840 km^2, and is home to the most extensive coral reef system of the entire red Sea, diverse reef-associated fauna, seagrass beds and mangroves. It is inhabited by marine turtles and seabirds, and is a key area for dugong.

Qalib Islands: Actually included in the Al-Wedj bank, these islands are surrounded by fringing reefs and are important nesting sites for seabirds and marine turtles.

Al-Hasani and Libanah Islands: These are high-aspect islands with extensive fringing reefs and are important nesting sites for seabirds and marine turtles.

Ras Abu Madd and Sharm Hasi: Scenic sharms and high quality fringing coral reefs, fossil reef terraces and important seabird area. To be combined with the Al-hasani and Libanah island protected area. Threatened by fishing activities.

Ras Baridi and Sharm al-Khawr: The area encompasses sand beaches, small islands, high quality coral reefs and seagrass beds. It is the most important marine turtle nesting site in the Red Sea. It is threatened by unchecked fallout from a nearby cement factory.

Sharm Yanbu: Enclosing 50 km^2, the sharm is a deep, bi-lobed lagoon that contains mangrove and seagrass beds and fringing reefs, and is an important seabird area.

Shi'b al-Qirin: Extending over 30 km^2, this a high quality inshore reef complex that is also an important seabird area.

Marsa as-Sarraj: Proposed to cover 200 km^2, this is the largest land-locked lagoon on the Saudi Arabian Red sea coast. Seasonally inundated, it contains mangroves, halophytes, seagrass beds and high quality coral reefs. It is threatened by agricultural development and fishing activities.

Ras Hatiba: covering ca. 450 km^2, this is a large lagoon with sandy and coraline spits, small mangrove stands, extensive offshore reefs and is a prime site for environmental and extension education programmes. Currently threatened by recreation and unregulated development.

Jaddah Salt Marsh: Proposed to cover 100 km^2, this is a marshland area with extensive offhsore reefs, threatened by oil pollution and other waste disposal.

Ash-Shu'aybah and Mastaba: Proposed to cover ca. 100 km^2, this is a large lagoon with extensive mangroves, fossil reef terraces and good quality offshore reefs. It is a key site for seabirds, and is threatened by unregulated development and mangrove felling, and a possible major highway project.

Qishran: This is a complex of coral reefs, coral spits, seagrass beds and extensive mangroves. It is an important seabird and dugong habitat.

Outer Farasan Bank: This is a major reef and island system contiguous with the Farasan Islands. It has diverse mangrove, seagrass and coral reef habitats, and is an important turtle and seabird nesting area.

Khawr Nahoud: Proposed to cover ca. 33 km^2, this is a lagoon with fringing corals, seagrass beds and mangroves. It is an important dugong and seabird habitat.

Khawr Itwad: Proposed to cover ca. 70 km^2, this is a lagoon with fringing corals, seagrass beds and mangroves.

Shi'b Abu al-Liqa and Shi'b al-Kabir: Proposed to cover ca. 140 km^2, these are two lagoons with abundant fringing corals and mangroves.

8. Current and Potential Climate Change Impacts

Mass coral bleaching occurred in the central-northern Saudi Arabian Red Sea in late 1998. Up to 65 % of total coral cover was bleached or recently dead at Rabigh (20 - 40 % absolute cover). Bleaching was most intense in depths < 6 m, where greater than half the coral species had been affected. Bleaching followed surface water temperature increases in the Red Sea in August 1998, when temperatures elevated by > 1 ºC above mean monthly averages for over a month (from NOAA satellite imagery). By contrast, reefs bathed by cool waters (< 28 ºC) associated with coastal upwelling, particularly on steep coasts near Ras Baridi and the Gulf of Aqaba, were little affected. Most susceptible taxa are temperature-sensitive species with restricted distribution ranges and low population sizes. The high level of endemism in the Red Sea highlights the importance of careful selection of Marine Protected Areas including 'viable' populations of such species and incorporating a wide variety of habitat types and environmental conditions (DeVantier et al. 2000).

In the Arabian Gulf, the average live coral cover in shallow lagoon was not significantly different from that found in previous years (1992 - 1994). On the reef slope however, live coral cover was virtually non existent in 1999, and at Abu Ali there was mortality of nearly 99 %. It was believed that the mortality in shallow waters was associated with the high sea surface temperatures, which exceeded 34 ºC in the summer of 1998 (Vogt & Al Shaikh 2000).

The bleaching formed part of a global event affecting reefs in both the Red Sea and Arabian Gulf and indeed all oceans during 1997-98. In the global context, most reefs in the Saudi Arabian Red Sea were little affected. Most notably, reefs bathed by cool waters (< 28 ºC) associated with coastal upwelling, particularly those near Ras Baridi (N of Yanbu) and in the Gulf of Aqaba, were little affected or unaffected by bleaching, as were reefs in the Al Wajh Bank. In the Arabian Gulf, intense bleaching killed many reef slope corals, particularly species of Acropora on near-shore froinging reefs (Vogt & Al Shaikh 2000).

Proximate cause of the bleaching was clearly attributable to elevated sea surface temperatures, however ultimate cause(s) remains unclear. In some reef regions of the world bleaching was associated with the major 1997-98 ENSO climate event, the largest on record, perhaps compounded by global warming. Substantial coral mortality had occurred in the southern Farasan area and adjacent mainland in 1996, again following elevated sea surface temperatures (Rouphael & Al Yami 1999).

A further major global threat to coral reefs arises from increasing levels of carbon dioxide in the atmosphere and ocean. is expected to alter the alkalinity of the world's oceans over the next century, making it increasingly difficult for corals and other carbonate secreting organisms to grow. Present predictions are that calcification rates may slow by as much as 2/3 over the next 50 years, with catastrophic effects on reef growth and marine biodiversity in general (Kleypas et al. 1999).

9. Current Monitoring and Management Capacity to Conserve Coral Reef Resources

i. Monitoring Capacity

Long-term monitoring of coral reefs along the Saudi Arabian Gulf coastline has been carried out on a continuous basis for the past 14 years by Saudi Aramco and the King Fahd University of Petroleum and Minerals Research Institute (KFUPM-RI). Other shorter term studies have also been conducted documenting the many variables affecting coral survival in this extreme Gulf environment. Documentation of impacts (bleaching, coral disease, and coral death) from extremely cold and hot temperatures, as well as impacts from extremely low meteorologically induced tides, have all been recorded through techniques involving regular photographic quadrates for quantitative documentation. Associated populations along permanent fish and macroinvertebrate transects have also been continuously monitored (Allen 2000). Two Universities carry out research and monitoring of marine habitats:

Faculty of Marine Science, King Abdul Aziz University: The objectives are teaching and research. The main geographic area of research is the Red Sea and the Arabian Gulf. Research is practical in nature and relates to resource exploitation which include fisheries, aquaculture, mangroves, microfauna distribution, coastal processes, pollution, circulation, mixing and fronts and other related subjects. The faculty has sites at Obhur on the Red Sea

coast north of Jeddah and on the University campus. Facilities include research laboratories (3000 m^2), aquarium (17 tanks), a small museum, workshop, computers, a research vessel, well established library and teaching facilities.

King Fahd University of Petroleum and Minerals Research Institute: Carries out research projects related to the protection of Saudi Arabian environment. These include research and studies of natural ecology of marine environment. Facilities include laboratory space (2200 m^2) research vessels, aquarium and museum, library and teaching facilities. The Arabian Journal of Science and Engineering is published by the University (4 issues a year). Has cooperative programmes with many institutions including Austrian Academy of Science, KISR (Kuwait), MEPA/ROPME and UNESCO.

The geographic scale of the reef tracts of Saudi Arabia (both in the Red Sea and Arabian Gulf) are such that an adequate long-term monitoring program would require a minimum of four dedicated NCWCD personnel. Following training and technology transfer (DeVantier et al. in press, Vogt & Al Shaikh in press, Rouphael & Al Yami pers. comm.), sufficient expertise exists within the NCWCD to develop such a team. This would facilitate coral reef monitoring and research within the Kingdom, essential adjuncts to future MPA management.

ii. Management Capacity

The key to any efforts to reconcile environmental concerns with economic and population expansion in Saudi Arabia will be the establishment of the institutional basis for coordination and implementation of necessary economic expansion in a sustainable manner. Several institutions in the Kingdom are mandated through a variety of mechanisms to carry out conservation tasks that in one way or another impact coral reefs:

National Commission for Wildlife Conservation and Development (NCWCD): NCWCD is responsible for management of protected areas (Royal Decree No. M/22, dated 12/9/1406). The NCWCD's main role is to preserve, protect and develop the wildlife within the Kingdom. Specific objectives are to develop and implement projects to protect wildlife and their habitats conduct surveys and promote research and public interest in environmental issues related to the wildlife in Saudi Arabia; and co-ordinate different ministries, authorities and national and international institutions to accomplish these objectives.

Meteorology and Environmental Protection Administration (MEPA): Established by Council of Ministers decision No. 157, Dated 20/11/1411 and Royal Decree No. 7/505M, dated 28/3/1406, MEPA has jurisdiction for prevention of pollution in the territorial seas. MEPA is the central environmental agency in the Kingdom of Saudi Arabia. However, the Kingdom distinguishes between the establishment of environmental criteria such as standards, and actual operational management. Thus operational agencies such as the Ministry of Petroleum, Ministry of Agriculture and Ministry of Industry and Electricity retain regulatory control over activities carried out under their respective mandates while MEPA sets environmental performance standards, monitors the activities of operational agencies and serves as a central coordinator for environmental management. MEPA is the Kingdom's central coastal zone management agency. Despite this, institutionalization of authority for centralized coastal zone management has not been achieved, and each individual agency operates under its own specific mandate and numerous overlaps and potential conflicts abound. Day-to-day coordination mechanisms and central planning authority specific to the coastal zone are lacking. MEPA also has jurisdiction for oil spill response (coordination

mechanism established under Royal Decree 7/B/13307, dated 22/7/1411), and for prevention of pollution including effluent from land fill ports (Royal Decree No. 7/505M, dated 28/3/1406). MEPA is responsible for setting standards for the environment (Royal Decree No. 7/M/8903, dated 2/14/1401) and for carrying out a program of environmental impact assessment. It is also the designated coastal zone management agency.

Saudi Arabian Coast Guard: Established by Royal Decree No. 33, dated 27/7/1377, the coast Guard has jurisdiction between the border of the territorial seas (12 miles offshore) and 10 km inland .

Ministry of Transport: Has responsibility for Marine Navigation in Territorial Sea

Sea Ports Authority: Has responsibility for ports (Royal Decree No. 7/505M, dated 28/3/1406) and has been directed by Royal Decrees to enforce a moratorium on land fill in ports (Royal Decree No. M/9, dated 27/3/1408).

Ministry of Agriculture: Has jurisdiction for fishery activities (Royal Decree No. 7/505M, dated 28/3/1406), and issues permits for extensive filling of submerged lands have been granted in the Eastern Province.

Royal Commission for Jubail and Yanbu: Responsible for industrial development within the two industrial cities. It is also responsible (under a MoU with MEPA) for environmental management within the two industrial cities

10. Government Legislation, Strategies and Policy Pertinent to Reef Conservation

i. Summary

Saudi Arabia is signatory to regional and international agreements which place obligations upon it for prevention of pollution and protection of resources, including coral reefs. Among these are a number of international agreements and memoranda of understanding, and a series of national laws and royal decrees that are pertinent to coral reef conservation.

ii. International Agreements

The Kingdom of Saudi Arabia is a signatory to the Kuwait Regional Convention on the Protection and Development of the Marine Environment from Pollution (1978); the Protocol Concerning Regional Cooperation in Combating Pollution by Oil and other Harmful Substances in Cases of Emergency (1978); the Regional Convention for the Conservation of the Red Sea and Gulf of Aden against Pollution from Land-based Sources (1982); the Protocol on Marine Pollution Resulting from Oil Exploration Activities in the Arabian Gulf Region (1989), the ROPME protocol for Protection of Pollution of the Sea from Land-based Sources (1990) and the Declaration of the Regional Organization for the Conservation of the Environment of the Red Sea and Gulf of Aden (1995).

iii. National Legislation

A number of national decrees and laws affect coral reef conservation measures in the Kingdom, including the Environmental protection Standards Document No. 1401-01 (1402 H); the National Oil Spill and hazardous Substances contingency Plan; the resolutions adopted by EMCCOM and proposed to the Council of ministers for their consideration (in

particular those concerning the designation of coral and sandy islands as marine protectorates); the Council of ministers Decision no. 271 (23.11.1404) obliging the use of best available technology to reduce pollutant emissions (such as cement dust); the Rules and Regulations for Saudi Arabian Seaports; the draft national Fisheries Regulations; and the establishment of the National Commission for Wildlife Conservation and Development (NCWCD). Among these are:

Royal Decree 7/B/13307 (22/7/1411)concerning oil spill response activities.

Royal Decree No. 7/505M (28/3/1406) concerning effluent from land fill ports.

Royal Decree No. 7/M/8903 (2/14/1401) concerning standards for the environment

Royal Decree No. M/9 (27/3/1408) establishing a moratorium on landfilling in port areas.

Royal Decree No. 7/505M (28/3/1406 concerns jurisdiction for fishery activities.

11. Gaps in Capacity and Requirements for Improved Conservation

i. Summary

One of the major gaps in the process of coral reef conservation, in particular in the Red Sea, is the lack of established marine protected areas. It is envisaged that the establishment of a series of protected areas in which development was limited or non-existent would ensure the continued development of coral reefs in the region. This will need strict enforcement, and further research to acquire baseline information. There is a general lack of funding for marine research activities, and most research is currently funded through GEF, World Bank or UNDP projects. Specifically, the Kingdom needs to address the following issues:

ii. Research

Research needs to be carried out in order to update baseline environmental conditions, and follow-up monitoring should refer to these baselines to detect changes in environmental quality.

iii. Networking

There is a need to integrate current research into global initiatives such as ICRI and GCRMP, and regionally among PERSGA members.

iv. Planning and Coastal Development

Direct use and indirect development activities that affect reef systems need to be carefully evaluated in the design stages, and be subject to continued monitoring through the implementation stages.

vi. Community Education

There is a need to develop community education programmes that highlight the role of communities in reef ecology, including degradation.

vii. Legislation

The Kingdom needs to take bold steps in the establishment of marine protected areas, and monitor the implementation of legislation concerning these areas with regard to coastal development, fisheries and tourism. The designation of marine protectorates needs to become a priority issue within the country.

viii: Funding and Expertise
A larger proportion of funds allocated to protected areas and environmental research needs to be appropriated for marine conservation efforts. With the NCWCD for instance, this would also require the expansion of the Marine Department which is currently staffed by only three people with limited research funds and equipment.

12. Recommendations to Improve the Conservation of Coral Reef Resources

i. Summary
Saudi Arabia has carried out a number of programmes and adopted a n umber of legal measures to conserve coral reefs. These include laws on pollution discharges and the establishment of protected areas. However, a number of issues remain unresolved or poorly addressed. These include foremost enforcement of existing emission standards, industrial development which includes landfilling, and integration of the public and private sectors in reef conservation. Specifically:

ii. Legislation and Environmental Management
There is a need to strengthen enforcement of legislation related to management of coastal and marine areas. The Kingdom must effectively implement the Coastal Zone Management Plan; improve mechanisms for co-ordination of environmental activities among sectoral ministries and review each institution's mandates; and expand the EIA requirements for industrial, municipal and private sectors.

iii. Habitat and Biodiversity Conservation
Saudi Arabia must implement a management programme for the Farasan islands, and develop and implement a management programme for marine protected areas at Al Wedj bank, the Straits of Tiran and other areas in the Red Sea. For coral reef resources, the Kingdom must establish measures to control intensive collection of fish and invertebrates on reef flats and spearfishing. Update current fisheries management programme.

iv. Tourism Management
Saudi Arabia should further enforce regulations and develop public awareness programmes for coral reef conservation, including control of overfishing, anchor damage, littering and souvenir collection.

v. Navigation Risks
There is a need to improve navigational aids and radio communication in Saudi Arabian waters, especially on major shipping channels and implement current Oil Spill Contingency Plan, including the development of site specific plans, improve capacity to respond to spills of oil and other hazardous materials, including a review and upgrading of port reception facilities for solid and liquid waste.

vi. Industrial Development

Saudi Arabia needs to improve the management of air pollution, brine disposal and thermal discharges (from desalination plants), and improve control of emissions from cement plants such as the one at Ras Baridi. Control dredging and landfilling in the development of ports.

vii. Research

Strengthen current programme for development of a national database of biological resources and environmental information, and further strengthen and expand monitoring programmes to support operations and enforcement activities.

viii. Environmental Education

There is a need to expand environmental education activities in both public and private sectors, and to encourage public participation in conservation efforts, much as the way in which they were invited to participate in the rescue efforts after the Gulf war.

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Appendix III: Principal species of the six most common fish groups observed in artisanal catches from the Saudi Arabian Red Sea.

Family Group	*Species*
Mackerel	*Rastrelliger kanagurta*
	Scomberomorus commersoni
Jack	*Cranx sexfasciatus*
	C. bajad
	Scomberoides commersonianus
	Trachinotus blochi
Snapper	*Lutjanus bohar*
Grouper	*Epinephelus tauvina*
	E. microdon
	E. chlorostigma
Mullet	*Valamugil sp.*
	Crenimugil sp
Emperor	*Lethrinus miniata*
	L. lentjan
	L. mahsena

Source: MEPA/IUCN (1992).

Appendix IV: Habitat, Food Preference and Species Numbers for Major Fish Groups in Coral Reefs of the Saudi Arabian Red Sea.

Family		*Food and Habitat*	*No. of species*	
			Red Sea only (endemic)	Red Sea and Indo-West Pacific
Chaetodontidae	(Butterflyfishes)	Coral-eaters, territorial in/on reefs	7	5
Pomacanthidae	(Angelfishes)	Sponges/algae, Territorial in/on reefs	3	3
Pomacentridae	(Damselfishes)	Several specialist groups: reef edge planktivores, deeper water planktivores, reef-face planktivores, coral associate planktivores, algal lawn herbivores.	12	16
Scaridae	(Parrotfishes)	Algal grazers-some scrape living coral	3	9
Acanthuridae	(Surgeonfishes and Unicornfishes)	Algal browsers	3	7
Labridae		Gastropods and crustacea	7	34
Lutjanidae	(Snappers)	Predators of medium-sized invertebrates and small fish	2	5
Lethrinidae	(Emperors)	Predators of medium-sized invertebrates		10
Balistidae	(Triggerfishes)	Invertebrates, including echinoids, *A. planci*	2	5
Tetradontidae	(Pufferfishes)	Coral and invertebrates	1	2
Diodontidae	(Porcupinefishes)	Invertebrates including echinoids		4

Source: MEPA/IUCN (1992).

Appendix V - Acknowledgements

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