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# Implications of Climate Change in the Red Sea and Gulf of Aden Region: An Overview

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# PREFACE

The closely-related issues of greenhouse gas emissions, global warming and climate change have recently come to the top of the international environmental agenda. In particular, concerns over the problems expected to be associated with the potential impacts of climate change have grown over the past decade and captured the attention of the scientific community, the politicians, decision makers, as well as the private and public sectors. These problems may prove to be among the major environmental problems facing the marine environment and adjacent coastal ares in the near future. Therefore, and in line with UNEP Governing Council decision 14/20 on "Global Climate Change", the Oceans and Coastal Areas Programme Activity Centre (OCA/PAC) of the United Nations Environment Programme (UNEP) launched and supported a number of activities designed to assess the potential impact of climate change and to assist the Governments concerned in identification and implementation of suitable response measures which may mitigate the negative consequences of the impact.

Since 1987 to date, Task Teams on Implications of Climate Change were established for eleven regions covered by the UNEP Regional Seas programme (Mediterranean, Wider Caribbean, South Pacific, East Asian Seas, South Asian Seas, South-East Pacific, Eastern Africa, West and Central Africa, the Kuwait Action Plan Region, the Red Sea and Gulf of Aden and the Black Sea). Some of these Regional Task Teams enjoy the support of the Intergovernmental Oceanographic Commission (IOC) of UNESCO and other relevant international, regional and non-governmental organizations.

The initial objective of the Task Teams was to prepare regional overviews and site-specific case studies on the possible impact of predicted climate change on the ecological systems, as well as on the socio-economic activities and structures of their respective regions based on the climate change models/scenarios developed by the Intergovernmental Panel on Climate Change (IPCC) and widely accepted by the international scientific community.

The overviews and case studies were expected to:

- examine the possible effects of the sea-level rise on the coastal ecosystems (deltas, estuaries, wetlands, coastal plains, coral reefs, mangroves, lagoons, etc.);
- examine the possible effects of temperature elevations on the terrestrial and aquatic ecosystems, including the possible effects on economically important species;
- examine the possible effects of climatic, physiographic and ecological changes on the socio-economic structures and activities; and
- determine areas or systems which appear to be most vulnerable to the above effects.

The regional overviews were intended to cover the marine environment and adjacent coastal areas influenced by, or influencing, the marine environment. They are to be presented to intergovernmental meetings convened in the framework of the relevant Regional Seas Action Plans, in order to draw the countries' attention to the problems associated with expected climate change and to prompt their involvement in development of policy options and response measures suitable for their region.

Following the completion of the regional overviews, and based on their findings, site-specific case studies are developed by the Task Teams and are planned to be presented and discussed at national seminars. The results of these case studies and the discussions at the national seminars should provide expert advice to the national authorities concerned in defining specific policy options and suitable response measures.

The Task Team on the Implications of Climate Change in the Red Sea and Gulf of Aden Region was established and met in its first meeting at the Suez Canal University in Ismailia, Egypt, 22-25 February 1992, and in its second meeting at the Suez Canal University's Research Centre, Saint Catherin, Sinai, Egypt, 9-12 December 1992. The meetings were attended by experts from the region invited by UNEP in their personal capacities, taking into account the need for expertise relevant to the work of the Task Team and for a balanced geographical representation. It was also attended by representatives of the Intergovernmental Oceanographic Commission (IOC) of UNESCO and the Program for the Environment of the Red Sea and Gulf of Aden (PERSGA). Each member of the Task Team was assigned a specific subject to address in detail, and the present overview is largely based on the contributions by the individual members of the Task Team.

The Task Team members who contributed to the present overview are: Dr. Moustafa M. Fouda (Coordinator),Dr. Abdel Fattah Abdel Wahab, Dr. Abdel Rahman A. Ahmed, Dr. Abdul Kader El-Hag, Dr. Ali A. Salem, Dr. Atef A. Moussa, Dr. I. El-Shamy, Dr. Girgis F. Soliman, Dr. Mohamed Ben Afif, Dr. M. Noman Noufel, Dr. Makram A. Gerges (UNEP), Dr. Amin H. Meshal (IOC), Mr. David Medio (UNESCO) and Dr. Dirar H. Nasr (PERSGA).

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# I. INTRODUCTION

The natural resources of the Red Sea and Gulf of Aden are diverse, comprising a wide range of tropical marine habitats, some of considerable conservation, scientific, economic or recreation value. However, they are often impoverished, both faunastically and in the range of available microhabitats. These are due to the recent isolation of the Red Sea from the Indian Ocean, the severe environmental regime imposed by the arid zone climate, the sheltered nature and unusual geographical location of the Red Sea, and the relatively small tidal range. Consequently, there is a greater range of marine environments providing biota with both optimal and highly stressed conditions resulting in a high degree of endemism with many species capable of tolerating high water temperature and salinity. As a result, many coastal organisms appear to be close to their physiological limits.

For the above reasons, the region of the Red Sea and Gulf of Aden offers much that is of interest and importance to our understanding of diverse marine habitats and processes in general, and of responses of ecosystems to natural environmental stress (Sheppard, *et al* 1992). The current exploitation of the Red Sea and Gulf of Aden resources is causing great economic and ecological changes. Conflicting human interests are taking a toll on the region's natural resources. It is important, therefore, to note that any additional stress imposed by human activities and pollution will cause serious problem to the unique environments of the Red Sea and Gulf of Aden.

The anticipated global warming as a result of greenhouse gases emission into the atmosphere is becoming a pressing environmental problem to the extent that it encompasses many scientific and socio-economic disciplines and hence, presents major challenges of this decade and undoubtedly for the next century. Obviously, serious environmental problems are likely to rise in association with potential impacts of expected climate change in the marine and coastal areas of the Red Sea and Gulf of Aden.

The United Nations Environment Programme, in response to the above concerns, and in line with Decision 14/20 of its Fourteenth Governing Council, established Regional Task Teams on the Implications of Climate Change in all the areas covered by its Regional Seas Programme. The Task Team on the Implications of Climate Change in the Red Sea and Gulf of Aden was established in February 1992. Similar to the other Task teams, it has the following objectives:

<u>Long-Term Objectives</u>

a) to assess the potential impact of climatic changes on the coastal and marine environment as well as on the socio-economic structures and activities; and

b) to assist Governments in the identification and implementation of suitable policy options and response measures which may mitigate the negative consequences of the impacts.

<u>Short-Term Objectives</u>

a) to analyze the possible impact of expected climatic changes on the coastal and marine ecological systems, as well as on the socio-economic structures and activities; and,

b) to prepare overviews and selected case studies relevant to the Red Sea and Gulf of Aden.

This overview is expected to specifically address the following:

a) the possible effects of the sea-level changes on the coastal ecosystems (deltas, estuaries, wetlands, coastal plains, coral reefs, mangroves, lagoons, etc.)

b) the possible effects of the temperature elevations on the terrestrial and aquatic ecosystems, including the possible effects on economically important species;

c) the possible effects of climatic, physiographic and ecological changes on the socio-economic structures and activities; and

d) areas or systems which appear to be most vulnerable to the expected impact.

In addressing the above questions, the work of the Task Team was based on:

a) the best available existing knowledge of and insight into the problems relevant to the subject of the study; and

b) assumptions accepted at the UNEP/ICSU/WMO International Conference in Vilach, 9-15 october, 1985, i.e. increased temperature of 1.5 - 4.5°C and sea-level rise of 20 -140 cm before the end of the 21st Century. However, for the purpose of this overview and the various studies by members of the Task Team, temperature elevation of 1.5°C and sea-level rise of 20 cm by the year 2025 were accepted with the understanding that these estimates may have to be revised on the basis of new scientific evidence. An IPCC (1990) scenario, for example, estimates the mean global sea rise to be between 10 - 30 cm by the year 2030, and 20 - 100 cm by the end of the next century.

## 2. DESCRIPTION OF THE RED SEA AND GULF OF ADEN

### 2.1 GEOMORPHOLOGY

#### 2.1.1 Geological History

The Red Sea was originated, at first, in the Eocene period as a Gulf of the Mediterranean Sea which extended as far south as Qosèir. By the movements of the earth's crust, active during the subsequent geological periods, this gulf, later became separated from its father sea, but itself increased both in depth and extent and was thus transformed into a separate ditch-like depression (Gohar, 1954).

During the late Eocene, the Oligocene and the Miocene periods respectively, it separated from, rejoined and became separated again from its father sea. However, it gained in depth and length, and toward the close of the Miocene period, it was converted into a great lake separated entirely from the ocean. In this way, the Red Sea primordium was formed.

At the commencement of the Pliocene period, not only was it again connected with the Mediterranean, but through its further sinking became for the first time connected with the Indian Ocean. The Gulf of Aqaba was then also formed and connected with the Dead Sea.

This state of affairs did not last long, for toward the end of the Pleistocene period, the Red Sea was finally separated from both the Mediterranean and Dead Seas. It was left to man at successive historic eras to effect the connection with the Mediterranean Sea. Its connection with the Indian Ocean, however, has been maintained since the Pliocene period.

### 2.1.2 Marine Geomorphology

#### 2.1.2.1 The Red Sea

The Red Sea is a flooded valley that can be described as a young ocean (about 70 million years), created by the pulling apart of Africa and Arabia (Fig. 1). It extends SE-NW between 12°N, 43°E and 30°N, 32°E and has a surface area of 44000 km$^2$. It communicates at its northern end with the Mediterranean Sea through the man-made Suez Canal and at its southern end with the Indian Ocean through the straight of Bab el Mandab. Near the latitude 28°N, the Red Sea branches into the Gulfs of Suez and Aqaba.

The Gulf of Suez extends for about 255 km with widths of 17 - 45 km and maximum depth of 83 m (U.S. Navy Charts, 1968). Throughout its geological history, the Gulf of Suez has always been a site of immense sediment accumulation (Said, 1969). Accordingly, its bottom morphology is smooth and simple, having likewise gentle submarine coastal slopes. This excessive sedimentation has also restrained the development of coral reefs.

By contrast, the Gulf of Aqaba is shorter, narrower, and much deeper. It extends for 180 km with widths varying from 25 km in its southern part to 16 km at the north. The Gulf proper is divided into three elongated deep basins striking North East. The northern deep is the shallowest (900 m deep) and is characterized by its flat bottom, while the other two deeps have irregular bottom topography and much greater depths. The maximum water depth in the Gulf reaches up to 1850 m in the central basin (Friedman, 1985). With the exception of the northernmost part of the Gulf, fringing coral reefs grow luxuriously along the entire coastline varying in width between 10 and 100 m depending on the slope gradients at the shelf edge (Friedman, 1985).

The Red Sea proper itself extends for about 2000 km. The shorelines of the sea are straight in the north but notably sinuous in its central and southern parts where they encroach vast bays. The distance between the eastern and western Red Sea coasts is 180 km at its narrowest part and double this value at the widest part at Massawa (Coleman, 1974); meanwhile its average width at Bab el Mandab is only 27 km.

The most important feature of the Red Sea is the deep, narrow axial trough cutting the medial axis of the large main trough. The main trough extends from a northern point close to Ras Muhammad southward to Zubayer islands. The southern part of the trough is straight, whereas, further north it goes in a crooked way revealing the influence of transform faults (Ross and Schelee, 1974). The axial trough, however, is well developed only in the central part and the adjacent northern areas, but missing in the extreme northern and southern parts. Yet, it is assumed that it might be covered by the thick accumulation of Pleistocene sediments in the southern part of the Red Sea (Ross and Schlee, 1974). The axial trough is only 10-30 km wide having steep-sided walls and very irregular bottom topography (Coleman, 1974). It is famous for its numerous isolated deeps, generally filled with hot brine and economically important metalliferous deposits. The water depth in the deepest pool is 2850 m (Backer and Schoell, 1972). Generally, the Red Sea rift system is characterized by extensive volcanic activity throughout the whole area (Fig. 2).

The continental shelf of the Red Sea is 15-30 km wide in the north and about 120 km wide in the south. However, in the most southern part of the sea, the Farasan and Dahlak banks are considered as parts of a shallow shelf extending to the centre of the sea. The inner part of the continental shelf is dissected by various reefs, rocky shoals, banks and islands resulting in a rough bottom topography. The outer shelf, however, slopes rather gently with a distinct break at 500-600m depth marking the edge of the main trough (Schlumberger, 1984).

Among the attractive geomorphic features in the Red Sea are the reef-island complexes forming the archipelagos of Dahlak, Farason, Suakin and Hurghada (Ghardaqa). The Red Sea islands typically range in height from less than one meter to hilly ones rising up to 300 m above sea level.

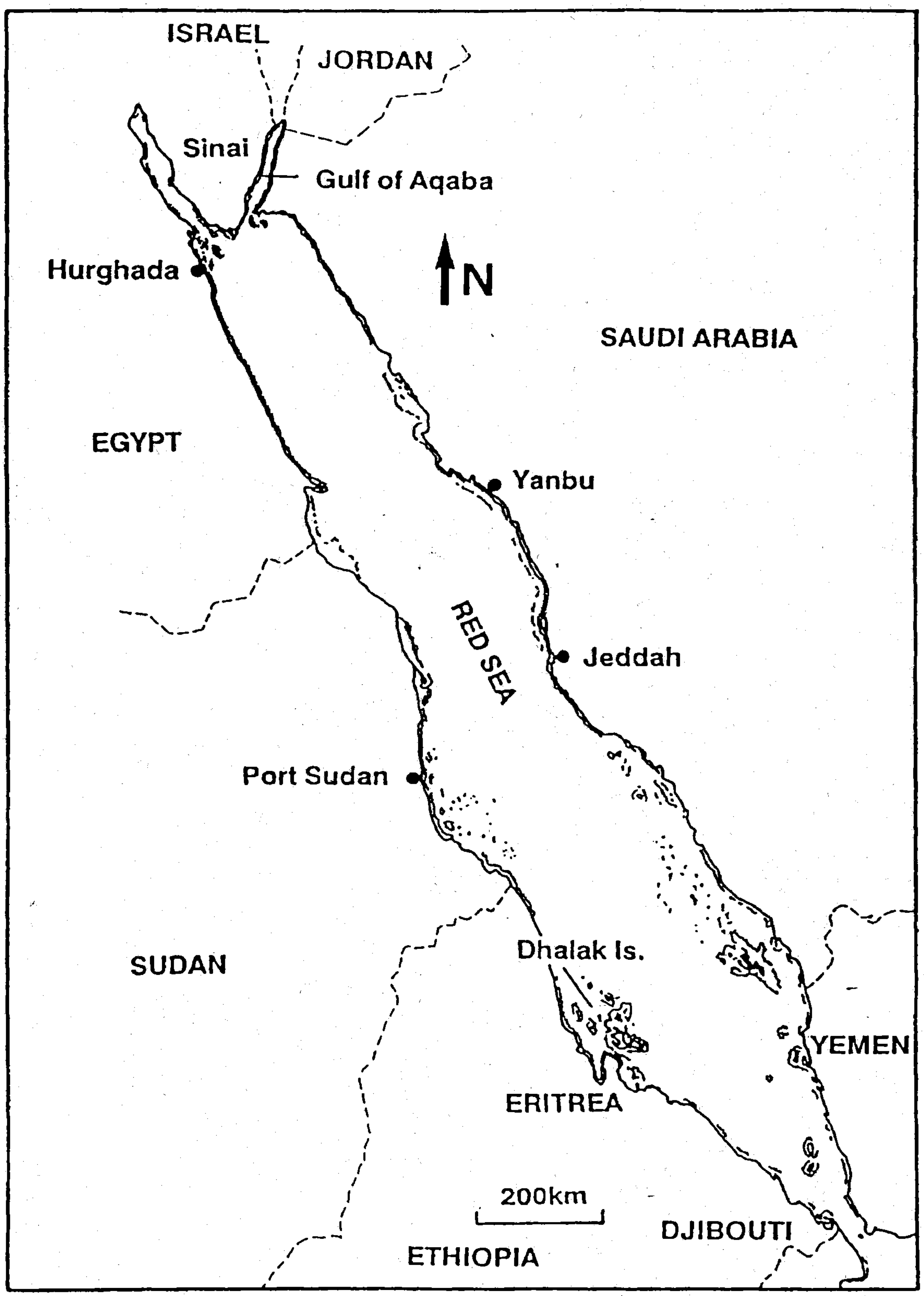



Fig. 1: Geographical presentation of the Red Sea (Source : Behairy et al., 1992)

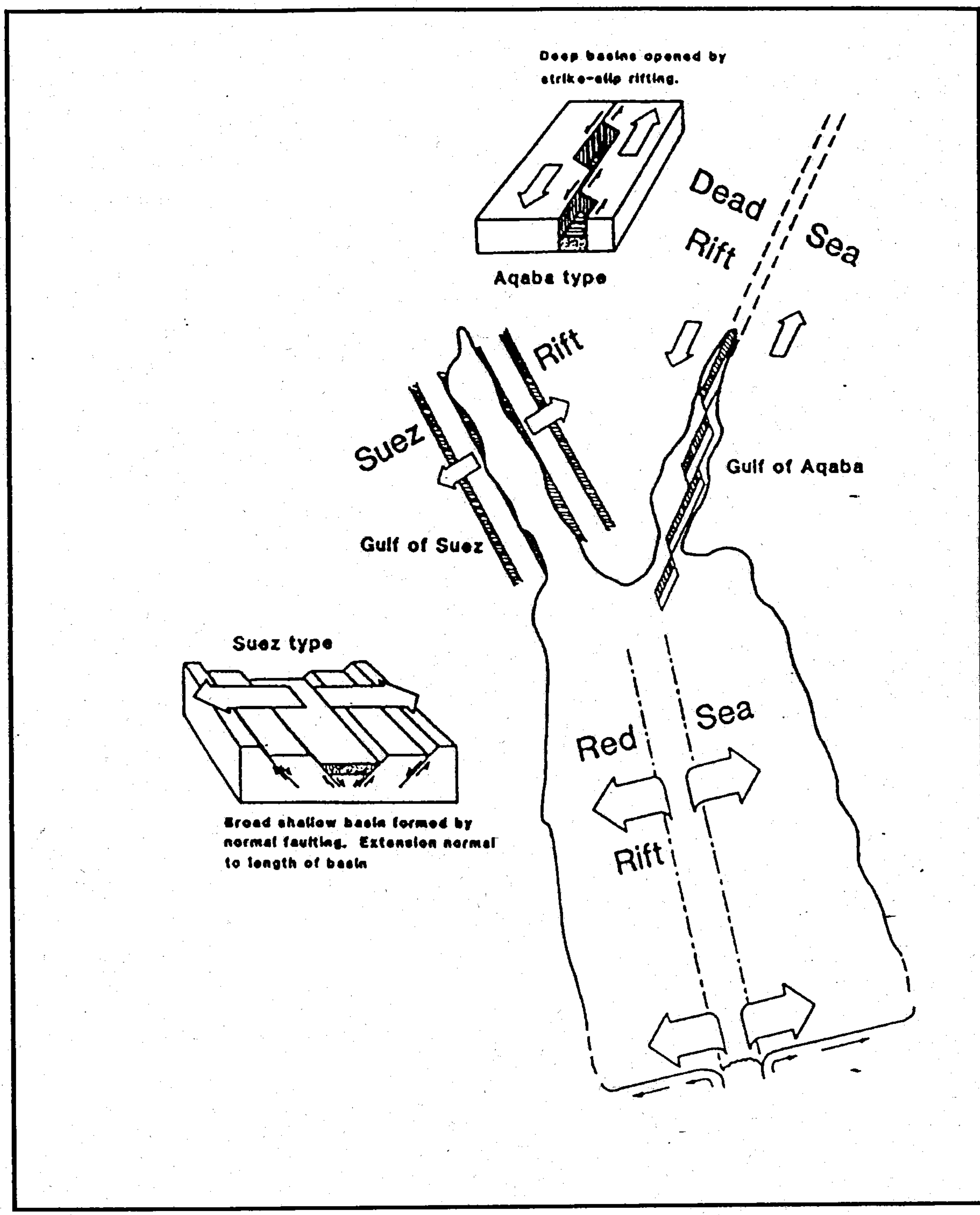



Figure 2 Tetonicframework of the northern Red Sea Gulfs of Aqaba and Suez, showing different rifting and formation. Northern Red Sea is a spreading centre. Gulf of Aqaba is formed by strike-slip faulting and its depth is attributed to basinsformed by grabens (inset). Gulf of Suez is formed by normal faulting . From Friedman (1985)

Finally, all these geomorphic features are framed by a strip of splendid coral reefs. Coral reefs fringe the entire Red Sea coast except for local break-ups at the mouths of ephemeral streams.

### 2.1.2.2 The Gulf of Aden

The Gulf of Aden trends West-Soutwest - East-Northeast between 10°N, 43°E and 15°N, 52°E. It extends for 900 km from the western shore of the Gulf of Tadjura to a medial point between Ras Fartak and Ras Asir. The distance between the northern and southern shores of the Gulf is 125 km in the west, increasing gradually eastward to 375 km between Ras Fartak and Ras Asir (Geological-geophysical Atlas, Indian Ocean, 1975). Comparing to the younger Red Sea rift, the Gulf of Aden is much deeper and has markedly complicated bottom topography. It is characterized by a central rough zone occupied by the West Sehba Ridge with its rift valley running west through the Tadjura Trench.

The Gulf of Aden is flanked by a narrow continental shelf in the south and relatively wider one in the north. Meanwhile, the seafloor slopes steeply in the south and more gentle in the north.

## 2.1.3 Coastal Geomorphology

### 2.1.3.1 The Red Sea

The northern Red Sea gulfs differ not only in their submarine morphology but also in their coastal geomorphology. The Gulf of Suez is bordered by relatively wide and moderately high to low sandy plains in many parts of it. Typical low points occur in the Northern, Northeastern and Eastern coasts.

By contrast, the coasts of the Gulf of Aqaba are steep all along the gulf with very narrow or missing coastal plains. The bordering mountains rise up abrupt from the water edge. However, the head of the gulf is low lying; only rises 2 m above sea level (The Red Sea and Gulf of Aden Pilot, 1980).

The coastal plains of the Red Sea proper are bordered by high mountains rising about 1000 m in the north and more than 3500 m in the south. In Egypt, Sudan and Saudi Arabia pediments and fan systems merge seaward of the mountain slopes, whereas, in Eritrea, Southern Saudi Arabia and Yemen, the coastal plains are bordered by high erosional escarpments extending 50-100 km inland (Coleman, 1974). The coastal plains are generally narrow and high in the north and more wide and low in the south. The relative submergence of the southern coasts could have resulted from the down warping of the coastal plains accompanying the uplift of the Yemeni and Ethiopian Arches during the Oligocene-Miocene times (Coleman, 1974). The width of the coastal plain is 5-35 km in the north and increases to about 50 km in the south. However, the break in the Red Sea hills at Tokar, Sudan has resulted in a low and broad coastal plain thereat.

A set of seaward stepped terraces of emergent old coral reefs lying parallel to the Red Sea coast manifest themselves at distances of 0.5-10 km from the shoreline. Late Pleistocene reefs comprising the most recent of such occur as wave cut terraces directly on the shoreline (Behairy, 1983). The same and one terrace shows horizontal as well as vertical succession of reef environments. The horizontal zonation is inherent to any reef framework, while the vertical alternations indicate various transgressions and regressions due to sea-level changes (Dullo and Jado, 1984).

The Red Sea coastlines frequently protrude out in the form of rocky headlines referred to, along the whole region as Ras (e.g. Ras Banas, Ras Ghareb, Ras Hatiba, etc.). Besides, the coastlines and the outlying fringing reefs are incised at irregular intervals by creeks known to for the local people as Sharms (e.g. Sharm esh Sheikh). These creeks "Sharms" are typically drowned stream valleys.

The southern Red Sea coastal zones have special characteristics of their own. In these areas, mangroves and marshes are well developing. The best example of these mangroves and marshes is found at Jizan in Saudi Arabia. It extends for about 1 km inland (The Red Sea and Gulf of Aden pilot, 1980; Crossland, *et al* 1987). In addition, the intensive accumulation of sediments in the south had resulted in the formation of sublittoral and supralittoral sand dunes, muddy embayments and sand spits.

Finally, one of the most important characteristic geomorphic features of the Red Sea region is the marginal sabkha flats and evaporites. These were developed due to the high rate of evaporation coupled with the tidal mechanisms.

#### 2.1.3.2 The Gulf of Aden

The Gulf of Aden is bordered on both sides by very high mountains with heights exceeding 3500 m in places. According to the Red Sea and Gulf of Aden Pilot (1980), the northern coastal plain is principally moderately low and sandy with several rocky headlands enclosing small sandy bays. It is about 60 km wide in the west and markedly decreased in the east where the mountains approach the sea closely.

The western coasts of the Gulf particularly those of the Gulf of Tadjura are exceptionally high. Extremes are found at Ghubet Kharab which is entirely surrounded by very steep cliffs. Hence, the coastal plains in this part are either very narrow or absent.

The southern coastal plain is less wide compared to the northern plain. But it is also wider in the west (30-40 km) and sloping gently towards a low coastal area covered by thick mangrove jungle. Eastward, it is narrow and slopes steeply (The Red Sea and Gulf of Aden Pilot, 1980).

## 2.2 Climate

The climate of the Red Sea Region is an arid type of climate with average annual rainfall of less than 250 mm.

The Region is considered as an extension of the great Sahara Desert. Most of the Region lies in the so called sub-tropical high pressure belt where there is large scale subsidence of the Hadley cell. The mean daily maximum temperature in January ranges from about 20°C in the far north to about 29°C in the far south and the corresponding figures for July are 35°C and 40°C respectively.

The rainy seasons are divided in to two distinct periods:

a. <u>The Winter Rainfall (November through February)</u>

(i) This affects mainly the northern parts of the areas adjoining the Mediterranean region. In this season, the hemispheric general circulation shifts southward with the sun position. The baroclinic zone which is essential for the formation of the extra tropical weather systems shifts southwards to the Mediterranean region. The depressions that form in the western Mediterranean region propagate eastwards with the general flow with or without intensification and occasionally reaching the northern Red Sea region. The frontal bands associated with these low pressure centres affect the weather of the northern and central parts, causing principally fall of temperature, cloudiness and occasionally thunder and rain.

(ii) Another important system affecting the weather and the climate of the central and south-western parts is the so called Sudan low, which is a heat low located over the southern Sudan and essentially stationary though it shifts its position a little to the northeast or to the southwest of its main position depending on the prevailing wind and temperature conditions. It is responsible for the surface easterlies that take occasionally a more southerly attitude. The southerly or south-easterly winds coming from the Arabian Sea provide the necessary moisture for the rainy weather that is observed over the southern and central parts of the regions especially over the escarpments.

(iii) The diurnal circulations ascending at both escarpments during daytime trigger convection clouds at the coastal regions and may develop into scattered showers and thunder activities.

b. The Summer Rainfall

It is mostly of convection type connected with the inter-tropical convergence zone (ITCZ) which prevails during summer. Its northerly penetration is governed by the humid south-westerly monsoon which causes rainfall on the southern parts of the Red Sea and Gulf of Aden.

### 2.2.1 Wind

Prevailing wind direction and rainfall tend to be determined by the northeast monsoon in winter and the southwest monsoon in the summer. The prevailing wind direction is North-Northwest throughout the year in the northern Red Sea except for occasional southerly winds that blow during winter. In the south (south of 20°N) the prevailing wind direction in the summer is northerly whilst in winter it is South-Southeast (Fig. 3).

An intermediate situation holds in the Central Red Sea between these northerly and southerly influences. The area is characterized by relatively low pressure calms. By the beginning of summer, this intermediate zone moves gradually south giving rise to the seasonal transition in wind direction in the southern Red Sea.

In addition, in the coastal zone, there is a diurnal change of wind direction from offshore during the day to onshore at night driven by differential heating and cooling of the land and sea.

In the Gulf of Aden, the high surrounding mountains reduce the influence of the south-west monsoon so that the prevailing wind direction is north-west in the summer. During the rest of the year, the northeast monsoon gives rise to eastern winds over the Gulf which veer to the southeast towards Bab el Mandab.

### 2.2.2 Air Temperature

It is lowest throughout the year over northern Red Sea (e.g. from 6.0°C to 39.0°C at Suez Canal and from 13.5°C to 42.0°C at Jeddah). The temperature increases rapidly south of 26°N. The warmest zone of the Red Sea is between 20°N and 16°N. The shores of the Gulf of Aden are considered to be among the hottest region of the world (e.g. from 19.0°C to 43.0°C at Massawa and from 24.0°C to 39.5°C at Perim).

### 2.2.3 Rainfall

Rain over the Red Sea as a whole is very sparse, occurs spasmodically and is very often localized. A particular location may receive no rain for months or years, then experience a brief heavy fall which may not be repeated for a similar lengthy period. In these circumstances a long series of data is required to establish reliable average figures, and for much of the Red Sea area such lengthy records are not available except for a few coastal locations (Figure 4).

The high mountains surrounding the Red Sea cause the southwest monsoon to lose its

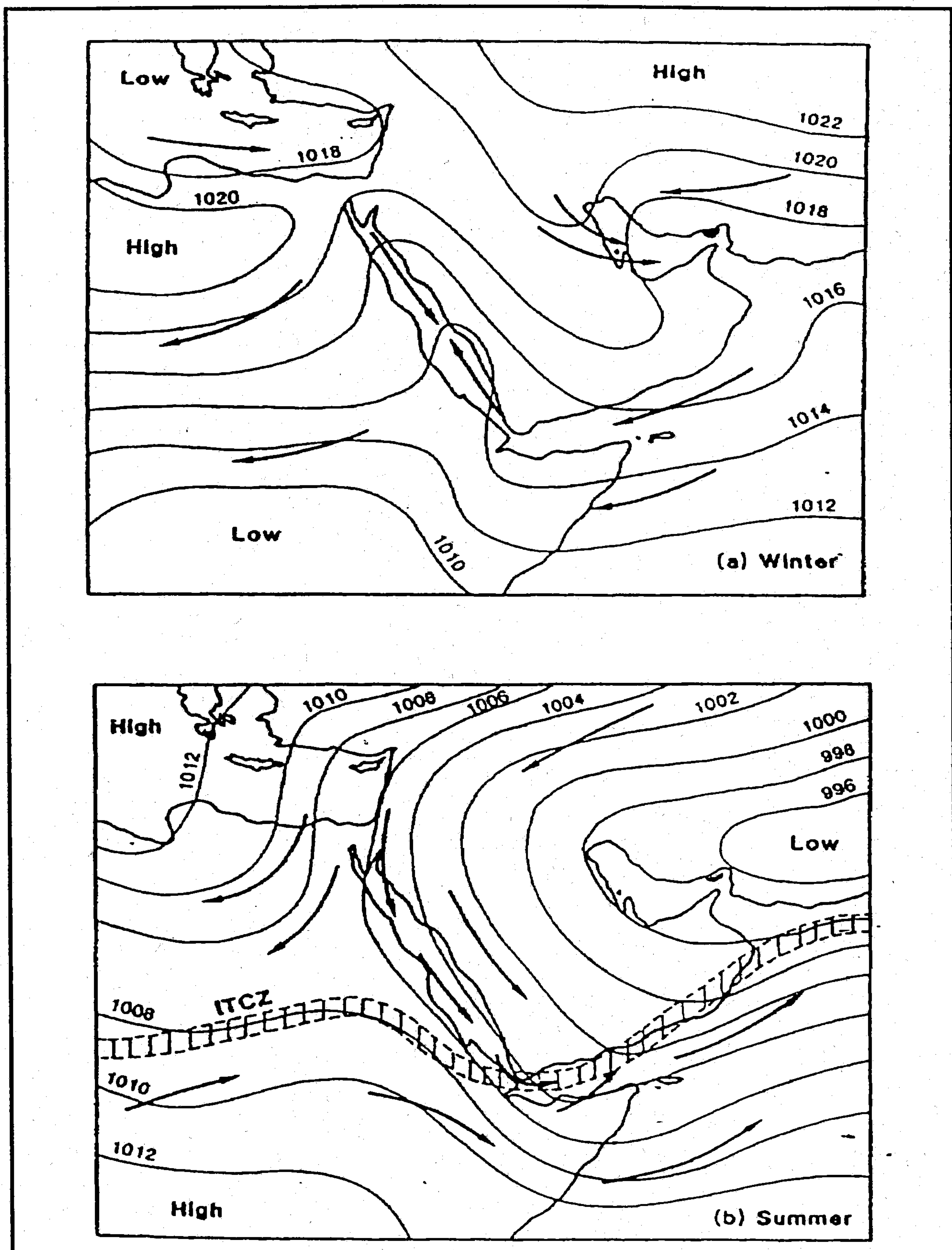
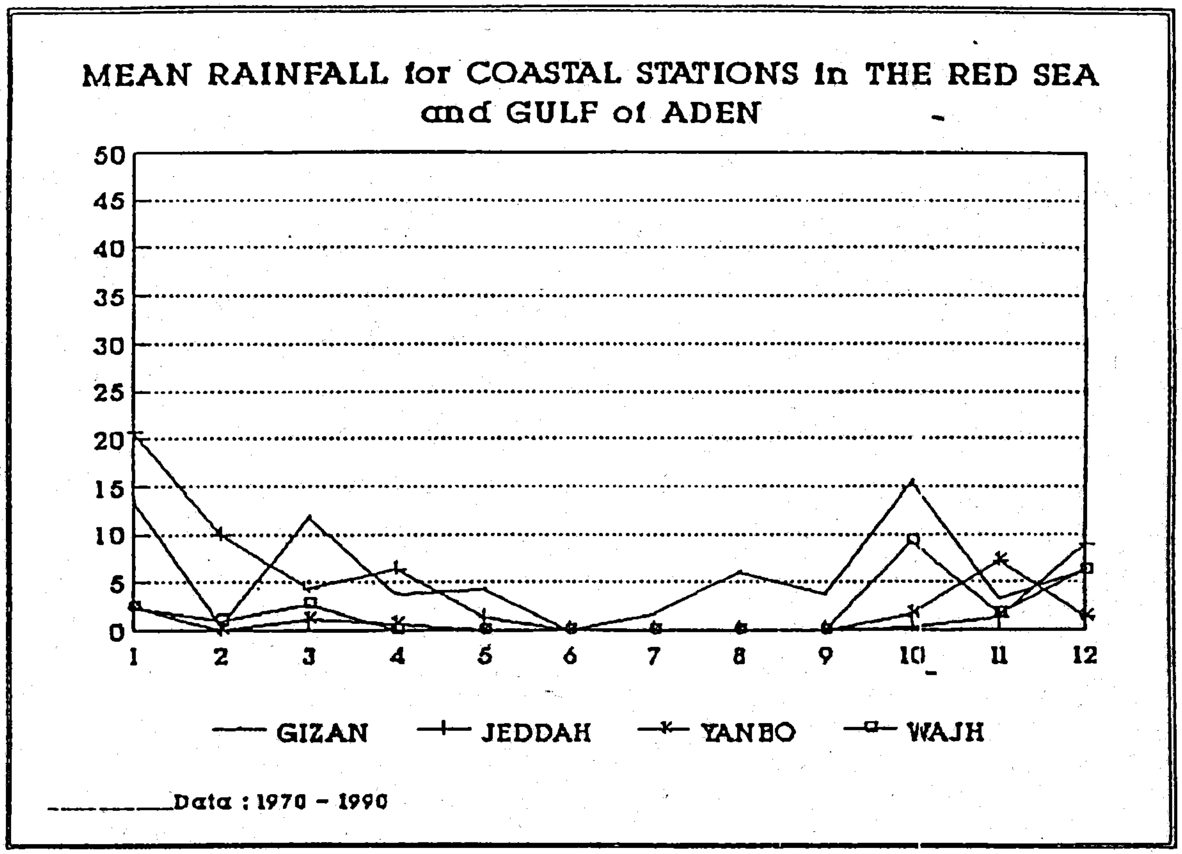



Figure 3 (a) (b) summer wind patterns: Major features are the summer winds causing upwelling off SE Arabia , the Shamal cold winter winds in the Gulf, the strongly evaporating winter winds over the northern Red Sea, and the seasonal changes of winds in the Gulf of Aden which are largely responsible for a 0.5 m seasonal tidal change in the Red Sea. Modified from Edwards (1987)



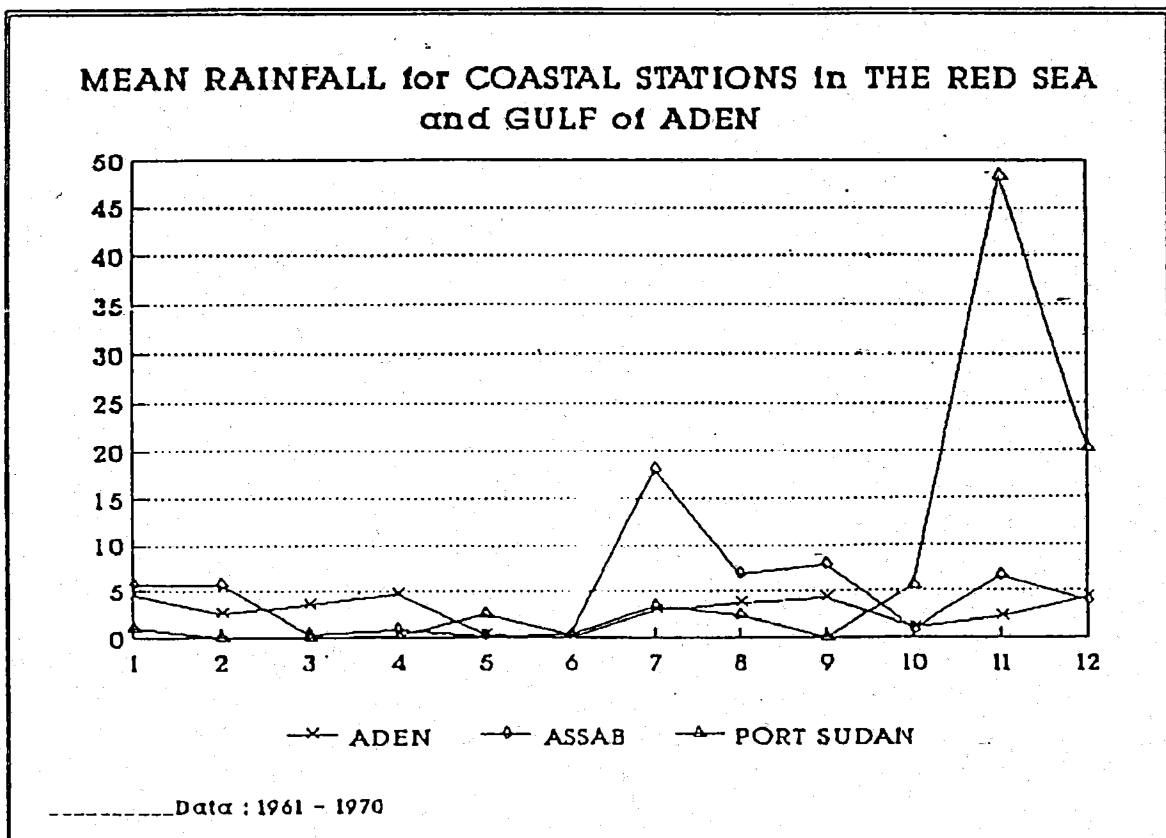




Figure 4 Mean Rainfall for Coastal Stations in the Red Sea and Gulf of Aden (Source: Ahmed, 1992)

moisture before reaching the Red Sea, consequently, rainfall is low during the summer. Most of the limited rainfall occurs in the winter when converging air masses give rise to showers of short duration often associated with thunderstorms and occasionally with dust-storms. The highest rainfalls (average 109 mm/yr at Port Sudan and 193 mm/yr at Massawa) are generally recorded from the Central Red Sea where the northern and southern Red Sea air masses meet.

In the Gulfs of Suez and Aqaba, rain amounts to about 25mm/yr and is confined almost entirely to the six months September to March. The western shore, from Hurghada (Ghardaqa) south to about 22°N is virtually rainless with any specific area only receiving the odd shower at intervals of several years and these sometimes amounting to only a few millimetres.

### 2.2.4 Humidity

Although most of the air which enters the Red Sea basin is fairly dry, the area has a reputation for hot, moist conditions, which render any prolonged human activity, at best, very difficult.

Over the open sea, the average annual humidity of about 70% is maintained. In the southern part of the Red Sea, humidity is higher in winter when the south-easterlies prevail than during the summer northwesterlies. Along the coasts, humidity is, usually, rather lower over the sea and generally increases from north to south.

### 2.2.5 Visibility

Over most of the Red Sea, visibility is greater than 20 km. for about 70% of the time. Water fog and mist occur occasionally but most restriction to visibility is due to sand or dust. Sandstorms occur only over the land and require a wind of force 5 or more but large area of wind raised dust may drift over the sea and remain suspended for considerable periods.

### 2.2.6 Cloud Cover

On the whole, the Red Sea is a very uncloudy place. At no time of the year is the mean daily cloud cover more than 50% at any location, and over large areas is often less than 25%. The southern parts of the Red Sea and Gulf of Aden experience high clouds, resulting from the blow of thunderstorm activities on the Arabian Sea and the Horn of Africa.

## 2.3 Oceanography

### 2.3.1 Water Temperature

The Red Sea is unique amongst deep water basins for having a stable warm temperature (of about 21.5°C) throughout its deeper waters. The mechanism which maintains this situation appears to be driven not only by winds but also through density gradient. Due to evaporation and cooling, inflowing surface water becomes more dense as it flows northward and sinks at its northern end near the month and in the Gulf of Suez. The sinking water in the north during winter causes the water inside the Red Sea basin to ascend and flow out of the sea over the sill of Bab el Mandab (Figure 5).

In summer, the northern Red Sea is characterized by its high temperature, low evaporation rate and hence, is occupied by a surface layer of relatively low density. This type of water prevents the formation of deep water during summer season (Wyrtki, 1974).

In winter, the water surface temperature at Suez is about 17.0°C, at the entrance of the Gulf of Suez is about 22.0°C and at the mouth of the Sea is about 27.0°C. The highest temperature

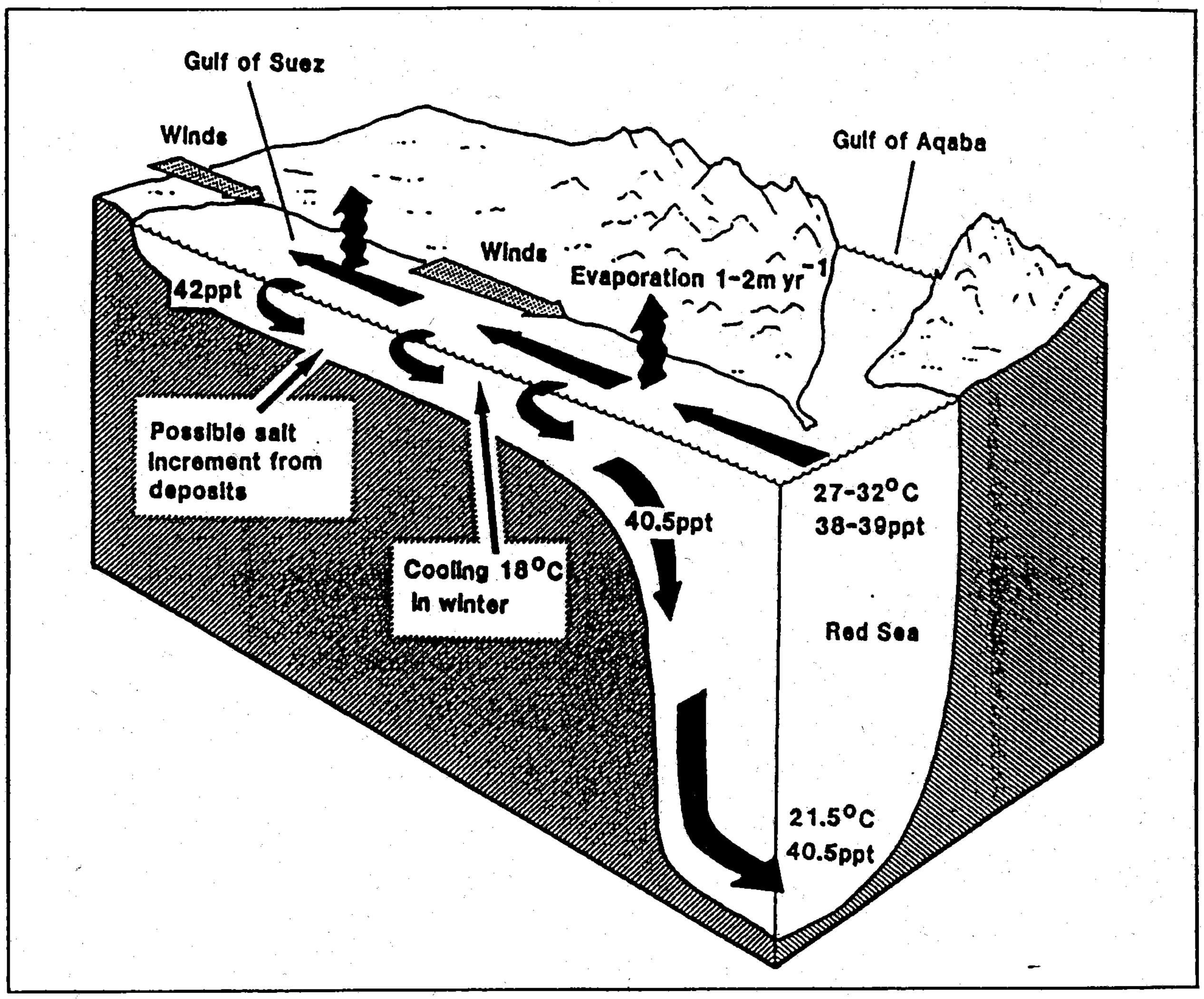



Figure 5: Mechanism of the density gradient in the Gulf of Suez. Northerly flowing water suffers evaporation and cooling, and "turns under" mainly near the mouth of the Gulf of Suez where there is considerable shallowing. Returning water flows south below the thermocline. A sill in the mouth of the Gulf of Aqaba (not shown) precludes a similar effect in that Gulf. Water in the Gulf of Aqaba is also subject to less cooling, since its greater depth buffers it against sharp temperaturechanges. Light arrows are winds, dark arrows are curents. (Source: Sheppard et al, 1992)

observed during that season is existing at latitude of 20°N showing values of about 28.2°C. During summer, the water temperature at the surface rises everywhere in the sea, showing values of about 28.5°C at Suez, 28.0°C at the entrance of the Gulf of Suez and 31.0°C at the mouth of the sea, but the highest temperature of 32.5°C is shifted a little to the south at 16°N latitude.

Generally, surface water temperature in the Red Sea increases from north to south showing wide variability between the different seasons. It varies seasonally between about 22°C and 32°C. At any one time, peak surface temperature is located between 15°N and 18°N, and ranges from 27°C to 32°C, according to season. Surface temperature declines slightly towards Bab el Mandab because of the influx of cooler shallow water from the Gulf of Aden.

It is to be noted that the variation in water temperature is more important in the northern part of the Red Sea where the difference between summer and winter values in the Gulf of Suez is 8° to 18°C; whereas at Bab el Mandab it is only 3° to 4°C. Data for water temperature from some coastal stations in the Red Sea and Gulf of Aden, collected during the last three decades are presented in Figures 6 & 7.

### 2.3.2 Salinity

Because of the high evaporation rate (about 200 cm/year in the Gulf of Aqaba and 235 cm/year in the Red Sea) and the complete lack of fresh water input, the Red Sea can be considered as the most saline body of water in direct connection with the world oceans. From an average salinity of 36.5 at Bab El-Mandab, the salinity increases to about 38.0 at 17.0°N latitude, to 39.0 at 22.0°N, 40.0 at 26.0°N and 40.5 at its northern end. In the Gulf of Suez, high salinity values of about 43.0 or higher are observed. These high salinities are not only due to intense evaporation and low renewal of the water mass, but apparently due also to the salt deposits in the Great Bitter Lakes of the Suez Canal, and to the extensive salt layers in the Gulf of Suez region.

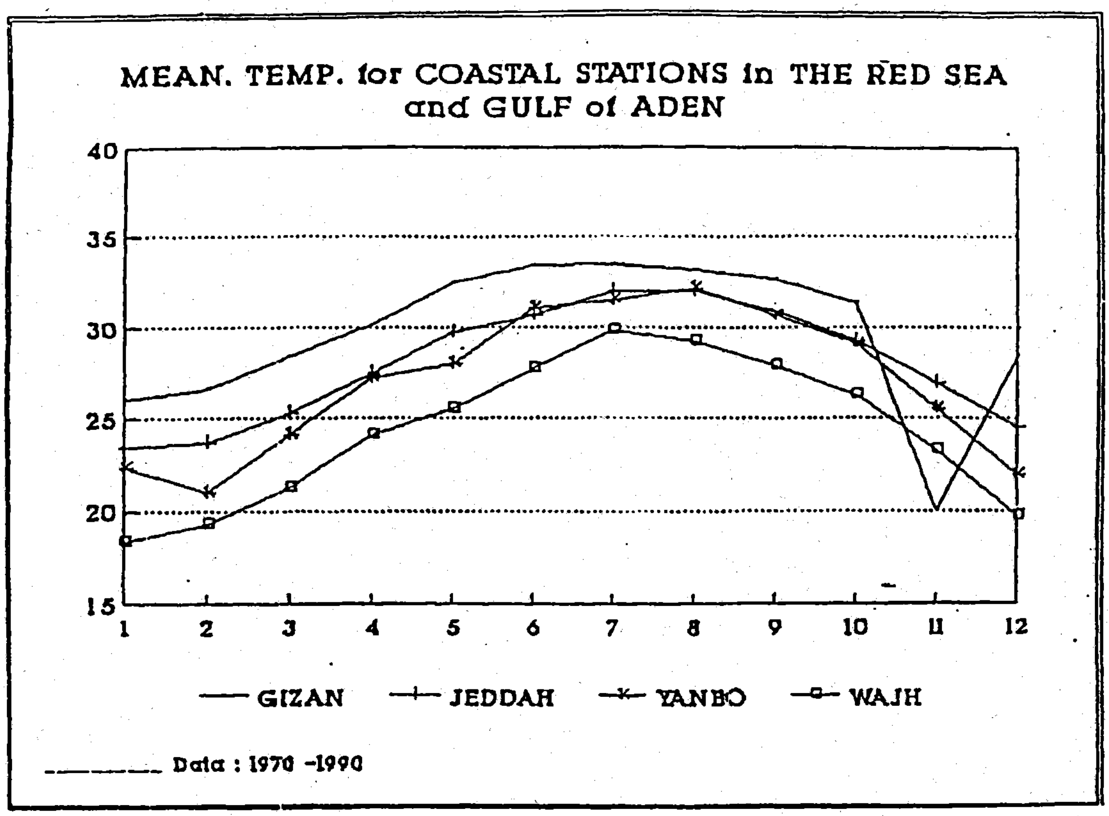
At any given latitude the salinity is generally higher in autumn than in spring, and the annual variation can be of the order of 1 in the north. Also, the salinity values are higher on the western side than on the eastern, with a difference of about 1.

### 2.3.3 The Tides

The tides of the Indian Ocean do not propagate into the Red Sea, i.e., there is no progressive tidal wave which moves through the strait of Bab el Mandab and raises and lowers the water level within the Red Sea basin. However, beside the independent tidal motion of the Red Sea, the sea is co-oscillating with the Gulf of Aden (Soliman, 1979; and Soliman and Gerges, 1983).

Within the Red Sea itself, there is a local oscillatory tide of small amplitude and semi-diurnal period which results in high water at one end of the sea when it is low water at the other end. The tidal ranges change widely from north to south, with greatest values being at the two ends. It is of about 1.5-1.8 m at Suez, 0.90 m at the entrance of the Gulfs of Suez and Aqaba, and about 0.9 m in the south between the Dahlak Archipelago and Kamarn Island. There is no appreciable diurnal tide towards the centre, near Port Sudan and Jeddah. Another nodal zone with negligible tide occurs just to the north of Bab el Mandab between Assab and Mocha. Thus, three nodal tidal zones exist across the Red Sea and Gulf of Aden; the first at the entrance of Gulf of Suez, the second at the centre and the third south of Assab. The tidal range in the Gulf of Aden is greater than in the Red Sea and reflects the unrestricted influence of tides within the Indian Ocean.

Nevertheless, a complete explanation of the Red Sea tides is not yet agreed (Edwards, 1987). It is probably that they are a combination of an independent oscillation of waters within the Red Sea and a forced, or co-oscillation, induced by the Gulf of Aden tides, perhaps also in combination with other influences (e.g. astronomical factors). Due to paucity of the available data, great accuracy in



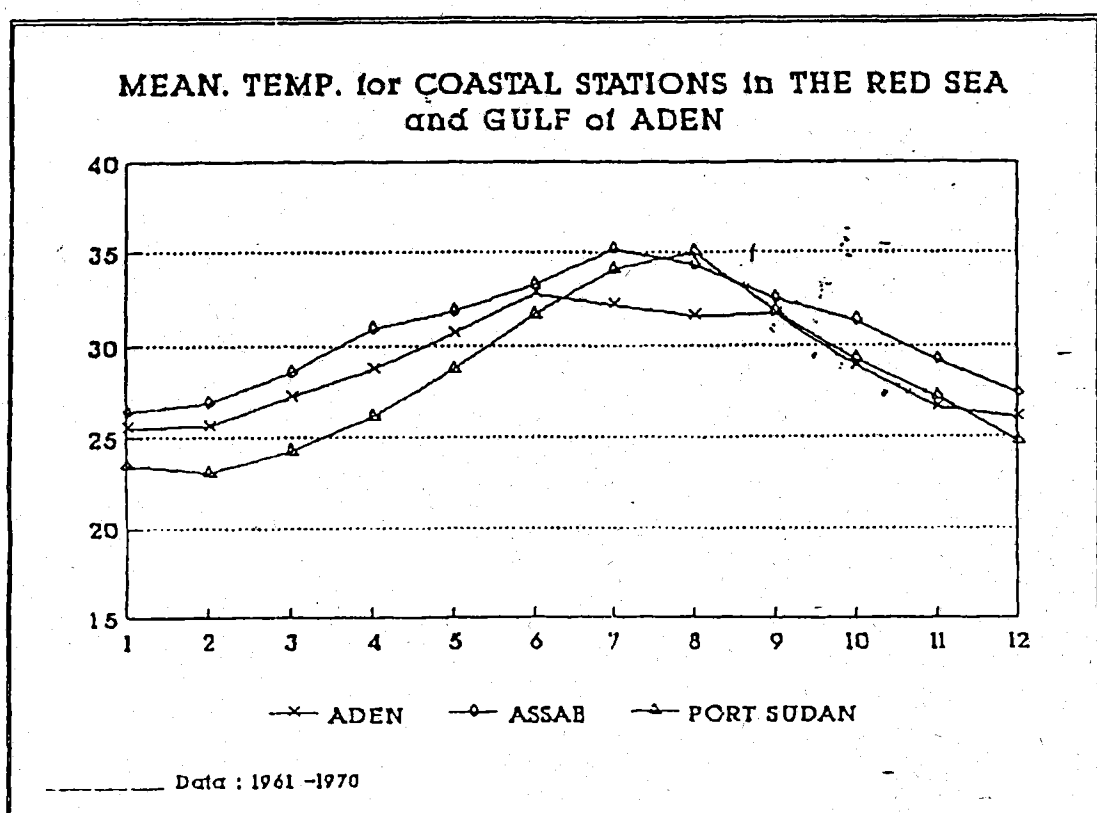
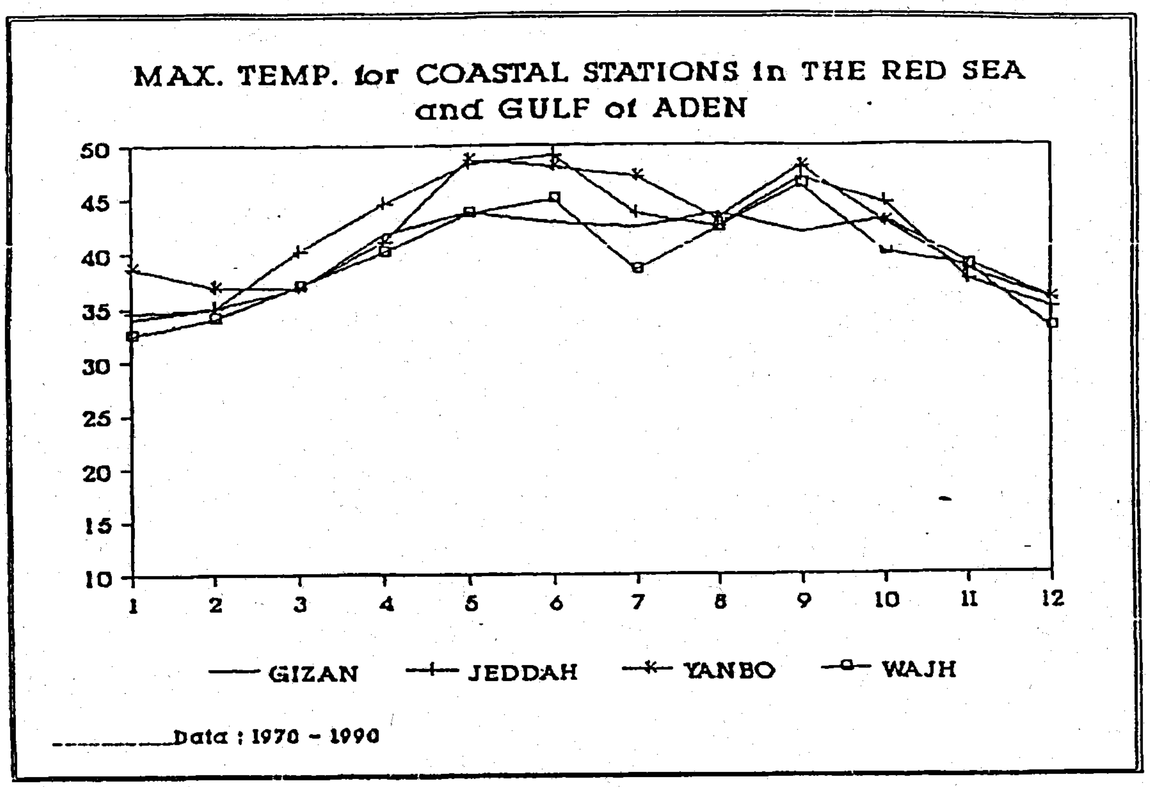




Figure 6: Mean temperatures for coastal stations in the Red Sea and Gulf of Aden
(Source: Ahmed, 1992)



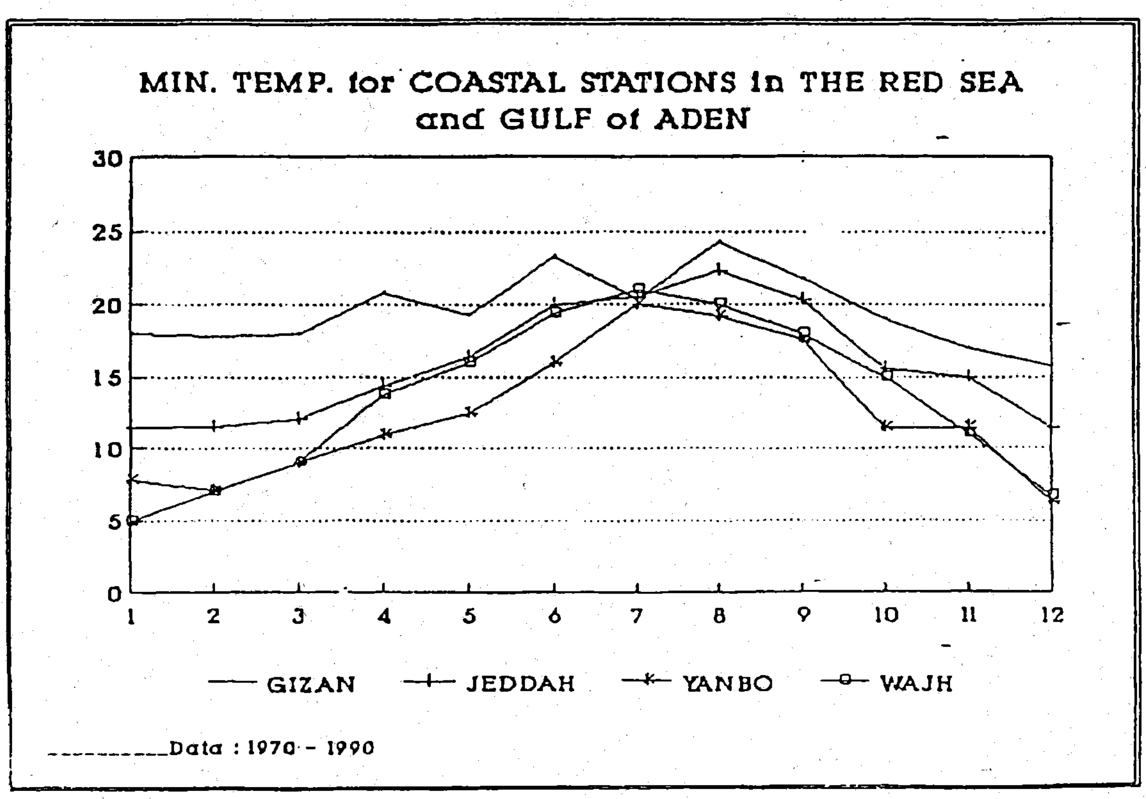




Figure 7: Maximum and minimum temperatures for Coastal Stations in the Red Sea and Gulf of Aden. (Source: Ahmed, 1992)

tidal prediction is not to be expected.

### 2.3.4 Currents

Provision of a clear and detailed description of Red Sea currents has proven to be difficult, partly because currents are generally weak and variable, both in time and space (Edwards, 1987), and are due to scarcity of direct current measurements along the Red Sea except through the straits and at its middle region.

Basically, it is known that the fundamental movements follow the winds, such that the northerly wind in summer drives surface water south for about 4 months, at a velocity of 12-50 cm/sec., while in winter the flow is reversed, pushing water into the Red Sea from the Gulf of Aden; the net value of the later movement is greater than the summer outflow, and the drift continues to the northern end of the Red Sea.

In winter, weak NNW winds exist in the north and strong SSE winds dominate in the south, converging near 19°N. The SSE winds push the Gulf of Aden water into the Red Sea and continues in its movement to the northern end of the sea where the deep water is expected to be formed and flow back to the south. Patzert (1974) explains this longitudinal type of motion as composed of a pair of counter rotating cells in the vertical plane that converge at the surface between 18° and 20°N. The convergence zone gradually moves southward until by June, the winds are from North-Northwest for the entire length of the Red Sea.

During summer, strong westerly winds dominate over the Gulf of Aden region, lowering its water level and causing a surface outflow from the Red Sea. On the other hand, a subsurface layer of low temperature is flowing into the Red Sea due to the upwelling processes in the Gulf of Aden region. The entrainment of such cold and relatively low saline water into the Red Sea could be traced up to Lat. 20.0°N. Maillard and Soliman (1986) concluded that the longitudinal temperature gradient of the deep sea water could be only a summer process, and the formation of intermediate water of high salinity in the northern Red Sea can be a step towards the winter deep water formation.

Surface cross currents are also existing in the sea which are frequently mentioned in the Red Sea Pilot. Wassef, *et al* (1983), Gerges and Soliman (1987) have concluded, on applying the numerical models to calculate the wind driven circulation in the Red Sea either as a homogeneous or as a two-layer basin, the existence of gyratory motions along the sea which are either cyclonic or anticyclonic in character. Maillard (1971) suggested that the currents during February 1963 were variable and directed across the sea. Gado (1978) reported some current observations recorded in the area between Jedda and Port-Sudan in November 1977. These observations indicated that surface currents in the region were of variable directions and speeds. Relatively high speed SE currents (24 - 47 cm/sec) were recorded along the Sudanese coast and lower speed NNE currents (8 - 29 cm/sec) along the Saudi coast. With the offshore observations, a counter clockwise eddy circulation prevails, which indicates again the presence of the transverse currents across the sea.

Figure 5 illustrates the water movement in the Gulf of Suez. It demonstrates the driving density gradient in the northern Red Sea. The net annual drift of surface water is therefore to the north. Evaporation in the Red Sea averages 1-2 m/yr, and continues in both summer and winter. This causes a gradual increase in salinity towards the north, from about 36.5 at Bab el Mandab to 40.5 at the entrance to the Gulfs of Aqaba and Suez. In addition, surface water temperature falls towards the north such that winter temperatures of about 22°C prevail in the north and at the same time evaporation continues strongly. Thus, as water drifts northwards its density increases. In the Gulf of Suez, water is cooled more rapidly in winter, to below 18°C, and evaporation helps to increase the salinity to 42.5 or more in the north. Thus, there is a steep salinity gradient along the Gulf of Suez, and a marked differential between the latter and the Red Sea. The dense, cool, saline water at the surface of the entrance to the Gulf of Suez pours downwards into the deeper Red Sea, turns under the surface water and returns southward. The turnover occurs near the mouth of the Gulf of Suez;

at the entrance to the Gulf of Aqaba there is a sill which precludes similar return. The returning water has the constant temperature of 21.5°C found throughout the Red Sea below the thermocline at 250-300m, and it has a constant salinity of 40.5, in other words close to the value of the water at the southern end of the Gulf of Suez. Thus, there are very little differences in either temperature or salinity between the surface and deep layers of water in the north of the Red Sea, and these differences increase southwards.

### 2.3.5 Red Sea-Gulf of Aden Water Exchange

The main surface drifts are slow moving and are easily modified and even reversed by local effects and by the small tides. Overall, there is a net flow into the Red Sea. The water balance in the Red Sea is negative in the sense that annual precipitation is rarely over 10mm while evaporation is about 2m/yr. In addition, there has been a further small net loss northwards into the Mediterranean since the opening of the Suez Canal because of a tidal height difference between the Red Sea and Mediterranean. The balance is made up by an inward flow through Bab el Mandeb. It is estimated that water renewal time in the upper 200m (i.e. the water above the thermocline) is in the order of 6 years, while the time for turnover of water for the whole Red Sea is about 200 years (Sheppard, *et al* 1992).

The flow through the Bab el Mandab Strait is not a simple one (Figure 8). Not only is there an inward flow to compensate the evaporation deficit but also a discharge outward of the more saline deeper layer. Both of these processes are affected by the sill of only 130 m deep just north of Bab el Mandeb, and by the strong winds which drive surface water in the Gulf of Aden.

In the winter, a double layered contra-flow system operates. At the surface, water is driven into the Red Sea from the Gulf of Aden by the prevailing winds; water of this surface flow has physical characteristics of the Gulf of Aden water, having a temperature of around 25°C and a salinity of about 36.6. Beneath this, there is a deeper outward flow which comes from the deeper Red Sea water body. The latter is both more saline (about 40.5) and cooler (about 21.5°C) than the inflowing water, and consequently, it is considerably more dense than the surface water. It is also denser than the Gulf of Aden water, and hence the outward flow of deeper water is maintained. This type of structure in a double layered system dominates for about three quarters of the year from September or October to late June.

For part of the summer from late June to September or October, another form of water movement exists. During this time of the year, the prevailing wind through Bab el Mandab changes from southeasterly to northwesterly, and therefore opposes the inward surface flow. During these hottest months, surface salinities in the southern Red Sea increase through evaporation to 38 or 39, and its temperature rises to over 30°C and the water, despite the raised salinity, becomes less dense. This causes the upper layer to divide vertically into two components, a wind-blown shallow flow travelling south and out of the Red Sea over the main part which still flows inward. Beneath the latter, the outflow of denser water continues as before. According to Mailland and Soliman (1986), and based on continuous current records at different depths in the strait, the three layers summer stratification was clearly observed in June and up to 18°N latitude in October. The Indian Ocean inflow takes place at the intermediate level through the upwelling processes having temperature and salinity of about 16.0°C, 36.0 respectively. Meanwhile, the Red Sea water is flowing out of the sea into the gulf both at the surface due to the effect of the monsoon with temperature and salinity of about 30.0°C and 37.0 and near the bottom with temperature and salinity of 21.5°C and 40.0 respectively.

The estimates of turnover time of the Red Sea surface water above the thermocline is of about 6 years, and that of all Red Sea water is approximately 220 years.

## 2.4 Mean Sea Level

The mean sea level in the Red Sea is strongly influenced in the long-term by the high rate of

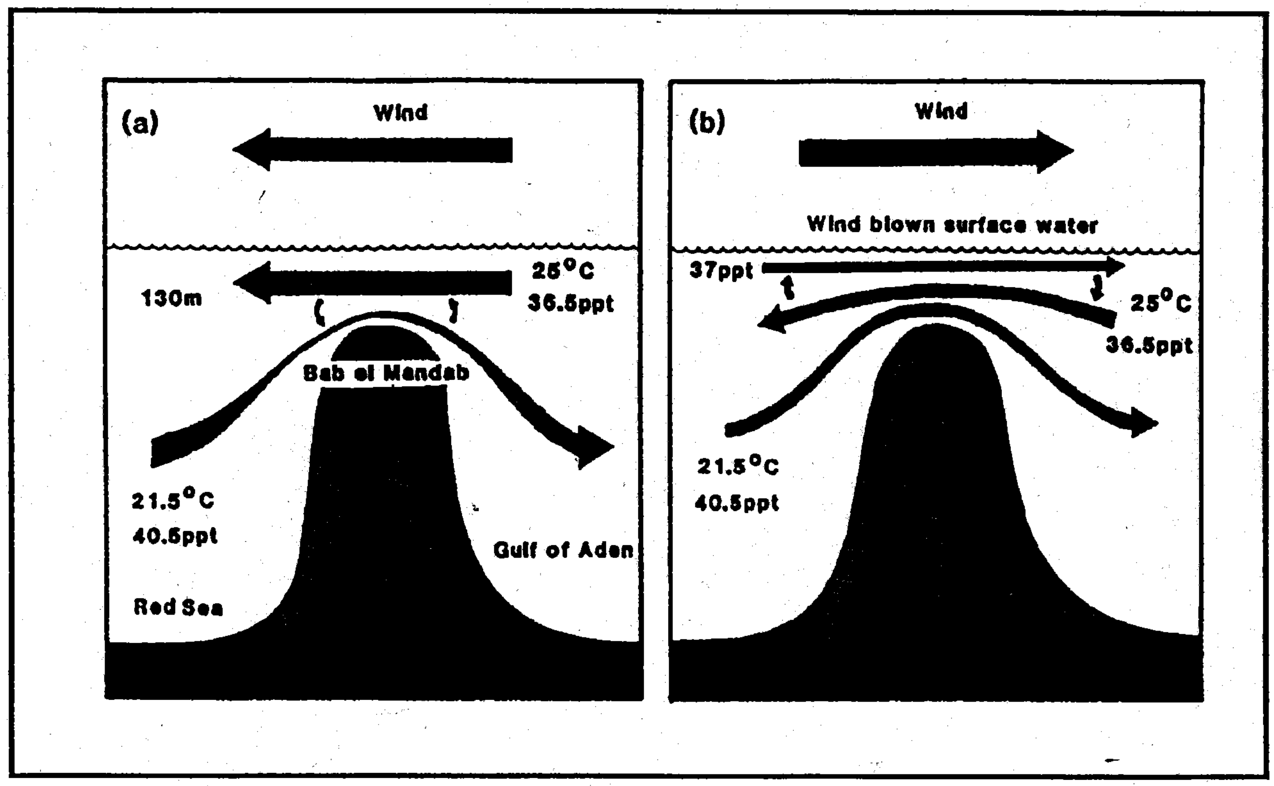



Figure 8: Sketch of (a) winter and (b) summer water flow through the entrance into the Red Sea. Section across the sill at Bab el Mandeb showing the layers of water flow.
(Source: Sheppard et al, 1992)

evaporation and the balance between the inflows and outflows during winter. In winter, the inflow exceeds the outflow and the loss by evaporation is combined in spite of the fact that evaporation is probably higher in winter than in summer. Consequently mean sea level rises over the whole of the Red Sea. In summer, the combined losses are greater, and the mean sea level falls. Based on the very few measurements of sea level available, the range is from a maximum depression of 20-30 cm in August-September, to an elevation of 10-20 cm in December-January. The mean sea-level changes are greater in the Red Sea and Gulf of Suez than in the Gulf of Aden, in winter, being 37 cm at Port Sudan, 12 cm at Suez and 6 cm at Perim (Morcos, 1970).

In addition to the seasonal variations, a slope downwards of mean sea level from south to north over the whole length has been computed but confirmation of this from geodetic survey is lacking (Edwards, 1987). Superimposed on these large scale variations are changes caused by meteorological factors which may be short and local in character. Chief of these is the effect of wind stress. For example, in the Gulf of Suez, a prolonged southerly wind is known to raise sea level at the northern end by up to about 2.5 m. Changes in atmospheric pressure also influence sea level but in the Red Sea the effects are generally small. Theoretically, sea level is depressed by one centimetre for every millibar increase in pressure. In practice, changes in level due to both short term and seasonal pressure changes are usually masked by other influences but are most likely to be seen in shallow lagoons. Periods of abnormally low pressure in the north in winter may be accompanied by unusually high water levels.

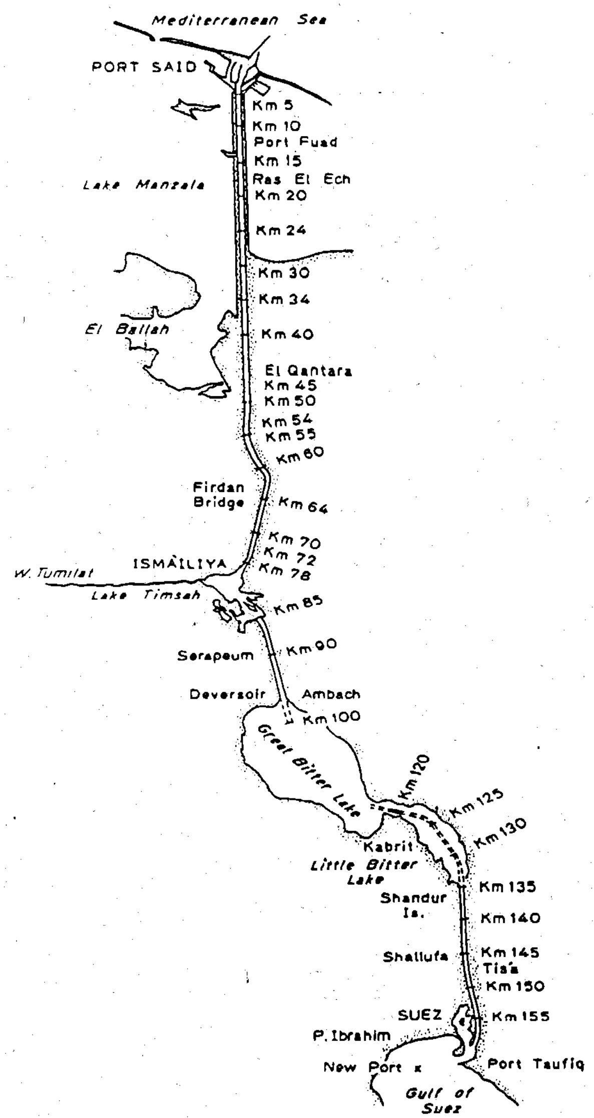
## 2.5 Suez Canal

The Suez Canal is not only the largest canal in the world, about 195 km today, but also the deepest, 19.5 m after the recent development project which involved both deepening and widening of the canal. It lies between latitudes 29°55' and 31°25', and longitudes 32°15' and 32°35'. It passes through a series of lagoons which are from the north to south, Lake Manzallah, Lake Timsah, the Great Bitter Lake and the Little Bitter Lake.

The tide in the southern part of the canal is influenced by the tide of the Gulf of Suez and hence co-oscillating with it, showing a wide range of 0.9 to 1.8 m between neap and spring tides at Suez. The high tide reaches the Deversoir at the northern end of the Bitter Lake, 2-3 hours after the tide of Suez. On the other hand, the northern part of the Canal is co-oscillating with the Mediterranean, showing a very small range of 0.3 - 0.5 m (Soliman, 1992).

Morcos and Gerges (1974) used the observations obtained from five tide gauges installed along the canal (at Port-Tawfik, Gineva, Kabret, Deversoir and Port-Said) in 1964 and 1966 to compute the monthly M.S.L. at these locations. They found that often Bitter Lakes occupy the intermediate height between the Red Sea and the Mediterranean when the current is predominantly northward in winter or predominantly southward in summer. However, Bitter Lakes are either higher or lower than the Mean Sea Level at both ends of the canal. They also showed that in January 1964, Port-Tawfik was 36.0 cm higher than Port-Said while in September 1964, it was 27.0 cm, lower than Port-Said. Sharaf El-Din (1975) showed that for the period 1956 - 1966, Port-Tawfik was 16.7 cm higher than Port-Said in winter, while in summer it was 8.5 cm lower than Port-Said.

The M.S.L. along the canal shows a wide monthly and annual variations (Figure 9). More recent study by Soliman and Morcos (1990) showed that over a period of 7 years from 1980 to 1986, the M.S.L. at Suez (Port Tawfiq) is about 19.5 cm higher than at Port-Said with a maximum difference of 31.0 cm in March. In summer, the M.S.L. at Suez (Port Tawfiq) is about 9.0 cm lower than at Port-Said with a maximum difference of 13.0 cm in July. It was also estimated that during this period (1980-86) MSL at Suez was 12 cm higher than Port Said compared to 10 cm during the period of 1956-1966 (Sharaf el Din, 1975). The increase (2 cm) of the MSL along Suez Canal (6.0 cm at Port Said and 8.0 cm at Suez) over the last two decades may be due to combined effect of continued subsidence, particularly in the Port Said area (Stanley, 1988) and sea-level rise (Soliman and Morcos, 1990).



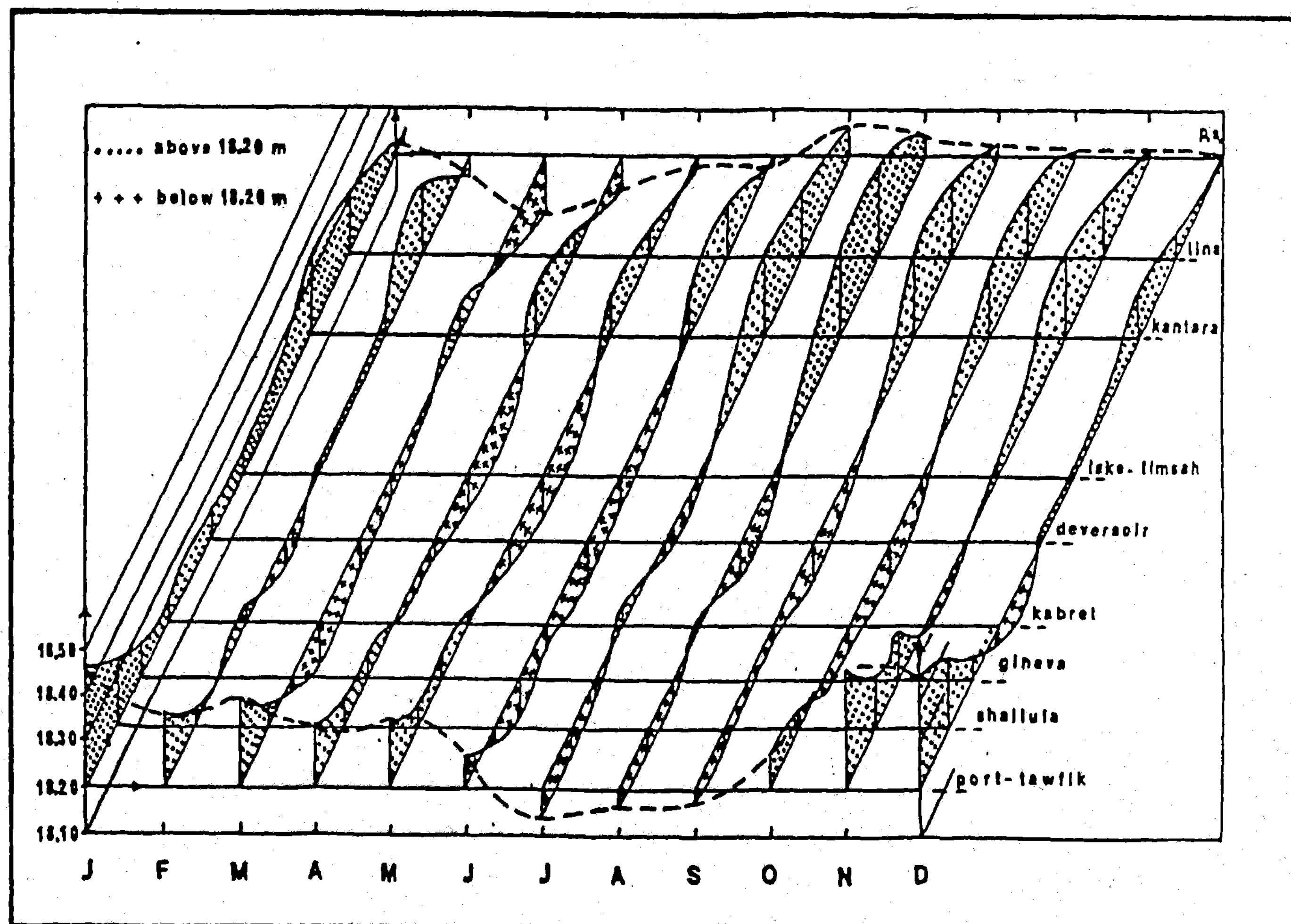




Figure 9. Map of Suez Canal. Alongside, diagram showing the monthly mean water level along the Canal averaged over the period 1980-1986. (Source: Soliman et al, 1988)

Other observation of the sea level at Port Said (1924-1973) indicated a relative sea-level rise of 3 mm/yr (Fanos, 1990) which is higher than the global mean sea-level rise by 1.8 mm/yr. This is explained as due to the local rate of subsidence of the ground on which the tide gauges were established. Emery (Sestini, 1988) reported a relative sea-level rise of 4.8 mm/yr (subsidence of 3.6 mm/yr at Port Said from tidal records). A precise levelling of Gobi (Sestini, 1988) in the Port Said area showed a relative subsidence of 50 cm in 80 years; 6.25 mm/yr (Delft Hydraulics, 1992).

During most of the year a current flows from the Red Sea into the Mediterranean through Suez Canal, whereas Mediterranean water rarely reaches the Red Sea. Lake Timsah has no thorough-going currents and the water are probably mainly wind driven. Between the Bitter Lakes and the Gulf of Suez, the currents in the canal are tidal reversing their direction twice daily and they are rapid. Between the Great Bitter Lake and Port Said the currents are slow and seasonal; following to the north for ten months, and to the south for only two months, mainly August to September.

Salinity of the Suez Canal does not result from a gradual mixing of the Red Sea and Mediterranean waters. This salinity results from the solubility of the fossil salt at the bottom of the Great Bitter Lake, the evaporative concentration in different lakes and shallows and an inflow of the Nile waters at different points (Por, 1978). In Lake Timsah, salinity may fluctuate between 7.8 and 47.6 (Fouda, 1990) whereas in the Bitter Lakes, it varies between 43 and 48 and is seasonal with a maximum in summer and minimum in winter. The Bitter Lakes will behave in the future as one of the littoral lagoons of the Red Sea, with salinity fluctuating seasonally around 44 (Por, 1978; Soliman, *et al* 1988; Soliman and Morcos, 1990).

The maximum temperatures recorded are around 30°C during the months of June-September and the minimum temperatures around 14-16°C during January-February.

## 2.6 Hydrology

The Red Sea coast has, in general, limited freshwater resources due to its geographical location in a subtropical arid region. In view of the expected global climate change, hydrological cycle and underground water in the region may seriously be affected (El Hag, 1992).

The groundwater resources along the Red Sea and Gulf of Aden coastal region depend mainly on rainfalls which are heaviest at Port Sudan and Suakin, ranging from an average of 20 to 160 mm/yr (Edwards, 1987; Basheir, 1990). At these two places, rainfall are drained into several runoff (khawrs and wadis). Khawrs Baraka and Arbaat represent important groundwater supply areas in Sudan coastal areas, constituting substantial deltas (El-Hag, 1992). Khawr Baraka is located about 200 km south of Port Sudan, forming Tokar Delta near the coast. This water reservoir with a catchment of 61,000,000 $km^2$, is very important as it supplies several agricultural schemes in the area beside the heavy domestic use by a large sector of inhabitants and their animals. Khawr Arbaat is situated just north of Port Sudan harbour, with a catchment area 4,000,000 $km^2$, and provides the whole city with freshwater (El Hag, 1992).

Groundwater seepage occurs also at a number of locations along the Red Sea coast of Saudi Arabia and Egypt. When it occurs, it gives rise to coastal palm groves (Ormond, 1980, Fouda, 1992). At the southern region of the Red Sea and Gulf of Aden, there are several flat coastal plains which receive water that drained from the surrounding high mountains during the rainy season in summer. Freshwater are stored either in wadis and khawrs or underground, hence considerable cultivated lands exist in places like Al-Hudaydah and Aden. Indeed, the only fresh water supply for the whole city of Aden comes from underground water.

The narrow coastal plains of the eastern Red Sea and Sinai include coastal aquifers mostly belonging to Quaternary times and consists of the weathering products of the adjacent height (El-Shamy, 1992). Locally, they are occupied by Pliocene Miocene formations in the form of elongated dissected ridges which prevent any connection with sea water. These coastal aquifers depend on their recent recharge on the local precipitation in the adjacent catchment area. Under definite geomorphic condition and according to precipitation intensity flash floods take place without appreciable recharge. Consequently, water quality of coastal aquifers deteriorates and the possibility of salt water intrusion increases. Therefore, the expected rise in sea level may increase inland salt water intrusion with great or complete damage of the existing aquifers. Increase of inland freshwater recharge by appropriate management of rainwater may prevent or at least minimize the aquifer damage (El-Shamy, 1992).

Further north along the Suez Canal region, considerable large areas of cultivated land receive water from Nile sources particularly at Ismailia and Fayed along the western side of the canal and to a lesser extent along the eastern side where modern large farms exist. Rain waters in such areas (e.g. average annual rainfall at Ismailia is 285 mm/yr) and groundwater resources are not used for agriculture. Complete picture of the hydrology of Suez Canal region and the extent of the cultivated land are needed to be studied.

Large communities along the Red Sea coast of Saudi Arabia and to some extent in Egypt along the western coast of Gulf of Aqaba are dependent, directly or indirectly on desalination water (Couper, 1983; Fouda, 1992). This supply of desalinated water is central to the development and increased direct and indirect exploitation of coastal resources of the region (UNEP, 1985). For example, the daily water consumption of Jeddah in 1985 was over 400,000 $m^3$, most of which from desalination plants (Aleem. 1988).

## 3. PRESENT STATE OF THE ENVIRONMENT

### 3.1. Natural Resources

The Red Sea contains representatives of all major tropical marine communities except estuaries, which can not be formed because it receives no permanent rivers. Figure 10 illustrates the principal communities (Head, 1987). In the present review, we shall deal mainly with the coastal communities (e.g. coral reefs, mangroves, seagrass beds) which are interdependent (Ogden and Gladfelter, 1983); some of the principal interactive routes are illustrated in Figure 11.

#### 3.1.1 Coral Reefs

Coral reefs rank as among the most biologically productive and diverse of all natural ecosystems, their high productivity stemming from efficient biological recycling, high retention of nutrients and a structure which provides habitats for a vast array of other organisms. They are tropical, shallow water ecosystems, largely restricted to the area between latitudes 30°N and 30°S (Wells, 1988).

The World Conservation Strategy (IUCN/UNEP/WWF, 1980) identifies coral reefs as one of the "essential life-support systems" necessary for food production, health and other aspects of human survival and sustainable development. Reefs protect the coastline against waves and storms surge, prevent erosion and contribute to the formation of sandy beaches and sheltered harbours. They are a source of raw materials for building, jewelry (black corals) and ornamental objects. Increasing numbers of reefs species are being found to contain compounds with medical properties (Wells, 1988).

The tube reef-building corals (hermatypic or stony corals) are animals (polyps) that collectively deposit calcium carbonate to build colonies. The coral polyps have symbiotic algae (zooxanthellae) within their tissues which process the polyp's waste products, thus retaining vital nutrients. Not all reefs are constructed predominantly of corals (Figure 12). In particular, several genera of red algae grow as heavily calcified encrustation which bind the reef framework together forming structures such as algal growth.

There are a number of different reef types: fringing reef which grow close to shore; patch reef which form irregularities or shallow parts of the seabed, bank reef which occur deeper than patch reefs; barrier reefs which develop along the edge of the continental shelf; and atolls which are regularly

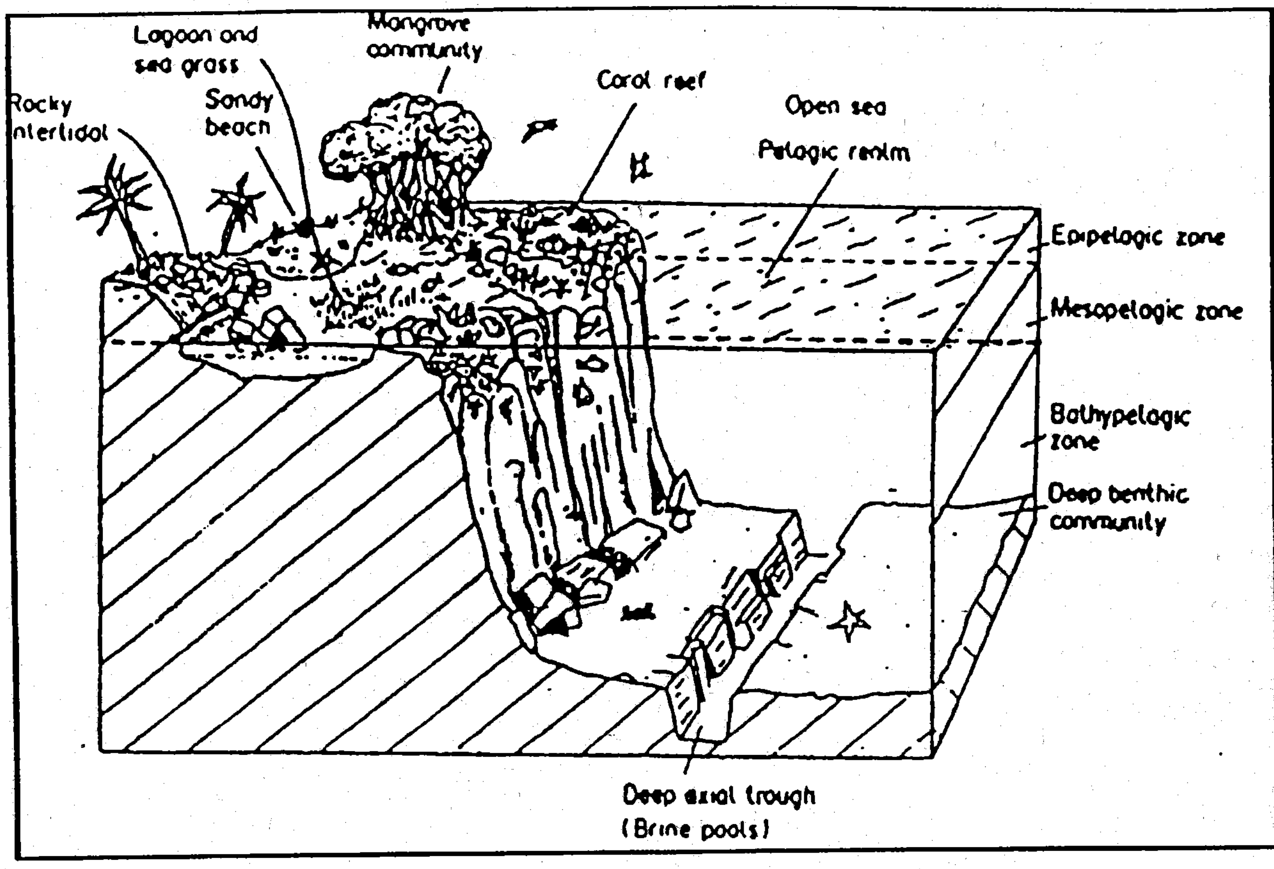



Figure 10: Sketch, not to scale of basic community types in the Red Sea (Source: Head, 1987)

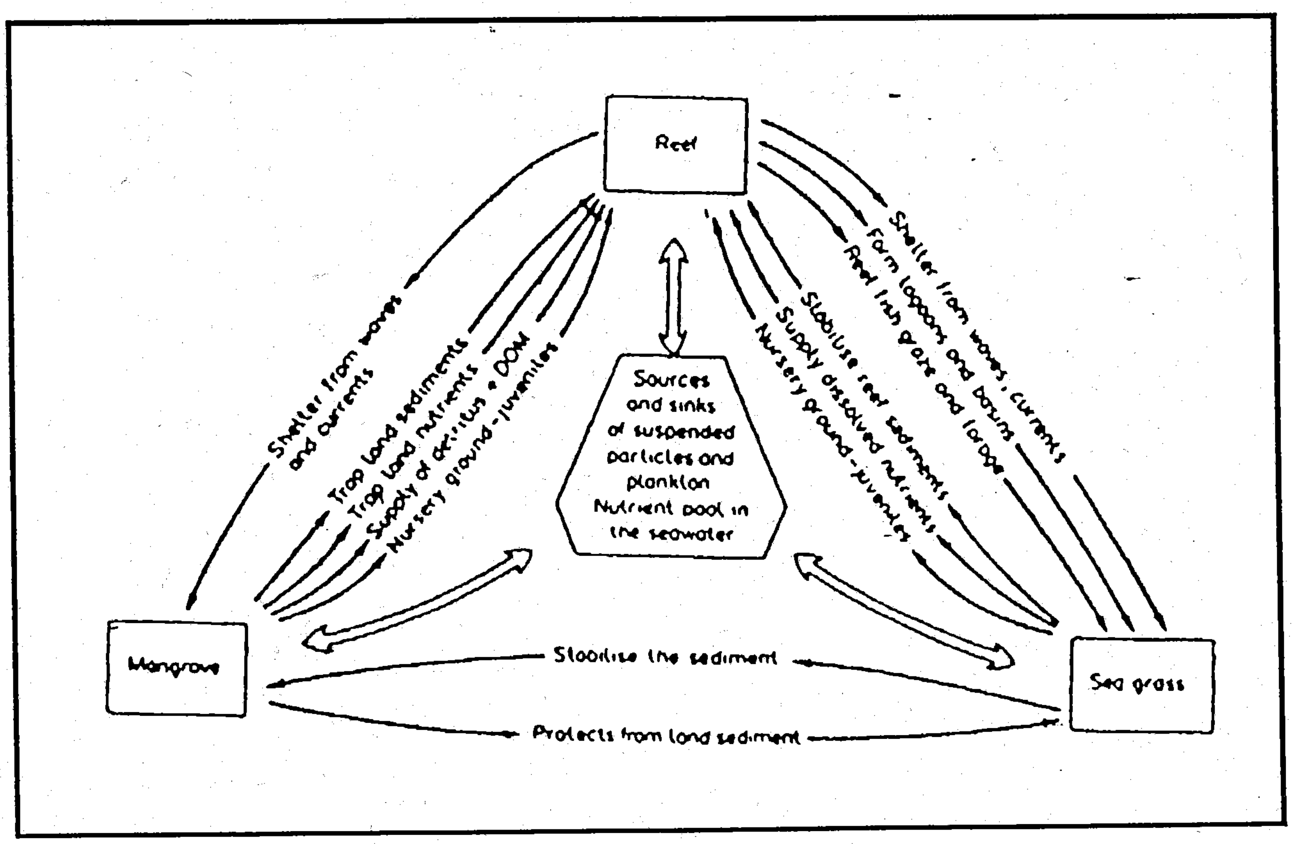



Figure 11: Diagram to summarize principal interactive mechanisms between reefs, seagrass beds and mangroves. Original, based on discussion in Ogden & Gladfelter (1983)

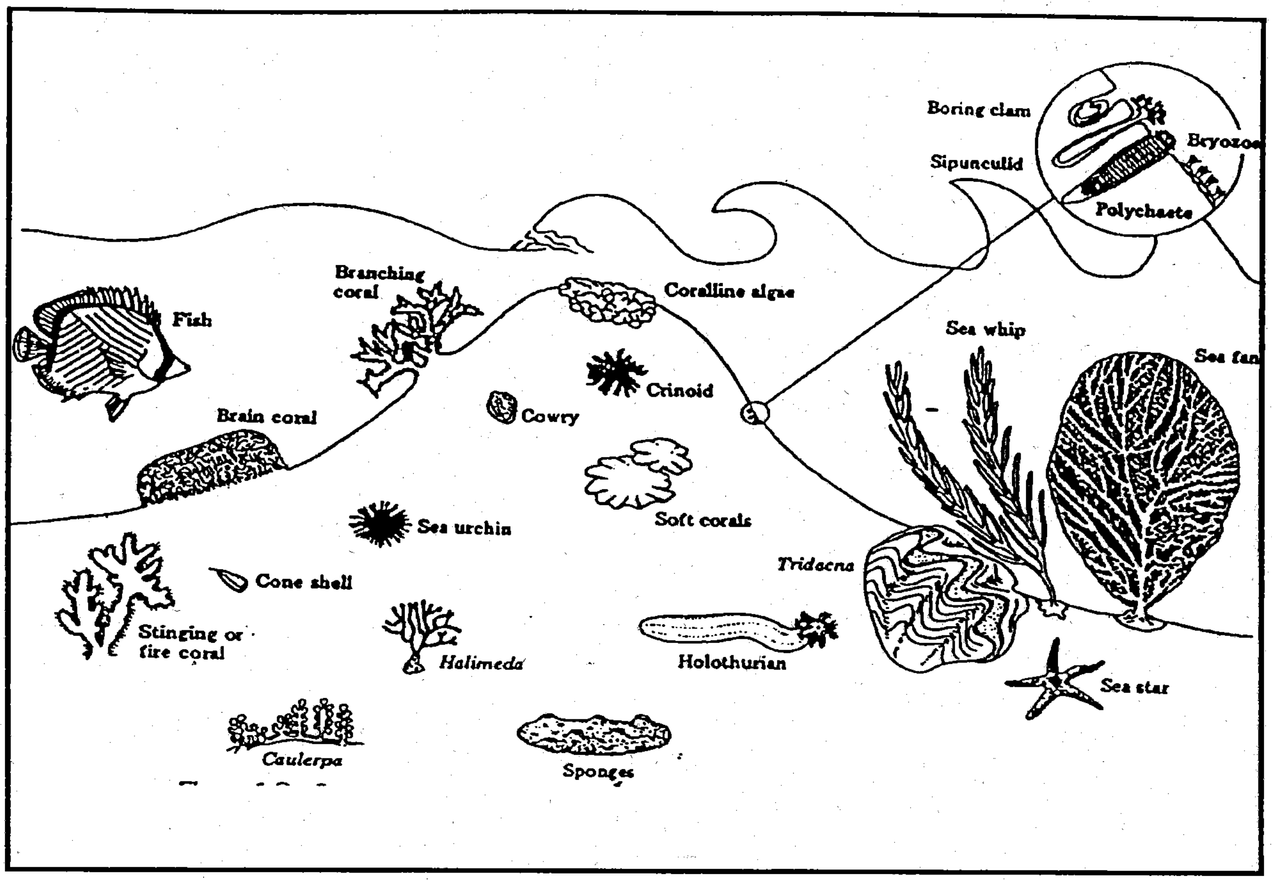



Figure 12 Some of the dominat and conspicuous components of a coral reef. (Source: Nybakken, 1988)

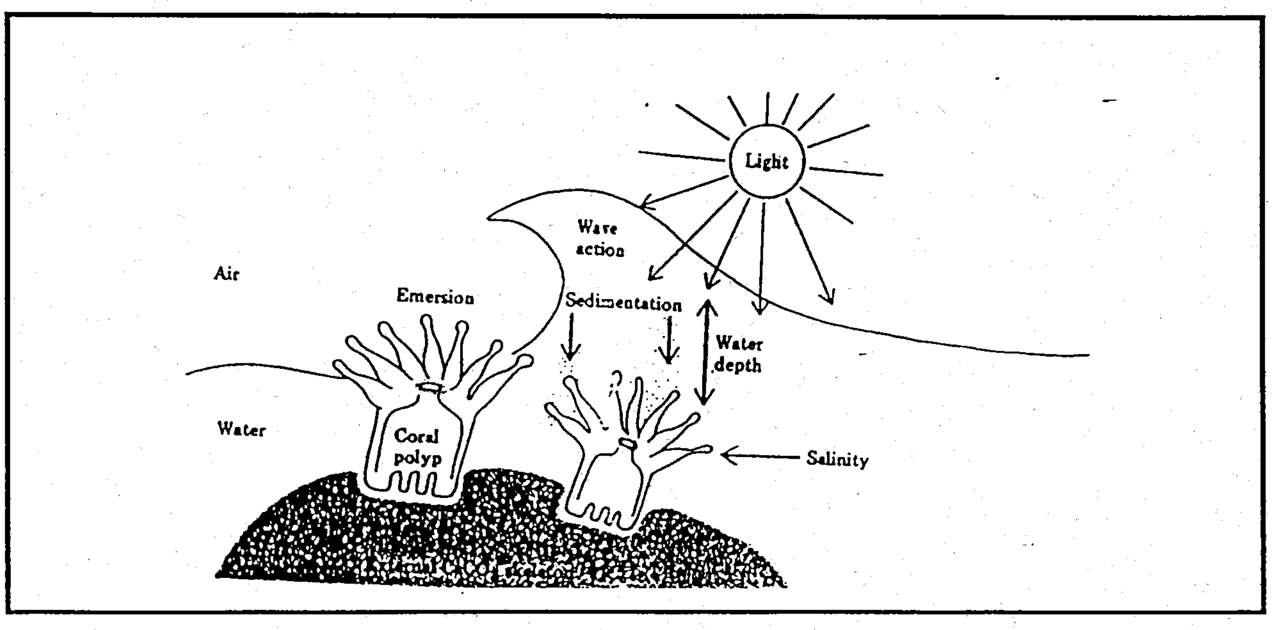



Figure 13 Summary of physicals factors acting on coral polyps and coral reefs that may act to limit their distribution (Source: Nybakken, 1988)

circular reefs around a central lagoon and are typically found in oceanic waters.

Coral growth is optimal only within a fairly narrow range of water temperature and salinities and reef structure and development is influenced by other oceanographic factors such as current and wave force (Figure 13). The monsoonal cycle of the Indian Ocean therefore exerts a major control on reef distribution. The Red Sea and Gulf of Aden fall outside the Indian Ocean monsoonal gyre and have climates which are essentially continental, with limited rainfall and high temperatures for most of the year, although in the north temperatures can be extremely low in winter.

The most conspicuous shallow water marine habitat in the Red Sea is formed by the extensive coral reefs which fringe much of the coastline and often extend offshore for many kilometres (UNEP, 1985). Coral cover is usually less than 50%, but in sheltered areas one or two species especially Porites, cover 80% of the substrate. The complexity of the ecosystem is illustrated by its high diversity, approximately 250 species of stony corals and 180 species of soft corals and even higher diversity of fishes may be found on Red Sea coral reefs (Sheppard, *et al* 1992).

Figure 14 shows the distribution of major reef areas in the Red Sea and Gulf of Aden. There is a strong pattern to the distribution of reefs in the Red Sea following that initially pointed out by Crossland (1907, 1913, 1939) based on observations in Sudan and Egypt, and further described by Mergner (1971), Ormond and Campbell (1971), Bemert and Ormond (1981), Sheppard (1983), and Ormond, *et al* (1984, 1985). The distribution of reefs through the Red Sea can be related to tectonic movements and block faulting of suitable foundations for reef growth (UNEP, 1985).

The northern and central Red Sea have the best developed reefs. In the central sections, reef complexes are found along the coast at about 3-10 km offshore, having developed on a series of narrow underwater banks of tectonic origin. In the southern third of the Red Sea, these banks are much wider and give rise to the Suakin, Dahlak and Farasan archipelagos, which may resemble atolls. Beyond the banks, the Red Sea drops rapidly to a stage at 500-1000 m, from which occasional very steep sided atoll-like pillar reefs may rise, often with impressive coral formation, for example, Sanganeb and parts of the Farasan Bank (Wells, 1988). South of 20°N, there is decrease in the quality, complexity and extent of reefs due to shallower bathymetry, higher turbidity and greater freshwater input. Little is known on the reefs in this area and the reefs of the Gulf of Aden, which has a coastline similar to the Red Sea. Suitable substrate often tend to be dominated by algae, partly due to influence of the upwellings (Wells, 1988).

A high coral diversity has been recorded from the reefs of the Aqaba Gulf although they have a simplified structure. About 129 species of hermatypic corals (Scheer and Pillai, 1983) and almost 120 species of soft corals have been recorded (Benayahu, 1985). Millepora dichotoma and *M. platyphyla* form dense belts along many coral platforms of Sinai coast. Fishelson (1980) describes other corals typical of the Gulf of Aqaba. Analysis of fish communities at Neweiba was carried out by Ben-Tuvia and Baranes (1982) and reef fish studies have also been carried out by Fishelson, *et al* (1974), Abu Zeid (1986) El-Sayed (1987) and Fouda, *et al* (1988, a, b). Echinoderms were studied by Hellal (1986, 1989) and Fouda and Hellal (1987, 1989, 1991). Kotb (1989) studied the structure and zonation of coral reef communities at Ras Mohammed.

Stony corals show a decrease of percentage cover with increasing depth (Kotb, 1989), while the soft corals (e.g. Xenia) exhibit an increase in cover with increasing depth down 15 m, and then decrease below. Branched and massive corals dominate the reef crest and the encrusting ones are abundant in deeper waters. Corals show definite zonation where *Acropora* are the shallow fore reef, followed by *Millipora* down to 10 m. The xenia zone continues from 10 to 40 m, but *Montipora* shares it at 20-25 m. The common corals include *Favia, Favites, Echinopora, Porites, Pocillopora, Fungia, Pavona, Gardineroseris* and *Dendrophyllia.*

Sponges have no definite pattern except a very low cover at the reef crest, while gorgonians and black corals inhabit the deep areas of the reef. Molluscs associated with corals include abundant spider conch, *Lambis lambis* and the giant clam *Tridacna squamosa*. There are about 30 species of

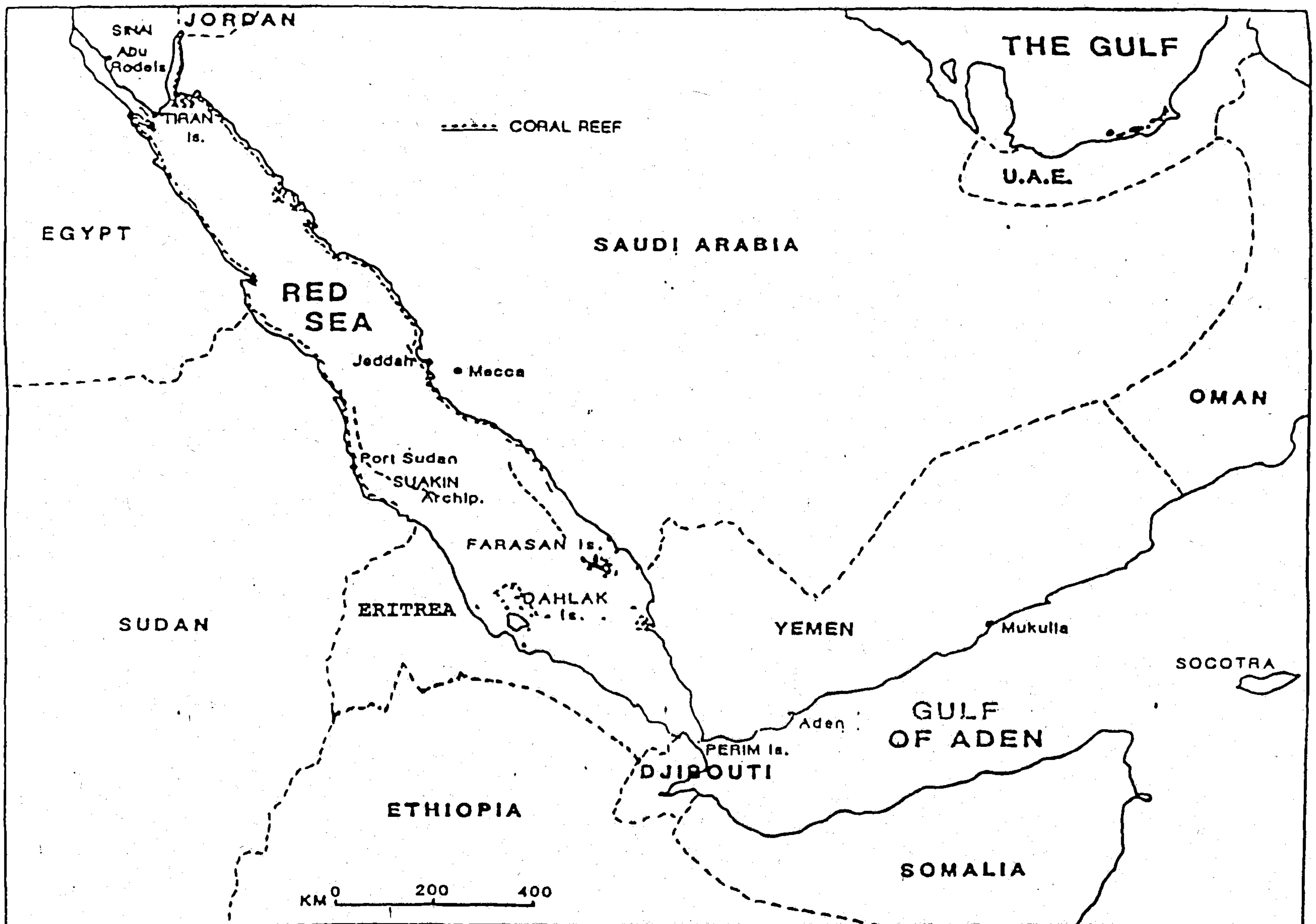



Figure 14. Distribution of major coral reef areas in the red Sea and Gulf of Aden region. (Dashed lines near-shore indicate fringing reefs and associated patch reefs. Dashed lines off-shore indicate complexes of islands, patch reefs, atolls, etc.).
(Source: UNEP, 1985)

sea stars (Fouda and Hellah, 1987), being dominated by *Gomophia aegyptia*, *Fromia ghardaqana* and *Astropectin hemprichi;* some 40 species of brittle stars (Hellah, 1990) and more than 25 species of sea urchins. Coral reef fishes are abundant and diverse (Randall, 1983, Abu-Zeid, 1986, El-Sayed, 1987).

Fringing reefs in the Gulf of Suez are less well developed than those in the Gulf of Aqaba. From Port Suez to Ras Shukheir, the bottom is mainly calcareous sand. In the northern half of the Gulf, there is little or no coral, the northern limit on the western shore being at Ain Sukhna. Suez Bay has a sandy and muddy bottom with coral limited to boulder as rocky outcrops. From Ain Sukhna to the Strait of Global, only patchy fringing with much dead coral and considerable cover of brown seaweed are found. In the northern half of the Gulf there are moderately reefs (Fishelson, 1980). Coral diversity is limited, 25 species having been recorded by Rosen (1972) and has increased to 45 by Scheer and Pillai (1983).

### 3.1.2 Fishes

The Red Sea is often considered as a rich area for fish. In reality this wealth is a wealth in diversity. The Red Sea is related to the Indo-Pacific group and is characterized by an impoverishment of the stocks and decrease in number of the species; for 2000 species of fishes of the Indian Ocean, 800 only are present in the Red Sea.

About 70% of Red Sea fish species are widespread in the tropical Indo-Pacific region and further 4% are known from the tropical Indian Ocean but do not occur in the Pacific, whilst only 9% are confined to the Western Indian Ocean. A substantial proportion (17%) of the fish species are endemic to the Red Sea and the Gulf of Aden (Ormond and Edwards, 1987). In addition, 27% of the western Indian Ocean are confined to the extreme north-west of the area and are probably of Red Sea origin (Figure 15).

The distribution of the Red Sea fishes is not all homogenous. Many species are found only in the central and northern Red Sea and not in the south including numerous endemic, particularly amongst dottybacks, wrasses and damselfishes, while a few others occur in the south but apparently not in the north (Sheppard et al, 1992). Many non-endemic fishes show similar, latitudinally related distributions which have predominantly ecological determinants, either through habitat effects or post settlement fishes, or water quality influences on survival of larvae. Habitat and food supply for nearshore fishes change markedly down the Red Sea, as does water quality. Numerous other species are common in either the central and northern and southern Red Sea but occur less frequently, or even only very rarely, at its other end.

It is evident from these distributions that the Strait of Bab el Mandeb and Gulf of Aden area is a barrier which can not be crossed successfully, on one hand by many species which have evolved to cope with the peculiar environment of the Red Sea, and on the other hand, by many of the species adapted to the conditions prevalent in the Indian Ocean. The high level of endemism may be ascribed to both the period of partial isolation from the Indian Ocean during the Pleistocene low sea levels and the unusual oceanographic conditions still prevailing.

Since the opening of the Suez Canal (1869), 51 Red Sea fish species have invaded the eastern Mediterranean (Golani and Ben-Tuvia, 1989; Golani 1992). Many of them are now widespread being found as far west as Sicily and Tunisia and as far north as the Southern Aegean Sea (Figure 16). Although few in number these Red Sea escapes have had a profound effect on the ecology of the Levant Basin (Por, 78; Ormond and Edwards, 1987), and now become important components of the fisheries. Currently about 12% of the eastern Mediterranean coastal fishes are of Red Sea origin. They appear to be restricted to the upper 100m of the water because of their intolerance to lower temperature, but it appears that they have added to the depauperate Mediterranean fish fauna and have not displaced any native species.

There are records of at least five presumed Mediterranean immigrant fish species in the Red Sea, and a further six species have been reported in the immediate vicinity of the southern end of the

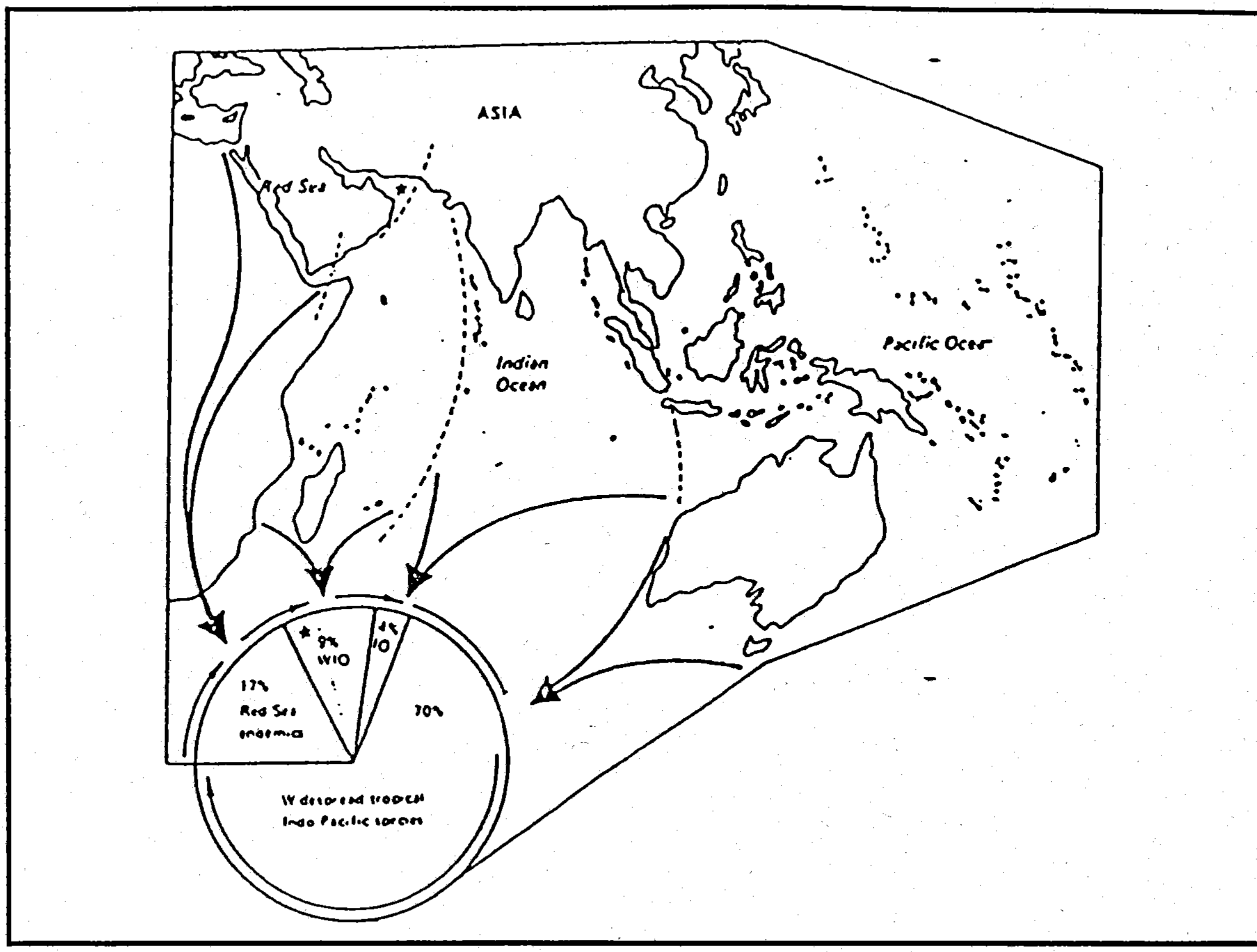



Figure 15. Zoogeographic composition and ranges of Red Sea fish species. WIO - Western Indian Ocean. IO - Indian Ocean. The black star denotes those species endemic to the Western Indian Ocean which, outside of the Red Sea/Gulf of Aden area, are found in only the Gulf of Oman or Arabian Gulf; such species probably originally evolved in the red Sea.
(Source: Ormond & Edwards, 1987)

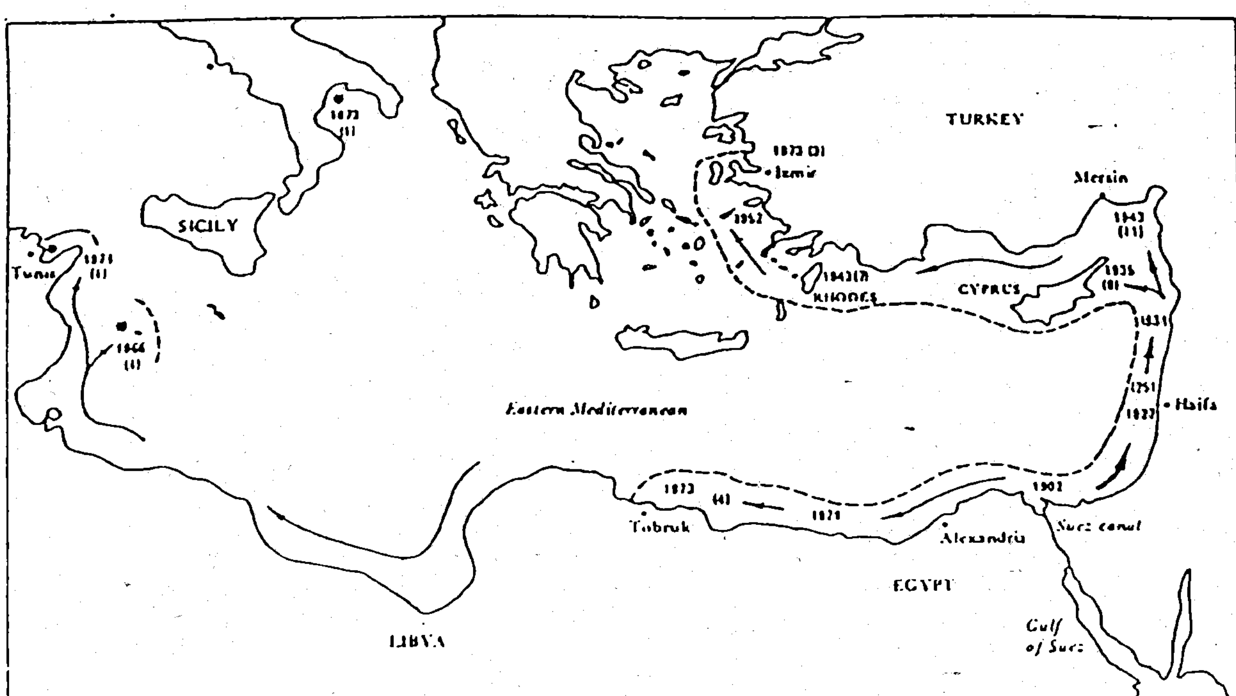



Figure 16. Invasion of the Eastern Mediterranean by Red Sea fish species which have escaped via the Suez Canal. The arrows show the major migrations from the beachhead at Port Said, the dates indicate the advent of the first published records at the various localities, and the the figures in parentheses show the numbers of Red Sea species

Suez Canal. However, one of these Mediterranean immigrants is confined to the northern Gulf of Suez and three are found no farther than 200 km south of Suez. Only the serranid Serranus cabrilla (the only representative of this genus in the Red Sea) has escaped from the Gulf of Suez reaching the southern Red Sea, however, it is frequently caught in the northern Red Sea. The serranid *Dicentrchus punctatus* and the mullet *Liza aurata* are quite common at the Gulf of Suez, otherwise the Mediterranean immigrants appear to be uncommon or rare (Por, 78).

### 3.1.3 Mangroves

Mangrove forest or mangal is a general term used to describe a variety of tropical inshore communities dominated by several species of trees or shrubs that have the ability to grow in salt water. The term mangrove refers to the individual plants, whereas forest, mangrove swamp, tidal forest and mangal refer to the whole community or association dominated by these plants (Walsh, 1974). Globally, mangal ecosystems are thought to contain about 60 species of mangroves and more than 20 additional species frequently associated with the mangrove flora, but not necessary restricted to it. Mangroves may form zones of dense forest, up to several kms wide, and contain as many as 20 different species. Such diverse and expansive communities are found in only a few areas and are not represented in the Red Sea. Although definite lists are not available, it is though that the mangrove environment also provides living space for a different biota of more than 2,000 species of fish, invertebrates and epiphytic plants (Hamilton and Snedaker, 1984).

Mangals have played an important part in the economics of people for thousands of years and constitute a reservoir and refuge for many unusual plants and animals. They support commercial and recreational fisheries and provide many other direct and indirect services. As a result mangals are being degraded and destroyed globally on a large scale through over-exploitation of their potentially renewable products.

Por (1984) suggests that there are probably two extreme types of mangal; 1) the estuarine, soft-bottom mangal; and 2) the euhaline-metahaline, hard-bottom mangal. The mangals of the Red Sea are of special interest since they include examples of the secondary category, which is by far the least known of the two types. Hard-bottom mangal are more prevalent in the northern Red Sea and found on substrate of relatively thin sediment over sub-fossil or raised coral/rock and typically occur in regions with high salinity (up to 47) and limited freshwater inflow (Por and Dor, 1975; Por, 1984). This contrasts with the classical mangal in the literature (e.g. West Africa, S.E. Asia) which are characterized by deep muddy substrate and occur in brackish water areas with appreciable freshwater inflow (MaCane, 1968).

Studies dealing specifically with the mangal in the Red Sea have been conducted principally in the Sinai (Por and Dor, 1975; Dor and Por, 1977, Por, *et al* 1977; Dor and Levy, 1984; Por, 1984), and have considered several aspects of mangal ecology and productivity. Mangal surveys have also been undertaken in other parts of the Red Sea, such as Egypt (Zahran, 1965; Kassas and Zahran, 1967; Zahran, 1977), Yemen (Draz, 1958; Ormond, 1980) and Saudi Arabia (Vesey Fitz Gerald, 1957; Zahran, 1974, 1980; EESAL, 1984; Price, *et al* 1987). The mangal of the Red Sea represents a composite habitat containing both hard and soft substrate, and is inhabited by fauna typical of each (Price, *et al* 1987).

Four species of mangrove are reported from the Red Sea and Gulf of Aden. They are Avicennia marina which is found throughout the area, *Rhizophora mucronata* which is found in a few very restricted locations in Egypt, Sudan and Saudi Arabia, *Bruguiera gymnorhiza* which is recorded from Sudan and North Yemen and *Ceriops tagal* which is mentioned by Por, *et al* (1977) and UNESCO (1984) but no locality is given.

The Red Sea lies at the geographical limits of mangrove growth (Figure 17). Mangrove is virtually absent from the Gulf of Aqaba (Por, *et al* 1977) and from the Gulf of Suez (Kassas and Zahran, 1967) where growth may be limited by low temperatures and a lack of suitable substrate (Ormond, 1984).

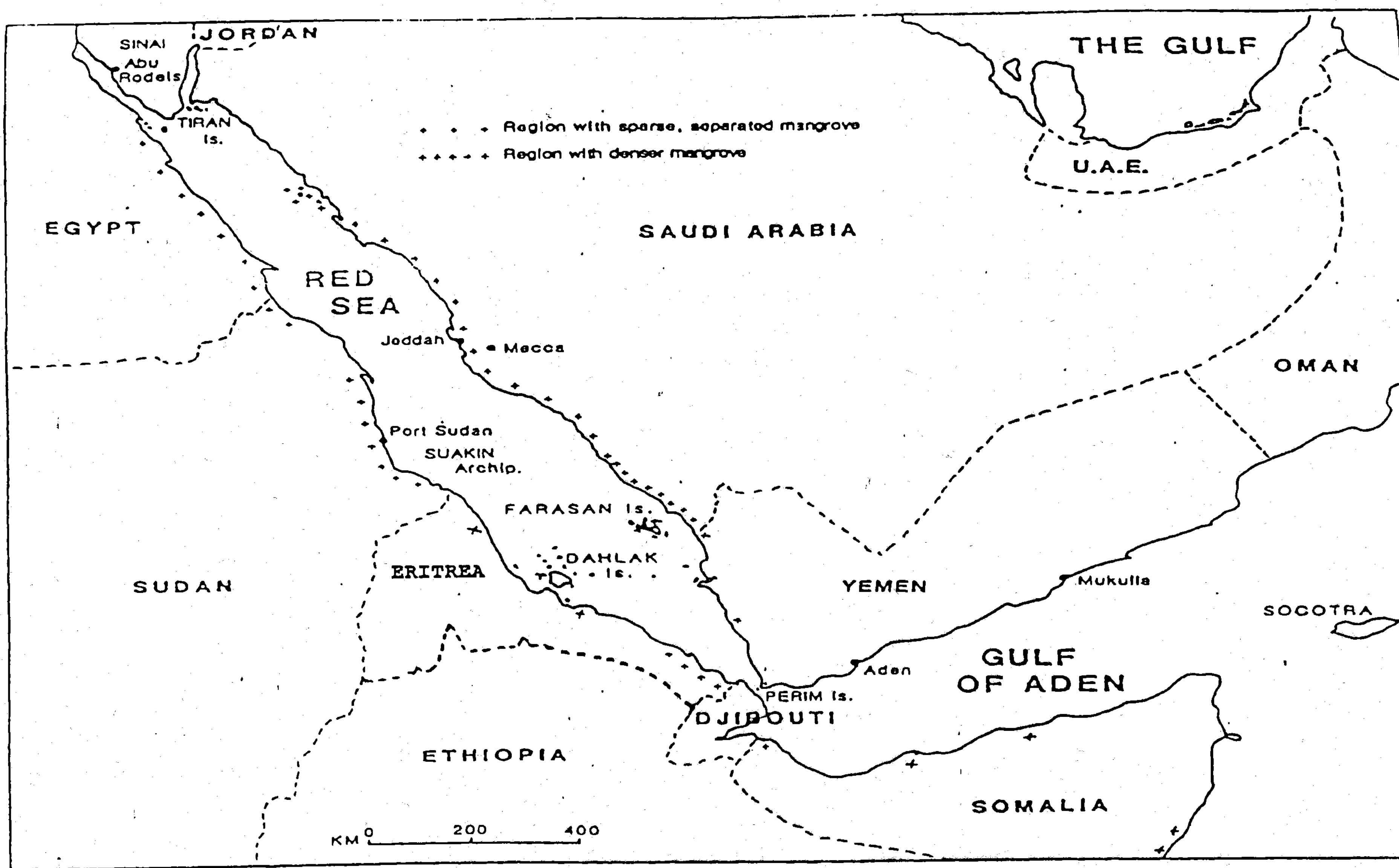



Figure 17. Distribution of known mangrove stands in the Red sea and Gulf of Aden region. [Note that for some countries of the region (e.g.Somalia, Djibouti, North and South Yemen and Ethiopia) information is incomplete.]
(Source: UNEP, 1985)

The mangal ecosystem is poorly developed in the Red Sea where beach rock is usually only thinly, overlaid with sediment even in the most sheltered areas. These reef mangroves along the length of the Red Sea, terminating in Sinai at 28°N to form the northernmost mangal in the Indo-Pacific. At this northern limit the mangal is composed solely of bushy growth of Avicennia marina, but further south in the Dahlak Archipelago in areas of deep soft mud the trees of *Rhizophora mucronata* and *Bruguiera gymnorhiza* also occur forming a more typical mangal ecosystem (Zahran, 1977).

In the Red Sea where rivers and estuaries are absent, mangroves have developed in high-lying and rather low salinity areas, and salinity levels together with high temperatures and low oxygen levels combine to limit the faunal diversity (Figure 18). However, reef dwelling species may live in close proximity to mangroves and changes in environmental conditions may move sand into established mangroves, bringing sand and mud fauna together (Fishelson, 1971; Por, *et al* 1977).

A general feature that may control the extent of individual mangrove stands is the tidal range which is low. Many of the most extensive stands occur in the south where tidal range is higher than in the central Red Sea. The increasing occurrence and development of the mangroves in the southern Red Sea may also result from other factors such as the wider continental shelf, more protected and gently inclining coastline, greater freshwater and availability of suitable substrate. Where extensive stands do occur in the central Red Sea, they tend to be associated with existing reef rock structures that mimic the dendritic system of consolidated mud tidal channels that supply and support large mangrove stands in areas with a higher tidal range. The mangals of Sinai are based on the recycling of the mangrove products. According to Por, *et al* (1977), the limit reached in Sinai is not determined by increased salinity but by the decrease in temperature (few days below 10°C).

Productivity of the Red Sea mangals is generally low, although few quantitative studies have been attempted (Por, 1975; Dor and Levy, 1984; Crossland, *et al* 1987). Gross productivity of the poorly-developed stands in the northern Red Sea is probably less than 0.5 kg. $cm^2$/year, whereas in well developed mangals of the southern Red Sea, it may be 1 kg $cm^2$/year or less (Sheppard, *et al* 1992).

The mangals of the Red Sea is a mosaic habitat, inhabited by species typical of muddy, sandy or rocky shore devoid of mangrove vegetation. Compared with Indian ocean mangals, the number of mangrove and associated species in the Red Sea is low, although most of the characteristic faunal zone are still present (Price, *et al* 1987; Sheppard, *et al* 1992). Table 1 provides data for mangal biota in the Red Sea and indicates approximate number of mangrove species in selected groups and examples. Low diversity is attributed to the general severe climatic and environmental conditions (e.g. high salinity) in conjunction with the more limited range of suitable habitats and niches.

### 3.1.4 Wetlands

Wetlands are among the most productive ecosystems in the biosphere. They provide tremendous economic benefits to mankind through fishery production. They also provide critical habitats for many species of birds as well as countless mammals, reptiles, amphibians, fish and invertebrates. Unfortunately, wetlands are among the world's most threatened habitats, due to accelerated drainage, land reclamation, pollution and other exploitation of wetland species (Fouda, 1989).

Wetlands are defined as "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine waters, the depths of which at low tides does not exceed six meters".

The Red Sea coast and Gulf of Aden and even Timsah and Bitter Lakes of the Suez Canal provide numerous wetland habitats of considerable importance to fisheries and wildlife. These include the extensive coastal plain areas with mangroves and other terrestrial vegetation, intertidal sand flats, intertidal mudflats and many other littoral and shallow water enclosed soft-bottom habitats.

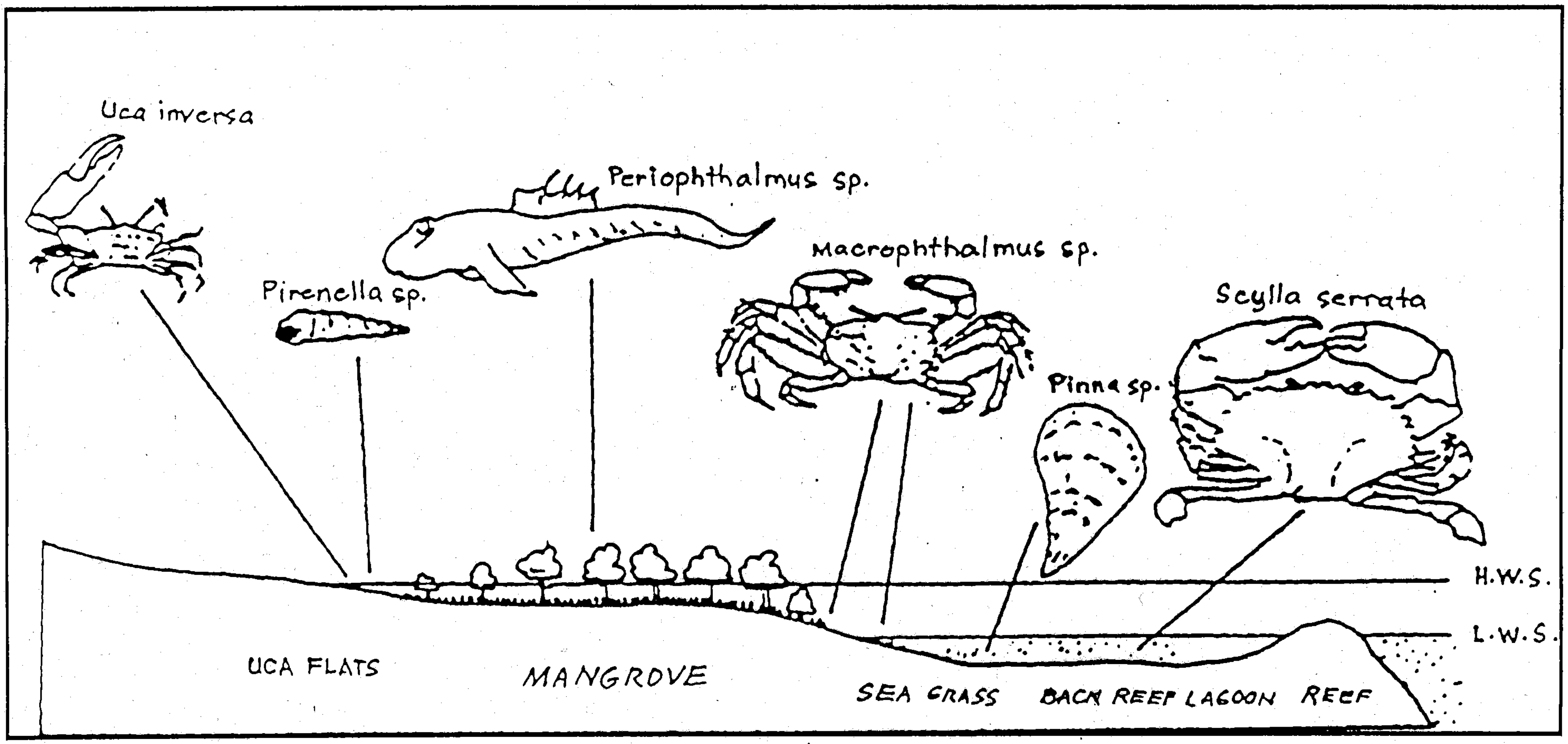



Figure 18. Characteristic zonation pattern shown by mangal fauna in the Red Sea. (Source: Jones, et. al., 1987)

Table 1: Summary data for mangal biota in Red Sea, showing approximate number of species in selected groups and examples (from Fishelson 1971, Por et al, 1977, I. Dor 1984 Price et al. 1987b).

| *Group* | *Appox. no. of species* | *Examples* |
|---|---|---|
| Algae (Cyanophata) | 47 | *Cyanohydnum sp*(p.), *Lyngbia sp*(p.) |
| Foraminiferans | 10 | *Peneroplis planatus, Spirolina arientina* |
| Sponges | 9 | *Heteronema erecta, Miemna fortis, Haliclona sp.* |
| Coelenterates | 14 | *Cassiopeia andromeda, Zoanthus bertholetti* |
| Polychaetes | 19 | *Clymene lobricoides, Perinereis nuntia typica, Nephthys sp.* |
| Crustaceans | 70 | *Uca (4 spp.), Dotilla sulcata, Perisesarma guttatum, Metapenaeus sp.* |
| Molluscs | 45 | *Pirinella conica, Cerithium scabridum, Cerithidea cingulata, Saccostrea cucullata, Littorina scabra* |
| Echinoderms | 8 | *Tripneustes gratilla, Ophiocoma scolopendrina, Holothuria sp* |
| Fish | 30 | *Aphanius dispar, Dasyatis uarnak, Lutjanus fulviflamma* |

#### 3.1.4.1 Intertidal Mudflat

In the Bay of Suez, there are some intertidal mudflats whereas in the Gulf of Aqaba only the area between Nabq and Ras Mohammed contains wetlands particularly at Wadi Kid where mangroves Avicennia marina are found. Low tide transforms much of the lagoon ecosystem and shallow water habitats in the Red Sea into an exposed sand-flat where crabs retreat to coral debris and small fishes to isolated pools. Low tides south of Gebel el Zeit expose mud-flats sheltered by large bays. These provide important habitats for breeding migrants, and winter visitor birds (Jennings, *et al* 1985).

Terrestrial reptiles, characteristics of the Red Sea islands are a colubrid snake, Psammophis aegyptius; gecko Hemidactylus turcicus; and a lacertid lizard, *Mesalina guttulata* (Werner, 1973; Goodman, *et al* 1989). An estimated 500 hawksbill turtles *(Eretmochelys imbricata)* and 100 green turtles *(Chelonia mydas)* nest on island and mainland stands of the Egyptian Red Sea (Frazier and Salas, 1984). There is also speculation that loggerheads *(Caretta caretta)* and leatherbacks *(Dermochelys coriacea)* lay eggs on Sinai beach (Groombridge, 1982).

Characteristic birds of the Red Sea Islands and coasts are the brown booby, western reef heron, spoonbill,, osprey, white eyed gull, caspian tern and white-cheeked tern (Goodman, *et al* 1989).

#### 3.1.4.2 Enclosed Soft-bottom Habitats

Enclosed shallow water soft-bottom habitats may be described as those habitats where water circulation is restricted. They tend to be subject to a higher range of temperatures, salinities and oxygen levels than in open water soft-bottom habitats. Because enclosed soft-bottom habitats occur in sheltered waters, substrate particle size is generally smaller than that found at equivalent depths in open water soft-bottom habitats. They are represented in the Red Sea by bays, sharms and mersas which typically have an entrance of 0.2 to 1 km. across. They may extend for up to 10 km inland and remain narrow and winding throughout or widen out into "lakes" several kilometres across. However many sharms and mersas are simply shallow bays partly or completely closed off by a coral fringing reef. Enclosed soft-bottom habitats are often backed by extensive flats that are inundated on a seasonal basis (Ormond, 1984, 1985). During this period of wetting, they often develop a growth of micro-algae that may have seasonal significance to the primary production of the coastal zone.

In general terms, a decrease in quantity and quality of coral reefs down the Red Sea is balanced by an increase in the quantity of soft-bottom communities (Ormond, *et al* 1985). However, because the Red Sea is probably made up of several zoogeographic provinces, each region may have a significance not simply related to the diversity of its fauna and flora (UNEP, 1985).

Fishelson (1971) described several faunal communities from the shallow sublittoral in the Red Sea. A Hippa/Mactra community occurs on coarse sand and gravels mixed with mud and contains the algae Caulerpa, Paclina and Cystoseira. It is dominated by mole crabs (Hippa), portunid crabs and stomatopods together with the molluscs *Mesoderma, Mactra and Strombus.* A ptychodera (acornworm/Radinathus (anemone) community extends sublittorally from sheltered sand beach on muddy calcareous sediment. This is mainly a burrowing fauna consisting of worms and bivalves penetrating the substratum to depths of up to 40 cm. Where the substratum is predominantly of dead corals or rubble interspersed with pockets of sand, Fishelson recognizes a community dominated by the trochid gastropod *Gena* and the sea urchin *Echinometra*. It is a rich community with many species of molluscs either sheltering under boulders or in the sand.

#### 3.1.4.3 Salt Marshes

Zahran (1977) identified three vegetation types associated with the Red Sea shoreline: mangrove communities, reed-swamp and salt marsh. The reed swamp vegetation of the Red Sea is predominantly found either at the mouths of major wadis (e.g. Wadi Gimal in Egypt) or at locations where springs (e.g. freshwater reaches the surface through springs (e.g. at Air Sukhna). The reed-swamps are dominated by *Phragmites australis* and *Typha domingensis*.

Salt marsh vegetation consists of about twenty community types dominated by: *Halocnemon strabilaceum, Arthocneumum glaucum, Zycophryllum album* and other (Zahran, 1977). The various community types occur in different coastal situations, mainly in low lying areas. These range from inland depression (e.g. south of Ras Gharib) to coastal depression subject to inundation by the sea, to sand flat fringing and penetrating inland desert habitat and sandy accumulation, next to the shoreline.

Of the three vegetation types identified by Zahran (1977), the last type is the most significant ecologically, mainly because of its biomass and wide distribution.

#### 3.1.4.4 Sabkhas

The term sabkha is used to denote low lying, sometimes intertidal but usually seasonally inundated areas. Sabkha forms very flat places in the coastal area, commonly with periodically filled pools, crusts of white salts and crusts of what are often called "algal mats". Most of the sabkha is usually near the high intertidal. Blue-green algae are the dominant flora of the sabkha region. Sabkha cover areas greater than mangroves and marshes, but studies on them are limited, mostly which are carried out in Sinai (Sheppard, *et al* 1992). Being located near the high intertidal, sea-level rise may alter this environment, thereby creating more hospitable areas with reduced salinities.

#### 3.1.4.5 Rocky Shores

In the Red Sea, rocky intertidal is restricted, occurring on undercut raised reefs in the northern half, with expanses of beach rock in the south. Although not abundant in biomass, rocky shores may have a high diversity. Intertidal rocky shores exhibit a pronounced zonation determined by sea-level and exposure to waves. The biotic communities are thus arranged in belts parallel to the shoreline. Typical faunal components are various species of gastropods, such as periwinkles and Conus species, crabs, bivalves, barnacles, sponges and associated crustaceans and seaurchins. Algae are also important in this ecosystem. On rock flats in sheltered shallow algae such as *Caulerpa, Laurencia and Sargassum* predominate, forming small pastures. The community is expected to adapt quickly to changing sea levels and if the elevation of the rocky shore above sea level is of sufficient height, shifts upwards with increasing sea level (Lipkin, 1991; Sheppard, *et al* 1992).

#### 3.1.4.6 Beaches and Dune Systems

Beach systems are common along the Red Sea coast, mostly forming in the northern part, narrow belts adjoining coral reef flats and marine pastures. Broader beaches occur where the reef edge swings further out from shore leaving a lagoon. In the extensive parts of the central Red Sea sand on such beaches has a significant proportion of aerolian sand mixed with marine carbonates. Where reef decline In the southern Red Sea, beaches became broader and higher, extending deeply into the subtidal. Most organisms of sandy shore are mobile. Many inhabitants of the intertidal soft bottoms keep moving with the fluctuations of the tide lying to hold the same position in relation to the changing water level. The nature of the substrate (e.g. coarse sands, fine sands, cobbles and pebbles) and wave exposure greatly determine which community develops. Another feature of beach systems is that organisms live within the sediments. The highest parts of the most beaches are marked by mounds produced by the ghost crab, Ocypode saratan.

Other macrofauna include the hermit crab and numerous small crustaceans, many of which are buried in the sand. On more muddy beaches fiddler crab *Uca* share in the community, which become dominant in extremely sheltered habitats such as the mangal stands (Lipkin, 1991). Plants are only found in the sheltered areas and high intertidal "dune" systems. Most coastal plants are low shrubs. Conspicuous is *Nitraria retusa*, a spreading shrub common in the northern Red Sea and Gulf of Aqaba where there are extensive stands (Sheppard, *et al* 1992). These plants were considered salt marsh plants in an earlier section because of the saline areas in which these systems will generally shift upwards with sea-level rise and are not really affected unless land use in the coastal zone hampers inland migration of these systems.

### 3.1.5 Seagrasses

Seagrasses are the only group of higher plants that have adapted to life submerged in sea water. As their name implies, they are grass-like and belong to a single order of the monocotyledons. They inhabit soft-bottom, shallow water areas of temperate, subtropical and tropical seas where they may form large meadows. Altogether 49 species of seagrasses are known from around the world; these are grouped into 12 genera, 9 of which are placed in one family, the Potamogetonaceae and three in another, the Hydrocharitaceae (Den Hartog, 1977). The plants are anchored to the soft sediments on which they grow by well-developed systems of underground rhizomes and roots. These form excellent anchorages which are especially important to wave action in shallow waters. The narrow, thin, flexible leaves are probably also significant in allowing the plant's survival in such habitats (Lipkin, 1979).

Seagrass beds are complex systems whose physical structure is dominated by the leaves, roots and detritus of the seagrasses themselves. Furthermore, they contain a large number of epiphytic and epizoic organisms, burrowers and motile animals. Thus the importance of seagrass is very evident. Their high productivity supports turtles, dugong, stocks of commercially important fish and invertebrates, and the detrital food chain. They can provide shelter for fish and invertebrates some of which are commercially important. Furthermore, their role in substrate consolidation and nutrient recycling is well documented (UNEP, 1985).

In the Red Sea, sea grasses are found from midtidal level, on shores receiving regular tides to about 70 m depth ; only one species tends to be restricted to a narrower depth range (Lipkin, 1977). Soft-bottom habitats suitable for seagrasses are relatively rare, particularly in the north, because much of the coastline is edged by a narrow reef leading to a well-developed fringing reef that drops off sharply into deeper water.

Ten species of seagrasses occur in the Red Sea belonging to 7 genera (Table 2): Halophila stipulacea, H. ovalis, H. ovata, Halodule uninervis, Thalassodendrun ciliatum, Thalassia hemprichi, Cymodocea serrulata, C. rotundata, Enhalus acoroides and *Syringodium isoetifolium* (see Den Hartog, 1970; Lipkin, 1975, 1976, 1977; Aleem, 1979). The commonest species are *Halophila stipulacea, H. ovalis, Halodule uninervis, Thalassodendrum ciliatum* and *Syringodium isoetifolium, Halophila stipulacea* and *Thalassomadendrum ciliatum* have the greatest distribution, the former extending from the lower shore to at least 70 m depth, and the latter from extensive low-water level to at least 40 m depth (Lipkin, 1979). The remaining species are restricted to seabed under less than 10 m of water.

The distribution of seagrass beds has been mapped only along the eastern Red Sea Coast. A progressive southerly increase in abundance occurs, despite the reverse trend shown by some individual species (Price, *et al* 1988). The overall increase in development to the south is attributed principally to the wider and shallower shelf, as well as the greater prevalence of unconsolidated sediment.

Although Red Sea seagrasses have not been adequately mapped (except Saudi Arabia), some general points have emerged from the studies of their distribution. Conditions in the Gulf of Aqaba and Suez, particularly the latter, appear to be at the limit of temperature tolerance for the majority of the species. Seven species have been recorded at the mouths of the Gulfs. Half way up the Gulf of Aqaba five or six species may be found but at the extreme northern end only Halophila stipulacea, H. ovalis and *Halodule uninervis* occur (Wahbeh, 1980). In the Gulf of Suez only these later three species are found half way up the Gulf and only *H. stipulacea* and *Halodule uninervis* occur at the northern extremity (Lipkin, 1977). Both species have also invaded the Suez Canal and *H. stipulacea*, having reached Port Said, has successfully colonized several area in the eastern Mediterranean (Fox, 1926; Aleem, 1962; Lipkin, 1972).

Table 2: The occurrence of seagrass species in the northern (north of 29°N), central (18-25°N) and southern (south of 18°N) Red Sea. For each area the percentage of sites at which each species occurs is given. (Source: Jones et.al., 1987)

| | **Northern** | **Central** | **Southern** |
|---|---|---|---|
| No. of sites studied | **36** | **23** | **15** |
| Species | | | |
| *Cymodocea rotundata* | 19 | 65 | 20 |
| *Cymodocea serrulata* | 6 | 30 | 20 |
| *Enhalus acoroides* | 0 | 9 | 27 |
| *Halodule uninervis* | 81 | 44 | 33 |
| *Halophila ovalis* | 67 | 35 | 33 |
| *Halophila ovata* | 0 | 17 | 0 |
| *Halophila stipulacea* | 78 | 48 | 20 |
| *Syringodium isoetifolium* | 19 | 13 | 27 |
| *Thalassia hemprichii* | 17 | 22 | 53 |
| *Thalassodendron ciliatum* | 44 | 22 | 40 |

*Halophila stipulacea* appears to be most abundant towards the northern and southern ends of its range in the western Indian Ocean and is perhaps best regarded as a sub-tropical rather than a true tropical seagrass. This would account for its pre-dominance in the waters of the northern Red Sea and for this reason, it has been the only Red Sea seagrass able to colonize the Mediterranean (Lipkin, 1977). The other seagrasses appear to have more restricted ecological ranges in the Gulf of Aqaba and Suez than they do elsewhere in the Indo-Pacific, a common feature of plant species near the limits of their distributions.

Neither *Cymodocea serrulata* nor *Enhalus acoroides* seem to have been reliably recorded from Sinai coast (Lipkin, 1977) though both species are known from the Saudi Arabia coasts in the vicinity of Jeddah (Aleem, 1979). The only records of *Halophila ovata* in the Red Sea are those of Aleem (1979) who reported it from three sites near Jeddah. The occurrences of the seagrass species are summarized in Table 2.

Wahbeh (1982) found more than 49 species of invertebrates in *H. stipulacea* beds in the northern Gulf of Aqaba; nearly 70% of which were molluscs. These lived either on the seagrass or buried in the sediment. Echinoderms also constituted a significant component of the seagrass associated fauna, notably the sea urchin *Tripneustes gratilla* and various sea cucumbers. Seagrass plants provided a surface on which many species of micro and macro-algae, discoid foraminifers, and a variety of sessile invertebrates such as bryozoans, hydroids and barnacles can be established. These species attract others, notably gastropod molluscs, polychaete worms and crustaceans which feed on the attached plants and animals. The leaves are available for colonization by epiphytes and epifauna may be up to 20 times the area of the sea bottom on which the seagrass plants are growing (Wahbeh, 1980).

Figures for the standing crops (biomass) of the Red Sea seagrass vary greatly, depending on the species and density of stands. Lipkin (1979) reports pure stands of *Thalassodendrum ciliatum* with average standing crops of 70 kg-dry/$m^2$. Lipkin also gives average standing crop values for seagrass communities dominated by *Thalassia hemprichii* (2.5 kg-dry/$m^2$), *Syringodium isoetifolium* (1.2 kg-dry/$m^2$), *Cymodocea rotundata* (0.5 kg-dry/$m^2$), *Halophila stipulacea* (0.33 kg-dry/$m^2$), *H. uninervis* (0.23 kg-dry/$m^2$), *H. ovalis* (35 g-dry/$m^2$). Aleem (1979) records a value of 0.5 kg-dry/$m^2$ for *Thalassia hemprichii* on the Saudi Arabian coast near Jeddah. Similar values were obtained by Wahbeh (1980) in the northern Gulf of Aqaba. For comparison, the standing crops of temperature grassland generally range Between 0.2 and 5 kg-dry/$m^2$.

Perhaps more information is needed for productivity estimation which tells us how fast new plant material is produced than just how much there is. The only figures for seagrass productivity in the Red Sea are those of Wahbeh (1980) from the Gulf of Aqaba. He estimated annual productivities at 61 g.C/$m^2$ for *Halophila stipulacea*, 1326 g.C/$m^2$ for *Halodule uninervis* and only 11 g.C/$m^2$ for sparse growth of *Halophila ovalis.*

There is little information on seagrass grazing in the Red Sea. Wahbeh and Ormond (1980) and Hellal (1986) reported significant grazing by the sea urchin *Tripneustes gratilla* and a little grazing by the surgeonfish *Zebrasoma xanthurum* and *Ctenochaetus striatus* and the rabbitfish *Signaus rivulatus* in the Gulf of Aqaba. Other significant seagrass grazers are dugong, *Dugong dugong*, and the sea turtles such as *Chelonia mydas*. *Halodule uninervis* and to a lesser extent *Syringodium isoetifolium* appear to be the favourite seagrass food of the dugong (Gohar, 1957).

### 3.1.6 Seaweeds

In the Red Sea, several areas with hard substrate are not dominated by corals but by algae instead. This may occur in shallow coral reef area, when the algae tend to be filamentous greens and small browns which grow as "algal lawn". Algal communities in most of these areas show a strong seasonality. Many appear to be annual, at least in terms of their fronds though many have substantial stipes and holdfasts which endure for several years. Their seasonality is correlated with water temperature (Sheppard, *et al* 1992).

Papenfaus (1968) recorded nearly 500 species of algae from the Red Sea, in a list derived from numerous earlier collectors, mostly around Sinai in the north and the Dahlak Archipelago in the south, which allowed Walker (1987) to remark on their latitudinal distribution (Figure 19). All three groups are least diverse in the central area, greens are common mainly in the north, while browns have the greatest diversity in the south.

Most species comprising the algal turf in northern and central areas of the Red Sea are macroscopic, non-calcarious forms of green, brown and red algae. One of the commonest species is the brown Sphacelaria tribuloides, which itself serves as a substrate for other epiphytic and turf algae including numerous species of greens. The red algae provide the highest diversity in northern areas (Benayahu and Loya, 1977).

All groups contribute to algal lawns. The latter commonly provide over 80% cover in a narrow zone where they have a corresponding trophic importance. As well as being a food source, their high cover affects coral recruitment and growth while supporting enormous densities of small herbivorous (Sheppard, *et al* 1992). Algal lawns on some reefs have standing stocks of approximately 25 g (dry wt)/$m^2$, and production rates of about 1-3 g (dry wt $m^2$/day, so standing stock is equivalent to only about 1-2 weeks growth (Walker, 1987). Standing crop at 3 m might be 20 g/$m^2$, but it decreases to 1 g/$m^2$ at 10 m deep. Another measure, cover, similarly drops from 50-90% of substrate in shallow water to 4% cover below 5 m deep in many Red Sea sites. These values, however, exhibit seasonal changes, ranging from a summer low value of >10% to a high spring value of 40-70% (Sheppard, *et al* 1992). Seasonal changes are not determined solely by temperature but by complex interactions with grazers.

A very conspicuous trend which occurs on the crest of the fringing reefs in the Red Sea, is the southward increase of large brown algae, mainly Sargassum. The greatest increase is seen in the south where there is a corresponding decline in the extent of reefs and coral diversity (Sheppard, 1985).

The *sargassum* grows in thick stands, with numerous plants in each square metre, up to 2 m tall. The plants possess air bladders, so that the fronds reach the surface. The bands in which this grows is generally 5-25m wide but may reach 50m wide in the far south and it lives the extreme edge of the reef flat, continuing down the reef slope to not more than about 2 m deep (Sheppard, *et al* 1992). In the central and southern Red Sea, it is dense enough to cause a noteworthy obstruction to swimming, and is very clearly visible on satellite images.

Several species of algae are endemic to the region. In the Red Sea, Walker (1987) separates known species into four geographical blocks of the gulfs, northern, central and southern regions and shows that between 8 to 40% of species occur in only one block. Many southern species include members typical of slightly cooler areas, the boundary in this case being drown approximately through the middle of the Red Sea between Jeddah and Suakin. The proportion of species endemic to the Red Sea is about 9%, which is not much lower than that for faunal groups. The major difference, however, appears to be that 64% of species are for tropical,occurring over extensive parts of the Indo-Pacific, as well as in the Caribbean or Mediterranean, too. No faunal group is known to have such a broad pattern (Sheppard, *et al* 1992).

### 3.1.7 Wildlife

#### 3.1.7.1 Marine Turtles

Marine turtles form a prominent part of the fauna of the Red Sea and Gulf of Aden. All five pan-tropical species of marine turtles are recorded from the Red Sea (Frazier, *et al* 1987). They are Hawksbill Turtle (Eretmochelys imbricata), Green Turtle (*Chelonia mydas*), Leather-backed Turtle (*Dermochelys coriacea*), and Loggerhead Turtle (*Lepidochelys olivacea*) (Frazier and Sales, 1984).

*Eretmochelys imbricata* is the most abundant and is highly associated with well developed

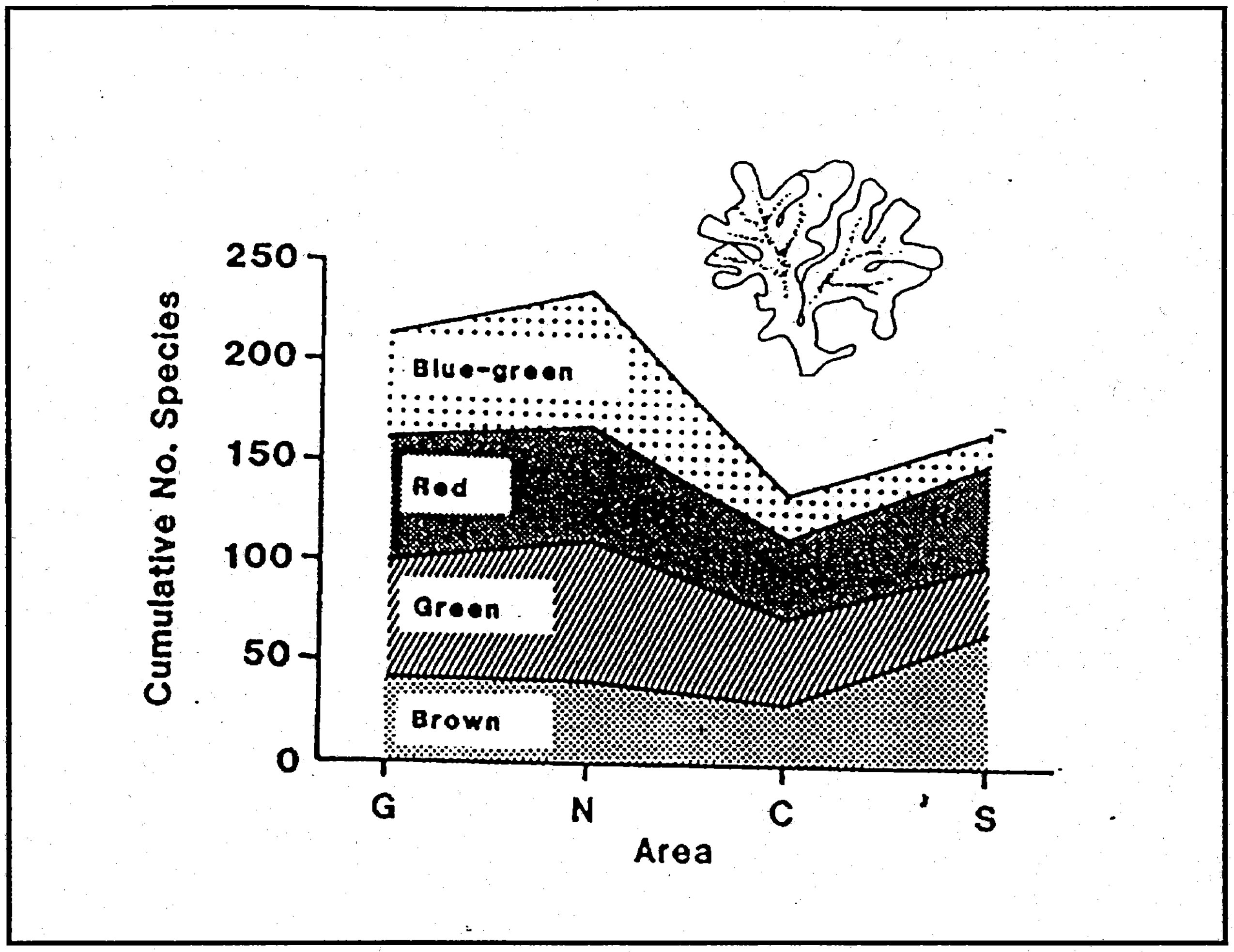


Figure 19: General distribution pattern of algae in the Red Sea. Data from Walker (1987). G, gulfs of Aqaba and Suez; N, north; C, central; S, south Red Sea. (Sheppard et al, 1992).

coral reefs, where it feeds on sponges and soft corals. The nests are usually a few meters from the shore (usually not exceeding 10 meters) and are about 50 cm deep. Females emerge for nesting during May and June, and hatchling leave their nests around August - September.

*Chelonia mydas* is the second most common marine turtle in the Red Sea, though far less common than the previous species. Because of their herbivorous diet, that are strictly associated with marine plants which are scarce in the Red Sea. *Dermochelys coriacea, Caretta caretta* and *Lepidochelys olivacea* are the least common species and are considered vagrants in the Red Sea.

Marine turtles spend all of their lives in the sea, except when mature females come briefly ashore to lay their eggs on sandy beaches. All Red Sea turtles are regarded as threatened and both *C. mydas* and *E. imbricata* are considered endangered.

### 3.1.7.2 Birds

Because the Red Sea lies amidst one of the driest ecosystems in the world, the significance of such a relatively small marine water body for birdlife is unique. For palaearchic migrants the Red Sea provides an important route which birds follow on their spring and autumn migrations. It also provides wintering grounds for shore and water birds. The Red Sea also supports internationally important numbers of some species of seabirds (Delft Hydraulics, 1992).

The intertidal zone is particularly important for migrants and wintering birds, which mostly tend to utilize the water edge for resting and feeding. On the other hand most resident and breeding birds usually nest above the high water line, and go out to sea for feeding. The only exception is the kentish plover, *Charadrius alexanderinus*; thus it appears that sea-level rise would not have any direct serious impact on most resident species. However, any impact, including sea-level rise which possibly result in a reduction of the habitat of migratory birds, in this case intertidal zone, may affect this avifauna. It includes soaring aquatic birds (e.g. white stork *Ciconia ciconia*, black stork *C. nigna*, white pelican *Pelicanus onocrotalus* and the common crane *Gurus gurus*), raptors, waders and waterfowl.

Perhaps the Red Sea marine ecosystem is more important for its resident breeding 17 species, including kentish plover (*Charadrius alexandrinus*), osprey (*Pandion haliaetus*), reef heron (*Egretta gularis*), green heron (*Ardeola striatus*) and spoonbill *Platalea leucorodia* (Evans, 1987).

Jennings, *et al* (1985), estimated that 30% of the world population of the Red Sea endemic white eyed gull, Larus Leucophthalmus which breeds on the islands at the mouth of the Gulf of Suez, making the islands of international importance to this threatened species.

### 3.1.7.3 Marine Mammals

The status of marine mammals in the Red Sea is unknown. The most famous and vulnerable of all is the Dugong, *Dugong dugong* which occurs in rather low densities throughout the area. This is due at least in part, to the relatively limited extent of seagrass beds. Nevertheless, this species is considered threatened throughout its range and even the smallest population should be treated with caution.

Other marine mammals include seven to eight species, mostly dolphins and whales. These are killer whale (*Orctirus orca*), false killer whale (*Pseudorca crassideus*), Risso's dolphin (*Grampus griseus*), plumbeous dolphin (*Sousa chinnensis*), spotted dolphin (*Stenella altemnata*), Red Sea bottle-nosed dolphin (*Tursiops truncatus*), bottle-nosed dolphin (*Tursiops trauncatus*) and rough toothed dolphin (*Steno rostratus*).

A number of reasons probably contribute to the low species diversity compared with the Indian Ocean with 44 species (Frazier, *et al* 1987). These include the enclosed nature of the Red Sea with a very shallow sill at the southern end and the relatively recent Suez Canal at the northern end, its high salinity and its relatively low primary productivity.

## 3.2 Non-Living Resources

### 3.2.1 Fossil Fuels

Perhaps the traditional and most important non-living resources in the Red Sea region is petroleum. This is absolutely true for Egypt, but for some other countries different types of resources could be more important.

Since early this century the Gulf of Suez has been known as an oil prone area. At present, the number of producing oil wells exceeds 30. In fact, the major part of oil production in Egypt comes from this prolific area.

Although information on hydrocarbon habitat along the Red Sea proper are scarce, promising fields are recently identified in southern Egypt, Sudan and Eritrea. It is realized however, that the abnormal geothermal gradients in the Red Sea must have an important effect on the generation of hydrocarbons. It has been revealed that the geothermal gradient increases towards the south. So, the southern Red Sea appears to be a gas prone province, whereas, in the northern Red Sea, gas and oil are expected (Schlumberger, 1984).

It should be emphasized that there exists a specific relationship between petroleum generation and sea-level changes. Petroleum-rich sediments accumulate at times of high sea-level stands, since at high stands shallow sedimentation basins with sufficient accumulation of marine organic matter do develop. On the other hand, considerable accumulation of coal occurred during low stands of sea level (Kennett, 1982). Therefore, the study of the old history of the region could be of great value.

### 3.2.2 Metalliferous Sediments

Deep trenches (c. 2000m) of the Red Sea are associated with rich deposit of metalliferous mud in association with hot brine (Figure 20). They are found a midway between Saudi Arabia and Sudan. Since the discovery of these hot brine over 40 years ago, a systematic exploration of the Red Sea has been carried out by many different groups. More than 15 deeps (Figure 21) were found, some of them lined with metalliferous mud (Nawab, 1983). It was established that the mud of the Atlantic II Deep offer the best economic potential. Geologists estimated that the mud could contain two million tones of zinc, 500 000 tones of copper, 80 tones of gold and 4 000 tones of silver. Pilot schemes for extraction (Figure 22) have been undertaken in 1979 by the Red Sea commission, and established the technical feasibility and environmental acceptability of Red Sea metalliferous mining (Abu Gideiri, 1983; Karbe, 1987). Despite research investment of over US$ 100 million, mining has still not commenced. The technology needed to extract valuable metals from such depths has not developed as fast as previously thought. However, the commercial mining operations are expected to commence in 1995.

The process of formation of metalliferous sediments in the Red Sea are different from those associated with the mid-oceanic ridges, although in all cases the metal-rich deposits are a result of hydrothermal activity (Kennett, 1982). The basic differences in the case of the Red Sea are: (1) the notable contribution of terrigenous materials from the nearby continents, and (2) the presence of the thick evaporite sequence contributes to the formation of anoxic dense brine pools. These conditions result in the precipitation of bright colored sulfide minerals such as sphalerite, pyrite and chalcopyrite in such pools. These sulfidic minerals occur interstratified with Fe and Mn hydrous oxides, iron-rich silicates and thyrogenous-biogenous sediments (Bischoff, 1969; Bonatti, 1984). Sulfides are most enriched with copper, zinc, silver, lead, iron and manganese (Emery and Skinner, 1977).

Hydrothermal deposits are also forming in the median valley of the Gulf of Aden. However, they are not comparable to those of the Red Sea, neither in their type nor in economic value. The Gulf of Aden hydrothermal deposits mainly comprise manganese oxides, green smectite with small amounts of iron oxide and mixed manganese oxide-smectite. These deposits do not contain sulfides neither

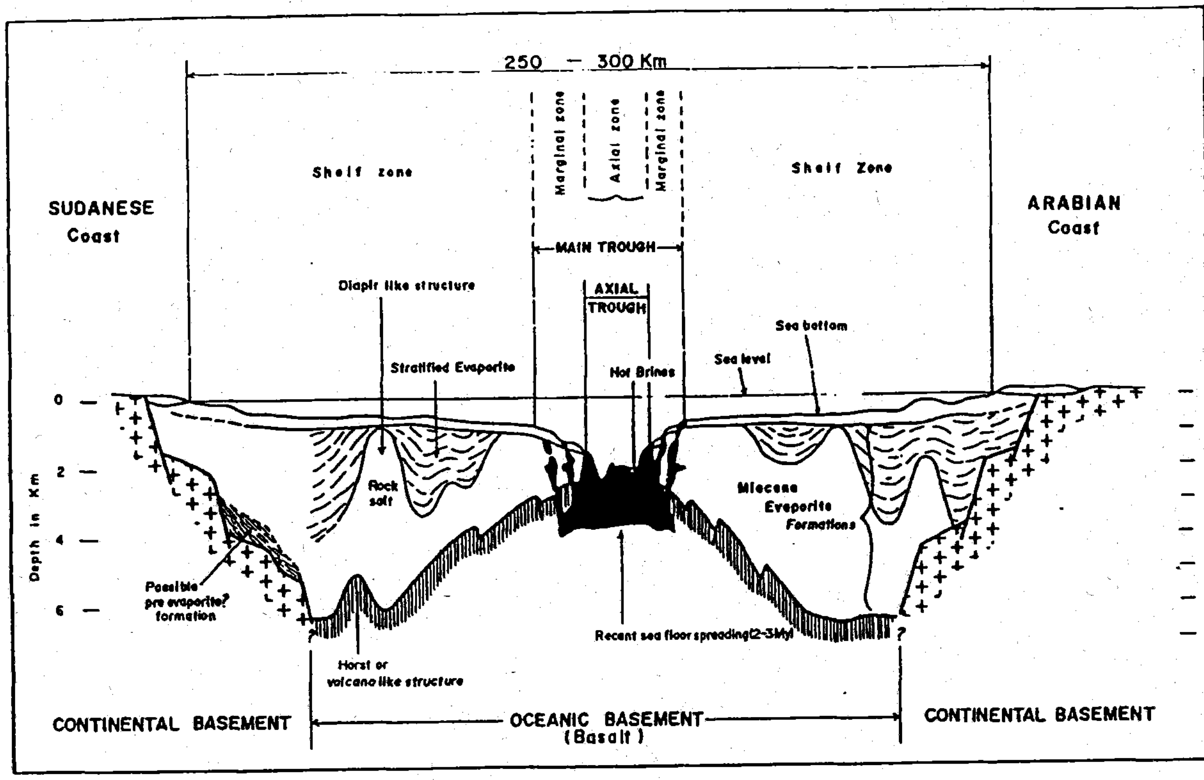



Figure 20. Schematic geological cross section in the Central Red Sea. (Source: Nawab, 1983).

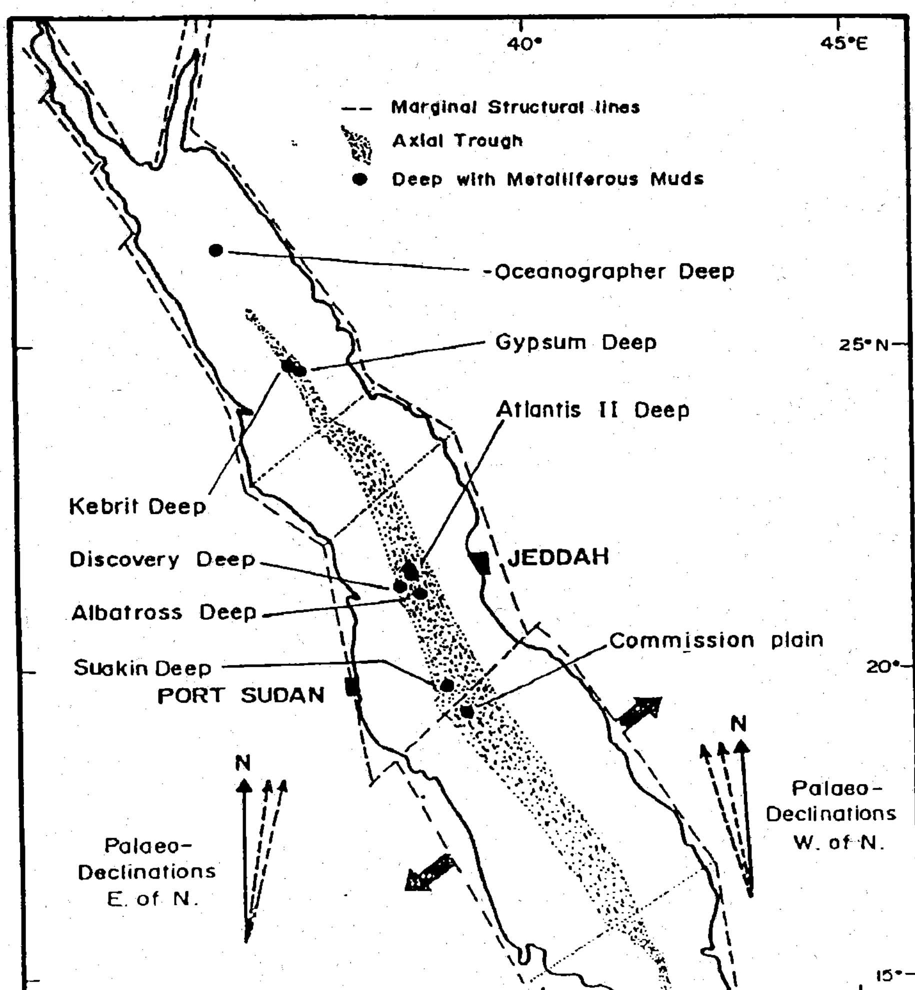



Figure 21: Red Sea structural map showing some of the metalliferous mud Deeps. (Source: Nawab, 1983).

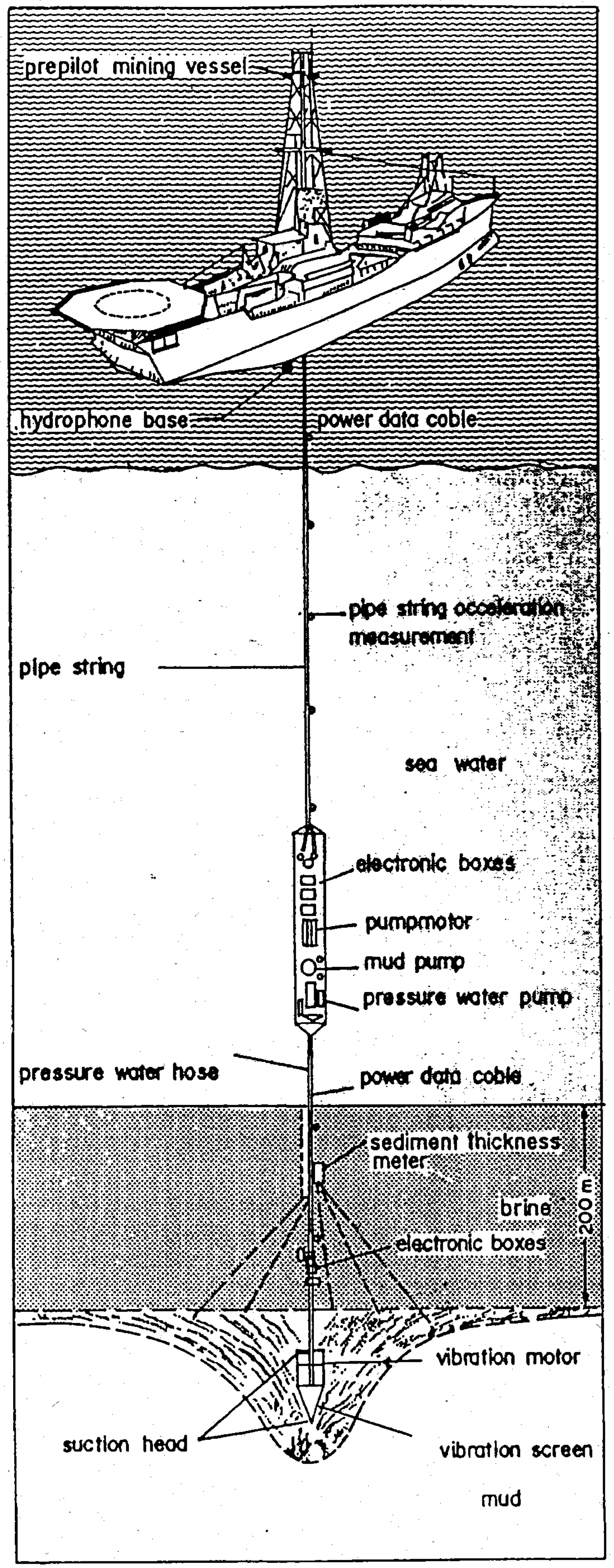



Figure22: Mining metalliferous sediments from a depth exceeding 2000 metres. (Source: Nawab, 1983).

they are enriched with zinc and copper. Nevertheless, the manganese oxides contain much more manganese metal than present in oceanic manganese nodules (Cann, *et al* 1977).

### 3.2.3 Sabkha-Evaporite Facies

The economic importance and applied aspects of sabkha-evaporite systems are beyond the imagination. In fact, the importance of coastal and inland sabkhas has been recognized long time ago. The ancient inhabitants of Africa and Arabia used to mine the principal salts of such environments for trading (Krumbein, 1985). The essential salts of sabkhas are halite, sylvite, polyhalites, glauberite, gypsum, anhydride, dolomite and other carbonates. Besides, the brine resulting from evaporite dissolution are important base-metal carries and may result in the formation of ore deposits (Warren, 1989). The most important heavy metals of these are iron, copper, silver and even gold and uranium (Krumbein, 1985).

Nevertheless, the depositional regime in these environments does not proceed according to simple chemical reactions, yet, it is biologically controlled. For example, sulfate reducing bacteria usually inherent to such hypersaline environments are responsible for sulfur production.

One and probably very important economic aspect of sabkhas is their close relationship with oil and gas occurrences. From the one hand, these environments develop adjacent to areas of high organic productivity. On the other hand, the evaporite digenesis lead to the formation of sucrosic dolomite in the adjacent limestones resulting in excellent potential reservoirs (Warren, 1989).

Finally, these natural systems offer the best grounds for the development of biotechnology and bioengineering. In some countries e.g. Mexico, people took advantage of such environments for mass cultivation of cyanobacteria, green algae and other microorganisms. These harvests were used for the production of large amounts of specific proteins for chicken and fish food pellets. Furthermore, other countries cultivate different species for the production of industrially important osmoregulators (Krumbein, 1985).

It is well shown then that the coastal sabkha environments can offer various types of wealth. Despite this fact, the widespread sabkhas along the Red Sea margin are neither properly studied nor exploited as they should be.

## 3.3 Pollution

The current exploitation of natural resources is causing great economic and ecological changes. Conflicting human interests are taking a toll of the region's natural resources, particularly between oil and tourist industries. Pollution from oil-rigs and merchant ships is damaging the main tourist attraction reefs; ironically so are the tourists, by spear fishing and shell collecting (Wells, 1988).

Tourism plays a major role in the economic activities of some countries like Egypt, and is generally concentrated in the coastal areas. The main tourist attractions are national parks (e.g. Ras Mohammed), sand beaches and the warm coastal climate. At present tourism is being affected by marine pollution and occasional accidental oil spills. However primary effects of coastal tourism include, in particular, inadvertent coral breakage by divers, other types of habitats damage, and the collection of souvenir species. Secondary effects include a range of impacts for instance from hotels and other infrastructures needed to support an expanding tourist industry (Sheppard, *et al* 1992).

Pressures for recreation and tourism are higher in the Gulf of Aqaba than other areas of the Red Sea and Gulf of Aden. The predicted number of tourists to Egypt for 1992 was estimated to be 3 million, a considerable number will visit Sharm el Sheik and Al-Ghardaqa. During the last 10 years these two cities have grown remarkedly to the extent that their beaches are fully occupied by many kilometres of touristic and recreational activities. The increased number of people require more sewage disposal and discharges which deplete the quality of the very amenities which attract tourism in the first place, i.e. the clean beaches and spectacular underwater reefs. Collection of corals, sea fans, starfish, urchins, crustaceans and mollusks are causing loss of diversity in marine habitats and degradation of coral reefs. Small boat activities also produce anchor damage to corals (Fouda, 1990).

Sources of contaminants to the Red Sea arising from the exploitation of non-living resources and human presence can be conveniently listed under three headings: urbanization with tourism, oil and other industrial inputs. The nature and magnitude of the pollution problem in the Red Sea do not necessarily follow trends elsewhere in the world. The enclosed nature of the Red Sea, in conjunction with the limited water exchanges with the Indian Ocean, considerably reduces the potential for dispersion of pollutants. This is especially so in the Gulfs of Suez and Aqaba which are relatively shallow compared to the main body of the Red Sea which is very deep along most of its length.

The Middle East harbours more than half of the world's proven oil reserves, thereby ranking as the world's largest oil production area (30%) (Dicks, 1987). Most of the oil produced is exported via sea or pipeline, while local refining and consumption constitutes less than 10% of total production (Dicks, 1987). It has been estimated that about 60% of the world's oil has been transported through the Arabian Sea and Gulf of Aden (Salem, 1992). For these reasons, reports of widespread pollution in the Red Sea are not surprising, Inputs from tanker and ship traffic originate primarily from the discharge of dirty ballast water and other oily water. Oil spills have been observed in the Gulf of Aden, near the Little Aden oil refinery (Salem, 1992), Gulf of Suez and the Egyptian Red Sea coast as well as many other places (Fouda, 1983).

The effects of oil on biota arise from mechanical smothering and from the presence of toxic substances. The overall severity of effects depends on the nature and quantity of oil spilled, in conjunction with factors such as wind, water movement, temperature and probably also salinity (Sheppard, *et al* 1992). Animals at particular risk include surface swimmers and feeders, such as waders and seabirds, marine reptiles and marine mammals.

The negative effects of oil on reproduction of corals in the Red Sea are well known (Rinkevich and Loya, 1979), resulted in colonization failure of some species such as Stylophora pistillata. Oil based drilling muds are known to affect corals and other ecosystems and may constitute an increasing problem in the Red Sea (Dicks, 1987). Drilling also produces rock cuttings (sediments) which, together with drilling muds, can produce various biological responses. In general, however, there is little clear evidence for significant deterioration of reefs due to oil pollution in the Red Sea (UNEP, 1985). Studies on oil mangroves (*Avicennia marina*) along the Egyptian Red Sea coast revealed that mangrove survival can be high in coarse, well-drained, oxygenated sediments, even with the pneumatophores and substratum completely coated with oil, but not in fine-grained anaerobic muds (Dicks, 1986, 1987).

Ecological effects of oil on other habitats such as seagrass, seabed sediments and open waters of the Red Sea are not known in detail. Results of laboratory tests on several macrofaunal species of coelenterates, molluscs, crustaceans, echinoderms and fish indicate a variety of lethal and sub-lethal effects (Eisler, 1973, 1975; Dicks, 1987). However, these findings can not readily be used to predict effects in the wild (Dicks, 1987). Little information is available on the effects of oil pollution on the fisheries of the Red Sea. However, concern arises from the known vulnerability of eggs, larval and juvenile stages of crustaceans and fish spawning and nursery areas occur in many shallow coastal areas.

Oil exploration in the Gulf of Suez (Figure 23) and the construction of the Trans-Suez pipeline with a terminal at Ain Sukhna have led to ever increasing pollution. As a major cause of reef deterioration oil may affect the breeding of commercial fishes (Ormond, 1981). The main sources are the offshore oil fields in the central Gulf of Suez at Ras Gharib and Ras Shukheir, largely as a result of ineffective and inefficient operation of equipment, illegal discharge of dirty ballast water from tankers and lack of supervision and prosecution of offenders. Oil exploitation is expanding and there is therefore an increased likelihood of spills such as those of 1982 (Fouda, 1983) where 75% of the Egyptian Red Sea coast was blanketed with oil affecting intertidal and shallow subtidal habitats (Figures 24, 25). Oil exploration is being extended further to south of Al-Ghardaqa and down to the Egyptian-Sudanese border. An additional problem is the use of seismic explosions during exploration

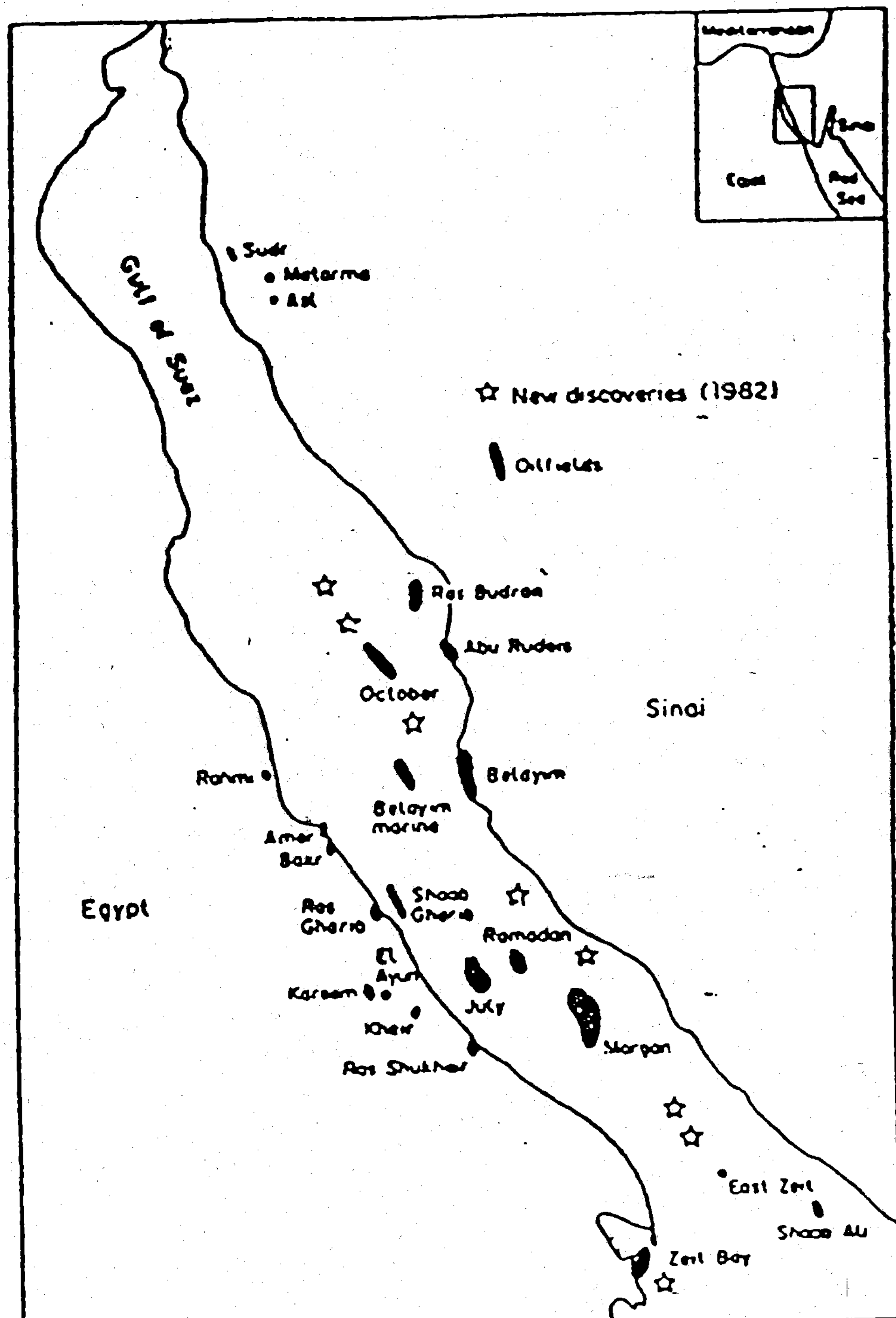



Figure 23: Existing oilfields and new discoveries in the Gulf of Suez, Red Sea up 1982. (Dicks,1871)

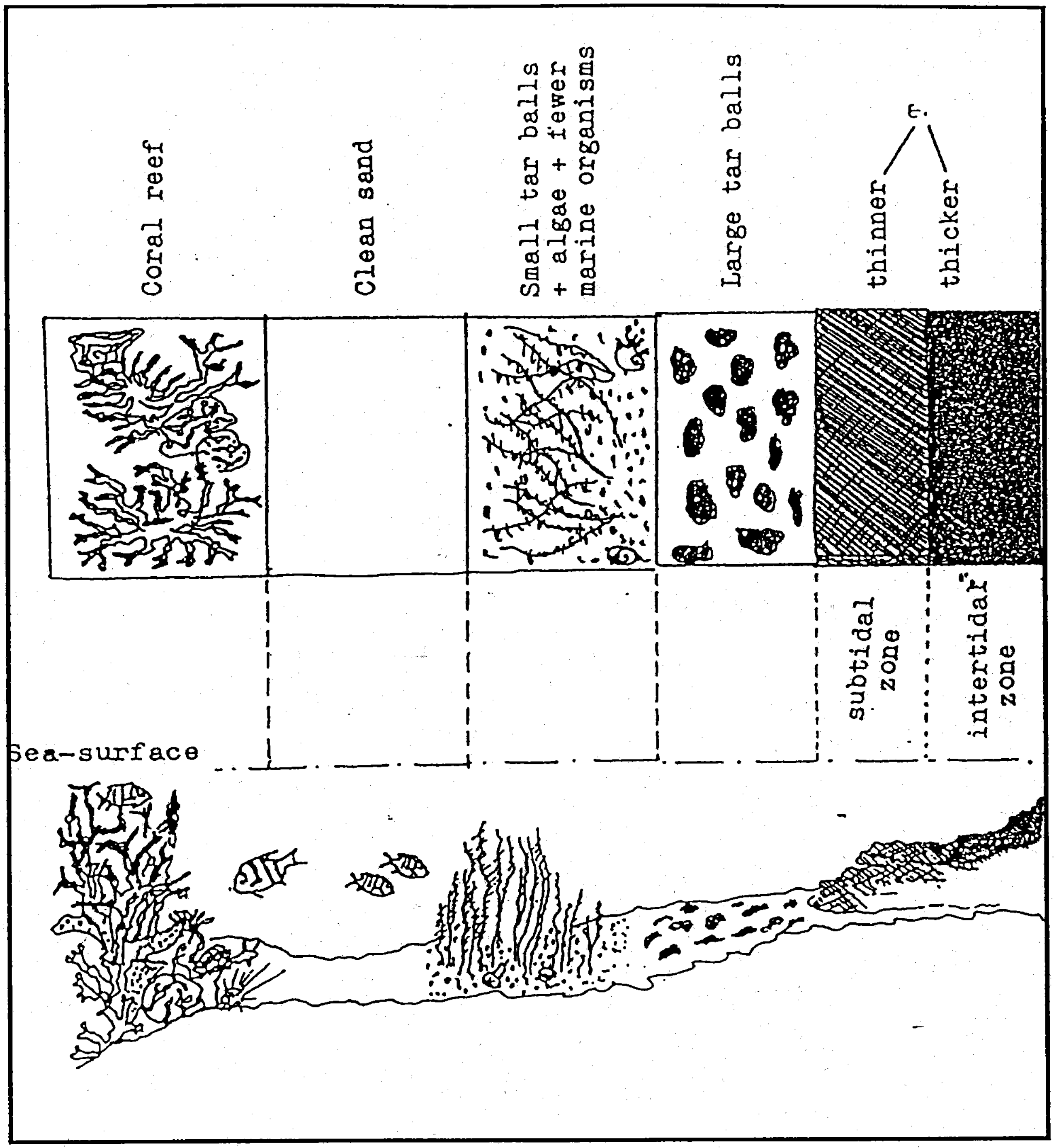



Figure 24. Diagramactic representation for the distribution of marine organisms in a rock-flat shore and coral reef area after the oil spill. (Fouda, 1990)

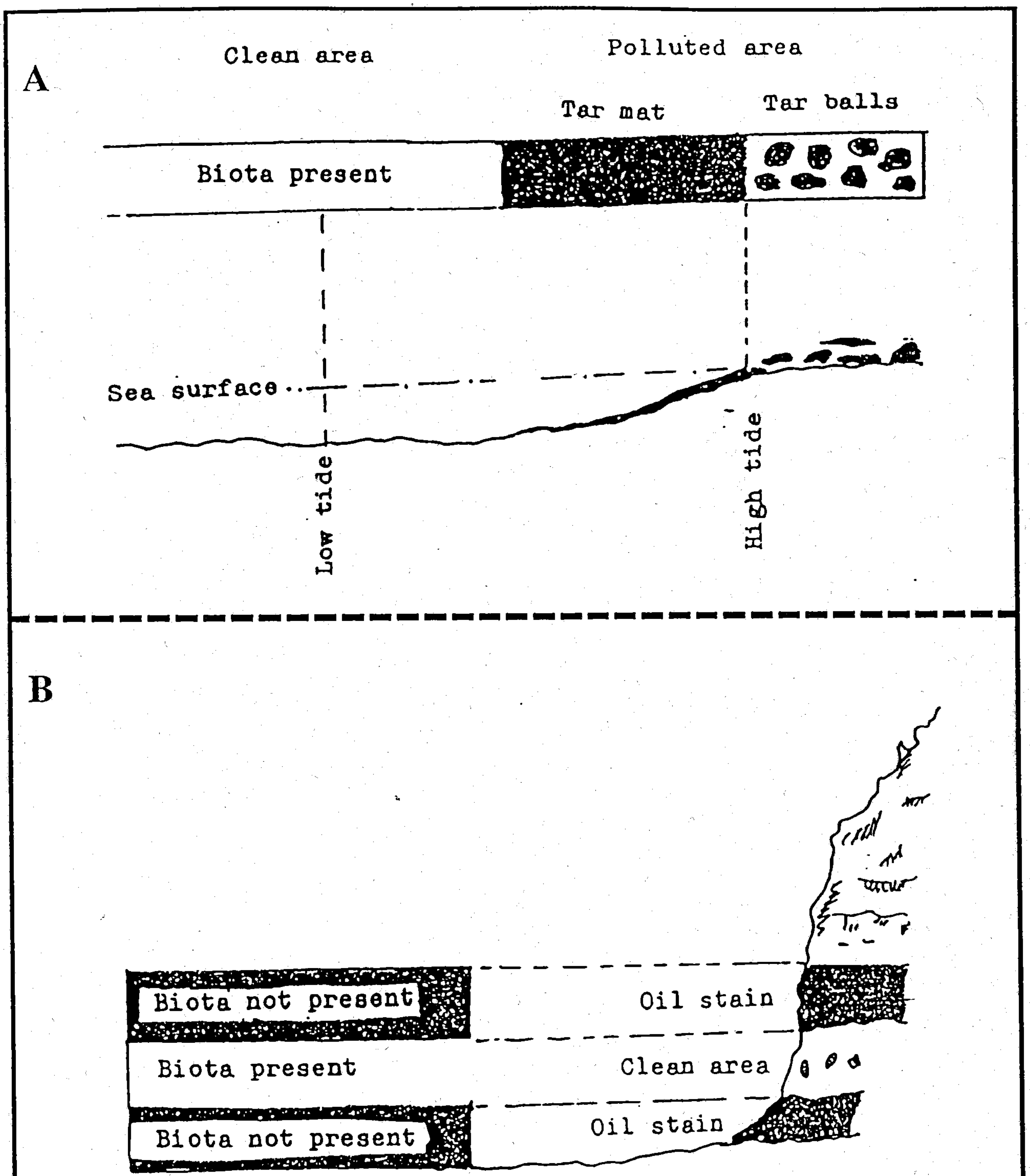



Figure 25. Diagramatic representation for the re-distribution of marine organisms in the inter-tidal zone after oil spill. (Fouda, 1990)

A - Sandy or Rocky shore B - Rock Cliff

which damage the reefs.

In parts of the northern Red Sea inputs of phosphate, manganese and bauxite minerals, through loading onto ships, are major pollutants. In the Gulf of Aqaba, death of corals was observed to be four to five times greater in an area of phosphate spillage as in a control area (Walker and Ormond, 1982).

Other types of pollution that contaminate inshore waters include sewage effluent and industrial wastes. Sewage, treated and untested, is usually discharged to or just below the intertidal zone via pipelines and is thus mostly a coastal problem. The problem, and thus areas of effects, depends on the number of people involved and considerable inputs may occur around the cities and large towns (e.g. Suez, Jeddah). The composition of sewage varies considerably, but major effects result from increased nutrient and suspended solid loading or from human health problems associated with coliform bacteria on recreational beaches (Dicks, 1987).

In addition to the sewage, considerable amounts of garbage (especially plastic containers) also enter the sea from urban and recreational areas and from ship traffic and offshore platforms. Such deposits occur in the strand zone on many Red Sea beaches; shores in the Gulf of Suez are particularly affected (Figure 26). When combined with oil pollution, garbage can seriously inhibit clean-up operations.

Land reclamation and coastal road construction also affect shore zones and nearshore waters. Apart from areas of the sea which are lost, sediment loading of the water increased and may affect coastal habitats in a similar manner to dredging (Aleem, 1988). At least part of a motorway construction project just completed to the north of Jeddah has been built on a reef flat, and any further building in this manner could cause serious losses to coastal habitats.

Among the industrial wastewater inputs are desalination effluent, wastewater from fertilizer plants (e.g. ureal as in Suez, and refinery and other industrial effluent containing heavy metals). Elevated concentration of lead, mercury and copper in bivalves and fish have been reported around some parts and industrial areas (e.g. Suez and Jeddah).

Finally there is another potential source of pollution to the Red Sea: the possible Saudi-Sudanese exploitation of metalliferous mud on the sea bottom. The operation could pose real problem especially if the wastes are dumped into coastal waters or spread out over the open sea.

### 3.4 Coastal Degradation

Whilst Red Sea coastal regions include examples of most of the tropical habitats found elsewhere in the Indian Ocean, they are often impoverished, both faunastically and in the range of available microhabitats. These are almost certainly due to the severe environmental regime imposed by the arid zone climate, the sheltered nature of the Red Sea and small tidal range. As a consequence of these factors and recent period of isolation of the Red Sea from the Indian Ocean a high degree of endemism has developed and many species show far higher tolerances to temperature and salinity than their Indian Ocean counterparts. Many intertidal and shallow subtidal organisms appear to close to their physiological limits. For this reason it is important that the additional stress imposed by human activities and pollution in the coastal zone are restricted. There is increasing evidence that industrial and domestic pollution can bring about the rapid collapse of Red Sea intertidal and shallow subtidal communities (Fishelson, 1977).

Much of the intertidal and shallow coastal water zone of the Red Sea is at risk from floating pollutants (e.g. oil) and coastal discharges (e.g. industrial effluent, sewage) as well as from disturbance. The coastal zone comprises extensive important habitats forming a rich and productive coastal ecosystem on which many fisheries depend, others are of considerable scientific and educational value while the coral reefs produce a coastal barrier against wave action and erosion, and

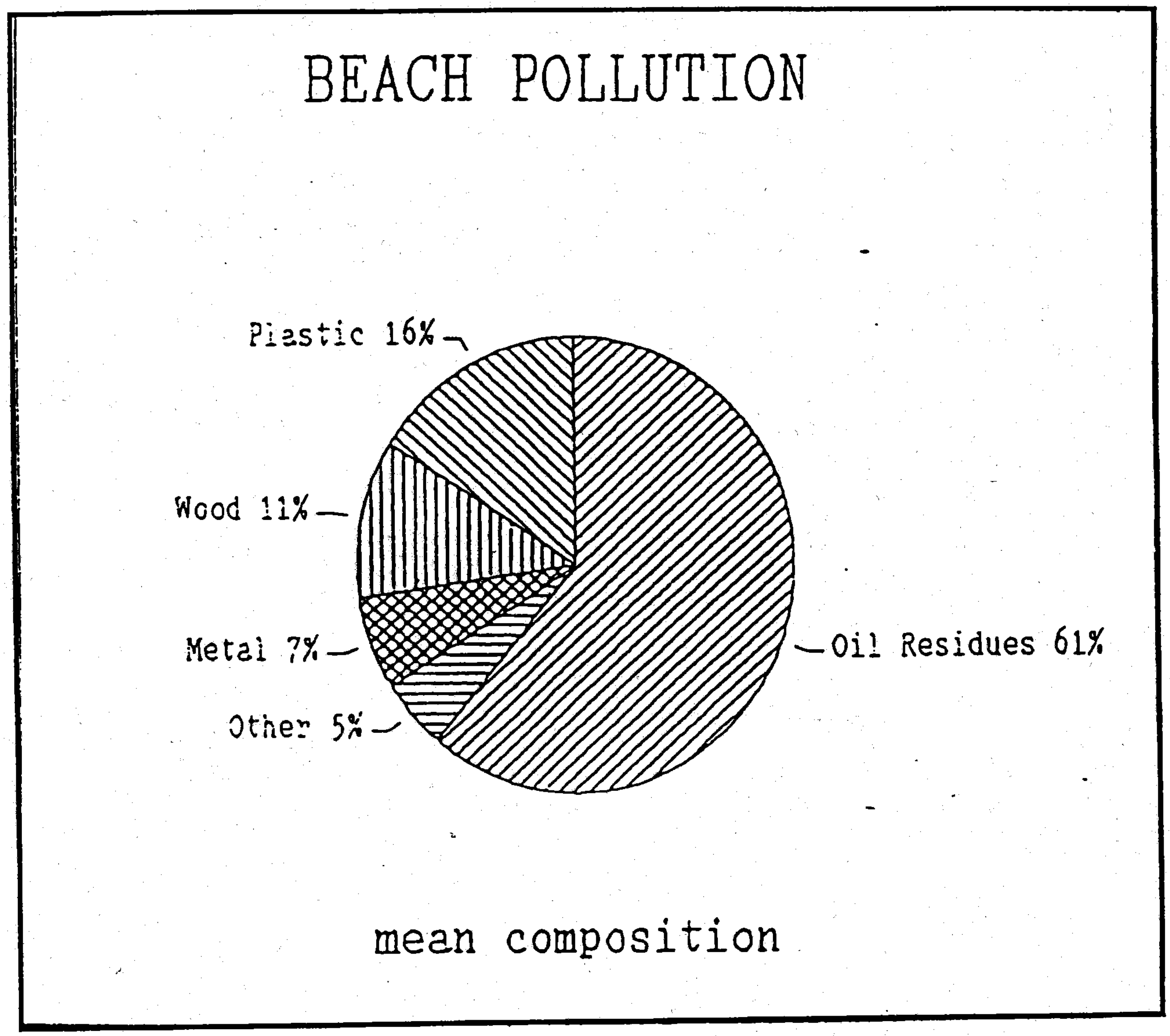



Figure 26. Mean composition of beach pollution, by volume, in the Gulf of Suez. (Source: Wild, 1990)

provide a tourist attraction.

These biological resources are however vulnerable to developmental activities, including new roads, industrial plants, new communities and hotel and recreational facilities (Fouda, 1990). No practical mechanism exists for reviewing potential environmental effects of proposed activities nor for anticipating and coordinating mitigation action for development activities likely to cause significant adverse impacts on biological resources (Baldwin, *et al* 1988).

Throughout much of the region, the coastal zone has become a repository for large quantities of industrial, commercial and residential trash and other solid waste (IUCN, 1967). Often this takes the form of plastics, metal containers, wood, tires and even entire scrapped automobiles at some localities.

In recreational areas, solid wastes can have ecological as well as aesthetic consequences. In some areas containing extensive metal and industrial debris, the potential exists for toxic substances to lead into the marine environment. Wooden pallets and driftwood may form a physical barricade to female turtles crawling up beaches to nest. Further, if such debris becomes impacted by an oil slick, the problem becomes compounded.

Damage to coastal and other vegetation from the use of off-road is also evident in the Red Sea. This not only reduces vegetation available for birds, grazing mammals and other wildlife, but also the loss of halophytes can destabilize sand dunes that border many shore areas.

Together with dredging, coastal reclamation probably represents one of the most significant impacts on the coastal marine environment of the Red Sea. Reclamation has been undertaken for residential developments, ports, bridges and other purposes. Favoured areas have often included intertidal flats with mangroves, shallow embayments and other biologically productive areas, the true bio-economic value of which is seldom recognized by developers.

Apart from the direct and permanent loss of habitat, land fill usually increases sedimentation. This may directly smother habitats or may limit photosynthesis of communities such as algal mats, seagrasses and coral reefs.

## 4. SOCIO-ECONOMIC ACTIVITIES AND STRUCTURES

### 4.1 Early Settlement

For three million years, man and his immediate ancestors have occupied the shores of the Red Sea, leaving behind a long and complex sequence of archaeological sites (Horton, 1987). The Red Sea is sited at the junction between Africa, Asia and maritime Europe. There is evidence for the migration of early man, and for the dissemination of food crops, technology, language and culture between continents. Despite its importance, the Red Sea region never spawned civilization of its own, those that developed nearby were based inland, in milder climate along rivers to ensure an adequate supply of water and where valuable raw materials were to be found.

Since the prehistoric times, the Red Sea has been one of the busiest and most important sea routes of the world. Despite the treacherous sea, difficult winds and currents, and the lack of water and food along its shores, the central geographic position of the Red Sea has guaranteed its importance, long before the construction of the Suez Canal. All ancient civilizations of the region have established outpost trading communities on the shores of the Red Sea. Between these outposts, lived scattered traditional societies. These pastoral or fishing groups never reached high population densities and the archaeological evidence suggests that way of live survived unchanged for thousand of years (Horton, 1987).

In 1869, the Red Sea was suddenly transferred into one of the most important seaways of the world. There are two related factors about this: the opening of the Suez Canal and the appearance of steam navigation. Powered ships were able to sail the narrow seas more easily, and the Canal allowed Ocean going vessels to pass directly between the Red Sea and the Mediterranean. The old ports such as Yanbu al Bahr, Jeddah and Massawa became thriving centres of mercantile activity. Railways soon became important in the development of the ports and their hinterland (e.g. Suakin-Nile Valley, Djibouti-Addis Ababa, Damascus-Mecca). These routes all had their effect on the pattern of trade and the prosperity of the sea ports. This resulted in the disappearance of long distance caravan everywhere except western Arabia and the decline of the maritime pilgrim trade, and of those medieval ports that no longer lay directly on the new maritime or railway network (e.g. Qoseir).

## 4.2 Present Day Settlement

Nine modern nations border the Red Sea and Gulf of Aden: Egypt, Sudan, Eritrea, Djibouti, Somalia, Yemen, Saudi Arabia, Jordan and Israel. Each nation has established important interests along the Red Sea and Gulf of Aden. Egypt earns about 1000 million US$ annually from approximately 20,000 merchant ships and smaller tanker sailing through the Suez Canal and the Egyptian economy has risen recently from the revenue of oil and tourism along the Gulf of Aqaba as well as the Red Sea coast. In Saudi Arabia, 60% of the population live along the Red Sea shores and the immediate hinterland. The annual pilgrimage still remains an important source of employment. Jeddah became an important communication centre and increased harbour facilities. Aqaba is Jordan's only port on the sea and therefore, very important especially in the export of bulky materials - phosphates account for 95% of the export of Aqaba.

## 4.3 Population and Development

Table 3 gives some basic socio-economic data of the Red Sea countries as reported by the World Bank in 1992. The Table shows that countries bordering the Red Sea and Gulf of Aden are estimated to have a total population of about 165 million with an average annual growth rate varying from 2.4 to 4.7%. The population is unevenly distributed over the region. In addition, the number of people living along the shores of the Red Sea and Gulf of Aden is not known. But rough estimates put it at no more than five million (Hinrichsen, 1990). Migration and urbanization have played an important role in the overall growth of the coastal region of the Red Sea and Gulf of Aden. Diversification of socio-economic activities in the coastal cities has enhanced employment opportunities in the cities and hence, unprecedented drift to the coast. For example, Jeddah grew from a small town, of 2-3 $km^2$ in area with less than 20,000 inhabitants at the beginning of the century, to a metropolis covering an area of 350 $km^2$ with a population exceeding 1.5 million (Aleem, 1988).

The wide variation in natural political and economic system within the region as well as the variation in disposable resources have resulted in great differences in the level of development along the coasts of the Red Sea and Gulf of Aden. There exist more than 25 urban centres scattered along the coast and vary from a small town with limited harbour facilities to a very sophisticated area such as Jeddah, Aqaba, Suez, Hurghada and Sharm El-Sheikh. Most of these urban centres are connected with road network along the coast and are adequate for accessibility to the interior. In addition to land transport, countries rely on sea transport among themselves (e.g. Jeddah-Suez). Various sizes of airports exist and are associated with international travel in support of tourist industry (e.g. Sharm el-Sheikh). Most of the coastal areas have light industry or at least the level of industrialization is relatively low (including oil refinery at Suez, fishing, phosphate mining, etc.). Thus, the role of the coastal region as local point of development and construction (for commercial, fishing and recreation) is particularly pronounced in the Red Sea and Gulf of Aden. If such growth continues, the population of urban centres is expected to double, probably every 10 years.

## 4.4 Socio-Economic Data

Socio-economic data for the entire countries of the Red Sea and Gulf of Aden is not available. However, a recent vulnerability assessment to accelerated sea-level rise was made by a joint Egyptian/Dutch team (Delft Hydraulics, 1992) who collected and analyzed socio-economic data.

Table 3. Some basic data of Red Sea and Gulf of Aden countries

| Country | Area 1000's $Km^2$ | Population (in mid of 1990) (millions) | Average Growth of Pop. 1980-1990 | Coast (km) | GDP (U$B) 1990 | *GDP per Capita (US$) 1990 | Average growth rate of GDP (1980-1990) |
|---|---|---|---|---|---|---|---|
| Egypt | 1001 | 52.1 | 2.4% | 2420 | 33.21 | 637 | 5.0% |
| Saudi Arabia | 2150 | 14.9 | 4.7% | 1840 | 80.89 | 5429 | -1.8% |
| Sudan | 2506 | 25.1 | 2.7% | 717 | n.a. | n.a. | n.a. |
| Ethiopia | 1222 | 51.2 | 3.1% | 1011 | 5.49 | 107 | 1.8% |
| Yemen | 528 | 11.3 | 3.1% | 1902 | 6.69 | 592 | n.a. |
| Djiboti | 23 | 0.427 | n.a. | 300 | n.a. | n.a. | n.a. |
| Somalia | 638 | 7.8 | 3.1% | 2957 | 0.89 | 114 | 2.4% |
| Jordan | 89 | 3.2 | 3.7% | 28 | 3.33 | 1041 | n.a. |

Source: Development and Environment, World Bank 1992

* Computed Data

Note: The average growth rate of GDP was computed to the GDP values with current prices, hence the inflation affects the average growth rates.

Although the main part of the study has dealt with the Nile delta, such a study could be used as model if an opportunity arises and be extended to include the entire region of the Red Sea and Gulf of Aden.

Under the condition of socio-economic data scarcity for most of the countries of the Red Sea and Gulf of Aden, data model was constructed to analyze the socio-economic status of the region (Noufel, 1992). This model is based on the main data categories suggested by the Egyptian/Dutch team. (Delft-Hydraulics, 1992) with some modifications.

The main data categories considered were:

1. General economic information (GDP, GDP per capita, average growth rate of GDP, the proportions of main economic activities in GDP, the average growth rate of national investments, total depth as % of GNP, and Debt Service as % of exports of goods and services.

2. *Population* (present, average growth rate, projected population by the year 2025. Labour force as % of total population, tertiary graduates as % of corresponding age group, and Science graduates as % of total graduates).

3. *Spatial pattern of economic activities* (agriculture industry, fisheries/aquaculture and tourism/recreation).

4. *Land and capital values* (average land and capital values of beach area per coastal segment; replacement values of capital facilities at direct exposure by coastal segment). Tables 4, 5 and 6 provide information on these capital values and replacement costs relevant to the situations in 1990 and the projected values for 2020, according to a report published by Delft Hydraulics (1992)

### 4.4.1 General economic information

Information on general economic for each of the Red Sea countries are shown in Table 7 giving the respective GDPs, GDP per capital and the average growth rate as well as other relevant data for 1990 and for the period 1980-1990.

### 4.4.2 Population

Display of population information is shown on Table 8.

### 4.4.3 Spatial Pattern of Economic Activities

The main economic activities in the Red Sea region and their spatial pattern of distribution are as follows for six of the Red Sea Countries.

<u>*Agriculture*</u>

| | | |
|---|---|---|
| Egypt | - | restricted to Suez Canal region usually from north of Ismailia to south of Suez |
| Sudan | - | some sites near Port Sudan |
| Eritrea | - | some pastures near the coast |
| Yemen | - | agricultural activities more common in the southern part |
| Djibouti | - | pastures |
| Somalia | - | pastures |

<u>*Industry*</u>

| | | |
|---|---|---|
| Egypt | - | Mainly along Suez Canal, with some mining activities in Safaga |
| Saudi Arabia | - | oil industry near Jeddah |

## 4.5 Fisheries

Table 4: Capital values of beach areas for 1990 (Egypt)

| Coastal (sub) segments Name | Length (km) | L. beach (km) | Situation 1990 | | | |
|---|---|---|---|---|---|---|
| | | | LHV (km) | HV (Le/m$^2$) | AV (Le/m$^2$) | F. Nour. |
| Suez Bay | 120 | 72 | 8 | 400 | 46 | 0.111 |
| W. Sinai | 260 | 182 | 4 | 400 | 11 | 0.022 |
| S. Sinai | 125 | 100 | 15 | 1000 | 152 | 0.150 |
| E. Sinai | 210 | 84 | 6 | 400 | 30 | 0.071 |
| G. Suez | 255 | 180 | 4 | 400 | 11 | 0.022 |
| Red Sea | 1000 | 700 | 40 | 400 | 25 | 0.057 |
| Total | 1970 | 1318 | 77 | 3000 | 275 | 0.433 |

Source: Delft Hydraulics, 1992

Legend:

| | |
|---|---|
| LHV | - Length of beach with high value |
| HV | - Capital value with high value beach |
| AV | - Average value of total beach area |
| F.nour | - Fraction of beach to be potentially protected by artificial nourishment |

Table 5. Additional Replacement Cost Capital Facilities Situation - 1990 (Egypt)

| Coastal Segments | Facilities | Rep.v. (MLe) | D-Rep.v (%) | CP (MLe) | FP (Mle) | RP (MLe) | Other (MLe) |
|---|---|---|---|---|---|---|---|
| Suez Bay | Suez CP's | 500 | 15 | 75 | | | |
| Suez Bay | Adaqa CP | 0 | 20 | 0 | | | |
| Suez Bay | Adaqa FP | 100 | 30 | | 30 | | |
| Suez Bay | Ayan Muza RP | 0 | 25 | | | 0 | |
| Suez Bay | Suez Wat.fr. | 100 | 20 | | | | 20 |
| W. Sinai | El Tor RP | 0 | 25 | | | 0 | |
| W. Sinai | Ham. Far. RP | 0 | 25 | | | 0 | |
| W. Sinai | Ras Sudr RP | 0 | 25 | | | 0 | |
| S. Sinai | Sharm E.S. RP | 10 | 25 | | | 3 | |
| S. Sinai | Ras Moh. RP | 15 | 25 | | | 4 | |
| E. Sinai | Taba RP | 0 | 25 | | | 0 | |
| E. Sinai | Nureiba RP | 10 | 25 | | | 3 | |
| E. Sinai | Dahab RP | 10 | 25 | | | 3 | |
| E. Sinai | Nabq RP | 10 | 25 | | | 3 | |
| G. Suez | Ain Suk RP | 0 | 25 | | | 0 | |
| Red Sea | Safaga CP | 350 | 20 | 70 | | | |
| Red Sea | Hurgh. FP | 60 | 30 | | 18 | | |
| Red Sea | Other RS CP | 300 | 30 | 90 | | | |
| Red Sea | Other RS FP | 30 | 25 | | 8 | | |
| Red Sea | Hurghada RP | 0 | 25 | | | 0 | |
| Red Sea | Safaga RP | 0 | 25 | | | 0 | |
| Suez Canal | Ismaillia WF | 60 | 20 | | | | 12 |
| Suez Canal | Lake border | 190 | 33 | | | | 63 |
| Total | | 1745 | 568 | 235 | 56 | 16 | 95 |

**Legend:**
CP = Commercial Ports
FF = Fishing Ports
RP = Recreational Ports
Rev.v = Replavement Value
D-rep v. = additional replacement value in case of 1m sea level rise

Source: Delft Hydraulics, 1992

Table 6. additions ReplacementCost Capital Facilities Situation - 2020 (Egypt)

| Coastal Segments | Facilities | Scen Factor | Rep.v. (MLe) | Dprep.v. (%) | CP (MLe) | FP (Mle) | RP (MLe) | Other (MLe) |
|---|---|---|---|---|---|---|---|---|
| Suez Bay | Suez Bay | 1.5 | 750 | 15 | 113 | | | |
| Suez Bay | Ataqa CP | | 500 | 20 | 100 | | | |
| Suez Bay | Atoqa FP | 1.5 | 150 | 30 | | 45 | | |
| Suez Bay | Ayan Musa RP | | 10 | 25 | | | 3 | |
| Suez Bay | Suez Wat.Fr. | 2 | 200 | 20 | | | | 40 |
| W. Sinai | El Tor RP | | 10 | 25 | | | 3 | |
| W. Sinai | Ham. Far. RP | | 10 | 25 | | | 3 | |
| W. Sinai | Ras Sudr RP | | 10 | 25 | | | 3 | |
| S. Sinai | Sharm E.S. RP | 2 | 20 | 25 | | | 5 | |
| S. Sinai | Ras Moh. RP | 2 | 30 | 25 | | | 8 | |
| E. Sinai | Taba RP | | 20 | 25 | | | 5 | |
| E. Sinai | Nuweiba RP | 2 | 20 | 25 | | | 5 | |
| E. Sinai | Dahab RP | 2 | 20 | 25 | | | 5 | |
| E. Sinai | Nabq RP | 2 | 20 | 25 | | | 5 | |
| G. Suez | Ain Suk RP | | 10 | 25 | | | 3 | |
| Red Sea | Safaga CP | 1.5 | 525 | 20 | 105 | | | |
| Red Sea | Hurgh. FP | 1.5 | 90 | 30 | | 27 | | |
| Red Sea | Other RS CP | 1.5 | 450 | 30 | 135 | | | |
| Red Sea | Other RS FP | 1.5 | 45 | 25 | | 11 | | |
| Red Sea | Hurglads RP | | 15 | 25 | | | 4 | |
| Red Sea | Safaga RP | | 15 | 25 | | | 4 | |
| Suez Canal | Ismaillia WP | 2 | 120 | 20 | | | | 24 |
| Suez Canal | Lake border | 3 | 570 | 33 | | | | 190 |
| Total | | 25 | 3610 | 568 | 453 | 83 | 56 | 254 |

Legend: see Table 8

Table 7. General Economic Information

| Country | GDP US$B 1990 | *GDP par capita 1990 | Average growth rate of GDP(%) 1980-90 | GDP | | | Average Growth rate of national investment 1980-1990 | Total Debt as % of GNP 1990 | Debt Service as % of exports of goods and services |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Agriculture % 1990 | Industry % 1990 | Services % 1990 | | | |
| Egypt | 33.21 | 637 | 5.0% | 17 | 29 | 53 | 0.2 | 126.5 | 25.7 |
| Saudi Arabia | 80.89 | 5429 | -1.8% | n.a. | n.a. | n.a. | n.a. | - | - |
| Sudan | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | 5.8 |
| Ethiopia | 5.49 | 107 | 1.8% | 41 | 17 | 42 | n.a. | 54.2 | 33 |
| Yemen | 6.69 | 592 | n.a. | 20 | 28 | 47 | n.a. | 97.1 | 5.4 |
| Djiboti | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. |
| Somalia | 0.89 | 114 | 2.4% | 65 | 9 | 26 | -2.6 | 276.9 | 11.7 |
| Jordan | 3.33 | 1041 | n.a. | 8 | 26 | 66 | n.a. | 221.1 | 23 |

source; Development and Environment, World Bank 1992

* Computed Data

Table 8. Population information by country

| Country | Total Population (millions) | *Average growth rate 1980-90 % | *Projected Population by the year 2025 (millions) | **Labour Force as % of total population 1988-90 | **Tertiary graduates as % of corresponding age group 1986-88 | **Science graduates as % of total graduates 1986-88 |
|---|---|---|---|---|---|---|
| Egypt | 52 | 2.4 | 86 | 27.7 | 3.8 | 22 |
| Saudi Arabia | 15 | 4.7 | 43 | 29.1 | 2.5 | 13 |
| Sudan | 25 | 2.7 | 55 | 35.1 | 0.4 | 24 |
| Ethiopia | 51 | 3.1 | 156 | 42.7 | 0.2 | 23 |
| Yemen | 11 | 3.1 | 37 | 24.7 | 0.2 | 11 |
| Djibouti | 0.427 | n.a. | n.a. | n.a. | n.a. | 36 |
| Somalia | 8 | 3.1 | 21 | 29.4 | n.a. | 13 |
| Jordan | 3 | 3.7 | 10 | 23.1 | 5.6 | 28 |

* Source: Development and environment, World Bank, 1992
** Source: Human Development Report, 1992, UNDP

Fisheries of the Red Sea and Gulf of Aden are not only of immediate importance in supplying the marine fish resources for the bordering countries but their development and management could contribute significantly in the future to both reducing dependence on imported fish and increasing per capita fish consumption. Fisheries may also represent an important source of employment in countries with a small industrial base. Most of the fish landing in the region (Table 9) originates from small scale, artisanal fishing activities. The artisanal fishermen commonly use gill nets, handlines and other fishing methods to take their fish in shore waters. However, some large scale industrial fishing is also undertaken particularly in Yemen where various joint venture arrangements with other countries exist (Sanders and Morgan, 1989). The importance of marine resources to the total fish supply in the countries varies widely and ranges from total dependence (e.g. Yemen) to only minor importance (e.g. Sudan) (Table 9). Only Yemen is able to achieve full self sufficiency in fisheries products combined with a high per capita consumption of fish. Half of the countries import a significant proportion of their total fish supplies.

A summary of recent marine landings in the Red Sea and Gulf of Aden countries is given in Table (10), based partly on FAO statistics. Table (10) indicates that landings from the region as a whole have remained relatively stable over the years despite significant changes in the industrial fisheries (Sanders and Morgan, 1989).

The shallow areas in the region support mostly reef associated demersal fish and lobster while upwelling areas result in high productivity and abundance of associated small pelagic species. The deeper water areas in both the Red Sea and Gulf of Aden are apparently less productive although an important trawl fishery for deep water lobster and shrimp exists off Yemen.

The monsoon system is a controlling factor for the whole area. Sharp seasonal patterns in wind and currents provide constraints to the fisheries, making weather conditions hazardous for small crafts, and causing seasonal changes in the availability of different fish species (FAO, 1980).

Fish production from the Red Sea is small, accounting for only 0.7% of the world total, although the surface area of the Red Sea (400,000 km$^2$) represents about 0.123% of the total area of the ocean. Historically, fishing has been an important element in the economy of the countries bordering the Red Sea. The historical artisanal fisheries of the Red Sea were limited in scope by the sparseness of the population, poor communication and water supplies and by the primitive harvest methods employed. These fisheries seem to have been perfectly in harmony with their fishing grounds, removing insignificant proportions of the fish stock and scarcely influencing the ecology of the area. Today communications have changed beyond recognition, large centres of population have sprung up along the coasts, and the fishing industry is moving into a more sophisticated phase, raising the need for scientific assessment and management of the limited fish stocks (Head, 1987).

Assessment of the various major fish stocks which comprise the fisheries of the area indicates that in general, the marine resources are not fully exploited and that additional catches can be taken (Sanders and Morgan, 1989). However, this potential for increased catches varies greatly between species group and many of the more important species are near to their maximum potential yields.

The species with the greatest potential for increased catches are, by contrast, those small and pelagic and mesopelagic species for which an industrial rather than a food use is the most appropriate method of utilization. Capture of such species in large quantities to justify industrial processing and marketing of the products currently involves significant difficulties, and hence, the realization of the potential of these species in an economically feasible way may present some problems.

The biggest fisheries potential lies in the more productive southern Red Sea waters, where Yemen could probably triple its catch, and Eritrea could more than double its early 1970s production. The artisanal fishery potential of Saudi Arabia is already well exploited, but there appear to be considerable resources for trawling and purse seining. Shrimp trawling probably represents the greatest potential fishery resource in Yemen. Egypt, more than any other Red Sea nation has experience in modern fisheries, but is already very close to its potential production limits.

Table 9. Sources of fish supply (food and non-food) for countries bordering the Red Sea and Gulf of Aden together with per capita annual fish consumption (kf) and current (1986) landings from the Red Sea/Gulf of Aden

| Country | Percentage of fish supply from: | | | | | 1986 Red Sea Gulf of Aden Landings (t) | Per Capita Consumption (kg) 1982-1984 Average |
|---|---|---|---|---|---|---|---|
| | Red Sea/ Gulf of Aden | Other Marine | Inland Fisheries | Aquaculture | Imports | | |
| Egypt | 8 | 12 | 27 | 20 | 33 | 13908 | 5.5 |
| Israel | <1 | 5 | 2 | 11 | 82 | 150 | 14.2 |
| Jordan | <1 | - | - | - | 99 | 65 | 4.0 |
| Sudan | 6 | - | 1 | 1 | 2 | 1190 | 1.4 |
| Saudi Arabia | 13 | 12 | 1 | 1 | 74 | 22700 | 9.9 |
| Yemen, A.R. | 73 | - | - | - | 27 | 22341 | 3.4 |
| Djibouti | 100 | - | - | - | - | 385 | 6.2 |
| Ethiopia | 15 | - | - | - | 1 | 600 | 0.1 |
| Yemen, P.D.R. | 100 | - | - | - | - | 91216 | 25.1 |
| Somalia | 50 | 50 | - | - | - | 8250 | 2.0 |

Source: FAO (1988) (Sanders & Morgan, 1989)

Table 10. total marine landings (103 t) for the Red Sea and Gulf of Aden

| | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Egypt | 9.3 | 7.9 | 9.1 | 17.5 | 14.8 | 15.8 | 13.4 | 13.6 | 13.7 | 13.8 | 13.9 |
| Sudan | 0.8 | 0.6 | 0.8 | 0.7 | 1.0 | 0.9 | 1.1 | 4.4 | 4.4 | 1.2 | 1.2 |
| Ethiopia | 1.0 | 0.2 | 0.2 | 0.2 | 0.4 | 0.3 | 0.4 | 2.0 | 0.8 | 0.6 | 0.6 |
| YAR | 16.5 | 17.5 | 19.3 | 19.3 | 17.0 | 16.0 | 14.0 | 18.0 | 18.6 | 20.6 | 22.3 |
| Saudi Arabia | 11.6 | 11.7 | 13.3 | 13.3 | 13.2 | 13.2 | 13.2 | 13.2 | 13.2 | 21.8 | 22.7 |
| Jordan | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Israel | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.3 | 0.1 | 0.1 | 0.1 | - | - |
| Red Sea | 39.4 | 38.1 | 42.9 | 50.0 | 47.0 | 46.9 | 42.6 | 51.7 | 50.8 | 58.2 | 60.9 |
| Djibouti | 0.2 | 0.2 | 0.2 | 0.2 | 0.3 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| Somalia | 4.1 | 4.9 | 4.6 | 5.5 | 7.2 | 7.5 | 7.4 | 7.8 | 7.8 | 8.2 | 8.2 |
| South Yemen | 64.1 | 64.0 | 48.1 | 51.6 | 89.7 | 78.0 | 69.7 | 74.1 | 74.1 | 85.2 | 91.2 |
| Gulf of Aden | 68.2 | 68.9 | 52.7 | 57.1 | 96.9 | 85.5 | 77.1 | 81.9 | 91.7 | 93.4 | 99.4 |

Source: FAO (1988) with added information. (Sanders & Morgan, 1989)

Various estimates of the total potential annual landing range up to 360,000 tons for the Red Sea. (Gulland, 1971) and 267,000-414,000 tons for the Gulf of Aden (Kesteven, *et al* 1981). The latter value does not include the mesopelagic fishes estimated at 20 million tons (Gjosaeter, 1983).

However, fisheries management in the region is in its early stages and is seriously hampered by lack of data on most stocks. Stocks of some species are being heavily overexploited but still have no form of management, for example spiny lobsters in the northern Red Sea (Sheppard, *et al* 1992). Since many stocks are shared among several countries, multinational coordination of data collection and management are essential to safeguard future yields.

Two potentially serious problems face countries bordering the Red Sea and Gulf of Aden. These are the increasing pollution (mainly in the Gulf of Suez) and degradation or loss of nursery areas. Both could cause declines in yield.

Aquaculture development has proceeded slowly in the countries bordering the Red Sea and Gulf of Aden with the exception of Egypt, having a significant proportion of its total fish supply being derived from pond culture of tilapia and carp species along the River Nile. Marine fish farming is not undertaken in the Red Sea region with the exception of small pilot-scale commercial production of penaeid shrimp in Saudi Arabia (Sanders and Morgan, 1989). The mother-of-pearl oyster cultivation in Dongonab Bay in Sudan has been intermittently successful since 1904 (Nasr, 1982).

The Egyptian economic development plan incorporates a production target of 100,000 tons of farmed fish by the year 2000. Accordingly, potential aquaculture along the Red Sea coast has been investigated and possible aquaculture models were brought from other areas, including the Red Sea itself (shrimps and sea-breams) and from surrounding seas. Recent studies recommended 5 different aquaculture techniques: 1) extensive culture in coastal lagoons, 2) extensive fish culture in artificial lakes, 3) extensive fish and shrimp culture in enclosures, 4) semi-intensive fish or shrimp culture in earth ponds, 5) intensive culture in floating cages. As each of the different aquaculture technology envisaged for use has its own requirements, the site selection of 41 areas along the Sea were surveyed.

### 4.6 Tourism

Tourism is almost exclusively limited to the north-eastern part of the Red Sea, i.e. Egypt and Jordan. This is because of political and social instability on the western shores and socio-political policies on the eastern areas (Medio, 1992). Only Yemen may soon resort to tourism as a main income resource.

As far as Egypt is concerned, tourism represents the third revenue after oil and foreign remittances. According to the Egyptian Tourism Development Authority (TDA), tourism in Egypt has and will continue to be a key contributor to national income growth, foreign exchange earnings, employment generation, regional development and population redistribution (TDA, 1992). Tourism has been the fastest growing sector of the Egyptian economy over the last five years, reaching its peak during the first half of 1990 (Table 11). Between 1985 and 1989, the number of international arrivals grew on average by 13.2% per annum, from 1.5 million tourists in 1985 to 2.5 million in 1989. Over the same period, tourism growth throughout the world increased at an average annual rate of 5.9% (TDA, 1992).

Although tourism has been almost exclusively oriented toward Egypt's antiquities, concentrated in Cairo, Luxor or upper Egypt, recent tourist establishment are in the vicinity of Hurghada (Ghardaqa) and Sharm El-Sheikh along the Red Sea coast and along the South Sinai coast in the Gulf of Aqaba. Therefore, the density of tourist establishments in some places, such as Sharm El-Sheikh, is approaching the saturation point (Giland, 1991). Tourism in these places relates principally to diving, snorkeling and other water sports because of the unique coral reefs of the Red Sea. Market demands studies for the South Sinai where facilities have become only recently available, have revealed a dramatic rate of growth in foreign tourism of 42% per year.

Table 11: Coast Related Tourist Capacity and Financial Data for the year 1990 (Egypt) (Source: Deft Hydraulics, 1990

| Coastal Segment | Scenario Factor | Capacity (beds) | Investment (MLE) | Occ. For. (1000TN) | Occ.Local (1000TN) | Exp. For. (MLE) | Exp.Local (MLE) | Jobs (#) | Val. Added (MLE) |
|---|---|---|---|---|---|---|---|---|---|
| Suez Bay | 1 | 3322 | 158 | 728 | 121 | 109 | 12 | 2492 | 61 |
| W. Sinai | 1 | 583 | 30 | 128 | 21 | 19 | 2 | 437 | 11 |
| S. Sinai | 1 | 7000 | 344 | 1533 | 256 | 230 | 26 | 5250 | 128 |
| E. Sinai | 1 | 800 | 40 | 175 | 29 | 26 | 3 | 600 | 15 |
| G. Sinai | 1 | 1929 | 97 | 422 | 70 | 63 | 7 | 1447 | 35 |
| Red Sea | 1 | 1282 | 55 | 281 | 47 | 42 | 5 | 962 | 23 |
| Suez Canal | 1 | 1282 | 55 | 281 | 47 | 42 | 5 | 962 | 23 |
| **Total** | | **20703** | **1014** | **4334** | **755** | **679** | **76** | **15528** | **379** |

Legend:

| | |
|---|---|
| Occ. For | - occupation by foreign tourists (1000 tourist nights) |
| Occ. Local | - occupation by local tourists (1000 tourist nights) |
| Val. Added | - value added (gross income) generated from tourism |
| Exp. For | - expenditure by foreign tourists |
| Exp. Local | - expenditure by local tourists |
| MLE | - Million Egyptian Pounds |

The Egyptian tourism sector has been reconstructed to improve its efficiency and ability to provide guidance and assistance to investors to make their participation successful and profitable. Accordingly, a national strategy for Egypt's tourism development programme has been formulated, and priority areas and projects identified. Among these, several areas on the coast of the Red Sea and South Sinai Peninsula have been selected for development as major touristic centres (Figure 27), and preliminary planning and feasibility analyses have been prepared for them (Sultan, 1992). Large scale development will be required, not only in terms of basic physical infrastructure, but also in terms of new settlements and the attendant social services needed to house and service new population clusters. The tourist related work force employed in South Sinai, for instance will be approximately 30,000 of which 50% will be in direct services (e.g. catering, reservations, recreation, shopping, etc.). A total of about 40,000 beds are planned to accommodate the projected tourist development by the year 2005 where the number of tourist is expected to reach five million annually. The estimated cost of tourist establishments (hotels and tourist villages) for the Red Sea and South Sinai is expected to be within the range of 3 billion Egyptian Pounds (LE), most of it will be spent on infrastructure. In addition, a comprehensive master plan for the establishment of a chain of marinas, serving sea yachts, pleasure boats and floating hotels is presently being studied in conjunction with international firms (TDA, 1992). The facilities are to be established along the Red Sea coast and the estimated development for Phase 1 of the marinas is in the magnitude of US$50 million.

## 5. EXPECTED CLIMATE CHANGE AND SEA-LEVEL RISE

There is an increasing evidence and strong belief among scientists that the accumulation in the atmosphere of the greenhouse gases such as $CO_2$, chlorofluorocarbons (CFCs), methane ($CH_4$), nitrogen oxides ($NO_2$), ozone ($O_3$), etc., would contribute to the increase of the temperature of the atmosphere worldwide, in a phenomenon now well known as the global warming. Human activities, e.g. burning of fossil fuels, deforestation, release of CFCs to the atmosphere etc. are responsible for the build up of these gases in the atmosphere and for the resulting greenhouse effect. Carbon dioxide was the first to be identified as the main cause of the global warming and is still the main contributor to this phenomenon. The concentration of $CO_2$ in the atmosphere in the 1800s, i.e. before the spread of the industrial revolution, was estimated as 270 ppm, became 315 ppm in 1957 and reached a present value of 355 ppm.

### 5.1 Increase in Temperature

The increase of the greenhouse gases concentration in the atmosphere will lead to the global warming. There is consensus that the doubling of $CO_2$ concentration from the background level of 270 ppm will increase the global mean temperature by 2°C. The increase in temperature predicted by different computer models varied between 0.5 and 4.5°C when the concentration of $CO_2$ is doubled. Variations of the model values are due mainly to the inability of the climate models to parameterize accurately the complex interactions between the land-ocean atmosphere processes and the response to the temporal variability in climate parameters. Therefore, for the purpose of this overview, the minimum increase of temperature of 1.5°C by the year 2030, was adopted.

Computer models predict that the greenhouse warming may be associated with more severe winters. The rise in the mean temperature of the atmosphere will not be the same everywhere on the globe. However, a recent two year study, which was conducted to develop three scenarios of future climate change in the Mediterranean (Palutikof, *et al* 1992) indicated that although temperature changes due to greenhouse effect for the Mediterranean should be similar to the global response, confidence in model scenario of precipitation was low because of uncertainty associated with the General Circulation Model (GCM) results. It was concluded that scenarios can only be taken as indication of the range of possible changes that might occur (Palutikof, *et al* 1992). In the Red Sea, the climate models have not given any accurate information on the temperature anomalies which can help in giving realistic estimation of the greenhouse impacts (Bin Afeef, 1992).

It is believed that the temperature increase at the equatorial and tropical regions will be 1/3 of that at the cold regions at higher latitudes. Accordingly, the temperature increase in the Red Sea

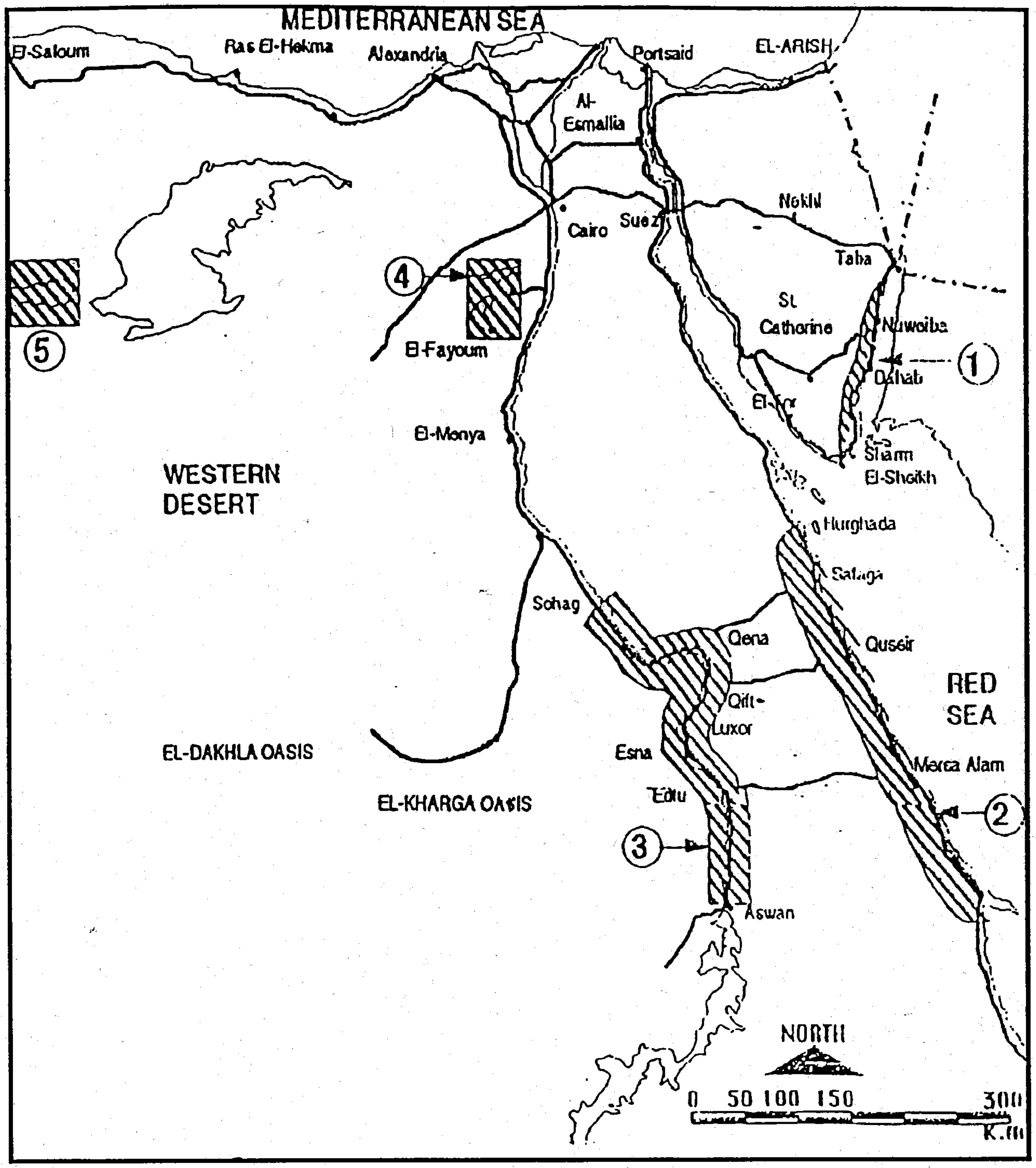



Figure 27: Priority Development Zones (Source: TDA, 1992)

and the Gulf of Aden region is expected to be less than the average global temperature increase (Meshal, 1992). However, the temperature change over the other parts of the world may affect the regional circulation pattern.

### 5.2 Changes in Precipitation Pattern

The region along the Red Sea and Gulf of Aden has an arid climate with an evaporation rate that exceeds precipitation. However, the expected temperature increase in the atmosphere would lead to increase in sea surface temperature and hence increase of evaporation. The effect of global warming on rainfall varies with model used and the change in precipitation is very unevenly distributed. The increase in evaporation rates may result in a rise in the global rainfall by an estimated 7-11% a year. Some models predict that the increase in precipitation in the Middle East region will be higher than the average increase worldwide. The tropics would become wetter but the subtropics, already dry could become drier still (Meshal, 1992). Other models predict that the rainfall will increase as we move northward. On the other hand some studies speculated that excess evaporation could lead to the increase of the cloud cover which may offset the impact of the global warming.

The predicted changes in the characteristics of the monsoonal wind systems may affect the precipitation over certain parts of Africa. Moreover, the increase in the surface temperature of the sea may lead to the shift of characteristics over the region (Meshal, 1992).

### 5.3 Sea-Level Rise

The increase in the mean temperature of the atmosphere is expected to warm up the oceans, leading to the expansion of their water causing a rise in sea level of between 20 and 140 cm if the average temperature is increased by between 1.5 and 4.5°C, respectively. Scientists expect the global warming to neither melt the ice at the Antarctica nor to cause the glaciers of the Antarctica to slip into the sea. This would require global rise in temperature of more than 20°C. However, global warming may lead to the melting of the glaciers cover over the high mountains like Kilimanjaro and Kenya. The melted water will eventually find its way and drain into the Indian Ocean thus contributing to the rise of its level. This may have an impact on the exchange of water between the Red Sea and the Gulf of Aden and hence influence the water circulation pattern in the Red Sea (Meshal, 1992).

Superimposed on sea-level rise, the Red Sea region can also be affected by local tectonic and sediment compaction. Local subsidence can occur at some locations but the rate is difficult to estimate (Bin Afeef, 1992). The Mediterranean Sea is a nearby example giving 5 mm/yr. All these possibilities will be subject to amendment by more detailed investigations using existing data and models (Bin Afeef, 1992). The Intergovernmental Panel on Climate Change (IPCC) models are being constantly improved and much better results can be expected to appear within the next 10 years. Incorporating IPCC models which also include the effects of $CO_2$ fertilization, feedback from stratospheric ozone depletion and the radiative effects of sulphate aerosols yields new projections for radiative forcing of climate and for changes in global mean temperature and sea level (Wigley and Raper, 1992). Changes in temperature and sea level are predicted to be less severe by about 20-30% than estimated previously, but are still far beyond the limits of natural variability.

## 6. POTENTIAL IMPACTS ON CLIMATE CHANGE AND SEA-LEVEL RISE ON COASTAL ENVIRONMENT

Future global warming could increase the rate at which sea level has been rising by 1) warming and expanding ocean water, 2) melting mountain glaciers, and 3) possibly causing polar ice sheets in Greenland and perhaps Antarctica to disintegrate. Current estimates are that sea level will rise between 30-50 cm by the year 2050 and possibly up to 1 m by the year 2100. In addition, global warming may increase storm frequencies and intensities (IPCC, 1990).

A rise in sea level would 1) inundate and displace wetlands and lowlands, 2) erode shorelines, 3) exacerbate coastal storm flooding, 4) increase the salinity of estuaries and threaten freshwater aquifers and otherwise impair water quality, 5) alter tidal range in rivers and bays, 6) alter sediment deposition patterns and 7) decrease the amount of light reaching water bottoms (Figure 28).

The foreseeable consequences of global warming and sea-level rise, heighten concerns for countries and citizens occupying these vulnerable areas. Other aspects of a country's economic and social well-being may be adversely affected by fundamental changes to its fisheries and agriculture or its economic base in tourism. Also, in some countries, beaches and other coastal features provide important cultural values, which may be threatened by sea-level rise. Furthermore, there may be impacts on bio-diversity as some localized habitats are lost or change faster than the plants or animals which depend on them can adjust (IPCC, 1990).

Since early in the Pleistocene period, the most important natural causes of changes included rises and falls of sea level (up to 150 m) associated with glaciations and accompanying fluctuations of sea-surface temperature (Salvat, 1992). Despite the fact that these changes were larger than those anticipated by mid 21st century, coastal massive communities survived on continental slopes. However there are two major differences between the previous and present cases. First it took thousands of years to affect the earlier change and even the last 10 thousand years, we face the prospect of rapid change over half a human life - albeit at a rate of sea-level rise that is less than of the post glacial transgression (i.e. 5 mm/yr compared to 13 mm/yr). Second, 50% of the world's population is located near coasts and about 300 million people live within 1 m of sea level. They will be seriously affected by sea-level changes, not least because of their impact on coastal ecosystems (Salvat, 1992).

Before evaluating the potential impacts of climate changes and sea-level rise on the coastal environment of the Red Sea and Gulf of Aden, it should be remembered that the Red Sea climate, particularly in the northern part was wetter than the extreme dry conditions now prevailing, with rare precipitation during winter. Klein, *et al* (1990) demonstrated that earlier in the Holocene, rainfall in the Sinai was considerably greater than it is today. The authors measured fluorescent landing attributed to humic materials in the fossils of the coral Porites from raised terraces, and showed that it was absent from present fringing reefs. They deduced that heavy summer rains supplied the former reefs. Climate models have been used to explain the monsoonal variability over the past 150,000 years. These models reveal that, under interglacial conditions, increased northern hemisphere solar radiation produced a larger land-ocean pressure gradient, strong winds and great precipitation over Southern Asia and North Africa.

Another important factor which should be considered before evaluating the potential impact of climate change is that the current sea level of the Red Sea fluctuates consistently with season because of the high rate of water evaporation - the highest in winter and lowest in summer. Considering the respective cycle of the tide and of the variation of the mean sea level, there is a possibility that the two movements would add their effects at same periods of the year. On the basis of the existing prediction tables, the maximum yearly variation is 2.4 m/yr at Suez and 1.15 m/yr at Quseir.

Finally, the current exploitation of the Red Sea resources is causing great economic and ecological changes. Conflicting human interests are taking a toll of the region's natural resources, particularly between oil and tourist industries, both are causing considerable changes to the coastal marine habitats.

The range of possible scenarios resulting from the complex interactions between several sets of abiotic variables and the dependent biological communities has not yet been well evaluated for any single coastal biological community (Pernetta and Elder, 1992).

Considerations of the impact of each parameter in isolation from the full range of climatic variables and their effects on processes in the biotic and abiotic environments of coastal zones will inevitably lead to simplistic and erroneous conclusions concerning the future stability of coastal systems (Pernetta and Elder, 1992). Difficulties of impact prediction are compounded when the

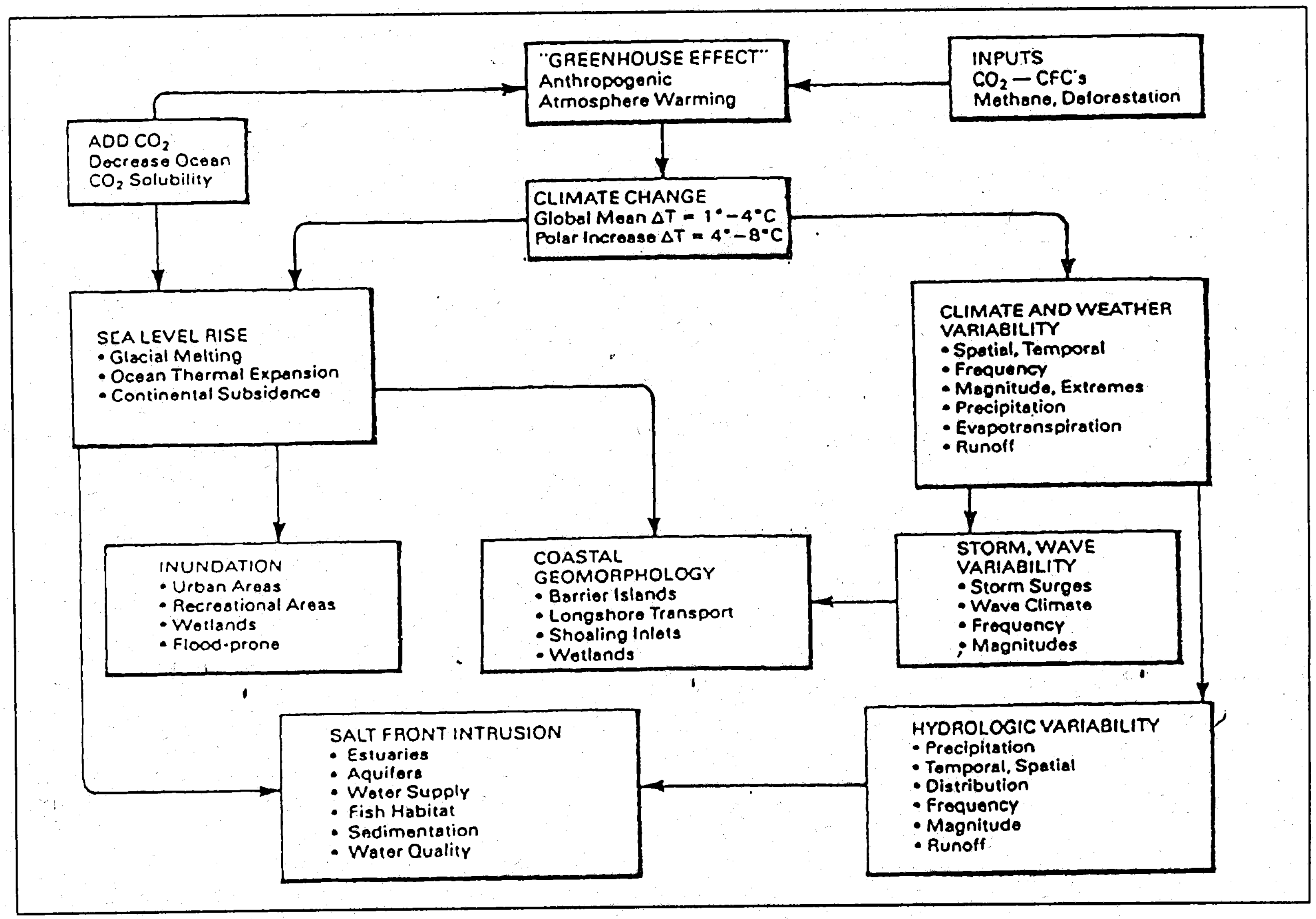



Figure 28: Physical consequences of climate change (Source : IPCC, 1990)

precision with which one source of change can be predicted is low, since each variable is linked both directly and indirectly with a large number of other variables.

### 6.1 Impacts on Meteorological Parameters

In the Red Sea and Gulf of Aden, the climate models can not provide accurate information on the temperature anomalies which can help in giving realistic estimation of the greenhouse impacts (Ben Afeef, 1992).

Such difficulty in climate prediction for the Red Sea and Gulf of Aden region is due to the scarcity and the scattered distribution of existing data on climate which can not be integrated into proper models. Therefore, the impacts of the increased concentration of greenhouse gases and of global warming on meteorological parameters in the Red Sea and Gulf of Aden region can not be predicted properly without integrating detailed and accurate climate data of the region into the global climate.

Nevertheless, the predicted increase of the temperature on the Red Sea region "though it is expected to be spatially variable" can lead to two significant results:

i) An intensification of the heat lows already existing in the region and therefore an increase in the frequency of the prevailing dusty conditions, and

ii) On the southern parts, and the escarpment especially the convection mechanisms is more likely to increase which will eventually result in an increase in the percentage of convective clouds and hence, in the amount of rainfall.

### 6.2 Impacts on Marine Parameters

To assess the impacts of climate changes on the marine parameters in the Red Sea and Gulf of Aden, one has to understand how they will affect certain functions affecting these parameters. Parameters like pressure, rainfall and temperature will be influenced by climate change. To what extent does the upwelling regime in East Africa affect the Red Sea? The high surrounding mountains in the Gulf of Aden reduce the influence of monsoon, therefore, it is unlikely that changes in pressure in East Africa will have a dramatic effect on the Red Sea environment. However, the arid climate of the Red Sea and the possible impact of global climatic changes could result in serious local changes in the Red Sea region, hence the marine ecosystem will also be influenced.

The pressure distribution and consequently the wind patterns are mainly attributed to changes in air temperature, hence any increase in air temperature due to the global warming will change the wind cycle either near the ground or at higher altitudes. The strength of the winds and storms is likely to change from one location to another according to the intensity of the pressure gradients (Soliman, 1992). In addition, the convergence zones will face some shift to the north or to the south. Accordingly, a consequence of events are likely to take place in the region, and are summarized as follows:

i. The increase of the wind stress will change the current pattern, wave height, rate of evaporation, water temperature and salinity.

ii. Changes in the strength of the equatorial jet on the Indian Ocean at higher altitudes will influence greatly the amount of rainfall over Ethiopia and Sudan.

iii. The increase of the strength of the southwest monsoon in summer will press down the water level in the Gulf of Aden region more and more, and hence may increase the outflowing warm saline Red Sea water at the surface into the Gulf of Aden. To acquire the stability conditions, more cold fresh sub-surface water will flow into the Red Sea through upwelling processes. Meanwhile, in winter it is expected to attain strong water flow into the Red Sea from the Gulf of Aden. Therefore, the convergence zone in the northern part of the Red Sea may be displaced northward and hence, increasing the fertility of that region.

v. Through convection and advection processes, the water temperature and salinity in the deep regions may show only minor changes, while in shallow and sheltered areas these parameters will show significant seasonal changes, which in turn indicate different impacts on the habitats along the shallow coastal zones. Generally, one can expect strong gradient in temperature and salinity from north to south. These features will cause some changes in the water circulation in the Red Sea particularly the cross currents.

vi. The rise in sea level may change the tidal range in the Gulf of Suez and consequently in the Suez Canal as the oscillations in the Gulf may closely approach the resonance conditions. Therefore, the sea-level rise in this case will not simply show 20.0 cm as suggested by IPCC, but will sharply increase, which may inundate most of the low lands and cultivated landform along Suez Canal.

### 6.3 Impacts on Hydrology and Water Resources

The Red Sea and Gulf of Aden coast has in general, freshwater resources due to its geographical location in a subtropical arid region. In view of the expected global climate change, hydrological cycle and underground water in the region may be seriously affected (El Hag, 1992). These water resources depend mainly on rainfalls which are heaviest along the Sudanese Red Sea coast at Port Sudan and Suakin. They provide several agricultural schemes, in Sudan and Yemen, beside the heavy domestic use by a large sector of inhabitants and their animals (El Hag, 1992). In addition there are other water resources including coastal aquifers belonging to Quaternary times, underground water and Nile water around Suez Canal. The expected increases in sea water level and temperature are likely to increase inland salt water intrusion with great or complete damage of the existing water resources. Therefore, it is imperative that measures should be taken to, at least, minimize inland intrusion of seawater, and hence protect water resource assets along the Red Sea and Gulf of Aden Coast (Shami, 1992).

### 6.4 Impacts on the Coastal Zone

Climatic changes that lead to sea-level rise will affect coastal zones of the region considerably. The direct effect of inundation would produce a large loss of inhabited areas, wetlands and low islands of the Red Sea. The soil of the coastal plain of the Red Sea ranges between a few centimetres and a few metres and is very hard but porous.

Any sea-level rise will allow waves to cover the coral reefs, increasing coastal vulnerability to erosion and storms, at least until reef growth can catch up with the sea level. Rising sea levels will also affect the growth of coral reefs themselves, producing an increase in sedimentation rate and temperature which are limiting factors for coral reef growth. The rise in sea level may also lead to destruction (submersion) of some islands in the Red Sea.

In many areas, the shoreline retreat from rising sea level would be greater than from inundation alone, because land well above sea-level could also erode. This would eliminate existing recreational beaches at the major resorts of the Red Sea, hence billions of dollar would be required to protect or replace these tourist resorts.

Other impacts of sea-level rise will be on the turtles which are recognized throughout the world as one of the endangered species, threatened by extinction (Everett and Pastula, 1990). As nesting beaches are lost, either by sea-level rise or by human development, additional significant stresses will be placed on turtle populations which are quite small in the Red Sea (Frazier and Salas, 1984). The effect of global sea-level rise will depend on the geological situation of each location. Areas that are subsiding will be under greater pressure than those that are stable or uplifting, with contribution of tectonic or isostatic movement to relative sea-level change.

As mentioned earlier, among the attractive geomorphic features in the Red Sea are the reef-island complexes forming the archipelagos of Dahlak, Farasan, Suakin and Harghada (Ghardaqa). These reef islands protect the coastline against waves and storm surge, prevent erosion and contribute to the formation of sandy beaches and sheltered harbors. The Red Sea islands typically range in height from less than one meter to hilly ones rising up to 300 m above sea level (Moussa, 1992). Low islands such as Abu-Mounkar and Twaal around Ghardaqa will be susceptible to flooding as sea level increases.

In addition, the coastal plains typically range in elevations from 0 to 200 m above sea level (Moussa, 1992). In most parts they are rising deeply to the base of the bordering mountains, however, most of the beach environments and some low coastal segments are subject to inundation.

In the northern parts of the region, the heads of the Suez and Aqaba Gulfs should be classified among areas at risk of coastal flooding. Marked effect of sea-level rise is particularly expected at the head of the Gulf of Suez where tidal range exceeds two metres. In addition to the possibility of coastal flooding, the dual effect of the rise of water level in the Mediterranean and Red Sea may accelerate the rise of water level in the Suez Canal. This combined effect may ultimately exacerbate the inundation of the northern Nile Delta, including the western side of the Suez Canal.

Extended wetlands along the Red Sea are liable to inundations, some of these in Sudan, Eritrea and Yemen have already experienced coastal flooding at time of storm surges (The Red Sea and Gulf of Aden Pilot, 1980). The Gulf of Aden coastal areas are not expected to suffer much of the sea-level rise except some parts which are relatively low and sandy (Moussa, 1992). Yet the coastal segment around Zeila in Ismaillia may be classified among the areas at risk. However, coastal embayments surrounded by low-lying wetland areas may be expected to increase in extent with consequent increase in available habitats for subtidal communities such as seagrasses.

Salt marsh plants are susceptible to changes in salinity and water level as a consequence of relative rises in sea-level. The distribution of ecotones will shift in a landward direction (Mehta and Cushman, 1989).

The Red Sea and Gulf of Aden coastal cities are generally not densely populated except a few cities such as Jeddah, Suez, Aqaba and Djibouti. Most cities and towns of low population are situated well above sea-level. Yet, the most important factor is that many activity centres are concentrated at the front, directly on beaches. The best example is the numerous recreational centres of Hurghada (Ghardaqa) and Sharm el Sheikh in Egypt. If the sea level rises, beaches will erode and these centres will be adversely affected (Moussa, 1992).

Whilst it is generally true that rising sea-level will result in increased coastal erosion and recession, the extent of this impact will vary from one site to another, depending on a wide variety of local specific process rates including rates of vertical movement of the land; the present and future rates of erosion in each watershed; the offshore bottom profile; the latitudinal profile of the coastal land; present and future pattern of long-shore sediment transport; and intensity of human modifications of the coastline (Pernetta and Elder, 1992).

Generally speaking, each coastal location represents a unique set of interrelated physical biological and human components and processes, and therefore the extent and nature of impacts on coastal locations will obviously differ from one site to another.

## 6.5 Impacts on Marine Ecosystems

Physico-chemical parameters are the primary determinants of the distribution of marine habitats, communities and ecosystems. A change in these parameters will have broad impacts on basic ecological structures and processes. These changes will in turn cause impacts on marine and coastal resources.

The predicted temperature rise of surface waters and a change in the water circulation would have substantial impact on the structure and location of marine habitats. However, marine organisms as a rule have rather high genetic and behavioral plasticity, allowing them to adapt to constantly changing environmental conditions. This property is a basis for the relative stability of zoogeographical patterns under the conditions of natural climate variation (Odum, 1986).

The marine coastal habitats of the Red Sea, particularly coral reefs, seagrass beds and mangroves appear to be close to their physiological limits. Temperature, rather than salinity, seems to be the main limiting factor for the distribution and development of these habitats in the northern Red Sea (Lipkin, 1977; Por, *et al* 1977; Wahbeh, 1980; Jones, *et al* 1987). Out of 10 species of sea-grass in the Red Sea, only two species, Halophila stipulacea and *Halodule uninervis* occur at the northern extremity of the Gulf of Suez and have also invaded the Suez Canal, however, *H. stipulacea* has successfully colonized several areas in the eastern Mediterranean (Fox, 1926; Aleem, 1962). Similarly, the Sinai mangal which is the northern mangal of the Indo-Pacific at 28°N, is quite poor on its fauna and flora as well as developmentally limited because of the low water temperatures (below 10°C) (Por, *et al* 1977; Por, 1984).

If the water temperature of the Gulf of Suez and Suez Canal increases with global warming, it would mean that mangroves and possibly other populations may invade the Mediterranean through the Suez Canal. Other factors which may contribute to such changes are water currents and suitable substrates. If this assumption will prove to be true, it will have serious implications especially if coral reefs could flourish in the Gulf of Suez more than at the present time and block the Suez Canal for navigation.

As a result of changes in the ocean and coastal zone, there may be impacts on biodiversity. In the open sea the effects on biodiversity will likely be less than those expected in the estuaries and wetlands. The oceanic communities populations will be relatively free to move to new geographic areas while the near-shore communities are more constrained by the physical features of the shore. Thus, global warming may cause considerable changes in structure and distribution of marine ecosystems.

The following account provides the responses of different coastal ecosystems on Accelerated Sea-Level Rise (ASLR). It is stressed that the responses of the different systems are generalized. In certain situations, different responses may be encountered because the environmental settings of the area does not comply with the generalized response. Moreover, there are natural responses which may clearly be affected by human activities such as coastal development, tourism and sewage discharge.

### 6.5.1 Mangroves

It is suggested, on the basis of an evaluation of records of mangrove response to past sea-level rise events that such communities may be highly susceptible to small changes in the present rate of sea-level rise (Allison, 1989). On the basis of geomorphological and palaeobotanical evidence, Ellison (1989) concludes that when rates of sea-level rise were rapid in the early Holocene, expansive system did not exist, but that such mangrove communities developed only following the stabilization of sea-levels in the mid-Holocene.

In low island environments and areas with low inputs of thyrogenous sediments, mangrove ecosystems may be able to keep up with a rise of 8 cm/century but at rates in excess of 12 cm/century such communities may not persist. Stratigraphic evidence from high islands where more sediments are derived from land-based sources indicates that mangrove ecosystems may be capable of keeping pace with rises as high as 25 cm/century. The survival of mangrove ecosystems in low island environments is therefore threatened by the current projected rates of sea-level rise (Ellison; 1989).

Figure 29 depicts the three main settings where mangroves are found growing along the Red Sea. Example A shows the setting of the extensive growths of mangroves in the area south of Ras Banas. Example B shows the typical situation of the mangroves growing along most of the mangrove grows within a channel surrounded from two sides by elevated coralline ridges (e.g. Ras Mohammed and Abu Mingar (Delft Hydraulic, 1992).

In the case of one metre sea-level rise, the mangroves in example C are likely to die, since there is no space where the community can expand to accommodate rising water. The same is the case with example B, where some plants might be able to regenerate if small enclave of suitable substrate are found, or formed. In the case of example A the mangrove community is likely to survive in one form or another. This is dependent on the growth and regeneration rates of mangrove trees, and/or on sustained sedimentation in the area, either from land runoff or tidal import, necessary for the accretion of the mangrove area. On the basis of the expected considerable loss of some habitats mangrove are classified as highly vulnerable to accelerated sea-level rise.

### 6.5.2 Coral Reefs

On the basis of coral reef response, evidenced by growth rates during periods of increasing sea level in the Pleistocene, reefs have been classified into three groups: Keep up, Catch up and Give up. The assumption underlying the IPCC workshop conclusion concerning atoll islands is that the only variable affecting reef growth under global climate change is rising sea level and that upward reef growth will keep pace with the projected rate of change, that is, all present day reefs will *Keep up* (Pernetta and Elder, 1992).

Reef flats are at or near present sea level, and their communities are less diverse and the growth rate is less vigorous than at slightly greater depth. Consequently the response to rising sea level of the reef flat community in terms of upward growth is unlikely to be immediate.

According to Salvat (1992) a sea-level rise of 0.5-1 m will allow corals to colonize the present fringing reefs and reef flats. As a result, corals may gain more shallow surface than they will lose in deeper waters and calcium carbonate deposition may double in the next century.

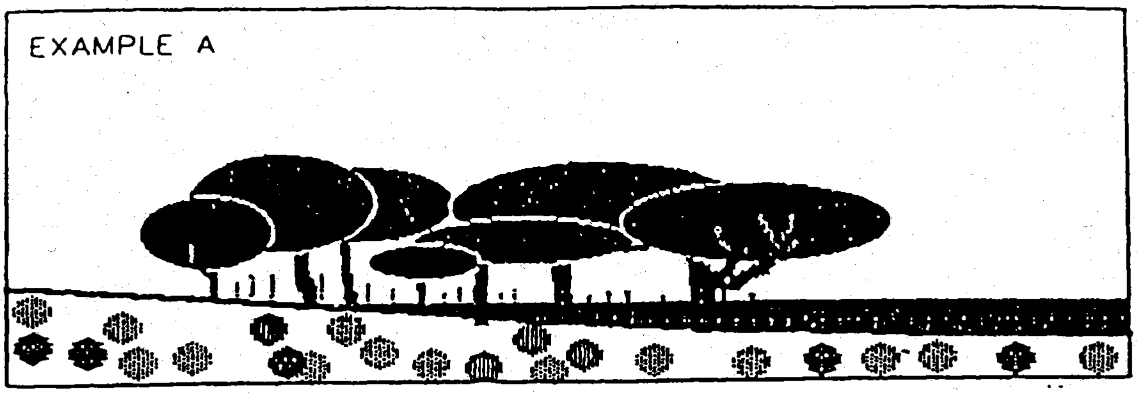
Extension of coral reef surface and increase of calcium carbonate deposition due to sea-level rise is a primary effect of global change that may produce overall benefit for the ecosystem (Salvat, 1992). But secondary and tertiary effects that are open to debate, do not favor coral reefs. An increase of temperature could be catastrophic for coral reefs, as occurred during the bleaching events of the 1980s. Increased water temperature may lead to decrease in growth rate of individuals, increase frequency of coral bleaching and mortality, changes in coral species composition and finally changes in growth rate of algal sand producers (e.g. *Halimeda*). Increased rainfall may lead to heavier sedimentation and consequent destruction of some coral reefs.

Thus because of the complexity of the coral reef system, which is characterised by a large number of coral and associated species, it is very difficult to predict the likely changes induced by sea-level rise. Yet, some preliminary remarks can be made.

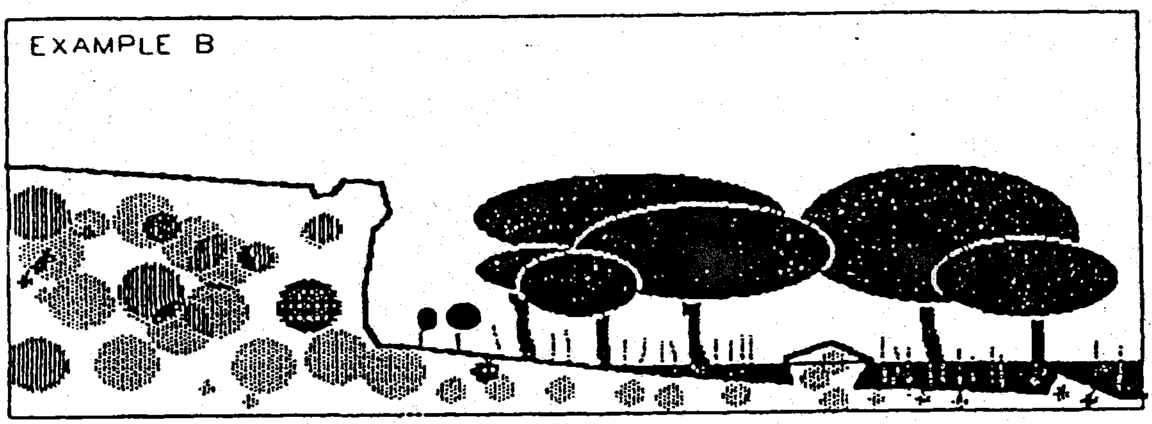
The type of response will differ according to the various zones of the coral reef. The biotic community, its biodiversity and species composition is to a large extent determined by abiotic factors, such as light , water temperature and salinity. These factors will definitely change due to sea-level rise, as the reef will be submerged under a higher water column. However, it should be noted that for instance a one meter sea-level rise does not necessarily imply that the reef will be situated at one meter increased depth, as the reef itself, or at least the living part of it, is able to grow with the rising sea to a certain extent.

If we assume a very limited growth, then the following changes are likely:

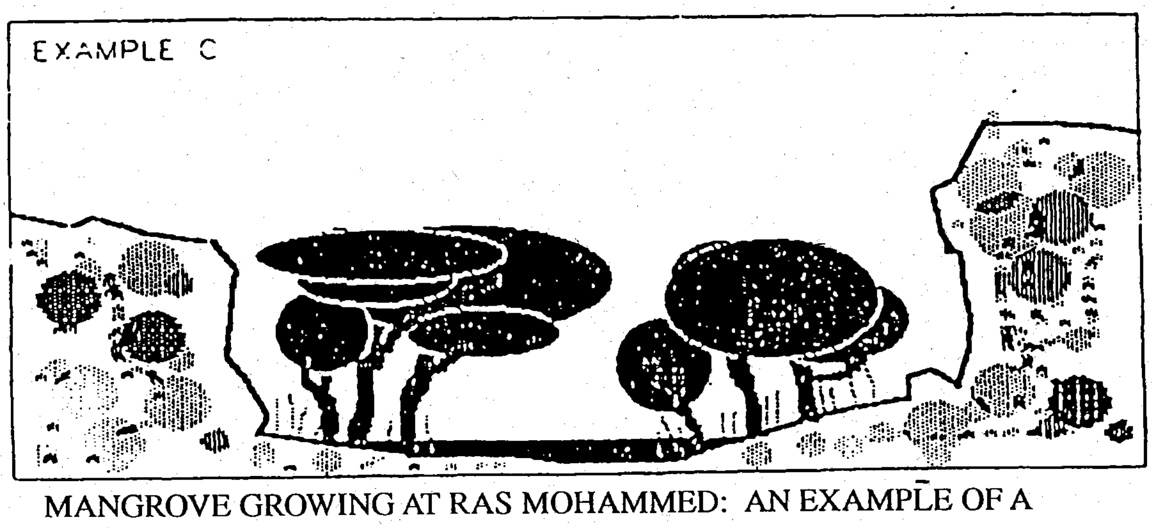
a) In the deepest zones on the reef slope, the reef will start to die off, because of




MANGROVE AT 5km SOUTH OF SHALATINE: AN EXAMPLE OF A COMMUNITY GROWING ON AN EXTENSIVE INTER-TIDAL FLAT




MANGROVE 23km SOUTH OF SAFAGA: AN EXAMPLE OF A COMMUNITY GROWING IN AN ENCLOSED BAY, PROTECTED BY A CORALINE RIDGE




MANGROVE GROWING AT RAS MOHAMMED: AN EXAMPLE OF A COMMUNITY IN A CHANNEL

Figure 29. Examples of mangrove settings. (Source; Delft Hydraulics/Resource Analysis)

increased light attenuation.

b) In the reef flat conditions, coral growth will improve, as temperature and salinity, which pose stress to corals, will decrease somewhat due to greater dilution.

c) The lagoon area between the reef and the shore will increase in depth. No significant changes in biotic communities are likely.

In rapidly calcifying area, for instance with reef accretion rates of above 8 mm/yr, it is obvious that the reefs will not "drown" in the long term.

Coral reefs from the Red Sea and the Gulf of Aqaba, being located along extremely arid lands, suffers only little from runoff and associated sedimentation. Water clarity is high. Unless unstable beach systems adjoin coral reefs which in the event of ASLR release increasing amounts of sediments over the reef, this implies that although minor changes may occur in the species composition of corals, no serious damage of the reef due to ASLR is to be expected. The picture changes, however, in a situation in which reef is already under great stress. Increased pollution, for instance, reduces the viability and the growth rate of the coral. Therefore, reefs which are currently at great pressure of tourism development and oil pollution will face with ASLR an extra stress, and hence may eventually succumb.

### 6.5.3 Seagrass Beds and Algae

Seagrass beds are not likely to be affected by accelerated sea-level rise as both their depth tolerance and growth rate is relatively high. Seagrass beds exhibit vertical accretion in time due to their capability of trapping and accumulating sediments. It is likely, however, that species composition will alter due to the increase in water temperature, with more species colonizing the Gulfs of Aqaba and Suez and possibly Suez Canal.

Macro-algae also attain high growth rates but in time a population of one algal species may be replaced by more shade tolerant species, whilst new submerged areas may turn into algal or seagrass beds (Delft Hydraulics, 1992).

### 6.5.4 Rocky Shores

The intertidal ecosystem, ranging from the splash zone to subtidal rock pavement of rocky shores is capable of shifting upward with predicted sea-level rise and overall is not expected to change.

### 6.5.5 Salt Marshes

In many areas, these marshes border dunes and sandy ridges. It is likely that the salt marsh zones will shift concurrently with an inward migration of the dunes and sandy ridges.

### 6.5.6 Lagoons

Lagoons will become deeper, as sedimentation may not be able to keep pace. Although the productivity of bottom vegetation may be slightly reduced as a result of increased light attenuation, it is not considered a serious loss.

### 6.5.7 Dunes and Beaches

With human encroaching on the inland site and other coastal ecosystems and the sea on the other side, dunes could be threatened. However, the natural response is an inland migration, and provided that this is not hampered by such developments, ASLR does not constitute a threat to either dunes or beaches. These ecosystems can adapt quickly to new situations. As mentioned above, unstable dune and beach systems may well be at risk, because ASLR may result in sand loss and subsequent accelerated degradation of these areas.

### 6.5.8 Low Islands

Low islands will most likely be drowned. The shoreline will retreat owing to erosion processes and this might in its turn accelerate the drowning. As such, the islands are lost as habitats and breeding sites for birds and turtles. Eventually, the island may end up as a sandy intertidal or subtidal area with its associated biota such as corals or seagrass beds.

The above account on susceptibility of different ecological systems to accelerated sea-level rise allows us to classify the different systems according to their respective vulnerability. Three qualitative degrees of vulnerability are distinguished: **High** (mangroves and low islands); **Medium** (coral reefs); **Low** (rocky shores, salt marshes, lagoons, dunes and beaches, seagrass beds and macro-algae).

## 6.6 Impacts on Fisheries

Climate change is one of the important factors affecting fisheries. The level of the impact varies widely and depends on attributes of the species as well as on their regional specificity.

Fish populations are influenced by many elements of their natural environments during all phases of their life cycle. Slight changes in environmental variables such as temperature, salinity, wind speed and direction, ocean currents, strength of upwelling as well as predators can sharply alter their abundance, distribution and availability. Changes in climate will alter the species composition and productivity of marine ecosystems supporting major fisheries.

A rise in sea level, for instance, could inundate and displace wetlands which are regarded as important nutritional basis for fish population and could also erode shoreline. It can be expected that nitrogen and phosphorous concentrations may increase as well as the release into the marine environment of pesticides and toxic substances resident in the ground thereby changing the nutrients and chemical nature of the sea water and hence, affecting the corals and their community which are also regarded as very important ecosystems for fish population.

On the other hand the erosion of shorelines may increase the turbidity resulting from siltation and decreasing the amount of light reaching water bottoms thus interfering with productivity of coral reefs and their normal physiological activities.

However, it could happen that as a result of rapid sea-level rise, production of fisheries could rise as marshes flood, die and decompose thus providing more nutrients. This temporary benefit for fisheries may be balanced by negative impacts on birds and other wildlife as the habitat area is decreased. In the longer term, by 2050 the overall impact on fisheries and wildlife will probably be negative (IPCC, 1990).

An obvious environmental effect of a global warming will be changes in sea surface temperatures which will have an effect in turn on fish populations during all life stages. However, the relationship between climate change and fisheries will not be easy to define and most likely will have to depend, at least for the near future, on generalizations derived from case assessments of past and present experience (Glantz and Feingold, 1990).

What will happen to the productivity and fisheries of Gulf of Suez, the most productive area of the whole Red Sea? If seagrass beds and mangroves will flourish in the Gulf of Suez, certainly fish production will increase because these habitats function as nursery grounds for many commercial fishes. In addition, more fish will invade the Mediterranean Sea through the Suez Canal. Since the opening of Suez Canal in 1869, a total of 51 species of the Red Sea fish have acclimatized in the Mediterranean, some of them (e.g. rabbitfish) are caught in much higher quantities than in the Red Sea itself. In contrast, few Mediterranean fish species migrated in the opposite direction, but are mostly confined to the Gulf of Suez. Shrimps, crabs and even bivalves have migrated from the Red Sea into the Mediterranean through the Suez Canal. Thus any increase in water temperature will have substantial impact on the distribution and biology of fish stocks and other invertebrates.

The impact of UV-B radiation is of concern because fish eggs and larvae that float close to the surface, as well as near surface phytoplankton, zooplankton, corals and wetlands plants, could be exposed to levels which may cause genetic abnormalities or direct mortality (IPCC, 1990).

Mariculture will also be affected by climate change. Species that are cultivated in shallow bays will be affected by turbidity and siltation resulting from sea-level rise. The pearl oyster *Pinctada margaritifera* for instance which is cultivated in Dongonab Bay (Sudan) in shallow waters with an average depth of 3m could be affected by higher seawater temperature which induce algal blooms resulting in mortality (Nasr, 1992).

Many examples were cited in literature on how environmental changes have led to collapse of some fishery industries and how societies have dealt with major changes in fishery resources availability. It is likely that global warming will produce collapses of some fisheries and expansion of others. The likelihood of collapse may be aggravated by inadequate management due to insufficient authority, unwillingness to act or lack of knowledge (IPCC, 1990).

As for mitigation of impact of climate change on fisheries it is necessary to improve the fishery management. There is progress on understanding fish and their environment. If the direction of potential changes in ocean circulation could be known, useful assumptions could be made on the likely changes in fish stock abundance and hence, on fisheries management (Troadec, 1989).

Case studies of societal response provide insight into how people and their governments can better prepare for regional changes in distribution and abundance that might accompany global warming. If, in the face of climate change, it is desired to maintain fisheries at levels matching societies needs, higher levels of international collaboration might be needed, for which there is no global analogy from the past (IPCC, 1990).

## 6.7 Impacts on Socio-Economic Activities

The aim of the modern concept of strategic planning is to face the relatively short and long term consequences of climate change (Noufal, 1992). In dealing with socio-economics, one has to differentiate between two main concepts: the economics facing the risk of climate change and those which will deal with the consequences of climate change.

The first economic concept deals with the direct impacts of socio-economic activities, and is called "*Economics of Environmental Protection*". The main task of this conceptual approach is the minimization of costs of Socio-Economic activities alteration as a result of the environmental changes.

The second economic concept deals with the consequences of climate change. Although it is early at this stage, the features of such economics will be based on new technology dealing with the new setting of the Red Sea and Gulf of Aden environment. They will apply new mathematical models to suit the new environment expected by the end of the next century. This will involve monitoring all economic resources likely to disappear due to climate change and those likely to appear due to the setting of the new ecosystem and its new resources.

According to the Common Methodology (IPCC, 1991), the following major impact categories should be considered:

a. **Values at loss.** These pertain to capital, subsistence, and ecological values in relation to losses of land area. Such land losses may follow from:

- loss of area because of accelerated coastal erosion (shoreline retreat);
- loss of area because of (permanent) flooding of land areas.

b. **Values at risk,** including people, capital and subsistence values. Values at risk may change because of changes of flood risk and/or the extent of the values which are subject to flood risk.

c. **Values at change.** This category includes all other impacts related to changes of the physical environment and the physical, ecological or socio-economic responses which may follow from these changes. A common characteristics of this impact category is the need for an additional specification of responses in order to be able to assess the effects. Relevant values to be considered in this category are:

- coastal ecology, which may be affected by changes in e.g. flooding frequency, exposure to the coastal environment (water levels, waves), sediment flows, and salinity conditions.
- fisheries, which may be sensitive to changes as mentioned above;
- agriculture yield, cost, or water use, due to changes of salinity conditions;
- drainage conditions due to changes in water quantities and levels;
- use potential of man-made facilities directly exposed to the coastal environment (ports,fish farms, and other infrastructure, located at the waterfront);
- fresh groundwater availability due to changes in salinity conditions;
- urban and urbanization activities and related socio-economic effects, due to changes in capacity or attractiveness of recreational sites (beaches, nature areas and coastal habitats).

d. **New values which will result from the new production activities related to the environmental changes on coastal areas.**

**The above impacts all follow from one or more of the physical mechanisms involved, mainly:**

changes in shoreline (shoreline retreat); flooding and flood risk; direct exposure to the coastal environment; salinity intrusion and seepage; and increase of temperature.

Block diagrams as shown in Figure 30 summarize the impacts assessment expected on socio-economic activities, as a result of increasing temperature, and dependently increasing sea water level.

## 7. CONCLUSION

### 7.1 Summary

It is generally agreed that enhanced greenhouse effects and the associated impacts will have severe impacts on climate and the ecosystems. It is however, not definite as to the precise magnitude of the temperature and sea-level changes at the regional level. Models have estimated the average rise in mean global temperature and sea-level to be about 1°C and 20 cm respectively by the year 2030.

The temperature increase in the Red Sea and the Gulf of Aden is expected to be less than the average global temperature increase. On the other hand, the increase in precipitation rate in the Middle East region is expected to be larger than the average increase worldwide. The tropics would become wetter but the subtropics, already dry, could become still drier.

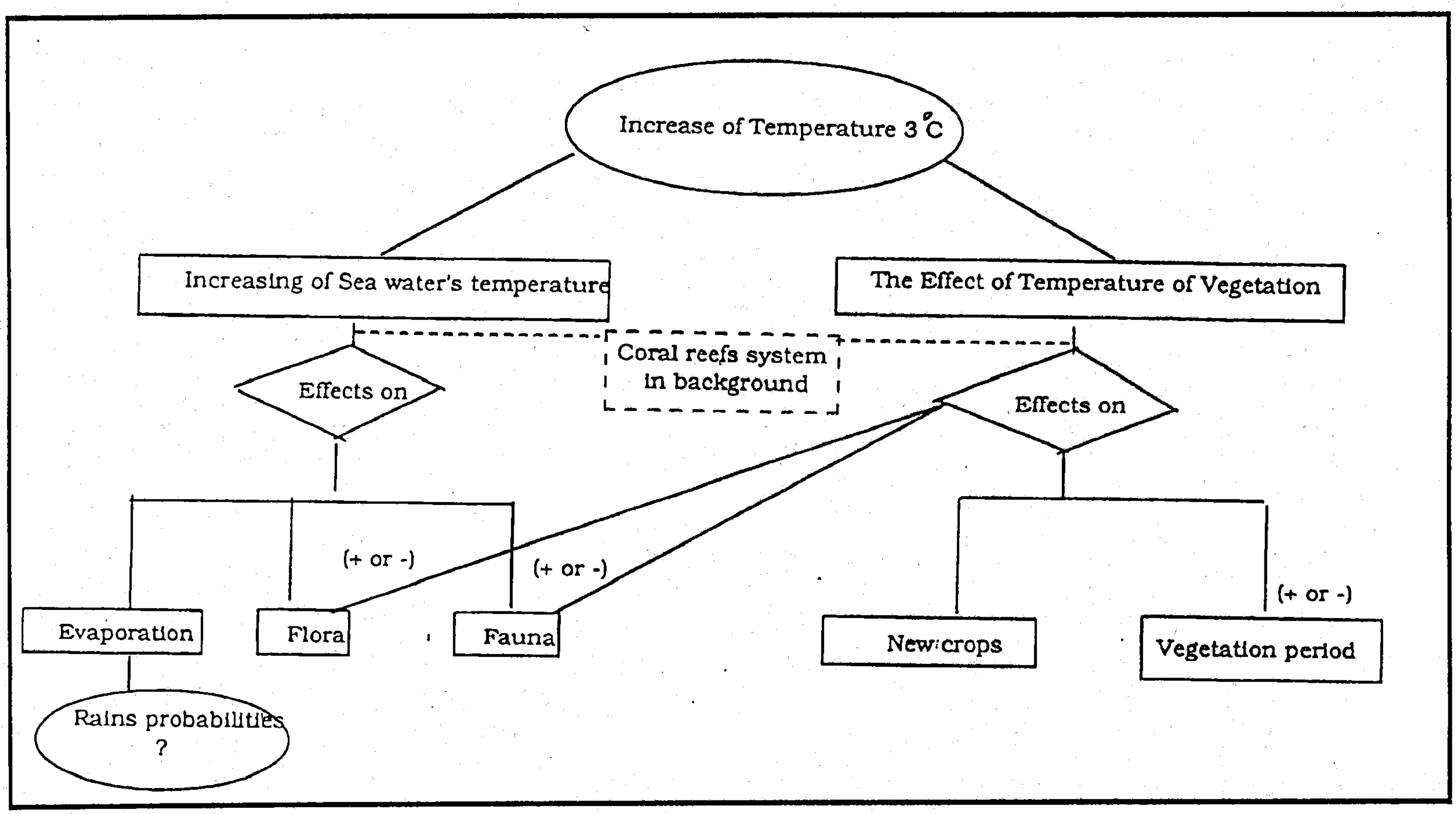



Figure 30: The Main Assumptions of Environmental Changes which Affect the Socio-Economic Activities

With the assumed temperature changes, it is expected that there will be changes in the characteristics of the monsoon winds which could lead to changes in precipitation patterns over the parts of Gulf of Aden and probably southern Red Sea. However, it is expected that many differences in topography and other aspects will lead to extreme variability in the impacts of precipitation. Changes in temperature will further lead to changes in the evapo-transpiration rates, with deleterious effects of increased evapo-transpiration rates on crops in the drier areas, where the water resources are generally limited.

The need for a regional $CO_2$ doubling climate scenario is critical for an accurate forecast of the impact of temperature increase and sea-level rise. Such a scenario would cognizance of the varied topography within the region. Until then, the impacts will remain in the realm of educated guesses based on presumed scenarios which are themselves not adequately well known.

The effect of sea-level rise would appear much easier to forecast but no clear indication of the expected regional sea-level rise scenario has evolved. Assuming a global sea-level rise of 20 cm, the local sea-level rise could be much more than this. The global warming may lead to the melting of the glaciers cover over the high mountains in East Africa. The melted water will drain into the Indian Ocean, thus contributing to the rise of its level which may have an impact on the water exchange between the Red Sea and Gulf of Aden and hence influence the water circulation pattern in the Red Sea. The effects could be more serious if subsidence occurs which would mean high sea-level rise, as evident in the northern part of Suez Canal at Port Said (3 mm/yr).

Climate changes that lead to sea-level rise will affect coastal zones of the region considerably. The direct effect of inundation would produce a large loss of inhabited areas, wetlands and low islands of the Red Sea. Any sea-level rise will allow waves to cover the coral reefs, increasing coastal vulnerability to erosion and storms, at least until reef growth can catch up with the sea-level. The rise in sea level may also lead to destruction (submersion) of some islands in the Red Sea.

In many areas, the shoreline retreat from rising sea level would be greater than from inundation alone, because land well above sea level could also erode. This would eliminate existing recreational beaches at the major resorts of the Red Sea, threaten wildlife (particularly turtles and birds), mineral resource development (including oil pipeline terminals and other oil infrastructure in the Gulf of Suez), human settlement and harbor facilities. Capital values at loss from shoreline retreat and especially from flooding will be of enormous proportion; the proper functioning of infrastructure facilities directly exposed to the sea will be disrupted and a great number of people may have to retreat especially if Suez Canal region is threatened by flooding.

However, the effect of global sea-level rise will depend on the geological situation of each location. Areas that are subsiding will be under greater pressure than those that are stable or uplifting, with contribution of tectonic or isostatic movement to relative sea-level change.

Physico-chemical parameters are the primary determinants of the distribution of marine habitats, communities and ecosystems. A change in these parameters will have broad impacts on basic ecological structures and processes. These changes will in turn cause impacts on marine coastal resources.

The marine coastal habitats of the Red Sea, particularly coral reefs, seagrass beds and mangroves appear to be close to their physiological limit. Temperature rather than salinity seems to be the main limiting factor for the distribution and development of these habitats particularly in the northern part of the Red Sea. Temperature sensitivity in corals, mangroves and seagrass beds seems to be adaptational and the vulnerability in a given locality varies by taxon and is related to the long-term historical record. That may explain why coral bleaching in the Red Sea is not a phenomenon associated with global warming as documented elsewhere including the Arabian Sea. other possible effects associated with sea-level rise may include shifts in distribution, zonation and community structure. The combined effects of both global warming and sea-level rise may lead to extend the geographical distribution of such habitats possibly into the Mediterranean Sea, provided suitable substrate are available. On the other hand, on the basis of the expected loss of some habitats, these tropical communities will be vulnerable to sea-level rise and the degree of vulnerability will be very high for mangroves, medium for coral reefs and low for seagrass beds.

Climate change is one of the important factors affecting fisheries. However, the level of impact varies widely and depends on attributes of the species as well as on their regional specificity. A rise in sea level could inundate and displace wetlands, the nursery grounds for small fishes. On the other hand, production of fish could rise as marshes flood, die and decompose thus providing more nutrients. The relationship between climate change and fisheries can not be easily defined. However, it is likely that the global warming will produce collapses of some fisheries and expansion of others.

Finally, our present knowledge of coastal zone processes is inadequate to enable clear definition of potential impacts likely to result from global change. The inadequacies of current global impact models require improved data collection systems in the coastal zone of the Red Sea and Gulf of Aden region together with the establishment of management structures for rapid exchange of such data and their use in verification of model predictions.

## 7.2 Vulnerable Areas/Systems and Future Strategies

Coastal zone management problems are already critical in many parts of the Red Sea and Gulf of Aden. The potential impacts of predicted global changes will be diverse and important for human population in coastal zones. The major impacts will follow from one or more of the following main physical-mechanisms: shoreline retreat, flooding and flood risk, direct exposure to coastal environment and salinity intrusion and seepage.

It is important that strategies be evolved now to respond to expected climatic changes. To be able to do this, however, it is important that global climate change scenarios be refined and having been refined, they be particularized for the Red Sea and Gulf of Aden Region, through the development of regional models (scenarios)

The Intergovernmental Panel on Climate Change (IPCC) Working Group I is presently evolving climate change scenarios on the basis of which impacts can be assessed, and global response strategies can be evolved. Details of the most recent scientific assessment of the impacts on enhanced greenhouse effects can be obtained from IPCC (1992).

Research will need to be carried out now and in future to attempt to regionalize the climate change scenarios. There are also considerable gaps in the area (particularly in Sudan, Somalia and Yemen) and inventory of such gaps needs to be made in order to quantify impacts and facilitate the formulation of response strategies. The incidence of accelerated sea-level rise should be fully integrated in land use planning in general and coastal development plans in particular. To do this, practical methods should be adopted to integrate the inherent uncertainties within the planning process.

It is strongly recommended that all Red Sea and Gulf of Aden countries embark a coastal zone management planning effort, which will establish the required integration and will combine the required knowledge and capabilities.

Response strategies must be based on climate change scenarios, expected impacts and future plans for the coastal areas of the region. Plans such as land use, human settlement, port development, tourism development (hotels and resort areas), etc., are necessary in this respect.

Sestini, *et al* (1989) speak of two types of response strategies - preventive and reactive. Preventive strategy addresses itself to protecting present investment while reactive strategy seeks to adjust, react and adapt to changes as they arise. The preventive strategy requires a prior knowledge of economic worth of present investment and its relative significance vis-a-vis the cost of erecting preventive structures or creating new ones if damaged. The reactive strategies respond to events as need arises and basically is "adaptive". Resettlement of populations is a reactive strategy and need not be done before the event. However, reactive strategies need to be based on predictable developments so that planning can be made to deal with developments.

To the extent that climate change and sea-level rise scenarios at regional level are unlikely to be available in the next ten to twenty years, reactive strategies might be the most plausible in the Red Sea and Gulf of Aden. This is all the more significant in view of the level of economic in the region which can ill-afford an investment into protective structures that, in time, may prove not to have been necessary.

Notwithstanding the above, cost effective management strategies should be put in place towards the sustainable exploitation of the natural resources. Land use practices should be geared towards sustainable development with climate change impact taken into account. Likewise, settlement of large populations along coastlines and water masses should bear in mind the risks of flooding due to excess rain or sea-level rise.

Research programmes to monitor water resources and natural coastal resources should be carried out in order to evolve adjustment activities to climate change. It is important to mount educational programmes to sensitize the coastal area communities to the risks posed by expected climate change and sea-level rise. This will lead to the development of a state of preparedness in coastal settlement communities for any reactive strategy in the event the expected impacts occur.

Plans to mitigate the effects of droughts and floods should be prepared (in terms of storage of food, and distribution of the same to the needy areas). Water resource projects should bear in mind the expected climate change impacts such as high evaporation rates, low inflows (droughts) and silting (floods).

There is an essential need for in depth research into the likely implications of climate change and especially sea-level rise on the components of the Red Sea and Gulf of Aden States.

Governments should be encouraged to review all proposed major investment decisions, especially on coastlines or on coral islands under their control. Such decisions are to be confirmed only after a review of the sea-level rise impact. Governments should also screen private sector projects along the littoral and on coral island and establish locational and siting criteria that would ensure longevity of structure as well as effluent disposal systems relating thereto.

Finally, it is evident from this review that the coastal areas or systems are more vulnerable to the expected climatic changes. The impacts at the individual coastal locations will however, depend on the height of the location above the sea-level, geology of the area, time-space patterns of the climatic changes, the degree of preparedness of the local ecosystems to the expected climate change and many other related factors. The expected climatic changes include changes in sea-level, sea temperature, wind and rainfall patterns, ocean currents, etc. Regional scenarios for these changes are not well known.

A multi-disciplinary project for the region will therefore not only address itself to the various issues which have been raised in this overview, but will first define more precisely the vulnerability of the coastal areas and systems to the expected regional climate change scenarios.

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