

III Red Sea and Gulf of Aden

III-6 Red Sea LME

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The Red Sea LME is bordered by Djibouti, Egypt, Eritrea, Israel, Jordan, Saudi Arabia, Sudan and Yemen. It has a surface area of 458,620 km², of which 2.33% is protected and includes 3.8% of the world's coral reefs (Sea Around Us 2007). It is characterised by dense, salty water formed by net evaporation with rates up to 1.4 - 2.0 m yr⁻¹ (Hastenrath & Lamb 1979) and deep convection in the northern sector resulting in the formation of a deep water mass flowing out into the Gulf of Aden underneath a layer of less saline inflowing water (Morcos 1970). A dominant phenomenon affecting the oceanography and meteorology of the region is the Arabian monsoon. In winter, northeast monsoon winds extend well into the Gulf of Aden and the southern Red Sea, causing a seasonal reversal in the winds over this entire region (Patzert 1974). The seasonal monsoon reversal and the local coastal configuration combine in summer to force a radically different circulation pattern composed of a thin surface outflow, an intermediate inflowing layer of Gulf of Aden thermocline water and a vastly reduced (often extinguished) outflowing deep layer (Patzert 1974). Within the basin itself, the general surface circulation is cyclonic (Longhurst 1998).

High evaporation and low precipitation maintain the Red Sea LME as one of the most saline water masses of the world oceans, with a mean surface salinity of 42.5 ppt and a mean temperature of 30° C during the summer (Sofianos *et al.* 2002). Three depressions greater than 2,000 m in depth occur in the axial trough of the LME. Here the water is heated by mineral-rich thermal vents (hot brine regions), reaching up to 62 °C (Scholten *et al.* 1998) and being enriched with various heavy metals such as manganese, iron, zinc, cadmium and copper. Book chapters and reports pertaining to the LME are by Baars *et al.* (1998), Getahun (1998) and UNEP (2005).

I. Productivity

The Red Sea LME, at >300 gCm⁻²year⁻¹, can be considered a Class I, highly productive ecosystem. Baars *et al.* (1998) described the seasonal fluctuations in plankton biomass and productivity in the southern Red Sea, based on research cruise data. During spring and summer, the LME is oligotrophic, while in winter (northeast monsoon) productivity is higher in the upper layers of the southern Red Sea. During this monsoon period, diatom blooms occur and mesozooplankton biomass increases, attributed to the entrainment of nutrients from below the thermocline due to wind-induced mixing and winter cooling. The phytoplankton community is dominated by the dinoflagellate *Pyrocystis pseudonociluca*, *Ceratium carriense*, *C. trichocerus* and *C. massiliense* (Getahun 1998). Prominent blooms of *Oscillatoria erythraeum* are frequent in the open parts of the Red Sea LME (Longhurst 1998). The Red Sea is a net importer of zooplankton from the Indian Ocean, though many species do not survive the extreme conditions of this LME.

The phytoplankton, zooplankton and fish fauna bear more similarity to the Indian Ocean biota than to the Mediterranean Sea. Its complex reefs, together with extensive mangroves, seagrass and macro-algal beds form highly productive habitats for unique species assemblages. Endemism is very high, especially among reef fishes and invertebrates, the latter including a number of dinoflagellates and euphausiids (Roberts *et al.* 1992, Getahun 1998). Several species of marine mammals, as well as turtles and seabirds also occur in the LME.

Oceanic fronts (after Belkin *et al.* 2008): The Red Sea LME has the highest temperatures and salinities observed in the World Ocean. The extremely high

evaporation rate leads to formation of salinity fronts, on which temperature fronts tend to develop. Despite the relative uniformity of meteorological conditions over the Red Sea, fronts emerge owing to wind-induced upwelling, whose effect is accentuated by steep bathymetry and local orographic features. Three groups of fronts are distinguished north to south: (1) Egypt-Saudi Arabia Front (ESSF); (2) Sudan-Saudi Arabia fronts (SSAF); and (3) Eritrea-Yemen fronts (EYF) (Figure III-6.1). Although these fronts are poorly studied *in situ*, satellite observations hold promise given the largely cloud-free conditions over the Red Sea.

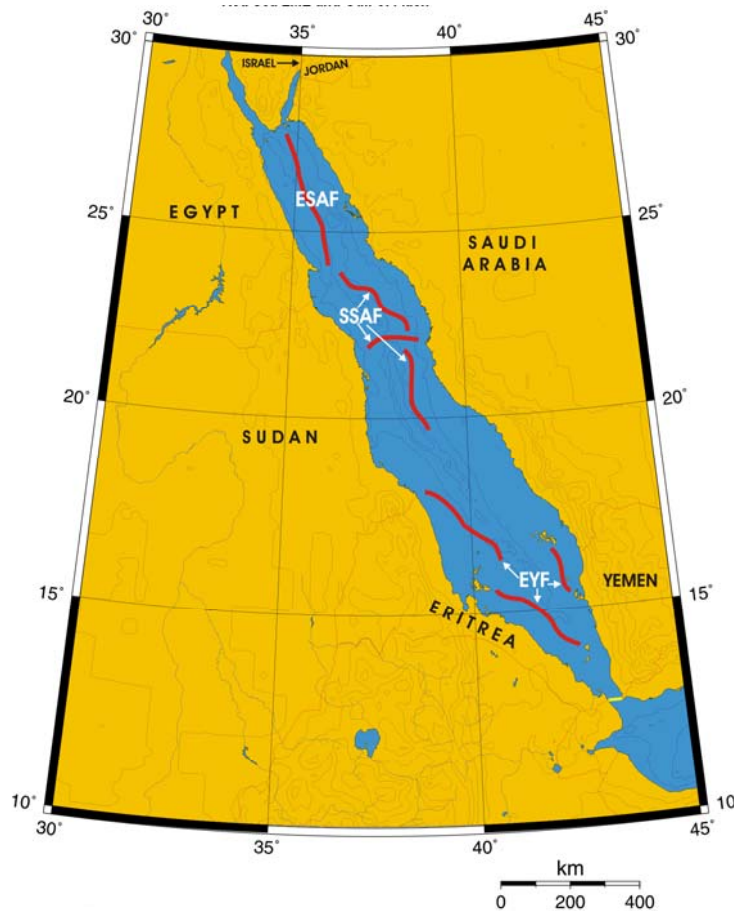


Figure III-6.1. Fronts of the Red Sea LME. ESSF, Egypt-Saudi Arabia Front; EYF, Eritrea-Yemen fronts; SSAF, Sudan-Saudi Arabia fronts. Yellow line, LME boundary.

Red Sea LME SST (after Belkin et al. 2008).

Linear SST trend since 1957: 0.29°C .

Linear SST trend since 1982: 0.74°C .

The long-term warming of the Red Sea is modulated by moderate-to-strong decadal variability while interannual variability is relatively small (Figure III-6.2). Since the Red Sea is almost completely land-locked, any correlations with other LMEs must have been caused by large-scale factors and teleconnections. The most pronounced warming event peaked in 1969 at $>28.5^{\circ}\text{C}$. This mark has not been surpassed since, even in 1998-1999, during and after the strongest El-Niño of the last 50 years, when SST reached 28.5°C in 1999. The coolest event bottomed out in 1975 at $<27.5^{\circ}\text{C}$, after which SST rose by $0.7\text{-}0.8^{\circ}\text{C}$ in 31 years, a relatively fast rate. Even though SST slightly decreased after the peak of 1999, the present period can be considered as a warm one.

The Red Sea circulation features a series of eddies or sub-gyres that vary spatially and temporally depending mostly on wind forcing (Sofianos and Johns, 2007). The Red Sea response to wind forcing strongly depends on wind direction: Along-axis winds do not interact with the surrounding topography, whereas cross-axis winds interact with high, steep mountains surrounding the Red Sea, resulting in a highly structured wind field conducive to oceanic eddy formation (Clifford et al., 1997). Since oceanic eddies modulate SST, long-term variability of the Indian monsoon could strongly affect SST field in the Red Sea.

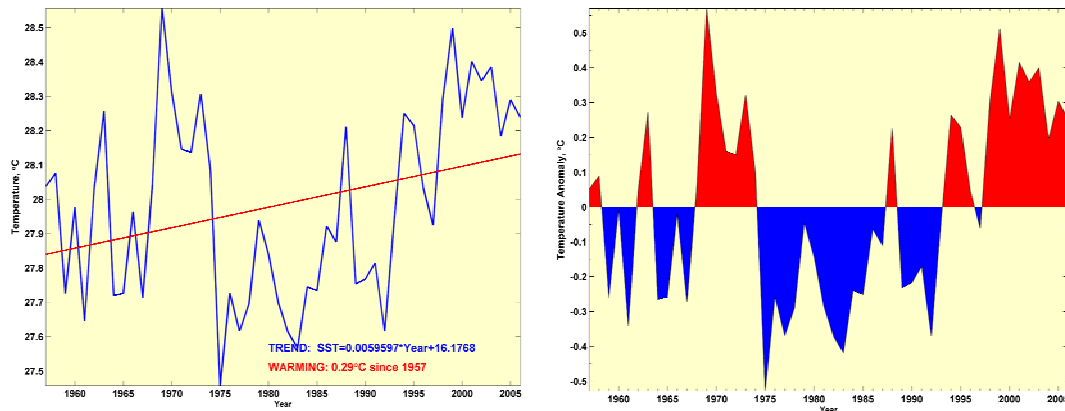


Figure III-6.2. Red Sea LME annual mean SST (left) and SST anomalies (right), 1957-2006, based on Hadley climatology (after Belkin, 2008).

Red Sea LME Trends Chlorophyll and Primary Productivity: The Red Sea LME, at $>300 \text{ gCm}^{-2}\text{year}^{-1}$, can be considered a Class I, highly productive ecosystem.

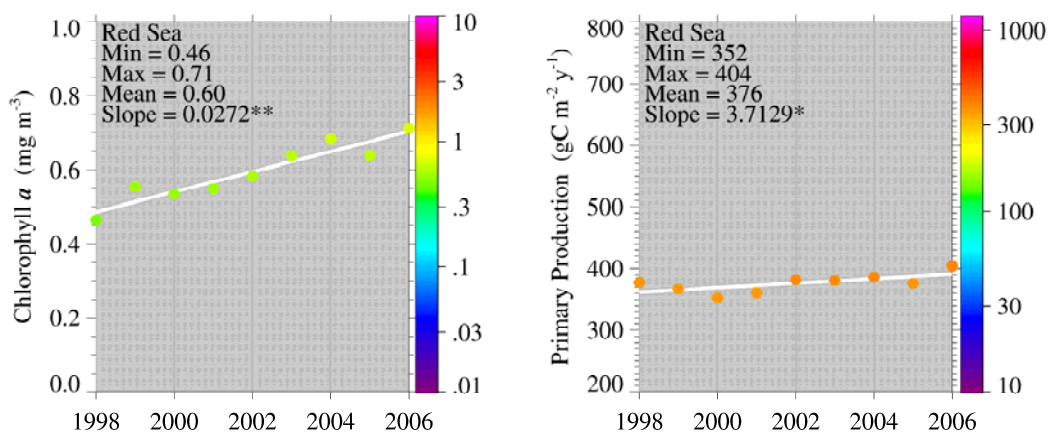


Figure III-6.3. Red Sea LME Trends in chlorophyll *a* (left) and primary productivity (right), 1998-2006. Values are colour coded to the right hand ordinate. Figure courtesy of J. O'Reilly and K. Hyde. Sources discussed p. 15 this volume.

II. Fish and Fisheries

About 1,200 species of fish are known to occur in the Red Sea LME (Ormond & Edwards 1987). Marked differences occur in fish species richness, assemblage compositions and species abundance in different parts of the Red Sea, reflecting the heterogeneous nature of its environment (Sheppard *et al.* 1992). Fishing occurs mainly at the subsistence or

artisanal levels, although commercial trawling and purse seining are also carried out in Egypt, Saudi Arabia and Yemen (FAO 2005).

Total reported landings from this LME have increased steadily, recording over 130,000 tonnes in 2004, most of it in the 'mixed group' (Figure III-6.4). The value of the reported landings has also increased to about US\$130 million in 2004 (in 2000 US dollars; Figure III-6.5).

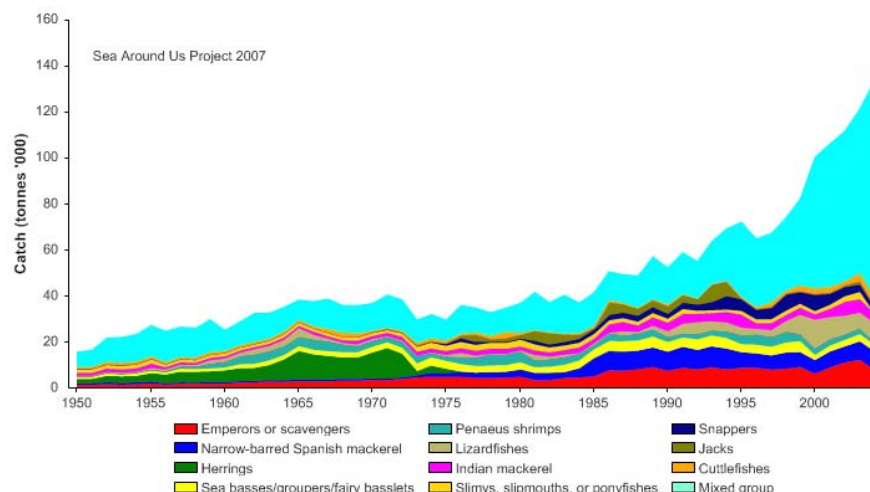


Figure III-6.4. Total reported landings in the Red Sea LME by species (Sea Around Us 2007).

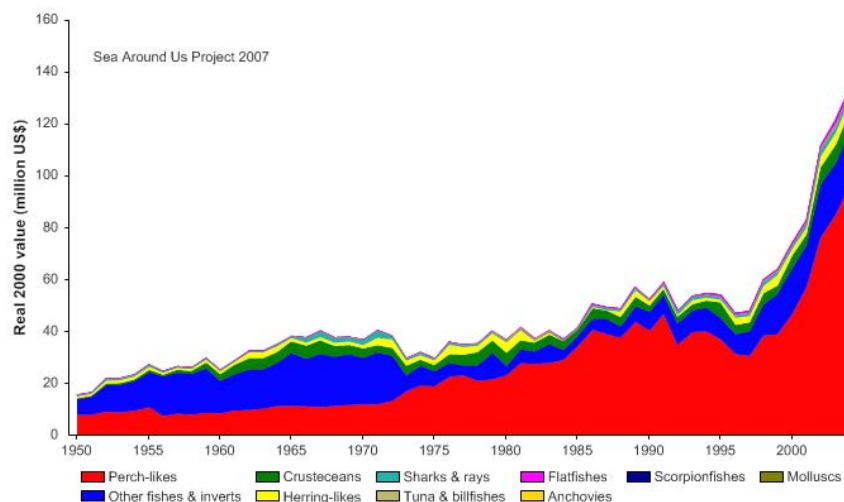


Figure III-6.5. Value of reported landings in the Red Sea LME by commercial groups (Sea Around Us 2007).

The primary production required (PPR; Pauly & Christensen 1995) to sustain the reported landing in this LME is increasing in recent years, but has yet to reach 10% of the observed primary production (Figure III-6-6). A large share of the ecological footprint in the region is accounted for by the countries bordering the LME, namely Yemen, Egypt and Saudi Arabia. The fisheries of the Red Sea LME are still expanding, and therefore,

they show high and stable mean trophic levels (i.e., the MTI; Pauly & Watson 2005; Figure III-6.7 top), with a increase in the FiB index (Figure III-6.7 bottom).

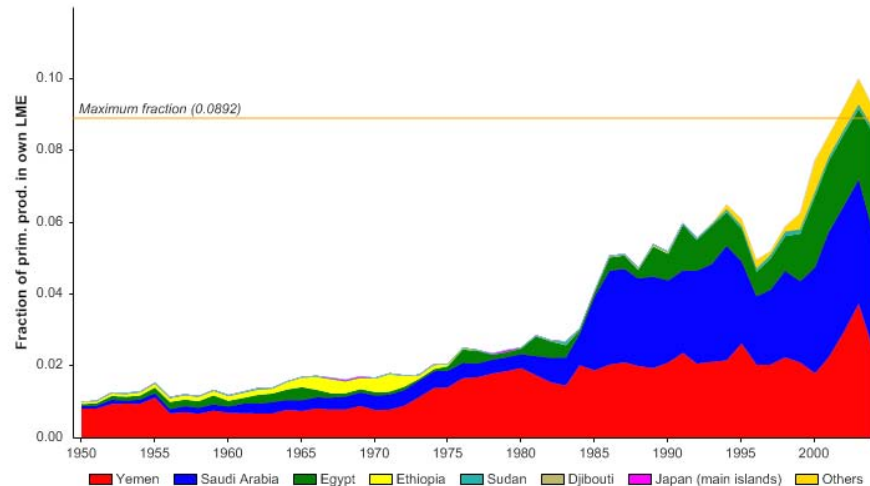


Figure III-6.6. Primary production required to support reported landings (i.e., ecological footprint) as fraction of the observed primary production in the Red Sea LME (Sea Around Us 2007). The 'Maximum fraction' denotes the mean of the 5 highest values.

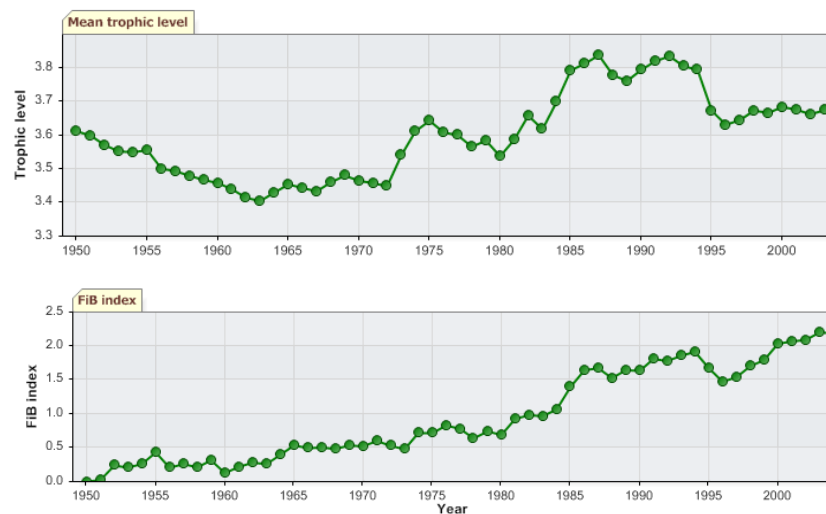


Figure III-6.7. Mean trophic level (i.e., Marine Trophic Index) (top) and Fishing-in-Balance Index (bottom) in the Red Sea LME (Sea Around Us 2007).

The Stock-Catch Status Plots indicate that although a few stocks have recently collapsed (Figure III-6.8, top), about 90% of the catch still originates from fully exploited stocks (Figure III-6.8, bottom).

Overexploitation, destruction of spawning, nursery and feeding grounds, and inadequate resource management and regulations, in conjunction with a lack of enforcement, are main barriers to the sustainable development of the LME's fisheries resources (PERSGA 1998). The absence of effective control and surveillance has also resulted in widespread illegal fishing and habitat destruction by both national and foreign vessels (PERSGA

2000). Ultimately, these factors may pose a serious threat to the LME's biological diversity and productivity.

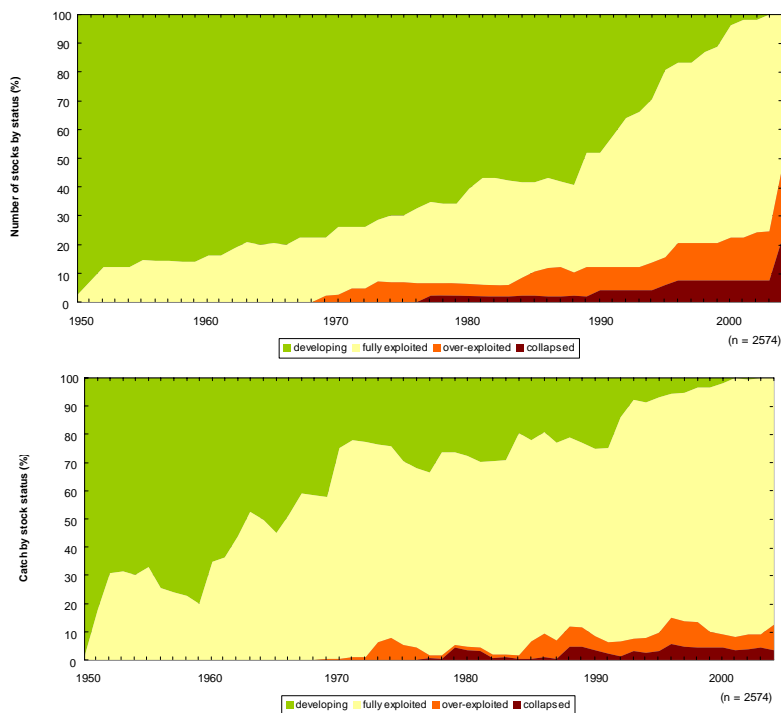


Figure III-6.8. Stock-Catch Status Plots for the Red Sea LME, showing the proportion of developing (green), fully exploited (yellow), overexploited (orange) and collapsed (purple) fisheries by number of stocks (top) and by catch biomass (bottom) from 1950 to 2004. Note that (n), the number of 'stocks', i.e., individual landings time series, only include taxonomic entities at species, genus or family level, i.e., higher and pooled groups have been excluded (see Pauly *et al*, this vol. for definitions).

The lack of stock assessments and incomplete fisheries statistics (see for example Tesfamichael & Pitcher 2007) causes major uncertainties in the status of the LME's fish stocks (PERSGA 1998). Reported declines in catches and in the average size of fish landed are indicators of overfishing (PERSGA 1998, 2000) and may illustrate the incomplete nature of the official reported landings data. With the exception of some small pelagic resources, most fish stocks are assumed to be fully exploited while others are overexploited (FAO 1997, PERSGA 1998). These include finfish and shark at the ecosystem scale and mollusc (*Strombus*), lobster and shrimp in the southern areas. Overexploitation of shark species is severe, especially in Sudan, Djibouti and Yemen as a result of a large-scale illegal fishery for the East Asian shark fin market (PERSGA 1998, 2000).

Overall, prevalence of bycatch and discards and destructive fishing practices is considered to be limited (UNEP 2005). Where such fishing practices do occur, they involve the use of small meshed nets and dynamite fishing. These practices remove many reef herbivores, resulting in increased algal growth with reduced grazing pressure on algae (Pilcher & Abdi 2000). Trawl fisheries using very small meshes take a wide variety of small perciform fishes. Bycatch from net fishing also includes turtles, dugong and dolphins, which almost invariably, are discarded dead (PERSGA 1998). The fisheries resources of the Red Sea LME are also stressed by the destruction of coastal

habitats resulting from uncontrolled land-filling and land-based pollution (see Pollution and Ecosystem Health).

III. Pollution and Ecosystem Health

Pollution: The slow water turnover times of six years for the surface layer and 200 years for the whole water body (Maillard & Soliman 1986, Sheppard *et al.* 1992), combined with its small size makes the Red Sea LME particularly vulnerable to pollution build-up, requiring careful consideration of any development activities in the coastal zone (Gerges 2002). The major sources of pollution in the LME are related to land-based activities as well as oil production and transportation. Pollution is severe in localised areas, including the Gulf of Aqaba (UNEP 2005).

Although its effects are usually limited to a small area around urban areas and large tourist developments (PERSGA 1998), sewage is a major source of coastal contamination throughout the LME (UNEP/PERSGA 1997). Because of rapid population growth and inadequate treatment and disposal facilities, poorly treated or untreated sewage is dumped in coastal areas. Sewage from ships also contributes to this problem at the regional scale (PERSGA 1998). The input of nutrient-rich sewage water also results in eutrophication of the coastal waters around some population centres, major ports and tourist facilities (Gerges 2002). Pollution from solid waste is a major problem in, although it is limited to small areas around urban centres, coastal villages, large tourist developments and major shipping lanes (PERSGA 1998, Gladstone *et al.* 1999).

Chemical pollution is limited to the vicinity of industrial zones and facilities (PERSGA 1998), which usually discharge their effluents directly into the sea. These industries include phosphate mines, desalination plants, chemical industrial installations and oil production and transportation facilities. Povelsen *et al.* (2003) identified a number of hotspots where the sediments were polluted by heavy metals (copper, mercury, lead, zinc) and hazardous organic pollutants such as polycyclic aromatic hydrocarbons ((PAH), aliphatic hydrocarbons, DDT, aldrin and dieldrin. The major sources of PAH and aliphatic hydrocarbons are oil production and transportation activities in the region.

Routine operational leaks and spills from oil and gas exploration and production in the Gulf of Suez and the northern and southern Red Sea LME have resulted in contamination of beaches and water by tar balls and oil slicks in localised areas throughout the LME (PERSGA 1998). Chronic oil pollution has already been observed in the immediate vicinity of some major Red Sea ports as a result of operations at oil terminals or discharges from power plants (Gerges 2002). Petroleum hydrocarbon levels are relatively high in the Gulf of Suez, with substantial oil and tar on the shores (Sheppard 2000). The risks of oil well blowouts, spills and other production accidents associated with the offshore oil industry in the northern Red Sea constitute another significant potential environmental threat to this LME (PERSGA 1998).

A major transboundary concern in the Red Sea LME is maritime pollution caused by international shipping. The Red Sea-Suez Canal is one of the world's busiest industrial shipping routes. About 25,000-30,000 ship transits occur annually in the Red Sea, mostly involving the transport of petrochemical products (Gladstone *et al.* 1999), including more than 100 million tonnes of oil (UNEP 2002a). As a consequence of the high volume of shipping traffic combined with insufficient tanker safety specifications and poor navigation aids, the potential for large oil spills and disasters at sea is high (PERSGA 1998). The discharge of ballast and bilge water and bunker oil spills are also a significant source of pollution, as a result of the lack of reception facilities at the region's ports.

Habitat and community modification: The Red Sea LME is globally renowned for its unique and attractive marine and coastal habitats with high species diversity. For example, the coral community of the Red Sea/Gulf of Aden is composed of more than 250 species of stony corals. This is the highest diversity in any part of the Indian Ocean (Pilcher & Alsuhaibany 2000). Of these, 6% are believed to be endemic (Sheppard & Sheppard 1991). These habitats are under variable anthropogenic pressures, especially adjacent to urban and industrial areas, port facilities, major shipping lanes and in the vicinity of coastal tourist developments (PERSGA 1998). The widespread destruction of coastal and marine habitats is a major transboundary concern in the region, with habitat and community modification considered severe in the Red Sea LME (PERSGA 1998).

Mangrove degradation is severe and widespread throughout the LME (PERSGA 1998). Urban and tourist development in coastal areas and extensive land filling have contributed to the decline of the region's mangroves (UNEP/PERSGA 1997). The combined effects of grazing by domesticated animals and cutting of mangroves for firewood, charcoal production and construction material have accelerated the degradation of mangroves near major human settlements (PERSGA/GEF 2004). This has been exacerbated by droughts that have forced nomads into the coastal areas, especially in Sudan (Gladstone *et al.* 1999). Mass mortality of mangrove trees appears to be a serious problem along the southern coasts of Yemen and Sudan, attributed to construction activities involving dredging and sediment dumping on the shore, diversion of tidal water and excessive sedimentation through the remobilisation of sand dunes. The recently emerging and growing shrimp farming industry also poses a serious threat to the region's mangroves (PERSGA/GEF 2004). Mangroves already exist near their upper limits of temperature and salinity tolerance in the Red Sea LME, which makes them very sensitive to disturbance (PERSGA 1998).

The status of Red Sea coral reefs is of concern. Recent declines have been reported in various locations (Pilcher & Alsuhaibany 2000, Hassan *et al.* 2002, PERSGA/GEF 2003). Major threats to the region's coral reefs include land filling and dredging for urban and tourism developments, sedimentation, destructive fishing methods, discharge of sewage and other pollutants and direct damage by tourists and boats in high-use areas (PERSGA 1998, PERSGA/GEF 2003). Anchor damage to corals and re-suspension of sediments and subsequent siltation caused by passing ships has also been implicated in the degradation of coral reefs in this LME.

Added to direct human impacts is coral bleaching, which caused extensive coral mortality, including near total mortality on several reefs in 1998 (Pilcher & Alsuhaibany 2000, Spalding *et al.* 2001). Several outbreaks of the crown-of-thorns starfish (COTS) (*Acanthaster planci*) and an increase in bio-eroding organisms such as the urchin *Diadema setosum* and the coral-eating gastropods *Drupella* and *Coralliophila* have also damaged coral reefs in some localised areas, for example, in Yemen and Djibouti (Hassan *et al.* 2002). A decline of 20-30% in coral cover, corresponding with COTS outbreaks, has been recorded at most sites surveyed in the Egyptian sector of the LME (Wilkinson 2000). Damage to seagrass beds and loss of associated species are moderate to severe in areas adjacent to urban and industrial developments (PERSGA 1998). This has been attributed to the release of untreated waste water from municipalities and aquaculture farms, coastal dredging and filling, as well as trawling, including illegal trawling by foreign vessels. Trawling impacts are particularly severe in the Gulf of Suez and the southern Red Sea LME.

Growing human populations, coastal urbanisation and tourist development as well as increasing oil and gas exploitation and transport in the region are expected to place increasing pressures on the health of the Red Sea LME (PERSGA 1998, Gladstone *et al.* 1999). Most of the environmental threats and impacts can be prevented by proper

environmental planning and management, use of environmental assessments and through the enforcement of appropriate regulations, most of which are already in place (PERSGA 1998).

IV. Socioeconomic Conditions

The Red Sea LME is of major socioeconomic importance to the bordering countries. Much of the urban and industrial expansion, as well as the development of tourism has occurred in the coastal zone. The population along the shores of the LME and the Gulf of Aden has been estimated at five million (Hinrichsen 1990). Coastal urbanisation has been driven mainly by oil discoveries and industrialisation in or near the coastal zone and the associated new economic opportunities (UNEP 2002b). Accompanying the rapid expansion of urban centres has been the extensive desalination of seawater to meet the demands of the population and industry in some of the countries such as Saudi Arabia (UNEP/PERSGA 1997).

Oil production is by far the most important industry in several of the bordering countries. For example, Saudi Arabia has the largest reserves of petroleum in the world (26% of proven reserves), and ranks as the largest exporter of petroleum. In this country, the petroleum sector accounts for roughly 75% of budget revenues, 45% of GDP and 90% of export earnings. In the Red Sea LME as well as the Gulf of Aden, exploration, production, processing and transportation of more than half the world's proven oil reserves take place (PERSGA 1998). Most of the oil produced from both inland and offshore wells is exported, transforming the Red Sea LME into an oil tanker highway.

The value of the LME's biological resources to the prosperity of the region, particularly among the coastal populations, has long been recognised. The contribution of fisheries to GDP is relatively small (less than 1%), except in Yemen, where this sector accounts for 15% of GDP (FAO 2005). Nevertheless, fisheries, particularly artisanal fisheries, provide food and employment for thousands of the region's inhabitants. For example, in Yemen, more than 220,000 people depend on fishing as their principal source of income (FAO 2005). The fish resources of the Red Sea LME are regarded as an important source of domestic protein for coastal communities. Marine fisheries have potential for further development, for example, in Djibouti, where the potential contribution to GDP could rise substantially from 0.1% to around 5% (FAO 2005). However, realisation of that potential will depend on the continued upgrading of infrastructure and development of export markets.

Pollution and habitat degradation have negative impacts on the fisheries and tourism industries (UNEP 2005). Sewer outflows and runoff from farms and urban areas are also endangering human health. The high concentration of carcinogenic chrysene in fishes in Yemen is of concern. Based on the country's fish consumption, the daily intake of total carcinogens was calculated at $0.15 \mu\text{g person}^{-1}\text{day}^{-1}$ (DouAbul *et al.* 1997).

V. Governance

In their determination to strengthen participation in regional and international agreements, the nations bordering the Red Sea LME have signed or ratified a number of international conventions and adopted various other legal instruments. While they have approved many new environmental laws and standards in the last decade, implementation and enforcement remain generally poor (Pilcher & Alsuhaybany 2000).

The Regional Convention for the Conservation of the Environment of the Red Sea and Gulf of Aden (the Jeddah Convention) provides the legal framework for cooperation in marine environmental issues. This convention, which was adopted by the Regional

Conference of Plenipotentiaries, held in Jeddah, Saudi Arabia, in 1982, is supported by UNEP under its Regional Seas Programme. Also arising from the conference was the Action Plan for the Conservation of the Environment of the Red Sea and Gulf of Aden, as well as the Protocol Concerning Regional Cooperation in Combating Pollution by Oil and other Harmful Substances in Cases of Emergency. In addition, the Jeddah Conference adopted a Programme for the Environment of the Red Sea and Gulf of Aden (PERSGA), an official regional organisation responsible for the development and implementation of regional programmes for the protection and conservation of the marine environment of the Red Sea and Gulf of Aden. PERSGA was formally established in September 1996, with the signing of the Cairo Declaration by all cooperating parties to the Jeddah Convention. Major functions of PERSGA include the implementation of the Jeddah Convention, the Action Plan and the Protocol (PERSGA 2005).

PERSGA has prepared a Regional Action Plan for the Conservation of Coral Reefs in the Red Sea and Gulf of Aden, which was formulated from the Regional Action Plan for the Conservation of Coral Reefs in the Arabian Seas Region. The former provides a set of priority actions for the conservation and sustainable development of coral reefs in the Red Sea and Gulf of Aden. The Red Sea LME contains a number of MPAs (UNEP-WCMC 2005), and the formation of a regional network of MPAs has been proposed (PERSGA 2001). Annex 1 of the International Convention for the Prevention of Pollution from Ships (MARPOL) identifies the Red Sea as a special area in terms of the prevention of oil pollution from ships. GEF has supported the preparation of a SAP for the Red Sea and Gulf of Aden, which was led by PERSGA. The SAP identifies actions needed to protect the LME's unique and fragile coral reefs, seagrass beds and mangroves. Implementation of the SAP is being supported by GEF through the project 'Implementation of the Strategic Action Programme for the Red Sea and Gulf of Aden'. The long term objective of the project is to safeguard the coastal and marine environments of the Red Sea and Gulf of Aden and ensure sustainable use of its resources.

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