VI-9 Arabian Sea: LME #32

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The Arabian Sea LME lies in the northwestern Indian Ocean between the Arabian Peninsula and India, and is bordered by Bahrain, India, Iran, Iraq, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia, Somalia, United Arab Emirates and Yemen. It covers an area of about 3.9 million km^2, of which 0.21% is protected, and contains 1.84% and 0.62% of the world's coral reefs and sea mounts, respectively (Sea Around Us 2007). Three sub-systems, each with distinct physical, physio-chemical and biological characteristics can be identified within the LME: the Western Arabian Sea along the African coast; the Central Arabian Sea bordering Iran; and the Eastern Arabian Sea bordering the coasts of Sri Lanka, India and Pakistan (Dwivedi & Choubey 1998). An extensive interchange of surface waters occurs between this LME and the Somali Coastal Current and Bay of Bengal LMEs. Freshwater run-off from the Indus River, the Arvand (Shattolarab) [Euphrates, Dejla and Karoon] and Tigris Rivers also influences this LME. Book chapters and reports pertaining to this LME are by Baars *et al*. (1998), Bakun *et al*. (1998), Desai & Bhargava (1998), Dwivedi & Choubey (1998) and UNEP (2006).

I. Productivity

The Arabian Sea LME is considered a Class I, highly productive ecosystem (>300$gCm^{-2}year^{-1}$). The LME is strongly influenced by a monsoon regime, which causes significant seasonal variations in marine productivity (Baars *et al*. 1998, Desai & Bhargava 1998). During the southwest monsoon (June-September), strong southwesterly winds blow across the Arabian Sea, producing intense upwelling along the Oman and Somalia coasts. This is the most intense large-scale seasonal coastal upwelling system in the world (Bakun *et al*. 1998), making the Arabian Sea one of the most productive regions of the world's ocean (Codispoti 1991). Desai & Bhargava (1998) estimated the rates of primary, secondary and tertiary production, as well as fishery potential of the Indian EEZ.

Despite its high primary productivity, the abundance of coastal pelagic fish is anomalously low and catch of this group is not consistent with other similar world regions (Bakun *et al*. 1998). In fact, their production is similar to that of large oceanic pelagic fish such as tunas. An explanation for these anomalies is sought in the extremely dissipative feature of the region's physical systems. A combination of trophic enrichment, as well as concentration and retention processes provides a favourable reproductive regime for coastal pelagic fishes. Surface mixing due to the intense monsoon winds and strong current flows as well as wind-driven surface transport in the western and northern part of this LME disrupt these processes, periodically resulting in unfavourable feeding conditions for coastal fish larvae. On the other hand, the offshore transport of coastal production coupled with the strong monsoonal wind circulation and prevalence of strong current jets may favour the highly-evolved life-cycle strategies of oceanic tunas.

More than 330 species of corals, 500 species of molluscs, 200 species of crabs, 20 species of marine mammals and more than 1,200 species of fish are found in the LME (Fouda *et al*. 1998).

Oceanic fronts (Belkin et al. (2009). The Arabian Sea features several fronts, whose development is governed by the seasonal monsoon winds and their reversals (Figure VI-9.1). The most stable, seasonally persistent front develops in the Gulf of Aden. This front cuts across the Persian Gulf, from the Arabian Peninsula to the Somali coast, with the cross-frontal temperature range up to 5°C. Upwelling fronts are ubiquitous off the Pakistan coast and, to a lesser extent, off the western coast of India; these fronts are also seasonal and their development is similar to the seasonal evolution of major upwelling frontal zones off Northwest Africa and off the U.S. West Coast, in the California Current System. A meso-scale front is observed near the entrance to the Persian Gulf (Belkin *et al*. 2009).

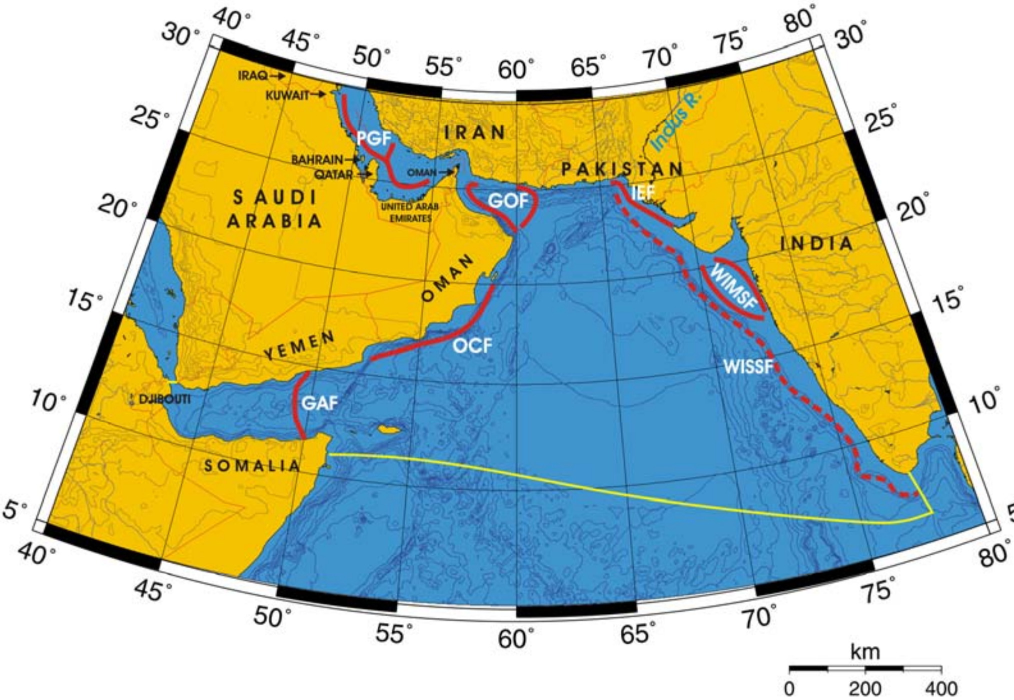


Figure VI-9.1. Fronts of the Arabian Sea LME. GAF, Gulf of Aden Front; GOF, Gulf of Oman Front; IEF, Indus Estuarine Front; OCF, Oman Coastal Front; PGF, Persian Gulf Front; WIMSF, West Indian Mid-Shelf fronts; WISSF, West Indian Shelf-Slope Front (most probable location). Yellow line, LME boundary. After Belkin et al. (2009).

Arabian Sea SST (after Belkin 2009)
Linear SST trend since 1957: 0.42°C.
Linear SST trend since 1982: 0.26°C.

Like all Indian Ocean LMEs, the Arabian Sea warmed slowly and steadily. Its interannual variability has an average magnitude of approximately 0.5°C. The most pronounced event, the all-time minimum of 1975, was likely caused by large-scale forcing since it occurred simultaneously across the entire northern Indian Ocean, including the Red Sea LME and the Bay of Bengal LME. The all-time maximum of 1998 occurred simultaneously with most Indian Ocean LMEs and only one year before a near-all-time maximum of 1999 in the Red Sea.

The rapid warming between 1985 and 1987 ushered in the modern warm epoch in the Arabian Sea. This warming occurred nearly synchronously with a similar warming in the

Somali Current LME. It is likely that the Somali Current transported the warm signal to the Arabian Sea. Alternatively, both events may have been caused by a large-scale atmospheric forcing that spanned the entire northwest Indian Ocean.

Our results compare favorably with a recent study by Kothawale et al. (2007) who used the Arabian Sea SST data from 1901-2002 and found a significant warming trend of 0.7°C between 1901 and 2002 (cf. our warming rate of 0.42°C/50 years between 1957-2006 or 0.84°C/100 years), and an accelerated warming of 0.16°C/10 years between 1971 and 2002 (cf. our rate of 0.10°C/10 years between 1982 and 2006).

Most extreme surface temperatures are observed in the Persian Gulf. In 1998, following a major El Niño, local SST here reached 34°C, which caused mass mortality of corals and widespread bleaching of coral reefs (Rezai et al., 2004). Additionally recent bleaching events in hermatypic corals due to high temperatures between 10.08.2007 and 28.08.2007 amounting to approximately 20% of bleached branching corals *Acropora* was observed in Kish Island (northern Persian Gulf) (Maghsoudlou 2008).

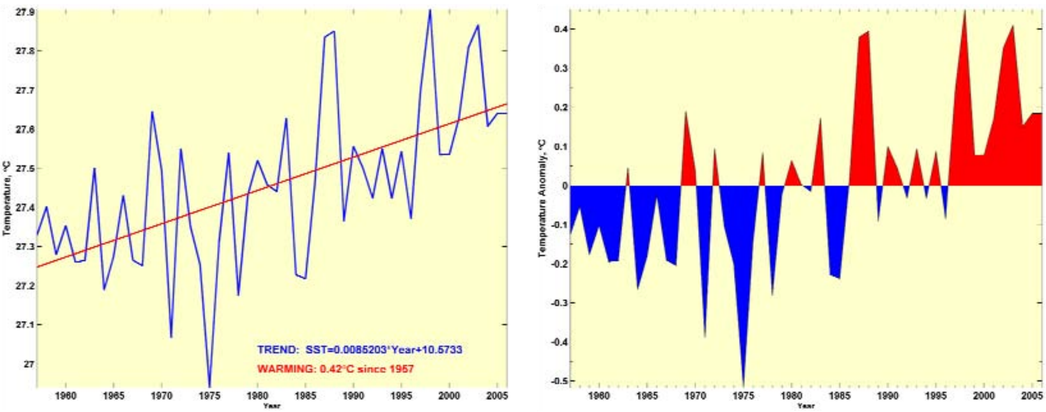


Figure VI-9.2 Arabian Sea LME annual mean SST (left) and SST anomalies (right), 1957-2006, based on Hadley climatology. After Belkin (2009).

Arabian Sea LME Trends in Chlorophyll and Primary Productivity: The Arabian Sea LME is considered a Class I, highly productive ecosystem (>300gCm^{-2}year^{-1}).

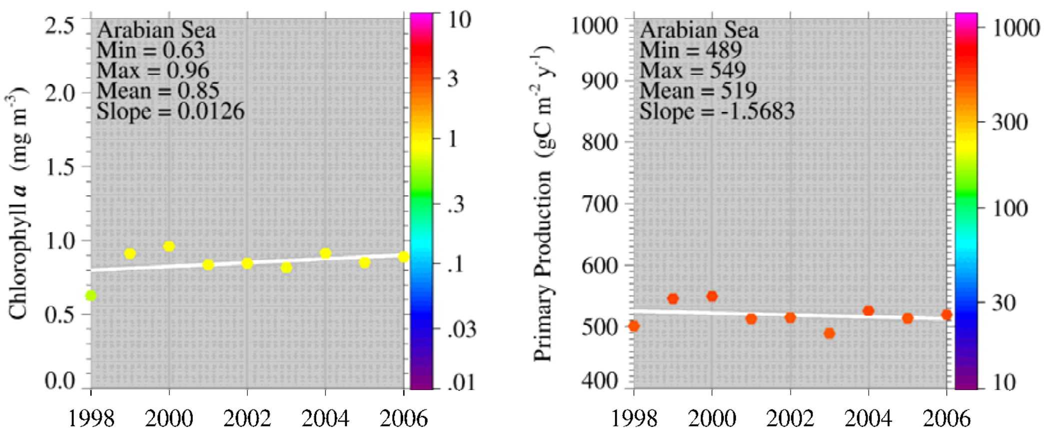


Figure VI-9.3 Arabian Sea LME trends in chlorophyll *a* (left) and primary productivity (right), 1998-2006. Values are colour coded to the right hand ordinate. Figure courtesy of J. O'Reilly and K. Hyde. Sources discussed p. 15 this volume.

II. Fish and Fisheries

The fisheries of the Arabian Sea LME are multi-gear and multi-species and include both artisanal and commercial sectors, with the former being dominant. Among the major exploited groups are Indian oil sardine (*Sardinella longiceps*), caught mainly off India's west coast (Bhathal 2005), as well as drums and croakers (Family Sciaenidae), however, nearly half of the reported landings in the LME are identified only as 'marine fish' (included in 'mixed group' in Figure VI-9.4) which can cause difficulties in diagnosis of various marine indicators. Fisheries for large oceanic pelagic fishes in the region are substantial and lucrative (Bakun *et al*. 1998). Total reported landings increased steadily, reaching 2 million tonnes in 1992 (Figure VI-9.4). The Arabian Sea LME is one of the six LMEs in which reported landings have remained relatively constant or shown increases over the past few decades (FAO 2003), however, precautionary allowable catch levels have been recommended for these LMEs to ensure that fisheries remain sustainable (Sherman 2003). According to FAO (2005a), the increase in total reported landings may be attributed to an increase in fishing effort. The value of the reported landings reached 1.6 billion US$ (in 2000 value) in 2003 (Figure VI-9.5).

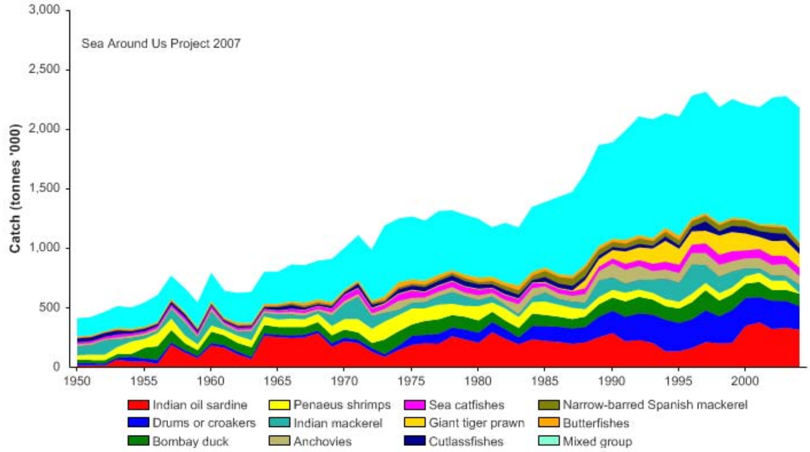


Figure VI-9.4. Total reported landings in the Arabian Sea LME by species (Sea Around Us 2007).

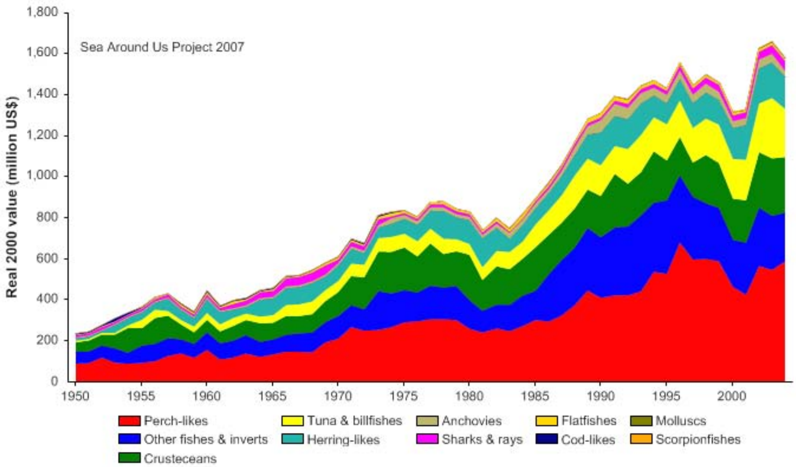


Figure VI-9.5. Value of reported landings in the Arabian Sea LME by commercial groups (Sea Around Us 2007).

The primary production required (PPR; Pauly & Christensen 1995) to sustain the reported landings in this LME reached 20% of the observed primary production in the mid 1990s, but has since declined to 17% (Figure VI-9.6). India has the largest ecological footprint in the LME, with other bordering countries such as Pakistan and Iran also accounting for a large share of the footprint.

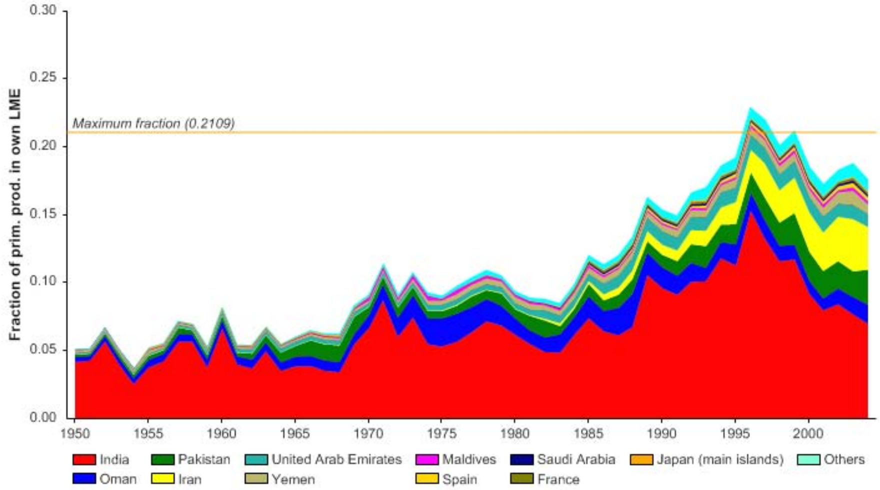


Figure VI-9.6. Primary production required to support reported landings (i.e., ecological footprint) as fraction of the observed primary production in the Arabian Sea LME (Sea Around Us 2007). The 'Maximum fraction' denotes the mean of the 5 highest values.

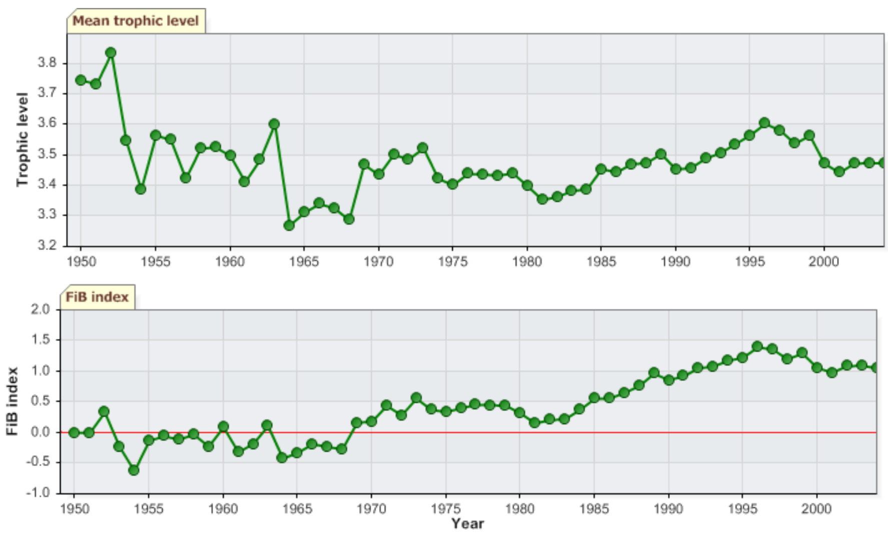
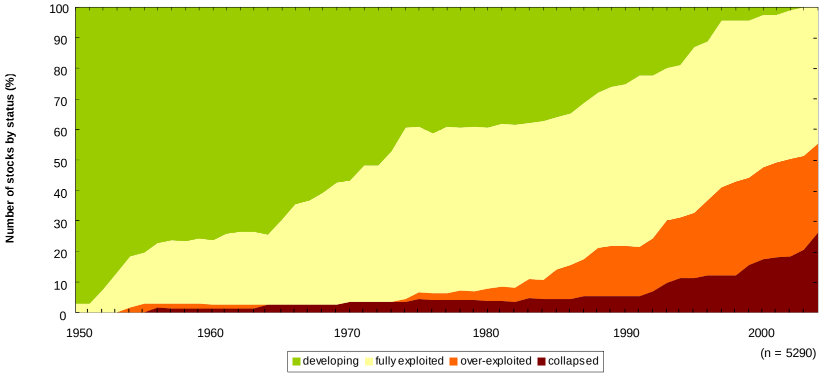


Figure VI-9.7. Marine trophic level (i.e., Marine Trophic Index) (top) and Fishing-in-Balance Index (bottom) in the Arabian Sea LME (Sea Around Us 2007).

From the early 1980s to late 1990s, both the mean trophic level of the reported landings (i.e. the MTI; Pauly & Watson 2005, Figure VI-9.7 top) and the FiB index (Figure VI-9.7 bottom) showed an increase, consistent with a spatial (offshore) expansion of fisheries targeting high trophic level large pelagic fishes in the region. However, the mean trophic levels computed without the landings of tuna and other large pelagic species, as proposed by Pauly & Palomares (2005), show a steady decline from 1975 to 2004. Such a decline agrees with Bhathal (2005) and Bhathal & Pauly (in press), who found, for India, a strong fishing down effect when the national data are disaggregated by State and Union Territories.

The Stock-Catch Status Plots indicate that the number of collapsed and overexploited stocks in the LME have been rapidly increasing, to about 50% in 2004 (Figure VI-9.8, top), but that over 80% of the catch is still taken from fully exploited stocks (Figure VI-9.8, bottom).



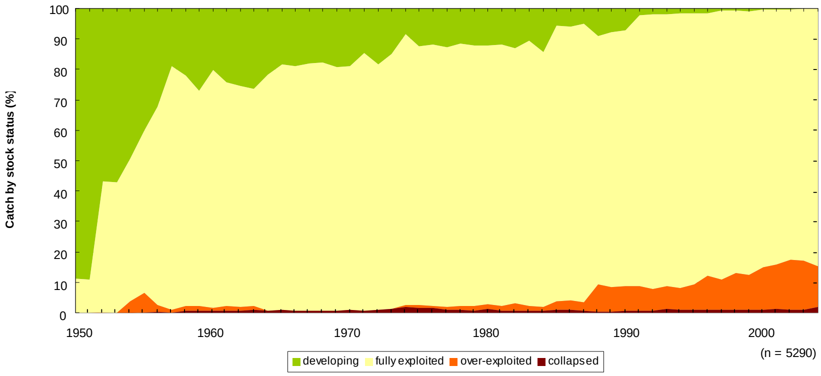


Figure VI-9.8. Stock-Catch Status Plots for the Arabian Sea LME, showing the proportion of developing (green), fully exploited (yellow), overexploited (orange) and collapsed (purple) fisheries by number of stocks (top) and by catch biomass (bottom) from 1950 to 2004. Note that (n), the number of 'stocks', 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).

Overexploitation was assessed as moderate in the LME (UNEP 2006). Fleet overcapacity remains a significant issue in the region, particularly for shrimp fisheries in countries such as Kuwait, Pakistan and Saudi Arabia (FAO 2005a). For instance, stock assessments in Pakistan indicated that the size of the shrimp trawler fleet is almost three times that required for MSY. Despite the increase in total catch, as a result of heavy fishing pressure, especially on inshore stocks in all the bordering countries, catches of certain preferred species have declined dramatically over the last 10 years (Dwivedi & Choubey 1998, FAO 2005a). India's marine fisheries production has reached a plateau and, at best, only a marginal increase is predicted in the near future. Most major stocks are fully exploited and any further increase can only be expected from exploitation of deep-sea resources. In Oman, demersal stocks are already overexploited and some high value fish have shown considerable declines. The state of the fishery resources in

Somalia is little known. While it is thought that Somalia's inshore marine resources are lightly exploited, those targeted by both the artisanal and industrial sectors may have declined in the past few years. Shrimp and finfish resources off the coast of Kuwait and Saudi Arabia are already intensely exploited and catches of major finfish species are declining. Overexploitation is likely to be a contributing factor, as indicated by fish length/age distributions (FAO 2005a).

While UNEP (2006) suggested that bycatch and discards and destructive fishing practices are limited in the LME, large quantities of bycatch are taken by both commercial and artisanal shrimp trawlers (FAO 2005a). In fact, the total bycatch of demersal fish is probably much higher than the recorded landings. Various types of destructive fishing gear, including shrimp trawl nets and explosives, have contributed to localised fish population declines and habitat degradation in the region.

Population expansion is expected to continue to put pressure on the coastal resources in this LME. Several surveys have indicated the presence, outside the traditional fishing grounds, of unexploited demersal and pelagic fish stocks, for example, of mesopelagic lanternfishes (e.g., Shotton 1997). Utilisation of these stocks, however, would require further research and assessment, as well as the introduction of suitable fishing and processing technology (FAO 2005a).

III. Pollution and Ecosystem Health

Pollution: Overall, pollution was assessed as severe in coastal hotspots but in other places it is evaluated to be of moderate value overall (Eghtesadi et al. 2002). The major issues in these hotspots are oil hydrocarbons and heavy metals (Al-Majed Butayban 2006). Other pollution hotspots are found at the mouths of some rivers (e.g., Tigris, Euphrates, Karun, Hileh and Monds Rivers) and domestic and industrial sewage outfalls. The massive increase in population and rapid economic growth in coastal areas are leading to the release of vast quantities of untreated sewage and industrial wastes into the sea through sewers and rivers, resulting in highly polluted coastal areas (Dwivedi & Choubey 1998). Marine pollution also arises from sea-based activities, including marine transportation and offshore oil exploration and production activities. The potential for transboundary impacts of pollution is significant in the LME, with monsoons playing a significant role in the long-range transport of Persistent Toxic Substances (PTS) in the region (UNEP/GEF 2002).

Sewage, fertilisers and other effluents have resulted in eutrophication in coastal areas (e.g., Karachi). Fish-kills in some localities such as off the Karachi coast and Gawadar Bay have been attributed to harmful algal blooms caused by the growing pollution (Abbani *et al*. 1990). Coastal water quality at the Iraq-Kuwait border has declined as a result of increased agricultural pollution due to the draining and subsequent loss of the filtering role of the Mesopotamia marshlands (UNEP 2001). As a consequence of growing economic activity as well as rising production and use of consumer items, the generation of solid wastes from both land-based sources and ships is increasing rapidly. Throughout much of the LME, the coastal zone is becoming a repository for solid wastes because of inadequate waste collection and disposal facilities in the region. Heavy metal deposition has been increasing in localised areas, for example, off Maharashtra and Gujarat (Dwivedi & Choubey 1998) and the coastal area at the mouth of the Indus River (Tariq *et al*. 1993).

Large quantities of hazardous waste have exacerbated the waste management problem in the Arabian Sea countries, and these as well as organo-metallic compounds are of regional concern (UNEP/GEF 2002). Observations after the Persian Gulf War showed moderate marine pollution by PTS. Non-pesticide chemicals are more significant for the

Persian Gulf countries due to major activities in the petroleum sector. Pockets of high contamination of PAHs have been recorded in coastal areas receiving effluents from highly industrialised zones (Beg *et al*. 2001). In India and Pakistan, chlorinated pesticides are more prominent due to major agricultural activities in these countries. Large amounts of pesticides are deposited in coastal areas and high concentrations have been noted, for example, off the Bombay coast (Dwivedi & Choubey 1998). Since persistent organic pesticides such as aldrin, chlordane, DDT, dieldrin and others are either banned or not registered in the Arabian Sea countries, their presence in the environment may be due to their excessive use in the past and there is evidences of their presence in muddy fine sediemts (Eghtesadi-Araghi 2005; Eghtesadi, P., G. Riazi, et al. 2002). There is increasing evidence that some toxic substances are entering the food chain, with low levels of accumulation of organochlorine pesticide residues in marine fauna and flora and wildlife (UNEP/GEF 2002). Mass mortalitiy of Dolphins near Chabahar was referred to as a possible example of this event.

The LME has one of the highest oil pollution risks in the world, as a consequence of the concentration of offshore petroleum installations, tanker loading terminals, and the large volume of oil transportation (Al-Majed Butayban 2006). In 2003, the region (with the exception of Oman) produced about 27% of the world's oil while holding 57% of the world's crude oil reserves. The LME contains one of the world's busiest oil tanker routes, with more than 70% of the oil produced in the northern areas transported through the Arabian Sea. Significant levels of marine pollution have been detected around coastal petroleum refining and shipping localities from which oil, grease, and other hydrocarbon compounds are released into coastal waters (Al-Majed Butayban 2006). Six out of 20 worldwide cases of oil spills greater than 10 million gallons have occurred in the ROPME region (SOMER 2003). Roughly 1 to 2 million barrels of oil are spilled into the region's waters every year from the routine discharge of ballast water and tanker slops, as well as from the 800 offshore oil and gas platforms (Hinrichsen 1996). Between 1998 and 2002, a total of 25 oil spill incidents took place, spilling an estimated 10,000 – 1.8 million gallons of oil (SOMER 2003).

Habitat and community modification: Coastal habitats in the Arabian Sea LME include numerous deltas and estuaries with extensive inter-tidal mudflats, wetlands, mangroves, coral reefs and seagrass beds. Physical damage to marine and coastal habitats is of major concern in the region (Al-Majed Butayban 2006), with habitat and community modification assessed as moderate in the Arabian Sea LME. Throughout the LME, coastal habitats and the biodiversity they support are subject to increasing pressures arising from human activities, including those related to war . For instance, massive coastal development projects in most of the countries have resulted in changes to vast coastal areas (Al-Majed Butayban 2006). Climate change is expected to exacerbate the vulnerability of the LME's coastal habitats to an increasing range of stresses especially on coral reefs as they are very vulnerable to temperature changes (ROPME Sea Area 2008).

Mangrove forests are among the most threatened habitats in the LME. The mangrove forest along the Indus Delta constitutes the largest arid climate mangrove forest of the world. This national heritage, however, is quickly disappearing (Saifullah 1997). The reduction in the flow of the Indus River by dams and barrages is probably the most serious threat to the delta. Mangrove cover in the delta has been reduced by 50% from 2,600 km^2 in the late 1970s to 1,300 km^2 in the mid-1990s (Pernetta 1993). A reduction of mangrove area is evident in other countries bordering this LME. In western and southern India, much of the originally extensive mangrove stands have been removed (Wells *et al*. 2003). There are few remaining mangrove stands in some areas in Oman and Yemen (Al-Muscati *et al*. 1995, Baldwin 2005). In the Persian Gulf, the extent of mangroves has been declining as a result of coastal development, with only about 125-

130 km^2 remaining. More than 40% of the Saudi Arabian coast has been filled in and 50% of the mangroves lost (Jameson *et al*. 1995). Coastal development and urbanisation are thought to contribute to the declines in abundance of demersal fish stocks in the Persian Gulf (FAO 2005a).

As a result of the extreme environmental conditions, the development of coral reefs is generally limited to a few areas (Pilcher *et al*. 2000). Although large parts of these reefs are in a pristine state, they are subjected to increasing environmental threats from coastal development, dredging, land reclamation, overexploitation, pollution and recreational activities in all the bordering countries (Pilcher & Alsuhaibany 2000, Pilcher *et al*. 2000, Wilson *et al*. 2002). Furthermore, coral bleaching has already caused extensive damage to reefs throughout this LME. The reefs in Somalia and Yemen are generally considered to be in good condition, although they have been affected by bleaching and outbreaks of crown of thorn starfish, among other threats (PERSGA/GEF 2003). Bleaching events in 1996 and 1998 led to near-complete mortality of the reefs in Bahrain, Qatar, Saudi Arabia and the United Arab Emirates (Pilcher *et al*. 2000). The reefs of the Lakshadweep islands were reported to have lost between 43–87% of the live coral cover during the 1998 bleaching event, whereas in the Gulf of Kutch less than 30% of the corals were destroyed (Pet-Soede *et al*. 2000). Reefs in Iran, Kuwait and Oman have varying live coral cover and in some areas have been impacted by bleaching, pollution and other anthropogenic pressures (Pilcher *et al*. 2000). Recent oil and gas installation construction has severely damaged Iran's reefs.

The Persian Gulf exhibits marked seasonal variability in oceanographic factors. Extremes of temperature characterize the region and constrain the development of coral reefs. Coral reefs in the Persian Gulf are routinely exposed to annual ranges of temperatures that exceed the temperature extremes reported for any other reef area in the world (Coles, 1988). Normal winter water temperatures in the Persian Gulf rank among the lowest recorded on coral reefs (Downing, 1985; Coles, 1988). In the shallow waters of the southern Persian Gulf , salinity exceeds 50 ppt and reaches 70 ppt in some places (Grandcourt, 2003). Its reefs are bathed by high salinity water of > 45 ppt due to the substantial excess of evaporation (up to 3000 mm y^{-1}), and the Persian Gulf's annual water input (< 50 mm y^{-1}), and the Gulf's annual water temperature fluctuations of > 25^o C, depending on location, are amongst the highest known for reef areas (Sheppard and Loughland, 2002).

Some coastal areas in the Persian Gulf have been affected by the drying out of the Mesopotamia Marshlands of Iraq (UNEP 2001). Considering that the Tigris-Euphrates basin is the largest river system draining into the Gulf, reduced discharge and changes in river flow patterns and quality will have an important impact not only on inland freshwater habitats, but also on the marine environment in the northwestern Gulf. The draining of these marshlands has posed serious threats to the wildlife and to the ecological balance of vast areas, affecting water quality and the spawning grounds of shrimp and migratory species of fish, with harmful impacts on regional fish resources.

V. Socioeconomic Conditions

In 2002, the countries bordering the Arabian Sea LME had a total population of about 1.2 billion, a large part of which is concentrated in coastal areas, particularly in cities such as Mumbai and Karachi. Rapid economic growth accompanied by high population growth and increased urbanisation has been associated with increasing pollution levels and the destruction of fragile coastal habitats.

Marine fisheries generally play an important role in the national economies of some of the countries, providing an important source of foreign exchange earnings, employment and food to a large number of people. In India, where more than 70% of fisheries catches come from the Arabian Sea LME, almost 6 million people are employed in the fisheries sector which contributes nearly 1.5% of GDP. This country's annual export of marine products is worth 1.2 billion US$. In Oman's economy the fisheries sector is considered to be the second most important, whereas it is the third most important in Yemen, with a total contribution to this country's GDP of about 15%. In contrast, the contribution of the fishing industry to the economy of the Persian Gulf countries is small relative to the oil industry. Nevertheless, in these countries the sector is important in that it provides the main economic activity and employment for numerous coastal villages (FAO 2005a). Population expansion in the Arabian Sea countries, particularly India, will continue to place increasing pressures on the marine resources of this LME. Overexploitation and habitat destruction could have significant negative socioeconomic impacts, especially since some of these countries (India, Iraq, Pakistan, Somalia and Yemen) are considered to be Low-Income Food-Deficit countries (FAO 2005b).

V. Governance

Governance in this LME is made complex by the multiplicity of national boundaries and EEZs as well as the large expanse of international open waters. A number of international, regional and bilateral environmental agreements and other legal instruments have been adopted by the ROPME (Regional Organisation for the Protection of the Marine Environment) countries. ROPME was established in 1979 with eight member states: Bahrain, Iran, Iraq, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates. ROPME acts as the secretariat of the Kuwait Action Plan for the Protection and Development of the Marine Environment and the Coastal Areas, which was established under the auspices of the UNEP Regional Seas Programme. The eight countries have adopted the Kuwait Regional Convention for Cooperation on the Protection of the Marine Environment from Pollution and its two protocols (Protocol concerning Marine Pollution resulting from Exploration of the Continental Shelf and Protocol for the Protection of the Marine Environment against Pollution from Land-Based Sources). The Gulf of Aden comes under the Programme for the Environment of the Red Sea and Gulf of Aden, of which Saudi Arabia, Somalia and Yemen are members (see the Red Sea LME).

India and Pakistan, along with Bangladesh, Maldives and Sri Lanka support the South Asian Seas Action Plan (SASAP), established in 1995 under the UNEP Regional Seas Programme and with the South Asia Cooperative Environment Programme acting as secretariat. The overall objective of SASAP is to protect and manage the marine environment and related coastal ecosystems of the region in an environmentally sound and sustainable manner. Although these regional initiatives have made a significant positive impact towards the protection of the marine environment and coastal areas, the region is still faced with major environmental challenges. A holistic ecosystem approach is needed for the conservation and sustainable development of the Indian Ocean LMEs, including the Arabian Sea LME.

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