VII-10 Bay of Bengal: LME #34

S. Heileman, G. Bianchi and S. Funge-Smith

The Bay of Bengal LME is a relatively shallow embayment in the northeastern Indian Ocean encompassing the Bay of Bengal, Andaman Sea and Straits of Malacca. It is bordered by Bangladesh, India, Indonesia, Malaysia, Maldives, Myanmar, Sri Lanka and Thailand. The LME covers an area of about 3,660,130 km^2, of which 0.49% is protected, and contains 3.63% and 0.12% of the world's coral reefs and sea mounts, respectively (Sea Around Us 2007). It is influenced by the second largest hydrologic region in the world, the Ganges-Brahmaputra-Meghna (GBM) Basin, which covers nearly 1.75 million km^2 spread over five countries (Bangladesh, Bhutan, China, India and Nepal).

Located in the tropical monsoon belt, the LME is strongly affected by monsoons, storm surges, cyclones and tsunamis. During the northeast monsoon, an anticyclonic gyre forms in the Bay and reverses during the southwest monsoon (Wyrtki 1973, Longhurst 1998). The LME shows considerable spatial and temporal variability because of seasonal river discharges, particularly the surface water along the coast. Monsoon rain and flood waters produce a warm, low-salinity, nutrient and oxygen-rich layer to a depth of 100 - 150 m; this layer floats above a deeper, more saline, cooler layer that does not change significantly with the monsoons (Dwivedi & Choubey 1998). Large quantities of fresh water and sediment discharged into the LME have also contributed to the formation of the largest mangrove system in the world, the Sunderbans, covering an area of 12,000 km^2 and shared by India and Bangladesh. Books and book chapters, reports and articles pertaining to this LME include Dwivedi (1993), Aziz *et al*. (1998), Desai & Bhargava (1998), Dwivedi & Choubey (1998), Ittekot *et al.* (2003), Silvestre and Pauly (1997), Silvestre *et al.* (2003) and UNEP (2006).

I. Productivity

The Bay of Bengal LME can be considered a Class I, highly productive ecosystem (>300 gCm^{-2}yr^{-1}).While large nutrient input from river run-off supports high primary production in coastal waters, the central parts of the bay are less productive because of the absence of large-scale mixing or upwelling (Dwivedi 1993). The presence of different water masses in coastal areas has produced sub-systems along the coast that differ in their environmental characteristics and community composition. These sub-systems are described by Dwivedi (1993). Secondary production is highest in the post-monsoon period (October to January) and lowest during the monsoon period from June to September (Desai & Bhargava 1998). Zooplankton biomass is low near the shore but increases towards the EEZ boundary (Desai & Bhargava 1998). Further information on biological production and fishery potential in India's EEZ is given in Desai & Bhargava (1998). Wetlands, marshes, mangroves, backwaters and coastal lakes play an important role in overall productivity (Dwivedi 1993). The coastal forested areas of Sri Lanka and Malaysia are biodiversity hotspots, with a large number of threatened endemic plants and animals (Aziz *et al*. 1998).

Oceanic fronts (after Belkin et al. (2009)): The principal front in the Bay of Bengal is maintained by the huge fresh outflow from the Ganges-Brahmaputra estuary (Figure VII-10.1). This is a year-round front, whose cross-frontal TS-ranges vary seasonally. Another estuarine front is maintained by the Irravadi River outflow in the northern

Andaman Sea. In both cases the location of estuarine fronts coincides with the shelf break. A front east of Sri Lanka has been recently described from satellite data (Belkin *et al*. 2009); its origin is related to the wind-induced upwelling off the east coast of Sri Lanka. A bathymetrically-trapped front exists along a sill at the northern entrance to the Palk Strait between India and Sri Lanka.

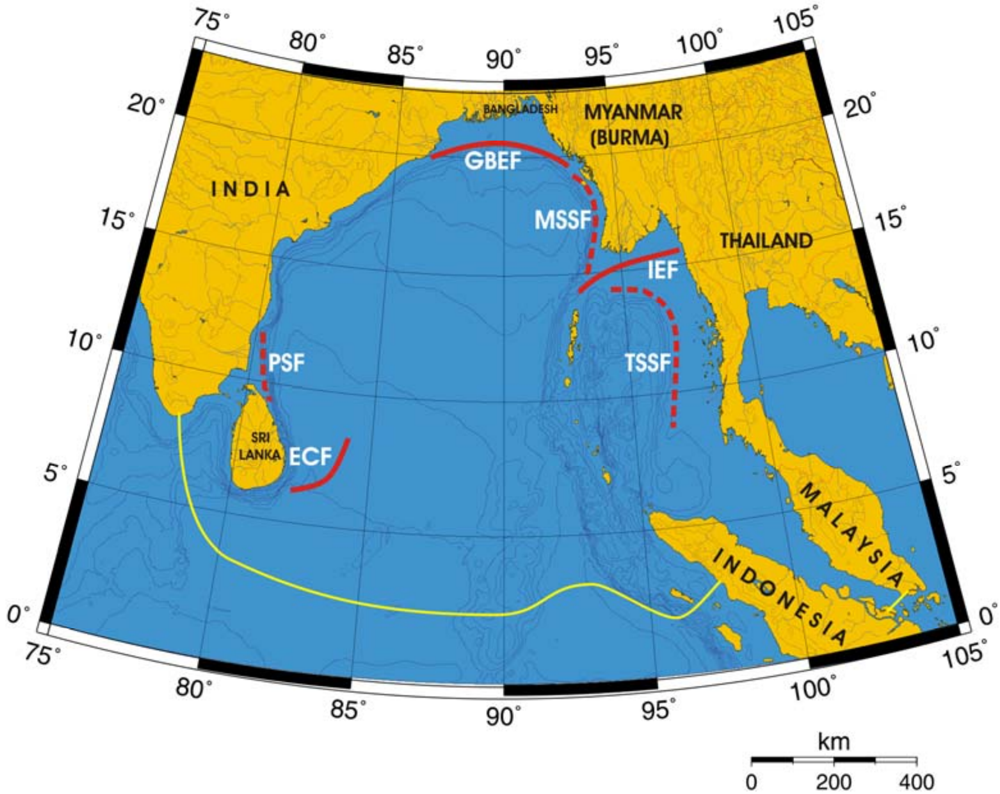

Figure VII-10.1. Fronts of the Bay of Bengal LME. ECF, East Ceylon Front; GBEF, Ganges-Brahmaputra Estuarine Front; IEF, Irravadi Estuarine Front; MSSF, Myanmar Shelf-Slope Front; PSF, Palk Strait Front; TSSF, Thailand Shelf-Slope Front. Red dashed lines, most probable locations of fronts. Yellow line, LME boundary. Belkin et al. (2009).

Bay of Bengal SST (after Belkin 2009
Linear SST trend since 1957: 0.50°C.
Linear SST trend since 1982: 0.24°C.

The steady, slow warming of the Bay of Bengal was modulated by quasi-regular interannual variability with an average magnitude of <0.5°C. The dominant mode of variability has a scale of 3 to 5 years, whereas decadal variability is not distinct. The all-time maximum of 1998 occurred simultaneously with other Indian Ocean LMEs and could be linked to El Niño 1997-1998. It is more difficult to correlate other extrema with similar events elsewhere since the Bay of Bengal LME has no immediate LME neighbors. For example, the all-time minimum of 1961 has no contemporary counterparts elsewhere in the Indian Ocean and therefore must be explained locally.

The temperature history of the Bay of Bengal is strongly coupled with its salinity regime, since the upper layer stability here is largely dependent on the freshwater discharge of three great rivers, the Ganges, Brahmaputra and Irrawaddy. The river discharge is seasonal to the extreme, governed by the Indian monsoon, which brings heavy precipitation to the Indian subcontinent (e.g. Salahuddin et al. 2006). Therefore interannual variability of the Indian monsoon largely determines the river discharge, hence salinity regime and eventually SST variability, in the Bay of Bengal. The Bay of Bengal is not spatially uniform, notwithstanding the existence of a quasi-stationary gyre circulation encompassing the Bay. The horizontal non-uniformity is caused by the perennially low salinity in the northern Bay owing to the Ganges-Brahmaputra river discharge. As a result, the upper mixed layer in the northern Bay is much shallower than in the south. The boundary between these two regimes runs zonally along ~15°N (Narvekar and Kumar 2006). This separation of the Bay of Bengal into two parts, northern and southern, with different SST regimes, must have important ecosystem ramifications.

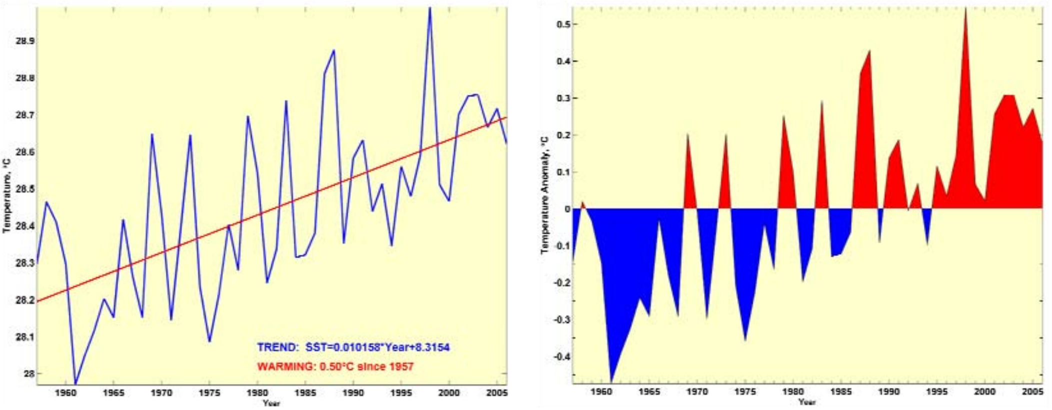

Figure VII-10.2. Bay of Bengal LME annual mean SST (left) and SST anomalies (right), 1957-2006, based on Hadley climatology. After Belkin (2009).

Bay of Bengal LME trends in Chlorophyll and Primary Productivity: The Bay of Bengal LME can be considered a Class I, highly productive ecosystem (>300 $gCm^{-2}yr^{-1}$).

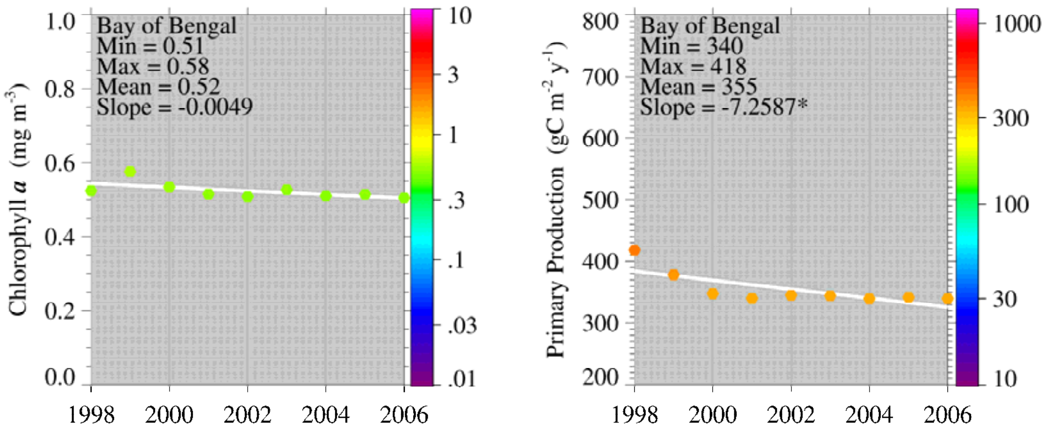

Figure VII-10-3. Bay of Bengal LME annual trends in chlorophyll a (left) and primary productivity (right), 1998-2006. Values are colour coded to the right hand ordinate. Figure courtesy of J. O'Reilly and K. Hyde. Sources discussed p. 15 this volume.

II. Fish and Fisheries

Fisheries of the Bay of Bengal LME target a wide range of species, including sardine, anchovy, scad, shad, mackerel, snapper, emperor, grouper, pike-eel, tuna, shark, ornamental reef fish, shrimp, bivalve shellfish and seaweed (Preston 2004). Catches from commercial and subsistence fishing equal or exceed those from industrial fisheries. In Bangladesh, for example, less than 5% of marine landings are estimated to come from industrial fishing, with the rest coming from the artisanal sector (Hossain 2003; Chuenpagdee *et al.* 2006). During the last decade, some countries have developed offshore fishing for tuna, notably Indonesia, Thailand and Sri Lanka and while most of the tuna catch comes from coastal fisheries, offshore fisheries provide the majority of export-grade tuna (Preston 2004). Crustacean catch is slightly less than 15% of the total catch, with penaeid shrimp accounting for about 40% of the total crustacean catch and being the major export earner (FAO 2003). Most of the countries are also major producers of farmed shrimps, with Thailand and Indonesia among the world's top producers (FAO 2005a).

Statistics on fisheries catch and effort are highly fragmented, especially in the artisanal and subsistence fisheries, two very important sectors in the region (Preston 2004). There are also indications that a continuous increase in the reported landings, particularly of unidentified fishes (included in 'mixed group' in Figure VII-10.4), may be a product of deficiencies in the underlying statistics, rather than improvements in the performance of the fisheries in the LME (Figure VII-10.4. If so, such deficiencies would have serious implications on the effectiveness of the fisheries management regimes in the LME and would also affect the value of the reported landings, which, according to Figure VII-10.5, rose to about over 2.7 billion US$ (in 2000 real US$) in 2004.

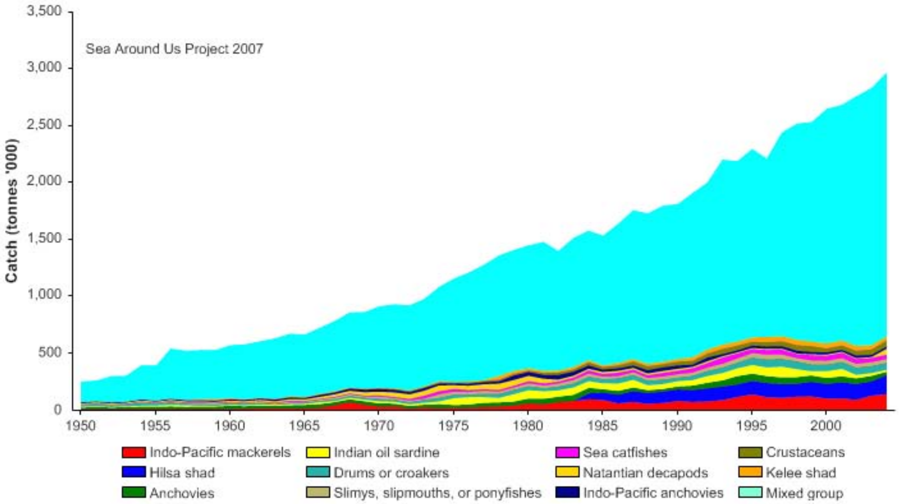

Figure VII-10.4. Total reported landings in the Bay of Bengal LME by species (Sea Around Us 2007).

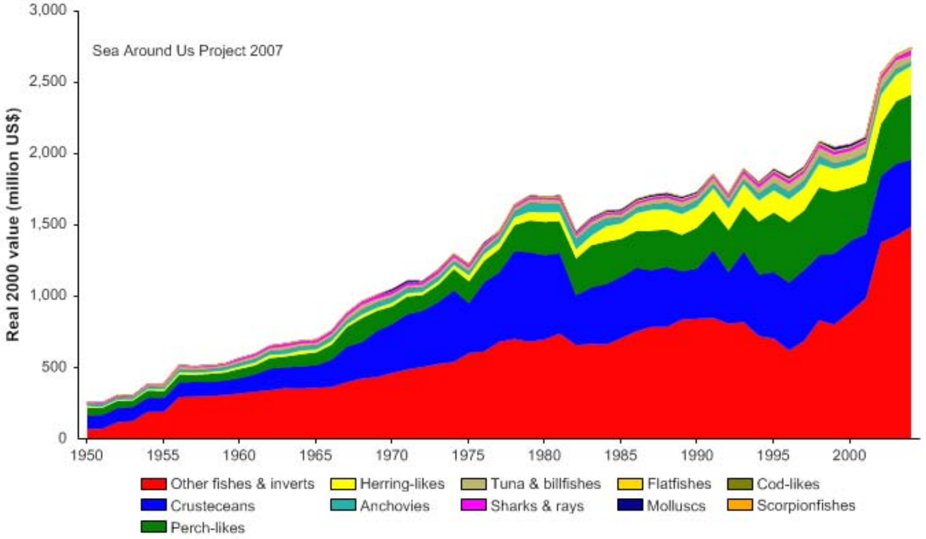

Figure VII-10.5. Value of reported landings in the Bay of Bengal LME by commercial groups (Sea Around Us 2007).

The primary production required (PPR; Pauly & Christensen 1995) to sustain the reported landings in this LME has increased over the years, and reached 20% of the observed primary production in 1998 (Figure VII-10.6). Such high PPR is another indication that the reported landings for this LME may be exaggerated. Bordering countries, namely India, Myanmar, Malaysia and Thailand account for the largest shares of the ecological footprint in the region.

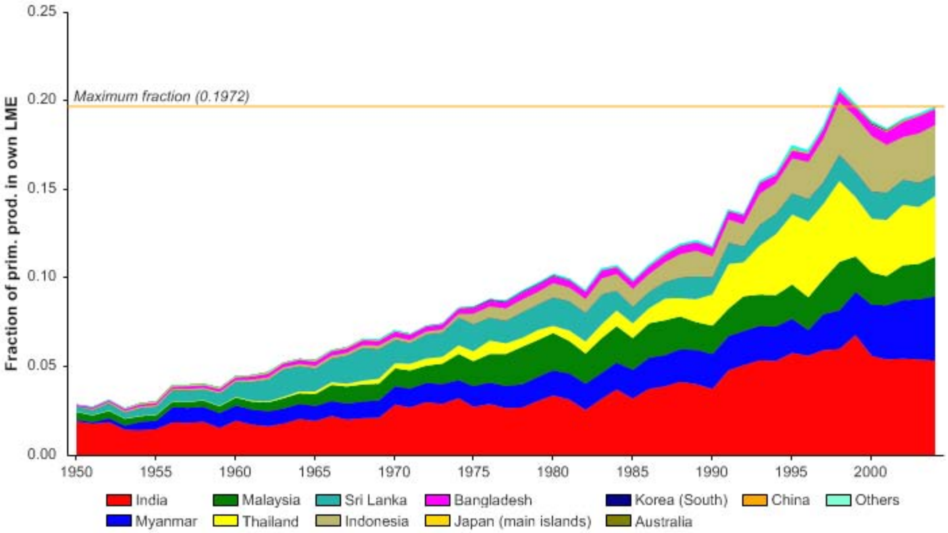

Figure VII-10.6. Primary production required to support reported landings (i.e., ecological footprint) as fraction of the observed primary production in the Bay of Bengal LME (Sea Around Us 2007). The 'Maximum fraction' denotes the mean of the 5 highest values.

The mean trophic level of the reported landings (i.e., the MTI; Pauly & Watson 2005) show a steady decline over the past 50 years (Figure VII-10.7 top) while the FiB index increased over the same period (Figure VII-10.7 bottom). Due to the nature of the underlying landings statistics, it is not possible to draw any reasonable conclusions from these indices, however, a detailed analysis of the MTI and FiB index of Western India, based on independently validated catch data from the States and Union Territories (Bhathal 2005), found that a 'fishing down' of the food webs (Pauly *et al.* 1998) is indeed occurring in the region (Bhatal and Pauly, in press).

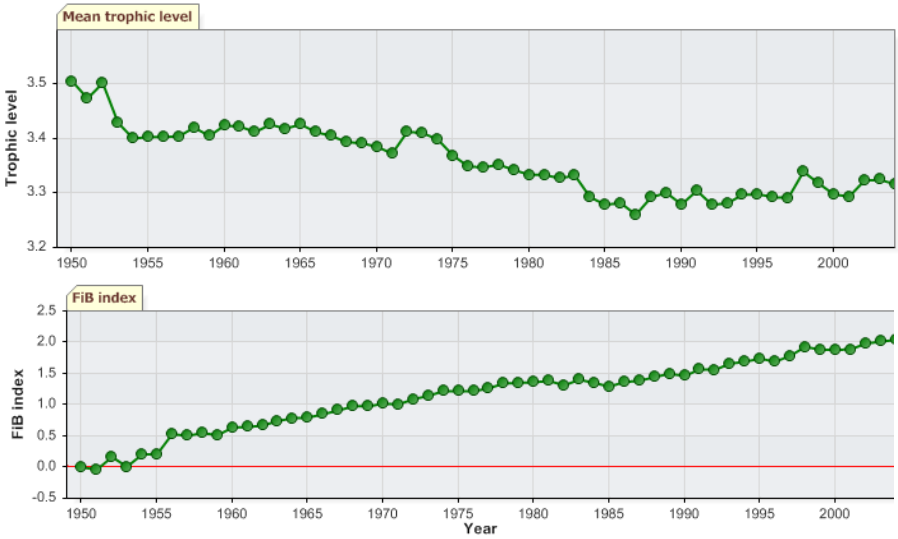

Figure VII-10.7. Mean trophic level (i.e., Marine Trophic Index) (top) and Fishing-in-Balance Index (bottom) in the Bay of Bengal LME (Sea Around Us 2007).

The Stock-Catch Status Plots indicate that the number of collapsed and overexploited stocks in the LME is low but on the rise (Figure VII-10.8, top), with over 80% of the reported landings from fully exploited stocks (Figure VII-10.8, bottom). Again, the questionable quality of the underlying landings statistics must be noted.

As should be expected, given the amount of fishing pressure present in this LME (Gelchu and Pauly 2007), both the catch per unit effort and the average size and weight of the catches have been on a decline (Preston 2004). Excess fishing capacity in many of the region's coastal fisheries is reducing the productivity of the local stocks and threatening their long-term sustainability (Preston 2004). In fact, intensive fishing has been identified as the primary force driving biomass changes in the LME (Sherman 2003). These changes are well illustrated on the southeast coast of India, where high density of coastal fishing craft is inducing changes in the ecosystem, as evident in the trophic level declines (Bhathal 2005, Vivekanandan *et al*. 2005). India, for example, is experiencing serial depletions of coastal fish stocks, where the increase in its fisheries catch is maintained only by the expansion of its range. Indeed, there are now signs that this expansion phase has reached its limit, with stagnation of its catch (Bhathal 2005). Other indicators of unsustainable resource use are described in the Bay of Bengal LME national reports for a wide range of resources including finfish, shark, crustacean, mollusc and echinoderm (Preston 2004).

Destructive fishing practices of various kinds are commonplace in the LME. Continued growth of commercial fishing effort, especially by trawlers, is increasing the fishing mortality of non-reef species. In the southern Indian maritime states of Tamil Nadu and

Andhra Pradesh, the decline in the catch has been associated with an increase in unregulated trawling for shrimps.

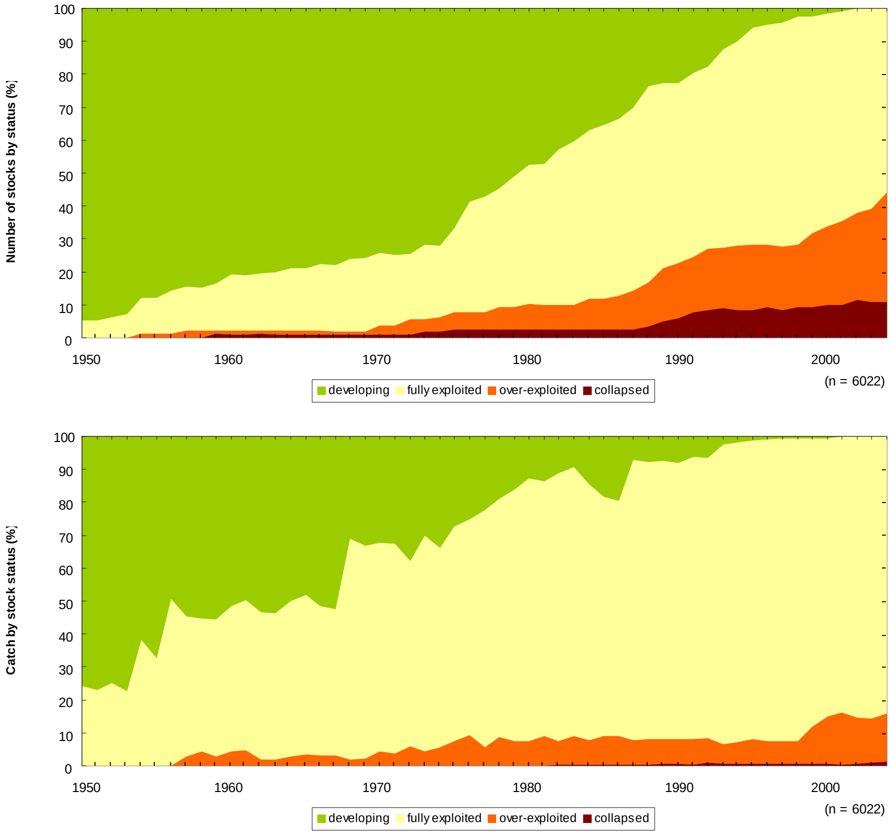

Figure VII-10.8. Stock-Catch Status Plots for the Bay of Bengal LME, showing the proportion of developing (green), fully exploited (yellow), overexploited (orange) and collapsed (purple) fisheries by number of stocks (top) and by catch biomass (bottom) from 1950 to 2004. Note that (n), the number of '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).

Excessive bycatch is of concern, although all captured fish are generally used either for human consumption or as aquaculture feed. The accidental capture of endangered fish species, dolphin and sea turtle is also of concern. The large-scale collection of fish and shrimp larvae for aquaculture using destructive methods may be seriously damaging wild stocks of both shrimp and other species (FAO 2005a), which typically make up more than 99% of the catch (Preston 2004). Dynamite fishing, often for small pelagic species, and the use of cyanide and other toxins for capturing ornamental and live food fish, are both increasing, and may lead to long-term damage, not only to the target resources, but to their associated habitats (FAO 2002, Preston 2004).

Expanding human populations of the Bay of Bengal LME region has created an increasing demand for fish as a source of animal protein. Furthermore, trade liberalisation and rising demand for export have contributed to the rapid development of marine fisheries and aquaculture in recent years. The steady decline in the abundance of the fisheries resources is expected to continue, despite a number of regulatory measures in force in some of the bordering countries. Bilateral or multilateral collaboration would greatly assist the efforts of individual countries in addressing the problem of overexploitation, given the transboundary nature of most of the fish stocks.

III. Pollution and Ecosystem Health

Pollution: Human activities are causing serious environmental degradation, threatening the sustainable management and health of the near-coastal waters. Among the major threats to the LME's health and productivity is pollution from land-based sources, particularly related to sewage, agriculture, aquaculture and industries (Kaly 2004, Samarakoon 2006). These are also the main land-based pollution categories of transboundary significance in the region. The mobilisation of pollutants through rivers, run-off and floods, as well as cross-border movements of pollutants through international rivers, are of concern (Kaly 2004). Pollution from sea-based sources (oil spills, oil exploration and production) is also among the main recognised threats (Kaly 2004).

Sewage was identified as a major priority issue (Chia & Kirkman 2000). This includes nutrients, POPs, household chemicals, medical wastes, excreted pharmaceuticals and sediments. The use of chemicals and irrigation in agriculture and aquaculture, as well as sediment inputs to the coastal areas compounds this problem. High amounts of organic and inorganic nutrients reach the LME (Kaly 2004). Although the ecological effect of nutrient enrichment of the coastal environment of the LME are poorly documented and understood, reported localised problems of eutrophication, hypoxia and algal blooms are likely to be related. Over the past 20-30 years, an increase in both the frequency and persistence of algal blooms in coastal waters and enclosed sea areas in India has been reported (Sampath 2003). The GBM river system is a major recipient of waste from industries in Bangladesh and India. High levels of pesticides can be found along the coast, especially near cities and ports (Dwivedi 1993).

Pollution by suspended solids is common to the entire LME, including the Andaman Sea. Although sediment mobilisation occurs with urban and port developments, the most important sources are probably deforestation together with agriculture and aquaculture (Kaly 2004). The GBM river system delivers 30% of the world's total load of river sediment (Milliman & Meade 1983), and provide high turbidity in the coastal waters, as has been shown in satellite photos.

Oil spills are a major concern. There is heavy oil tanker traffic between Japan and the Middle East, with the main shipping route passing south of Sri Lanka before entering the Straits of Malacca. Along the Indian coastline, there is also intense shipping traffic, and associated chronic oil pollution through operational discharge of waste, mostly by medium and small ships where installation of oil-water separators is not mandatory (Sampath 2003). Increasing shipping activity and increasing emphasis on offshore oil exploration in many countries of the region makes the northern Indian Ocean very vulnerable to oil pollution.

Habitat and community modification: Among the coastal habitats of the Bay of Bengal LME are several wetlands of international importance (WRI 2005). Six areas of critical biological diversity are the Sundarbans, Palk Bay and the Gulf of Mannar, the Marine (Wandur) National Park in the Andaman and Nicobar Islands, the Maldives Atolls, Mu Ko Similan National Park and Mu Ko Surin National Park in Thailand. The Sundarbans, a UNESCO World Heritage Site, represents the most economically important production forest and natural wildlife habitat in Bangladesh.

Extensive habitat modification has occurred, but was considered to be moderate in Bangladesh, India, and Sri Lanka, and severe in the Andaman Sea. The major problems are sedimentation and siltation, reclamation, coastal aquaculture, illegal fishing, and oil pollution, as well as global warming and sea level rise (Angell 2004). Climate change is likely to have severe impacts on the LME as it is closed in the north, preventing the migration of endemic species to higher latitudes. The impact on the ecosystem of the recent start of dredging in the Gulf of Mannar for the Sethusamudram Ship Canal is also of grave concern.

Weakened traditional common property management, growing human population in coastal areas, and development of brackish water shrimp farming have contributed to the increasing pressure on mangrove forests and their resources in the last few decades (Angell 2004, Samarakoon 2004). With a few exceptions, most mangrove habitats in the Bay of Bengal LME region are degraded or threatened. For instance, in the Sundarbans, some 150,000 ha of mangrove forest disappeared during the past 100 years, as a result of reclamation for agriculture settlement sites, industrial estates and roads (Govindasamy *et al*. 1997). More than half of the total area (some 208,220 ha) of Thailand's mangrove forests disappeared between 1961 and 1993 (GESAMP 1993). Between 1991 and 1995, approximately 50,000 ha of coastal wetlands along the east coast of India were converted to shrimp farms (Government of India 2002). In Sri Lanka, mangrove conversion to shrimp ponds has considerably reduced mangrove forest (Joseph 2003). Agriculture and land reclamation for urban settlements have also reduced the mangroves and peat swamps of the Malacca Straits by about 50-60% (Thia-Eng *et al*. 1997). Similarly, the Merbok mangroves in Malaysia, with one of the highest recorded levels of species diversity in the world, have been reduced by about 65% through conversion to rice paddies, shrimp farms and housing estates (Samarakoon 2004).

Among the pressures on the region’s coral reefs are destructive fishing practices, siltation and pollution, unplanned tourism development and coral mining (Angell 2004) are prominent. Coral reefs have also been damaged by bleaching, as a consequence of periodic increases in sea surface temperatures. The most notable bleaching event occurred in 1997-1998, and caused extensive bleaching and in numerous instances, over 90% mortality of corals, in some parts of the LME (Wafar 1999, Chou *et al*. 2002, Wilkinson 2002). Pollution and related disease are also threatening some reefs. For instance, oil spills and ballast water discharges are a significant threat to 85% of Thailand’s reefs (Angell 2004). Destructive fishing practices such as the use of cyanide and explosives are a major cause of coral reef degradation in most of the countries, particularly in Indonesia, where 67%-98% of the reefs are seriously degraded. Furthermore, reefs are generally depleted of high value food fish due to the demand for both the local tourism industry and export. Although this practice has been banned, coral mining has destroyed coral reefs in many areas, including in Sri Lanka, India and, to a lesser extent, in Bangladesh. Only the Maldives government has had some success in reducing this destructive practice by subsidising the import of alternative materials.

Extensive damage to coastal and marine habitats was caused by the tsunami of 26 December 2004 (CORDIO 2005a, 2005b, IUCN/CORDIO 2005). Places along the coast that were most affected were those that have been previously disturbed by anthropogenic activities. For example, mangroves and vegetated coastal dunes seem to have dissipated the wave energy and provided protection to coastlines, coastal inhabitants and infrastructure. Surveys have shown significant damage to coral reefs over extensive areas from mechanical damage, deposition of debris, sand, silt, and rubble, as well as impacts on the diversity of benthic organisms and fish. Fish populations, which in many cases were depleted by overexploitation, showed varying levels of impact, seemingly correlated with loss of habitat. In general, a higher impact was observed on smaller fish, notably damselfish, gobies, butterfly fish and wrasse; this may have adverse consequences for the ornamental fish trade.

The impact of the tsunami is also very visible on turtle nesting sites (Kulkarni 2005, CORDIO 2005b). The nesting beaches of leatherback, green, hawksbill and olive ridley turtles in South Andaman, Little Andaman and the Nicobar Group of islands have almost vanished. Sand and sediment deposited on sea grass beds will have a long term-impact on dugongs, which feed in these areas. Severe beach erosion has occurred at all sites, with some beaches suffering over 50% reduction in width and up to one meter loss in height.

IV. Socioeconomic Conditions

The eight countries bordering the Bay of Bengal LME include some of the most populous in the world, with India, Indonesia and Bangladesh being among the world's top ten. An estimated 400 million people live in the LME's catchment area (Preston 2004). The LME and its natural resources are of considerable social and economic importance to the bordering countries, with activities such as fishing, shrimp farming, tourism and shipping contributing to food security, livelihoods, employment and national economies. Marine fisheries make a modest contribution to the GDP of the bordering countries, with the exception of the Maldives, where this sector contributes 11% to GDP and 74% of the country's export commodities (FAO 2005a). Primary export commodities are shrimp and tuna, which make a significant contribution to national foreign exchange earnings. For example, in Bangladesh, fisheries account for more than 11% of annual export earnings, while in Indonesia, the value of fisheries exports amounted to about US$1.6 billion in 1998 (FAO 2005a).

Rapid development of aquaculture, mainly of shrimp, in the extensive coastal and brackish-water areas has made a significant contribution to the growth of national export earnings, and aquaculture is now an important element in both the local and national economies. Based on statistics in FAO (2005b), the combined output of the region's farmed shrimp and fish in 2003 was estimated at about 5.3 million tonnes, equivalent to 35% of total production from capture and aquaculture. It should be noted, however, that these statistics are based on the countries' total production, and not only that from the LME, although most of the aquaculture production comes from the LME. Tourism also makes a substantial contribution to the national economies of some of the Bay of Bengal LME countries. Coastal tourism in western Thailand, Peninsular Malaysia, Sri Lanka and the Maldives continue to gather momentum and is being promoted in India and Bangladesh.

Many of the region's poor are dependent primarily or entirely on marine resources, and have few, if any alternatives to fishing, even when overfishing is clearly occurring (Preston 2004, Samarakoon 2004). Fisheries also provide employment for millions of people. For example, in Indonesia, over 5 million people are directly involved in fishing and fish farming. Together with their families, they make up at least 4 percent of the total population (FAO 2005a). In Bangladesh, this sector provides income to some 1.5 to 2 million full-time and around 12 million part-time fishers, while in the Maldives, fisheries account for 20% of employment. Fisheries also make a very important contribution to the national diet in the bordering countries (FAO 2005a). For example, about two-thirds of Bangladesh, Indonesia and Sri Lanka national protein supply comes from fish. This is even higher in Mayanmar, where fish makes up 80% of the animal protein for most people.

The socioeconomic impacts of over-exploitation were assessed as severe in the Bay of Bengal LME countries, particularly for the millions of poor coastal fisher families. Increasing fishing effort and declining resources are leading to increased competition for access to these resources, with negative impacts, especially on poorer resource users (Townsley 2004). Reduced benefit flows from resource use lead to reduced livelihood security, including reduced food security. The localised decline of fisheries resources also forces resource users to migrate to other areas in search of new opportunities. This creates new vulnerabilities for those affected as it means abandoning familiar environments and social support networks. Without the capacity to adopt alternative strategies, poorer groups continue to exploit fisheries resources, further exacerbating the decline of the resources (Townsley 2004).

Pollution is affecting both critical habitats in coastal and marine areas, and the livelihoods that depend on them. Those making direct use of these resources see decreasing access to resources, declining environmental conditions that may affect their access to safe water and necessary livelihood resources and specific health risks generated by increased pollution (Townsley 2004). Over 60% of reported diseases in the two countries are linked to pollution discharged from point and diffuse sources. Pollution impacts are often particularly severe in coastal areas where pollution from multiple sources may be concentrated.

The coastal and marine habitats of the Bay of Bengal LME serve as nursery areas for fish and shellfish species that contribute substantially to income, livelihood, food security and employment in the bordering countries. These benefits are lost or threatened when such habitats are destroyed. The extent to which this affects other countries around the LME is unclear, but the interconnectedness of marine ecotones suggests that there are likely to be impacts, particularly in adjacent areas but also potentially further away (Townsley 2004; Bhattacharya and Sarkar 2003). For instance, distant fisheries may be affected by the destruction of habitats that are critical to the life cycle of their target species.

Many of the marine and coastal environmental problems faced by the Bay of Bengal LME are inextricably linked with the large populations of the region's coastal areas, and their impoverished status. Continued population growth, and the increasing concentration of people in coastal areas will exacerbate these problems in the future. Unless addressed, environmental degradation and unsustainable resource use practices will reduce the capacity of fisheries to provide sustenance and income for coastal people, thus leading to increased poverty in a spiralling effect. Preston (2004) notes the growing need to address coastal management, pollution, fishery management and alternative livelihood issues in parallel.

V. Governance

The LME is bordered by Bangladesh, India, Indonesia, Malaysia, Maldives, Myanmar, Sri Lanka and Thailand. At the national level, environmental and fisheries regulations and management initiatives have been developed by the countries bordering the LME (Edeson 2004, FAO 2005a). However, their results have been mixed, with effectiveness hampered largely by inadequate implementation, surveillance and enforcement. Attempts to conserve coral reefs focus on the establishment of MPAs. These may be internationally recognised biosphere reserves or nationally established marine protected areas or parks (Angell 2004). For instance, the Sundarbans and the Gulf of Manner were named biosphere reserves in 1986 and are recognised by UNESCO under their 'Man in the Biosphere' programme. The effectiveness of these MPAs, however, varies considerably. Problems include intrusion of local fishers, weak to non-enforcement of MPA regulations, and lack of coordination among responsible government agencies.

A multitude of international, regional, and sub-regional organisations and programmes operate in the Bay of Bengal LME. The only regional fisheries management organisation whose jurisdiction extends into the LME is the Indian Ocean Tuna Commission. There are also numerous stakeholder groups and policy frameworks (Aziz *et al*. 1998). In March 1995, the South Asian Seas Action Plan (SASAP) was adopted by Bangladesh, India, Maldives, Pakistan and Sri Lanka. The South Asia Cooperative Environment Programme is the Action Plan secretariat. Although there is not yet a regional convention, SASAP follows existing global environmental and maritime conventions and considers the Law of the Sea as its umbrella convention. One of SASAP's priorities focuses on National Action Plans and pilot programmes to implement the GPA.

The regional Bay of Bengal Programme (BOBP) started out in 1979 as a fisheries development oriented-programme, and moved progressively towards fisheries management. The BOBP has been succeeded, in a reduced form, by the Bay of Bengal Programme Inter-Governmental Organisation, which continues to promote responsible management of small-scale fisheries and related activities. This organization has a membership of Maldives, India, Sri Lanka and Bangladesh and focuses largely on coastal fisheries related issues of these countries.

Recognising the need for integrated and coordinated management of their coastal and near-shore living marine resources, the eight countries bordering the LME have embarked on the development of a Bay of Bengal Large Marine Ecosystem Project with support from GEF to address critical threats to the coastal and marine environment, and to promote ecosystem-based management of the LME's coastal and marine resources. This project has recently been endorsed by GEF and will be implemented 2008-2013 by FAO with the aim of increased national institutional capacity in participating countries. Through this process, the outcomes will be a Trans-boundary Diagnostic Analysis, including assessments of critical coastal/marine habitats providing a location-specific assessment of critical transboundary concerns and the identification of "hotspots". As a part of regional cooperative arrangements, a permanent, partially financially-sustainable institutional arrangement will be established, that will support the continued development and broadening of commitment to a regional approach to BOBLME issues. The Strategic Action Plan that will be developed will guide future BOBLME Programme activities leading to improved wellbeing of rural fisher communities through incorporating regional approaches to resolving resource issues and barriers affecting their livelihoods.

The BOBLME will be largely based around regional and sub-regional activities for collaborative ecosystem approaches leading to changes in sources and underlying causal agents contributing to trans-boundary environmental degradation. The programme also envisages action to promote the restoration of depleted stocks and develop a better understanding of the BOBLME's large-scale processes and ecological dynamics. Basic health indicators in the BOBLME will be established as part of this. As a goal over the longer-term, and foreseen within the Strategic Action Plan, the sustained commitment from the BOBLME countries to collaborate will be achieved through adoption of an agreed institutional collaborative mechanism.

References

Angell, C.L. (2004). Review of Critical Habitats- Mangroves and Coral Reefs. Bay of Bengal Large Marine Ecosystem (BOBLME) Theme report, FAO-BOBLME Programme.

Aziz, A.H., Ahmed, L., Atapattu, A., Chullasorn, S., Pong Lui, Y., Maniku, H.M., Nickerson, D.J., Pimoljinda, J., Purwaka, T.H., Saeed, S., Soetopo, S., and Yadava, Y.S. (1998). Regional stewardship for sustainable marine resources management in the Bay of Bengal, p 369-378 in: K. Sherman, E. Okemwa and M. Ntiba (eds), Large Marine Ecosystems of the Indian Ocean: Assessment, Sustainability, and Management. Blackwell Science.

Bhattacharya, A. and Sarkar, S.K. (2003) Impact of overexploitation of shellfish: Northeastern coast of India. Ambio 32(1) 70-75.

Belkin, I.M. (2009) Rapid warming of Large Marine Ecosystems, Progress in Oceanography, in press.

Belkin, I.M., Cornillon, P.C., and Sherman, K. (2009). Fronts in Large Marine Ecosystems of the world's oceans: An atlas. Progress in Oceanography, in press.
Bhathal, B. (2005). Historical reconstruction of Indian marine fisheries catches, 1950-2000, as a basis for testing the 'Marine Trophic Index'. Fisheries Centre Research Reports 13(4), 122 p.
Bhathal, B. and Pauly, D. (in press). 'Fishing down marine food webs' and spatial expansion of coastal fisheries in India, 1950-2000. Fisheries Research
Chia, L.S. and Kirkman, H. (2000). Overview of Land-Based Sources and Activities Affecting the Marine Environment in the East Asian Seas. UNEP/GPA Coordination Office and EAS/RCU (2000). Regional Seas Report and Studies Series.
Chou, L. M., Tuan, V.S., Philreefs, Yeemin, T., Cabanban, A., Suharsono and Kessna, I. (2002). Status of Southeast Asia coral reefs, p 123-152 in: Wilkinson, C.R. (ed), Status of Coral Reefs of the World 2002. GCRMN Report, Australian Institute of Marine Science, Townsville, Australia.
Chuenpagdee, R., Liguori, L., Palomares, M.L.D. and Pauly, D. (2006). Bottom-up, Global Estimates of Small-Scale Marine Fisheries Catches. Fisheries Centre Research Reports 14(8). Fisheries Centre, University of British Columbia, Vancouver, Canada, 105 pp.
CORDIO (2005a). Assessment of tsunami damage in the Indian Ocean: First Report CORDIO online document. www.cordio.org/news_article.asp?id=11
CORDIO (2005b). Assessment of tsunami damage in the Indian Ocean: Second Report CORDIO online document. www.cordio.org/news_article.asp?id=12
Desai, B.N. and Bhargava, R.M.S. (1998). Biologic production and fishery potential of the Exclusive Economic Zone of India, p 297-309 in: Sherman, K., Okemwa, E. and Ntiba, M. (eds), Large Marine Ecosystems of the Indian Ocean: Assessment, Sustainability, and Management. Blackwell Science Inc. Cambridge, MA.
Dwivedi, S.N. (1993). Long-term variability in the food chains, biomass yield and oceanography of the Bay of Bengal Ecosystem, p 43-52 in: Sherman, K., Alexander, L.M. and Gold, B.D. (eds), Large Marine Ecosystems: Stress, Mitigation, and Sustainability. AAAS Press. Washington, D.C.
Dwivedi, S.N. and Choubey, A.K. (1998). Indian Ocean Large Marine Ecosystems: Need for National and Regional Framework for Conservation and Sustainable Development, p 361-368 in: K. Sherman, E. Okemwa and M. Ntiba (eds), Large Marine Ecosystems of the Indian Ocean: Assessment, Sustainability, and Management. Blackwell Science Inc. Cambridge, MA.
Edeson, W. (2004). Review of Legal and Enforcement Mechanisms in the BOBLME Region. Bay of Bengal Large Marine Ecosystem (BOBLME) Theme report. GCP/RAS/179/WBG. FAO-BOBLME Programme.
FAO (2002). The State of World Fisheries and Aquaculture. Food and Agriculture Organisation of the United Nations, Rome, Italy.
FAO (2003). Trends in Oceanic Captures and Clustering of Large Marine Ecosystems - 2 Studies based on the FAO Capture Database. FAO Fisheries Technical Paper 435.
FAO (2005a). Fishery Country Profiles at.www.fao.org/fi/fcp/fcp.asp.
FAO (2005b). World fisheries production, by capture and aquaculture, by country (2003). FAO Yearbook of Fisheries Statistics: Summary Tables 2003. www.fao.org/fi/statist/statist.asp
FAO (2007) Bay of Bengal LME Prospectus, www.fao.org/fi/boblme/website/index.htm
Gelchu, A. and Pauly, D. (2007). Growth and distribution of part-based fishing effort within countries' EEZ from 1970 to 1995. Fisheries Centre Research Reports, 15(4), 99 p.
GESAMP (1993). Joint group of experts on the scientific aspects of marine protection, impact of oil and related chemicals and wastes on the marine environment. Reports and Studies 50. IMO, London, U.K.
Government of India (2002). National Biodiversity Action Plan for the East Coast of India. http://sdnp.dehi.nic/nbsap/dactionp/ecoregion/ecoast/ecoast.html
Govindasamy C., Viji Roy, A.G., Prabhahar, C., Valarmathi, S. and Azariah, J. (1997). Bioethics in India, in: Azariah, J., Azariah, H. and Macer, D.R.J. (eds), Proceedings of the International Bioethics Workshop in Madras: Biomanagement of Biogeoresources, 16-19 Jan. 1997, University of Madras.
Hossain, M.M.M. (2003). National Report of Bangladesh on the Sustainable Management of the Bay of Bengal Large Marine Ecosystem. Bay of Bengal LME Project, FAO GCP/ RAS/ 179/ WBG, Chennai, India.
Ittekot, V., Kudrass, H.R., Quaddfasel, D. and Unger, D. (eds.) (2003). The Bay of Bengal. Deep Sea Research, Part II:Topical Studies in Oceanography. 50(5): 853-1045.
IUCN/CORDIO (2005). Initial Rapid Assessment of Tsunami Damage to Coral Reefs in Eastern Sri Lanka, 2-5 March 2005. www.cordio.org/news_article.asp?id=20

Joseph, L. (2003). National Report of Sri Lanka on the Formulation of a Transboundary Diagnostic Analysis and Strategic Action Plan for the Bay of Bengal Large Marine Ecosystem Programme. BOBLME Report. FAO-BOBLME Programme

Kaly, U.L. (2004). Review of Land-based sources of pollution to the coastal and marine environments in the BOBLME Region. Bay of Bengal Large Marine Ecosystem Theme Report. FAO-BOBLME Programme.

Kulkarni, S. (2005). Tsunami Impact Assessment of Coral Reefs in the Andaman and Nicobar. CORDIO online document. www.cordio.org/news_article.asp?id=13.

Longhurst, A.R. (1998). Ecological Geography of the Sea. Academic Press, California, USA.

Milliman, J.D. and Meade, R.H. (1983). Worldwide delivery of river sediment to the oceans. Journal of Geology 91:1-21.

Narvekar, J., and Kumar, S.P. (2006) Seasonal variability of the mixed layer in the central Bay of Bengal and associated changes in nutrients and chlorophyll *Deep-Sea Res. Part I*, **53**(5), 820-835.

Pauly, D. and Christensen, V. (1995). Primary production required to sustain global fisheries. Nature 374: 255-257.

Pauly, D. and Watson, R. (2005). Background and interpretation of the 'Marine Trophic Index' as a measure of biodiversity. Philosophical Transactions of the Royal Society: Biological Sciences 360: 415-423.

Pauly, D., Christensen, V., Dalsgaard, J., Froese R. and Torres, F.C. Jr. (1998). Fishing down marine food webs. Science 279: 860-863.

Preston, G.L. (2004). Review of the Status of Shared/Common Marine Living Resource Stocks and of Stock Assessment Capability in the BoBLME Region. Bay of Bengal Large Marine Ecosystem (BOBLME) Theme report, FAO-BOBLME Programme.

Salahuddin, A., Isaac, R.H., Curtis, S. and Matsumoto, J. (2006) Teleconnections between the sea surface temperature in the Bay of Bengal and monsoon rainfall in Bangladesh, *Global and Planetary Change*, **53**(3), 188-197.Samarakoon, J. (2004). Issues of livelihood, sustainable development and governance: Bay of Bengal. Ambio 33(1-2): 34- 44.

Samarakoon, J. (2006). South Asian Seas Region, p 137 – 155 in: UNEP/GPA (2006), The State of the Marine Environment: Regional Assessments. UNEP/GPA, The Hague.

Sampath, V. (2003). National Report on the Status and Development Potential of the Coastal and Marine Environment of the East Coast of India and its Living Resources. BOBLME, FAO GCP/ RAS/ 179/ WBG, Chennai, India.

Sea Around Us (2007). A Global Database on Marine Fisheries and Ecosystems. Fisheries Centre, University British Columbia, Vancouver, Canada. www.seaaroundus.org/lme/SummaryInfo .aspx?LME=34

Sherman, K. (2003). Physical, biological, and human forcing of biomass yields in Large Marine Ecosystems. ICES CM 2003/P:12.

Silvestre, G and Pauly, D. (eds). (1997). Status and Management of tropical coastal fisheries in Asia. ICLARM Conference Proceedings 53, 208 p.

Silvestre, G.T, Garces, L.R., Stobutzki, I., Ahmed, M., Valmonte-Santos, R.A., Luna, C.Z., Lachica-Aliño, L., Munro, P., Christensen, V. and Pauly, D. (eds). (2003). Assessment, Management and Future Directions for Coastal Fisheries in Asian Countries. WorldFish Center Conference Proceedings 67, 1120 p. [Also available as CD-ROM]

Thia-Eng, C., Ross, S.A. and Hu, Y. (1997). Malacca Straits Environmental Profile. GEF/UNDP/IMO Regional Programme for the Prevention and Management of Marine Pollution in the East Asian Seas.

Townsley, P. (2004). Review of Coastal and Marine Livelihoods and Food Security in the Bay of Bengal Large Marine Ecosystem Region. Report prepared for the Bay of Bengal Large Marine Ecosystem Programme. FAO-BOBLME Programme.

Vivekanandan, E., Srinath, M. and Kuriakose, S. (2005). Fishing the marine food web along the Indian coast. Fisheries Research 72 (2-3): 241-252.

Wafar, M.V.M. (1999). Status report India, p.25-26 in: Linden, O. and Sporrong, N. (eds), Coral Reef Degradation in the Indian Ocean (CORDIO). Status Reports and Project Presentations 1999. Stockholm, Sweden.

Wilkinson, C. (2002). Coral bleaching and mortality - the 1998 event 4 years later and bleaching to 2002, p 33-44 in: Wilkinson, C.R. (ed), Status of Coral Reefs of the World: 2002. GCRMN Report, Australian Institute of Marine Science, Townsville, Australia.

WRI (2005). Coastal and Marine Ecosystems: Country Profiles. http://earthtrends.wri.org/ country_profiles/index.cfm?theme=1&rcode=1

Wyrtki, K. (1973). Physical Oceanography of the Indian Ocean, p 18-36 in Zeitzschel, B. (ed), Biology of the Indian Ocean. Springer-Verlag, Berlin.