X-28 Yellow Sea: LME #48

S. Heileman and Y. Jiang

The Yellow Sea LME is bordered by China and the Korean Peninsula. It is one of the largest shallow continental shelf areas in the world, covering an area of about 437,000 km^2, of which 1.75% is protected (Sea Around Us 2007) and with an average depth of 44 m and maximum depth about 100 m (Tang 2003). The Kuroshio Current is the major driver of the shelf water circulation. There are 10 major estuaries (Sea Around Us 2007), and some of the rivers discharging directly into the Yellow Sea include the Han, Yangtze and Huanghe. River discharges peak in the summer and have important effects on the LME's salinity and hydrography. In addition to river runoff, other major potential sources of nutrient input into the Yellow Sea LME are the atmosphere and intrusion of oceanic water from the Kuroshio Current (Zhang *et al*. 1995). A monsoon climate regime prevails in this region. Book chapters and reports pertaining to this LME are by She (1999), Tang (1989, 2003), Tang & Jin (1999), Tang *et al*. (2000), Zhang & Kim (1999) and UNEP (2005).

I. Productivity

The Yellow Sea LME is a Class I, highly productive ecosystem (>300 $gCm^{-2}y^{-1}$). Spring and autumn peaks in the production cycle have been observed. Neritic diatoms, dominated by species such as *Skeletonema costatum*, *Coscinodiscus* sp., *Melosira sulcata* and *Chaetoceros* sp., are the major constituents of the phytoplankton. Zooplankton biomass increases from north (5-50 mgm^{-3}) to south (50-1,000 mgm^{-3}), with the dominant zooplankton species being *Sagitta crassa*, *Calanus sinicus*, *Euphausia pacifica* and *Themisto gracilipes* (Tang 2003).

The LME supports substantial populations of fish, invertebrates, marine mammals and seabirds. Its fauna is recognised as a sub-East Asia province of the North Pacific Temperate Zone (Zhao 1990). Thirty-one marine mammal species are found in the LME (Sea Around Us 2007). All the living components of the ecosystem show marked seasonal variations (Tang 2003). There is evidence of change in the composition of both phytoplankton and zooplankton communities in the Yellow Sea (GEF/UNDP 2007). Climatic variability is a secondary driving force of biomass change in this LME, following overfishing (Sherman 2003).

Oceanic fronts (after Belkin et al. 2009): Several tidal mixing fronts (Figure X-28.1) exist within this LME, which includes the Yellow Sea and Bohai Sea (Hickox *et al*. 2000, Belkin & Cornillon 2003). The most conspicuous fronts are observed around Shandong Peninsula (between Yellow Sea and Bohai Sea), off Jiangsu Shoal, and off two major bays west of the Korean Peninsula. A new front identified in Bohai Sea (Hickox *et al*. 2000) is likely a water mass front between waters that flow in and out of the Bohai Sea. The freshwater discharge of the Yellow River plays a minor role in maintaining the Yellow Sea fronts compared with the Yangtze River discharge's role in maintaining the East China Sea LME fronts. A subsurface front in the central part of the Yellow Sea surrounds a cold water mass formed by wintertime cold air outbreaks (Belkin *et al*. 2003).

Yellow Sea LME SST (after Belkin 2009) (Fig. X-28.2)
Linear SST trend since 1957: 0.97°C.
Linear SST trend since 1982: 0.67°C.

The Yellow Sea experienced long-term fast warming superimposed over a regime shift in the late 1970s-early 1980s. The regime shift was accentuated by two cold events that peaked in 1977 (when SST dropped by >3°C, from 15.5°C in 1975 to 12.4°C in 1977) and in 1981. These cold spells were barely noticeable in the adjacent East China Sea LME. However, the year of 1981 was anomalously cold in the Kuroshio Current LME, Sea of Japan/ East Sea LME, and Oyashio Current LME. Therefore the event of 1981 was of a large scale. The cold peak of 1977 was confined to the Yellow Sea. The previous year of 1976, with a 2°C drop in just two years, was relatively cold in the adjacent East China Sea LME. This extreme event was likely caused by cold air outbreaks from Siberia.

A recent study of the ERA-40 reanalysis and other data sets, including HadISST and SODA (Simple Ocean Data Assimilation), has shown the observed warming of the Yellow Sea to have likely been a result of global climate warming, which caused a weakening of the winter and summer monsoons over the Yellow Sea after 1976, hence a weakening of wind stresses (Cai et al. 2006).

The East China Sea warming was not spatially uniform (Wang, 2006). In summer, the SST warmed in the north and cooled in the south. Warming rates exceeded 0.02°C per year in the coastal zones of the northern Yellow Sea, whereas cooling rates exceeded -0.02°C/a in the south. In winter, the SST warmed at a rate of >0.04°C per year in the Yellow Sea Warm Current contained within the central Yellow Sea, suggesting rapid warming of its source, the Kuroshio Current.

Figure X-28.1. Fronts of the Yellow Sea LME. BSF, Bohai Sea Front; JF, Jiangsu Shoal Front; KyBF, Kyunggi (Kyonggi) Bay Front; SPF, Shandong Peninsula Front; WKoBF, West Korea Bay Front. Yellow line, LME boundary. (After Belkin et al. 2009).

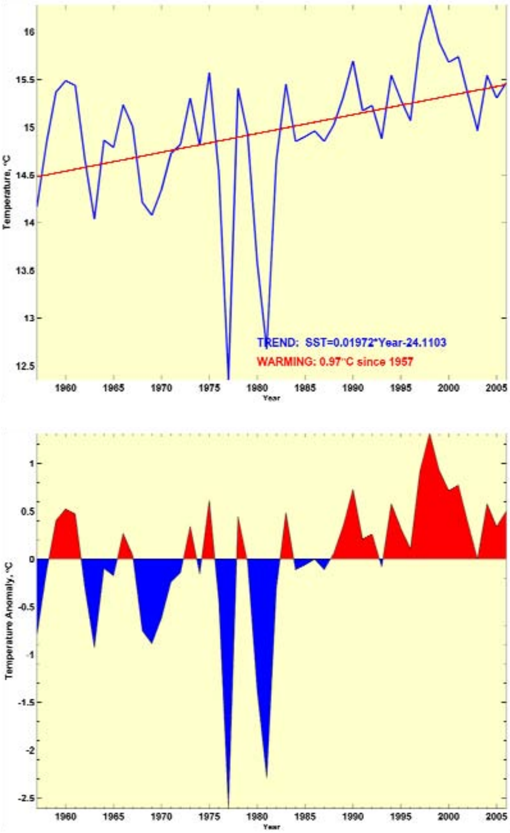


Figure X-28.2. Yellow Sea LME annual mean SST (top) and SST anomalies (bottom), 1957-2006, based on Hadley climatology. After Belkin (2009).

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

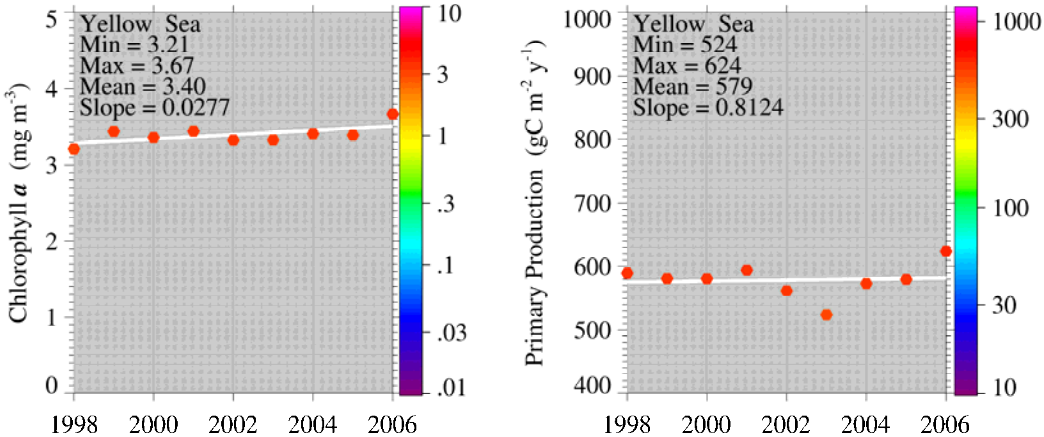


Figure X-28.3. Yellow Sea LME trends in chlorophyll *a* (left) and primary productivity (right), 1998-2006. Values are colour coded to the right hand ordinate. Figure courtesy of J. O'Reilly and K. Hyde. Sources discussed p. 15 this volume.

II. Fish and Fisheries

The Yellow Sea LME has well-developed multispecies and multinational fisheries. The fish communities are diverse, ranging from warm water species to cold temperate species (Tang 2003). About 100 species of fish, squid and crustaceans are commercially fished, among which are Pacific saury (*Cololabis saira*), chub mackerel (*Scomber japonicus*), hairtail (*Trichiurus lepturus*), Japanese anchovy (*Engraulis japonicus*), yellow croaker (*Pseudosciaena polyactis*) and Japanese flying squid (*Todarodes pacificus*). In addition to the capture fisheries, the culture of seaweeds and shellfish is an important economic activity, particularly in China. The growth rate of sea farming and ranching production is greater than the growth rate of marine capture fisheries in China.

Total reported landings in the LME have been on the rise, recording 3.3 million tonnes in 2000 and 3 million tonnes in 2004 (Figure X-28.4). The value of the reported landings peaked at 6.8 billion US$ (in 2000 real US$) in 1977 (Figure X-28.5).

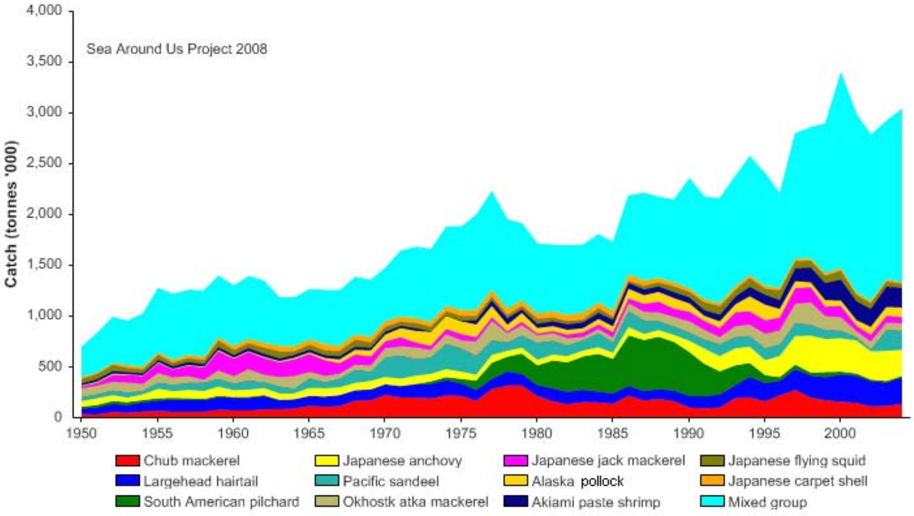


Figure X-28.4. Total reported landings in the Yellow Sea LME by species (Sea Around Us 2007).

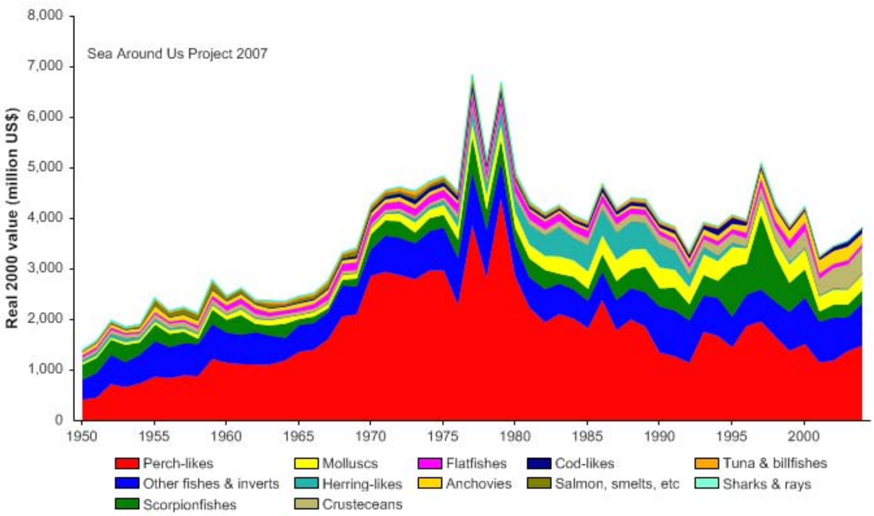


Figure X-28.5. Value of reported landings in the Yellow Sea LME by commercial groups (Sea Around Us 2007).

The primary production required (PPR) (Pauly & Christensen 1995) to sustain the reported landings in this LME reached 90% of the observed primary production in the late 1990s, a level far too high to be realistic (Figure X-28.6). Such PPR is likely a result of an over-reporting of catches in the underlying statistics by misreporting of catches outside the LME as local catch, or an under-estimate of primary productivity in the region, or both. The dominance of China in this ecosystem, however, is not likely to be an artefact of the estimation errors.

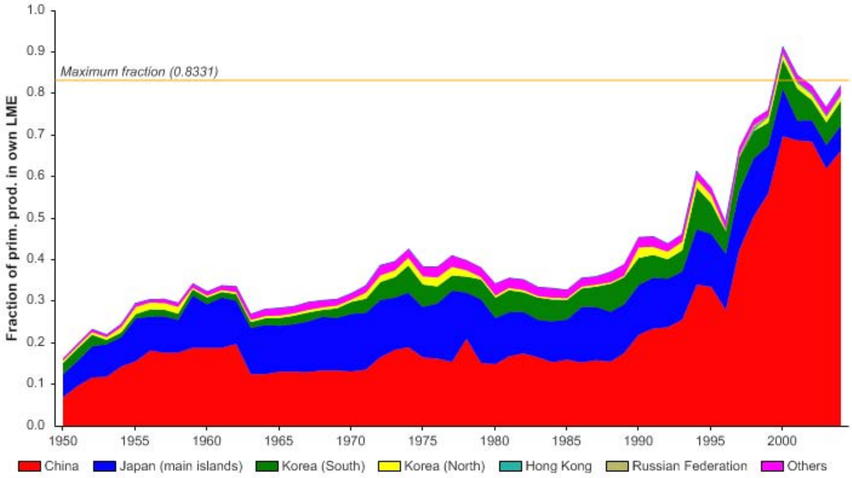


Figure X-28.6. Primary production required to support reported landings (i.e., ecological footprint) as fraction of the observed primary production in the Yellow Sea LME (Sea Around Us 2007). The 'Maximum fraction' denotes the mean of the 5 highest values.

The mean trophic level of the reported landings (Pauly & Watson 2005; Figure X-28.7 top) and the Fishing-in-Balance index (FiB) (Figure X-28.7) are difficult to interpret, likely due to the possible misreporting in the underlying catch statistics (see above).

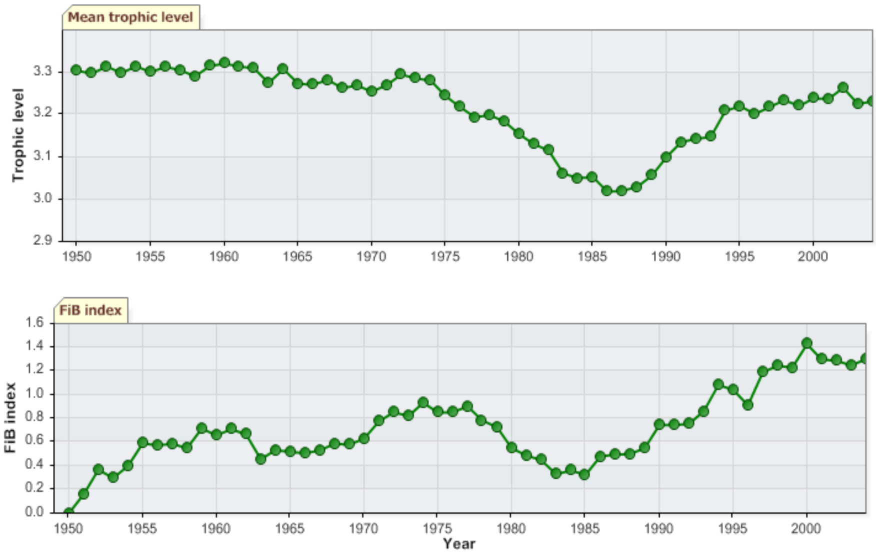
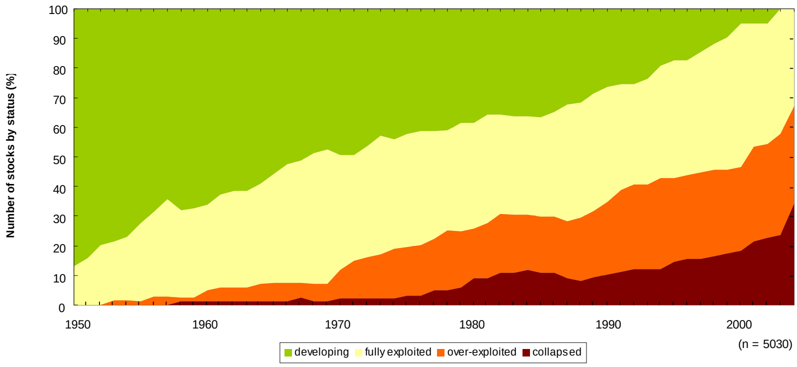


Figure X-28.7. Mean trophic level (i.e., Marine Trophic Index) (top) and Fishing-in-Balance Index (bottom) in the Yellow Sea LME (Sea Around Us 2007).

The Stock-Catch Status Plots indicate that the number of collapsed and overexploited stocks have been increasing, accounting for 60% of the commercially exploited stocks in the LME (Figure X-28.8, top). However, 70% of the catch is still supplied by fully exploited stocks (Figure X-28.8, bottom). Again, the quality of the underlying catch data must be questioned.



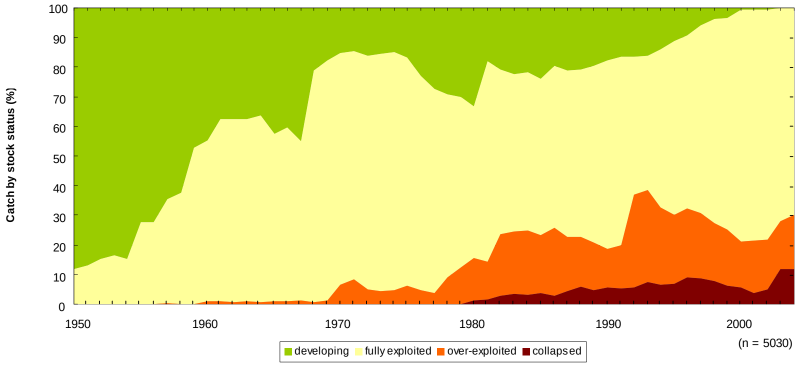


Figure X-28.8. Stock-Catch Status Plots for the Yellow Sea LME, showing the proportion of developing (green), fully exploited (yellow), overexploited (orange) and collapsed (purple) fisheries by number of stocks (top) and by catch biomass (bottom) from 1950 to 2004. Note that (n), the number of 'stocks', i.e., individual landings time series, only include taxonomic entities at species, genus or family level. Higher and pooled groups have been excluded (see Pauly *et al*, this vol. for definitions).

The Yellow Sea LME Transboundary Diagnostic Analysis (TDA) (GEF/UNDP 2000) for the Yellow Sea LME Project funded by the Global Environment Facility (GEF), has identified the decline in commercial fisheries as one of the major transboundary concerns in the LME. The 2007 TDA on reducing environmental stress in the Yellow Sea Large Marine Ecosystem (GEF/UNDP 2007) identifies over-exploitation of target wild fish species and the impact of climate change, the decline in landings of many traditional commercially important species, increased landings of low value species, overcapacity of the fishing sector, and unsustainable mariculture as the issues of greatest concern. It notes the dominance of the overall fisheries catch by China for all species, the apparent decline of the Pacific herring, the rapid growth of the anchovy fishery in China to a level of 0.6 million tons in 1996, and the recovery of small yellow croakers, a species that is economically important in the Yellow Sea LME. The increased presence of jellyfish is a reflection of changes in primary and secondary productivity in the system and alterations to the food web of the Yellow Sea (GEF/UNDP 2007). Despite the increase in annual catch, overexploitation was found to be severe in this LME (UNEP 2005), one of the most intensively exploited areas in the world. Changes in the dominant species are believed to reflect a response to overexploitation of the dominant stocks as a result of increased fishing effort (GEF/UNDP 2007). While natural environmental perturbations might have contributed to an increase in the abundance of small pelagic species (Tang & Jin 1999), intensive fishing is the primary driving force of biomass changes in this LME (Sherman 2003, Tang 2003). Many stocks became intensively exploited by Chinese, Korean and Japanese fishers following the introduction of bottom trawlers in the early 20th Century. The increase in fishing effort and its expansion to the entire LME resulted in almost all major stocks being fully fished by the mid-1970s and overfished by the 1980s (Zhang & Kim 1999, Tang 2003). Dramatic declines in CPUE of the Korean fleet occurred in the late 1970s and the average CPUE in the 1990s was less than one tenth of the highest CPUE in the mid-1970s (GEF/UNDP 2000). Similarly, catches of major fish species on the Chinese side of the LME also showed a dramatic decline, particularly yellow croakers.

Overexploitation of the major stocks has had a significant impact on the ecosystem as a whole, as reflected by major biomass flips (Sherman 1989, Tang 2003). In the 1950s-1980s, the larger demersal and predatory pelagic species with a higher commercial value were replaced by low value species, primarily small pelagic fish such as chub mackerel, black scraper (*Navodon modestus*) and Japanese anchovy. Accompanying the changes in species composition were changes in the size structure of the fish populations. In 1986, about 70% of the biomass consisted of fish and invertebrates with a mean standard length of 11 cm and a mean weight of 20 g. In contrast, the mean body length in the 1950s and 1960s exceeded 20 cm. The mean trophic level of the catch also declined between the 1950s and 1980s.

Overexploitation has transboundary implications because many fish species in this LME migrate among the common fishing grounds of China, Korea and Japan. Destructive fishing practices, such as indiscriminate trawling in coastal waters and the use of explosives and chemicals, are of transboundary importance as these practices have a detrimental impact on the spawning and breeding grounds of the shared fish stocks. Up to 30% of all the catch from the Chinese and Korean sides consists of bycatch, which occasionally includes seals (Jin 2003). In recognition of the severe overexploitation condition, fishing effort has been reduced for Chinese fishers with a suspension of fishing during the 3 months of summer initiated in 1995 to protect juveniles (Tang 2003).

III. Pollution and Ecosystem Health

Pollution: In general, pollution was found to be severe in localised hotspots (UNEP 2005). The rivers that discharge into coastal areas and harbours are the most serious sources of pollution (She 1999; Chua 1999). Major pollutants include organic material, oil, heavy metals and pesticides that come mainly from industrial wastewater, domestic sewage, coastal cities, agriculture and mariculture areas (Zhou *et al*. 1995, She 1999). More than 100 million tonnes of domestic sewage and about 530 million tonnes of industrial wastewater from coastal urban and rural areas are discharged into the nearshore areas of the Yellow Sea each year (GEF/UNDP 2000). Some improvements may be expected in the future through efforts by both the Chinese and Korean governments to improve capacity in treating industrial wastes and domestic sewage.

Eutrophication is severe in this LME (UNEP 2005), with an increase in the frequency, extent and duration of HABs since the early 1970s, mainly on the Chinese side, as a result of increasing nutrient inputs, mariculture and weather anomalies (She 1999). HAB organisms may be introduced by shipping traffic and the huge discharge from the Changjiang River during the summer monsoon. China’s State of the Environment for 2007 reports, for 2005, 82 cases of red tides with “large-scale red tides concentrated in the middle Zhejiang Province, outer Yangtze River Mouth, Bohai Bay, Meizhou Bay”

(SEPA 2007). This results in reduced diversity among algal and zooplankton species and is harmful to higher organisms such as fish (GEF/UNDP 2007). There has been a significant increase in the abundance of jellyfish and jellyfish blooms in the Yellow Sea LME (GEF/UNDP 2007). Jellyfish cause interference with fishing activities and pose threats of stinging to sea bathers.

The concentration of metals, pesticides and petrogenic hydrocarbons in marine organisms is gradually increasing, sometimes to levels exceeding those allowable for consumption (She 1999). Pollution by suspended solids is localised in coastal areas (SEPA 2004). Indiscriminate discharge of garbage and other solid wastes from mariculture, urban centres and tourism has greatly increased the amount of floating solid wastes in rivers and coastal waters (UNEP-RRC.AP 2003, SEPA 2004). Existing sanitary landfills are not sufficient to effectively handle the solid wastes, particularly on the Chinese side. Although the impacts are largely localised, solid wastes may have transboundary impacts since they can be carried across national borders by ocean currents.

Effective enforcement by both the Chinese and Korean governments in recent years has helped to control oil spills from maritime activities (SEPA 2004). Nevertheless, oil spill incidents on the Chinese side of the Yellow Sea LME have increased substantially over the years, and are expected to rise with increasing oil and natural gas exploration and exploitation activities. Furthermore, increasing economic development in the region is expected to triple the shipping traffic over the next 25 years, increasing the likelihood of oil spills (GEF/UNDP 2000).

Habitat and community modification: The main cause of habitat loss has been land reclamation, especially in estuaries and shallow bays (GEF/UNDP 2007). Coastal habitats, especially estuaries and shallow bays, are threatened by intensive coastal development and land filling that destroys wetlands, resulting in severe overall habitat and community modification (UNEP 2005). More than 30% of the mud bottom habitat was lost over the past 30 years due to agriculture, increased mariculture activities, and the opening up of salt-pans (GEF/UNDP 2007). Effluents from industrial complexes, coastal cities, tourism and recreational activities also contribute to the degradation of coastal habitats. Heavy erosion has occurred in about 30% of the sandy foreshore on the Chinese side, mainly from beach sand mining, road construction and recreational activities along the coastal plains (SEPA 2001). China’s State of the Environment for 2005 (SEPA 2007) reports good coastal seawater quality in Hainan, Guangxi, Shandong and Guangdong, while Shanghai and Shejiang suffered from bad coastal seawater quality.

Habitat modification has resulted in changes in biodiversity, species composition and community structure in some areas. Many commercial species of shrimp, crab and shellfish, especially in nursery and spawning areas, as well as benthic communities, have been seriously affected or have disappeared as a result of pollution and high sediment loads (She 1999). For example, species from the family *Nereidae* and lancelets (*Amphioxus*) have become rare and biodiversity has been significantly reduced in sandy foreshore areas. Substantial changes in the biodiversity of benthic organisms in the muddy foreshore of the region have also occurred. For instance, in the 1950s, the benthos in some areas contained about 170 species, which were reduced to some 70 species in the 1980s and to only a few pollution-resistant species in the 1990s (NEPA 1997). The number of economically important species has been reduced in estuaries and the ecological function of these habitats as spawning and nursery grounds for fish and shrimps has been impaired. The decline of vulnerable species is attributed to loss of habitat along with overexploitation of fisheries and destructive fishing practices, climatic change, rapid economic development, the increased demand for seafood, and engineering works on watercourses (GEF/UNDP 2007).

IV. Socioeconomic Conditions

The areas that drain into the Yellow Sea LME are inhabited by about 600 million people or 10% of the world's population (GEF/UNDP 2000). The inhabitants of large coastal cities such as Qingdao, Tianjin, Shanghai and Pyongyang are dependent on the LME as a source of food, economic development, recreation and tourism. Petroleum exploration and exploitation form an important economic sector in the Chinese and North Korean parts of the Yellow Sea. In addition, the sea is becoming increasingly important to shipping, with a growth in international trade in the region.

Fishing and mariculture constitute an important source of food, employment and foreign exchange to the bordering countries. Overfishing has reduced the available food supply for local communities. Poor catches have reduced business activities in the seafood processing industry by around 10%, with obvious economic implications (Pauly et al. 1998; UNEP 2005). The decline in capture fisheries has promoted the development of mariculture in China. Mariculture for shellfish and seaweeds has a long history in the region. The combined production of mariculture and aquaculture has grown to a level of 6 million tons in 2004 (GEF/UNDP 2007).

Over the past decades, increased pollution has had severe socioeconomic impacts (UNEP 2005). Pollution of localised near-shore areas, bays, and coastal habitats from land-based sources is affecting the livelihoods of the local population. There has been a loss of 30-50% of the development potential of the coastal areas for recreational activities (SEPA 2004), and drastic declines in fisheries and the production of penaeid shrimp and scallop in some areas (Jin 2003). The high concentrations of heavy metals and pesticides in some species have reduced the commercial value of these products (She 1999). SEPA 2007 reports that direct economic losses caused by red tides exceeded 69 million yuan in 2005. Pollution has also affected human health, with an increase in the incidence of diseases, seafood poisoning and death from the consumption of contaminated seafood. Habitat degradation has affected not only the value and ecological functions of habitats, but also the livelihoods of coastal communities (Xie & Wang 2003). Improved governance mechanisms are needed to better balance socioeconomic development and environmental protection.

V. Governance

Governance of the LME is shared by China, North Korea and South Korea. While the three countries have different governmental structures and national laws in place relating to the management of aquatic resources and environmental protection, they are parties to international conventions such as UNCLOS, MARPOL, the Convention on Biodiversity (CBD), Ramsar, the Basel Convention, and the FAO Code of Conduct for Responsible Fisheries, and to bilateral treaties. Regional and international programmes, organisations with water-related activities such as NOWPAP and PICES (see the East China Sea LME for information on NOWPAP and PICES), and the UN Economic and Social Commission for Asia and the Pacific form a strong institutional framework for the marine environment. The transboundary issues of concern in the LME are the management of living marine resources, industrial pollution and ecosystem health (GEF/UNDP 2000 and 2007). To aid the recovery of depleted fish stocks, China has started to close the Yellow Sea LME to Chinese fishers for 2 -3 months in the summer to protect juvenile stages of fish (Tang 2003). Marine protected areas were established in 2005 in Ximen Island off Leqing City and in the Ma'an Islands of Shengsi County, Zhejiang Province to protect marine species resources, terrestrial features and intertidal wetlands.

Progress is being made in the introduction of ecosystem-based management in this LME (Zhang & Kim 1999). GEF supported a Regional Programme for Marine Pollution Prevention and Management in the East Asian Seas region from 1994 to 1999. At present, China and South Korea are partnering in the GEF-supported project 'Reducing Environmental Stress in the Yellow Sea Large Marine Ecosystem'. The long-term objective of this project is to ensure environmentally sustainable management and use of the LME and its watershed by reducing stress and promoting the sustainable development of the LME. This project has prepared a Preliminary TDA (GEF/UNDP 2000) which was updated in 2007 (GEF/UNDP 2007), along with National Yellow Sea Action Plans and a regional SAP, to be implemented by the Yellow Sea LME project. The TDA has identified governance and capacity building as major transboundary issues to be addressed. This LME is also included in the PEMSEA project (see the Gulf of Thailand LME, Chapter VIII). To strengthen regulations pertaining to environmental protection and resolve issues effectively in the Yellow Sea LME, a governance commission is being developed as a non-legally binding cooperative institution run by the participating governments to carry out joint scientific research projects and improve legal institutions and partnerships for the protection of the Yellow Sea marine environment.

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