Changing States of the Yellow Sea Large Marine Ecosystem: Anthropogenic Forcing and Climate Impacts

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The Yellow Sea Large Marine Ecosystem is a semi-enclosed shelf sea with distinctive bathymetry, hydrography, productivity, and trophically dependent populations. Shallow but rich in nutrients and resources, the Yellow Sea LME has productive and varied coastal, offshore, and transboundary fisheries. Over the past several decades, the resource populations in the Yellow Sea have changed greatly. Many valuable resources are threatened by unsustainable exploitation and by natural perturbations. To promote sustainable exploitation of the sea and implement effective management strategies is an important and urgent task.

The purpose of this chapter is to describe the Yellow Sea LME, emphasizing the changing states of productivity and biomass yields in the ecosystem and their causes, affected by both anthropogenic forcing and climate impacts. Suggestions for adaptation actions for ecosystem-based management in the LME are discussed in the final section.

The Setting

The Yellow Sea LME is located between continental North China and the Korean Peninsula. It is separated from the West Pacific Ocean by the East China Sea in the south, and is linked with the Bohai Sea, an arm of the Yellow Sea in the north. It covers an area of about 400,000 km^2, with a mean depth of 44m. Most of the Sea is shallower than 80m. The central part of the sea, traditionally called the Yellow Sea Basin, ranges in depth from 70m to a maximum of 140m.

The general circulation of the Yellow Sea LME is a basin-wide cyclonic gyre comprised of the Yellow Sea Coastal Current and the Yellow Sea Warm Current. The Yellow Sea Warm Current, a branch of the Tsushima Warm Current from the Kuroshio Region in the East China Sea, carries water of relatively high salinity (> 33 PSU) and high temperature (> 12°C) northward along 124°E and then westward, flowing into the Bohai Sea in winter.

This current, together with the coastal current flowing southward, plays an important role in exchanging the waters in this semi-enclosed sea (**Figure 1**).

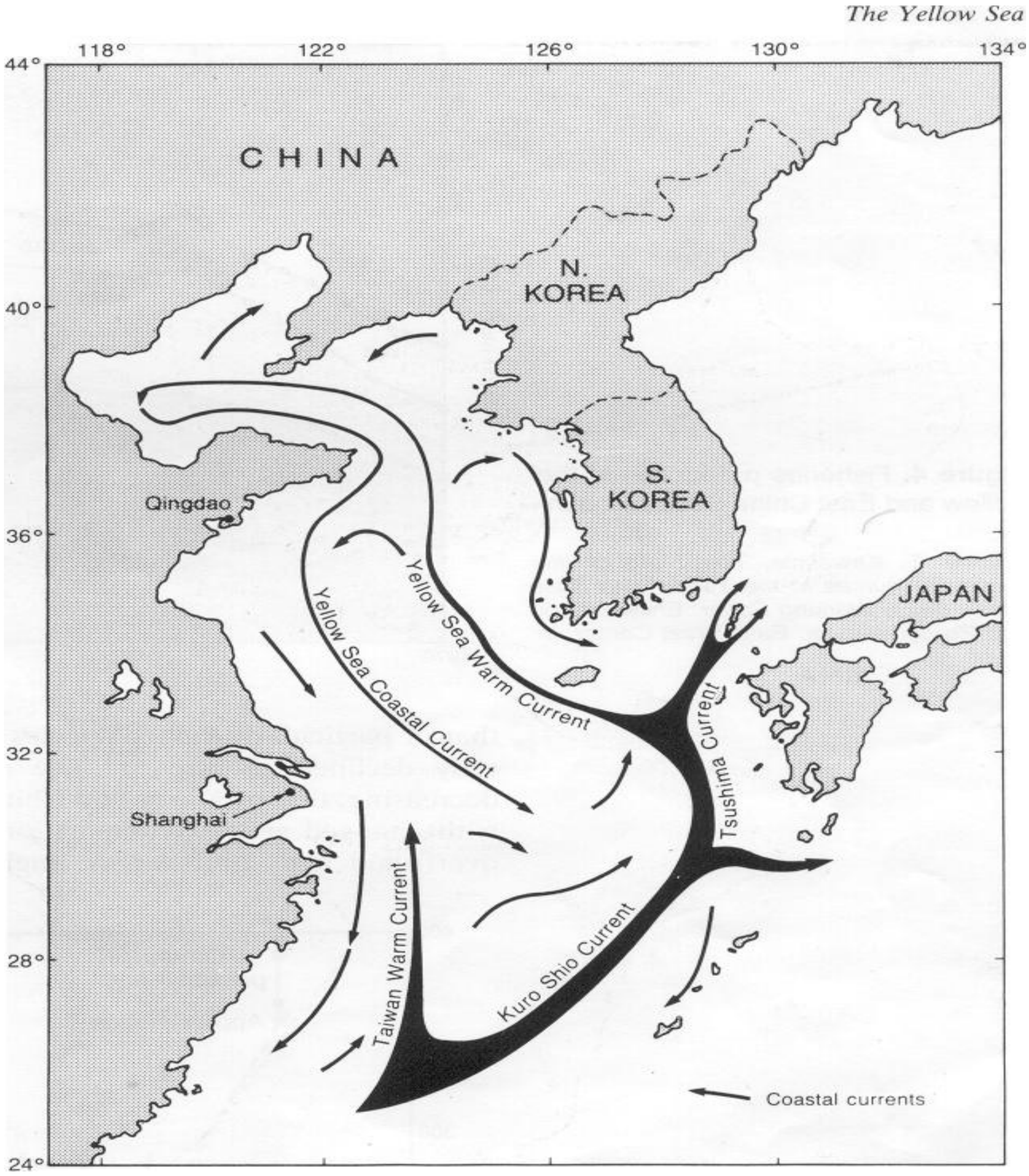

Figure 1. Schematic diagram of the winter current system
in the Yellow Sea LME (from Gu *et al*. 1990).

Below 50m, the Yellow Sea Cold Water Mass forms seasonally and is characterized by low temperature with the bottom temperature lower than 7°C in its central part. It is believed to be the remnant of local water lifted over from the previous winter due to the effect of cold air from the north (Ho *et al.* 1959; Guan 1963). Stratification is strongest in summer, with a vertical temperature gradient greater than 10°C/10m. All rivers into the Yellow Sea LME have peak runoff in summer and minimum discharge in winter, which has important effects on salinity of the coastal waters.

The Yellow Sea LME lies in the warm temperate zone, and its communities are composed of species with various ecotypes. Warm temperate species are the major component of the biomass, accounting for about 60 percent of the total biomass of resource populations; warm water species and boreal species account for about 15 percent and 25 percent, respectively. The Yellow Sea LME food web is relatively complex, with at least four trophic levels (Tang 1993). There are two trophic pathways: pelagic and demersal. Japanese anchovy and macruran shrimp (e.g., *Crangon affinis* and southern rough shrimp) are keystone species. About 40 species, including almost all of the higher carnivores of the pelagic and demersal fish, and the cephalopods, feed on anchovy. *Crangon affinis* and southern rough shrimp, which are eaten by most demersal predators (about 26 species), are numerous and widespread in the Yellow Sea LME. These species occupy an intermediate position between major trophic levels and interlock the food chain to form the Yellow Sea food web.

The resource populations in the Yellow Sea LME are multispecies in nature. Approximately 100 species are commercially harvested, including demersal fish (about 66 %), pelagic fish (about 18 %), cephalopods (about 7 %), and crustaceans (about 9 %); about 20 major species accounted for 92 percent of the total biomass of the resource populations, and about 80 species accounted for the other 8 percent. With the introduction of bottom trawl vessels in the early twentieth century, many stocks began to be intensively exploited by Chinese, Korean, and Japanese fishermen (Xia 1960). The stocks remained fairly stable during World War II (Liu 1979). However, due to a remarkable increase in fishing effort and its expansion to the entire Yellow Sea LME, nearly all the major stocks were fully fished by the mid-1970s, and the resources in the ecosystem began to be over-fished in the 1980s (Tang 1989). Aquaculture is a major utilization of the Yellow Sea coastal waters. Major species of mariculture include scallops, oysters, clams, mussels, seaweed, shrimp and some fish.

Changing States of the Yellow Sea Ecosystem

(1) Changes in Ecosystem Biodiversity

Over the past 50 years, dramatic changes in species composition, dominant species and community structure of resource populations in the Yellow Sea LME have been observed — from small yellow croaker and hairtail in the 1950s and early 1960s to Pacific herring and chub mackerel in the 1970s，to Japanese anchovy and sandlance after the 1980s. Small-sized, fast-growing, short-lived, and low-valued species increased markedly in abundance during the 1980s and assumed a prominent position in the ecosystem’s resources and food web thereafter (**Figure 2** and **Figure 3**).

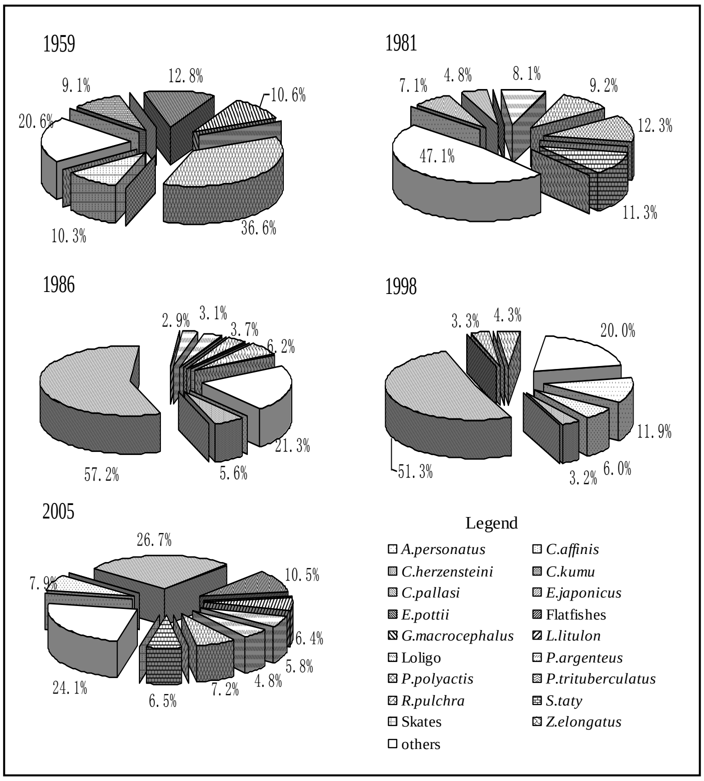

Figure 2. Changes in species composition of resource populations in the Yellow Sea LME (based on biomass yields data of spring survey).

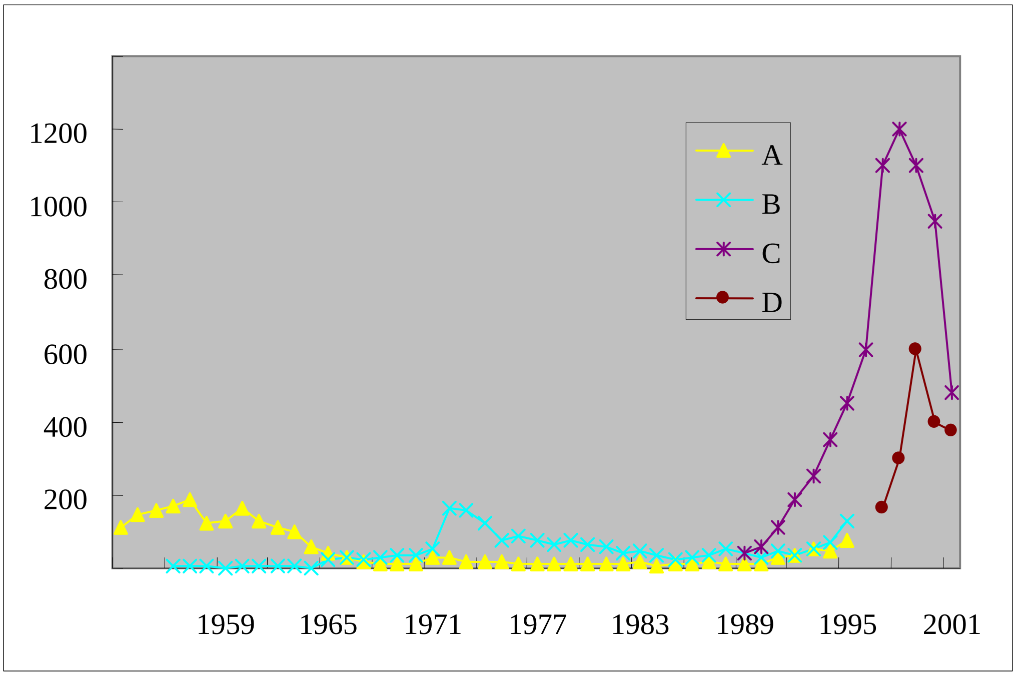

Figure 3. Changes of annual catch in dominant species of resource populations in the Yellow Sea: (A) small yellow croaker and hairtail, (B) Pacific herring and chub mackerel, (C) anchovy, and (D) sandlance.

As a result, larger, higher trophic level, and commercially important demersal species were replaced by smaller, lower trophic level, pelagic, less-valuable species. The most recent surveys indicate that the abundance of pelagic species such as the Japanese anchovy is declining, while the biomass of demersal species is increasing (**Figure 4**). The stock of small yellow croaker has shown a recovery trend since middle 1990s.

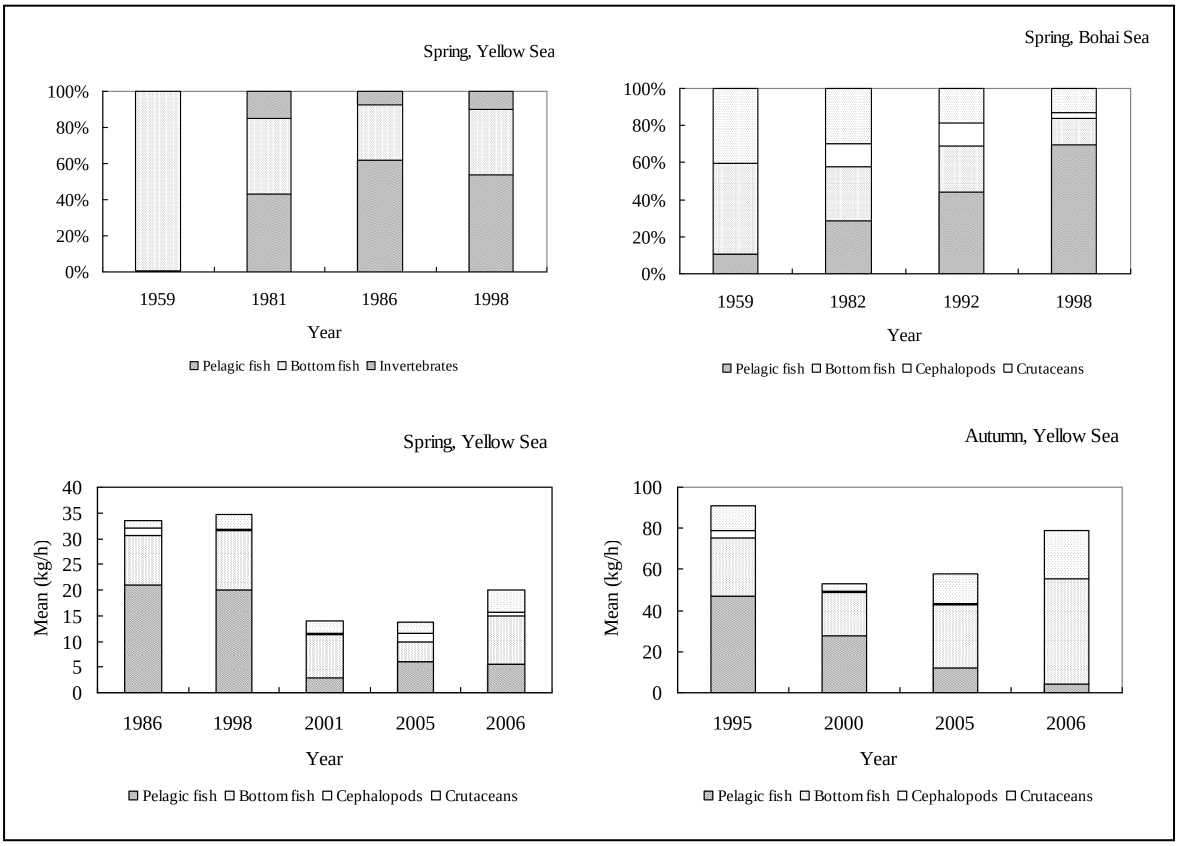

Figure 4. Changes in community structure of resource populations in the Yellow Sea LME (based on biomass yields data of survey).

Changes in Ecosystem Productivity

Annual variation of ecosystem productivity has been observed in the Yellow Sea LME. As shown in **Figure 5**, primary productivity in the Bohai Sea decreased noticeably from 1982 to 1998. Over the past 40 years, a trend of obvious decline of phytoplankton biomass has been observed, seemingly linked with nutrient changes (Tang 2003). Zooplankton is an important component in Yellow Sea communities. The dominant species, *Calanus sinicus*, *Euphausia pacifica*, *Sagitta crassa*, and *Themisto gracilipes*, are all important food for pelagic and demersal fish and invertebrates. The annual biomass of zooplankton in the Bohai Sea has decreased noticeably since 1959. However, zooplankton biomass increased in the sea in 1998, possibly due to the decline of the anchovy stock, which was the most abundant species before 1998. Fish stocks have decreased since the 1980s, although biomass yields were at a high level in 1998-2000 in the Yellow Sea LME. As a result, the trophic level of fish stocks declined from 4.1 in 1959-60 to 3.4 in 1998-99 in the

Bohai Sea; and from 3.7 in 1985-86 to 3.4 in 2000-01 in the Yellow Sea (Zhang and Tang 2004). `

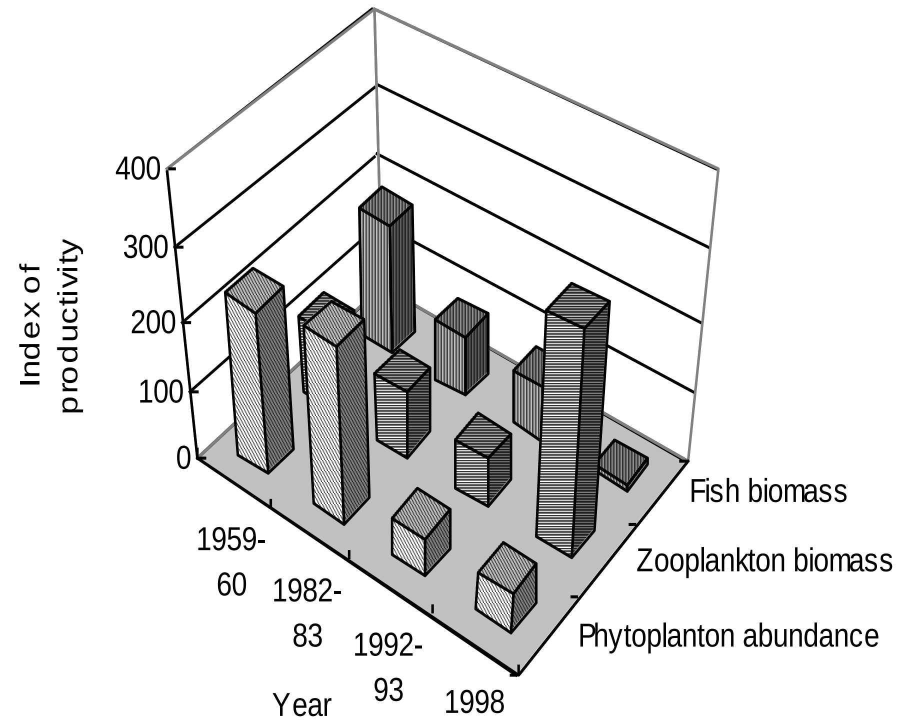

Figure 5. Decadal-scale variations of ecosystem productivity at different trophic levels in the Bohai Sea (phytoplankton abundance, $\times 10^4$cell m^{-3}, zooplankton biomass, mg m^{-3}, fish biomass, kg $haul^{-1}$ h^{-1}; from Tang et al. 2003.

Changes in Ecosystem Health

Major pollutants entering the Yellow Sea LME are organic material, oil, heavy metals and pesticides. Pollutants from municipal, industrial and agricultural wastes and run-off, as well as atmospheric deposition, are ‘fertilizing’ coastal areas triggering harmful algal blooms and oxygen deficient ‘dead zones’. The harmful algal blooms and low levels of dissolved oxygen in the water make it difficult for fish, benthic fauna and other marine creatures to survive and for related social and economic activities to be sustainable. Since the 1970s, the annual mean of water temperature and dissolved nitrogen in the sea increased by 1.7°C and 2.95 μmol $L^{-1,}$ respectively, while those of dissolved oxygen, phosphorus, and silicon decreased by 59.1, 0.1 and 3.93 μmol L^{-1}, respectively (Lin *et al.* 2005).

As a result, the frequency of occurrence of harmful algal blooms has gradually increased, and the size of hypoxia areas (where DO≤2mg/l) is on the rise in coastal areas (**Figure 6**). These events affect the most productive areas of the marine environment leading to the destruction of habitats of vital importance for maintaining ecosystem health.

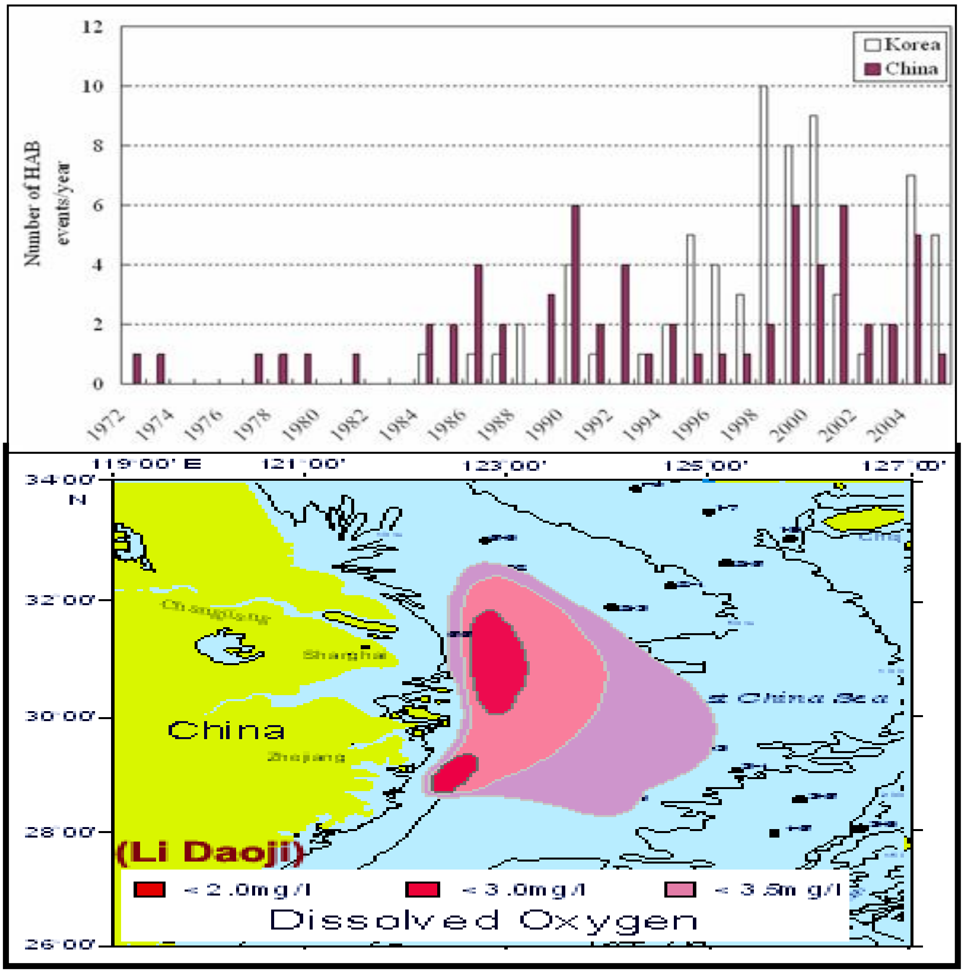

Figure 6. Serious eutrophication, harmful algal blooms and dead zones in coastal areas.

Changing courses

Generally speaking, changes in the quantity and quality of marine ecosystem resources are attributed principally to human predation, as demonstrated by many studies (e.g., Tang 1989, 1993; Zhang and Kim 1999). However, an analysis of inter-decadal variations of ecosystem production in the Bohai Sea indicates that it is difficult to use traditional theory (e.g. top-down control, bottom-up, or wasp-waist control) to explain directly and clearly the long-term variations of production levels in the coastal ecosystem (Tang *et al.* 2003). We observe that under the same fishing pressure, the biomass yields of some exploited stocks in the Yellow Sea appear to be fairly stable (e.g. Spanish mackerel), or recovered (e.g. small yellow croaker). Changes in biomass yields and species shifts in dominance cannot be explained merely by fishing pressure. Climate change may have important effects on the recruitment of pelagic species and shellfish in the Yellow Sea LME. A new study identifies four SST regimes in the Yellow Sea LME over the past 138 years: a warm regime (W) before 1900, a cold regime (C) from 1901 to 1944, a warm regime with a cooling trend (WC) from 1945 to 1976, and a warm regime with a warming trend (WW) from 1977 to 2007 (**Figure 7**). SST regime shifts and fluctuations in herring abundance in the Yellow Sea LME show a very good match.

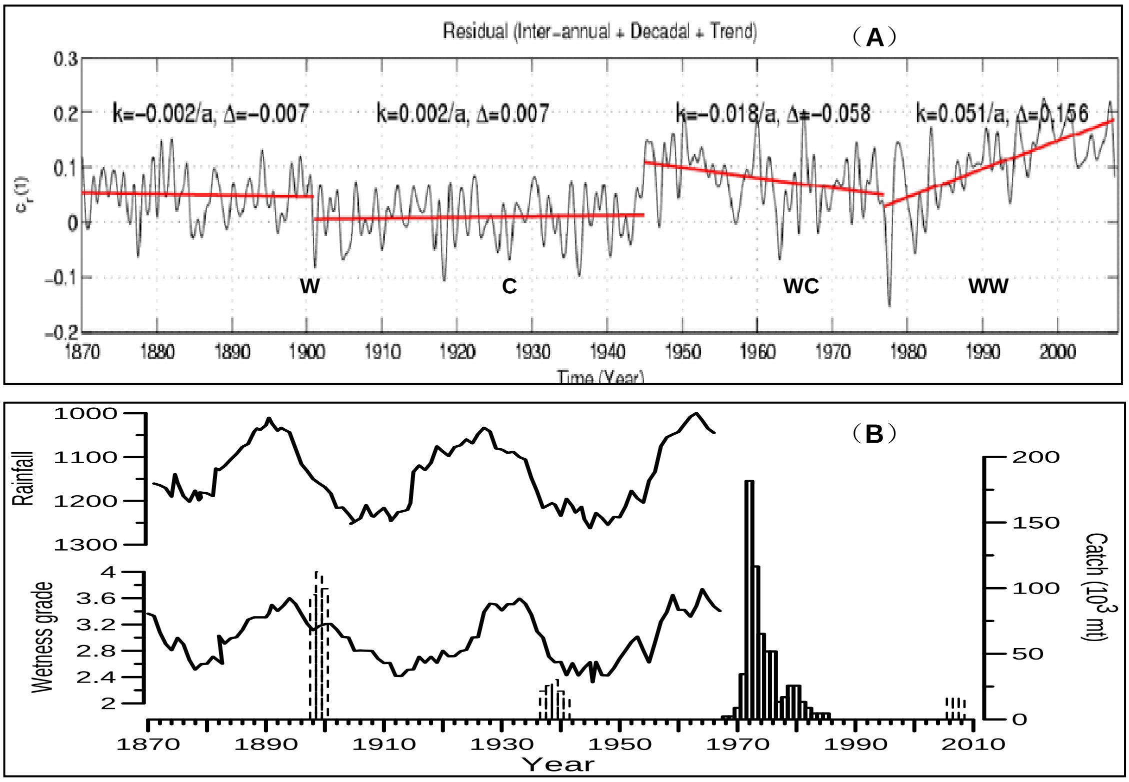

Figure 7. (A) The residual SST after removing its annual signal. W, C, WC and WW refer to the four regimes characterized by, respectively, warm, cold, warm with cooling trend, and warm with warming trend (unpublished data, from Daji Huang et al.); **(B)** Relationship between the fluctuations in herring abundance of the Yellow Sea and the 36-yr cycle of wetness oscillation in eastern China (adapted from Tang 1981).

Pacific herring in the Yellow Sea LME has a long history of extreme variability in exploitation. In the last century, the commercial fishery experienced three peaks (in 1900, 1938 and 1972), followed by periods of little or no catch (Tang 1995). Since 2005, both herring stocks and eelgrass, where herring spawn, have increased in Sungo Bay, a former major herring spawning ground and now a large scale mariculture area. However, the recovery is not complete. At the same time, several unusual events have occurred in the coastal areas. A false killer whale visited Qingdao Bay. The last time local people saw false killer whales was more than 30 years ago. On 18 January 2008, a sperm whale landed on ‘Herring Beach’ in Sungo Bay. This was the first time local people saw a species this large (body length, 19.6 m; weight, 51.1 t). We believe that there may be two types of shifts in ecosystem resources: systematic replacement and ecological replacement. Systematic replacement occurs when one dominant species declines in abundance or is depleted by overexploitation, and another competitive species uses the surplus food and vacant space to increase its abundance. Ecological replacement occurs when minor changes in the natural environment affect stock abundance, especially pelagic species. In the long term, the effects of the two types of shifts on the marine ecosystem may be mingled. The regime shifts in the Yellow Sea LME are likely to have important effects on ecosystem resources as found in other areas of the North Pacific Ocean.

Adaptation Actions

Mitigation and Recovery Practice

There are many ways to recover the resources in a stressed LME, such as reducing excessive fishing mortality, controlling point sources of pollution, and gaining a better understanding of the effects of natural perturbations. After 1995, China closed fishing in the Yellow Sea and East China Sea LMEs for 2-3 months in the summer. This fishing ban has effectively protected juvenile fish, leading to an increase in the quantity and quality of fish catches. In addition to these efforts, artificial enhancement in the Yellow Sea LME has been encouraged. Since 1984, the release of penaeid shrimps in the Bohai Sea, the north Yellow Sea and in the southern waters off the Shandong Peninsula has achieved remarkable ecological, social, and economic benefits. The release of scallops, abalone, and arkshell was also successful. These successes point the way forward for artificial enhancement programs in the Yellow Sea LME, and also bring hope for the recovery of ecosystem resources. Artificial enhancement practices are an effective resource recovery strategy that should be expanded to the LME scale.

In studies of the trophodynamics of many important species at high trophic levels, we observed a negative relationship between ecological conversion efficiency and trophic level (**Figure 8**). This new finding indicates that the ecological efficiency of species at the same trophic levels would increase when fishing down marine food webs at lower trophic levels. Based on this new finding, several ecosystem-based management strategies should be considered:

- **Develop a new harvest strategy**: the strategy of ecosystem resource use and management depends on different requirements. If we are concerned with big fish, **A** (harvest species at high trophic levels) will be selected; if we want more seafood, **B** (harvest species at low trophic levels) will be selected. In the case of China, **B** should be selected.

- **Develop a new mariculture model:** integrated multi-trophic aquaculture (IMTA), and shellfish and seaweed mariculture (e.g. scallop, oyster, mussel, clam, Laminaria) should be given priority, because these species not only provide more production but also indirectly or directly reduce atmospheric CO^2 (Zhang *et al.* 2005).

Scientific Support

An essential component of effective ecosystem management is the inclusion of a scientifically based strategy to monitor and assess the changing states and health of the ecosystem by tracking key biological and environmental parameters (Sherman and Laughlin 1992; Sherman 1995). Under this requirement the Block B proposal of the Global Environmental Facility (GEF) for the Yellow Sea LME Project is currently underway.

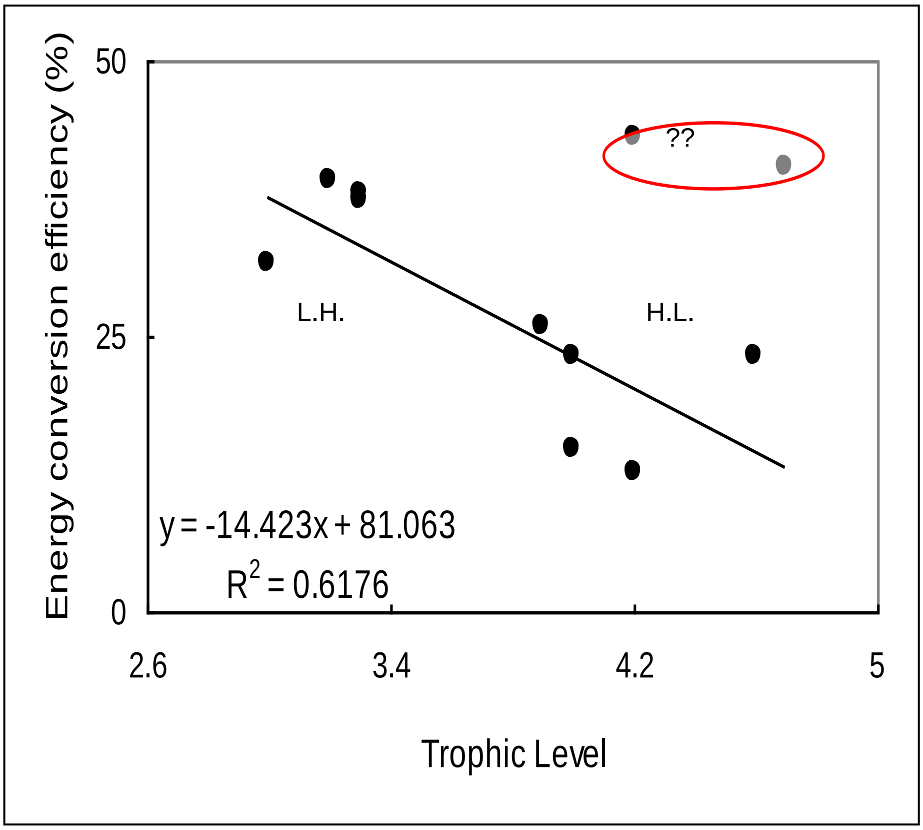

Figure 8. Relationship between ecological conversion efficiency and trophic level in high trophic levels in the Yellow Sea ecosystem (L.H., low Trophic level (TL) and high Energy Conversion Efficiency (ECE): rednose anchovy, sand lance, gizzard shad and finespot goby. H.L., high TL and low ECE: red seabream, black porgy, tiger puffer, fat greenling, black rockfish, and chub mackerel. From Tang et al. 2007.

The long-term objective of the project is to ensure environmentally sustainable management and use of the Yellow Sea LME and its watershed by reducing stress and promoting the sustainable development of a marine ecosystem that is bordered by a densely populated, heavily urbanized, and industrialized coastal area (Project Brief of the Yellow Sea LME, 2000). In order to further understand the Yellow Sea LME, the ongoing China-GLOBEC III/IMBER I Program, entitled “Key Processes and Sustainable Mechanisms of Ecosystem Food Production in the Coastal Ocean of China” (Tang *et al.* 2005), has been approved for the National Key Basic Research and Development Plan of the People’s Republic of China in 2006-2010. The program goals are to identify key processes of food production in the coastal and shelf ecosystems and provide a scientific basis for ensuring food supply in the new century, by establishing a marine management system based on sustainable food production and protection of the ecosystem before the year 2015. Therefore, it is necessary to promote further synergies with other research projects and establish joint programmes for monitoring and assessment for ecosystem-based management in the Yellow Sea LME:

- Monitoring and assessing the changing states and health of the ecosystem represents a scientifically based strategy for effective ecosystem management and recovery.
- A comprehensive process-oriented study of ecosystem goods and services should be considered, for a better understanding of the interactions among the important physical, chemical and biological characteristics of the ecosystem. This will increase the predictive capability of Yellow Sea LME managers.

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