CHAPTER 7

IMPACT OF HUMAN ACTIVITIES ON THE HEALTH OF ECOSYSTEMS IN THE CHANGJIANG DELTA REGION

JING ZHANG, SHI LUN YANG, ZHAO LI XU,

AND YING WU

1. INTRODUCTION

Most of the world mega-cities are located within the distance of 100-200 km from the coast, and the delta region is the place where the modern civilization developed in human history. In the mainland of China, the eleven provinces in the coastal region represents ca. 15 % of the national land surface area, but sustain 40 % of national population with 60 % of total GDP.

Coastal environment represents one of the most dynamic habitats on the earth, i.e. land – ocean interface, and supports some of the most diverse and productive ecosystems (LOICZ: www.loicz.org). Vulnerable coast environments have been disturbed by anthropogenic activities, particularly owing to the rapid industrialization and urbanization in the 20th Century (Kim et al., 1999; Bouloubassi et al., 2001). Land-based activities over the drainage basin (i.e. land clearing, damming, harbor construction and land reclamation) have a profound impact on the coastal environment by changing the fluvial fluxes of water and sediments, perturbation by navigation and engineering construction (e.g. tunnel and bridge), and loss of delta habitat, for example, the Changjiang (Zhang et al., 1999). Moreover, the projected future climate changes will affect the physical, sedimentary and ecological processes in coastal environment, which can be considered an added stress on already overstressed ecosystems; this will further reduce the ability of coastal systems to provide goods and services. For instance, the loss of habitat by coastal erosion, changes in biogeochemical processes by altering nutrient fluxes, and shifts in adjacent marine biological community structure by pollution as well as overfishing, have all been identified as major, on-going impacts. Their occurrence, particularly in areas where rapid economic innovation and population growth take place like China, can be severe (World Resources Institute: www.wri.org).

E. Wolanski (ed.), The Environment in Asia Pacific Harbours, 93–111.

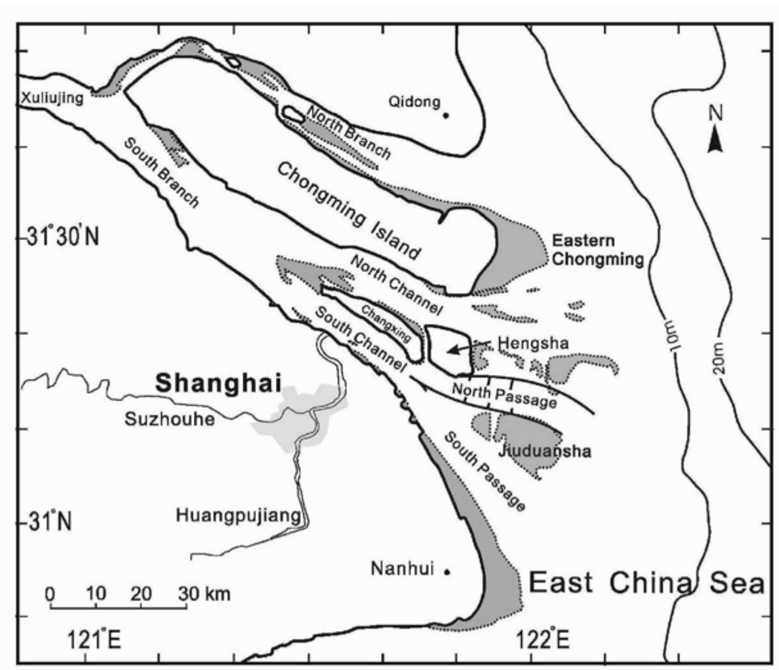

Figure 1. *Study area of the Changjiang Delta Region, which shows the two tributaries, i.e. Huangpujiang and Suzhouhe, draining into the Changjiang Estuary after flowing through Shanghai. The shadowed areas in the figure illustrate the inter-tidal zones of delta region. The Shanghai Port together with ship yards are along the Huangpujiang from its confluence with Changjiang upstream over a distance of ca. 30 km, which will be moved to Changxing and Hengsha in the main stream before the 2010 World Exhibition at Shanghai.*

Prolonged and intensive use of inorganic fertilizer in agriculture, changes in land use patterns, deforestation, and discharge of industrial and municipal wastes have all contributed to the eutrophication of coastal waters on a global scale. The estuarine and coastal regions showing such degradation include the North Sea, Baltic Sea, Adriatic Sea, and North America (De Jonge et al., 1994; Richardson and Heilmann, 1995). Over last 50 years, flux of natural and synthetic materials from the terrestrial sources to the coastal environment has increased by 1.5-2 folds (Meybeck & Ragu, 1995).

Salt marshes are an important sink for nutrients and anthropogenic substances, such as heavy metals in the continuum from land to the ocean (Gambrell, 1994; Callaway et al., 1998; Olivie-Lauquet et al., 2001). The impact of heavy metals and synthetic organic pollutants discharged into salt marshes can be substantial and have potential threat to the health of aquatic food-web (Turner, 1990; Wright & Mason, 1999). Pollutants (e.g. heavy metals) accumulated in the coastal sediments can be remobilized and removed to the deep-water area, impacting on the health of ecosystems (Cundy et al., 1997). Requirement for the protection of coastal environment has promoted the monitoring of pollutants in anthropogenically disturbed ecosystems, particularly harbours and delta regions (Wises et al., 1995; Wright & Mason, 1999; Olivie-Lauquet et al., 2001).

In this study, the status of the Changjiang (Yangtze River) Delta Region is examined (Figure 1). The emphasis is given to the anthropogenic impact on the health of the ecosystem in the delta and adjacent coastal waters, along with the progress of urbanization of Shanghai.

2. CIVILIZATION AND SHANGHAI HARBOR

The early development of civilization in Shanghai can be traced back to the 751 AD in the Tang Dynasty. In the early 1950s, the population of Shanghai was 5.72 million (Figure 2). Shanghai's population increased rapidly to reach over 10 million in 1960, by expansion into urban areas. In 2003, the population of Shanghai reached up to 13.4 million. Concurrently, the proportion of agricultural population in 1950s was 5-10 %, indicating the industrial and commercial character of the city; the population of farming inhabitants was increased to ca. 40 % in 1970-1980 owing to the incorporation of rural regions into the administration of the Shanghai (Figure 2). The agricultural population drops after 1980s following the innovation of economics nation wide and reaches 20 % in the new millennium.

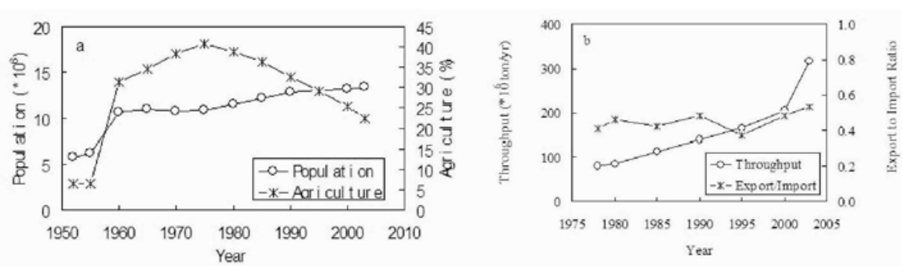

Figure 2. Evolution of Shanghai in the second of 20th century, with (a) change in population for the city and proportion of habitants in agriculture, and (b) increase in the throughput of the harbor after 1975 with the ratio of export to import values (Data Source: www.shtong.gov.cn).

Cargo throughput data for Shanghai harbour were first recorded in the Ming Dynasty, 500-600 years ago, when the annual throughput was ca. 200×10^3 tons, of which about half was for agricultural products and food-stuff transportation (Data Source: www.shtong.gov.cn). In the late 1970s, this throughput amounted to 80×10^6 tons, with the export to import ratio of 0.41 and 30×10^3 of TEU (i.e. standard container). In 2003, the cargo throughput was ca. 320×10^6 tons, with 11.3×10^6 for TEU and an export to import ratio of 0.53 (Figure 2).

3. CHANGES IN RIVERINE FLUXES

The Changjiang carries 1×10^{12} m^3 yr^{-1} of fresh water and 0.4×10^9 tons yr^{-1} (i.e. average from 1951-2004) of terrestrial sediments to the East China Sea. In Figure 3 is shown the DIN (i.e. dissolved inorganic nitrogen) concentration ($DIN=NO_3^-+NO_2^-+NH_4^+$) measured in the main channel at 180 km inland from the river mouth.

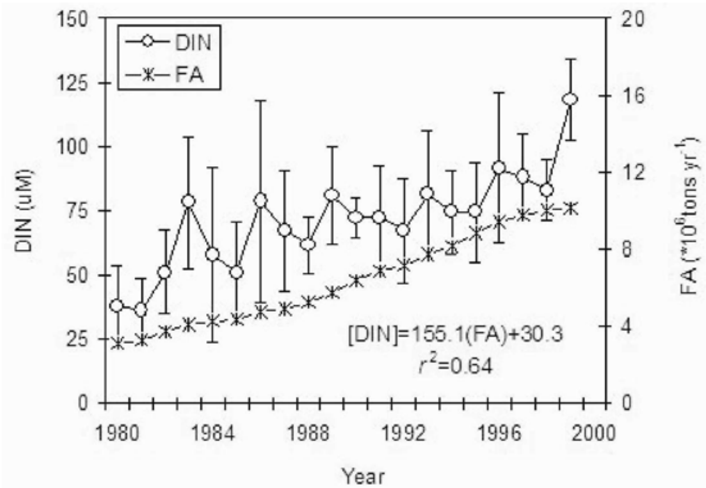

Figure 3. *Change in river composition of nutrients in the Changjiang Estuary, with DIN (i.e. $DIN=NO_3^-+NO_2^-+NH_4^+$) measured at Nantong (180 km inland from the river mouth) and the application of chemical fertilizers (FA) in the Changjiang Drainage Basin after 1980 (Data Source: Zhang, 2002).*

The concentrations of DIN increased from 40-50 μM in early 1980s to ca. 120 μM by 2000, that is, at a rate of increase by 2-3 μM yr^{-1} over last two decades (Figure 3). In the mean time, the application of chemical fertilizers in agriculture over the Changjiang Watersheds increased by 3-4 folds (Figure 3); 60 % of the fertilizers are composed of nitrogen compounds, with 20 % for phosphorus-containing chemicals (Zhang, 2002). In the lower reaches of Changjiang, the DIN to DIP (i.e. dissolved inorganic phosphorus, PO_4^{3-}) ratio in the main stream was ca. 50 in 1980s and 100-150 in 2000; this induces the photosynthesis in the estuarine and coastal waters turning to be phosphorus limited (Zhang, 2002). The concentration of nutrients in tributaries of the Changjiang is even much larger when flowing through the urban areas due to sewage discharges. For example, in the Huangpujiang and Suzhouhe, which flow through the Shanghai, the concentrations of NH_4^+ and PO_4^{3-} can be up to 450 μM and 25-30 μM, respectively (Zhu et al., 2004).

In addition, the Changjiang River carries also other pollutants to the East China Sea. For instance, the COD (i.e. chemical oxygen demand) load of the river is $2\text{-}8\times10^6$ tons yr^{-1} in 2002-2004; also oil pollutants amount to $20\text{-}70\times10^3$ tons yr^{-1} (Table 1). Concentrations of oil pollutants in the Changjiang Estuary can be up to 30-60 μg l^{-1} (State Oceanic Administration, 2004).

The ∑-PCBs in the surface sediments from the Changjiang Delta range from 0.2 ng g^{-1} to 20 ng g^{-1} (Liu et al., 2003). Low concentrations (e.g. <1.0 ng g^{-1}) of ∑-PCBs can be found in the rural area along the coast, while elevated levels (i.e. 5-20 ng g^{-1}) occur in the main channel and near the Shanghai. The concentrations of DDT in surface sediments are 0.5-3.5 ng g^{-1}, showing also higher values in the region affected by urban waste discharges (Chen et al., 2002). Sediment core samples collected from the adjacent coastal region show a considerable variation of deposition rate, i.e. 1-4 cm yr^{-1}, depending on the location of stations. Sediment cores in the delta front and the pro-delta region reveals a minimum concentration of HCH and DDT before 1950s; the concentrations of HCH and DDT increased to reach a maximum in the 1970s; they decreased thereafter (Chen et al., 2002). This implies that the quality of coastal environments has been recovered in recent decades after the national ban issued in 1980s on the use of some of organic pesticides in agriculture (e.g. HCHs and DDTs), although trace amount of these kind of organic pollutants are still reported from sediments in coastal environments (Wu et al., 1999).

Table 1. *Change in discharge of pollutants from the Changjiang to the East China Sea. (Adapted from State Oceanic Administration, 2002-2004).*

Year	COD ($\times 10^6$ tons yr^{-1})	Oil pollution ($\times 10^3$ tons yr^{-1})
2002	2.48	49.6
2003	2.72	69.9
2004	7.80	24.9

4. CHANGE IN HABITATS OF THE DELTA REGION

In the Changjiang Delta, salt marshes typical of a temporal climate zone are well developed; however, these have been increasingly reclaimed in past five decades. The total area of wetlands in the Changjiang Delta is estimated at about 1550 km^2, with an elevation of -6 to 5 m. More than one-third of the inter-tidal wetland is colonized by marsh vegetation, including, for example, *Phragmites* and *Scripus*, providing crucial habitats for a wide variety of widlife, e.g. migratory birds and water fowls (Shi et al., 2001). Previous studies in this region revealed the rapid adjustment of the coastal area after the reclamation, following sedimentation and biomass allocation (Yang, 1998; Sun et al., 2002). A rapid interaction between the estuary and salt marsh in terms of exchange of sediment, leading to erosion at one site and accumulation in another site, has also been noted (Hutchinson and Yu, 1998; Xu et al., 2001).

With the rapid increase in the population in coastal areas of China, the reclamation of tidal wetlands has become a common solution to provide land for the human settlement. Nearly 1000 km^2 of wetland has been reclaimed in the Changjiang Delta Region since the 1950s, which is 65 % of the whole wetland area of delta region and about twice the current total area of inter-tidal zone. For instance, more than half of Chongming Island is derived from reclamation in the period 1940-2003, and newly formed wetlands in the delta region, e.g. Hengsha and Jiuduansha show also rapid changed in surface areas, accelerated by the human activities (Figure 4).

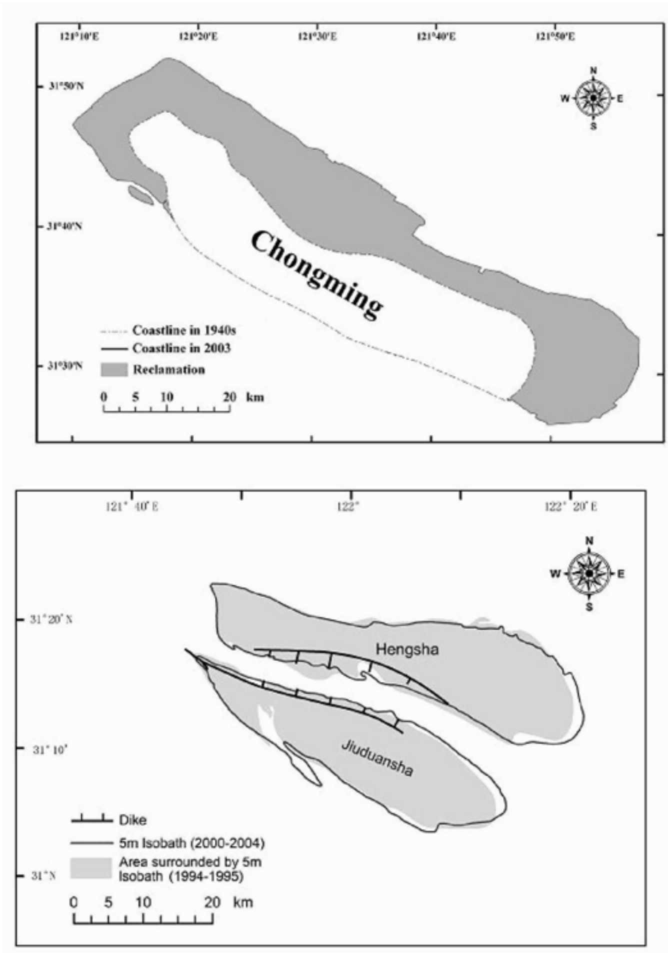

Figure 4. *Anthropogenic perturbations of the wetlands of the Changjiang estuary resulted in the expansion of Chongming Island due to the reclamation of tidal areas since the 1940s (upper panel), and effect of dikes constructed in 1999 on the 5 m isobath in the Hengsha and Jiuduansha shoals (lower panel).*

In the growing seasons, *Scirpus*, the pioneer plant, and *Phragmites* colonize the upper part (i.e. high marsh) of the inter-tidal zone. In the period of 1950-1990, several seawalls were constructed in salt marshes. Although most of the original vegetation of marsh areas (e.g. reeds) was destroyed, the *Scirpus* marsh and the bare mud flats were preserved. In recent years, a seawall was constructed at 0 to -2 m elevation. For example, in the reclamation of Nanhui, the southeast part of the Changjiang Delta Region, a seawall was built at the mean low tide line in 1999 (unpublished data).

The annual sediment load of the Changjiang decreased from 0.5×10^9 tons yr^{-1} in 1950s to $0.3\text{-}0.4\times10^9$ tons yr^{-1} in the 1990s. As a result, the delta responded by decreasing its rate of progradation by 60-65 %, while the vertical accretion rate decreased from 50-60 mm yr^{-1} in 1960-1980 to 10-15 mm yr^{-1} in the 1990s (Yang et al., 2002). In Figure 5 are shown two typical profiles of delta accretion. These data point to rapid accretion of the delta front in the period 1958-1978, stability in 1978-1998, and some recent erosion in the lower reaches of this region. This implies that the sub-aqueous delta front is sensitive to changes in fluvial sediment flux; however the delta accretion is not simply proportional to the fluvial sediment flux (Yang et al., 2003).

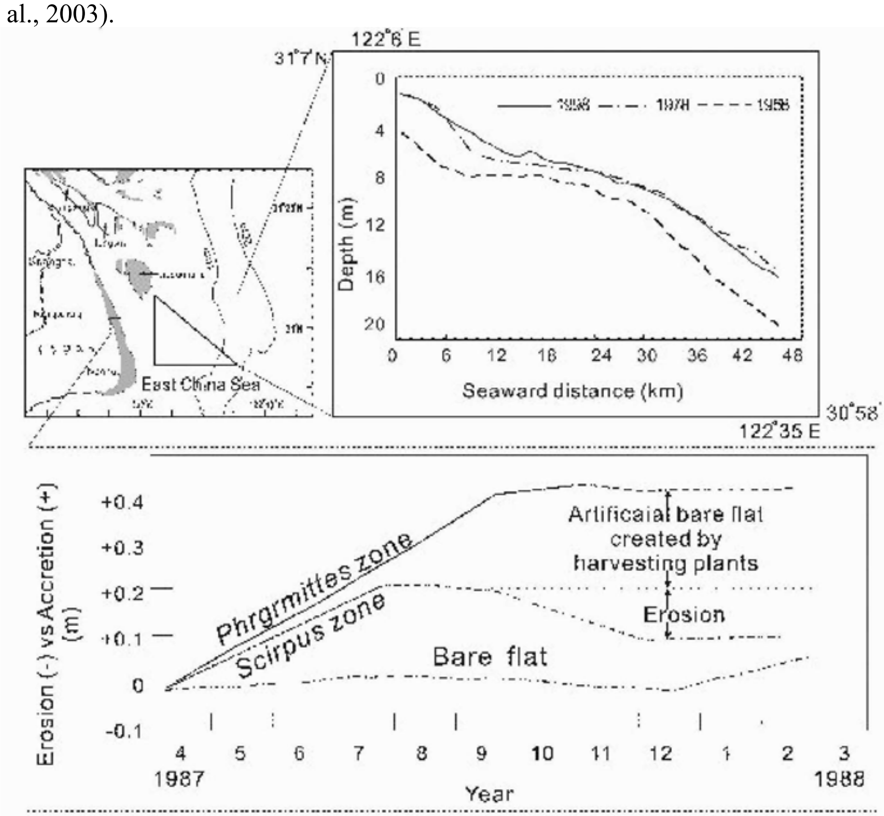

Figure 5. *Map of the Changjiang Delta Region with the major inter-tidal zone as shaded areas (upper left), change in evolution of delta front profiles after 1958 (upper right, and effect of vegetation on the change in salt marsh elevation (bottom).*

The human impact on the wetlands can be deduced from a study of erosion and accretion processes in salt marshes and adjacent bare mudflats. During the growth seasons of spring and summer, the marsh surface is rapidly covered by vegetation (e.g. *Phragmites* and *Scirpus*), which induces a rapid vertical accretion of the marsh area by up to 30-40 cm, while the adjacent mudflat remains relatively stabile. *Phragmites* vegetation is more efficient at trapping sediment than is *Scirpus* vegetation; hence the marsh surface colonized by *Phragmites* accretes almost twice as fast as the area with *Scirpus* cover (Figure 5). When the plant vegetation of the salt marsh is harvested, the surface area becomes a "bare mudflat" and is readily eroded. Hence the accretion of delta region is then stopped and replaced by erosion, and marsh retreats. In winter, the natural bare mudflats accrete considerably by storm-induced sediment deposition; the harvested marsh areas remain largely unchanged, because they are seldom submerged by the tides with elevation being higher than the high tide level (Figure 5).

The Changjiang Estuary has a large block-bar and/or shoal at river mouth that impedes navigation. To improve navigation, a deep channel was dredged and two jetties were constructed in the North Passage in 1998, and later two jetties were constructed to narrow the navigation channel and increase the water depth by dredging. After the construction of these jetties, a significant deposition of sediments occurred in the areas sheltered by these dikes. For instance, the transverse creeks deeper than 5 m disappeared due to sediment depositions at Hengsha and Jiuduansha (Figure 4). For instance, at the Jiuduansha the progradation rate of the area at 0-5 m depth greatly increased since the construction of the dikes (Table 2).

Table 2. *Progradation rate ($km^2\ yr^{-1}$) of area at <5 m isobaths in the Jiuduansha area of the Changjiang Delta.*

Period	Progradation rate ($km^2\ yr^{-1}$)
1989-1995	5.5
1995-1999	2.4
1999-2000	10.1
2000-2004	1.0

5. CHEMICAL COMPOSITION OF DELTA SEDIMENTS

Across the tidal flat of Chongming Island, surface sediment fine landward, for instance, the medium size is ca. 20 μm in the high marshes and 60 μm in the bare mudflats in both the wet and dry seasons (Kang et al., 2003). The 4-63 μm size fraction dominates the sediment distribution, being 80 % in the high marshes and ca. 40 % in the bare mudflats.

The concentration of heavy metals (e.g. Co, Cr, Cu, Fe, Mn, Ni, Pb, V and Zn) decreases by a factor 2-4 from the high marsh to the bare mudflat, heavy metals, even after the normalization of absolute values to Al (Figure 6). The total organic carbon (TOC) in the high marsh (ca. 0.8 %) is four times higher than that in the bare mudflat (ca. 0.1-0.2 %), and shows a positive correlations with metal composition

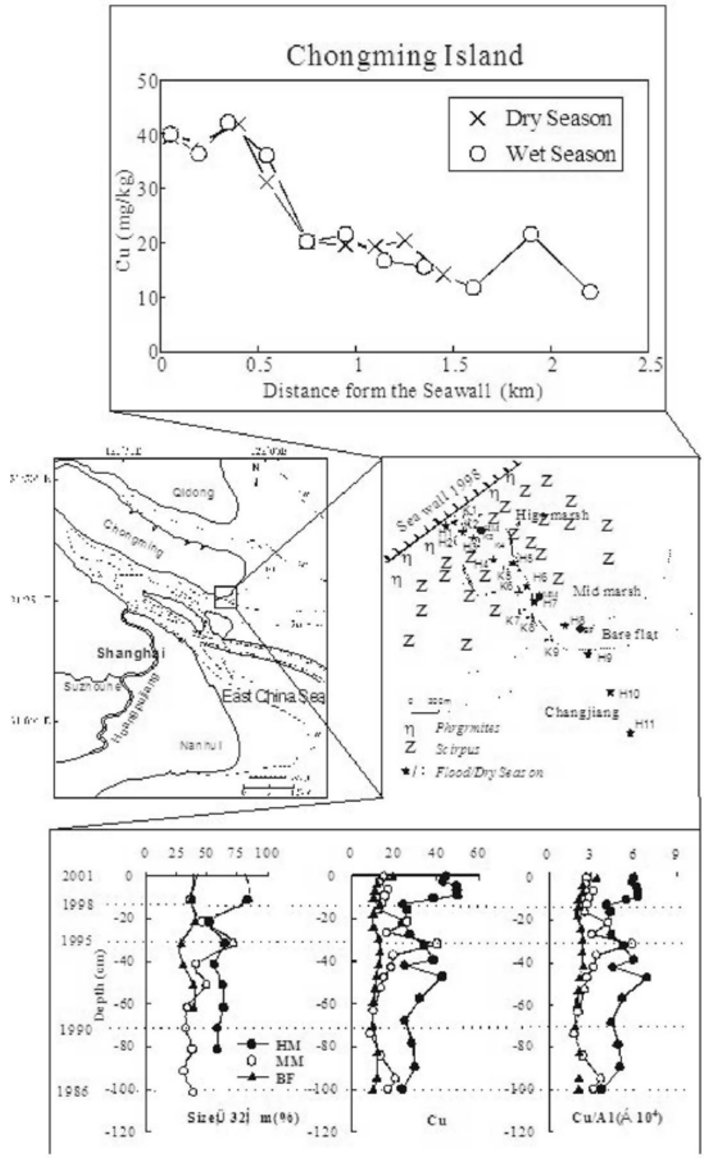

Figure 6. *Map of the Changjiang Delta Region showing the field measurements at the salt-marsh area of the Chongming Island. It shows the profiles of fine sediment (<32 μm), trace metals (e.g. Cu) and Cu/Al ratio from core samples from high marsh (HM), mid-marsh (MM) and bare-flat (BF) in the lower panel, and metal concentrations in surface sediments in a cross-section from high marsh to bare mudflats in wet and dry seasons in the upper panel, respectively.*

(Kang et al., 2003). The concentration of total organic carbon in core samples of salt marsh increases with higher content of clay component of sediments.

Sediment cores collected from high and low marshes and bare mudflat from Chongming Island show that the concentrations of trace metals increase with higher fine sediment fractions, e.g. size fraction of ≤32 μm, indicating the dominance of active sedimentary dynamics (e.g. fine sediment exchange between wetland and water channel) on the metal distribution (Kang et al., 2003). The metal concentrations in the bare mudflats are comparable to that in the suspended materials, showing dominance of terrestrial source in the delta region. There has been no significant difference in the chemical compositions for sediment samples from the Changjiang Estuary in last two decades (Zhang, 1999).

The sediment cores collected from the salt marsh in the Changjiang Delta Region show a wide range of deposition rates, up to 0.1-0.2 m yr^{-1}, depending upon the position of samples. The ^{210}Pb profiles in core sediments from salt marsh indicate rapid adjustment of sediment accumulations following anthropogenic perturbations. For instance, the seawall constructed in 1998 on Chongming Island has induced change in sediment accumulation rate in the high marsh from 8-10 cm yr^{-1} to 4-5 cm yr^{-1} soon after construction. Also as a result of the seawall construction, there was a higher component of fine sediment; as a result the metal concentrations increased, while in the deeper part of the sediment cores the metal concentrations were more stable and within the range of chemical compositions for the water column of Changjiang Estuary (Figure 6). Again, the reclamation of wetland in the delta region of Changjiang dramatically reduces the sediment delivery from the water channel to the marsh area, the limited supply of sediment particles in the high marsh can be trapped by the vegetation, such as *Phragmites* and *Scirpus*, particularly in spring tides of summer and fall (Yang et al., 2003), which can induce the higher metal concentrations as compared to the bare flat where the sediment size composition usually have more abundant coarse mineral particles.

The concentrations of heavy metals in delta sediments are higher in the area off the sewage drainage, but relatively low in other samples and comparable to the national background value for soils. Moreover, the metal concentrations from salt marsh sediments in the Changjiang Delta Region are lower than those from Europe, for example, the Thames Estuary and salt marsh along the Atlantic coast of Spain, either in absolute levels and metal to Al ratio (Attrill and Thomes, 1995; Carimen et al., 1997).

6. FISHERIES IN THE ESTUARY

The spawning, hatching, and recruitment of fish species have been greatly impacted by the engineering activities in the Changjiang Estuary, including dredging of navigation water-way port and seawall construction. The salinity at the river mouth has decreased by up to 10-15 after the construction of jetties of the deepwater navigation channel (see also Zhu et al., 2005). Also, the changes in dynamic conditions generate more frequent resuspension of bottom sediments and increase the sediment flux through the channel area, which affects the composition of benthic fauna. The biodiversity of benthic fauna has decreased for the last 25 years. Within the benthic fauna, polychaeta, mollusca, and crustacea show a dramatic reduction in species composition and biomass.

The dredging of bottom sediments for navigation causes the loss of habitat for benthic fauna, for example, *Eroicheir sinensis*. Moreover, the resuspension of bottom sediments in dredging activity results in the alteration of life history of crab (e.g. zoea and megalopa); high turbidity affects the feeding and food-size selectivity of larvae and induces the retard of the molt cycle of stage zoea I (Wang et al., 1999a). Also, the remobilization of heavy metals by dredging in the Changjiang Estuary causes a negative physiological behavior (e.g. spawn and hatch) of benthic fauna; the release of metals (e.g. Cd^{2+}, Cu^{2+}, Hg^{2+}, Pb^{2+} and Zn^{2+}) from resuspended sediments can induce high mortality of crab larva (i.e. stages of zoea I-IV), with 24 hr – LC_{50} at metal level of 100 μM (Wang et al., 1999b).

The benthic fauna were relatively abundant in the 1970s, with species number of 150-160 (Figure 7). The species abundance for benthic fauna fell to 30-40 in 1990 and then to 10-20 in 2002 (Ye et al., 2004a). At the same time, the major components of the benthic fauna, i.e. polychaeta, mollusk and crustacean, all show a concurrent reduction of species abundance by 80-90 % from 1970s to 2002. After the 1990, the species abundance of benthic fauna remains low but rather stable, with polychaeta and mollusk being more abundant than crustacean (Figure 7).

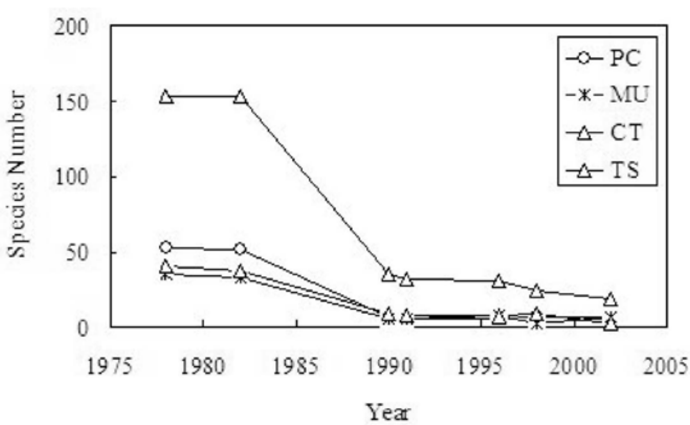

Figure 7. *Changes in benthic fauna in the Changjiang Estuary, which indicates that the total species (TS) number of community decreased by 6-8 times in the period 1978-2002, together with reduction in species compositions for major benthic structure, including polychaeta (PC), mollusk (MU) and crustacean (CT), respectively (Adapted from Ye et al., 2004b).*

The comparison to the data of 1990s reveals that traditional key species of benthic fauna, such as *Palaemon gravieri*, *Exopalaemon annandalei*, *Collichthys lucidus*, *Harpodon nehereus*, *Eriochier leptognathus*, *Ericthonius sp.*, and *Capitellethus sp.* were not found anymore in 2002 (Ye et al., 2004a-b). Moreover, the biomass abundance of benthic fauna in sediments in areas affected by the engineering activity is on average only 21.6 individuals m^{-2} in 2003-2004, which is 85.9 % that in the 1980s, that is, before the substantial dredging for navigation (Ye et al., 2004b).

Dredging induces the systematic excavation of bottom sediments; constructions for harbor and bridge destroy habitats necessary for the spawning and recruitment of fish species, while reclamation of salt marsh for agriculture and human settlements result in further loss of habitat in the Changjiang Delta Region. Consequently, wildlife is dramatically impacted and become less abundant than in the past. For instance, the biomass of *Stolephorus*, a traditional commercial fish species in the region, has been considerably reduced after 1990 and shows almost no landing records in last 5-10 years (Data Source: www.shtong.gov.cn). In the early 1960s, the catch of *Stolephorus* in the Changjiang Estuary, as reported from the Year Book of Shanghai, was 560 tons yr^{-1}, the landing of this species dropped to 5-10 tons yr^{-1} in 1990 (Figure 8). Although the extinction of *Stolephorus* is believed to have started from the destruction of spawning ground by pollution before the construction of the jetties, the jetty construction interferes, however, with the recruitment of adult species by blocking the migration routes, making reproduction unsustainable. Similarly, the landing records for crabs in this region show shut-down of commercial values after 1980s owing to the over-fishing and destroy of habitats by human beings in coastal environment (Figure 8), and the catch of crabs was banned in 1990 owing to a population crash.

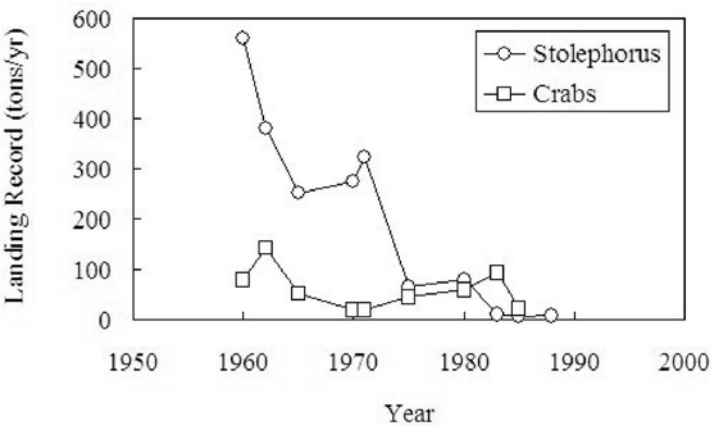

Figure 8. *Change in landing records for Stolephorus and crabs in the Changjiang Estuary based on the data from municipality of Shanghai, which shows the dramatic reduction in fish catch in the period of 1980-1990 (Data Source: www.shtong.gov.cn).*

From the local government statistics, the fishery industry has collapsed since the initiation of channel dredging and construction of jetties in the Changjiang Estuary in 1990s. *Coilia mystus* (Linnaeus) and *Coilia nasus* Temminek et Schlegel are two of few remaining native fish species and once served as most important fishery resources with important commercial value (Ni, 1999). One of the plausible explanations for their decreased biomass is the combination of two factors, namely the pollution-induced change in plankton community and the function of jetty modifying the bottom morphology, the hydrographic conditions (e.g. circulation) and the salinity as well as blocking the migratory routes of fish (Figure 9). As the jetties narrow the water channel and increase the water depth by dredging, the natural structure of bottom sediments in adjacent areas is under continuous modification, e.g. by erosion and dredging, and the dredged sediments are removed to the wetlands nearby, which causes the irreversible damage to benthic fauna. As shown in Figure 9, the construction of jetty can eventually block the migratory routes and damage the spawning ground for certain important fishery species in this region, inducing collapse of recruitment.

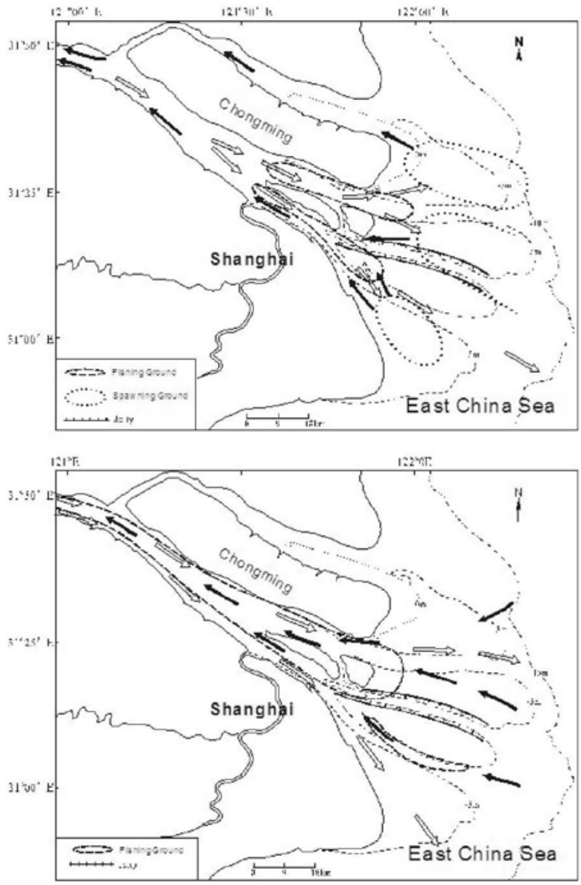

Figure 9. *Map of the Changjiang Estuary, which shows the migration routes of Eriochier sinensis (upper panel) and Coilia mystus (lower panel) with fishing and spawning/hatching fields; the two jetties in the main channel are also shown. The full and open arrows show the up-river and down-river migration routes of the adults and larvae, respectively. (Adapted from Yu, 1998, and Ni et al., 1999).*

Acipenser scnensis Gray migrates up-stream the estuary to spawn; it has now become so rare that it has been put in the national list of threatened and endangered species. The reason for the population crash is that from May to September the larvae of *Acipenser scnensis* migrate down the estuary to feed and grow before going offshore as adults migrating to the Yellow Sea and the East China Sea. Based on field observations, dense populations for *Acipenser scnensis* larvae were found to the southeast of Chongming Island. As fish habitats in that region were destroyed by coastal engineering (i.e. reclamation) in the Changjiang Estuary after 1990, the recruitment of this species decreased. This effect is compounded by overfishing and the construction of the jetties, putting the standing stocks of this species into a critical status.

7. HARMFUL ALGAL BLOOMS IN THE ADJACENT COASTAL WATERS

The records of harmful algal blooms (HABs) in China can be traced in literature back to 1950s (Zhang, 1994). In the periods of 1950s-1990s, 118 HABs were reported in the coastal environment of East China Sea, accounting for 35-40 % of total national records (Zhou et al., 2001). It is indicated that after the 1990s, the appearance and economic loss caused by HABs in China have dramatically increased, e.g. by 5-10 folds. For instance, in 2004 four major HABs are reported in the region off the coast from Shanghai (i.e. off the Changjiang Estuary), i.e. about 10 % of total events recorded for the East China Sea (Table 3), and 60 % of HABs recorded in 1990-2001 in the region off the Changjiang Estuary occur in spring of the year (Zhou et al., 2003), which is further increased to 60-80 % in the new millennium. Moreover, the HABs off the coasts from Changjiang Delta Region differ from those in other areas of China Seas by longer duration, larger area and diverse species compositions. The most extensive HABs in the East China Sea are usually found 50-100 km off the river mouth from Changjiang at water depth of 30-40 m, with surface area up to 1000-1500 km^2 along the coastal front region further offshore from high turbidity Changjiang effluent plume that can be easily seen from satellite images. Concentrations of chlorophyll-a can be as high as 300 mg m^{-3} induced by HABs in the region of salinity for 25-30. In this region, the HABs in spring are usually caused by dinoflagellates, notably the *Prorocentrum dentatum*, while in summer and autumn the dominated species become the diatoms, for example, *Skeletonema coastum*, when Changjiang floods. Data from mesocosm experiments show that diatoms (e.g. *Skeletonema coastum*) become more abundant

Table 3. *Records of HABs in the coastal waters off Shanghai with comparison to the East China Sea (Data are from State Oceanic Administration, 2001-2004).*

Year	Shanghai	East China Sea	All China Seas
2001	2	34	77
2002	5	51	79
2003	8	86	119
2004	4	53	96

than dinoflagellates (e.g. *Prorocentrum dentatum*) towards the addition (e.g. riverine input) of plant nutrients (e.g. PO_4^{3-}) and hence the overwhelming species through competition, whereas at low nutrient case dinoflagellates remain dominant (Li et al., 2003).

Frequent HABs in the region offshore from the Changjiang Estuary is believed to be linked with increase in land-source input of plant nutrients and coastal eutrophication (Zhou et al., 2003), however, new evidence from field observation suggests that in the early spring the blooms of harmful algal species be affected by the coastal circulation that brings the nutrients from offshore waters (e.g. Kuroshio) and hence maintains high biomass via vertical mixing. Indeed, the blooming of harmful algal species in spring is facilitated by the change in weather from northerly to southerly monsoons, which induces coastal upwelling. One of the questions with the mechanism of spring blooming of dianoflagellates (e.g. *Prorocentrum dentatum*) rather than diatoms is the life history is poorly understood, although it is hypothesized that dinoflagellates (i.e. *Prorocentrum dentatum*) may have over-winter strategy as resting cysts of in the southern part of the East China Sea, this needs to be tested by the carefully designed field measurements in the near future.

8. DISCUSSION AND CONCLUDING REMARKS

Traditionally, the Changjiang Delta Region delivers extensive services to human beings, and this plays an important role in the civilization, economy and social development of China. The historical records of early settlement can be traced back to ca. 1500 years ago. It was one of the trade centers in Ming and Qing dynasties and became the most densely populated area in China in the 20th century. The Changjiang Delta Region is among the most economic advanced regions in China. The GDP value of Shanghai, for example, reached about 650×10^9 Yuan of RMB in Year 2003, with a rate of economic increase by >10 % on average over the last decade (Data Source: www.shtong.gov.cn). Also, the delta region serves as critical connection between oceanic trade and inland transportation upstream the Changjiang over a distance of 4000 km. The port of Shanghai had in 2004 a throughput of about 0.35×10^9 tons yr^{-1}, among the top three of the world.

The delta region sustains a richness of biological resources. For instance, in the Changjiang Estuary, about 160 species for phytoplankton and 174 species for zooplankton have been reported. Moreover, there are 14 orders and about 120 species of fish, with 92 % from *Teleostean* and 8 % from *Elasmobranch*, respectively. The fish ecosystem in the delta region is composed of fresh-water, brackish-water, marine and migratory species (Table 4).

To describe the human impact on the health of ecosystems in the Changjiang Delta Region in full dimension (i.e. time and space), like in many other world systems, is difficult, if not impossible, because of the multitude of direct and indirect effects. Land-based activities in the river basin result, for the delta region, in an increase in nutrient influx and other pollutants. While the resulting high level of nutrients may not necessarily result in a serious eutrophication and in blooms of harmful phytoplankton species in the inner part of delta region, owing to high

Table 4. *List of the major components for the fish in the Changjiang Estuary. (Adapted from Zhang and Jiang, 1983, and Chen et al., 1999).*

Category of fish	Contribution (%)	List of Major Species
Riverine Species	17.4	*Coilia*, *Protosalanx hyalocranius*, *Mylopharyngodontis piceus*, *Hypophthalmichthys molitrix*, *Aristichthus nogilis*, *Carassius auratus*, *Parapelecus argenteus*, *Leiocassis longirostris*
Brackish Species	21.6	*Fugu xanthopterus*, *Leiocassis longirostris, Lateofabrax japonicus*, *Mugil cephalus*, *Mugil soiuy*, *Hemisalanx prognathus*, *Chaeturivhthys* , *Periophthalmus cantonensis*
Marine Species	57.2	*Muraenesox cinereus*, *Clupanodon punctatus*, *Llisha clongata*, *Selipinna taty*, *Harpodonle nehereus*, *Zebrias zebra*, *Eleutheronema tetradactylum*, *Pneumatophorus japonicus*, *Scomberomorus niphodius*, *Trichiurus haumela*, *Stnomateoides argenteus*, *Collichthys lucidus*
Migratory Species	3.8	*Anguilia japonica*, *Psephurus gladius*, *Acipenserda bryanus*, *Trachidermus faxciatus* , *Tenualoosa reevesi*, *Coilia nasus*, *Coilia mystus*, *Acipenser sinensis*

turbidity, other pollutants (e.g. sewage from urban source) have been identified to induce detrimental effect on the water quality and aquatic ecosystems. For instance, the landing records of *Stolephorus* by the municipality of Shanghai show a dramatic decrease of recruitment in the 1980s, that is, due to pollution from urban waste discharge in their spawning ground in the upper part of the estuary; the problem was exacerbated by overfishing and it became critical by construction of the jetties in the Changjiang Estuary. Hence the resource has never recovered after 1990 (Figure 8). Similarly, the over-fishing of *Eriocheirs sinensis* in the delta region caused the collapse of the fisheries, which later further deteriorated by the loss of hatching ground by coastal engineering works; the situation is critical for this species for which a fishing ban has been issued in the late 1980s (Figure 9). Other important species in this region include *Coilia ectenes*, *Coilia mystus*, and *Exopalaemon annandalei*; their growing and/or hatching grounds in the estuary are affected by the construction of the jetties (Figure 9).

The estuary is a multi-functional system, providing foods (e.g. fishery) and variety of services to the society, including biodiversity, transportation, recreation, agriculture and urbanization, which is under the regulation of human activity and react with positive and/or negative feed-back to the human society, being either sustainable (i.e. negative) or unsustainable (i.e. positive).

While human settlement in the Changjiang Delta Region is expected to continue in the near future, the conflicts of shortage of land for human settlement and is becoming critical. While reclamation of wetlands in the coastal area is required to maintain the progress of urbanization in the Shanghai, the environmental consequences include the loss of habitats for wildlife, the destroy of spawning and hatching grounds for marine living resources, and this change their community structure and put those economically valuable species in danger of extinction.

Pollution by trace metals and synthetic organic materials can cause the problems at molecular level and induce the genetic diseases, which in turn alter the strategy at organism level and change the whole food-chain. An increased waste discharge from Changjiang into the East China Sea has caused frequent harmful algal blooms in coastal waters further offshore from delta region, and a serious hypoxia problem has recently reported in literature, which induces the concern of public society nation wide. Dredging in the Changjiang Estuary for navigation and construction of jetties in the main channel have been reported to further destroy the fishing grounds and block the migratory route of traditional economic species in the region. The Changjiang Estuary is losing its traditional values at the ecosystem level; its historical role of providing multiple services to society is changing to a simplified service system, e.g. land area for settlement and waterways for transportation and trade.

The on-going engineering constructions in the Changjiang Delta Region are expected to further modify the habitats and affect community structure of wildlife, which can affect the whole ecosystem via food-web interactions, unless proper management is made to protect the habitats and to improve the water environment at the ecosystem level.

9. ACKNOWLEDGEMENTS

This study was funded by the Ministry of Science and Technology (No.: 2001CB4097-03) and Natural Science Foundation of China (No.: 40476036 and 40476037). We express our gratitude to Drs. P.Q. Wang, X.M. Shen, M. Li, A. Gao and J.L. Du for help in preparation of this manuscript.

10. REFERENCES

Attrill, M.J., Thomes, R.M., 1995. Heavy metals concentrations in sediment from the Thames estuary, UK. Marine Pollution Bulletin 30, 742—744.

Bouloubassi, I., Fillaux J., Saliot, A., 2001. Hydrocarbons in surface sediments from the Changjiang (Yangtze River) Estuary, East China Sea. Marine Pollution Bulletin 42, 1335-1346.

Callaway, J.C., Delaune, R.D., Patrick, Jr. W.H., 1998. Heavy metal chronologies in selected coastal wetlands from Northern Europe. Marine Pollution Bulletin 36, 82-96.

Carimen, I., Jose, U., Ignacio, G., 1997. Speciation of heavy metals in sediment from salt marshes on the southern Atlantic coast of Spain. Marine Pollution Bulletin 34, 123-128.

Chen, J.F., Xia, X.M., Ye, X.R., Jin, H.Y., 2002. Marine organic pollution history in the Changjiang Estuary and Zhejiang coastal area – HCHs and DDTs stratigraphical records. Marine Pollution Bulletin 45, 391-396.

Chen, Y.Q., Gong, Q., Huang, W.P., 1999. A study on the characteristics and status of fishery resources in the Changjiang Estuary. Journal of Fishery Sciences of China 6 (5), 48-51 (in Chinese).

Cundy, A.B., Croudace, I.W., Thomson, J., Lewis, J.T., 1997. Reliability of salt marshes as “geochemical recorders” of pollution input: a case study from contrasting estuaries in southern England. Environmental Science & Technology 31, 1093-1101.

De Jonge, V.N., Boynton, W., D’Elia, C.F., Elmgren, R., Welsh, B.L., 1994. Responses to developments in eutrophication in four different North Atlantic ecosystems. In: K.R. Dyer and R.J. Orth (Eds.), Changes in Fluxes in Estuaries. Pp 179-196, Olsen & Olsen.

Gambrell, R.P., 1994. Trace and toxic metals in wetlands – a review. Journal of Environmental Quality 23, 883-891.

Hutchinson, S.M., Yu, L.Z., 1998. Heavy metal contamination of tidal flat sediments in the Shanghai region of the Yangtze (Changjiang) Estuary, P. R. China. International Journal of Environmental Education and Information 17, 423-432.

Kang, Q.S., Wu, Y., Zhang, J., Zhou, J.L., Cheng, H.Q., 2003. The distribution and pollution of heavy metals in Chongming Wetland. Acta Oceanologica Sinica 25 (Supp. 2), 1-7 (in Chinese).

Kim, G.B., Maruya, K.A., Lee, R.F., Koh, C.H., Tanabe, S., 1999. Distribution and sources of polycyclic aromatic hydrocarbons in sediments from Kyeonggi Bay, Korea. Marine Pollution Bulletin 40, 7-15.

Li, R.X., Zhu, M.Y., Wang, Z.L., Shi, X.Y., Chen, B.Z., 2003. Mesocosm experiment on competition between two HAB species in the East China Sea. Chinese Journal of Applied Ecology 14, 1049-1054 (in Chinese).

Liu, M., Yang, Y., Hou, L., Xu S., Ou, D., Zhang, B., 2003. Chlorinated organic contaminants in surface sediments from the Yangtze River Estuary and nearby coastal areas, China. Marine Pollution Bulletin 46, 659-676.

Meybeck, M., Ragu, A., 1995. Water Quality of World River Basins. UNEP GEMS Collaborating Center for Fresh Water Quality Monitoring and Assessment, United Nations Environment Program.

Ni, Y., 1999. Fishery and resources conservation for *Coilia mystus* in the Changjiang Estuary. Journal of Fishery Sciences in China 6 (5), 75-77 (in Chinese).

Ni, Y., Wang, Y.L., Jiang, H., Chen, Y.Q., 1999. Biological characteristics of *Coilia mystus* in the Changjiang Estuary. Journal of Fishery Sciences in China 6 (5), 69-71 (in Chinese).

Olivie-Lauquet, G., Gruau, G., Dia, A., Riou, C., Jaffrezic, A., Henin, O., 2001. Release of trace elements in wetlands: role of seasonal variability. Water Research 35, 943-952.

Richardson, K, Heilmann, J.P., 1995. Primary production in the Kattegat: Past and present. Ophelia 41, 317-328.

Shi, C., Hutchinson, S.M., Yu, L.Z., Xu, S.Y., 2001. Towards a sustainable coast: An integrated coastal zone management framework for Shanghai, People's Republic of China. Ocean Coastal Management 44, 411-427.

State Oceanic Administration, 2000-2004. Bulletin of Marine Environmental Quality in China. China Ocean press, Beijing, 26 pp (in Chinese).

State Oceanic Administration, 2001-2004. Bulletin of Marine Disasters in China. China Ocean press, Beijing, 17 pp (in Chinese).

Sun, S.C., Cai, Y.L., An, S.Q., 2002 Differences in morphology and biomass allocations of *Scrirpus mariqueter* between creek-side and inland communities in the Changjiang Estuary, China. Wetlands 22, 786-793.

Turner, D.R., 1990. The chemistry of metal pollutants in water. In Harrison, R.M. (ed.), Pollution: Causes, Effects, Control. pp 19-32, Cambridge Press.

Wang, Y.L., Cheng, Y.X., Xu, Z.L., Chen, Y.Q., 1999a. Effects of suspended dredging sediments on the larval development and molt of Chinese crab *Eroicheir sinensis*. Journal of Fishery Sciences in China 6, 20-23 (in Chinese).

Wang, Y.L., Cheng, Y.X., Xu, Z.L., Chen, Y.Q., 1999b. Effects of suspended dredging sediments and its dissolved Zn^{2+} on the early development of Chinese crab *Eroicheir sinensis* in the Changjiang Estuary. Journal of Fishery Sciences in China 6, 24-28 (in Chinese).

Wises, S.B.O., Bubb, J.M., Lester, J.N., 1995. The significance of sediment metal concentrations in two eroding Essex salt marshes. Marine Pollution Bulletin 30, 190-199.

Wright, P., Mason, C.F., 1999. Spatial and seasonal variation in heavy metals in the sediments and biota of two adjacent estuaries, the Orwell and the Stour, in eastern England. Science of Total Environment 226, 139-156.

Wu, Y., Zhang, J., Zhou, Q., 1999. Persistent organo-chlorine residues in sediments from Chinese river/estuary system. Environmental Pollution 105, 143-150.

Xu, S.Y., Gao, X.J., Liu, M., Chen, Z.L., 2001. China's Yangtze Estuary: Phosphorus and polycyclic aromatic hydrocarbon in tidal flats sediments. Geomorphology 41, 201-217.

Yang, S.L., 1998. The role of *Scipus* marsh in attenuation of hydrodynamics and retention of fine sediment in Yangtze Estuary. Estuarine, Costal and Shelf Science 47, 227-233.

Yang, S.L., Zhao, Q.Y., Belkin, I.M., 2002. Temporal variation in the sediment load of the Yangtze River and the influences of human activities. Journal of Hydrology 263, 56-71.

Yang, S.L., Belkin, I.M., Belkina, A.I., Zhao, Q.Y., Zhu J., Ding, P.X., 2003. Delta response to decline in sediment supply from the Yangtze River: Evidence of the recent four decades and expectations for the next half-century. Estuarine, Coastal and Shelf Science 57, 689-699.

Ye, S.F, Lu, J.B., Ding, D.W., Huang, X.Q., 2004a. A preliminary study on the impacts of large-scale engineering on habitat fragmentation in the Yangztze River Estuary. Ocean Engineering 22, 41-47 (in Chinese).

Ye, S.F., Ji, H.H., Cao, L., Huang, X.Q., 2004b. Study on the impacts of large-scale estuarine engineering on species composition and biomass of benthos in Yangztze River Estuary. Marine Science Bulletin 23, 32-37 (in Chinese).

Yu, L.F., 1998. Investigation report on the *Eriochier sinensis* larvae in the Changjiang Estuary in 1997. Modern Fisheries Information 13, 17-20 (in Chinese).

Zhang, J., 1994. Atmospheric wet depositions of nutrient elements: Correlation with harmful biological blooms in the Northwest Pacific coastal zone. Ambio 23, 464-468.

Zhang, J., 1999. Heavy metal compositions of suspended sediments in the Changjiang (Yangtze River) Estuary: Significance of riverine transport to the ocean. Continental Shelf Research 19, 1521-1543.

Zhang, J., 2002. Biogeochemistry of Chinese estuarine and coastal waters: Nutrients, trace metals and biomarkers. Regional Environmental Change 3, 65-76.

Zhang, J., Zhang, Z.F., Liu, S.M., Wu, Y., Xiong, H., Chen, H.T., 1999. Human impacts on the large world rivers: Would the Changjiang (Yangtze River) be an illustration? Global Biogeochemical Cycles 13, 1099-1105.

Zhang, L.S., Jiang, Z.Z., 1983. Observations on the marine living resources and fishery status in the lower reaches of the Changjiang at Shanghai. In: Proceedings on the Investigation of Littoral Living Resources in Shanghai, Bureau of the Littoral Observations of Shanghai. pp 182-198, Shanghai.

Zhou, M.J., Zhu, M.Y., Zhang, J., 2001. Status of harmful algal blooms and related research activities in China. Chinese Bulletin of Life Science 13, 54-60 (in Chinese).

Zhou M.J., Yan T. and Zou J.Z., 2003. Preliminary analysis of the characteristics of red tide areas in Changjiang Estuary and its adjacent sea. Chinese Journal of Applied Ecology 14, 1031-1038 (in Chinese).

Zhu, Z.Y., Zhang, L.H., Zhou, J.Z., Zhang, J., 2004. Variation of nutrients in the Suzhouhe and Huangpujiang in spring and summer of 2002. Marine Environmental Science 23, 19-23 (in Chinese).

Zhu, J., Ding, P., Zhang, L., Wu, H., Cao, H., 2005. Influence of the deep waterway project on the Changjiang Estuary. In Wolanski, E. (ed.), The Environment in Asia Pacific Harbors. Springer. pp. 79-93.