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# Response of coastal marine eco-environment to river fluxes into the sea: A case study of the Huanghe (Yellow) River mouth and adjacent waters

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## Abstract

The impact of the Huanghe (Yellow) River outflows on its estuary was investigated with river gauging and shipboard hydrographic observations. The river flux has been decreasing dramatically; the discharges of water and sediment in the 1990s dropped to 27.4% and 31.9% of those in the 1950s, respectively, resulting in frequent and lengthy events of downstream channel dry-up since the 1970s. There were accumulatively 897 zero-flow days during the 1990s in the river course below the Lijin Hydrological Station, 100 km upstream from the river mouth, which is 82.4% of that in 1972. As freshwater input decreases, river-borne nutrients to the estuarine increased significantly. Concentration of DIN (dissolved inorganic nitrogen) in the 1990s was four times of that in 1950s. Changes in amount and content of the riverine inputs have greatly affected the estuarine ecosystem. Over the past several decades, sea surface temperature and salinity in the estuary and its adjacent waters increased and their distribution pattern altered in response to the reduction of freshwater inflow. The distribution of and seasonal succession in nutrient concentrations in the surface layer have also changed with a shift of river outlet and the decrease in riverine nutrient loads. Furthermore, deterioration of estuarine ecosystem by less river input has decreased primary productivity in the deltaic region waters, and

in turn depressed the fishery.

*Keywords:* Huanghe (Yellow) River Estuary; dissolved inorganic matter; marine ecosystem; river flux; coastal water

## 1 Introduction

Estuaries are resources of consequence for human being because they contribute greatly to global primary productivity and fish captures, and support a fast-growing mariculture industry (Cracknell, 1999; Kennish, 2002; LOICZ, 2004). They are also sources of terrestrial materials for the marine environment. Their functioning depends to great extent on natural dynamics of river outflows. Without adequate supplies, seasonal inflows, and freshwater qualities from inland rivers, they would not function well ecologically (Benson, 1981).

The amount and timing of discharge of most rivers in the world has been markedly altered in the past several decades, due to dam construction for hydroelectric power development, water diversion for agricultural, domestic, and industrial use, and uncontrolled urban expansion related to rapid population growth in many catchments (Berkamp et al., 2000; Syvitski et al., 2005; Wilber and Bass, 1998). The changes in these rivers have significantly affected hydrographic conditions, salinity and temperature patterns, nutrient loads, dissolved oxygen (Skirris and Lascaratos, 2004), and, in turn, the primary productivity, biotic community structure and distribution, and the trophodynamics of estuarine systems (Grange and Allanson, 1995; Grange et al., 2000; Howden and Murtugudde, 2001; Kennish, 2002; Kimmel and Roman, 2004; Kimmerer, 2002). It is generally acknowledged that these kinds of changes have brought about detrimental outcomes, such as eutrophication, sediment deprivation, hypoxia, and contamination, as well as habitat loss and decreased bio-diversity, in many estuarine and coastal areas worldwide (Grange et al., 2000; Kennish,

2002; Rodriguez et al., 2001; Sklar and Browder, 1998; Wilber and Bass, 1998). Very few estuarine and coastal systems remain intact in the world.

The Huanghe (Yellow) River, the most turbid one among the world's major large rivers (Ren and Shi, 1986), is no exception. It originates from the Yueguzonglie basin on the northern part of the Bayankala Mountain in the Tibet Highlands and flows through the Loess Plateau. The river is ca. 5,460 km long with a drainage basin covering ca. 752,000 km<sup>2</sup> (Qian et al., 1993). Since its migration in 1855, the river flows into the Bohai Sea and has developed a delta of about 6,000 km<sup>2</sup> with the apex at Ninghai (118°24' E, 37°36' N) (Fig. 1). Historically, the river discharged an average of  $574 \times 10^8$  m<sup>3</sup> of water and  $10.0 \times 10^8$  t of sediment annually, corresponding approximately 50%-60% of the freshwater and more than 90% of the sediment received by the Bohai Sea (Cheng and Zhao, 1985). The amount and nature of the river outflows drastically changed in the past half century due mainly to the increasing river regulation (SPSTC, 1991; Xia et al., 2002) and these changes may have significantly influenced the local estuarine and coastal environment. Our knowledge of the nature, and extent of these impacts is still scant. This paper summarizes a variety of data collected over a long period of time. It is the aim of the paper to synthesize the general trends that have occurred with major changes in the flow of the Huanghe River, one of the world's major rivers, and its estuary.

## 2 Study site and data materials

### 2.1. Study site

The Huanghe River discharges into the shallow semi-closed Bohai Sea, with an average water depth of ca. 18 m and an area of ca. 80,000 km<sup>2</sup>, containing the Liaodong Bay, the Bohai Bay and the Laizhou Bay. Before 1976, it discharged to the Bohai Bay; in 1976, it was rerouted into the Laizhou Bay. At the mouth of the outlet, the tidal amplitude is about 0.6-1.3 m (Chen, 2001). Tidal currents around the river mouth are

irregular, semi-diurnal and bidirectional. The surface residual current and local waves are subject to monsoon, and are generally directed southward in winter and northward in summer (SPSTC, 1991). The residual current has a mean velocity of 0.1-0.25 m s<sup>-1</sup>. Wave height in the river mouth is about 0.8 m under normal weather conditions (Chen, 2001). The water residence time can reach 3-4 months in the Laizhou Bay (Zhang et al., 1990).

## 2.2. Data materials

At the Lijin Hydrological Gauging Station, the furthest downstreammost in the Huanghe River (about 100 km upstream from the river mouth), the fluxes in discharges of the river to the sea were daily monitored by the Yellow River Conservancy Commission (YRCC) since the 1950s and water quality monitoring has been conducted monthly since the 1980s. The methods and procedures of field measurements of water quantity and quality were described by Li et al. (1998) and Duan and Zhang (1999), respectively. In this study, consecutive 53-year hydrological data (1950-2002), including water flow and suspended sediment concentration (SSC) were collected from the YRCC. The river water quality data also came from the YRCC, except that data from 1959 and 1984 were cited from the paper by Shen et al. (1989).

Field observations off the active mouth of the Huanghe River were aperiodically conducted with about 30-50 sampling stations since the late 1950s. Vertical profiles of temperature, conductivity, and nutrient concentrations were determined by sampling at standard water depths. In this paper, data on sea surface temperature, nutrient concentration and prawn catches over a long period of time were collected from the sources of Wu et al. (2004b), Shen and Le (1993), Tang and Meng (1997), SPSTC (1991), and Huang and Su (2002). Detailed information on these data sources is listed in Table 1. The methods used to make the chemical measurements were described previously (Shen et al. 1989).

## 3. Changes in the riverine water quantity and water quality

### 3.1. Water and sediment discharge

The hydrological records at the Lijin Station show that fluxes of the river had decreased dramatically since the 1970s (Fig.2), especially since the late 1980s. In the 1950s, the median annual water discharge was  $429.7 \times 10^8 \text{ m}^3$  and the sediment discharge from the river was  $13.4 \times 10^8 \text{ t}$ . Although the annual water discharge increased somewhat in the 1960s, the sediment loads decreased by 31.2%. Water discharge decreased by 45.6% in the 1970s and sediment loads by 27.4% in the 1980s. Up to the 1990s, the two indicators were reduced to only  $135.22 \times 10^8 \text{ m}^3$  and  $4.92 \times 10^8 \text{ t}$ , 27.4% and 31.9%, respectively, of values in 1950s. Furthermore, in the first five years of the 21st century, they dropped sharply again to  $48.6 \times 10^8 \text{ m}^3$  and  $0.54 \times 10^8 \text{ t}$ , which is 35.9% and 12.6% of those in the 1990s, or 11.3% and 4.0% of those in the 1950s.

The inter- and intra-annual fluctuations of the river's flux are also of considerable significance. Channel dry-up events occurred downstream in the Huanghe River since 1972. There were 1088 dry-channel days from 1972 to 2000: 86 d in 1970s, 105 d in 1980s, and 897 d in 1990s (Fig.3). The most extreme case occurred in 1997, when there were 226 dry channel days involving 704 km of channel upstream from the river mouth.

### 3.2. Quality of the river water into the sea

Sufficient nutrient supply is crucial to primary production in the estuary, coastal waters and even in the whole Bohai Sea. According to *in situ* measurements at the Lijin Station, in 1958, about  $72.9 \times 10^3 \text{ t}$  DIN was the annual input from the river (Fig. 4), which increased to  $84.5 \times 10^3 \text{ t}$  in 1984.

As fluvial flux severely decreased, the concentration of nutrients in the waters increased significantly since the mid-1980s due to overuse of chemical fertilizer and the discharge of untreated household and industrial sewage. Concentrations of DIN in the river water increased noticeably since the 1990s, reaching  $376.3 \mu\text{mol l}^{-1}$  in 1999, over 4 times that in 1958 ( $87.3 \mu\text{mol l}^{-1}$ ) (Fig. 4). Due to drastic decreases in river

runoff, total amount of DIN discharged annually into the estuary decreased significantly, dropping to  $7.46 \times 10^3$  t in 1997, 1/10 of that in 1984, because of serious and lengthy channel dry-up events in the downstream channel. As previously reported, the peak concentrations and dry-up events occurred in parallel (Chen et al., 2001).

#### **4. Changes in water quality within the estuary and adjacent waters**

##### *4.1. Temperature*

Freshwater flow plays an important role in controlling sea surface temperature in coastal waters. Sea surface temperature (SST) distribution in the Bohai Sea recorded in two cruises in August 1958 and 2000 were very similar (Fig. 5). However, a significant SST high occurred in the estuary region in August 2000. Long-term time series data (1960-1997) in several tide-monitoring stations in coastal waters of the Bohai sea showed that the SST increased by  $0.011-0.015$  °C per year, which was mostly ascribed to the drastic reduction of the river runoff (Lin et al. 2001, Fang et al. 2002).

##### *4.2. Salinity*

Salinity is another important factor influencing coastal and estuarine ecosystems and is easily affected by river runoff. Less freshwater flow would reduce freshwater/seawater mixing areas in an estuary. The sea surface salinity (SSS) distribution patterns have considerable discrepancies between 1958 and 2000 (Fig. 6). The surface salinity shows the important diluting effect that the Huanghe River had upon most of the estuarine waters. A tongue-like low salinity (<22.0 psu) area was near former Yellow River outlet in August 1958. By 2000, the coverage of low salinity area in the sea surface layer off the river mouth shrank considerably.

The SSS of the Bohai Sea depends on the freshwater budget. As the largest river discharging to the bay, the Huanghe River controls its freshwater budget. Additionally, river outflow also has an effect on freshwater

and saltwater mixing in the estuary. Fresh-salt water mixing off the Huanghe River outlet, referred as to the Huanghe River diluted waters (Le,1995), changed its extent and depth responding to the fluctuations of river discharge. Zhao (1996) reported a significant positive correlation between the extent of the Huanghe River diluted waters and the amount of the river runoff. Recent works proved that decreased inflow in the past decades was the major reason for the increase in the SSS (Liu and Jin, 1998; Lin et al., 2001; Fang et al., 2002; Wu et al., 2004a and 2004b). Wu et al. (2004a) estimated that about 75% of the SSS rise in the area was due to the reduction of Huanghe River runoff. Considering the steep drop of river runoff and the lengthy channel dry-up events, Liu and Jin (1998) concluded that the rise in average annual SSS near the estuary in the 1990s was greater than that in any of other decade.

#### 4.3. Nutrients

The distribution pattern of nutrients in the estuary and its adjacent waters changed considerably in the past decades (Fig. 7). In August 1959 there was a tongue of high nutrient concentrations in the sea surface layer located offshore the Shenxiangou distributary, an active outlet of the Huanghe River from 1953 to 1964. In August 1984, it shifted to the vicinity of the Qingshuigou distributary, an active outlet of the Huanghe River from 1976 to the present. In 1992, the nutrient concentrations became relatively uniform in the whole study area.

Nitrate concentrations in the deltaic waters increased significantly from 1959 to 1984 and then dropped (Fig. 7 a). In August 1984 there was a  $60 \mu\text{mol l}^{-1}$  isoline near the estuary, which was six times as great as that of  $10 \mu\text{mol l}^{-1}$  in August 1959, with a steeper gradient off the river mouth. But nitrate concentrations in the study area in 1992 were less than  $10 \mu\text{mol l}^{-1}$ . In contrast, temporal variation in phosphate concentrations showed a negative trend during the study period (Figure 7 b). The highest concentration isoline value was  $2.0 \mu\text{mol l}^{-1}$  in August of 1959 and dropped to  $1.0 \mu\text{mol l}^{-1}$  in 1984, and further to  $0.3 \mu\text{mol l}^{-1}$  in 1992.

Changes in silicate concentrations were different from the above two nutrients. The highest isoline value of silicate varied slightly from 1959 to 1984, but decreased rapidly from 1984 to 1992 (Fig.7 c).

Seasonal variations in nutrient concentrations in the estuary are illustrated in Fig. 8. In 1959 and 1984, the DIN concentration in dry season (November-June in the next year) was greater than that in flood season (July-October). However, it was opposite in 1998 (Fig. 8 a), which was likely associated with the dry-up event in lower reaches of the river. The highest DIN concentration occurred in 1984 as enormous riverine DIN input occurred in the same period. The seasonal DIP concentration changes were quite different from those of DIN concentrations. The flood season had higher DIP concentration than the dry season in 1959, whereas the opposite occurred in 1984 and 1998 (Fig. 8 b). Higher silicate concentrations appeared in the dry seasons of 1959 and 1998, in contrast to the flood season in 1984 (Fig. 8 c). As shown in Fig. 8(d), a significant and continuous high ratio of DIN and DIP concentrations occurred from 1959 through 1984 to 1998. The estuarine waters generally had higher DIN/DIP ratio in the dry season. However, the situation was reversed in 1998 because of the channel dry-up event.

Phosphorus is a major limiting factor for phytoplankton growth due to very high N: P ( $\gg 16$ ) in estuarine waters (Redfield, 1958; Turner et al., 1990; Zou et al., 2001). Moreover, the N: P ratio in the estuary was less than that in oceanic waters (Zou et al., 2001). Discrepancy between the DIN and DIP with seasons may be due to phosphorus being taken preferentially by phytoplankton when a high N: P occurred. Previous work by Shen et al. (1989) and Shen and Le (1993) remarked that variation in DIP concentrations in the estuary is complex, because it was influenced by phytoplankton blooms or certain buffering mechanisms. Recent research showed that the adsorption and desorption of phosphate at the surface of suspended particles played important roles in phosphate buffering in the Huanghe River estuary (Shi and Shi, 1999).

The above analyses show that sea surface temperature and salinity rose in the study area due mostly to the rapid reduction of the total river flow, and the changes in nutrient concentration are linked mainly to the amount of riverine nutrient input. These changes in the estuarine environment are thought to have a significant influence on the coastal ecosystem near the Huanghe River discharge (Lin et al., 2001).

## **5. Response of estuarine and coastal aquatic ecosystem to the riverine fluxes**

### *5.1. Changes in primary productivity in the Huanghe River estuary and its adjacent waters*

Hydrochemical environment changes in an estuary directly affect its primary productivity (Shen, 1999). The previous investigation showed that the mean annual chlorophyll-*a* concentration and primary productivity in the Huanghe River estuary were  $3.56 \text{ mg m}^{-3}$  and  $358 \text{ mgC m}^{-2} \text{ d}^{-1}$  in the 1984, respectively, in contrast to  $4.40 \text{ mg m}^{-3}$  and  $498 \text{ mgC m}^{-2} \text{ d}^{-1}$  in the southern part of the estuary (offshore the Shenxiangou distributary) (SPSTC, 1991). In 1998 their values dropped to  $2.80 \text{ mg m}^{-3}$  and  $274 \text{ mgC m}^{-2} \text{ d}^{-1}$ , respectively (Wang and Li, 2002). Similar changes appeared throughout the Bohai Sea, where the two indicators ranged from  $1.05 \text{ mg m}^{-3}$  and  $312 \text{ mgC m}^{-2} \text{ d}^{-1}$  in 1982-1983 to  $0.61 \text{ mg m}^{-3}$  and  $216 \text{ mgC m}^{-2} \text{ d}^{-1}$  in 1992-1993, respectively (Lu et al., 1999).

Nutrient concentrations in seawater, especially phosphate and silicate, are crucial for phytoplankton growth and primary productivity in the area. For example, chlorophyll-*a* concentrations were correlated positively to silicate concentrations (Gao et al., 2003; Wei et al., 2004). Therefore, it can be inferred that decreases of the amount of these nutrients in the river discharge impaired phytoplankton growth in the study area.

### *5.2. Change in fish resource in the Huanghe River estuary and its adjacent waters*

With abundant freshwater and nutrient inputs, the study area is an ideal habitat for feeding, spawning and raising young of many species. Any large decrease in river discharge would inevitably influence primary

production in the deltaic area and thereby affect fish community structure, biomass, density and biodiversity (Zhu et al., 1996 and 2001; Zhu and Tang, 2002; Jin and Deng, 1999 and 2000; Jin, 2004). As early as the 1960s, some Chinese fishery experts observed that inter-annual variation in river runoff was a major factor affecting local fish catches (YSFRI, 1960). As decreases in river discharge occurred with frequent dry-ups since the 1970s, more in-depth studies were made on the impact of decreased flow on composition, distribution, diversity, density and spatiotemporal dynamics of fish communities, agreeing that a drastic reduction of the river runoff brought very negative consequences to the fishery in the estuarine waters, even in the whole Bohai Sea (Jin and Deng, 1999; Zhu et al., 2001; Zhu and Tang, 2002).

Previous researches (Zhu et al., 1996 and 2001; Zhu and Tang, 2002) demonstrated that the number of species, density of fish communities and biomass decreased. The number of fish species was 146 in the 1950s, 119 in the 1980s, and 73 in the 1990s. The species number, density, and biomass dropped by 38.7%, 35.5% and 46.0% from 1982/1983 to 1992/1993, respectively. The seasonal community persistence dropped from 0.697 in the 1980s to 0.590 in the 1990s in ISTR (index of species turnover rates) (Zhu et al., 1996). Furthermore, the fisheries productivity in the region suffered from decreased age, weak eco-trophic dynamics, and low turnover rate in production. The fish catch in Laizhou Bay in 1998 was only 3.3%, 7.3% and 11.0% of that in 1959, 1982 and 1993, respectively (Jin and Deng, 1999 and 2000). The same phenomenon occurred throughout Bohai Sea, where the mean catch per hour was 93 kg haul<sup>-1</sup> in 1959, then dropped to 85.2 kg haul<sup>-1</sup> in 1982, 104.3 kg haul<sup>-1</sup> in 1992, and further to 3.7 kg haul<sup>-1</sup> in 1998 (Jin, 2004). The relative biomass (mean catch) in 1998 declined correspondingly to 4.0%, 4.3% and 3.6% of that in the previous surveys (Jin, 2004).

Due to abundant river freshwater and nutrient supplies, the study area was an important spawning site and habitat for penaeid shrimp (*Penaeus chinensis*). Over the past four decades, the mean annual penaeid

shrimp catches in the Bohai Sea in autumn flood seasons varied greatly (Fig. 9). The high catch occurred during 1973-1981, and the low one in 1991-1998, which was mainly due to two reasons: overfishing in the 1970s and changes in water quality and flow. Nevertheless, previous studies reported strong and significant relationships between penaeid shrimp recruitment in the Bohai Sea in the flood season and the river runoff and the salinity/temperature in the nursery ground (Deng and Zhuang, 2002; Huang and Su, 2002).

## 6. Discussion and conclusion

Estuarine and coastal ecosystems are complex, often unique, and fragile. Abundant freshwater and nutrient supplies from inland rivers are ecologically vital to the survival and diversity of these ecosystems. Any fluctuation would exert crucial impacts on the normal physical and biological functions. The increasing anthropogenic disturbance has obviously worsened this situation.

The Huanghe River discharges large amounts of freshwater, sediment and nutrients into the Bohai Sea. Accordingly, its estuary and adjacent waters become essential for spawning and nursery habitats for many species of fish and shellfish. However, the river has undergone dramatic reduction in freshwater and sediment discharge, and even zero flow in its lower reaches, with lowering riverine nutrient material concentration since the 1970s, which was even lower after the late 1980s as the amount of river runoff and nutrient dropped to a historical low. Changes in the quantity and quality of river water would affect the SST, SSS and nutrient concentration in deltaic waters. In the study area, SST and SSS have been increasing in the past 5 decades, which has largely resulted from the serious reduction of the river discharge. Nutrient concentrations of the deltaic waters have also fluctuated with the changes in the river inputs. The maximum nitrate and phosphate concentrations occurred in the 1980s, corresponding to the maximum river discharge in the same period. There were different patterns of change in the three nutrients. In general, the nitrate concentrations in the 1990s were greater than those in the late 1950s, but phosphate concentrations showed

the opposite pattern. Silicate concentrations were highest in the late 1950s and then had lower values in the 1980s and 1990s. Changing with the river water quality, as a consequence, chlorophyll-*a* concentrations and primary productivity decreased, and the number of species, the values of density and biomass of fish community dropped radically. All the facts were consistent with a reduction of runoff and nutrients from the Huanghe River impacting negatively nutrient biogeochemical cycles and productivity of the coastal zone.

The above-mentioned physical and chemical changes tend to support the fact that the rapid reduction in the Huanghe River fluxes of water and nutrient was the key reason for the rises in sea surface temperature and salinity in the deltaic waters. The deterioration of the river water was responsible for the decline in productivity of the aquatic ecosystem in the estuary waters. Therefore, comprehensive river regulation from the source to the outlet should be imperatively managed by government in consult with knowledgeable scientists for sustainable development of the coastal zones.

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### **References**

Berkamp, G., McCartney, M., Dugan, P., McNeely, J., Acreman, M., 2000. Dams, ecosystem functions and environmental restoration, Thematic Review II.1 prepared as an input to the World Commission on Dams, Cape Town (<http://www.dams.org>)

- Benson, N. G., 1981. The freshwater-inflow-to-estuaries issue, *Fisheries* 6, 8–10.
- Chen, J., He, D., & Yuan, L., 2002. Relation between water quality changes and the “dryings-up phenomena” in the Yellow River, China. *Environmental Chemistry* 20, 205-211. (in Chinese with English abstract)
- Chen, Sh., Gu, Y., Liu, M., Zhang, M., Yang, Sh., Li, J., 1991. Nutrient distribution at the Huanghe River estuary. *Journal of Ocean University of Qingdao* 21, 34-42. (in Chinese with English abstract)
- Chen, Y., 2001. Study on the Yellow River mouth and its regulation experiences. Zhengzhou: Publishing House for the Huanghe River Water Conservancy. (in Chinese)
- Cheng, T., Zhao, Ch., 1985. Runoff and sediment discharge of the major rivers in China and their impacts on littoral areas. *Acta Oceanologica Sinica* 7, 461-471.
- Cracknell, A. P., 1999. Remote sensing techniques in estuaries and coastal zones-an update. *International Journal of Remote Sensing* 19, 485-496.
- Deng, J., Zhuang, Zh., 2002. Dynamic characteristics of prawn (*Peneous Chinensis*) community. In: Su J., (2002). *Ocean Ecosystem Dynamics Research in China Sea II. Ecosystem Dynamics Processes in the Bohai Sea*. Beijing: Science Press. (in Chinese)
- Duan, Sh. & Zhang, Sh., 1999. The Variations of Nitrogen and Phosphorus Concentrations in the Monitoring Stations of the Three Major Rivers in China. *Scientia Geographica Sinica* 19, 411-416. (in Chinese with English abstract)
- Fang, G., Wang, K., Guo, F., Wei, Z., Fan, W., Zhang, D., Bi, J., 2002. Long-term changes and interrelations of annual variations of the hydrographical and meteorological parameters of the Bohai Sea during recent 30 years. *Oceanologia et Limnologia Sinica* 33, 515-525. (in Chinese with English abstract)
- Gao, H., Wu, D., Bai, J., Shi, J., Li, Zh., Jiang, W., 2003. Distributions of environmental parameters in Laizhou Bay in summer, 2000. *Journal of Ocean University of Qingdao* 33, 185-191. (in Chinese with

English abstract)

- Grange, N., Allanson, B. R., 1995. The Influence of Freshwater Inflow on the Nature, Amount and Distribution of Seston in Estuaries of the Eastern Cape, South Africa. *Estuarine, Coastal and Shelf Science* 40, 403-420
- Grange, N., Whitfield, A. K., De Villiers, C. J., & Allanson, B. R., 2000. The response of two South African east coast estuaries to altered river flow regimes. *Aquatic Conservation: Marine and Freshwater Ecosystems* 10, 155-177.
- Howden, S. D., Murtugudde, R., 2001. Effects of river inputs into the Bay of Bengal. *Journal of Geophysical Research* 106, 19825–19843
- Huang, D., Su, J., 2002. The effects of the Huanghe River delta on the circulation and transportation of larvae. *Acta Oceanologica Sinica* 24, 104-111. (in Chinese with English abstract)
- Jin, X., 2004. Long-term changes in fish community structure in the Bohai Sea, China. *Estuarine, Coastal and Shelf Science* 59, 163-171.
- Jin, X., Deng, J., 1999. Yearly variations of fishery resources and biodiversity in the LaiZhou Bay. *Marine Fisheries Research* 20, 6-12. (in Chinese with English abstract)
- Jin, X., Deng, J., 2000. Study on variations of fish community structure and biodiversity in the LaiZhou Bay. *Biodiversity* 8, 65-72. (in Chinese with English abstract)
- Kennish, M. J., 2002. Environmental threats and environmental future of estuaries. *Environmental Conservation* 29, 78-107
- Kimmel, D.G., Roman, M. R., 2004. Long-term trends in mesozooplankton abundance in Chesapeake Bay USA: influence of freshwater input. *Marine Ecology Progress Series* 267, 71-83.
- Kimmerer, W. J., 2002. Effects of freshwater flow on abundance of estuarine organisms: physical effects or

- trophic linkages?. *Marine Ecology Progress Series* 243:39-55.
- Lavín, M. F., Sánchez S., 1999. On how the Colorado River affected the hydrography of the upper Gulf of California. *Continental Shelf Research* 19, 1545-1560.
- LOICZ (Land-Ocean Interactions in the Coastal Zone), 2004. Links and partners for “New” LOICZ: Global Nutrient Export from Watersheds (Global NEWS). *LOICZ Newsletter* 30, 1-2. (<http://www.loicz.org>)
- Le, K., 1995. Changes of the diluted water distribution caused by the fluvial process of the Huanghe River estuary. *Studia Marina Sinica* 36, 81-92. (in Chinese with English abstract)
- Li, G., Wei, H., Han, Y., Chen, Y., 1998. Sedimentation in the Yellow River delta, part: flow and suspended sediment structure in the upper distributary and the estuary. *Marine Geology* 149, 93-111.
- Lin, Ch., Su, J., Xu, B., Tang, Q., 2001. Long-term variations of temperature and salinity of the Bohai Sea and their influence on its ecosystem, *Progress in Oceanography* 49, 7-19
- Liu, Ch., Cheng, L., 2000. Analysis on runoff series with special reference to drying up courses of lower Huanghe River. *Acta Geographica Sinica* 55, 257-265. (in Chinese with English abstract)
- Liu, X., Jin, Y., 1998. On distribution and change of salinity in Laizhou Bay in recent years, *Shandong Fisheries* 15, 46-47.
- Lu, R., Xia, B., Li, B., Fei, Z., 1999. The fluctuations of primary productivity in Bohai Sea waters over ten years. *Journal of Oceanography of Huanghai & Bohai Seas* 17, 80-86. (in Chinese with English abstract)
- Pang, J., Jiang, M., 2003. On the evolution of the Yellow River estuary (I)—I. Hydrographic characteristics. *Transactions of Oceanology and Limnology* 3, 1-13. (in Chinese with English abstract)
- Qian, Y., Ye, Q., Zhou, W., 1993. Fluctuation of water and sediment discharge and riverbed evolution in the main channel of the Huanghe River. Beijing: China Building Material Industry Press. (in Chinese)
- Redfield, A. C., 1958. The biological control of chemical factors in the environment. *American Scientist* 46,

205-221.

Rodriguez, C. A., Flessa, K. W., Dettman, D. L., 2001. Effects of Upstream Diversion of Colorado River

Water on the Estuarine Bivalve Mollusc *Mulinia coloradoensis*. *Conservation Biology* 15, 249-258.

Shen, Zh., 1999. Hydrochemical elements in Bohai bay and its eastern part waters. *Studia Marina Sinica* 41,

51-59. (in Chinese with English abstract)

Shen, Zh., Le, K., 1993. Effects of the Yellow River estuary location changes on its hydrochemical

environment. *Studia Marina Sinica* 34, 93-105. (in Chinese with English abstract)

Shen, Zh., Liu, X., Lu, J., 1989. Inorganic nitrogen and phosphate in estuary of the Huanghe River and its

near waters. *Studia Marina Sinica* 30, 51-79. (in Chinese with English abstract)

Shi, X., Shi, Zh., 1999. Discussion of phosphate buffer mechanism in Huanghe River estuary II. The ionic

equilibrium of Ca-P mineral phases in the Huanghe River estuary. *Oceanologia et Limnologia Sinica* 30,

737-743. (in Chinese with English abstract)

Sklar, F. H., Browder, J. A., 1998. Coastal Environmental Impacts Brought About by Alterations to

Freshwater Flow in the Gulf of Mexico. *Environmental Management* 22, 547-562.

Skliris, N., Lascaratos, A., 2004. Impacts of the Nile River damming on the thermohaline circulation and

water mass characteristics of the Mediterranean Sea. *Journal of Marine Systems* 52, 121-143.

SPSTC (Shandong Province Science & Technology Committee). (1991). Collection of research reports on

coastal zone and tidal flat resources in Shandong Province, China—A research report on the Huanghe River (Yellow) River mouth research area. Beijing: Chinese Science & Technology Press. (in Chinese).

Syvitski, J. P. M., Vorosmarty, C. J., Kettner, A. J., Green, P., 2005. Impact of Humans on the Flux of

Terrestrial Sediment to the Global Coastal Ocean. *Science* 308, 376-380.

Tang, Q., Meng, T., 1997. Atlas of the Ecological Environment and Living Resources in the Bohai Sea.

- Qingdao: Qingdao Press. (in Chinese)
- Turner, R. E., Rabalais, N. N., Zhang, Zh., 1990. Phytoplankton biomass, production and growth limitations on the Huanghe River (Yellow River) continental shelf. *Continental Shelf Research* 10, 545-571.
- Wang, J., Li, H., 2002. Study on chlorophyll-a and primary production in in shore waters of the Bohai Sea. *Marine Fisheries Research* 23, 23-28. (in Chinese with English abstract)
- Wei, H., Sun, J., Andreas, M., Zhao, L., 2004. Phytoplankton dynamics in the Bohai Sea-observations and modelling. *Journal of Marine Systems* 44, 233-251.
- Wilber, D. H., Bass, R., 1998. Effect of the Colorado River Diversion on Matagorda Bay Epifauna. *Estuarine, Coastal and Shelf Science* 47, 309-318.
- Wu, D., Mu, L., Li, Q., Bao, X., Wan, X., 2004a. Long-term variation characteristic of the salinity of the Bohai Sea and the possible dominant factor. *Progress in Natural Science* 14, 191-195. (in Chinese with English abstract)
- Wu, D., Wan, X., Bao, X., Mu, L., Lan, J., 2004b. Comparison of summer thermohaline field and circulation structure of the Bohai Sea between 1958 and 2000. *Chinese Science Bulletin* 49, 363-369.
- Xia, X., Zhou, J., Yang, Z., 2002. Surface water quality: nitrogen contamination in the Yellow River Basin of China. *Journal of Environmental Quality* 31, 917-925. (in Chinese with English abstract)
- YSFRI (Yellow Sea Fisheries Research Institute). (1960). Impacts of the Huanghe River runoff on fish resources. *Yellow Sea fisheries Research Collections* 4, 1-16.
- Zhang, J., Letolle, R., Martin, J. M., Jusserand, C., Mouchel, J. M., 1990. Stable oxygen isotope distribution in the Huanghe (Yellow River) and the Changjiang (Yangtze River) estuarine systems. *Continental Shelf Research* 10, 369-384.
- Zhang, Sh., Gan, W., Ittekkot, V., 1992. Organic matter in large turbid rivers: the Huanghe and its estuary.

Marine Chemistry 38, 53-68.

Zhao, W., 1996. Sediment of the Yellow River. Zhengzhou: Publishing House for the Huanghe River Water Conservancy. (in Chinese)

Zhu, X., Yang, J., Tang, Q., 1996. Study on characteristics of fish community structure in Bohai Sea. Oceanologia et Limnologia Sinica 27, 6-13. (in Chinese with English abstract)

Zhu, X., Miu, F., Liu, D., Xian, W., 2001. Spatiotemporal pattern and dominant component of fish community in the Yellow River estuary and its adjacent waters. Studia Marina Sinica 43, 141-151. (in Chinese with English abstract)

Zhu, X., Tang, Q., 2002. Structuring dominant components within fish community in Bohai Sea system. Studia Marina Sinica 44, 159-168. (in Chinese with English abstract)

Zou, L., Zhang, J., Pan, W., Zhan, Y., 2002. *In situ* nutrient enrichment experiment in the Bohai and Yellow Sea. Journal of Plankton Research 23, 1111-1119.

**Figure captions**

Fig. 1. Location map of the Huanghe River estuary.

Fig. 2. The median and interquartile range of water (a) and sediment (b) discharge at the Lijin Hydrological Station (1950-2004).

Fig. 3. Annual cumulation zero-flow days of the Huanghe (Yellow) River at the Lijin Hydrological Station (1972-1999).

Fig. 4. Changes in the quantity and concentration of DIN in the Huanghe River waters during the past several decades (*Note: the data in 1959 and 1984 from SPSTC, 1991*).

Fig. 5. Variations of sea surface temperature in the Huanghe River estuary and its adjacent waters between 1958 and 2000 (adapted from Wu *et al.* 2004b).

Fig. 6. Variations of surface salinity in the Huanghe River estuary and its adjacent waters between 1958 and 2000 (adapted from Wu *et al.* 2004b).

Fig. 7. Variations of nutrient concentration ( $\mu\text{mol l}^{-1}$ ) in the sea surface layer in the Huanghe River estuary and its adjacent waters in August among 1959, 1984 and 1992 (a: nitrate; b: phosphate; c: silicate) (adapted from Shen and Le (1993) and Tang and Meng 1997).

Fig. 8. Seasonal variations of nutrient concentration ( $\mu\text{mol l}^{-1}$ ) in the Huanghe River estuary from 1959 to 1998 (a, DIN; b, DIP; c,  $\text{SiO}_3\text{-Si}$ ; d, DIN/DIP) (*Note: the data in 1959 and 1984 from Shen and Le 1993*).

Fig. 9. Variations in the mean annual penaeid shrimp (*Penaeus chinensis*) catches in the Bohai Sea during autumn floods (1962-1998) (*Note: the data from Huang & Su 2002*).

Table caption

Table 1. Data sources on physical and chemical parameters of the waters in the estuary of the Huanghe River

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Table 1

Data	Sources
Sea surface temperature in 1958 and 2000	Wu et al. (2004b)
Nutrient concentration in 1959 and 1984	Shen et al. (1989) ;SPSTC (1991);Shen and Le (1993)
Nutrient concentration in 1992	Tang and Meng (1997)
Nutrient concentration in 1998	provided by the Beihai Office, the State Oceanic Administration of China
Prawn catches from the 1960s to 1990s	Huang & Su (2002)

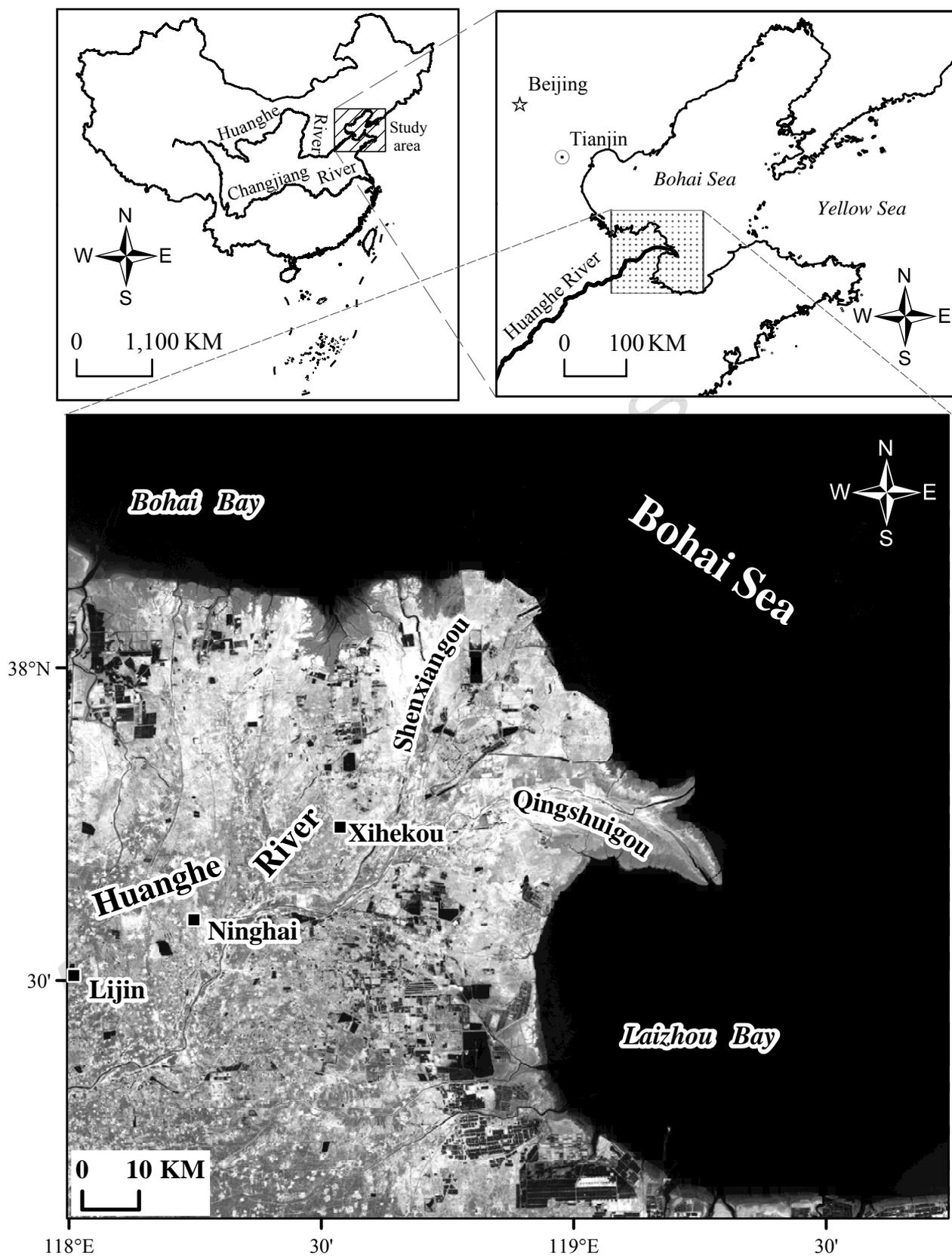


Fig. 1, Fan &amp; Huang, 2006

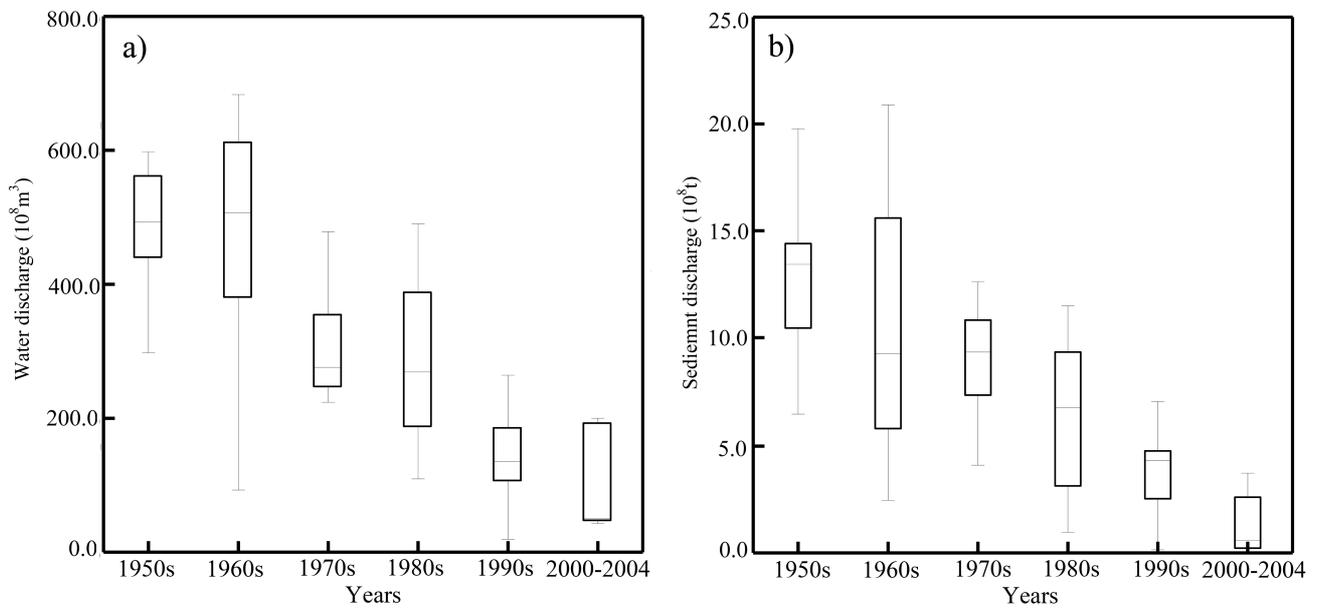


Fig. 2, Fan & Huang, 2006

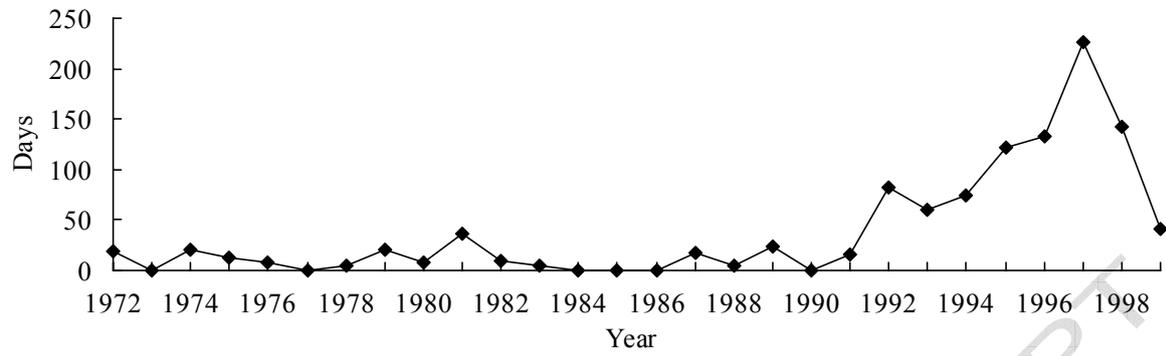


Fig. 3, Fan & Huang, 2006

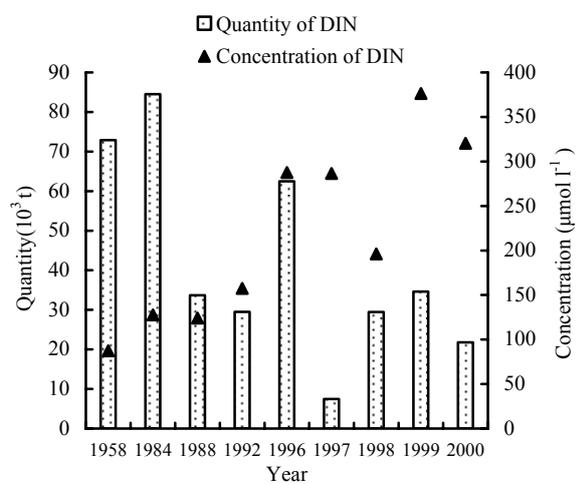


Fig. 4, Fan & Huang, 2006

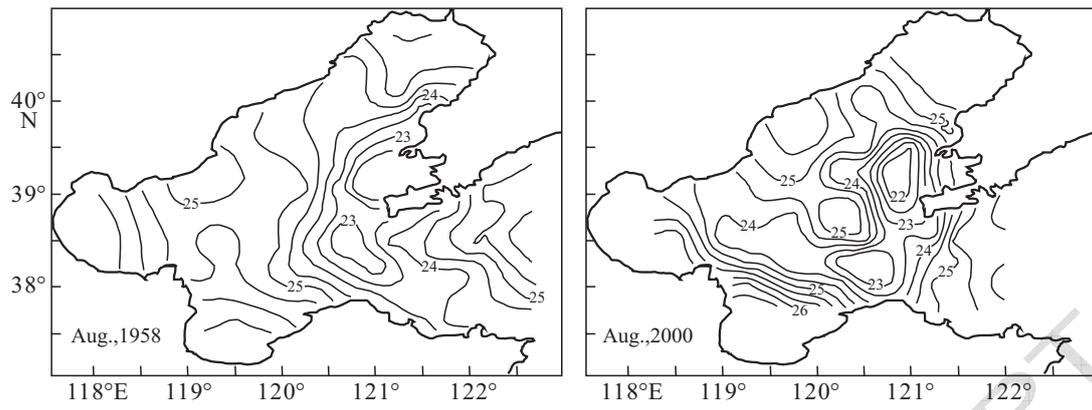


Fig. 5, Fan & Huang, 2006

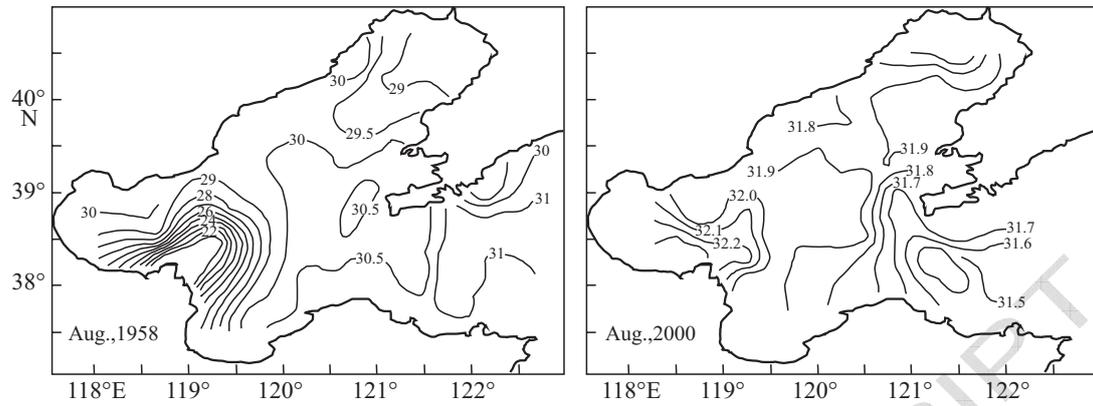


Fig. 6, Fan & Huang, 2006

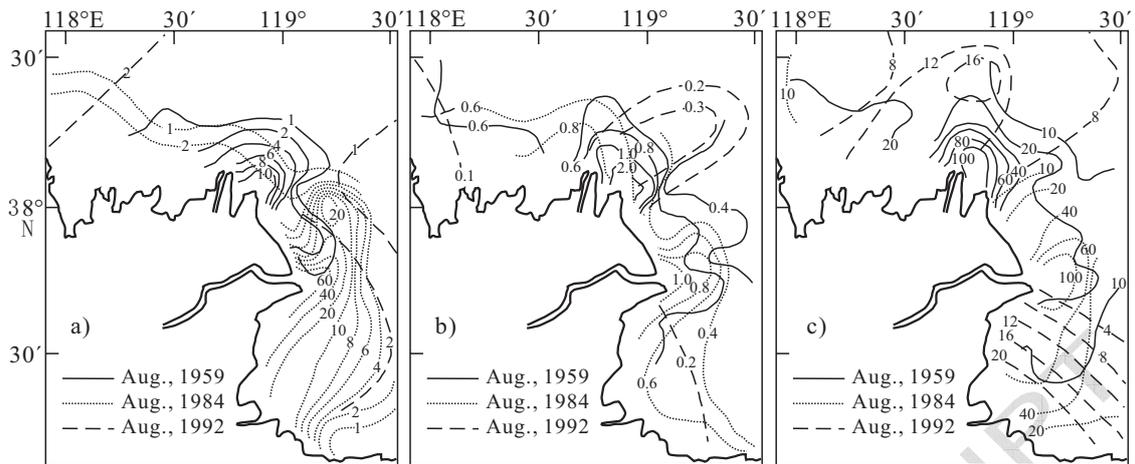


Fig. 7, Fan &amp; Huang, 2006

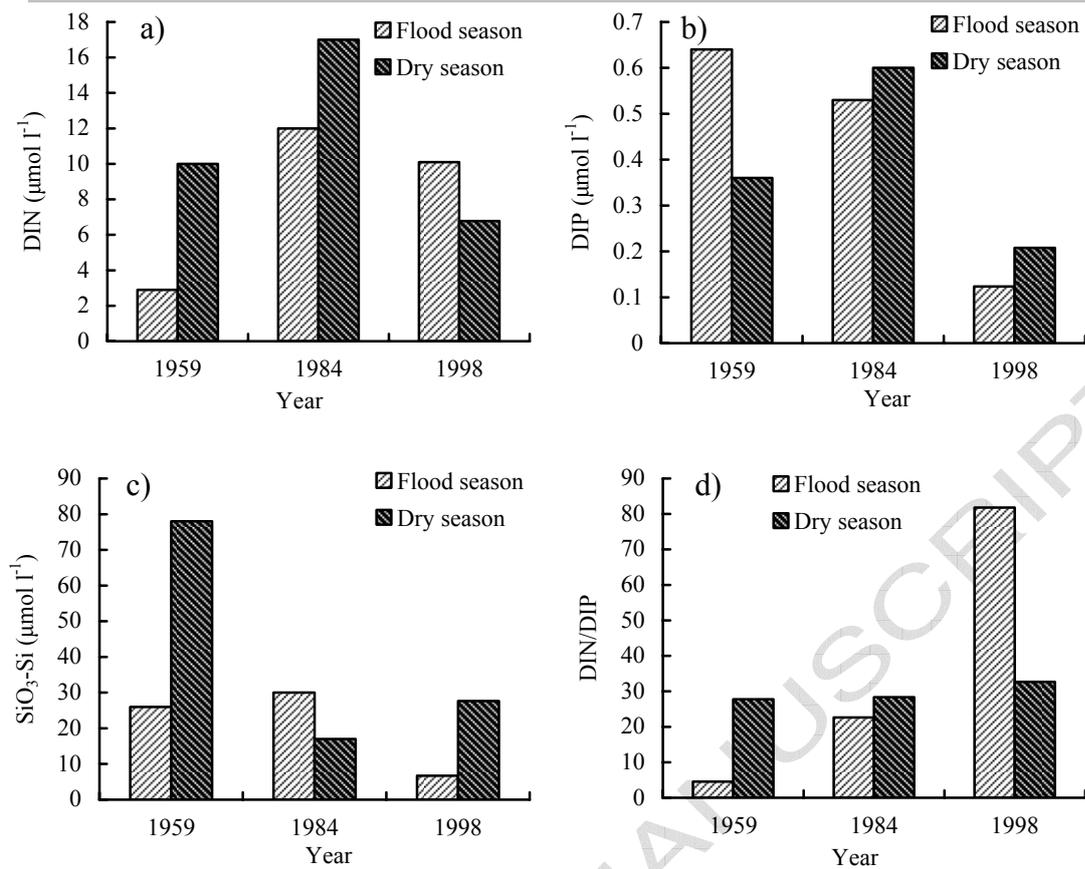


Fig. 8, Fan &amp; Huang, 2006



Fig. 9, Fan & Huang, 2006