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RESEARCH ARTICLE

Driving forces and management strategies for estuaries in northern China

Anning SUO (✉)[1,2], Dongzhi ZHAO[1], Fengshou ZHANG[1], Huaru WANG[2], Fengqiao LIU[2]

1 National Marine Environment Monitoring Center, Dalian 116023, China
2 Life Science College, Beijing Normal University, Beijing 100875, China

Abstract Estuaries, which lie at the end of rivers, belong to the interlocking area between marine ecosystems and terrestrial ecosystems. In the estuary region, there are plenty of biological resources that carry many important ecosystem services. However, severe degradation of the estuary ecosystem in northern China has been caused by anthropogenic disturbances, including water pollution from upstream area, change of marine environmental dynamics, animal habitat loss, and unreasonable exploitation in the estuary region. In order to provide scientific evidence for restoration and conservation of the estuary ecosystem, we collected data from published literature to analyze the ecological problems in several main estuary regions in northern China, such as the Yellow River estuary, Liaohe River estuary, Haihe River estuary, Yalu River estuary, and some others. The main ecological problems in the estuary region of northern China include the input decrease of fresh water from rivers, the change of the sediment input from rivers, the destruction of the estuary wetland ecosystem, the environmental pollution in the estuary region, the erosion in the estuary region, seawater encroachment, the biodiversity decline of the estuary region, and the depletion of the fish resources in the estuary region. Meanwhile, the driving forces for these ecological problems in the estuary region were also assessed. Based on the analysis of these driving forces, we propose several pieces of advice for integrated estuary management in northern China, including the creation of a management system for estuary conservation, improvement of the means and strength of the environmental law execution, increased investment on scientific research in the estuary ecosystem, improvement of public participation on the conservation for the estuary environment and biodiversity, and construction of a monitoring system for the estuary environment.

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E-mail: san720@sina.com

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1 Introduction

Located on the coastal zone of China, there are a lot of estuaries with different sizes and various shapes formed by the interactions of rivers and seas. The Yellow River estuary, Liaohe River estuary and Yalu River estuary are the most famous estuaries in northern China. These estuaries located in regions with dense human activities play a crucial role in many natural processes and are hotspots in wildlife conservation, biodiversity conservation and coast conservation (State Development Planning Commission, 1994; Chen and Chen, 2002). Recently, due to rapid economic and social development in the estuary regions, pressure on the environmental has grown higher and higher. The ecological problems such as animal habitat degradation, resource exhaustion and highly frequent disasters have been the adverse factors threatening the sustainable development in the estuary regions (Zhang, 1997). In this paper, the ecological status of the main estuaries in northern China is analyzed and the ecological problems that exist in these estuaries are assessed respectively. Some management strategies are proposed to solve these problems and maintain the stability of the estuary ecosystem in northern China.

2 Ecological problems in estuaries of northern China

2.1 Estuary of the Yellow River

The Yellow River estuary lies between Laizhou Bay and Bohai Bay. It belongs to Dongying City in Shandong Province. When the channel of the Yellow River changed in 1895, the Yellow River delta came into being by accumulation of mud and sand from upstream and the estuary-near region formed the modern Yellow River estuary. The large proportion of mud and sand from the Loess Plateau filled up the estuary and made the Yellow River estuary stretch to a bird-foot shaped peninsula. Thus, the most complete, vastest and youngest estuarine wetland ecosystem was composed by the palm-covered highland on the riverbed, the lowland in the river, the vast beach and the shallow sea.

Under the pressure of human activities, such as rapid population growth and industrial and agricultural development, the ecological environment in the Yellow River estuary has deteriorated day by day in the last 20 years. The ecosystem services of the estuarine wetland have been reduced with the shrinkage of the wetland area, decreased water quality, flood conservation loss and the decrease of pollution purification function. Several kinds of contaminations from the upstream polluted the beach and estuary, reduced the diversity of aquatic products and made the quantity and quality of aquatic products decrease dramatically (Xiao et al., 2001). The large quantity of nitrogen and phosphorus input from the watershed caused water eutrophication in the estuary and harmed the aquiculture. Air pollution, water population, and oil exploitation reduced the food source for avians, destroyed the avian habitat and severely affected avian diversity (Yang and Li, 1999).

About 11% of the Yellow River delta was built for residential and industrial areas, including the estuary wetland. Construction of irrigation projects, traffic transportation and town building destroyed the primary estuarine wetland (Cai et al., 2006). This caused most of the original vegetation and species to almost vanish. The great change of the wetland fragmented and caused many animal habitats to disappear and threatened the biodiversity. Crude oil pollution in the construction of oil fields and the emergent accidental pollution to some degree harmed the wetland ecosystem in the Yellow River estuary and these pollutions were not easy to eliminate. The fresh water consumption increase in industry, agriculture and living lowered the water table, dried the wetland and influenced the vegetation composition and growth in the estuary.

The runoff decrease of the Yellow River severely affected the estuarine wetland ecosystem (Feng and Li, 1998). The cutoff of the Yellow River in the last century reduced 5.67% of the fresh water and 5.30×10^8 t of sediment to the sea (Wang and Zhao, 2000). The decrease of runoff from the Yellow River to the sea decreased the sea temperature, increased the sea salinity, and indirectly affected the primary productivity of the sea. The decrease of fresh water input also reduced the nitrogen and phosphorus input, indirectly influenced the production of aquatic products and made the ecological environment of the beach and estuary significantly unstable. After the cutoff of the Yellow River, the hydrological balance of the estuary was disturbed and coastal erosion occurred under the sea tides due to the loss of sediment source. The decrease of runoff to the estuary also had complex effects on agricultural production, such as soil salinization, the decrease of surface water, and the change of crop pattern.

2.2 Estuaries in Liaodong Gulf

The Liaodong Gulf estuaries include the Daliaohe estuary, Shuangtaizi estuary, and Xiaolinghe estuary, which run across Jinzhou City, Panjin City and Yinkou City in Liaoning Province. The runoff input to these estuaries and the sediment input were about 9.14×10^9 m^3 and 4.33×10^4 t/a, respectively (Zheng et al., 2005). Such much sediment input formed a 4.4×10^5 hm^2 wetland in the Liaodong Gulf estuaries composed of reed field, swamp grassland, beach and shallow sea. As one of the globally significant estuaries, the Liaodong Gulf estuaries had high biodiversity with 273 kinds of terrestrial vertebrate species, 67 kinds of fish species in fresh water, 120 kinds of fish species in marine and 238 kinds of avian species (Tian and Li., 2003).

Recently, with the development of industry and agriculture, the ecological environment has come under stress and the conflict between wetland conservation and resource exploitation has become urgent. Large-scale agriculture and oil exploitation shrunk the primary wetland and expanded the shrimp and crab field and other artificial ponds. The area of primary reed wetland in Shuangtaizi estuary was reduced by 60.3% compared to that 15 years ago. Recently, the suitable area for red-crowned crane only accounted for 15.6% of the area. The natural habitat shrunk to the west of Shuangtaizi estuary. The runoff from Liaohe upstream to Liaohe delta decreased dramatically and endangered the water supply for the wetland. Only one-third of the reed field could be irrigated on time, due to the use of a water pump for oil exploitation. The lack of fresh water degraded a lot of reed fields. Before 1985, there were commonly about 3000–5000 wild geese and ducks in the flight season. Only 300–500 individuals were recorded in the field work of 1990. Recently, it has become difficult to see wild geese and ducks (Jiang et al., 2005).

The total yield of aquatic products in the 1950s was about 400–2000 t/a with a mean of 870 t/a. After a series of dam constructions on the rivers, water pollution and riverbed silting severely affected the fishery in Liaodong Gulf estuaries. Using river saury as an example, the production immediately decreased after dam construction. The beach in Liaodong Gulf estuary was the main production area of river crab. River crab was quite abundant with a production of 500–700 t/a before 1962. However, due to the anthropogenic disturbance, the production became unstable in the 1970s with less than 100 t/a after 1978. After artificial culturing from 1984, the production increased to 300–600 t/a (Yan and Guo, 2005).

According the result of seawater invasion in Liaodong

Gulf from 1993 to 2000, the area of the invasion in Shuangtaizi River and Daliaohe River was about 3350 hm^2 (Yan and Guo, 2005). The seawater invasion mixed sea water and fresh underground water. This made the fresh water supply difficult in Yinkou City. Human activities and tidal electric power generation eroded the beach of Liaodong Gulf. The reasons for sea beach erosion can be concluded as follows: 1) The construction of dams and reservoirs reduced the sediment and mud input from the upstream in each river in Liaodong Gulf. The runoff and sediment input of Shuangtaizi River decreased from 3.95×10^9 m^3 and 4.938×10^7 t before the dam construction to 2.75×10^9 m^3 and 8.99×10^6 t, respectively. 2) The sand resource mined on the beach interrupted the balance of sand between beaches and shore and exacerbated the coastal erosion. 3) The recent rising sea level also caused coastal erosion. From the change detected by remote sensing images in 1987, 1994 and the topographical map in 1971, the erosion rate was about 50 m/a between 1971 and 1987 and 100–200 m/a between 1987 and 1994. The latter was faster than the former.

2.3 Estuary of Haihe

The Haihe estuary is a muddy estuary located in the Bohai Gulf in Tanggu District, Tianjin City. The mud and sand from the Haihe River watershed deposited in the estuary and formed the estuary delta. The characteristics of the estuary are the runoff-tide type with a direct bank line and a gentle bottom. After the anti-tide dam construction in the Haihe estuary in 1958, the Haihe River estuary changed the tide channel to a multifunctional channel with the main service for fresh water storage.

With the social and economic development in the Haihe watershed, the water resource need increasingly rose and made the runoff lower. The dam was severely filled up. The runoff peak decreased from 2100 m^3/s in 1950s to 800 m^3/s in 2000. The reduced runoff caused sediment to accumulate in the estuary. The sediment accumulation was 2.259×10^7 m^3 with a height of 4.7 m. The width of the main stream of Haihe River changed from 250 m to less than 100 m and the runoff was reduced by 85%. In order to keep the estuary free, before the flooding season, the mud and sand in the near-dam river should be cleared (Liu, 2006).

The dam on the estuary of Haihe River blocked the migration route of some fish species. The dam construction with the decreased fresh water input affected the community composition and structure of the estuary. The size of the fish community in the estuary decreased and the fish quality also degraded. The Chinese crab was almost extinct and scallop resource also decreased. The industrial pollutant release from Dagu and Beitang in Tianjin City and the oil leakage from oil platforms in the harbor and the sea also affected the near coast. COD, inorganic phosphorus, heavy metals, polycyclic aromatic hydrocarbons and refractory organic pollutants were far below the standards and the detection rate was 50%–100% (Jin et al., 1990).

2.4 Estuary of Yalu River

The estuary of Yalu River locates on the eastern part of East Liaoning Peninsula and the most northern part of the North Yellow Sea. The Yalu River on the border of China and North Korea runs to the southeast and forms the estuary at the river sink, including estuarine shallow sea, estuarine beach, and estuarine reed wetland. The Yalu River estuary reserve founded in 1997 runs from Wenan Beach Island on the east, Heda Road on the north, 5 m deep line in the Yellow Sea on the south and Zhuanghe City on the west. There were 344 kinds of plants, 240 kinds of birds, 88 kinds of fishes, 3 kinds of amphibians, 6 kinds of mammals, 74 kinds of bottom-dwelling animals and 54 kinds of planktons. There were more than 30 seashells and clam species recorded in the east of the reserve and the total amount was estimated beyond 10 t. Historically, there were largely continuous reed fields and abundant avian resource. Local residents sometimes could find baskets of bird eggs.

With the social and economic development of Donggang City and the construction of Dadonggang Harbor, the exploitation intensified and the estuarine wetlands were gradually lost. In the recent 10 years, farmland expansion and the construction of industrial factories, dams and roads caused the shrinkage fragmentation and even clearing of continuous reed wetlands. Only the Dayanghe River estuary and the Yalu River estuary were conserved as complete reed wetlands, while the others were exploited and the trend lasted. Although the shrimp pools, paddy fields and fish ponds were also wetland, the ecological function and service of this kind weakened due to the anthropogenic interfaces (Wei and Cao, 1997).

Previously, because of the undeveloped Yalu River watershed and estuarine industry and sparse population, the environmental problems in the estuary were slight. In recent years, many highly polluting enterprises were built on the upstream and on the estuary of the Yalu River and the pollution emerged. The industrial wastewater and domestic sewage discharge into the Yalu River estuary was about 1.216×10^8 t in Dandong City and 8.245×10^6 t in Donggang City per year. The pollution load ratio of the main contaminations in Yalu River estuary containing petroleum, COD, volatile phenol and NO_3 were 58127%, 17137% and 8170%, respectively. The great input of polluted water stressed the estuarine ecological environment and induced the loss of many types of planktons and zooplanktons, the reduction of shellfish production and the frequent occurrence of red tide in the estuary (Wang, 1997).

2.5 Estuary of Luanhe

The Luanhe River empties into the sea in Douwang, south of Tangshang City in Hebei Province. The Luanhe River estuary across Qianghuangdao City and Tangshan City is a big estuary in Bohai Bay and there are no dams on the estuary. The estuarine delta was an alluvial sector-shaped beach wetland with an area of 20000 hm^2. The mud and sand mixed beach was formed by sediment from the river and tides. The seawater and fresh water were mixed from Jianggezhuang and below and the ratio of seawater increased. In low water periods, the line of seawater is as long as 9.6 km. With the decrease of discharge of mud and sand to the sea, the Luanhe estuarine delta changed from the alluvial type to the erosive type. Because of pollution from the paper-making industry, water quality showed a worsening trend. The permanganate index and the chemical oxygen demand were 54 mg/L and 181 mg/L, respectively, and the water quality belonged to the low V class while the near-sea water quality was still good (Qian, 1994).

2.6 Estuaries of other rivers

Besides the main estuaries, there are also many estuaries such as the Yongding River, Duliujian River, Ziyaxin River and Dayang River entering the Yellow Sea and Bohai Sea, respectively. The Yongdinghe estuary is the gate of Yongding River and Beisan River to the sea. Because of the lack of runoff into the sea, the channel was filled up, with sand quantity amounting to 6.159×10^7 m^3 from 1971 to 2000. The Duliujian River estuary is the end of the Daqinghe River and on the river there is a dam. With little runoff to the sea, the downstream channel was severely filled up with about 200000–500000 m^3/a of sand (Liu, 2006). Ziyaxinhe estuary is the end of Ziyahe River and the accumulated mud and sand amounted to 3.82×10^5 m^3 since the dam construction in 1967. The Dayanghe River estuary near Dagushan Town, Donggang City in Liaoning Province is the biggest estuary between Yalu River estuary and Liaohe River estuary. The estuarine plain was accumulated by the mud and sand from the mountains in East Liaoning. Recently, the development of agriculture and the exploitation of mines led to the abrupt eutrophication in the estuary (Shen, 1990).

3 Driving forces for ecological problems in estuaries of northern China

3.1 Decrease of watershed runoff input

The estuary is the sink for runoff, sediment and other chemical materials transported from watersheds. It is also the hot ecotone influenced by both the terrestrial and the sea (Kuang and Cheng, 1998; Jiang, 2000). The estuary is an open system under the dynamic balance between river runoff and sea tides. It is an integrated complex system involving freshwater ecosystem, sea water ecosystem, saline-freshwater ecosystem, and tidal flat wetland ecosystem (Nittrourer, 1994; Sun and Yang, 2005). Thus, it is necessary and important to maintain a certain amount of runoff into the sea to sustain estuarine water-sediment, water-salt, water-temperature, and ecosystem balance.

In recent decades, accompanied by global and regional climate change, runoff input to estuaries showed dramatic shrinkage in northern China, due to the increasing demand in fresh water resource for social and economic development of upward watersheds. For example, the hydrological process of the Yellow River estuary was dominated by watershed runoff input. However, recording of runoff input in Lijin station on the Yellow River estuary in the last 40 years showed that the runoff input of the Yellow River had shrunk dramatically since the 1970s. The actual runoff input of the Yellow River was only 177×10^8 m^3/a in the 1990s, decreased by nearly 50%, and the runoff cutoff days increased to 102d annually (Huang et al., 2006). A similar situation happened to the Haihei River estuary, with estuarine runoff input decreasing by about two thirds compared to that in the 1950s. Estuaries at Liaodong Gulf displayed a great decrease in runoff input under pressure of climate change and fresh water demand for social and economic development. The shrinkage of estuarine runoff input destroyed the balance of the temperature field and salt field in the estuary. This led to salt water invasion in the river channel and seriously destroyed the stability of the estuary’s aquatic ecosystem. Decreased runoff input also weakened the hydrological power in the estuary and made sand sediment continuous in the upward channel of the estuarine, which held up the flow of flood from the watershed and tide way from the estuarine sea field.

3.2 Change of sediment input

Sand sediment input to the estuary is the main material for estuarine topography evolution. The sand accompanied by runoff from upland watersheds disperses and suspends at the estuarine surface. It appears like a huge fan lying on the estuary and it is called an estuarine frontal surface. Plenty of suspended sediments deposit and silt gradually at the estuarine frontal regions, forming an estuarine delta. Therefore, sediment input to the estuary is the most important material for estuary renewal.

As with most other estuaries around the world, the main estuaries in China face challenges with the dramatic decrease of sediment input (Milliman and Syvitski, 1992; Dai et al., 2001). The sediment input of estuaries in China is nearly 2×10^{12} kg, which accounts for 10% that of the whole world. Of this sediment input, the Yellow River and Yangtze River have almost 80%. The Yellow River is famous for its great sediment transportation. Its sediment input has been about 1.2×10^{12} kg annually in the past decades. However, runoff cutoff of the Yellow River resulted in rapid shrinkage in sediment input. The sediment input only stayed 1/60 that of the 1950s and was less than 2×10^9 kg in 2000. In some other estuaries, such as the Yalu River estuary, Guan estuary, and Sheyang estuary, the dam construction at the upper, middle or lower part of the watershed not only changed the original hydrological sediment process, but also intercepted a lot of the sediment and led to huge sedimentation within the estuarine region. For example, in the Haihe estuary, average sedimentation accumulation was about 5.82×10^5 m^3 annually during 1958–1989, and this decelerated the flow rate of runoff from 1200 m^3/s to 200–400 m^3/s and raised the risk of flood disasters in the estuary.

3.3 Destruction of estuarine wetland

According to the wetland classification system, the estuarine wetland belongs to the class of coastal wetland, including river delta, estuarine water field, mangrove, and inter-tidal marsh. The estuarine wetland ecosystem plays many ecological functions such as material production, water purification, and flood regulation. The estuarine wetland is also an important habitat for many wild plants and animals, especially for endangered waterfowls. Therefore, protection and rational exploration of estuarine wetland resources has a great significance in biodiversity conservation, ecological balance maintenance, and sustainable social and economic development.

Natural environmental processes and human activities in estuaries are the two main factors that change the estuarine environment (Wang and Lin, 1999). As a result of irrational exploitation, many estuaries in northern China were degraded with desalting of the estuarine salt marsh as well as the loss of plenty of natural habitats. At the same time, some natural catastrophic events, such as hurricanes, floods, and droughts also changed the estuarine environment deeply (Millman and Meade, 1983). For instance, the original wetland area of the Yellow River delta was about 4.5×10^5 hm^2 composed of 2.0×10^5 hm^2 wetland in the supralittoral zone, 1.0×10^5 hm^2 wetland in the intertidal zone, and 1.5×10^5 hm^2 wetland in the subtidal zone. Since the 1980s, with rapid decrease and break in runoff input in the Yellow River, the wetland in the estuary of the river had encountered many challenges and serious threats in ecosystem structure and function. The large area of the original wetland shrunk in the intertidal zone due to invasion of seawater. Most natural wetlands in the Liaodong Gulf estuary had transformed into artificial wetlands, with the area of paddy fields surpassing that of reed marsh. The total area of the artificial wetland such as ditch, reservoir and pit-pond was already twice more than that of natural wetlands. The artificial wetland, paddy field as an example, is a seasonal water input wetland and the hydrological process is regulated by artificial measures, which is quite different from the processes of a natural wetland.

3.4 Pollution of estuarine environment

Besides freshwater runoff and suspended sediments, watershed runoff to estuaries includes chemical materials (pollutants and nutrients). Chemical input exhibited deterioration status due to human activities, mainly by heavy farmland fertilization and large amount of wastewater discharged from urban industrial development. Water quality for most estuaries in northern China was in the inferior V class, with the most serious contamination in the Huaihe estuary, Liaohe estuary, and Haihe estuary. The main pollutants include organic compounds, petroleum, pesticides, and heavy metals (Zhang et al., 2005). According to the monitoring data in 2002, the ratio of water quality reaching I standard was 16.16%, II standard was 43.15%, III standard was 33.13%, and IV standard was 41.14% in Liaodong Gulf, respectively (Zhang et al., 2005).

Rapid development in the industry, urban construction, tourism, aquaculture, and planting, and growth in population, industrial wastewater and domestic wastewater and their contaminants, especially organic pollutants, the increment of nitrogen and phosphorus, exacerbate dramatically the eutrophication of sea area. The frequent occurrence of red tide disasters was also a driving force (Liu, 1998). Since 1972, frequencies of red tide disasters exhibited an increasing tendency, with billions of yuan of economic loss each year. The East Sea had the highest frequency of red tide, followed by the Yellow Sea and Bohai Sea. In addition, a bottom hypoxia region had been found in the South Sea, Yangtze River estuary and Zhujiang River estuary. Eutrophication had been a main environmental threat for coastal areas in China.

In recent years, with the rapid economic development and population explosion, estuarine pollution became aggravated and displayed a trend of deterioration as a whole. Inorganic nitrogen and phosphorus contamination was characterized by serious and widespread features, which endangered estuarine ecosystems variously.

3.5 Erosion of estuarine and saltwater invasion

The hydrological process of sea tide dominated in the estuarine hydrology due to the weakening or even vanishing watershed runoff input, and this enhanced coastal erosion and salt water invasion in the estuary (Yang and Shi, 1995). The reduction of estuarine sediment input was much less than the quantity of sand reduced by tide process, exacerbating erosion of beaches and coastal areas. After the diversion of the Yellow River, the original deserted Yellow River estuary in Yancheng City, Jiangsu Province suffered a large area of erosion and plenty of scouring sediment transported outside under the combined forces of waves and tides. The waterline depth up to 5–15 m moved near the coastal zone (Yang, 1999). The balance of the underground water supply was disturbed and the water table dangerously dropped under the pressure of watershed runoff input reduction and over-exploitation of estuarine groundwater for industry and agriculture. The continuous lowering of the water table formed a great underground water funnel inducing seawater invasion from the coastal sea nearby. The mixture of seawater and fresh underground water made the fresh underground water undrinkable (Hao et al., 1998). According to the survey of seawater invasion in Liaodong Gulf estuary, the seawater invasion area in Shuangtaizi River and Daliao River reached 3350 hm^2 (Bruun, 1998). Seawater invasion in Yingkou City caused underground water contamination, induced geological disasters, and threatened fresh water supply for city development.

3.6 Decline of biodiversity and fish resource in estuary

The ecotone in estuarine regions provides diverse habitats for various aquatic organisms. The different kinds of nutritional inputs from the upland watershed supply abundant nutrient and bait resources for estuarine aquatic organisms. The estuary is the main biodiversity region with abundant fishery resources (Billen et al., 1985; Bai and Deng, 2001).

Because of resource exploitation and environmental change in the last four decades, the estuarine ecosystem in Liaodong Gulf had a significant degradation in structure and function (Zheng et al., 2005). Recently, the deepwater fish resources in Liaodong Gulf were only 10% of that in the 1950s. Some common fish species, such as hairtail and sea bream had disappeared, or severely declined. The fishing amount of small yellow croaker was more than 10000 t annually during 1956–1961, with 90000 t in 1959. However, it dropped to only about 100 t per year now. The fish community structure in the Liaodong Gulf has turned to miniaturization and changed to low age. The dominant species in the past was large fishes, such as small yellow croaker, hairtail, sea bream, and flounder. However, they had been replaced by small fishes (common hairfin anchovy) recently. The number of fish species in the coastal region dropped from 119 in the 1950s and 1960s to 93 in the 1990s.

The main reasons for the estuarine fishery resource decline include: 1) Overfishing seriously disturbed the fish community renewal, led to the decrease of the number of fish communities, changed community structure and made some large fish species extinct. 2) Fish habitat was destroyed and contaminated. Seriously degraded water quality in traditional spawning and infant rearing ground, together with high eutrophication and frequent occurrence of red tide, had seriously threatened the breeding and growth of fishes. Severe environmental pollution also stressed fishes to escape or disappear.

4 Management strategies for estuaries in northern China

4.1 Establishment and improvement of the management system for estuaries

The estuary is an integrated part of the watershed system and anthropogenic factors play an important role in promoting or delaying the watershed economic development in the watershed eco-economic system. In estuary management, both economy and ecology should be taken into account and an integrated watershed-estuary management strategy should be carried out in the estuary region. In order to improve the resource-use efficiency and maximize the economic and ecological benefit, the integrated watershed-estuary management strategy need to coordinate several related administrative sections such as department of marine environment protection, hydrological department, forestry department and fishery department in estuary management.

4.2 Enhancement of law implementation in estuarine management

The improving environmental law system is the premise for estuary protection and management. The overlapping and conflicting laws and rules from several administrative departments make estuary management difficult to operate. These active laws and rules should be revised and improved for effective estuary management. A perfect estuary monitoring and assessment system is also needed for estuary management. An estuary database and environmental standards in China should be established as soon as possible (Bai and Deng, 2001).

4.3 Improvement of monitoring system for estuarine management

Environmental monitoring that provides a lot of information for decision support is an important part in estuary protection and management (Liu and Wang, 2001). Different methods carried out in different estuaries limit the systematic analysis and assessment of the estuarine environment in China. Until now, there is still no united and canonical monitoring system for estuarine management in China. Modern monitoring techniques and a management information system are urgently needed for estuarine management, such as remote sensing, computing technique and telstar technique. Geographic information system, which is a good tool in estuarine management, can simulate and analyze the estuarine environment change and supply scientific evidence for protection and exploitation in different estuaries in China.

4.4 Strengthening basic research on estuarine ecology

Estuary protection and management should be based on the profound understanding of the mechanism of estuarine ecological and environmental processes. Environmental investigation, monitoring, assessment and modeling are necessary approaches to analyze the estuary change caused by ecological and environmental processes. Because of the lack of the necessary research funds, a lot of basic research on estuary protection has to be delayed and even given up, especially on ecological services and biodiversity. The application of many modern techniques in estuary protection and management stays low in most estuaries in northern China, such as treatment of polluted water, dynamics monitoring and endangered plant and animal species conservation. These problems put the estuarine environment in disorder.

4.5 Educating and participating of local people for estuarine protection

It is very advisable to make local people realize the value of estuary conservation and enhance their participation in estuary protection. Public participation in estuary protection is a wise approach to sustainable development of estuaries. The degree and the way of public participation can determine the progress of sustainable development of estuaries. The public can participate in investigation, research and management of estuaries. Meanwhile, they can also supervise the implementation of estuary protection projects. Participation of local people in estuarine protection and management is the necessary method to resolve ecological problems in estuaries of northern China.

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