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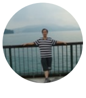

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Harmonious Development of Utilization and Protection of Tidal Flats and Wetlands - A Case Study in Shanghai Area

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ABSTRACT

Spatial, environmental, and material resources are important for tidal flats and wetlands, thus, a harmonious balance between utilization and protection should be maintained. In the present study, the concept of tidal flat is defined, and its spatial limitation is also clarified. Located at the Yangtze Estuary, tidal flats in Shanghai area are selected for study. The relationship between water discharge and sediment transport of the Yangtze River, allowed exploration intensity and needs for wetland protection are discussed in the paper. The dynamic process and changing trend for different types of tidal flats are illustrated in detail. Regulations are proposed for a reasonable exploitation, dynamic protection, and ecosystem restoration of each individual tidal flat and wetland. Some valuable suggestions are put forward for further study about the sustainable exploitation of offshore resources in Shanghai area.

Key words: *Shanghai area; harmonious development; utilization; protection; tidal flat; wetland*

1. Introduction

Tidal flats are inundated during high tide and exposed during low tide. They are similar to the intertidal zone; however, their motion is closely related to the mass exchanges with the supratidal and subtidal zone (Chen, 2000; Li *et al.*, 2005; Reineck, 1978). Very few supratidal zones exist now along most coastal areas of Shanghai and China coastal area, because most tidal flats on their landward side are limited by dikes and groins. The lower boundary of the subtidal zone is close to the - 10 m depth contour which in the Yangtze Estuary approximately follows the outer boundary of the maximum turbidity zone, where sediment is frequently resuspended and transported as well as deposited by the tidal currents.

Being a major ecosystem widely distributed in the world, wetlands are transitional zones between water and land. Its lower boundary reaches down to the - 6 m depth contour according to the Ramsar Convention (An, 2002; Chen, 1995), but the lower boundary of estuarine wetlands remains to be studied further, in particular in relation to the growth of vegetation around medium tidal sea level.

Tidal flats have very important spatial resources, abundant material resources, and environmental

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resources. In this paper, some innovative solutions are proposed for suitable exploitation and utilization of tidal flats in the estuary, and for the coordination between exploitation and protection. In this case, priority should be given to a sustainable utilization of tidal flat resources and a healthy resilience of the tidal flat environment.

2. Tidal Flats, Wetlands and Their Utilization in Shanghai Area

2.1 Background of Tidal Flats and Wetlands in Shanghai

Tidal flats and wetlands form a mosaic along the coastline of the Yangtze Estuary (Fig. 1). They cover an area of 660～700 km^2 above the 0 m contour, an area of 2300～2400 km^2 between the 0 m and -5 m depth contours, and an area of 2970～3100 km^2 between the -5 and -10 m depth contours. About 60 % of these areas consists of tidal flats that are open to the sea: eastern Chongming, eastern Hengsha, eastern Nanhui and Jiuduansha Sand, as shown in Table 1. 75 % of the tidal flat areas lies within the 0 m to -5 m depth contours. The other areas are bordered by a river channel, a sand island or a bay.

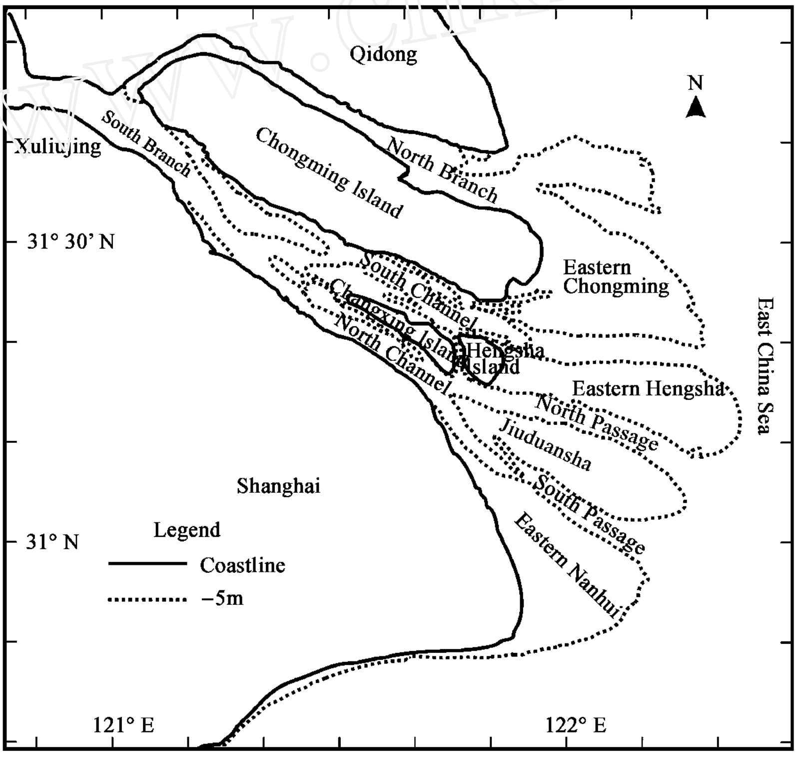

Fig. 1. Distribution of tidal flats in the Yangtze Estuary.

Table 1 Areas of tidal flats in Shanghai (Shanghai Water Burea, 2005) unit: km^2

Elevation	Island in the Estuary				Sand in the Estuary		Continental		Total
	Northern CM	Eastern CM	Eastern HS	CX Bank	BDS	JDS	Eastern NH	Northern HZB	
0 m	120	93	60	67	40	113	133	40	667
- 5 m	267	500	420	107	133	320	520	67	2333

* Chongming = CM; Hengsha = HS, Changxing = CX; Biandansha = BDS; Jiuduansha = JDS; Nanhui = NH; Hangzhou Bay = HZB.

2.2 Vegetation on the Wetlands in the Yangtze Estuary

Scirpus mariquete grows at the mean tidal level close to the 2.5 m contour. Pioneer individuals appear around the 2 m contour while patches of vegetation appear at higher elevations on the flats. *Phragmites australis tussocks*, appearing around the 2.8 m contour, a little lower than the high neap tide level, are widely distributed in high tidal flats. In the 1990s an exotic species, *Spartina alterniflora*, was introduced and cultivated at a lower level than where *Phragmites australis grows*, and it tends a wide distribution. At present, the entire vegetation on tidal flats covers 149.35 km^2: of which 85.44 km^2 for *Phragmites australis*, 28.22 km^2 for *Spartina alterniflora* and about 25 km^2 for *Scirpus* SC (Chen *et al*., 2007).

2.3 Balance Between Sediment Deposition on Tidal Flats and Land Reclamation

The economic development of Shanghai area has reached a bottleneck because of the shortage of land resources due to the tremendous expansion of civil engineering. The reclamation of tidal flats seems to be the only way to meet the demand of land resource for the largest metropolitan area in China. In the Yangtze Estuary, 425 million-ton sediment has been transported from 1951 to 2000. During the past half century, 2100 km^2 of land is enclosed, of which about 1007 km^2 is reclaimed, just meeting 47 % of the land demand in Shanghai.

A dynamic balance was maintained during the period between land reclamation on tidal flats and sediment deposition, while the annual average reclaimed land was about 20 km^2 during the past 50 years. This dynamic balance can be verified by comparing the area of tidal flats from 1980 to 2001 (Table 2), when large areas of tidal flats were reclaimed in Shanghai area. The significant decreasing tendency of the sediment discharge into the Yangtze Estuary, as reported by some administrative departments (Shanghai Water Bureau, 2005), will have a negative effect on this balance.

Table 2 Area of tidal flats between 0 m and - 5 m contour in Shanghai

	Year	1980[1]	1995[2]	2000[2]	2001[2]
Area (km^2)	0 m contour	688.58[3]	660.86	666.67	675.67
	- 5 m contour	2341.54	2410.27	2333.33	2413.54

[1] Shanghai Coastal Zone Comprehensive Investigation (in Chinese), 390 pp., Shanghai Sci. and Tech. Publ., 1988, China.

[2] Revised program of Shanghai the land reclamation from tidal flat, 2002, Shanghai Water Burea.

[3] Area above Wusong zero point.

2.4 Deepening of the Lower Limit for Land Reclamation from Tidal Flats

Before the 1980s, the lower limit for land reclamation was about +3.2～3.5 m (Wusong datum), closing to the mean high tide level of spring tide. This lower limit was deepened to the 0 m contour along the coast in the Nanhui Cape area in the middle of the 1990s and to the -2 m contour along the coastline at the Jinshan Petrochemical Corporation during 1979 and 1980. Progress in coastal engineering made it possible after the 1980s to substitute soft mattress for an aggregate mattress, and substitute slope protection for block stone with a lattice of concrete. This advanced technology was applied to deepen the lower limit of reclamation so as to meet local demands for land resources along the north bank of the Hangzhou Bay. During the past two decades, the lower limit of land reclamation in Shanghai area was set at the -2 m contour.

2.5 Engineering to Induce Sediment Deposition, Hydraulic Reclamation with Dredged Sediments and Sediment Resource Utilization

For a long time, it was only possible to reclaim tidal flats in Shanghai area where sediment was being deposited at the seaward side over a width of 200～300 m. This kind of reclamation had a low economic value because only a small strip of new land was obtained and had to be protected by dikes. However, during the middle 1990s, large areas of tidal flat could be reclaimed and dikes were constructed at the 0 m contour. For example, a high sediment deposition at a rate of 0.188～0.39 m/a was induced by spur dikes along the Pudong International Airport, the channels of the Dazhi River and the Nanhui artificial peninsula (Chen *et al*., 2001). Owing to these measures to promote deposition, 130 km^2 of tidal flat could be reclaimed along the eastern Nanhui tidal flat during ten years (Fig. 2). Meanwhile, the biological method for promoting deposition was also adopted in Shanghai area from the 1980s to 1990s. *Spartina alterniflora* was planted on the tidal flats of the Chongming Island, the Changxing Island, the Jiuduansha Sand and the the eastern Nanhui for promoting deposition at a rate of 0.1～0.2 m/a. Hydraulic reclamation with dredged sediment was promoted at the eastern Hengsha tidal flat during the second stage of dredging the Yangtze Estuary Deep Navigation Channel, which was an invaluable source of sediment in the Yangtze Estuary.

2.6 Exploitation of Tidal Flats and Protection of Wetland Ecosystem

Many practices in Shanghai area have revealed the favourable effects of promoting sediment deposition on tidal flats, on resilience of wetlands, and on maturing land resulted from wetlands that were formed on the flats. Therefore, promoting deposition is an effective method for protection and maintenance of wetland ecosystem. The wetlands of the eastern Chongming Island (326.07 km^2) and the Jiuduansha Sand (406.1 km^2) were designed and approved as Wetland Nature Reserves in the Yangtze Estuary in the 1990s (Li *et al*., 2005; Xie, 2004).

These wetland ecosystems provide favourable conditions for atmosphere adjustment, draught and water-logging defence, wave and storm attenuation, water purification, detoxification and decomposition of disposed sewage etc. The economic value of the ecological service provided by the saltmarsh on tidal flats was estimated as USD 99 per km^2 per year (Costanza *et al*., 1997), while the commercial

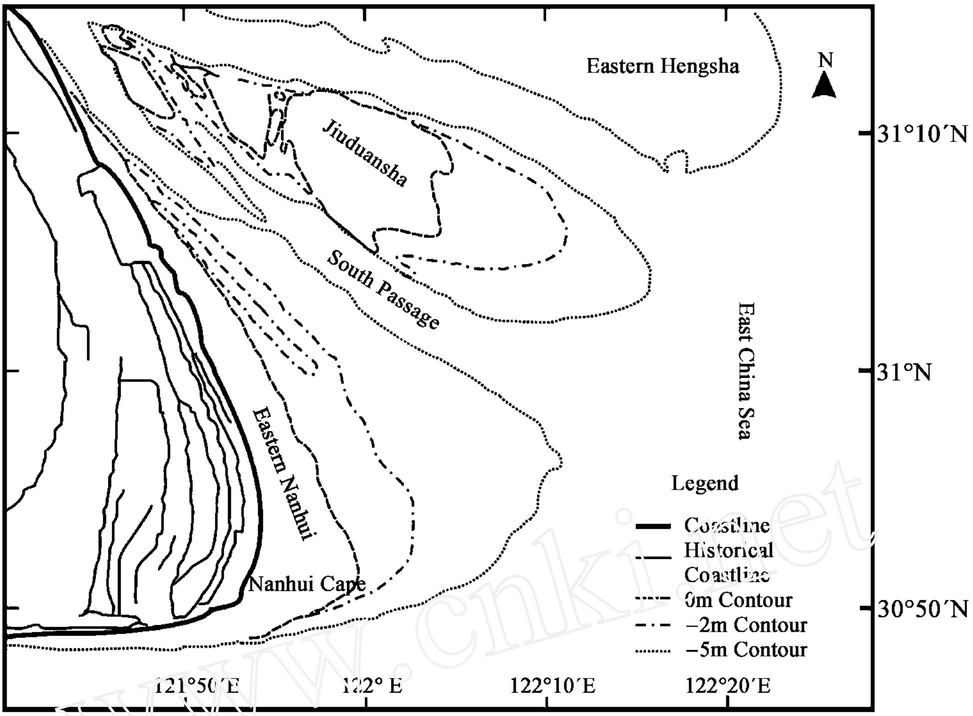

Fig. 2. Historical tidal flat reclamations in the Eastern Nanhui and Nanhui Cape area.

value of the saltmarsh vegetation in the Yangtze Estuary and the use of the reclaimed area for agriculture was appraised much lower, only USD 92 (see Table 5.9 in Sustainable Development Research Team, Chinese Academy of Sciences, 2000). The total commercial value of ecological effects provided by the wetland ecosystem in the Yangtze Estuary is estimated to be USD 190～348 million per year (Tong, 2004).

3. Distribution of Tidal Flats and Wetland in Shanghai Area

Tidal flats in the Yangtze Estuary can be divided into two types: one is a bank attached to the land, and the other is an offshore bar generated within the estuary. They can also be divided into three types according to their locations: those along the river mouth, those along the river channel, and those along an island. In several ways, wetland ecosystems can meet the demands for spatial resources and environmental quality in Shanghai area. However, to what extent the spatial resources issue could be harmonious with the service functions of wetland ecosystems very much depends on the wetland location.

3.1 Northern Chongming

Along the northern Chongming, located on the south bank of the North Branch in the Yangtze Estuary, accretion of tidal flats has resulted in a new land resource of about 406 km^2, or 40 % of the total area reclaimed in Shanghai during the past fifty years (Fig. 3). Another large area of land reclamation is being programmed by trapping sediment on the flats along the North Branch.

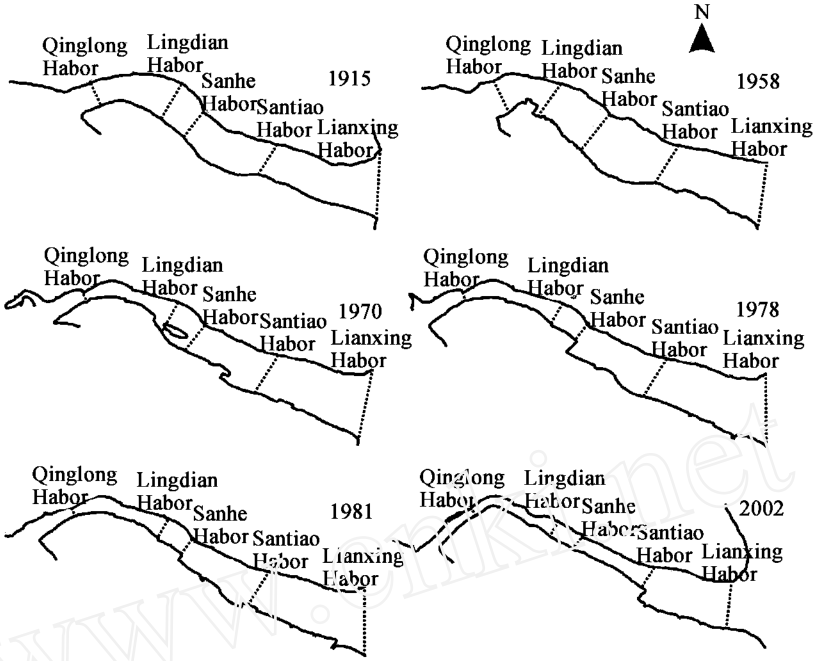

Fig. 3. Historical changes in the North Branch since 1915.

As the first bifurcation channel with a length of about 80 km in the estuary, the North Branch was the main river discharge channel of the Yangtze River in the 18th century. In 1915, it still discharged 25 % of the runoff and was ebb-dominated, however, it gradually evolved into a flood-dominated channel with the change of the Chentong channel in the upstream (Yun, 2005). Sediment was transported by tidal currents from the sea into the North Branch and deposited there, narrowing and shallowing the channel and finally resulting in a tidal bore. The discharge of runoff through the North Branch reduced to 3.3 % in 1958 and further decreased to 1 % in 1959. The sharp decrease led to a saltwater intrusion from the North Branch into the South Branch during spring tide (Mao, 1995). With the increase of the intrusion of salt, water and sediment from the North Branch into the river channel, the subsequent formation of a submarine delta around the upper entrance of the northern Baimaosha channel (Fig. 4) were attributed to the large-scale reclamation of tidal flats and some sands during the 1960s and 1970s. The analysis of historical data shows a significant relation between each individual major reclamation and each individual increase of the intrusion of salt, water and sediment from the North Branch.

At the end of the 1990s a strong saltwater intrusion was related to the reclamation of a large area of flats along the lower southern part of the North Branch. A sharp decrease in channel volume of the North Branch between 1997 and 2005 (Table 3) was attributed to the construction of a dam at Yongxingsha Sand in 2002 to connect it with Xinglongsha Sand. This led to a reduction of channel width from 57 km to 2～3 km and the formation of a straight flow of both the ebb and flood tidal currents over two third of the length of the North Branch. The also led to a decrease in flow size as well as a shift in the direction of the main channel, to the disappearance of the tidal bore that had been formed in the Lingdiangang channel, to a low bore of variable range around the Qinglonggang channel, to a smaller tidal range, to a decrease in saltwater intrusion and to finer local sediment. A low flow velocity field exists now between Qinglonggang and Weijiaogang along the upper channel, while the ebb tidal flow dominates the entrance to the North Branch. This ebb-dominated flow erodes a deep channel within the - 5 m contour that continues from the river mouth to the entrance, resulting in a favourable change of river channel in the North Branch.

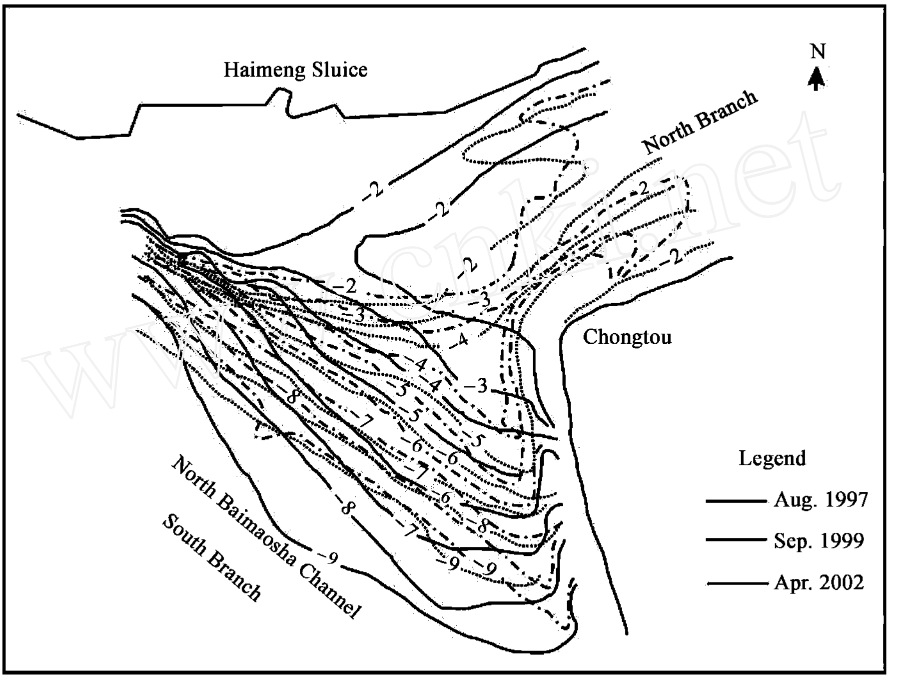

Fig. 4. The subaquatic delta around the entrance of the North Branch.

Table 3 The channel volume of 0 m contour within the North Branch for 50 years

Year	1958	1981	1997	2005
Channel volume (10^8 m^3)	20.6	12.8	9.8	6.6

Within half a century, the North Branch evolved from an ebb-dominated distributary channel to a normal flow channel because of decreasing runoff discharge, increasing tidal current velocity and the formation of a tidal bore (Fig. 3). This channel change should be attributed to reclamation associated with dam construction together with the river channel narrowing and a decrease of flood tidal current. It may become another artificial river channel after the successful regulation of the Qiantangjiang Estuary.

A sustainable development of the North Branch in the future can be expected because of the stabilization of the upper bifurcation of the North Branch, the utilization of the potential tidal flat resources along the lower channel of the North Branch, and the conservation of the present wetland saltmarsh.

3.2 Four Large Tidal Flats in the Mouth Bar Area in the Yangtze Estuary

Four tidal flats located in the mouth bar area in the Yangtze Estuary are open to the sea: eastern Chongming, eastern Hengsha, Jiuduansha, and eastern Nanhui (Fig. 5). All are attached to the coastal land or to islands and extend into the sea. Only Jiuduansha is isolated in the river mouth. The flats are bordered on two sides by a channel that ends in the sea, e.g. eastern Nanhui by the Hangzhou Bay and the South Passage of the Yangtze Estuary. Water flow and sediment flux exchange over the flats. Sediment at the river mouth bar system is finer in the channels (silty mud and muddy silt) and coarser on the flats (medium-fine sand) below mid-tide level down to low-tide level. Sediment becomes muddy silt at mid-tide level where vegetation grows and more muddy at higher elevations where estuarine saltmarsh occurs.

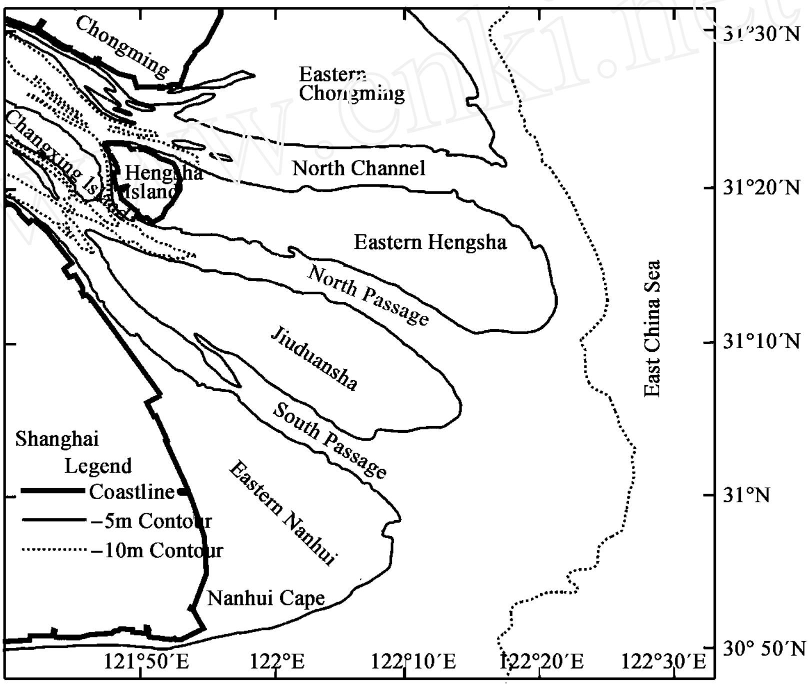

Fig. 5. Distribution of river mouth bars in the Yangtze Estuary.

The river mouth bar is located at the place where the river flow disperses. The dispersed flow from eastern Chongming enters the North Branch and the flow dispersed from eastern Nanhui enters the Hangzhou Bay or moves towards further offshore. The estuary is located in an area where salt water mixes with fresh water and an estuarine circulation develops. The salt water intrusion fronts enter the estuarine bar area and generate a salt wedge (Hu *et al*., 1995). The most inward point of the salt wedge coincides with the top sets of the river mouth bar in the navigation channel (Chen, 1995).

The estuary is a filter where the sediment from the drainage basin deposits, salt water mixes with fresh water and sediment in the maximum turbidity zone is suspended, deposited and resuspended (Chen, 1995; Shen *et al.*, 2001). Therefore, in this area, sediment and water movements are very complicated, chemical processes are very active and the ecosystem is special.

3.2.1 *Eastern Chongming*

Sediment deposits rapidly on the flats of eastern Chongming. The dongwangsha tidal flat, for an example, expanded in a seaward direction at a rate of 342 m/a from 1990 to 1996 at the 3.5 m contour. an area of 115 km^2 has been reclaimed since 1964. At present, the area of the National Nature Reserve is 241.5 km^2: of which 103 km^2 is intertidal flat within the 0 m contour and 138.5 km^2 is subtidal flat below the 0 m contour that extends over 3 km into the sea (Fig. 6). The eastern Chongming is an important area for migratory birds in Asia and the Northwest Pacific. The elevation now is higher than 3.5 m near the dike and the 3.5 m contour has progressed seaward by sediment deposition at a rate of 86 m/a, the 2 m contour at a rate of 80 m/a, but the 0 m contour at a rate of 25 m/a during the past three years because of lateral channel displacement leading to submarine erosion to recede 76 m annually.

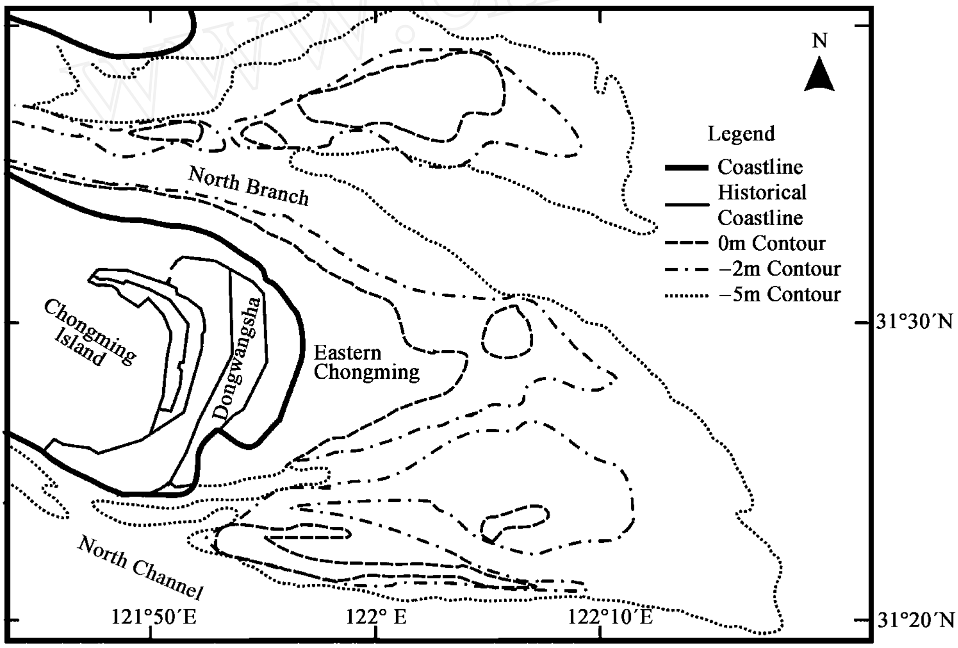

Fig. 6. History of reclamation of tidal flats at eastern Chongming.

Both deposition and erosion should be monitored for tidal flats in a natural state in order to obtain a balance between dynamic protection and dynamic changes of the National Nature Reserve in the eastern Chongming.

3.2.2 *Eastern Hengsha*

The eastern Hengsha tidal flat is located between the North Channel and the North Passage with the lowest deposition rate around the river mouth bar. Since the 1950s, the main ebb tidal current in the North Channel has been displaced southward, eroding the Hengsha Island and the northern bank of the Hengsha shoal, and forming an outlet on the eastern shoal that is connected with the North Passage. At the outlet an area (39.4~93.4 km^2) of strong turbulence and a small shoal has come into being. Tidal flats shallower than the - 2 m contour changed rapidly and were eroded over an area of 160 km^2 during the 1960s and 1970s. The area shallower than the - 5 m contour is 420 km^2 at present.

The eastern Hengsha flats changed greatly due to the construction of the deep navigation channel in the Yangtze Estuary. The Hengsha shoal was stabilized with the northern jetty of this channel, and the wetland ecosystem on the Hengsha flats was greatly improved because a large amount of dredged spoils deposited there. During the second stage of the Deep Navigation Channel Project, the dredged mud also deposited on the eastern Hengsha flats. Future reclamation on the eastern Hengsha flats has been programmed by use of dredged spoils during the completion of the second stage and the maintenance works thereafter, showing the prospect of a sustainable development of the Hengsha flats.

3.2.3 *Jiuduansha Sand*

The Jiuduansha Sand, located between the North Passage and the South Passage, consists of upper, middle and lower sands. The area above the - 5 m contour is 403 km^2, and the area above the 0 m contour is 144 km^2. The Jiuduansha Sand has changed considerably since the 1960s, when it emerged only during low tide. Subsequently Phragmites was cultivated there (on medium sand) in the 1980s and afterwards Phragmites together with Spartina alterniflora. That was part of an ecological engineering project to attract birds from the Pudong International Airport area. Now an area of 444000 hm^2 of vegetation covers the Jiuduansha Sand. The area covered with Spartina alterniflora is 128243 hm^2 and occupies about 29 % of the total vegetation (much smaller than the area covered with Phragmites).

The southern part of the Jiangya Sand became attached to Jiuduansha as a result of the construction of a fish-mouth-type dividing dike during the first stage of the deep navigation channel construction. Only a wide shallow channel now exists between the southern Jiangya Sand and the Jiuduansha Sand. Significant erosion occurred on the southern upper Jiuduansha Sand, while the whole Jiuduansha Sand accreted rapidly because of a wider divergence of the river discharge to the North Passage after the deep navigation channel works were completed. The area of the Jiuduansha Sand above the 0 m contour increased by 10 km^2 between 2002 and 2004.

Hopefully, the wide channel between the southern Jiangya Sand and the Jiuduansha Sand will be filled up with the dredged spoils from the deep water channel maintenance. This will benefit both the stability of the South Passage and the dynamic protection of the upper Jiuduansha Sand within the Jiuduansha Nature Reserve.

3.2.4 *Eastern Nanhui*

During the past half century, 201 km^2 of land was reclaimed on tidal flats of the eastern Nanhui which is located between Pudong and the Nanhui district. Now the area above the - 5 m contour is

546 km^2 (Fig. 2).

Tidal flat above the 0 m contour has been almost entirely reclaimed so that there is almost no intertidal area along most parts of this coast. The reclamation was made for an eastward enlargement of the Pudong International Airport. During the 1990s, longitudinal groins were made along both sides of the Dazhi River, and a reclamation area on the flats of eastern Nanhui within the - 2 m contour has been designated for a sedimentation programme. Sedimentation is effective even at a lower sediment supply from the Yangtze River in recent years, which is due to the highly suspended sediment concentration in the inner maximum turbidity zone, sometimes reaching 21 kg/m^3, which is transported by the tides or entrained, or scoured from the submarine delta. The reclamation of tidal flats of eastern Nanhui can provide sufficient spatial resources.

However, tidal flats without an intertidal zone and vegetation do not have much ecological value. It is therefore most important to provide the flats and wetlands with a resilient ecology, which as a matter of fact is equal to a resilient intertidal zone. In this case, as key water control projects, the Nanhui Cape and the Meimaosha reservoir Projects were proposed in 2003 for deposition, accretion and formation of an intertidal zone.

3.2.5 *Regulation of the Bifurcated Channel Between the South Channel and the North Channel*

Tidal flats are scattered along the river banks, sand spits and sand bars in the South Branch and the South and North Channels. Their total area above the 0 m contour is 99 km^2, above the - 5 m contour, 259 km^2. Very few reclamation projects have been carried out, and the planned reclamations mainly distribute on the Changxing Island. In the near future, tidal flats and wetlands on this island will be reclaimed and used for the construction of the Qingcaosha reservoir. Located north of the Changxing Island and with an area of 60 km^2 on the water surface. This reservoir will provide Shanghai with freshwater by pipeline.

Basic rules for the regulation of protection and exploitation have been proposed for the realization of sustainable utilization and protection of tidal flats around the Qingcaosha Sand along the bifurcation channel between the South Channel and the North Channel. Both regulation projects for the reclamation and for the ecological function of tidal flats are important. As to the reclamation of sand emerging at low tide and the stabilization of subaquatic sands, it is necessary to maintain a tidal flat composed of mobile sandy sediment and to maintain self-adjustment through a mass-balance during changes of the river channel.

3.2.6 *Tidal Flats Along the North Bank of the Hangzhou Bay*

At present, most tidal flats along the Hangzhou Bay are located within groins and a few of them are enclosed at the - 2 m contour. The left tidal flats above the 0 m contour cover only 17.4 km^2, and the area above the - 5 m contour is only 27.5 km^2. The location of the - 8 m contour varies with time, showing it necessary to strengthen the survey of this part of the coast.

4. The *Spartina Alterniflora* Problem

As an exotic species, *Spartina alterniflora* is said to be poisonous and sometimes harmful. However, as many cases show, it is certainly not true that all exotic species destroy the local biodiversity. The reason why the exotic species are imported depends on their functions. *Spartina alterniflora* was first introduced into China from the United States of America in 1979 for promotion of sediment deposition and protection of the coast against erosion. In 1979, a study group for *Spartina spp.* was organized by the Ministry of Science and Technology of China under the leadership of Prof. Chong. The first author of this paper was a member of the group. Late in 1979, a group of four persons made an investigation of *Spartina* along the east coast of the U. S. from Boston through North Carolina and Georgia to Florida. The first author of the paper collected seeds and germchits from the tussocks of *Spartina* in the water at the Sapelo Island, Georgia. When he was back to China, the seeds and germchits were successful cultivated in Nanjing University, and then the plants were distributed all over China. *Spartina* anguliea was introduced into China in 1983 and then widely cultivated, but it could not meet the optimum demands for promoting deposition because of its lower height and density. Along Shanghai coastline *Spartina* was cultivated on tidal flats in the 1980s. Also it was planted from the Changxing Island to the Jiuduansha Island for the eastward enlargement of the Pudong International Airport together with the eco-engineering of the Jiuduansha Island proposed by the first author of this paper in 1996. This produced highly effective *Spartina alterniflora* vegetation: individual plants cultivated in 1996 grew rapidly to a height of 2.3 m with the first tussocks trapping 20 cm of sediment in 1997. During coastal protection works in Shanghai a few rows of *Spartina* were cultivated on the flats and on the seaward slope for wave attenuation. It is also being tried out on the radial sand ridges in eastern Jiangsu province. These practices and experiments show that *Spartina* promotes sediment deposition and wave attenuation for coastal protection.

5. Recommendations

5.1 Dynamic Protection of A Nature Reserve

The requirement of reasonable utilization was added to the Revised Ramsar Conference on Nature Reserves. Under the headline WISE USE, several international conferences have been held recently on wetland protection. In Shanghai area, dynamic protection for the Nature Reserves has been conducted in recent years. Monitoring should be concerned with the dynamics of the Nature Reserves.

5.2 Exploitation by Offshore Engineering

Traditional understanding of the exploitation of spatial resources involves extrapolation towards adjacent areas, to beach resources and to sediment deposition for new land reclamation. Scientific developments make it possible to consider offshore projects. In Shanghai, this means considering land reclamation in water deeper than - 5 m. Artificial islands can be constructed with water depths between - 10 m and - 15 m. In contrast to Kobe, Japan, where an artificial island had to be made in a water depth of more than - 20 m due to the lack of filling material, Shanghai has abundant sediment resources: 3×10^7 m^3 of infill and 3×10^{11} m^3 of bed load can yearly be dredged from the Yangtze Estuary Deep Water Channel during the phase III of the project (the maintenance phase). It will be a valuable source for artificial island building.

6. Conclusions

For the study of the maintenance of a harmonious balance between utilization and protection of tidal flats and wetlands, tidal flats in Shanghai area of the Yangtze Estuary are selected for a case study. Maintaining balanced conditions between sediment deposition on tidal flats and land reclamation depends on the temporal variations as well as the more permanent changes in water discharge and sediment supply from the river, and the permanent changes due to reclamation. The balance will be negatively affected by the reduction of the Yangtze River sediment supply and by the increase of land reclamation, but can be favourably influenced by promoting sediment deposition on the flats through the increasing vegetation on the flats, in particular, by planting species that increase sediment deposition. This has been confirmed by recent researches in various sections of the estuary. Sediment deposition increases with the construction of jetties and channel regulation. Optimum conditions for sediment deposition can be created by planting *Spartina spp.*, especially *Spartina alterniflora* on the flats. Therefore, it is recommended that the construction of artificial islands, channel regulation and land reclamation are accompanied by maintaining tidal flats and stimulating the growth of tidal flats through sediment deposition. Sediment can be dredged during the maintenance of navigation channel.

References

An, S. Q., 2002. Wetland resources utilize and protect, in: *Wetland Ecological Engineering*, Chemical Industry Press, Beijing, China, pp. 4～7. (in Chinese)

Chen, J. Y., 1995. Sediment dynamics and evolution of the mouthbar and subaqueous delta and the deepwater channel regulation in the Yangtze Estuary, *Journal of East China Normal University*, Monograph of the deepwater channel regulation and port engineering in the Yangtze Estuary (in Chinese)

Chen, J. Y., 2000. To exploiting lower tidal flats for expending living space of China, *Engineering Science*, **2**(3): 27～31. (in Chinese)

Chen, J. Y., Li, D. J. and Jin, W. H., 2001. Eco-engineering of Jiuduansha Island caused by Pudong international airport construction, *Engineering Science*, **3**(4): 1～8. (in Chinese)

Chen, J. Y., Cheng, H. Q. and Dai, Z. J., 2007. Compatibility of utilization and protection of tidal flat and wetland: a case study in Shanghai area, *Engineering Science*, **9**(6): 11～17. (in Chinese)

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neil, R.V., Paruedo, J., Raskin, R.G., Sutton, P. and van den Belt, M., 1997. The value of the world's ecosystem services and natural capital, *Nature*, **15**(387): 253～260.

Hu, F. X., Hu, H., Gu, G. Z., *et al.*, 1995. Salinity fronts in the Changjiang Estuary, *Oceanologia et Limnologia Sinica Supplement*, **26**(5): 23～31. (in Chinese)

Li, C. X., Wang, P. and Fan, D. D., 2005. Tidal flat, open ocean coasts, in: *Encyclopedia of Coastal Science*, Schwartz, M.L. (ed.), 975～978.

Mao, Z. C., 1995. A study on salt fronts in the Changjiang Estuary, *Oceanologia et Limnologia Sinica*, **26**(6): 643～649. (in Chinese)

Reineck, H. E., 1978. Tidal Flat, in: *the Encyclopedia of Sedimentology*, R. W. Fairbridge and J. Bourgeois (ed.), Dowden: Hutehinsonand Ross Inc, 798～800.

Shanghai Water Bureau, 2005. A Case Study Report of Harmonious Development between the Tidal Flat Utilization and Wetland Protection within the Shanghai Area. (in Chinese)

Shen, H. T., He, S. L, Mao, Z. C. and Li, J. F., 2001. On the turbidity maximum in the Chinese estuaries, *Journal of Sediment Research*, (1): 23～29. (in Chinese)

Sustainable Development Research Team, Chinese Academy of Sciences, 2000. *The research report of the sustainable development strategy in China*, Shanghai Science and Technique Press, Shanghai, China, 229～232. (in Chinese)

Tong, C. F., 2004. *Structure, function and services of estuarine wetland ecosystem: A case study in the Yangtze Estuary*, Ph. D. thesis, East China Normal University, Shanghai, China, pp. 73. (in Chinese)

Xie, Y. M., 2004. *Wetland of Shanghai*, Shanghai Science and Technique Press, Shanghai, China. (in Chinese)

Yun, C. X., 2005. *Sustainable development and integrated management in coastal zone*, China Ocean Press, Beijing, China. (in Chinese)