

SUSTAINABLE DEVELOPMENT AND COASTAL MANAGEMENT OF TIDAL FLAT IN JIANGSU PROVINCE, CHINA^①

Huang Qiao ua(黄巧华)¹ C n Fang(陈 方)^{1,2} Z u Dakui(朱大奎)¹

1. *State Pilot Laboratory of Coast & Island Exploitation, Nanjing University,*

Nanjing 210093, P. R. China

2. *Department of Geography, Fujian Normal University, Fuzhou 350007, P. R. China*

(R c iv d 22 January 1997)

ABSTRACT: Wit ug ar a, favorabl lig t, at and wat r conditions, ric biological div rsity, and a uniqu cological syst m of submarin sand ridg s, Jiangsu tidal flat as gr at significanc to its economic d v lopm nt. Bas don t g omorp ological c aract ristics, Jiangsu tidal flat is dynamically divid d into stabl , rosional and accumulativ typ s. In lig t of r sourc s distribution, volution rul s of Jiangsu tidal flat, xisting probl ms in coastal manag m nt, xploitation and utilization, t sust ainabl d v lopm nt t ory is appli d to guid t compr nsiv xploitation and utilization of tidal flat. Taking diff r nt r gions wit diff r nt local conditions in consid ration, and in ord r to mak economic d v lopm nt coordinat wit local r sourc s and nvironm nts, four r gional sustainabl d v lopm nt mod ls, i. . (A) Abandon d Huang (Y llow) Riv r d lta s ction for salt and aquatic products industri s, (B) S yang s ction for r d, aquacultur and rar animal prot ction, (C) Daf ng and Dongtai s ction for agricultural compr nsiv xploitation, (D) Nantong s ction for aquacultur and agricultur , ar sugg st d. Manw il , t pap r tak st guiding id ology of sustainabl d v lopm nt to b r fl ct d in mod rn int grat d coastal manag m nt and lgislation.

KEY WORDS: tidal flat, sustainabl d v lopm nt, coastal manag m nt

Tidal flat r f rs to int rtidal silt zon and submarin s oals, many of w ic app ar out of wat r or b com s allow at low tid . It is nouris d and f rtiliz d by s dim nt from riv rs. T Jiangsu coastal zon is b tw n t Xiuz n Riv r mout int nort and t nort bank of t C angjiang Riv r in t sout . T total coastlin xt nds 953.9 km. It can b divid d into t r cat gori s in t rms of marin dynamics, mat rial compon nts and g omorp ological c aract ristics, i. . mudflat, sandy bac and b drock mbaym nt coasts (Fig. 1). T l ngt of mudflat coast is 883.6 km, mor t an 90% of t total l ngt of t Jiangsu

① Support d by Natural Sci nc s Foundation of Fujian (D 97006) and Stat Pilot Laboratory of Coast & Island Exploita tion, Nanjing Univ rsity.

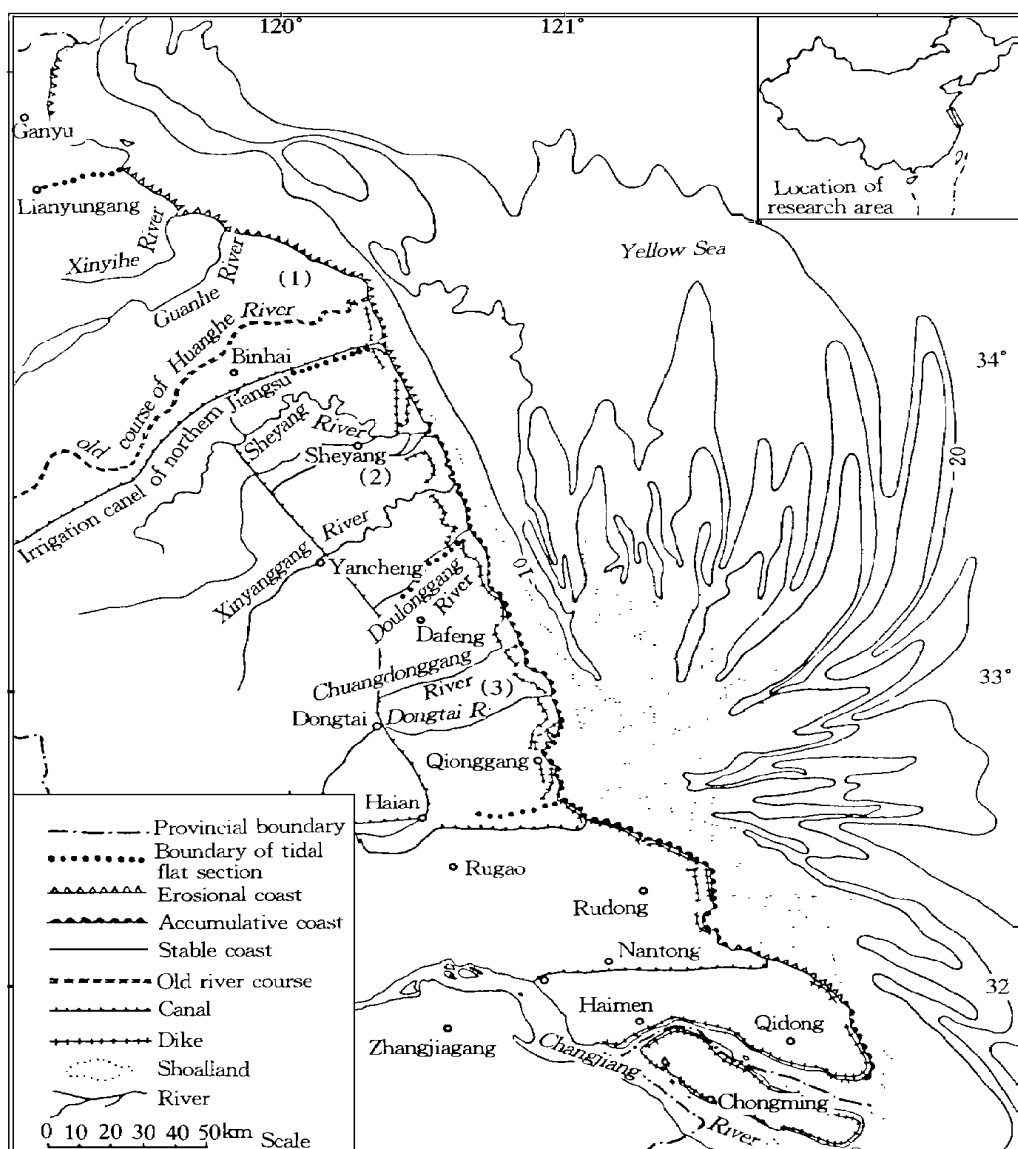


Fig.1 Coastal categories and development and utilization zones of tidal flat in Jiangsu

coastline (Coastal Zone and Tidal Flat Resources Comprehensive Exploitation Plan of Jiangsu Province, 1989).

Tidal flat, treated as a resource structure, is a great value to both its actual and great future exploitation. The development of tidal flat not only can provide a productive space, relax the pressure of tensions caused by large population and resource shortage, but also has great significance in protecting biological varieties and in economic sustainable development of the coastal area of Jiangsu Province. Furthermore, the Jiangsu coastal area will become a

which links the coastal areas of the north and south China and an important basis that promotes economic development from coastal areas to inland (Editorial Committee of Chinese Natural Resources Series, 1996).

I. THE CHARACTERISTICS OF JIANGSU TIDAL FLAT

The Jiangsu coast is based on a subsiding basin since the Cenozoic. The coastal plain was built up by sediment from the Huang (Yellow) River and the Changjiang (Yangtze) River. For example, during the 11th - 19th centuries the Huang River entered the Yellow Sea from North Jiangsu, in only more than 700 years about 15,700 km² of land gradually formed through the way of transforming tidal flat to land (Zu, 1986). Along Jiangsu coast there is about 6.0×10^5 ha tidal flat, which makes up 23.7% of the total tidal flat in China. Now it still expands to the sea at the rate of 1400 ha/a. No matter from the total area or the area of tidal flat owned by each kilometer mainland coastline, it all ranks first in China. The world-famous submarine sand ridges lie in the middle of Jiangsu nears the sea (Fig. 1). It is 200 km long and 90 km wide. The average water depth is 15-30 m. It consists of more than 70 radiating sand ridges and relevant tidal channels. The marine environment is unique in China and also rare in the world.

Tidal process is the predominant factor to create the coastal morphology. Tidal influence is of regular semi-diurnal type. Disturbed by runoff and local landform, it appears as irregular semi-diurnal on the nears and river mouths. The nears and area of Jiangsu is controlled by two major tidal wave systems. The south branch originating from the Pacific tidal wave transmits from the south to the north via the East China Sea, the north branch influenced by the Yellow Sea counterclockwise rotational tidal wave system forwards from the north to the south (Zu, *et al.*, 1982). These two major tidal wave systems converge in the vicinity of Qonggang, so that the biggest tidal range in China occurs there. The average tidal range is more than 3.9 m, with an observed maximum of 9.28 m. The tidal range reduces gradually toward the south and the north. Tidal elevation determines the altitude of tidal flat and also has an effect on its width (Wang *et al.*, 1990).

The Jiangsu tidal flat is well developed. In terms of the area of tidal flat owned by each kilometer mainland coastline, the value of Jiangsu is 538 ha/km, far more than the national average of 127 ha/km. The broad tidal flat usually has obvious zonations. There are grass, mud, mud-silt and silt zones from land to the sea respectively (Zu *et al.*, 1986), representing different developing processes. The Jiangsu tidal flat can be divided into three types in the light of dynamic statistics, i.e. stable, erosional and accumulative types with different characteristics and coastal profiles (Fig. 2).

In Fig. 2 (a) is coastal profile of accumulative tidal flat. This tidal flat is wide with gentle slope. It has obvious horizontal zonation in morphology and distribution. The profile of it is convex. The evolution trend is submarine coastal zone advances towards the sea as the form of sta-

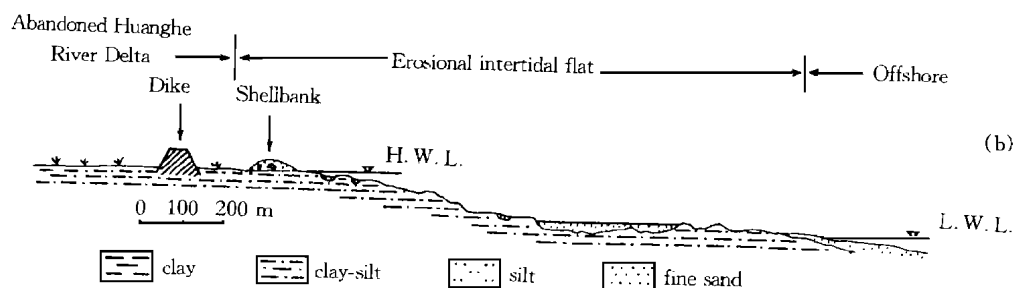
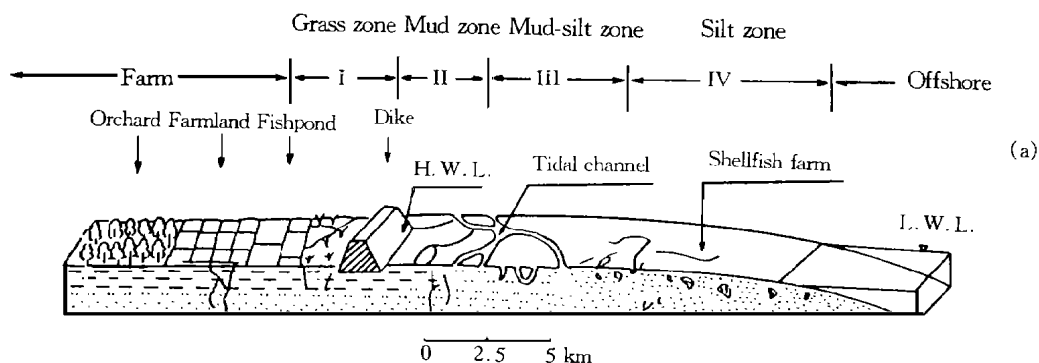


Fig. 2 Coastal profiles of different tidal flat types

(a) Coastal profile of accumulative tidal flat (b) Coastal profile of erosional tidal flat

bl profile.

(b) is coastal profile of erosional tidal flat. This tidal flat is narrow and steep, its morphology and distribution have no distinct zonation. The profile is a little concave. The evolution trend is coastline retreat at high tide level and tidal flat surface lowering. It is characterized by the coarse-grained sediment at low tide level and the marginal of flat ridge and channels at high tide level.

II. RESOURCES EVALUATION AND PRESENT UTILIZATION SITUATION OF JIANGSU TIDAL FLAT

1. Tidal Flat Resource Evaluation

Jiangsu Province is located in the key region with the economic zone along the Changjiang River taking Shanghai as its "dragon head" and the Changjiang River Delta as its main body in the littoral economic zone of the east China. It is one of the most developed regions of China in economy, culture and communications. Jiangsu tidal flat possesses rich resources of

land, fresh and salty water, salt and aquatic products and marine energy. The submarine-sand ridge region is a major fishing base of China, with vast latent land resources and urgently needed deep-water navigation channels. The tidal flat usually is broad area and various coastal types. It is advantageous to the comprehensive exploitation and the prosperous development of a series of marine industries. Because it is located in the transition region between the warm temperate and the north subtropical zones, and with natural environments suitable for growth and breeding of north and south organisms, Jiangsu tidal flat is rich in biological diversity. It is not only favorable conditions for agricultural production but also both the south and north regions benefit for its development and utilization. Compared with tidal flat in the north of China, it is rich in precipitation, irrigation and fresh water supply; compared with those in the south of China, it is more extensive area and various kinds of resources and more convenient for large-scale comprehensive exploitation.

2. Present Development & Utilization Situation and Problems

The exploitation of tidal flat in Jiangsu is a history of over 2000 years. Especially in recent dozens of years, there are a lot of systematic attempts to build dikes for reclamation, to construct water conservancy projects and transform soil for developing farming, forestry, salt and fishery industries. The tidal flat has become an important production base of food, cotton, silkworm, salt and inland fishing in China. Its aquatic breeding also is primarily regarded as a certain scale. Its exploitation and utilization have got a series of breakthroughs and possessed considerable economic strength and developing potentialities.

However, there is still no authoritative irrigation policy-making organization in the process of tidal flat exploitation, and the lack of unified planning and administration makes it unable to form large-scale integrated exploitation. The economic developing direction of tidal flat is unitary and confined to present benefits. Tidal flat is poorly managed, which is reflected by poor relations between exploitation and alignment, low utilization rate of resources, so that the irrigation owned by sustainable development could not be given full play. The superiority of resources and abundant labour have not been fully utilized. Therefore, in order to transform the resources superiority to economic superiority, and make the tidal flat be golden coast with rich products and fine environment, the urgent matter at the moment is to carry out researches on the problems of sustainable development.

III. THE SUSTAINABLE DEVELOPMENT OF TIDAL FLAT RESOURCES EXPLOITATION

1. Sustainable Development Principles of Tidal Flat Resources Exploitation

In order to achieve the goal of sustainable, healthy and rapid development of tidal flat in

Jiangsu, the theory and principles of sustainable development should be employed in the exploitation and utilization of tidal flat resources. From this point of view, we think the sustainable exploitation of tidal flat resources should follow the principles listed below:

1.1 *The principle of systematicness*

Sustainable development regards the entire and local regions, on which the mankind relies for existence, as a complicated system which is composed of many elements such as nature, society, economy, culture and so on. They interact each other. Thus, in making resource strategies, it is necessary to break the limitations among different departments and districts, to make comprehensive analysis and macroscopic readjustment and control from the angle of the world (Li 1994), and to maintain a proper balance between the part and the whole. It is necessary to establish the dominant direction in the light of comprehensive superiority, and around it to set up the comprehensive exploitation model which embodies the local characteristics, so as to give full play to the best overall function and comprehensive benefit of tidal flat.

1.2 *The principle of adaptation to local conditions*

Sustainable development emphasizes to take various countermeasures according to different kinds of resources and their disposition. The various resources are not balanceably disposed and distributed on the tidal flat, and the kinds of different industries for resources are also distinct. For this reason, in the coastal zone, it is imperative to regard resources and socio-economic conditions of every coastal section as its foundation, to make optimum combination of resource allocation, to raise the utilization rate of tidal flat exploitation and to develop specialized and intensive scale-production.

1.3 *The principle of benefit*

The economic view of sustainable development, which integrates exploitation with preservation, provides the guiding ideology for the exploitation and management of tidal flat resources. It should be based on natural resources and suitable ecological environments to develop economy and improve living quality, which the mankind has been in pursuit all the time. A system for resource management should try to pursue ecological, economic and social benefits, and the overall benefit of the system should be put in the first place (Li, 1994). The utilization of resources should be confined in the limits of its carrying capacity; at the same time artificial measures should be adapted to bring about the resources production and preservation of biological varieties. By raising the energy conversion rate, we must set up virtuous circles of biological chains, make multiple and tiered-dimensional exploitation and utilization of tidal flat, improve the processing level and add the value of products, enable the coordinated development of farming, forestry, animal husbandry, and keep the balance between natural ecology and socio-economic development.

2. Regional Sustainable Development Models of Tidal Flat

For comprehensive exploitation and utilization, guided by the principles of sustainable development,

vertical and basal on the producers' resources are active management, with dividing the Jiangsu tidal flat into four coastal sections.

2.1 Abandoned Huanghe River Delta section for salt and aquatic products industries

The coastline of this section is 140 km long. Since the Huang River returned to the north in 1855, sediment supply to the coast suddenly decreased, and the distributing direction of the coast is perpendicular to the wave ray, both of them making the coastline undergo erosion. Under the natural condition, nowadays the mean erosion rate is 2.223 km/a (Zu et al., 1982). The width of tidal flat is generally 0.5–1 km. The salinity and groundwater mineralization intensity of it are relatively high. The conditions for agricultural reclamation and the biological resources are comparatively poor (Table 1). However, with low precipitation, relatively high sunshine in percentage, and favorable seawater salinity, water quality and tidal flow retaining conditions, the tidal flat is suitable for salt chemical industry. In addition, the salt production of this section has a long history. With skilled workers and good technical condition, the salt-producing cost is low (about 70% lower than that of other sections). This area has been a main salt production base in China.

Table 1 Natural conditions of various sections of tidal flat coast in Jiangsu*

Coastal section	Coastline length (km)	Area of tidal flat (a)	Dynamic state	≥10℃ accumulated temperature (℃)	Precipitation (mm)	Evaporative capacity (mm)	Mean biomass (g/m ³)
(1)	140	4.28×10 ⁴	erosion	4500	950–980	1500–1700	34.13
(2)	110	8.80×10 ⁴	erosion-accumulation	4500–4600	1000	1500	37.83
(3)	177	28.0×10 ⁴	accumulation	4600–4700	1000–1100	1400	23.30
(4)	201	18.0×10 ⁴	accumulation intermingled by erosion and stabilization	>4700	1000	1100	78.58

* Converted from Coastal Zone and Tidal Flat Resource Comprehensive Exploitation Plan of Jiangsu Province, 1989, the code number is the same as the main body of the paper.

Therefore, the urgent matter of this section is to protect tidal flat so as to prevent the coastline from erosion and retreat. Meanwhile, for the reason to make full use of the superiority of salt industry, salt production should be taken as the dominant factor in the tidal flat exploitation and the policy of combining salt field with aquaculture should be practiced. Under the prerequisite of not influencing the output and quality of raw salt, multivariant exploitation to raise the efficiency ought to be advocated. For example, in the low salinity bittern prawn, shellfish, oyster etc. may be bred, while in the medium salinity bittern bittern insects cultivated, and in the high salinity bittern salt algae fostered and calcium sulphate collection practiced. The output value of this utilization model is estimated to be better than that of only raw salt production.

tion (Hu, 1992). Simultaneously, vigorously massed should be adopted to develop saline-alkali chemical industry.

2.2 *Sheyang section for reed-planting, aquaculture and rare animal protection*

The coastline of this section is 110 km long. Its northern part is dominated by erosion and most of the southern part is accumulative. The most notable feature of this section is that there are four major channels from the Lixia region converging to this area. Its terrain is low-lying; freshwater supply is sufficient and the area of river mouth shoal land is wide. It has favorable conditions for reed-planting and fish-farming. Planting reed calls for small investment and makes fast returns, as a kind of paper-making raw material on the one hand and can replace two cubic meters of timber, and it also can provide by-products such as binder or forage yeast. To plant reed on shoal land and build dams around it for fish-farming can improve soil and environment, and reed growing in symbiosis with fish can fertilize soil and water, it is obvious economically beneficial. So the utilization of this section should mainly focus on reed planting and aquaculture.

With large low-lying marsh and open shoal land, pleasant water and quiet environment, little disruption and rich food supply, in autumn the southern part of this section becomes the reasonable place for reed-crowned cranes in the world (Yong *et al.*, 1992). So it is favorable ecological environment should be rigorously protected. Reclamation, mowing and project construction should be strictly forbidden, which may enable it to become a natural reserve with comprehensive functions of protection, tourism, scientific research and education.

2.3 *Dafeng- Dongtai section for agricultural comprehensive exploitation*

The coastline of this section is 177 km long. Shaped by submarine sand ridges, the tidal flat is wide and in the ideal position environment (Zu *et al.*, 1982). It is generally more than 10 km wide with a maximum of 36 km, and it is still advancing rapidly to this area. Popular traditional experience in reclamation, cotton planting and saline soil improvement. The potential land resource is abundant, the terrain altitude of tidal flat is fairly high and the grassland is vast. Simultaneously, marshes on tidal flat and submarine sand ridges are rich in commercial fish resources, so it has the great potentialities in comprehensive exploitation on farming, forestry, animal husbandry and aquaculture. In future, it is necessary to hold on to the combination of farming and animal husbandry, to improve natural grassland and cultivate suitable breeds, to develop the livestock products and seafood processing industries so as to achieve better economic results and the self-expansion ability.

2.4 *Nantong section for aquaculture and agriculture*

The coastline length of this section is 201 km. It is dominated by accumulative tidal flat. The bottom material and water quality of tidal flat are very suitable for breeding and growing of shellfishes and larvae. This section is one of the main shellfish and larvae production and export bases in China. Tidal flat is rich in biological resources, its biomass occupies 40% of the total number in Jiangsu. And the tidal flat for aquaculture is particularly so. There are plenty of skilled farmers so that it enjoys exceptional advantages for aquaculture. Meanwhile, there are

many rivers entering into the sea in this section. The advantage of full of precious species resource in the rivers can be used to develop aquaculture, which is particular to high-output value products such as fish, prawn, crab, clam, soft-shelled turtle and so on, in low-lying flood plain, branching streams and tidal flat. Great attention should be paid to solving the problems that restrict aquaculture sustainable development such as water pollution, aquatic product virus, nitrogenous organic and etc. Integrated with the developed fisheries or fishing industry, the superiority of convenient traffic, well-informed information, high level technique, abundant labour and fairly strong economic strengths could be fully used to practice multi-layered and multivariate aquatic products processing and to form comprehensive superiority and systematic benefits. Aquaculture should advance toward the direction of outwardly development which is pluralistic, internationalized and forming groups in world economy, and to strengthen the competitiveness and occupation probability on international market. This section is located in the south most part of Jiangsu coastal zone. Precipitation and natural conditions are favorable, fresh water supplement sufficient, with the potentiality for expanding reclamation is limited. So the developing direction of agriculture is to make full use of the favorable natural conditions and the superiority of sufficient labour, and to concentrate on raising land bearing capacity, to regulate the rural structure and increase per unit area yield and intensive degree. Cotton, food and oil-bearing crops could be taken as the key link and organic support to the development of cash crops such as perfume, traditional Chinese medicine, asparagus, hemp, vegetables and etc. The salt pans which formed historically should be appropriately readjusted and transformed to farmland gradually.

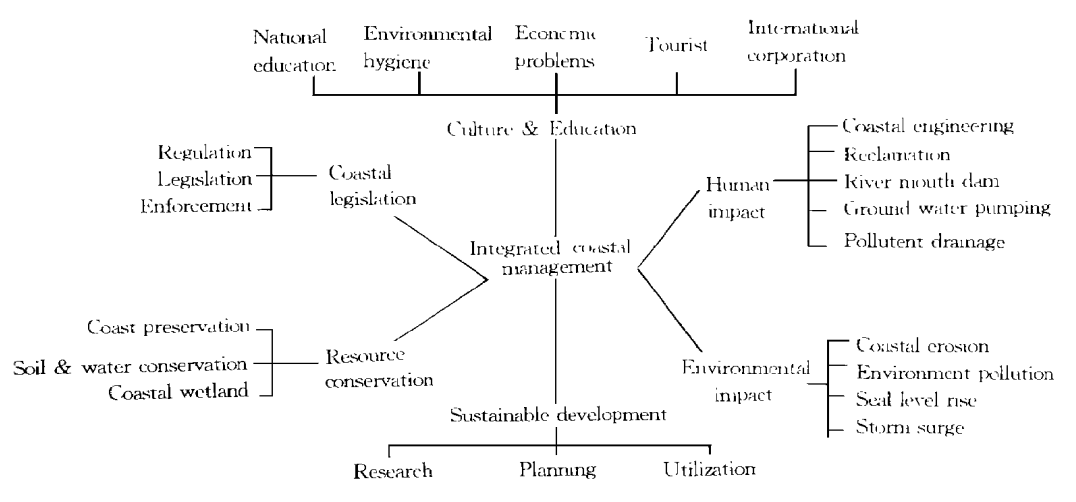


Fig. 3 System of integrated coastal management
(Modified after Wang *et al.*, 1996) ①

① Wang Ying, Luo Zhen, Zhu Dakui, 1996. The Coastal Zone Development and the Integrated Management Issue of the Mainland of China.

In its strategic objective for realizing sustainable development, the World Environment and Development Council pointed out that the problems concerned about environment and development must be carried thoroughly into the policies, laws and government's decisions (The World Commission on Environment and Development, 1987). Coastal zone is a kind of land with lands dual characteristics, any common law that is only accordance with either land or sea could not give the full consideration to the particularity of the coastal zone itself. Therefore, the emergence of coastal zone legislation is not only the internal demand of the particularity, but also the urgent need of coastal zone sustainable development. On November 19, 1985, the government of Jiangsu Province promulgated "Coastal Zone Management Provisional Regulations of Jiangsu Province", which is the first comprehensive coastal zone management regulations in China (Ren *et al.*, 1984). The kernel of the regulations is to advocate the combination of exploitation, utilization, protection and harnessing, and to emphasize the unified planning and management to the coastal zone resources. Since the implementation of the regulations, the incomparable superiority of comprehensive management to departmental management is preliminarily proved. Gratifying results have been acquired in the aspects of the formation of coastal unified planning, the comprehensive proof of developing projects, the relation coordination and contradictory condition among regions and departments, fund raising and using. For the reason of setting up the modern coastal management system which accords with the particularity of coastal zone, strengthening the coastal zone management consciousness of the whole people, accomplishing the harmonious and stable development of resources, environment and society in coastal zone, it is necessary to establish an integrated management system to improve the exploitation and utilization of the coastal environment and resources (Fig. 3). It is not only the objective of the coastal zone management, but also the powerful guarantee of coastal zone sustainable development.

REFERENCES

- Coastal Zone and Tidal Flat Resources Comprehensive Exploitation Terms of Jiangsu Province, 1989. *Coastal Zone and Tidal Flat Resources Comprehensive Investigation Report*. Beijing: China Ocean Press. (in Chinese)
- Editorial Committee of Chinese Natural Resources Series, 1996. *Chinese Natural Resources Series, Vol. Jiangsu*. Beijing: China Environmental Science Press. (in Chinese)
- Hu Wiming, 1992. Tentative assumption for development and comprehensive utilization of seawater resources and salt-manufacture field and seawater. *Ocean and Coastal Zone Development*, 9(4): 38-40. (in Chinese)
- Li Wenhua, 1994. Sustainable development and natural resource strategy for natural resource management. *Journal of Natural Resources*, 9(1): 97-106. (in Chinese)
- Ren Mifan, Wu Ping, 1984. The content and procedure of coastal zone management—Taking the coastal zone of Jiangsu Province as an example. *Natural Resources*, (3): 1-7. (in Chinese)
- The World Commission on Environment and Development, 1987. *Our Common Future*. Oxford: Oxford University Press.
- Wang Ying, Zhu Dakui, 1990. Tidal flats in China. *Quaternary Research*, (4): 291-300. (in Chinese)

- Yong Wanli, Kong Fanzhi, 1992. Ocean tourism resources and their exploitation in Jiangsu, Shanghai and Zhejiang. In: Zeng Hongyi (ed.) *Research on Ocean Development Base of Jiangsu, Shanghai and Zhejiang —Space Distribution and Regional Structure*. Nanjing: Nanjing University Press. (in Chinese)
- Zu Dakui, 1986. The utilization of coastal mudflat of China. *Scientia Geographica Sinica*, 16(1): 34–40. (in Chinese)
- Zu Dakui, Xu Tingguan, 1982. The coastal development and exploitation of middle part of Jiangsu coast. *Journal of Nanjing University (Natural Science)*, (2): 799–818. (in Chinese)
- Zu Dakui, K. Xiankun, Gao Su, 1986. Tidal flats distribution of Jiangsu coast. *Journal of Oceanography of Huanghai and Bohai Seas*, 14(3): 19–27. (in Chinese)